

Threats to Machine Learning Applications

Mark Sherman
Director, Cybersecurity Foundations, CERT
Oct 6, 2020

Software Engineering Institute
Carnegie Mellon University
Pittsburgh, PA 15213

Copyright 2020 Carnegie Mellon University.

This material is based upon work funded and supported by the Department of Defense under Contract No. FA8702-15-D-0002 with Carnegie Mellon University for the operation of the Software Engineering Institute, a federally funded research and development center.

The view, opinions, and/or findings contained in this material are those of the author(s) and should not be construed as an official Government position, policy, or decision, unless designated by other documentation.

NO WARRANTY. THIS CARNEGIE MELLON UNIVERSITY AND SOFTWARE ENGINEERING INSTITUTE MATERIAL IS FURNISHED ON AN "AS-IS" BASIS. CARNEGIE MELLON UNIVERSITY MAKES NO WARRANTIES OF ANY KIND, EITHER EXPRESSED OR IMPLIED, AS TO ANY MATTER INCLUDING, BUT NOT LIMITED TO, WARRANTY OF FITNESS FOR PURPOSE OR MERCHANTABILITY, EXCLUSIVITY, OR RESULTS OBTAINED FROM USE OF THE MATERIAL. CARNEGIE MELLON UNIVERSITY DOES NOT MAKE ANY WARRANTY OF ANY KIND WITH RESPECT TO FREEDOM FROM PATENT, TRADEMARK, OR COPYRIGHT INFRINGEMENT.

[DISTRIBUTION STATEMENT A] This material has been approved for public release and unlimited distribution. Please see Copyright notice for non-US Government use and distribution.

This material may be reproduced in its entirety, without modification, and freely distributed in written or electronic form without requesting formal permission. Permission is required for any other use. Requests for permission should be directed to the Software Engineering Institute at permission@sei.cmu.edu.

Carnegie Mellon® and CERT® are registered in the U.S. Patent and Trademark Office by Carnegie Mellon University.

DM20-0791

Carnegie Mellon Leads an Ecosystem of Innovation for Cybersecurity



CMU Campus – Global Research University

- Global research university known for its world-class, interdisciplinary programs in computer science, machine learning/artificial intelligence, engineering, business, arts, policy, and science
- Ranked #1 for Computer Science, #1 for Artificial Intelligence, #6 in Engineering (*U.S. News and World Report*)
- 1,442 total faculty and 130 research centers
- CyLab, CMU's security and privacy research institute, brings together experts from all schools across the university



CMU Software Engineering Institute (SEI)

- Founded in 1984 by the DoD as a Federally-Funded Research and Development Center (FFRDC) focused on software engineering
- Leader in software engineering, cybersecurity, and artificial intelligence research
- Established CERT in 1988
- About \$145M annual funding (~\$23M DoD Line)
- Critical to the DoD ability to acquire, develop, operate, and sustain software systems that are innovative, affordable, trustworthy, and enduring (*CMU SEI Sponsoring Agreement*)

CERT Division



Founded on a unique combination of experiential understanding of DoD missions, the cyber warfighter, the operational domain, and constantly changing technology

Adapts the best science to impact operational missions, increase the trustworthiness of technology, and develop cyber talent

Partners with DoD, non-DoD agencies, and the private sector enable CERT to maintain technical depth, attract top talent, amplify DoD financial investment, reduce the risk to DoD missions, and scale the research

Strengthens the resilience of critical national functions, increases the cybersecurity and resilience of DoD systems and Defense Industrial Base, and develops the cyber capacity of allies and partners

Outline

Introduction

Understanding the ML Attack Surface

Understanding Risks of Transfer Learning

Remedies and Limitations

Conventional Threats to Machine Learning

Stop signs that look like speed limit signs



K. Eykholt, et al, "Robust Physical-World Attacks on Deep Learning Visual Classification,"
CVPR 2018, April 10, 2018, <https://arxiv.org/pdf/1707.08945.pdf>

Turtles that look like rifles



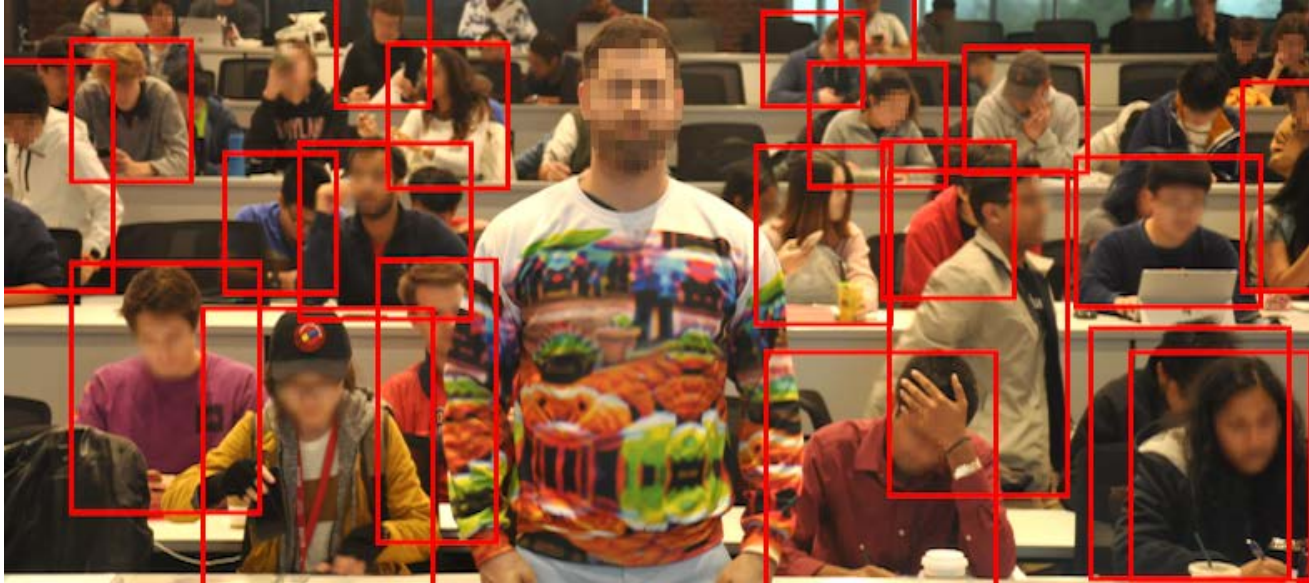
Source: Athalye, A., Engstrom, L., Ilyas, A., & Kwok, K. (2017, July 24). *Synthesizing Robust Adversarial Examples*. *arXiv [cs.CV]*. Retrieved from <http://arxiv.org/abs/1707.07397>

Glasses look like Milla Jovovich



M. Sharif, et al, Accessorize to a Crime: Real and Stealthy Attacks on State-of-the-Art Face Recognition. In *2016 ACM SIGSAC Conference on Computer and Communications Security (CCS '16)*. DOI: <https://doi.org/10.1145/2976749.2978392>

Tee shirts hide from facial recognition



Tom Goldstein, "Invisibility Cloak," 2018,
<https://www.cs.umd.edu/~tomg/projects/invisible/>

Pandas as Gibbons



“Panda”

+ .007 ×



=



“Gibbon”

I. Goodfellow, et al, "Explaining and Harnessing Adversarial Examples," ICLR 2015, Mar 20, 2015, <https://arxiv.org/pdf/1412.6572.pdf>

Outline

Introduction

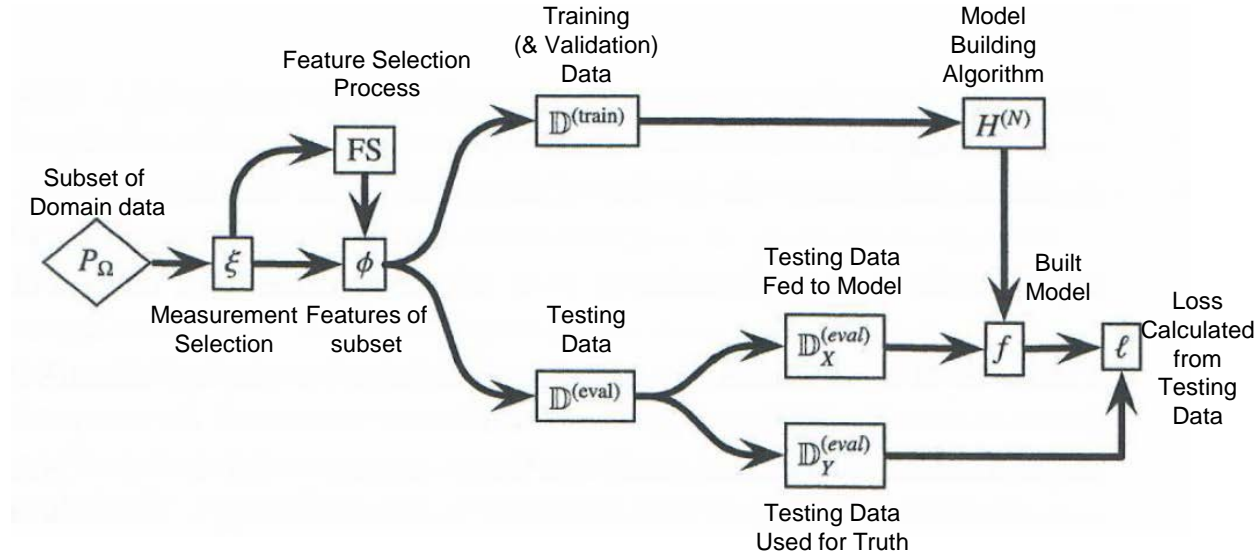
Understanding the ML Attack Surface

Understanding Risks of Transfer Learning

Remedies and Limitations

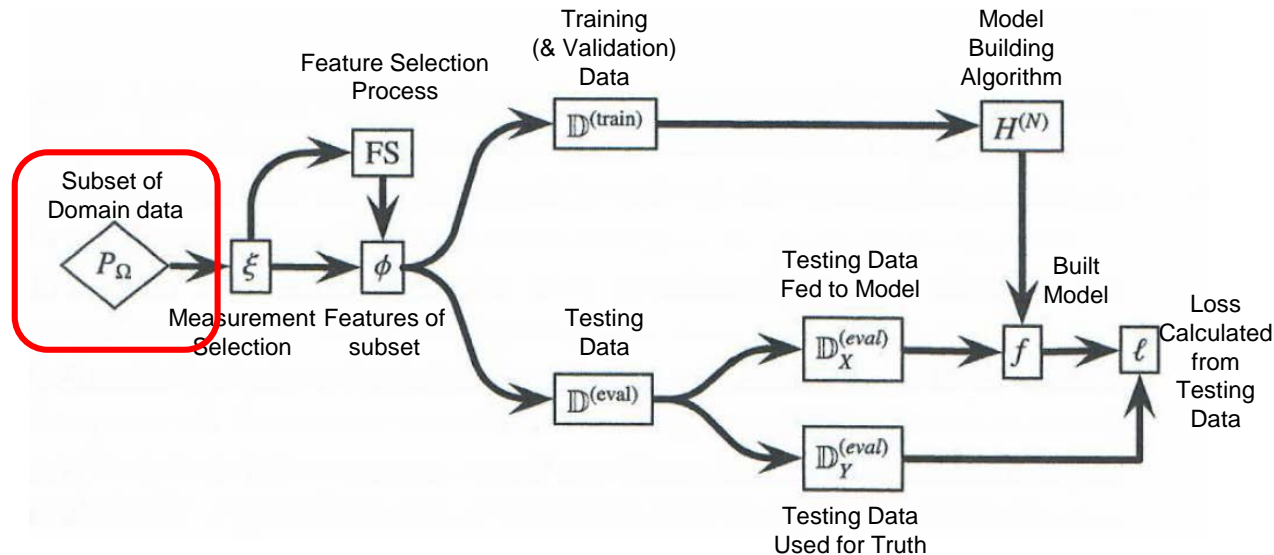
Conventional Threats to Machine Learning

Developing a Machine Learning Application



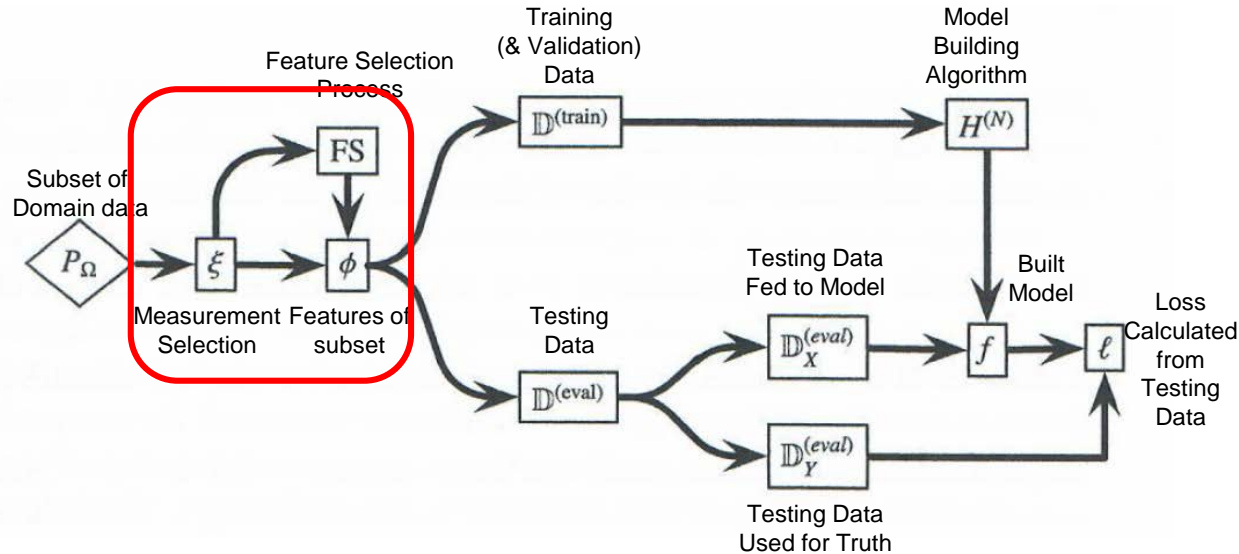
Adapted from Joseph, Nelson, Rubinstein, Tygar; Adversarial Machine Learning, Cambridge University Press, 2019

Data Attacks – Selected Domain Subset



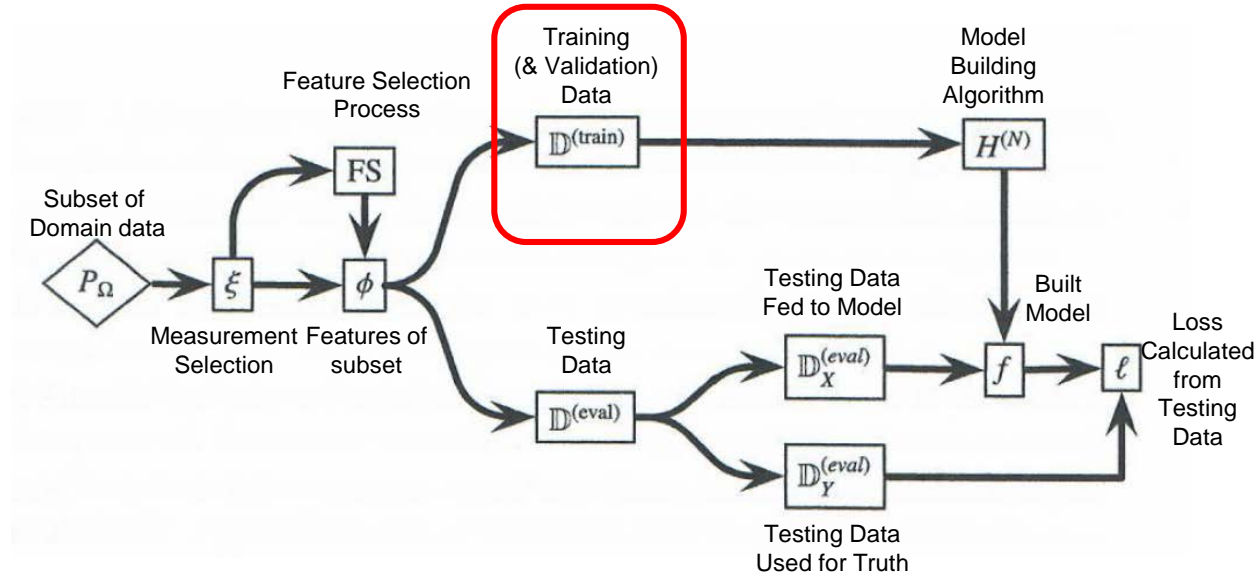
Adapted from Joseph, Nelson, Rubinstein, Tygar; Adversarial Machine Learning, Cambridge University Press, 2019

Data Attacks – Measurements and Features



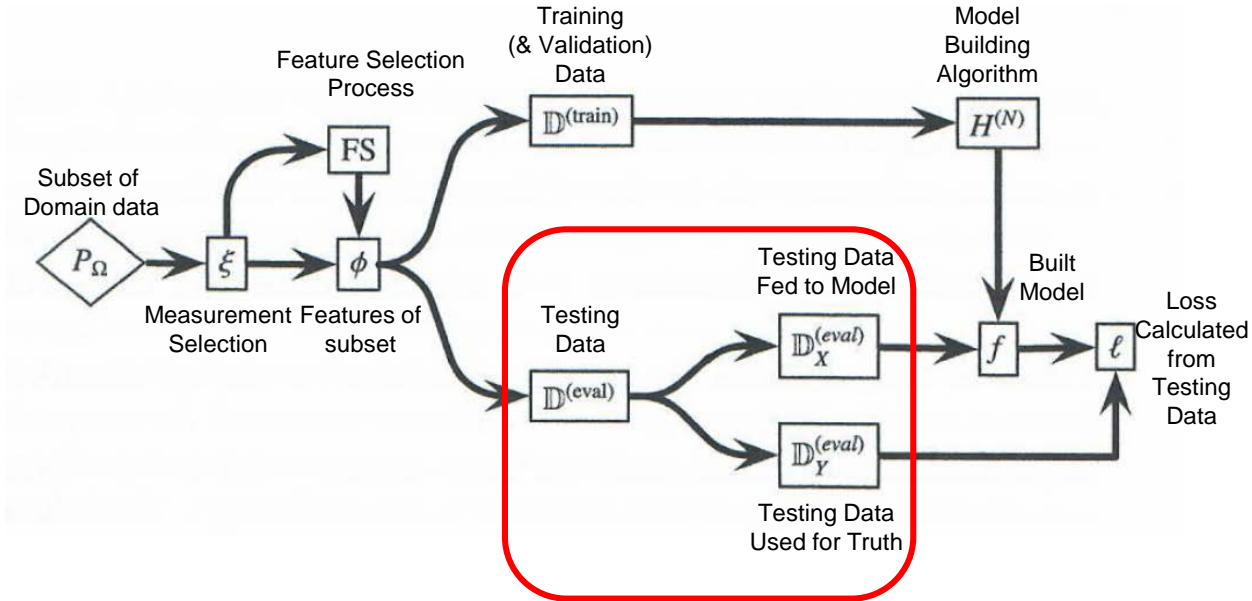
Adapted from Joseph, Nelson, Rubinstein, Tygar; Adversarial Machine Learning, Cambridge University Press, 2019

Data Attacks – Training Data



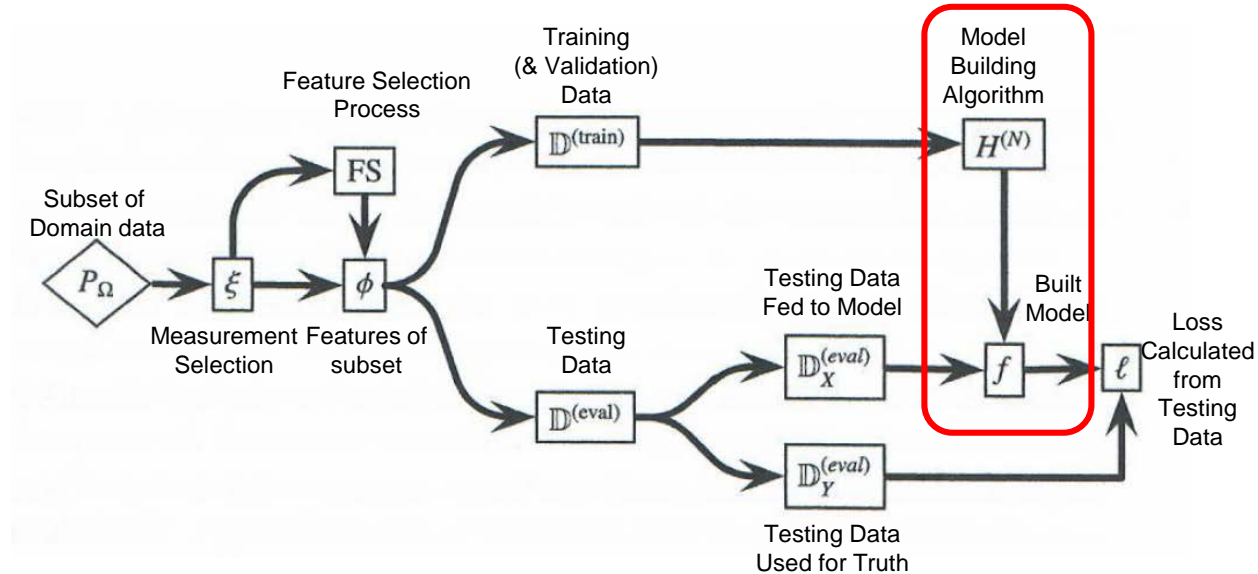
Adapted from Joseph, Nelson, Rubinstein, Tygar; Adversarial Machine Learning, Cambridge University Press, 2019

Data Attacks – Model Testing Data



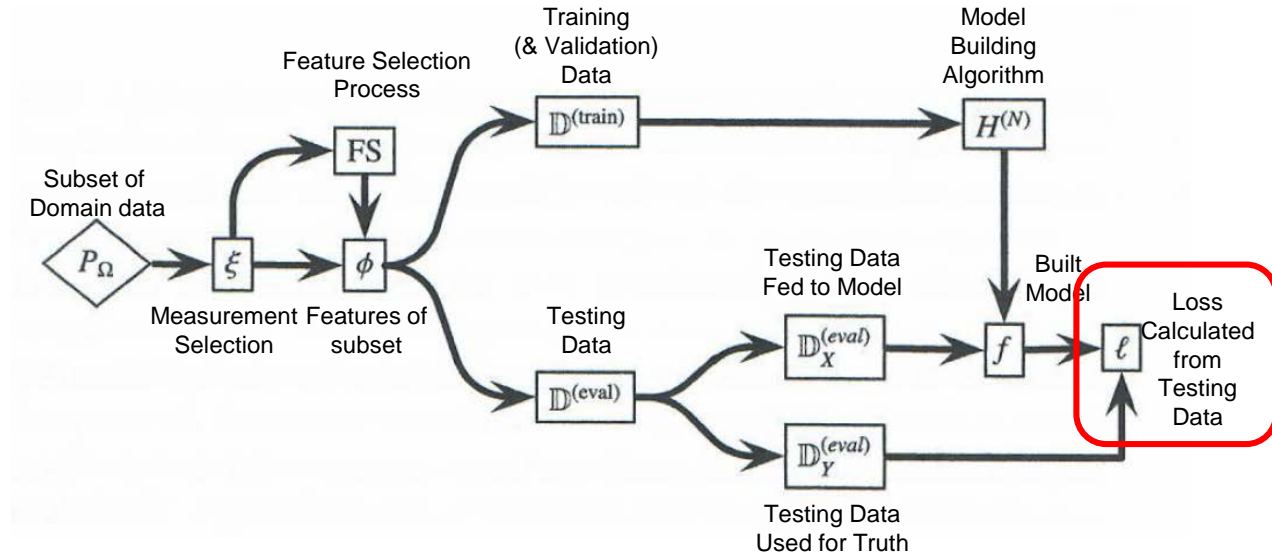
Adapted from Joseph, Nelson, Rubinstein, Tygar; Adversarial Machine Learning, Cambridge University Press, 2019

Algorithm Attacks – Model Construction



Adapted from Joseph, Nelson, Rubinstein, Tygar; Adversarial Machine Learning, Cambridge University Press, 2019

Data Attack – Loss Measurements



Adapted from Joseph, Nelson, Rubinstein, Tygar; Adversarial Machine Learning, Cambridge University Press, 2019

Outline

Introduction

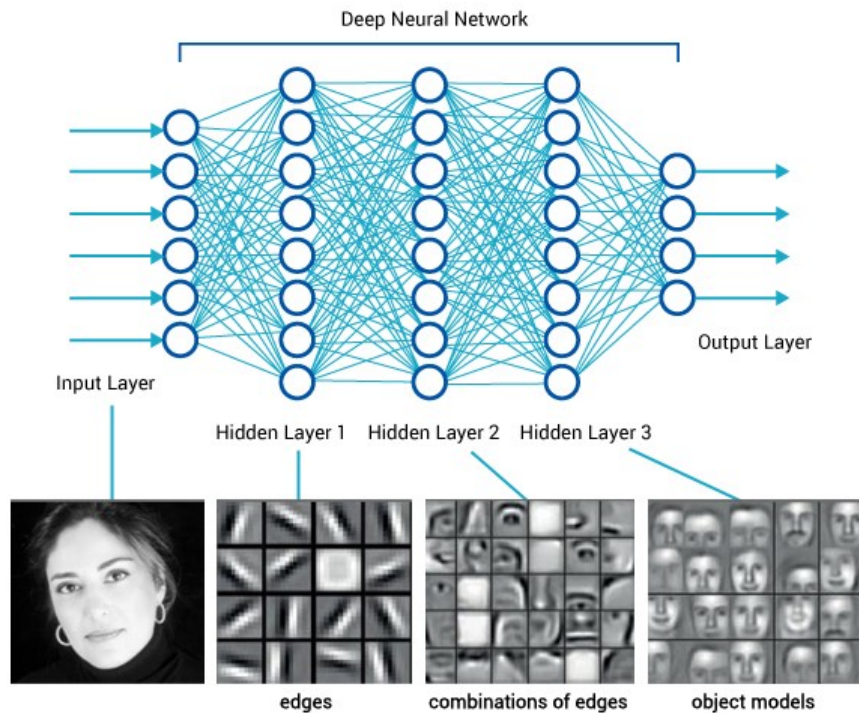
Understanding the ML Attack Surface

Understanding Risks of Transfer Learning

Remedies and Limitations

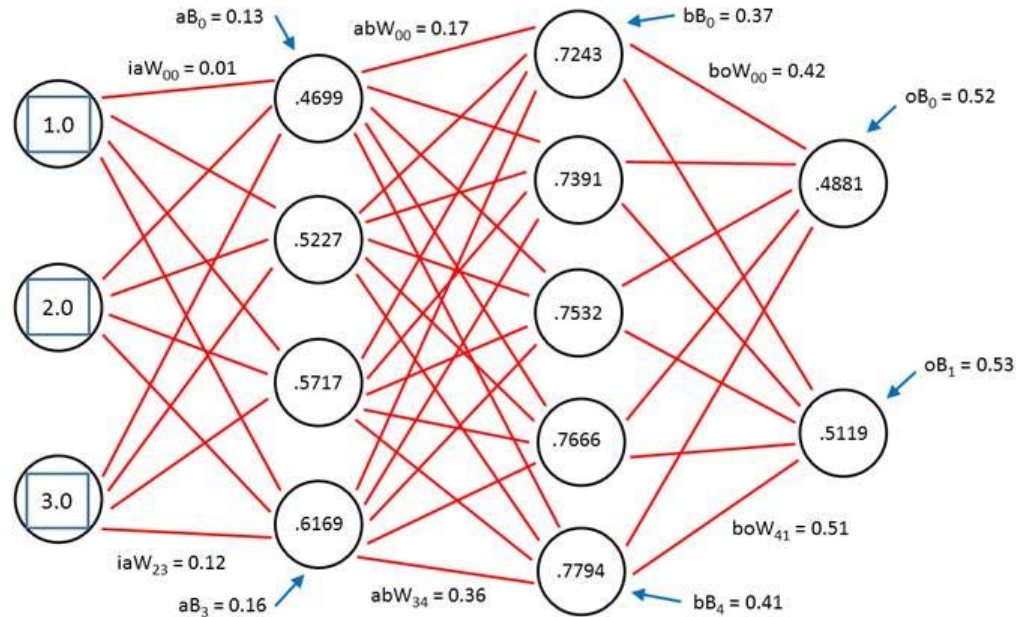
Conventional Threats to Machine Learning

Deep Neural Network Structure



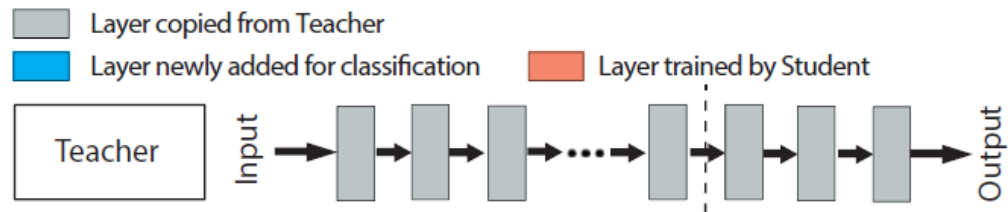
[Aashay Sachdeva](https://medium.com/diaryofawannapreneur/deep-learning-for-computer-vision-for-the-average-person-861661d8aa61), Deep Learning for Computer Vision for the average person, [Mar 6, 2017](#),
<https://medium.com/diaryofawannapreneur/deep-learning-for-computer-vision-for-the-average-person-861661d8aa61>

Trained Deep Neural Network



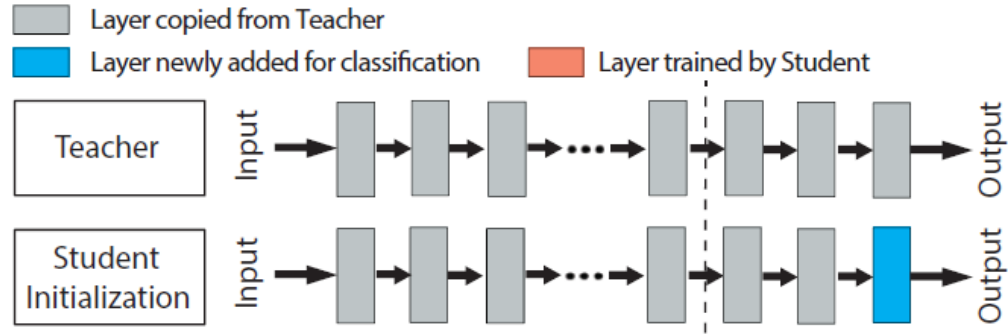
Sergey Golubev, Deep Neural Networks: A Getting Started Tutorial, Part #1, 30 June 2014, <https://www.mql5.com/en/blogs/post/203>

Overview of Transferring Learning



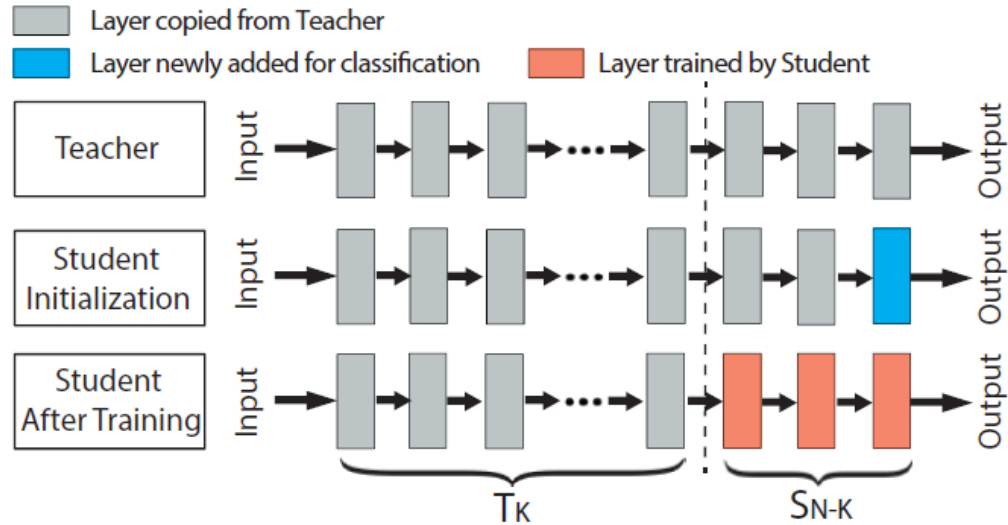
Bolun Wang, Yuanshun Yao, Bimal Viswanath, Haitao Zheng, Ben Y. Zhao; "With Great Training Comes Great Vulnerability: Practical Attacks Against Transfer Learning," 27th USENIX Security Symposium; Aug 15-17, 2018; pg 1281

Overview of Transferring Learning



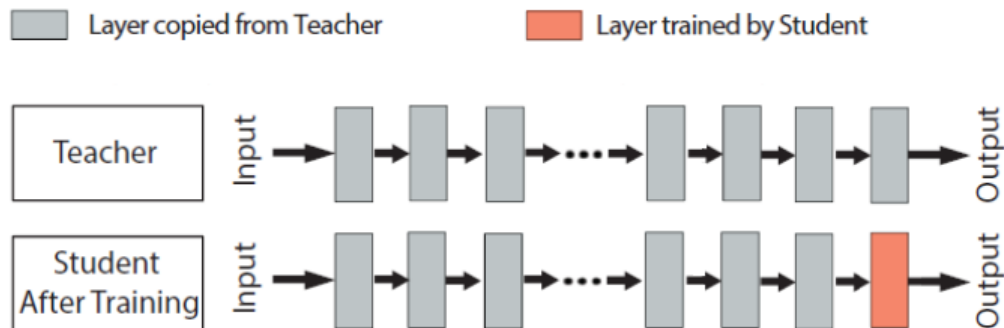
Bolun Wang, Yuanshun Yao, Bimal Viswanath, Haitao Zheng, Ben Y. Zhao; "With Great Training Comes Great Vulnerability: Practical Attacks Against Transfer Learning," 27th USENIX Security Symposium; Aug 15-17, 2018; pg 1281

Overview of Transferring Learning



Bolun Wang, Yuanshun Yao, Bimal Viswanath, Haitao Zheng, Ben Y. Zhao; "With Great Training Comes Great Vulnerability: Practical Attacks Against Transfer Learning," 27th USENIX Security Symposium; Aug 15-17, 2018; pg 1281

Deep Layer Feature Extraction



Used when domains are close

Pro: Cheap training; good accuracy

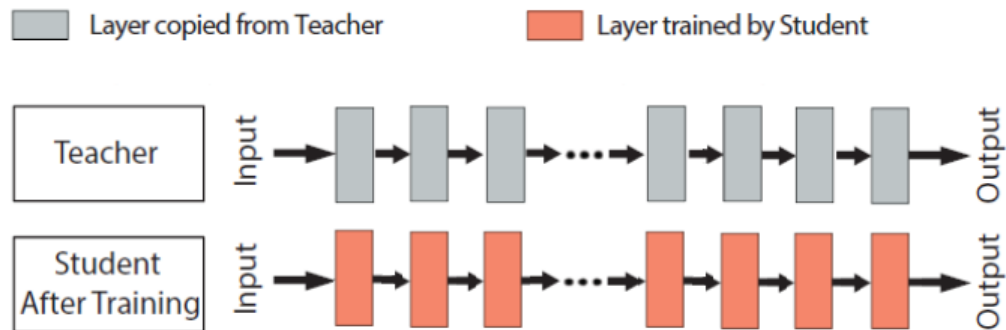
Con: Adversary has deep knowledge of teacher

Easier to exfiltrate model

Easier to create adversarial input

Bolun Wang, Yuanshun Yao, Bimal Viswanath, Haitao Zheng, Ben Y. Zhao; "With Great Training Comes Great Vulnerability: Practical Attacks Against Transfer Learning," 27th USENIX Security Symposium, Aug 15-17, 2018; pg 1281

Full model fine tuning



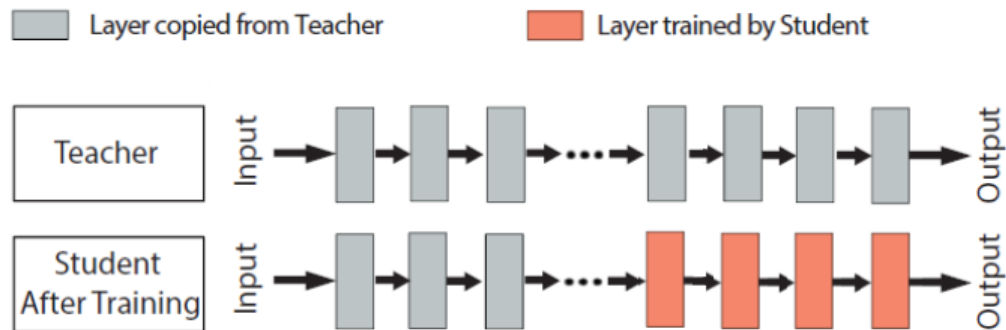
Used when domains are not close

Pro: Better accuracy than deep layer feature extraction
Resilient to teacher-specific attacks

Con: Costly to train

Bolun Wang, Yuanshun Yao, Bimal Viswanath, Haitao Zheng, Ben Y. Zhao; "With Great Training Comes Great Vulnerability: Practical Attacks Against Transfer Learning," 27th USENIX Security Symposium; Aug 15-17, 2018; pg 1281

Mid-Layer Feature Extraction



Compromise choice

- Accuracy depends on relationship between student and teacher domains
- Better resiliency than deep, not as good as full
- More costly to train than deep, cheaper than full

Bolun Wang, Yuanshun Yao, Bimal Viswanath, Haitao Zheng, Ben Y. Zhao; "With Great Training Comes Great Vulnerability: Practical Attacks Against Transfer Learning," 27th USENIX Security Symposium; Aug 15-17, 2018; pg 1281

Outline

Introduction

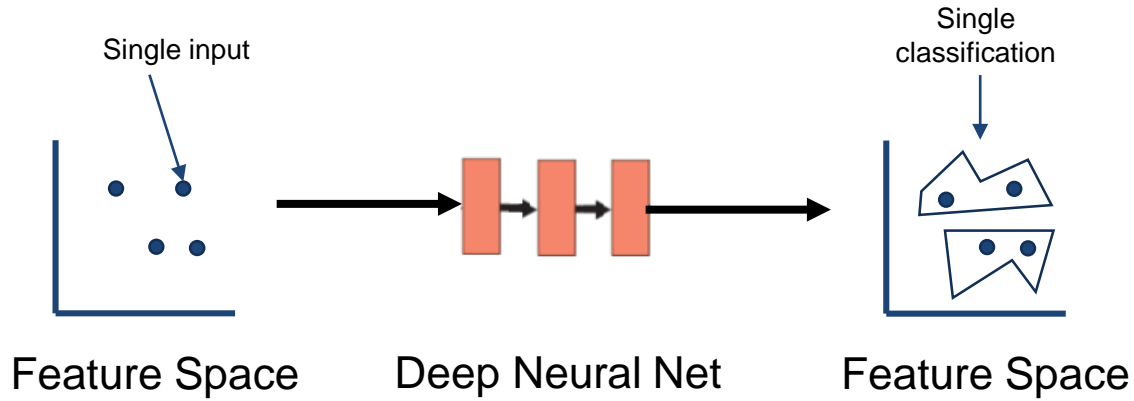
Understanding the ML Attack Surface

Understanding Risks of Transfer Learning

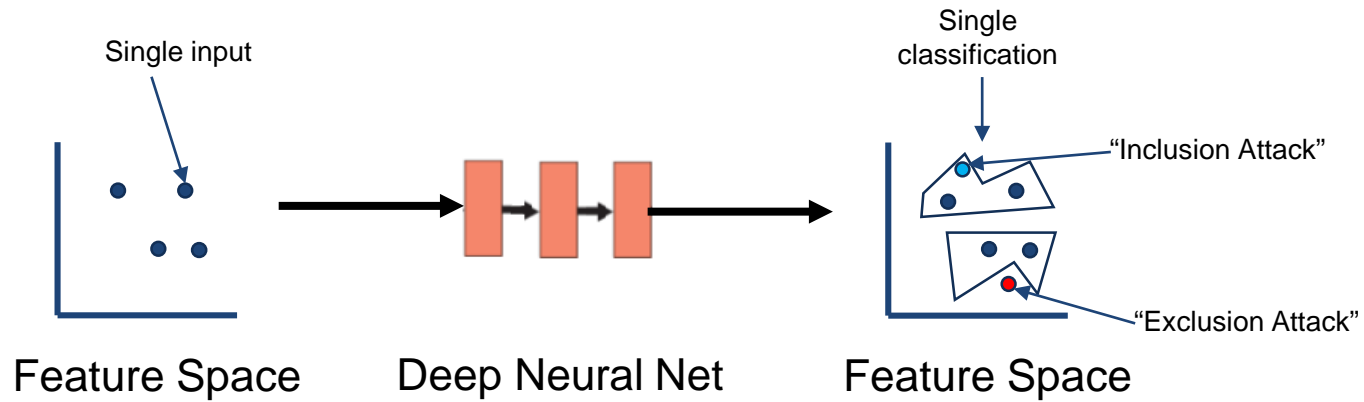
Remedies and Limitations

Conventional Threats to Machine Learning

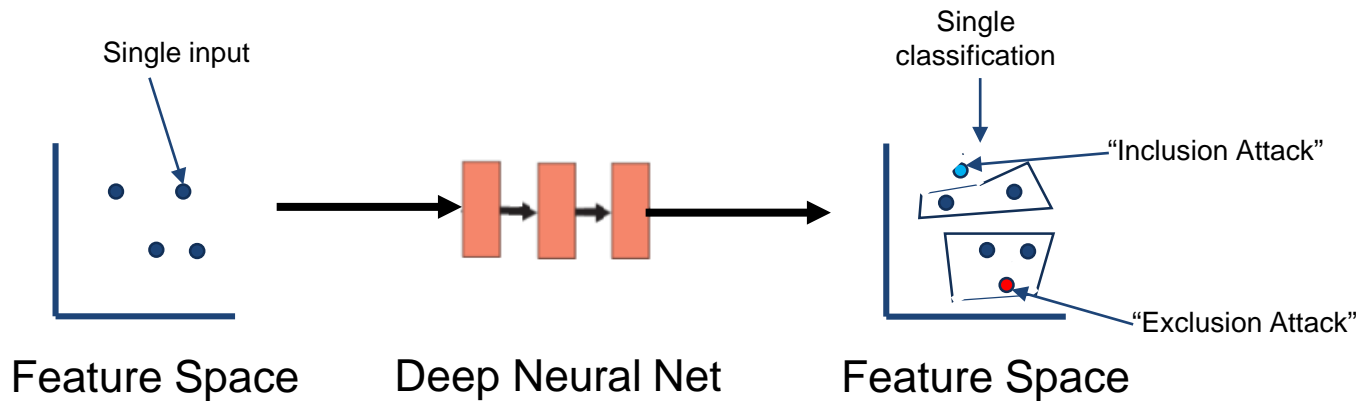
Creating Classifications



Adversarial Input



Adding Resiliency



- Cutting off spikes mitigates undesired “inclusions”
- Enclosing spikes mitigates undesired “exclusions”

Training for resilience

Methods to improve model resiliency

- Add adversarial examples in training
- Train with larger domain subset
- Calculate convex hull of classification boundary
- Apply statistical robust regression

All of these methods trade resiliency for accuracy

- Adversarial examples are noisy
- Overfitting creates raggedy boundaries
- Concave boundaries could be legitimate – should be excluded
- Looser boundaries could be legitimate – should be included

Redundancy is an alternative strategy – at a cost

Outline

Introduction

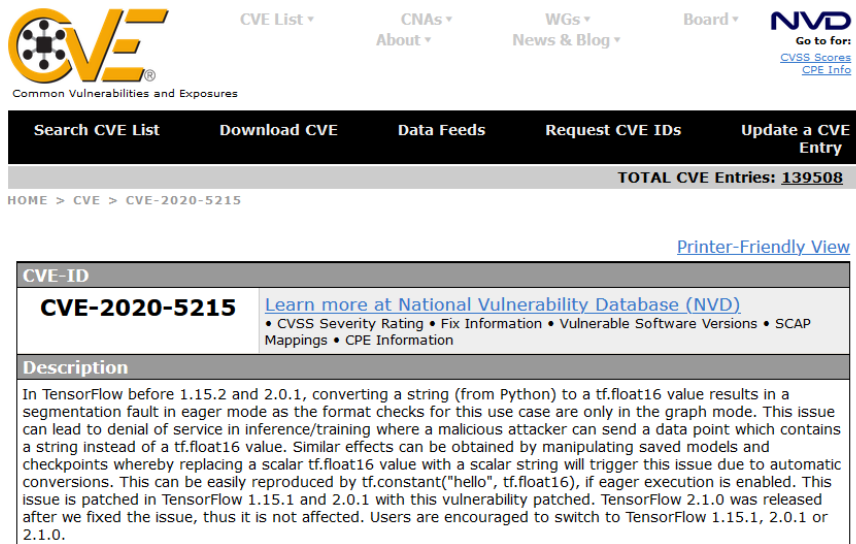
Understanding the ML Attack Surface

Understanding Risks of Transfer Learning

Remedies and Limitations

Conventional Threats to Machine Learning

Coding Hygiene



The screenshot shows the CVE Mitre website interface. At the top, there is a navigation bar with links for 'CVE List', 'CNAs', 'WGs', 'Board', and 'NVD'. Below this is a search bar and a navigation menu with options like 'Search CVE List', 'Download CVE', 'Data Feeds', 'Request CVE IDs', and 'Update a CVE Entry'. The main content area displays the CVE ID 'CVE-2020-5215' and a link to 'Learn more at National Vulnerability Database (NVD)'. Below this is a 'Description' section with the following text:

In TensorFlow before 1.15.2 and 2.0.1, converting a string (from Python) to a tf.float16 value results in a segmentation fault in eager mode as the format checks for this use case are only in the graph mode. This issue can lead to denial of service in inference/training where a malicious attacker can send a data point which contains a string instead of a tf.float16 value. Similar effects can be obtained by manipulating saved models and checkpoints whereby replacing a scalar tf.float16 value with a scalar string will trigger this issue due to automatic conversions. This can be easily reproduced by `tf.constant("hello", tf.float16)`, if eager execution is enabled. This issue is patched in TensorFlow 1.15.1 and 2.0.1 with this vulnerability patched. TensorFlow 2.1.0 was released after we fixed the issue, thus it is not affected. Users are encouraged to switch to TensorFlow 1.15.1, 2.0.1 or 2.1.0.

<https://cve.mitre.org/cgi-bin/cvename.cgi?name=CVE-2020-5215>

Any of the algorithms in creating the application or in the generated application could have coding weaknesses leading to vulnerabilities

Mitigation: Good cyber hygiene

Software supply chain for assembled software

Machine learning depends on frameworks and data sets
Relatively less is known about the security of these “supplies”

Machine Learning Frameworks

- Pandas
- Numpy
- Scikit-learn
- Matplotlib
- TensorFlow
- Keras
- Seaborn
- Pytorch & Torch

Data Sources

- Kaggle
- UCI Machine Learning Repository
- Find Datasets
- Data.gov
- xView
- ImageNet
- Google’s Open Images

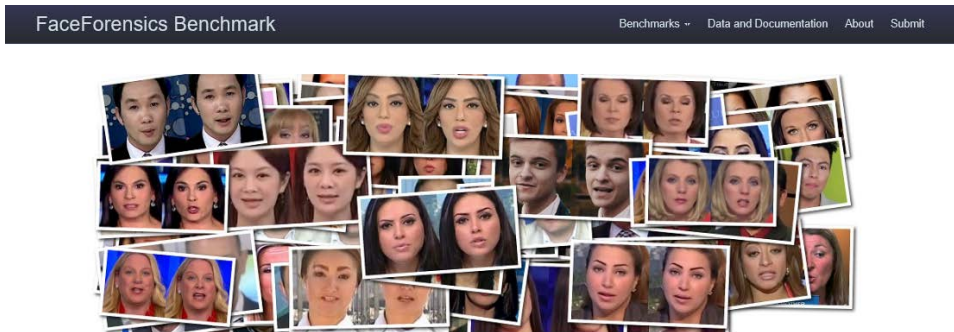
Machine learning system face training data supply challenges



Rich supplies of “deep fakes” are readily accessible

Source: <https://ai.googleblog.com/2019/09/contributing-data-to-deepfake-detection.html>

Poor detection of deep fakes



FaceForensics Benchmark

This table lists the benchmark results for the Binary Classification scenario.

Method	Info	Deepfakes	Face2Face	FaceSwap	NeuralTextures	Pristine	Total
Xception	P	0.964	0.869	0.903	0.807	0.524	0.710
<small>Andreas Rössler, Davide Cozzolino, Luisa Verdoliva, Christian Riess, Justus Thies, Mathias Nießner: FaceForensics++: Learning to Detect Manipulated Facial Images. ICCV 2019</small>							
MesoNet		0.873	0.562	0.612	0.407	0.726	0.660
<small>Darius Afshar, Vincent Nozick, Junichi Yamagishi, and Isao Echizen: MesoNet: a compact facial video forgery detection network. arXiv</small>							
XceptionNet Full Image	P	0.745	0.759	0.709	0.733	0.510	0.624
<small>Andreas Rössler, Davide Cozzolino, Luisa Verdoliva, Christian Riess, Justus Thies, Mathias Nießner: FaceForensics++: Learning to Detect Manipulated Facial Images. ICCV 2019</small>							
Bayar and Stamm		0.845	0.737	0.825	0.707	0.462	0.616
<small>Behlensen Bayar and Matthew C. Stamm: A deep learning approach to universal image manipulation detection using a new convolutional layer. ACM Workshop on Information Hiding and Multimedia Security</small>							
Rahmouni		0.855	0.642	0.563	0.607	0.500	0.581
<small>Nicolas Rahmouni, Vincent Nozick, Junichi Yamagishi, and Isao Echizen: Distinguishing computer graphics from natural images using convolution neural networks. IEEE Workshop on Information Forensics and Security</small>							
Recasting		0.855	0.679	0.738	0.780	0.344	0.552
<small>Davide Cozzolino, Giovanni Poggi, and Luisa Verdoliva: Recasting residual-based local descriptors as convolutional neural networks: an application to image forgery detection. ACM Workshop on Information Hiding and Multimedia Security</small>							
Steganalysis Features		0.736	0.737	0.689	0.633	0.340	0.518
<small>Jessica Fridrich and Jan Kodovsky: Rich Models for Steganalysis of Digital Images. IEEE Transactions on Information Forensics and Security</small>							

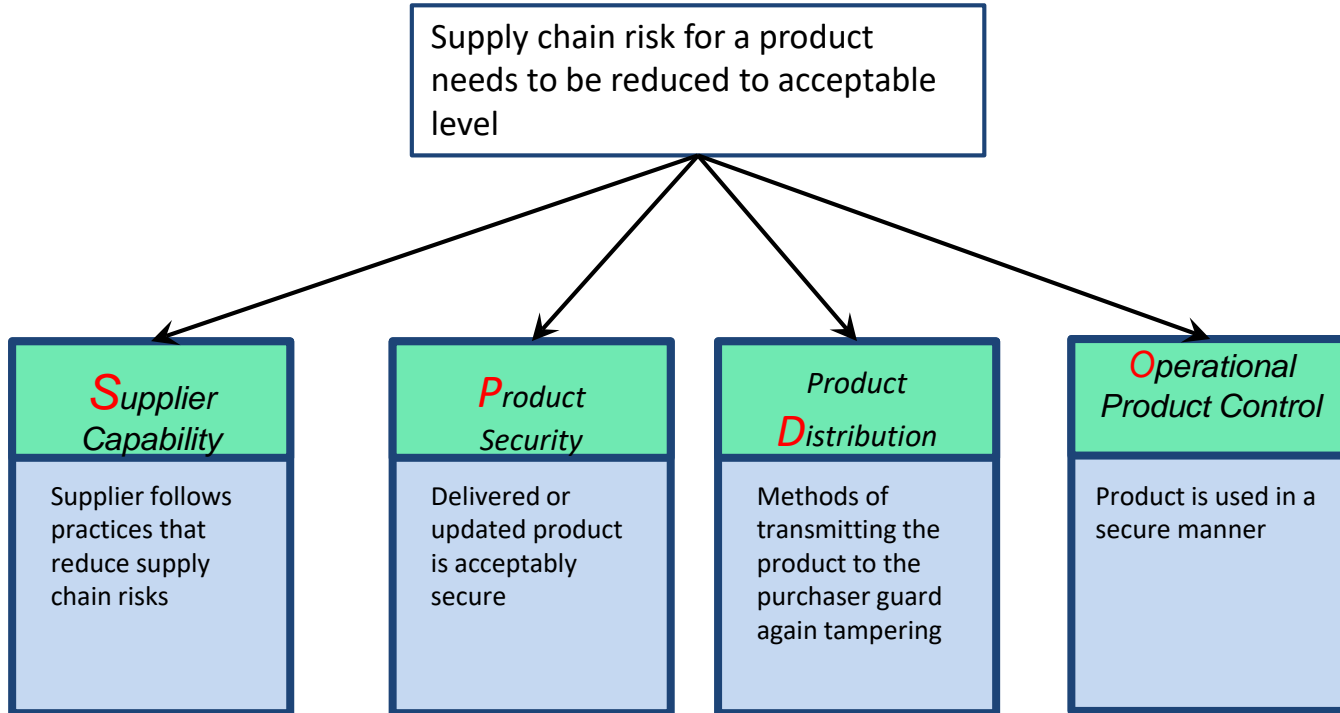
Cannot reliably verify that training data obtained through a supply chain

Preconfigured machine learning (i.e., teacher) systems provide a vehicle to distribute bad training data

Source:

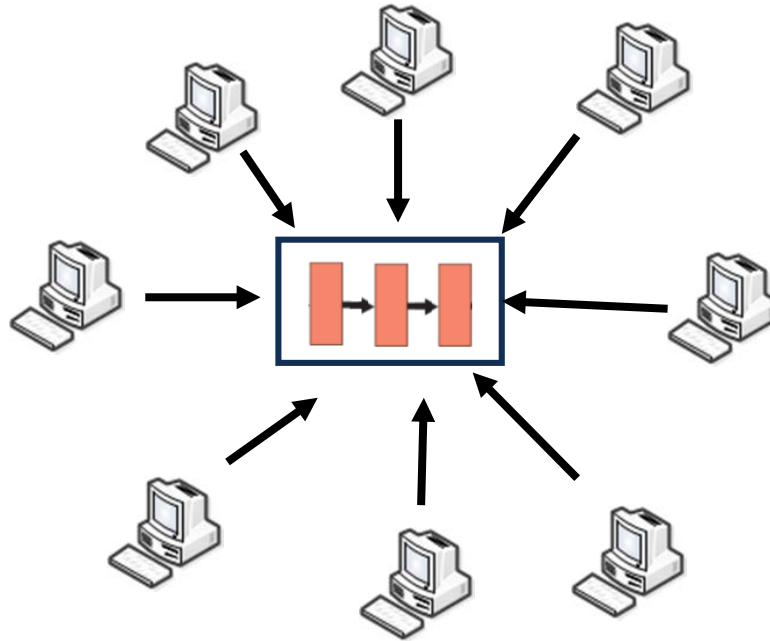
http://kaldir.vc.in.tum.de/faceforensics_benchmark/index.php (as of 9/25/19)

Reducing supply chain risk factors



Ellison, Alberts, Creel, Dorofee, Woody, "Software Supply Chain Risk Management: From Products to Systems of Systems," 2010, https://resources.sei.cmu.edu/asset_files/TechnicalNote/2010_004_001_15194.pdf

Denial of Service Attack



Remediation: Network hygiene
(<https://us-cert.cisa.gov/ncas/tips/ST04-015>)

Integration Points are Typically Weak



Machine learning applications are part of a system

New operating environments, i.e., interconnections between system parts, are a major cause of vulnerabilities

Extra-ML parts of the application are routes to ML attacks

Clark, Frei, Blaze, Smith, "Familiarity Breeds Contempt: The Honeymoon Effect and the Role of Legacy Code in Zero-Day Vulnerabilities," ACSAC '10 Dec. 6-10, 2010, p. 251-260."

Insider Threat



Easy vector for data attacks

Remediations:

- Organizational evaluation
- Organizational processes
- Tools
- Training

<https://www.sei.cmu.edu/education-outreach/courses/course.cfm?coursecode=V26>

“Fake News” and AI Untrustworthiness



People ultimately use output from ML systems

Reasoning from ML systems is generally opaque

Parties can amplify potential misgivings

“Through 2021, 80% of line of business (LOB) leaders will override business decisions made by AI,” Gartner survey*

Remediations:

- Technical: Improved explanations and expectations
- Social: Education and experience

Recognize: Machine Learning is Statistics

*Graham Peters, Alan D. Duncan, Gartner Group, “100 Data and Analytics Predictions Through 2024,” March 20, 2020, pg 4

Outline

Introduction

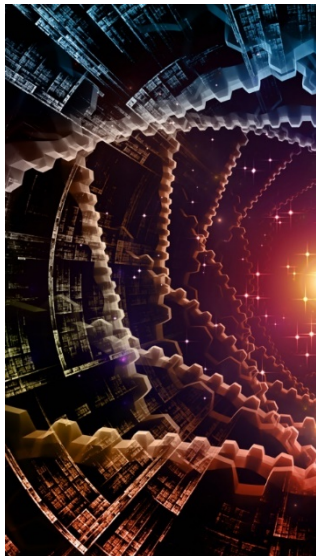
Understanding the ML Attack Surface

Understanding Risks of Transfer Learning

Remedies and Limitations

Conventional Threats to Machine Learning

Ways to Engage with Us



- Download [software and tools](#)
- Explore [research and capabilities](#)
- Participate in [education](#) offerings
- Attend an [event](#)
- Search the [digital library](#)
- Read the [SEI Year in Review](#)
- [Collaborate](#) with the SEI on a new project

Software Engineering Institute
Carnegie Mellon University
4500 Fifth Avenue
Pittsburgh, PA 15213-3890
412-268-5800 - Phone
888-201-4479 - Toll-Free
412-268-5758 - Fax
info@sei.cmu.edu - Email
www.sei.cmu.edu - Web