Common Issues and Challenges in AI for Cybersecurity

Or tinyurl.com/aisecab

Raj Jain

Washington University in Saint Louis

Saint Louis, MO 63130 Jain@wustl.edu

ACM Baltimore Chapter Seminar, August 11, 2022

These slides and a video recording of this talk are at:

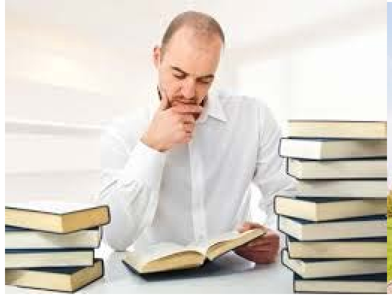
http://www.cse.wustl.edu/~jain/talks/aisecab.htm

Overview

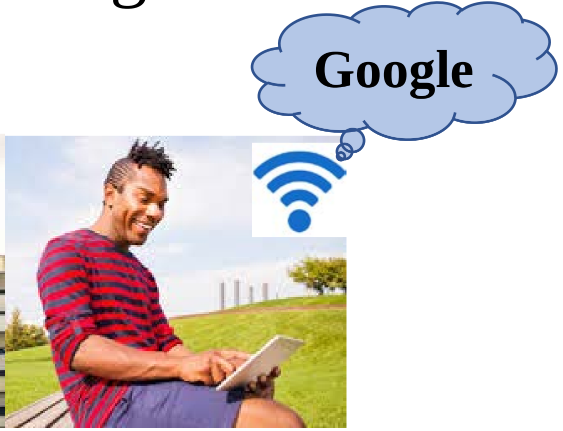
1. AI: Past, Present, Future
2. Our Research on AI: IoT and Security
3. Lessons Learnt: 9 issues with AI studies

Past: Smart Things

- ❑ IoT = Internet of Things = Connected Things
- ❑ Things=Anything (other than computers)
- ❑ Google made worldwide information retrieval instantaneous
- ❑ Instant knowledge ⇒ Smart



Not-Smart



Smart

Smart Watch

Smart Health

Smart Home

Smart Cities

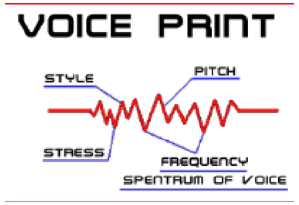
Present: Intelligent Things

❑ Recently, AI became a reality
(the concept of AI has been around since Turing's time but was limited)

❑ Trend: Smart ⇒ Intelligent (Like humans with five senses)

❑ Devices that can figure out what they touch, see, or hear
(Smell and taste are still in research)
Simple pattern recognition ⇒ intelligent touch/visual/sound recognition

Touch ID



Voice Print

Facial Recognition

Amazon Alexa

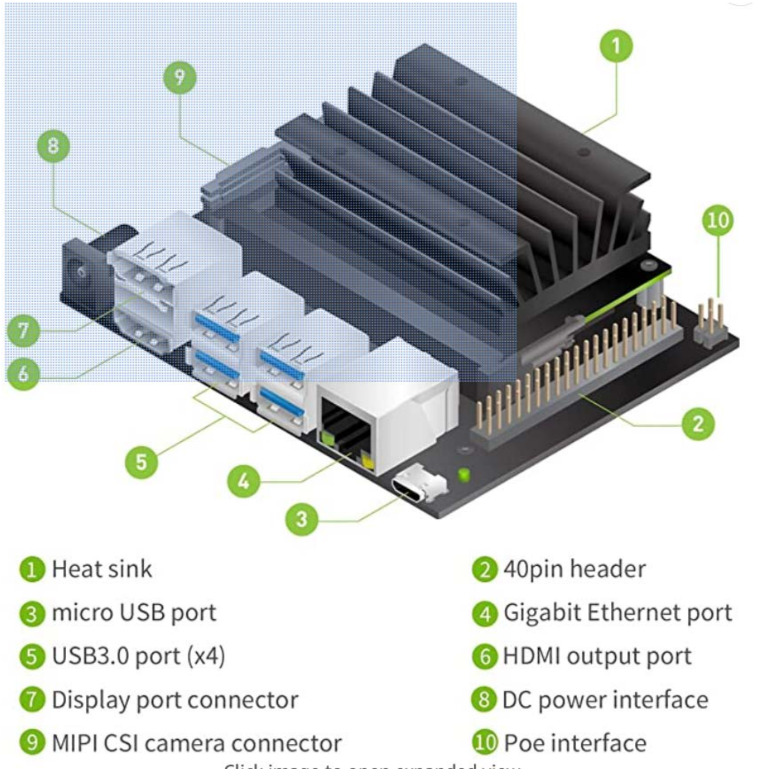
Self-driving Car

AI is everywhere

- ❑ Coffee Machines
- ❑ Vacuums
- ❑ Manufacturing Robots
- ❑ Self-Driving cars
- ❑ Self-Driving Networks
- ❑ Plane Auto-Pilot

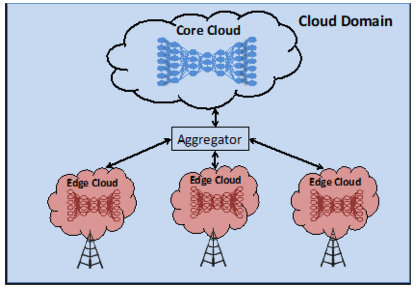
Coming: Edge Intelligence

- ❑ AI requires a significant amount of computation ⇒ Intelligence is in the cloud
- ❑ Only simplified recognition can be done in the devices
- ❑ Moore’s law and miniaturization of electronics are bringing cloud-like capabilities to the edge
- ❑ Edge is moving close to the devices ⇒ Self-Intelligent devices
  AI in end systems, gateways, servers, and clouds
- ❑ AI ASICs (Google Coral, Nvidia Jetson nano) are bringing AI to devices ≈ $200



Source: https://www.amazon.com//dp/B09T37PPRF

Also coming:



1. **Distributed/Federated AI**
2. **Transformers**: DNN models used in language translations
3. **Composite AI**: Using both existing techniques and machine learning
4. **Human-Centered AI**: Augmented intelligence with humans in the loop
5. **Responsible AI**: Fair, unbiased, explainable, regulation compliant
6. **Generative AI**: Generate new ideas, methods, knowledge
7. **AI TRISM** – AI Trust, Risk, Security Management (Explainability, adversarial attack resistance, data protection, anomaly detection, etc.)
8. **Artificial General Intelligence**: Human-like - reasoning, emotions, bias, …grow up more than 18 months old child

AI and IoT Research Funding

- ❑ Artificial Intelligence can be used to generate *Artificial Knowledge* fast
  ⇒ Lots of papers and research funding
- ❑ In 2019, news media reported China is ahead of the US in AI research
  ⇒ National AI Initiative Act 2020
  ⇒ Billions of dollars on AI. $20M each for several AI institutes
- ❑ European Union's Framework Program 7 (FP7) was the first to fund IoT research
- ❑ We discovered this during our research on "Next Generation Networks
  ⇒ IoT research since 2010.

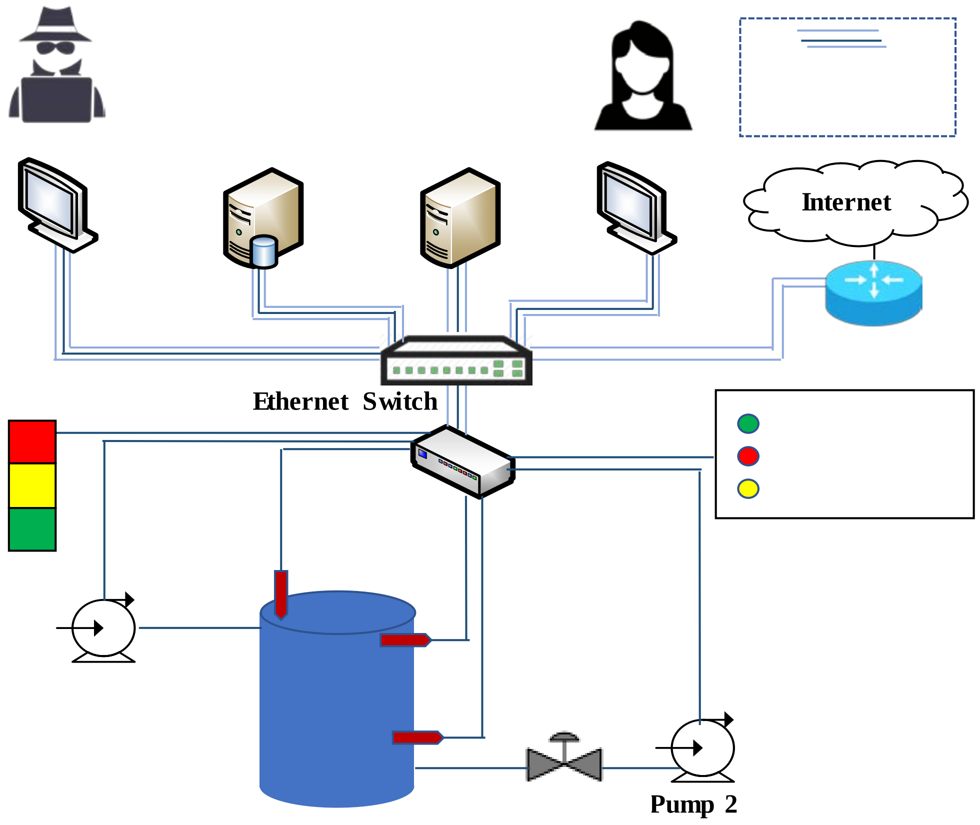
Artificial Intelligence can be used to generate Artificial Knowledge fast

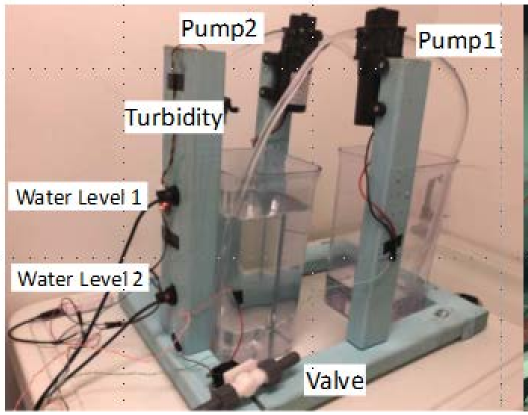
Ref: Subharthi Paul, Jianli Pan, Raj Jain, "**Architectures for the Future Networks and the Next Generation Internet: A Survey**," Computer Communications, UK, Volume 34, Issue 1, 15 January 2011, pp. 2-42, http://www.cse.wustl.edu/~jain/papers/i3survey.htm [299 citations]

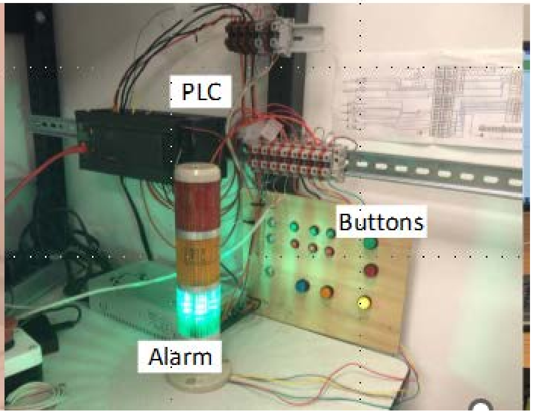
AI-Based Security of IoT: Our Research

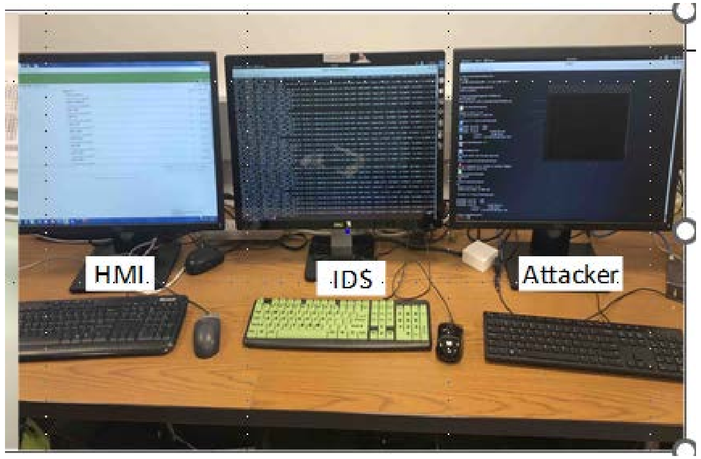
- ❑ Security research since 2009
- ❑ AI research since 2017
- ❑ Security of Industrial Internet of Things (IIoT)
- ❑ Security of Internet of Medical Things (IoMT)
- ❑ Security using blockchains
- ❑ 24+ papers
- ❑ AI = Pattern recognition, probabilistic reasoning, machine learning, deep learning, …
- ❑ Everything we say applies to all of these variations.

Industrial Control Systems Security Using AI



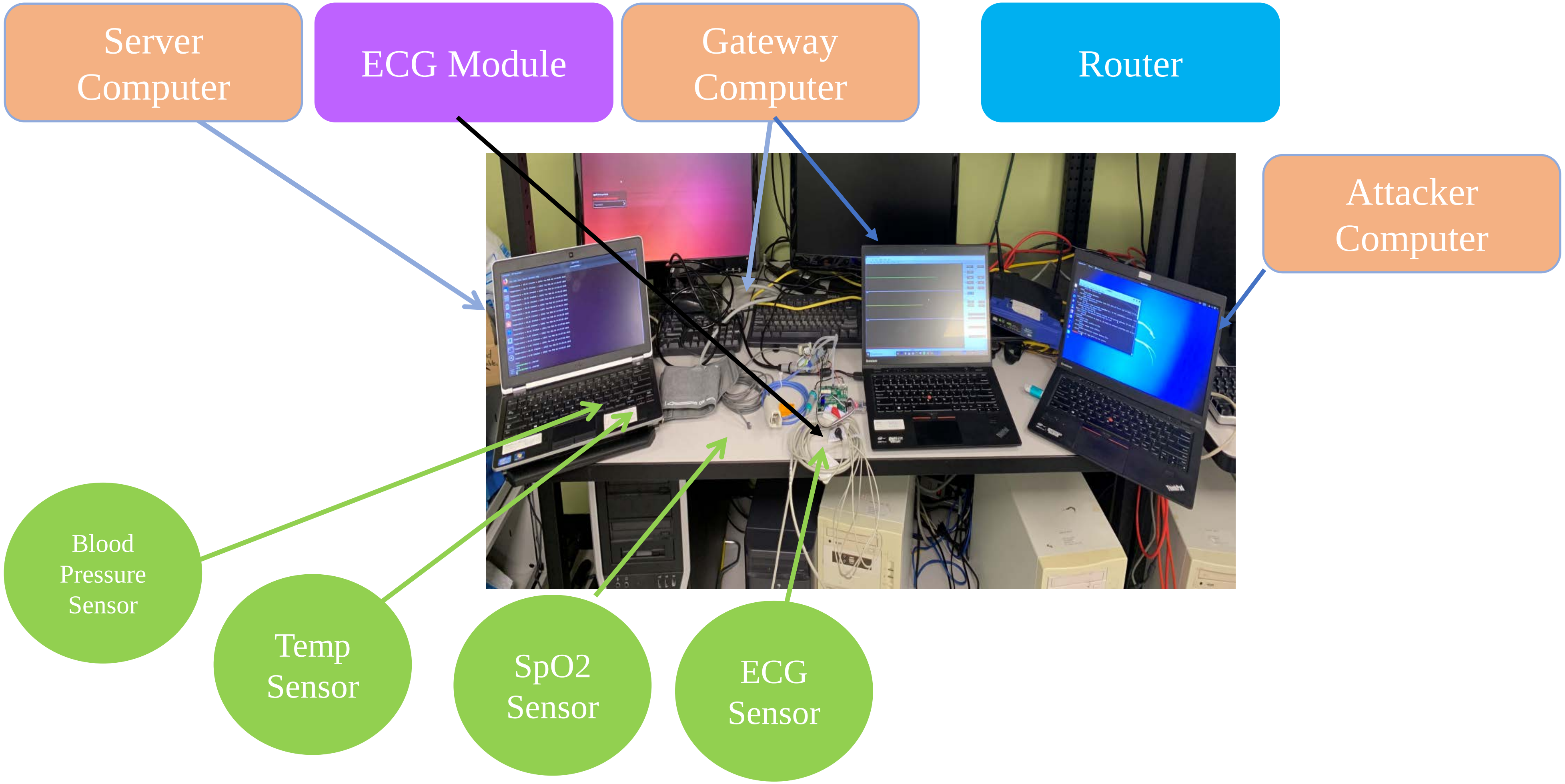






WUSTL-IIOT-2021 Dataset for IIoT Cybersecurity Research, http://www.cse.wustl.edu/~jain/iiot2/index.html

Internet of Medical Things Security Using AI



Server Computer

ECG Module

Gateway Computer

Router

Attacker Computer

Blood Pressure Sensor

Temp Sensor

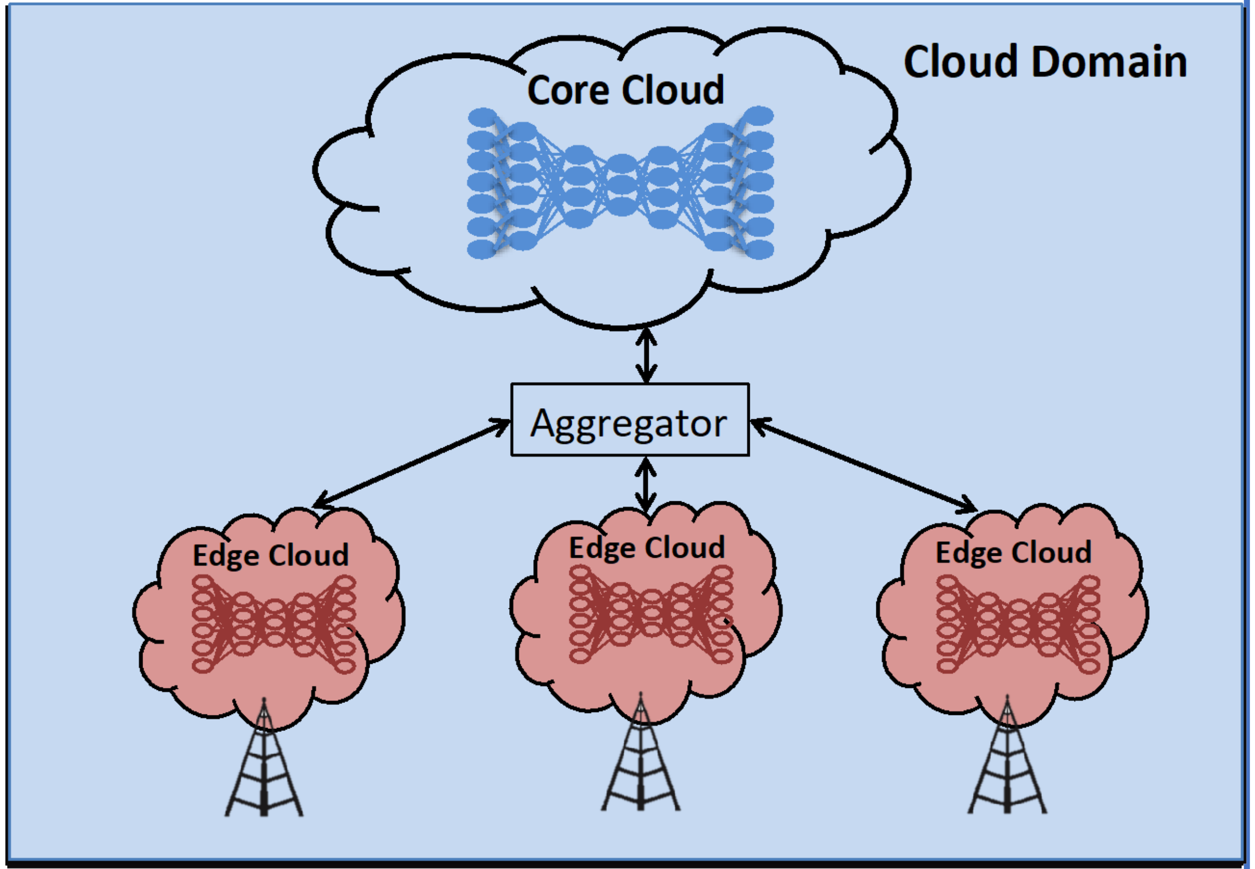
SpO2 Sensor

ECG Sensor

WUSTL EHMS 2020 Dataset for Internet of Medical Things (IoMT) Cybersecurity Research, http://www.cse.wustl.edu/~jain/ehms/index.html

Edge AI: Hierarchical Deep Learning

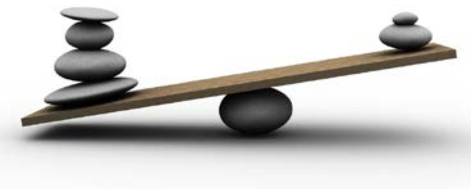
- ❑No need to send data to the core cloud
- ❑ Edge clouds send a preliminary model to the core
- ❑Also known as “Federated Learning”



Ref: L. Gupta, T. Salman, A. Ghubaish, D. Unal, A. K. Al-Ali, R. Jain, "**Cybersecurity of multi-cloud healthcare systems: A hierarchical deep learning approach**," Applied Soft Computing (2022), 5 January 2022, http://www.cse.wustl.edu/~jain/papers/muse.htm

Lessons Learnt: 9 Problems with AI Studies

1. No Domain Expertise
2. Random Datasets
3. Imbalance of Security Data
4. Wrong Performance Metrics
5. Too Few or Too Many Features
6. Results Not Explainable
7. No Sensitivity Analysis
8. No Real-World Validation
9. Omitting Assumptions and Limitations

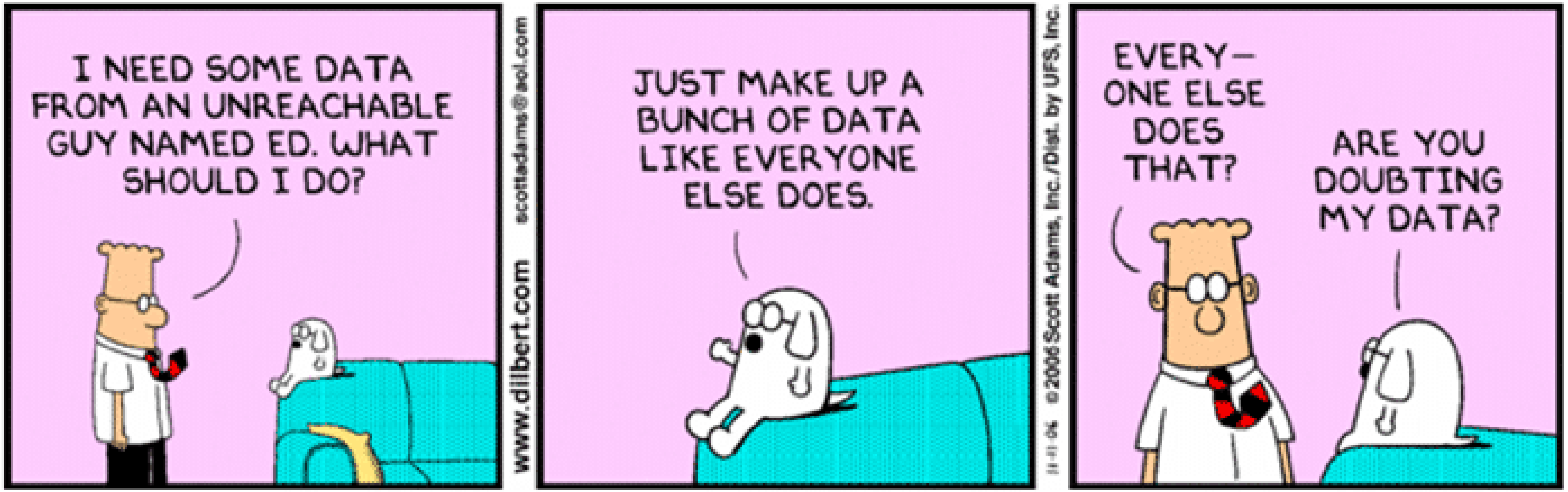


1. No Domain Expertise

- ❑ ML algorithms are used without domain expertise
- ❑ Data cleanliness, labeling, and feature extractions require domain knowledge, e.g., What is the distance between Port 80, Port 81, and Port 8080?
- ❑ To analyze medical data with AI, you don’t need to be a doctor

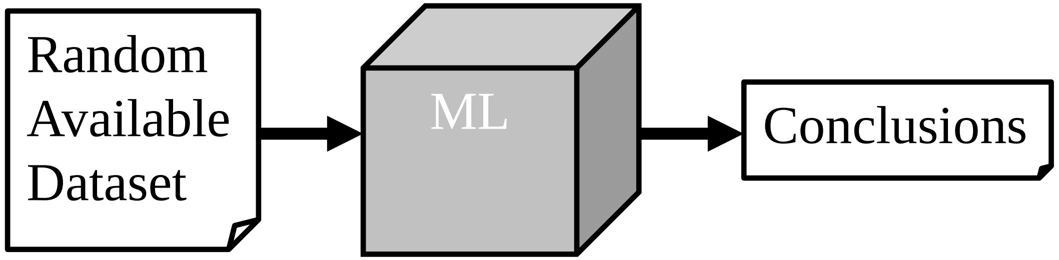
With AI, even a dog can be an “intelligent” doctor?

2. Random Datasets


I NEED SOME DATA FROM AN UNREACHABLE GUY NAMED ED. WHAT SHOULD I DO?
www.dilbert.com scottadams@aol.com
JUST MAKE UP A BUNCH OF DATA LIKE EVERYONE ELSE DOES.
©2006 Scott Adams, Inc./Dist. by UFS, Inc.
EVERY-ONE ELSE DOES THAT?
ARE YOU DOUBTING MY DATA?

2. Random Datasets

- ❑ Real data is usually private. Not published.
- ❑ Published data is either old or too generic.
- ❑ KDD, a commonly used dataset in intrusion studies, is a simulated dataset from 1999.

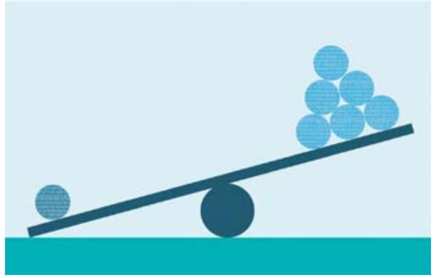


Garbage-In, Garbage-Out

Ref: KDD Cup 1999 Data, October 28, 1999, http://kdd.ics.uci.edu/databases/kddcup99/kddcup99.html

3. Imbalance of Security Data

- ❑ AI started with image analysis but needs to be extended for security
- ❑ Security data is very different from image data
  - ➢ Most security datasets are not representative of the real world.
  - ➢ In most papers, 10-15% of the packets are attack packets
- ❑ In real-world, 1 in several billion packets is an attack packet
  - ➢ Mis-classify the attack packet ⇒ 99.9999% accuracy
- ❑ **Extreme Data imbalance** is a critical issue in security



1% attack

Ref: Maede Zolanvari, Marcio A. Teixeira, Raj Jain, "**Effect of Imbalanced Datasets on Security of Industrial IoT Using Machine Learning**," 2018 IEEE International Conference on Intelligence and Security Informatics (ISI), Miami FL, Nov. 9 - 11, 2018, 6 pp., http://www.cse.wustl.edu/~jain/papers/imb_isi.htm

4. Wrong Metrics

- In Image analysis:
  Cost of predicting “0” when it is “1” = Cost of predicting “1” when it is “0.”
  ⇒ Cost of errors is symmetric ⇒ Almost all metrics are symmetric.
- In Cyber Security:
  - Cost of missing an attack = 10^6 × Cost of false attack prediction
  - Washington Post (5/30/22): 5 missiles hit Iraqi base hosting US troops
  - Would you live at the base protected with 90% accuracy?
- Need new metric to find the best algorithm ⇒ Use **Safety Score**

Ref: Tara Salman, Ali Ghubaish, Devrim Unal, Raj Jain, "**Safety Score as an Evaluation Metric for Machine Learning Models of Security Applications**," IEEE Networking Letters, Vol. 2, Issue 4, December 2020, pp. 207-211, http://www.cse.wustl.edu/~jain/papers/safety.htm

5. Too Few or Too Many Features

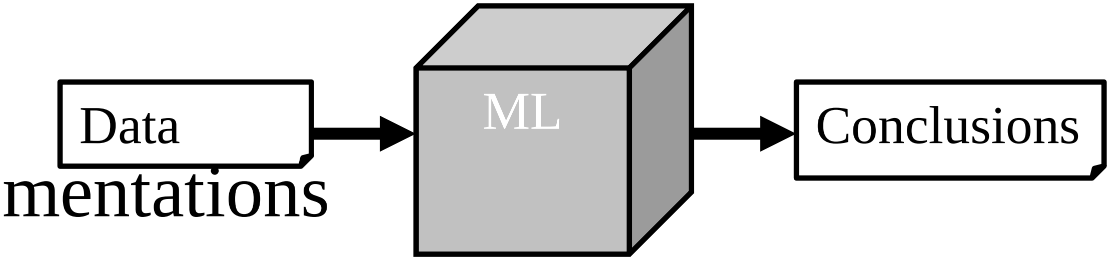
- ❑ Too few features can miss important factors
- ❑ Too many features do not always increase accuracy or validity
- ❑ Adding correlated features to a model (Multicollinearity) can adversely affect its validity
- ❑ Feature engineering techniques can not help add a missing feature

6. Results Not Explainable

- ❑ Would you trust AI to diagnose your disease?
- ❑ No, because you have no idea of why the results are what they are

Machine Learning is what only machines can do, but human cannot do and cannot explain

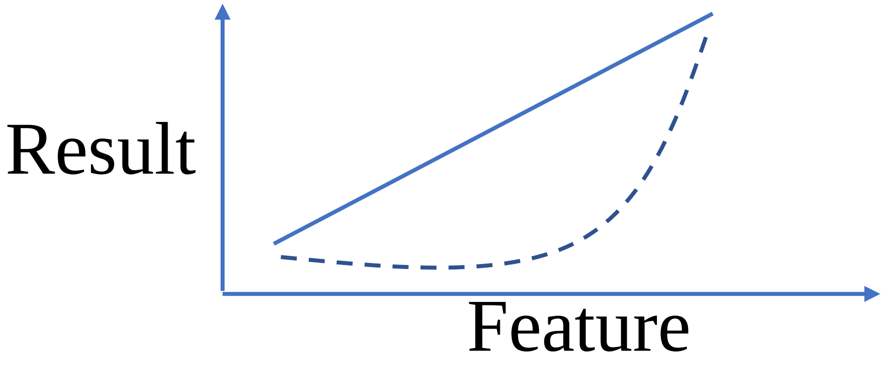
- ❑ AI is a black box
- ❑ Can't discover bugs in ML model implementations
- ❑ Need Trustable AI = Explainable AI
  ⇒ Models to explain the AI predictions so that humans can understand



Ref: Maede Zolanvari, Zebo Yang, Khaled Khan, Raj Jain, and Nader Meskin, "TRUST XAI: A Novel Model for Explainable AI with An Example Using IIoT Security," IEEE IoT Journal, preliminary acceptance, September 2021.

7. No Sensitivity Analysis

- ❑ In traditional analysis, simulation, or measurements, we vary each feature slightly to see which features have the most effects.
- ❑ Proper experimental design can help estimate interactions among features
- ❑ This is not easy in ML. Dataset is all that we can easily change. This can result in a bulk/uncontrolled change.
- ❑ Changing individual features has been suggested but may not be representative/valid.



8. No Real-World Validation

- Results are stated without model validation.
- A part of the same dataset is used as input (training) and to validate (test) the model
- Cross-Validation: Divide the dataset into *k* parts and use 1 part for testing and use the remaining *k-1* parts for training
- In traditional analysis, each method is validated with a different method, e.g., analysis by simulation or measurements, measurements via simulation or theory, theory by simulation or measurements
- To validate an AI model, it is necessary to measure its performance in the real world. Testing in production (TIP). This is hardly ever done.
- Validate at least the "corner" cases.

9. Omitting Assumptions and Limitations

- ❑ The dataset is assumed valid for contexts widely different from the one where it was generated
- ❑ It is vital to describe the context in which the data was gathered so that the users will not use it in out-of-context
- ❑ Security datasets assume specific attacks. The list of attacks in 2022 is very different from those just a few years ago, let alone 30 years ago.

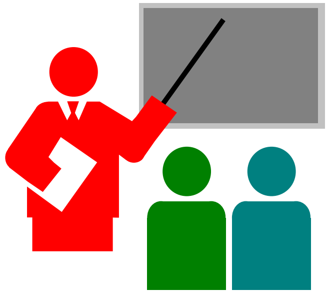
Ref: Raj Jain, "The Art of Computer Systems Performance Analysis: Techniques for Experimental Design, Measurement, Simulation, and Modeling," Wiley-Interscience, New York, NY, April 1991

Jain's List of ~~Issues~~ Challenges with AI

1. No Domain Expertise
2. Random Datasets
3. Imbalance of Security Data
4. Wrong Performance Metrics
5. Too Few or Too Many Features
6. Results Not Explainable
7. No Sensitivity Analysis
8. No Real-World Validation
9. Omitting Assumptions and Limitations

Issues ⇒ Challenges ⇒ Opportunities for Research.

Summary



1. AI is a prime topic for research. Especially for IoT and for Security.
2. AI for security is very different from that for image-based applications.
3. AI results will not be trusted without explainability.
   We have proposed "TrustXAI."
4. Extreme risk in security applications requires newer metrics.
   We have proposed a "Safety Score."
5. Intelligence is moving to the edge. Core cloud to edge cloud to the edge device. We have proposed hierarchical deep learning.

Our Publications on AI

- ❑ L. Gupta, T. Salman, A. Ghubaish, D. Unal, A. K. Al-Ali, R. Jain, "Cybersecurity of multi-cloud healthcare systems: A hierarchical deep learning approach," Applied Soft Computing (2022), 5 January 2022, http://www.cse.wustl.edu/~jain/papers/muse.htm
- ❑ Maede Zolanvari, Ali Ghubaish, and Raj Jain, "ADDAI: Anomaly Detection using Distributed AI," in Proceedings of IEEE ICNSC (International Conference on Networking, Sensing and Control), October 2021., http://www.cse.wustl.edu/~jain/papers/addai.htm
- ❑ M Zolanvari, Z Yang, K Khan, R Jain, N Meskin, "TRUST XAI: Model-Agnostic Explanations for AI With a Case Study on IIoT Security," IEEE Internet of Things Journal, 2021, http://www.cse.wustl.edu/~jain/papers/trustxai.htm
- ❑ Tara Salman, Ali Ghubaish, Devrim Unal, Raj Jain, "Safety Score as an Evaluation Metric for Machine Learning Models of Security Applications," IEEE Networking Letters, Vol. 2, Issue 4, December 2020, pp. 207-211, http://www.cse.wustl.edu/~jain/papers/safety.htm
- ❑ Lav Gupta, Tara Salman, Maede Zolanvari, Aiman Erbad, Raj Jain, "Fault And Performance Management In Multi-Cloud Virtual Network Services Using AI: A Tutorial And A Case Study," Computer Networks, Pre-Proof published on 14 Oct 2019, http://www.cse.wustl.edu/~jain/papers/fp_comst.htm

Our Publications on AI (Cont)

- Lav Gupta, Tara Salman, Ria Das, Aiman Erbad, Raj Jain, Mohammed Samaka, "HYPER-VINES: A HYbrid Learning Fault and Performance Issues ERadicator for VIrtual NEtwork Services over Multi-cloud," International Workshop on Computing, Networking and Communications (CNC19) at the International Conference on Computing, Networking and Communications (ICNC 2019), Honolulu, Hawaii, Feb. 18-21, 2019, 7 pp., http://www.cse.wustl.edu/~jain/papers/hypervin.htm
- Maede Zolanvari, Marcio A. Teixeira, Raj Jain, "Effect of Imbalanced Datasets on Security of Industrial IoT Using Machine Learning," 2018 IEEE International Conference on Intelligence and Security Informatics (ISI), Miami FL, Nov. 9 - 11, 2018, 6 pp., http://www.cse.wustl.edu/~jain/papers/imb_isi.htm
- Tara Salman, Deval Bhamare, Aiman Erbad, Raj Jain, Mohammed Samaka, "Machine Learning for Anomaly Detection and Categorization in Multi-cloud Environments," The 4th IEEE International Conference on Cyber Security and Cloud Computing (IEEE CSCloud 2017), New York, June 26-28, 2017, http://www.cse.wustl.edu/~jain/papers/cscloud.htm

Our Publications on AI (Cont)

- Deval Bhamare, Tara Salman, Mohammed Samaka, Aiman Erbad, Raj Jain, "Feasibility of Supervised Machine Learning for Cloud Security," 3rd International Conference on Information Science and Security (ICISS2016), December 19th - 22nd, 2016, Pattaya, Thailand, http://www.cse.wustl.edu/~jain/papers/iciss16.htm

Our Publications on ICS Security

- M Elnour, N Meskin, K Khan, R Jain, "Application of data-driven attack detection framework for secure operation in smart buildings," Sustainable Cities and Society 69, 102816, 2021, http://www.cse.wustl.edu/~jain/papers/secbldg.htm
- M Elnour, N Meskin, K Khan, R Jain, "HVAC System Attack Detection Dataset," Data in Brief, 107166, 2021, http://www.cse.wustl.edu/~jain/papers/hvac.htm
- MA Teixeira, M Zolanvari, KM Khan, R Jain, N Meskin, "Flow-based intrusion detection algorithm for supervisory control and data acquisition systems: A real-time approach," IET Cyber-Physical Systems: Theory & Applications, 2021, http://www.cse.wustl.edu/~jain/papers/ids_ijis.htm
- M. Elnour, N. Meskin, K. Khan, R. Jain, "A Dual-Isolation-Forests-Based Attack Detection Framework for Industrial Control Systems," IEEE Access, Vol. 8, 19 February 2020, pp. 36639 - 36651, http://www.cse.wustl.edu/~jain/papers/dif.htm
- Mariam Elnour, Nader Meskin, Khaled Khan, Raj Jain, "A Dual-Isolation-Forests-Based Attack Detection Framework for Industrial Control Systems," IEEE Access, Vol. 8, 19 February 2020, pp. 36639 - 36651, http://www.cse.wustl.edu/~jain/papers/dif.htm

Our Publications on ICS Security

- *Mariam Elnour, Nader Meskin, Khaled M. Khan, Raj Jain, Syed Zaidi, Hammadur Siddiqui, "Full-Scale Seawater Reverse Osmosis Desalination Plant Simulator," 21st IFAC World Congress in Berlin, Germany, July 12-17, 2020, 8 pp., http://www.cse.wustl.edu/~jain/papers/swrodp.htm*
- *D. Bhamare, M. Zolanvari, A. Erbad, R. Jain, K. Khan, N. Meskin, "Cybersecurity for Industrial Control Systems: A Survey," Computers and Security, Elsevier, Volume 89, February 2020, Article 101677, http://www.cse.wustl.edu/~jain/papers/ics_survey.htm*
- M. Zolanvari, M. Teixeira, L. Gupta, K. Khan, R. Jain, "Machine Learning Based Network Vulnerability Analysis of Industrial Internet of Things," IEEE Internet of Things Journal, Vol. 6, Issue 4, Aug 2019, http://www.cse.wustl.edu/~jain/papers/vulnerab.htm
- M. Zolanvari, M. Teixeira, R. Jain, "Effect of Imbalanced Datasets on Security of Industrial IoT Using Machine Learning," 2018 IEEE International Conference on Intelligence and Security Informatics (ISI), Miami FL, Nov. 9 - 11, 2018, 6 pp., http://www.cse.wustl.edu/~jain/papers/imb_isi.htm
- Marcio Andrey Teixeira, Tara Salman, Maede Zolanvari, Raj Jain, Nader Meskin, and Mohammed Samaka, "SCADA System Testbed for Cybersecurity Research Using Machine Learning Approach," Future Internet 2018, 10(8), 76, http://www.cse.wustl.edu/~jain/papers/ics_ml.htm

Our Publications on Healthcare Security

- Ali Ghubaish, Tara Salman, Maede Zolanvari, Devrim Unal, Abdulla Khalid Al-Ali, Raj Jain, "Recent Advances in the Internet of Medical Things (IoMT) Systems Security," IEEE Internet of Things Journal, Vol. 8, Issue 11, June 1, 2021, http://www.cse.wustl.edu/~jain/papers/iomt_iot.htm
- Anar A. Hady, Ali Ghubaish, T. Salman, Devrim Unal, and R. Jain, "Intrusion Detection System for Healthcare Systems Using Medical and Network Data: A Comparison Study," IEEE Access, June 2020, http://www.cse.wustl.edu/~jain/papers/hms.htm

Our Publications on Blockchains

- Tara Salman, Maede Zolanvari, Aiman Erbad, Raj Jain, and Mohammed Samaka, "Security Services Using Blockchains:A State of the Art Survey" IEEE Communications Surveys and Tutorials, First Quarter 2019, Volume 21, Issue 1, 858-880 pp., http://www.cse.wustl.edu/~jain/papers/bcs.htm
- Tara Salman, Raj Jain, Lav Gupta, "A Reputation Management Framework for Knowledge-Based and Probabilistic Blockchains," IEEE 1st International Workshop on Advances in Artificial Intelligence for Blockchain (AIChain 2019), held in conjunction with the 2019 IEEE International Conference on Blockchain, Atlanta, July 14, 2019, http://www.cse.wustl.edu/~jain/papers/rpmcewa.htm
- Tara Salman, Raj Jain, and Lav Gupta, "Probabilistic Blockchains: A Blockchain Paradigm for Collaborative Decision-Making," 9th IEEE Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON 2018), New York, NY, November 8-10, 2018, 9 pp., http://www.cse.wustl.edu/~jain/papers/pbc_uem.htm

Acronyms

❑ ADDAI	Anomaly Detection using Distributed AI
❑ AI	Artificial Intelligence
❑ AIChain	Artificial Intelligence for Blockchain
❑ AIIoT	AI IoT Congress
❑ FP7	Framework Program 7
❑ HVAC	Heating, Ventilation, and Air Conditioning
❑ HYPER-VINES	HYbrid Learning Fault and Performance Issues ERadicator for VIrtual NEtwork Services
❑ ICISS	Information Science and Security
❑ ICS	Industrial Control Systems
❑ IEEE	Institute for Electrical and Electronics Engineers
❑ IET	Institution of Engineering and Technology
❑ IFAC	International Federation of Automatic Control
❑ IIoT	Industrial Internet of Things

Acronyms (Cont)

IoMT	Internet of Medical Things
IoT	Internet of Things
ISI	Intelligence and Security Informatics
KDD	Knowledge Discovery and Data Mining
ML	Machine Learning
TrustXAI	Trustworthy Explainable AI
SCADA	Supervisory Control and Data Acquisition
TPU	Tensor processing units
XAI	Explainable AI

Scan This to Download These Slides

Raj Jain

Rajjain.com

Tinyurl.com/aisecab

http://www.cse.wustl.edu/~jain/talks/aisecab.htm