Synergy: Collaborative: Security and Privacy-Aware Cyber-Physical Systems

(NSF CNS-1505799 and the Intel-NSF Partnership for Cyber-Physical Systems Security and Privacy)

Insup Lee (PI)

PRECISE Center

School of Engineering and Applied Science

University of Pennsylvania

Intel-NSF Project Meeting

Stanford University

July 12 & 13, 2018

Penn Engineering

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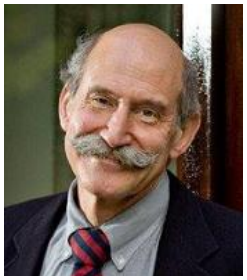

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James Weimer (Penn)

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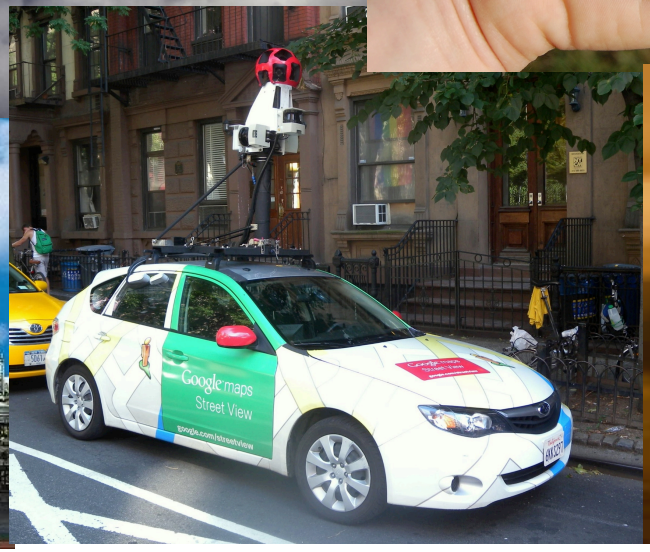
Outline

- Intro on CPS security
- What our team has done
- Lily's Questions

Cyber-Physical Systems

We are heading towards (living in?) a sensor-driven world



need control systems capable of operating in malicious environments

Cyber-Physical Systems Security

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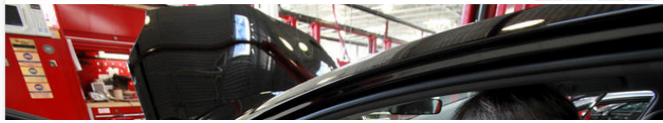
Hackers find weaknesses in car computer systems



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25 July 2013 Last updated at 19:04 ET

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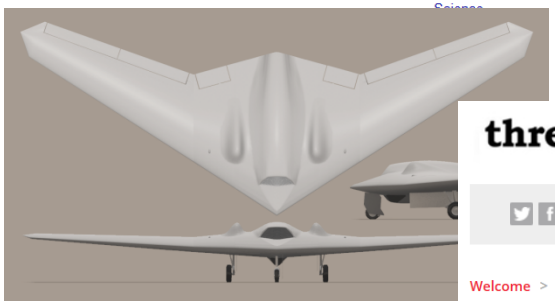
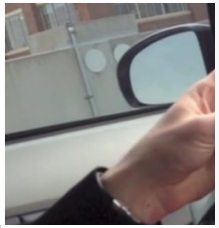
Car hackers use laptop to control standard car

By Zoe Kleinman
Technology reporter, BBC News





The New York Times

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Worm Was Perfect
By WILLIAM J. BROAD and DAVID E. SANG
Published: November 18, 2010

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08/22/14 6:13 NIST Releases Secure Shell Guidance Document
http://t.co/rHpQXdZojI

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National Security

Home > Collections > Surveillance

Iran says it downed U.S. stealth drone; Pentago acknowledges aircraft downing

By Greg Jaffe and Thomas Erdbrink, December 04, 2011

A secret U.S. surveillance drone that went missing last week in western Afghanistan appear have crashed in Iran, in what may be the first case of such an aircraft ending up in the hand an adversary.

Iran's news agencies asserted that the nation's defense force Iranian reports said was an RQ-170 stealth aircraft. It is des

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Hackers Remotely Kill a Jeep on the Highway—With Me in It

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Obama Order Sped Up Wave of Cyberattacks Against Iran

By DAVID E. SANGER
Published: June 1, 2012

WASHINGTON — From his first months in office, President Obama secretly ordered increasingly sophisticated attacks on the computer systems that run Iran's main nuclear enrichment facilities, significantly expanding America's first sustained use of cyberweapons, according to participants in the program.

Mr. Obama decided to accelerate the attacks — begun in the Bush administration and code-named Olympic Games — even after an

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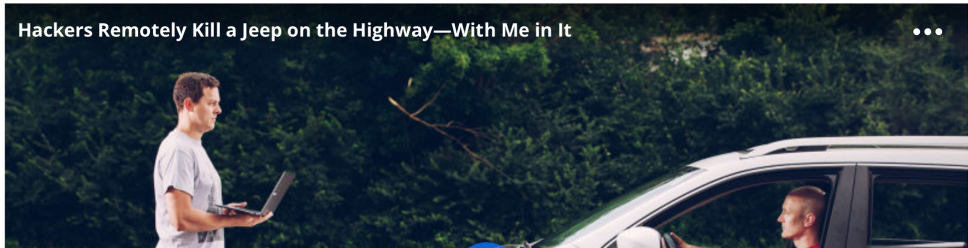
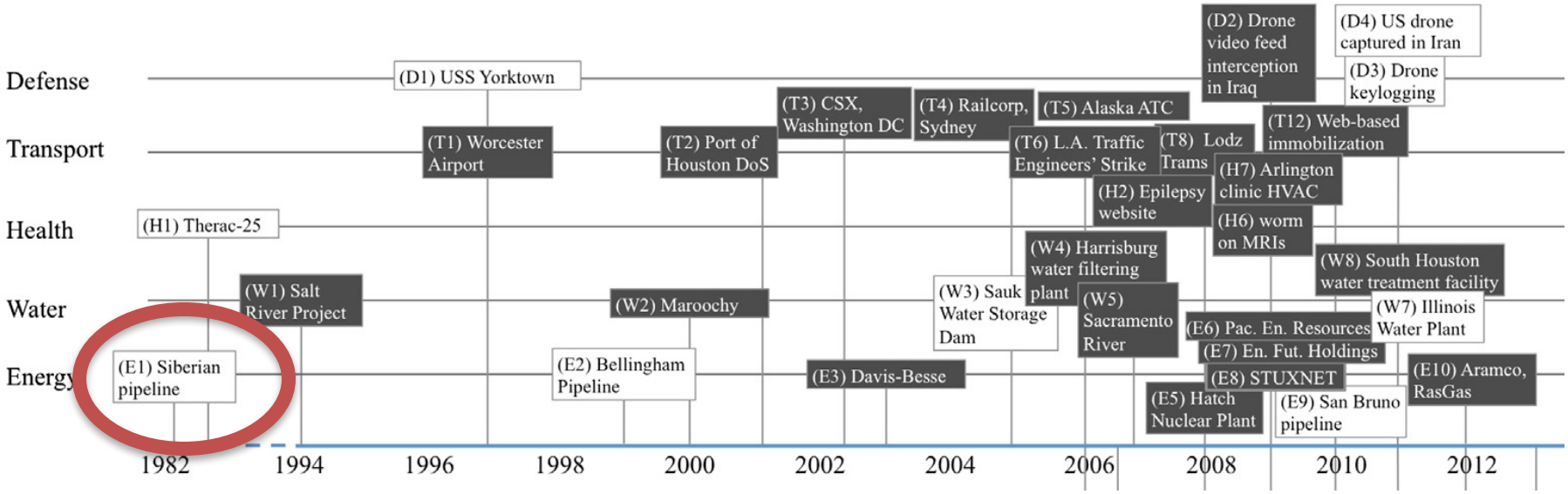
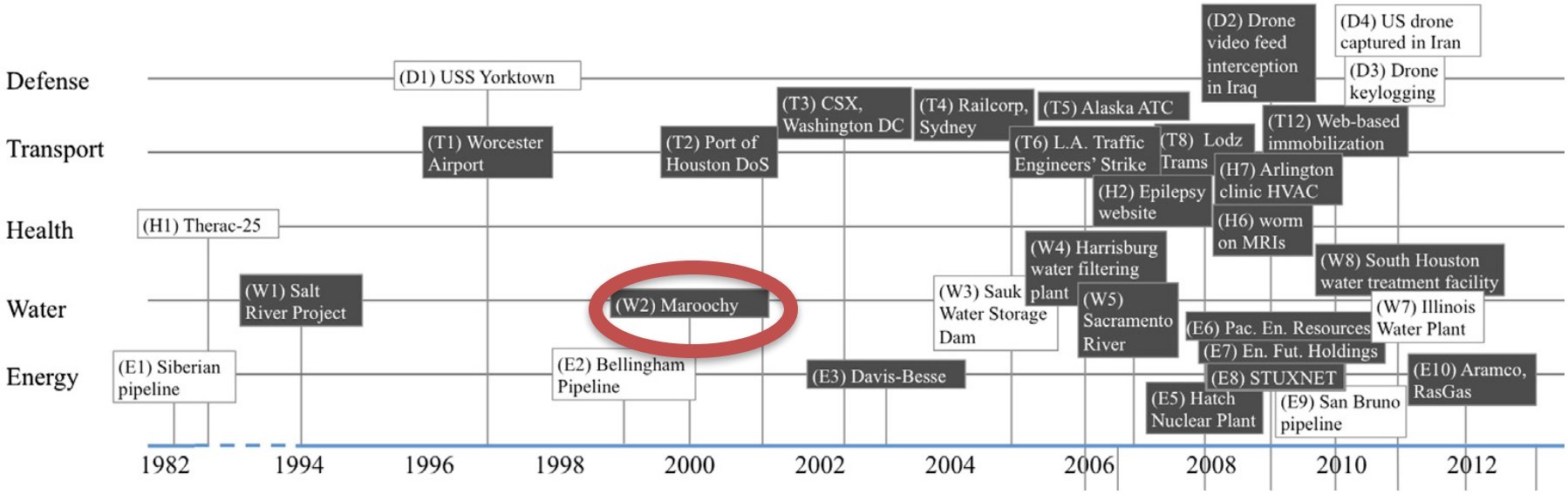


CPS security incidents



– Siberian pipeline: June 1982:
  - Soviets stole control software from Canadian company.
  - US influence Canadian company to alter code such that pipeline pressures would build up.
  - Explosion could be seen from space.

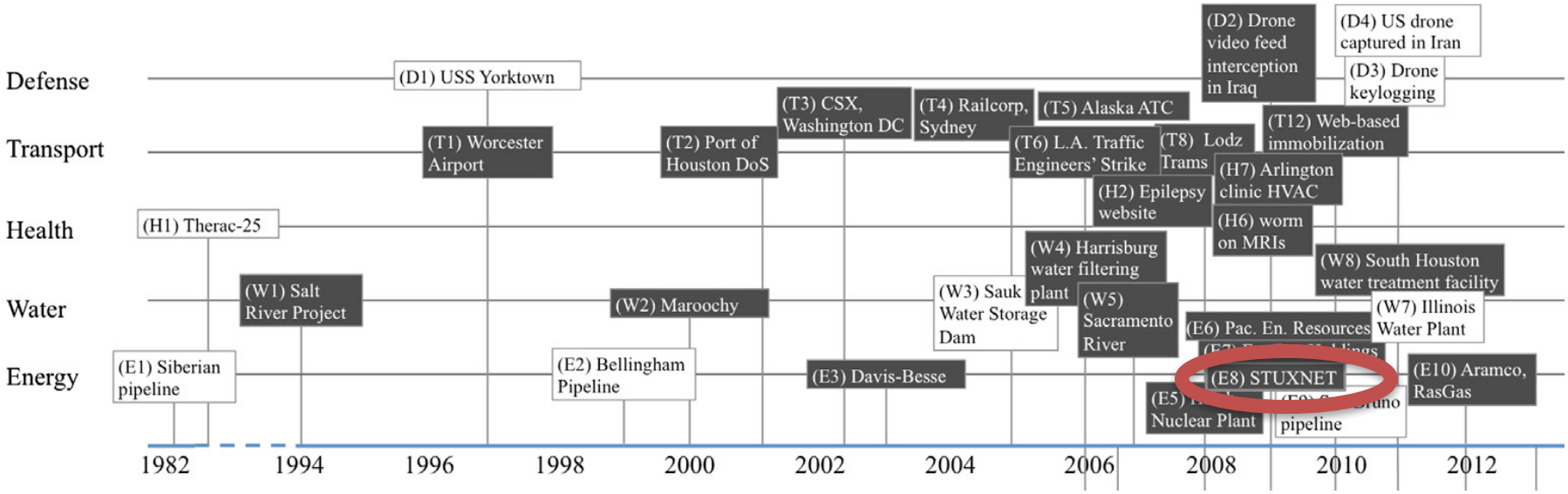
CPS security incidents



– Maroochi Shire sewage hacking, Spring 2000:

- Disgruntled employee hacked control system to release tons of raw sewage into the neighborhood

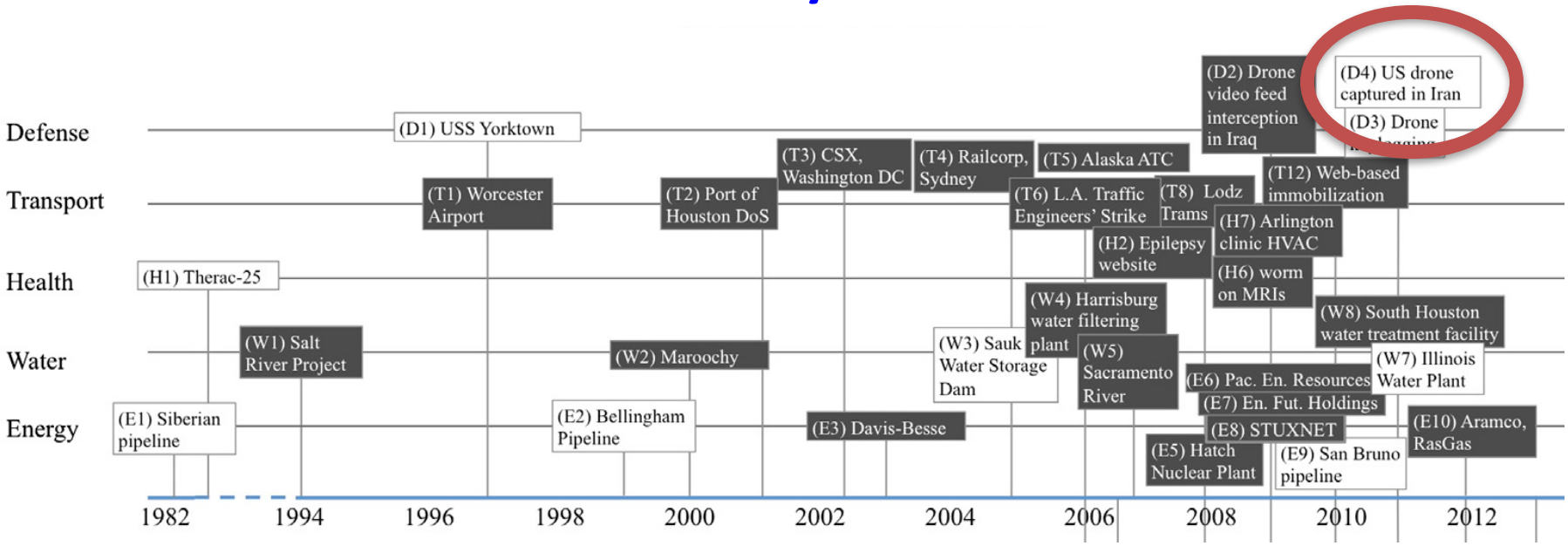
CPS security incidents



– Stuxnet: 2009:

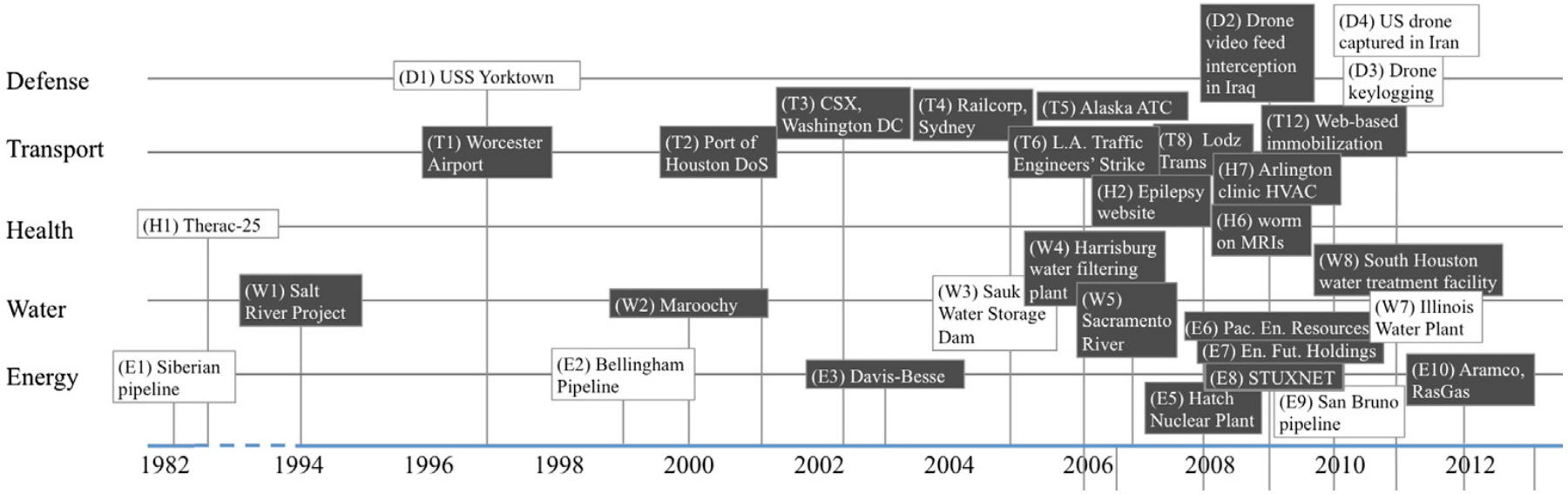
- Attack on Iranian nuclear facility
- Used 4 undiscovered exploits targeting control

CPS security incidents



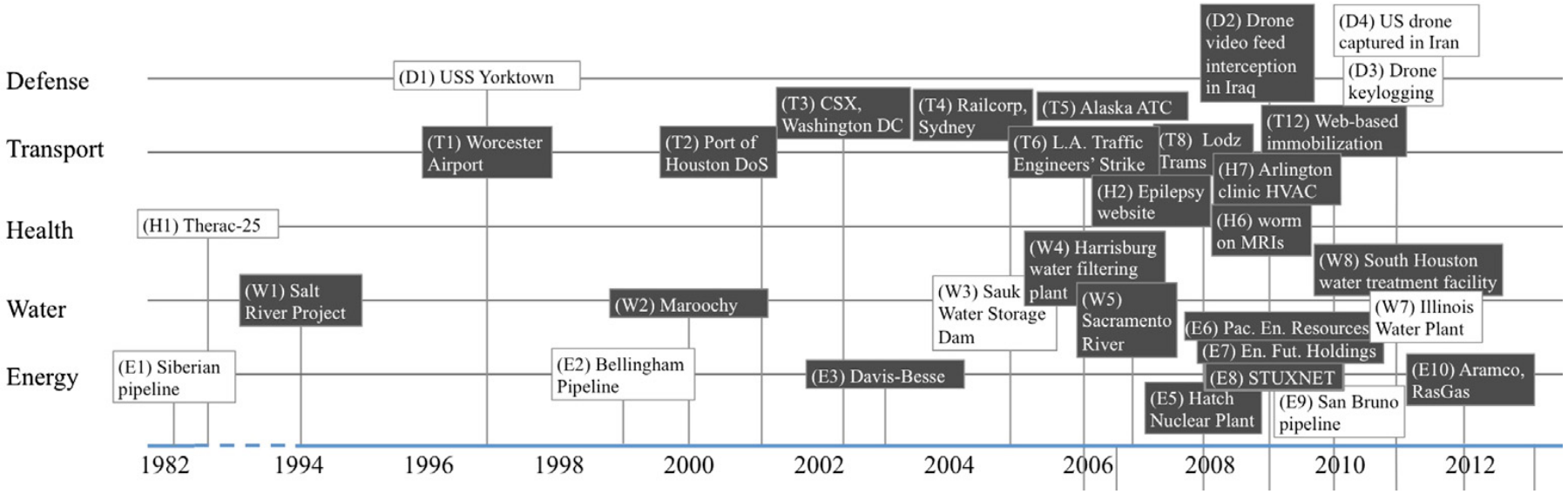
- US Drone captured: 2011:
  - Iran captured predator drone that landed in the wrong area.
  - GPS spoofing
  - "System" worked perfectly
    - sensor measurements were wrong

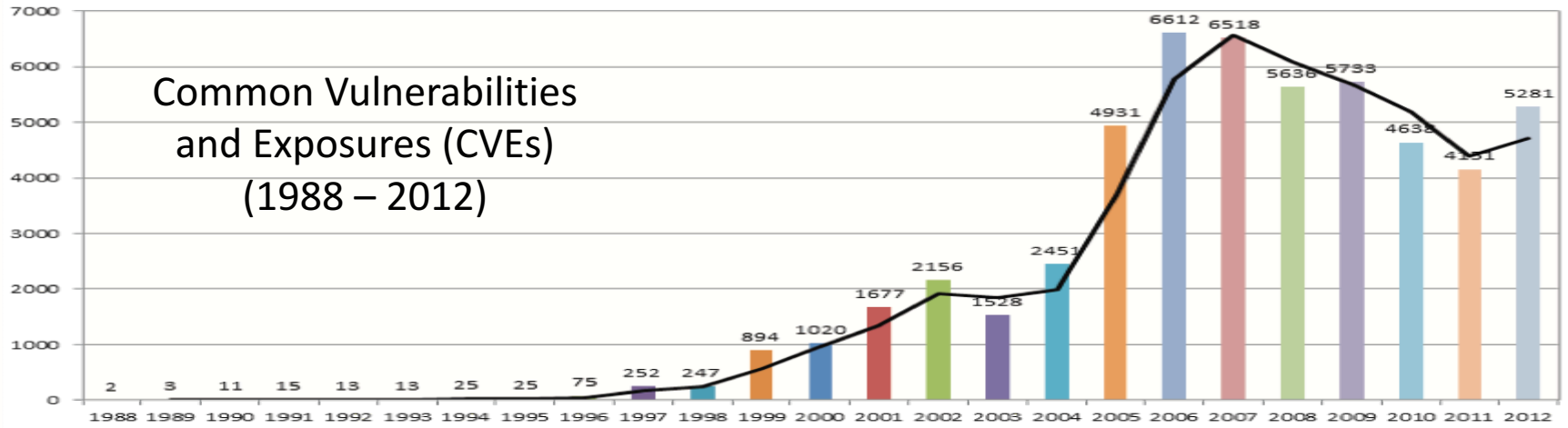
CPS security incidents



- IoT DDoS : October 21, 2016
  - Thousands of devices overtaken using default passwords
  - Organized into botnet to flood DNS provider
  - Took down many major websites
    - $17 Billion cost to economy (0.1% of GDP)

CPS security incidents

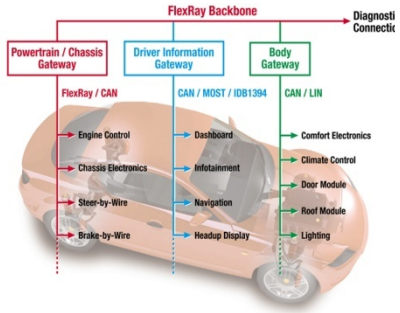




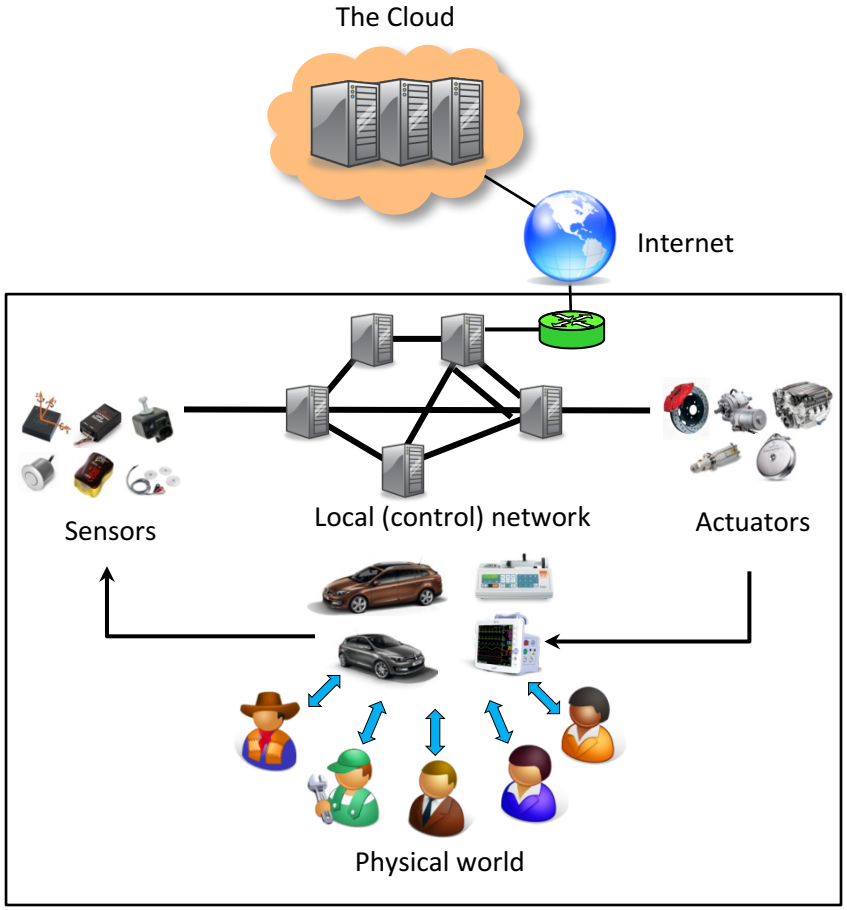
cyber-physical attacks: a growing invisible threat: George Loukas, 2015.

25-years of vulnerabilities, 1988-2012. Yves Younan.

Typical CPS Architecture

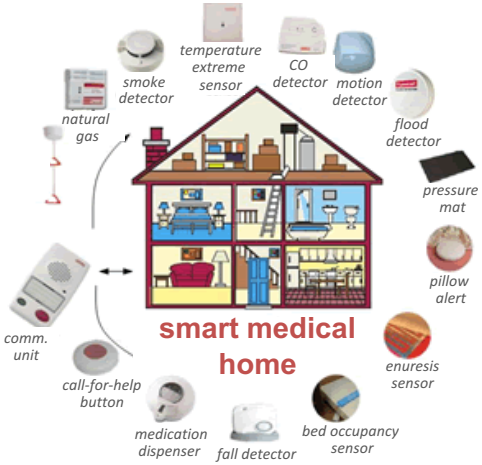


complex platform architecture



Internet-connected car

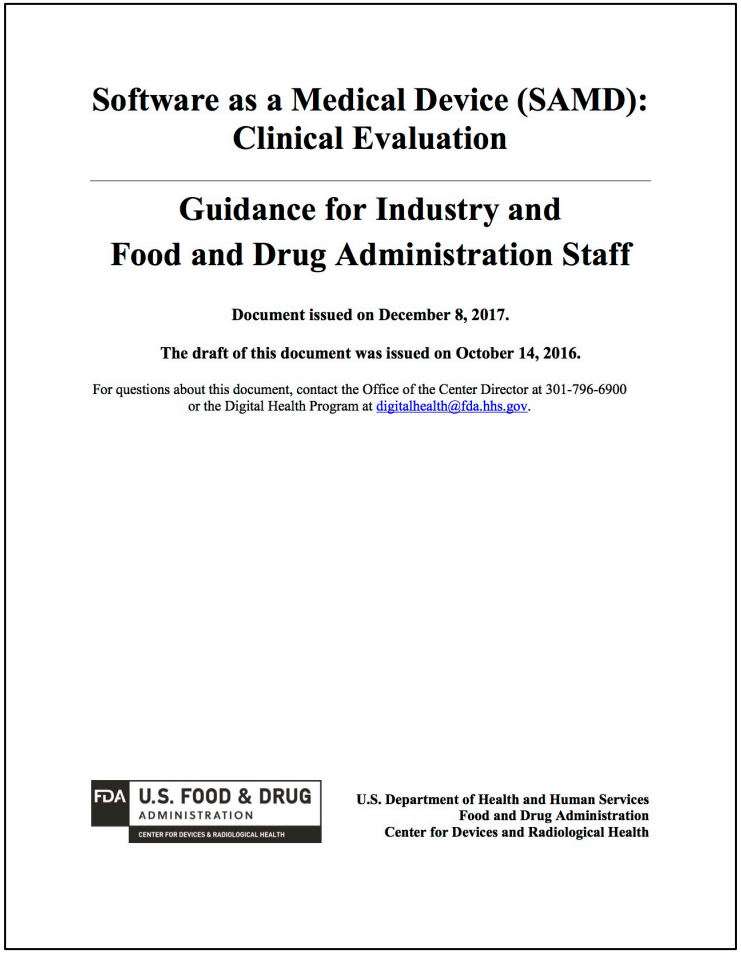
medical devices



Software as a Medical Device (SaMD)

- Medical device defined by software that interacts with existing FDA certified devices
- Benefits:
  - simplified pathway to certification
  - potential for formal safety guarantees
- Challenges:
  - tools to enable developers
    - lack of standardization makes development hard
  - IoMT infrastructure development
    - interfacing with devices
    - deployment hardware
    - real-time guarantees
    - EHR APIs

FDA release of clinical evaluation guidelines on Dec 8, 2017



Software as a Medical Device (SAMD): Clinical Evaluation

Guidance for Industry and Food and Drug Administration Staff

Document issued on December 8, 2017.

The draft of this document was issued on October 14, 2016.

For questions about this document, contact the Office of the Center Director at 301-796-6900 or the Digital Health Program at digitalhealth@fda.hhs.gov.

FDA U.S. FOOD & DRUG ADMINISTRATION CENTER FOR DEVICES & RADIOLOGICAL HEALTH

U.S. Department of Health and Human Services
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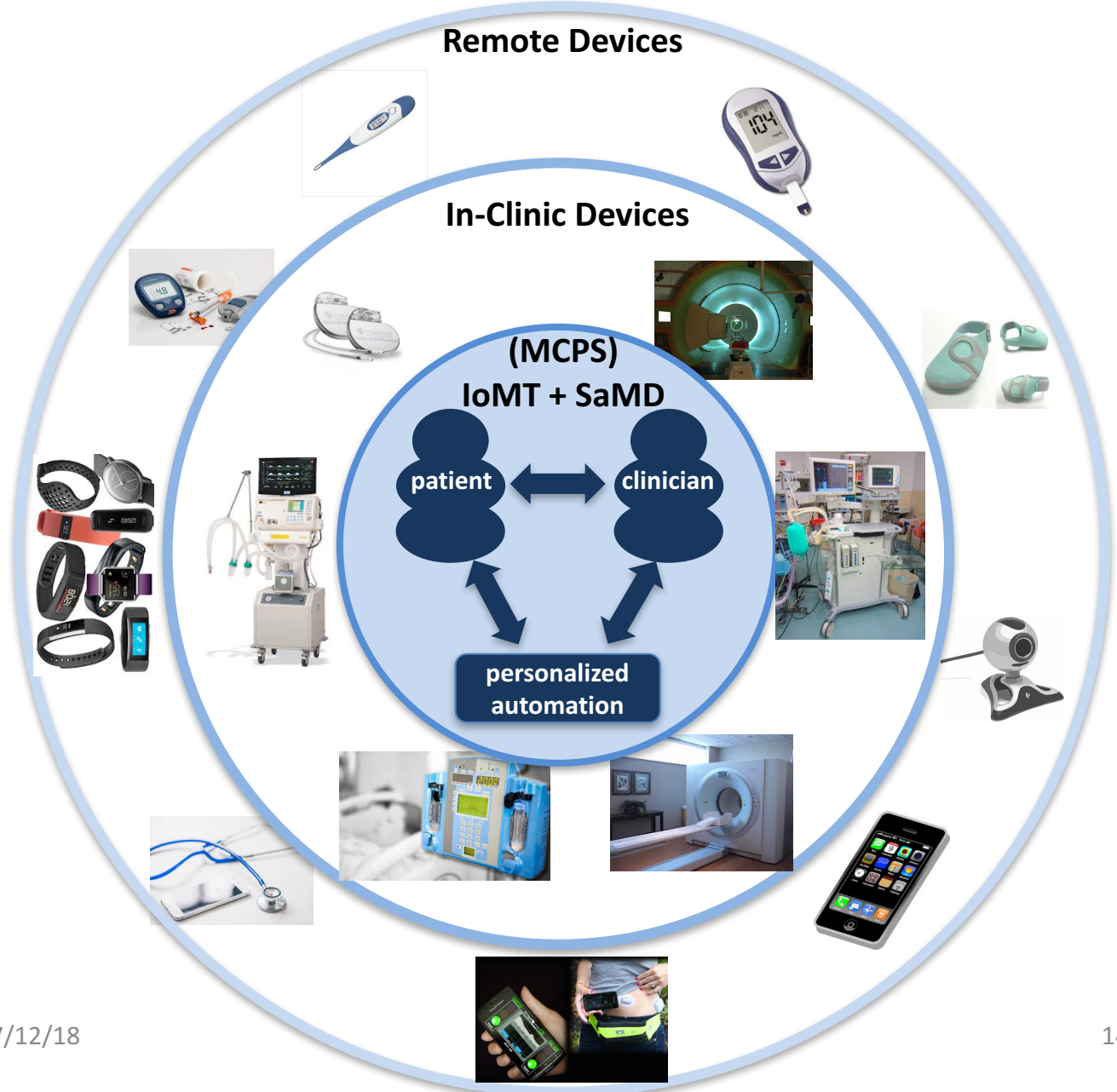
Internet of Medical Things (IoMT)



What is CPS Security?

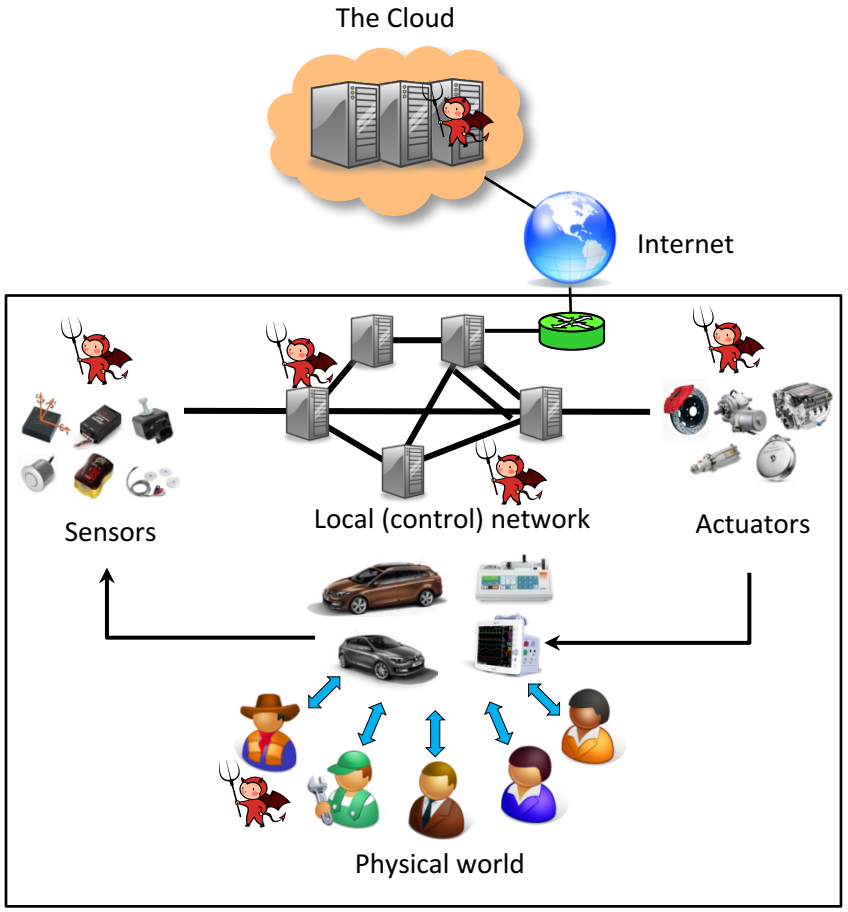
- A CPS attack whose goal is to (negatively) affect the interaction between a CPS and the physical world
  - Originates through any attack surface
    - cyber, physical, or any combination of cyber/physical
- CPS security concerns the development of technologies for defending against CPS attacks
  - e.g., discovering new vulnerabilities, techniques for detection/mitigation/recovery, …

Cyber- vs. CPS security

- All cyber-security challenges are still there!
- New challenges
  - Larger attack surface
  - New kinds of attacks
  - Imperfect system models
- New opportunities
  - Laws of physics
  - Natural redundancy
  - Operational context

CPS Attack Surfaces

- Cyber attack surfaces
  - e.g., communication, networks, computers, databases, ...
- Physical attack surfaces
  - e.g., locks, casings, cables, ...
- Environmental attack surfaces
  - e.g., GPS signal, electro-magnetic interference, battery draining/cycling/heating, …
- Human attack surfaces
  - e.g., phishing, bribing, blackmail, etc.



CPS Security Challenges

- Foundational Challenges
  - How to build an ideal resilient CPS?
  - Quantifying CPS attacks effectiveness
    - wide variability in metrics for CPS security
    - concerns depend on the CPS mission
  - System evolution
    - operate in many different physical environments
    - adapt to physical surroundings
  - Operating scenarios restrict defensive capabilities
    - patching and frequent updates, are not well suited for control systems
    - real-time availability provides a stricter operational environment than most traditional IT systems.
    - legacy systems may not be updated
- Social and Legal Challenges
  - What solutions will be accepted by practitioners?
  - Who/what is liable when such a system fails due to security and privacy attacks?

Interaction Complexity

- Cyber physical systems are systems of components
  - Heterogeneous computation and interaction models
- Composition of components are about the **interactions** of systems
- "Normal Accidents", an influential book by Charles Perrow (1984)
  - One of the Three Mile Island investigators
  - NRC Study "Software for Dependable Systems: Sufficient Evidence?"
- Posits that sufficiently complex systems can produce accidents without a simple cause due to interactive **complexity** and **tight coupling**

Unintended Feature Interactions

- A complex system exhibits complex interactions due to
  - Unexpected interferences that are not visible or not immediately comprehensible
  - Unfamiliar or unintended feedback loops
  - Limited isolation of failed components
- Examples of Security Vulnerabilities
  - Secure door lock and rollover
  - Meltdown/Spectra(?)

Improving CPS security

- Apply suitable best (cyber) security practices

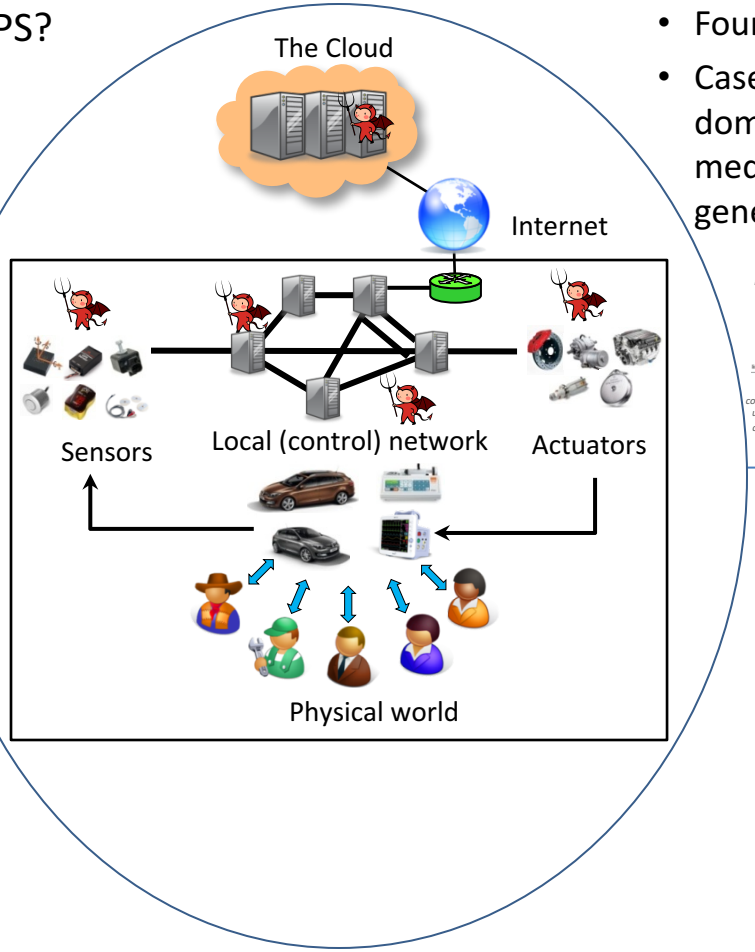
- CPS can provide additional information
  - CPS architecture / physical-world interface
    - e.g., multiple sensors, actuators, controllers
  - Environmental context
    - e.g., operating conditions (rain/snow), geographic location
  - Physical constraints and guarantees
    - e.g., laws of physics, bounds on power, CPU speed, network bandwidth

- How to leverage additional information to improve CPS security?

Security and Privacy-Aware Cyber-Physical Systems

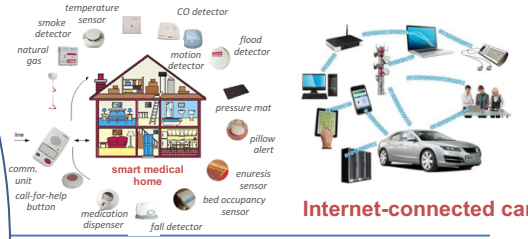
Challenges:

- How to build an ideal resilient CPS?
  - architecture, build blocks and capabilities, design requirements (technical, legal, social)
- What solutions will be accepted by practitioners?
- Who/what is liable when such a system fails due to security and privacy attacks?



Scientific Impact:

- Foundational understanding
- Case studies from different CPS domains (transportation, medical) to ensure that results are generally applicable



Solution:

- Platform support for security
- Security-aware control design
- Differential privacy in CPS
- Privacy-related tradeoffs for CPS
- Human-in-the-loop security assurance

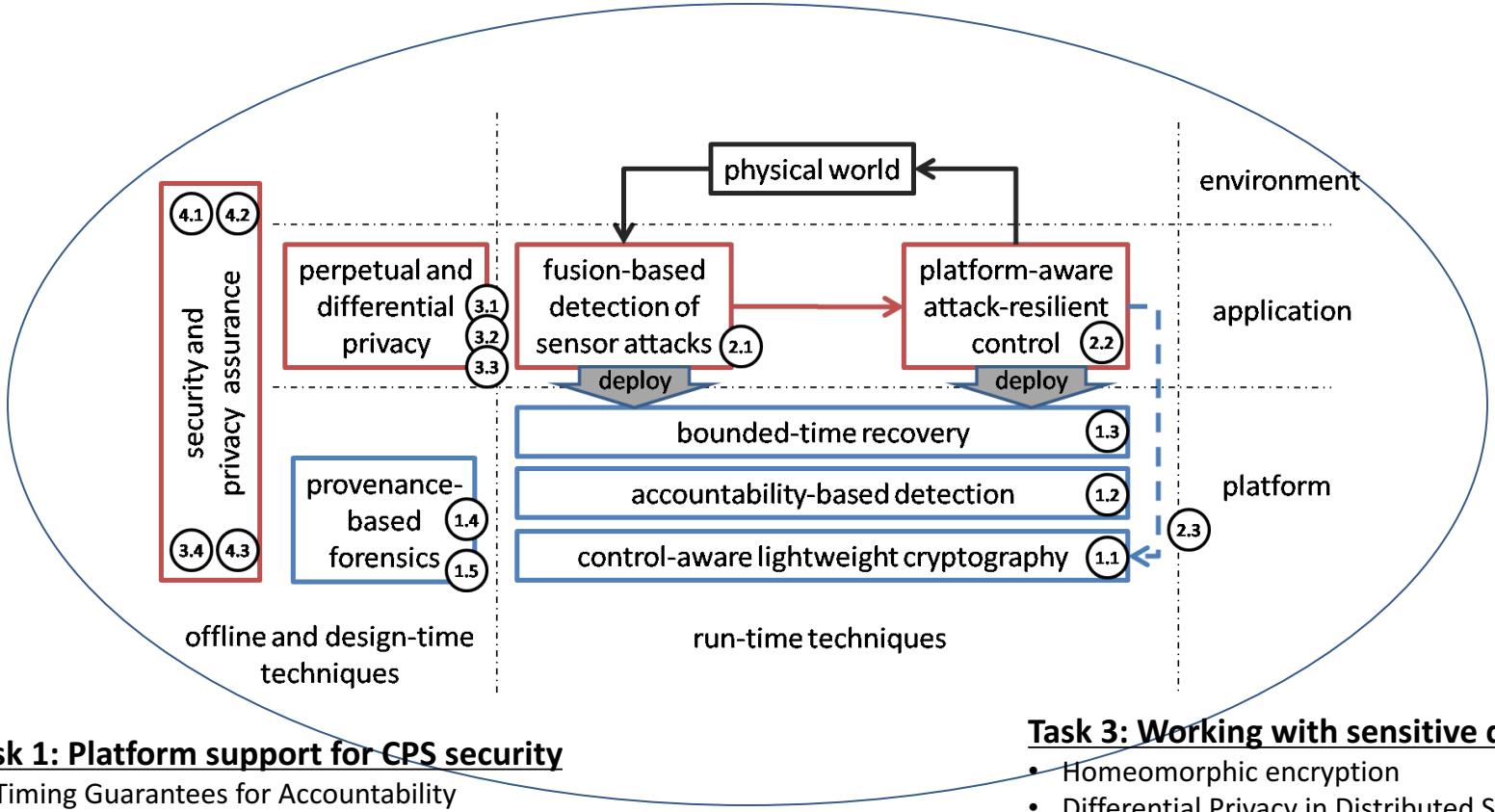
Broader Impact:

- Safer and more trustworthy CPS and IoT systems
- Clarification of legal consequences
- Joint law/engineering workforce training

Two Complementary Approaches

- Robustness
  - Employ preventive measures
  - Tolerate small problems with acceptable loss of performance
- Detection and recovery
  - Attack/anomaly detection: redundant sensors, models, laws of physics, context
  - Recover: forward recovery/mitigation
- Complementary
  - Not every attack can be masked
  - Attacks can exceed system robustness

Overall technical approach



Task 1: Platform support for CPS security

- Timing Guarantees for Accountability
- Bounded-Time Recovery
- Secure Synchronous Provenance

Task 2: Security-Aware Control Design

- Robust Attack Detection and Identification
- Platform-Aware Attack-Resilient Control Systems
- Control-Aware Cryptography

Task 3: Working with sensitive data

- Homeomorphic encryption
- Differential Privacy in Distributed Systems
- Differential Privacy for Medical Data
- Security and Privacy Duality in Control of CPS

Task 4: CPS security assurance

- Human factors in CPS security assurance
- Policy-Aware Modeling of CPS
- Security Assurance Cases for CPS

Research Results Summary

Task 1. Platform Support

- Attack Detection using Sensor Fusion
  - Attack-resilient Sensor Fusion with Fault Models
  - Incorporate Context in Sensor Fusion
- Forensics: Diagnosing Timing Faults
  - Timing Provenance
- CPS Checkpointing and (Forward) Recovery
- Bounded-Time Recovery
- Vehicle Security and Data Collection
- Design and Implementation of Secure Platform for IoMT: OpenICE-lite and LogSafe

Task 2. Resilient Control Design

- Attack-resilient state estimation in the presence of noise
  - Formal robustness guarantees even for the computationally efficient convex-optimization based estimator
- Control-aware *intermittent* integrity enforcement
  - e.g., using Message Authentication Codes (MAC)
  - Physics-aware Intermittent Message Authentication for Secure Control
- Security-Aware Scheduling for CPS
- Secrecy in Wireless Control Systems
- Resilient Linear Classification: An Approach to Deal with Attacks on Training Data

Task 3. Preserving Privacy

- Preserving Privacy in CPS
- Approaches
  - Partially Homomorphic Encryption
  - Differential privacy
- Optimization and Control using Partially Homomorphic Encryption
- Control with secrecy against eavesdroppers
- Distributed Differential Privacy
  - Approach #1: Crypto (MPC, secret sharing)
  - Approach #2: Trusted hardware (SGX)

Task 4. Security and Safety Assurance

- Security-Aware Human-on-the-Loop Protocols
- Security in Healthcare
  - Perspective on Healthcare Security
  - Understanding Circumvention/Workarounds of Cyber-Security Authentication
- Legal View on MCPS liabilities and HIPAA Compliance
- Safety Assurance
  - Verification Challenge Problem based on Proposed Self-Driving Car Policy

Talks by Penn/Michigan/Duke Team

- Who Killed My Parked Car?, Kang Shin
- Security and Privacy-Aware Cyber-Physical Systems: Legal Considerations, Christopher Yoo
- Integrating Security in Resource Constrained CPS + demo on eBuggy (electric vehicle), Miroslav Pajic + Vuk Lesi
- CPS Checkpoint and Recovery, Fanxin Kong + Oleg Sokolsky
- Bounded-Time Recovery, Andreas Haeberlen + Brian Sandler
- Timing Provenance, Linh Phan
- Control with secrecy against eavesdroppers, Tasos Tsiamis + Konstantinos Gatsis
- Self-Driving Vehicle Verification Challenges/ Benchmark, Nima Roohi

Lily's Questions

1. What have we achieved from the last 3 years against the original objective?
2. What are the most important things we discovered/learnt?
3. What surprised us, what new trends or changes emerged during the 3 years that we didn't anticipate at the beginning but turns out to be important?
4. What research you think are important to continue (outside of this program) in the general theme of CPS security/privacy going forward?
5. What feedback you may have for Intel

Additional CPS Security Challenges

- Security in autonomous CPS
  - Data-driven CPS
  - Attacks on training data
  - Learning enabled components in safety-critical CPS
- Human-in-the-loop CPS
- How to retrofit legacy systems to be resilient to newly discovered attacks?
- Formal modeling and synthesis techniques for evaluating resiliency to attacks/vulnerabilities
- Systematic understanding of exploitable side channels/unexpected feature interaction

Acknowledgements

- Special thanks to
  - Lily Yang, Intel
  - Richard Chow, Intel
  - Alan Tatourian, Intel
  - Jesse Walker, retired from Intel
  - David Corman, NSF
- Funded by NSF CNS-1505799 and the Intel-NSF Partnership for Cyber-Physical Systems Security and Privacy.

THANK YOU!

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