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The power of verifiable protection™

Dramatic Cyber-Physical Attack Surface Reduction Leveraging Integrity MAC Security Kernel

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at Urbana-Champaign
Streamed live on the Web
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Presentation Outline

- Problem: national existential risk
- Available solution technology: security kernel
- EDS delivery path: PLC technology transfer

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  - Poor energy delivery systems (EDS) resilience
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National Existential Risk
Poor EDS Resilience

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- Leon Panetta, former SecDef & CIA Director
  - "Biggest nightmare is of a computer virus
    - that attacks and disables US infrastructure"
  - "Could result in millions of lost lives" [Mar 2019]
- Both current and former Federal CISOs
  - "what keeps them up at night"
  - "Exposure of critical infrastructure to attacks
    - against industrial control systems [PLCs]" [Sep 2019]
- U.S. government claims Russian subversion
  - "power grid hackers left behind tools needed to
    - later disrupt grid by shutting off vital systems." [Jun 2019]

National Existential Risk
Critical Device **Physical** Damage

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- Computer systems all use operating system(OS)
  - Programmable Logic Controllers (PLC) have an OS
- Science: secure system requires trustworthy OS
  - Must withstand witted adversary cyber attacks
- EDS cyber physical PLCs use untrustworthy OSs
  - One of a few common OSs – none trustworthy
  - Evident by stream of regular "security patches"
- Cyberattacks inflict permanent physical damage
  - STUXNET destroyed Iranian enrichment centrifuges
  - Crash Override for physical Ukraine EDS destruction
  - Triton aimed for Saudi refinery destruction

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Security Kernel Technology
Solution Concept Introduction

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- Seminal (1972) concept description

  "*a compact security 'kernel' of the operating system and supporting hardware – such that an **antagonist could provide the remainder** of the system without compromising the protection provided.*"

- Early (1983) IEEE article characterization

  "*the security kernel approach provides controls that are effective against most internal **attacks** – including some that many **designers never consider**.*"

- Consistent history of mitigating attacks

  "*half dozen security kernel-based operating systems ran for years (even decades) in the face of nation-state adversaries **without a single reported security patch***"

Security Kernel Technology
Solution Concept Introduction

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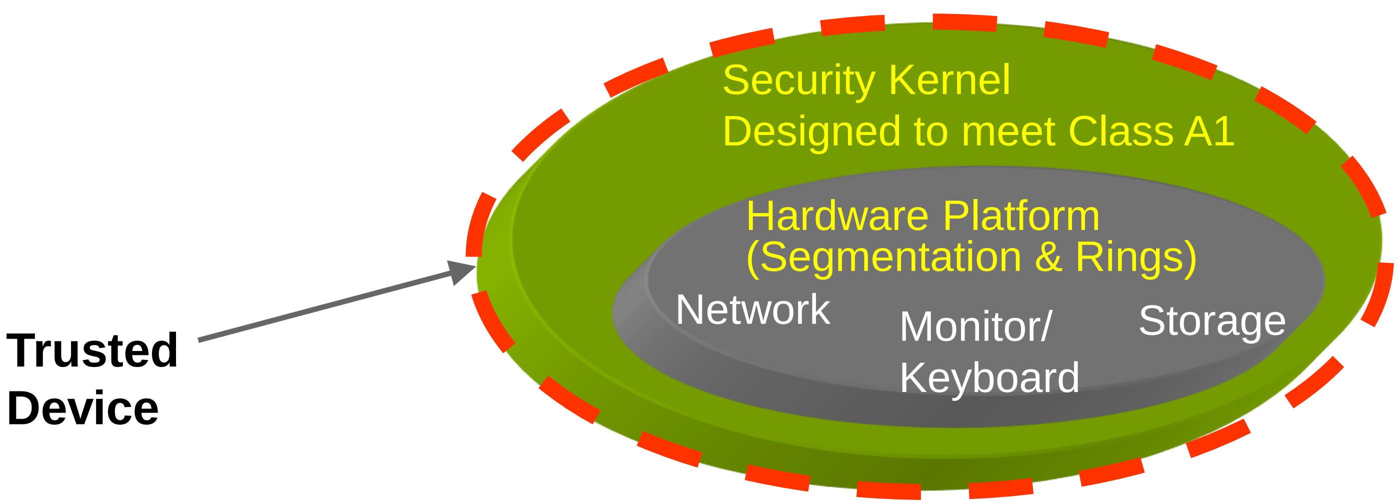
"The only way we know . . . to build highly secure software systems of any practical interest is the kernel approach."
-- ARPA Review Group, 1970s (Butler Lampson, Draper Prize recipient)

Still true today. Codified in TCSEC Class A1

TCSEC Glossary: "***Security Kernel*** *- The hardware, firmware, and software elements of a Trusted Computing Base that* ***implement the reference monitor*** *concept.*"'



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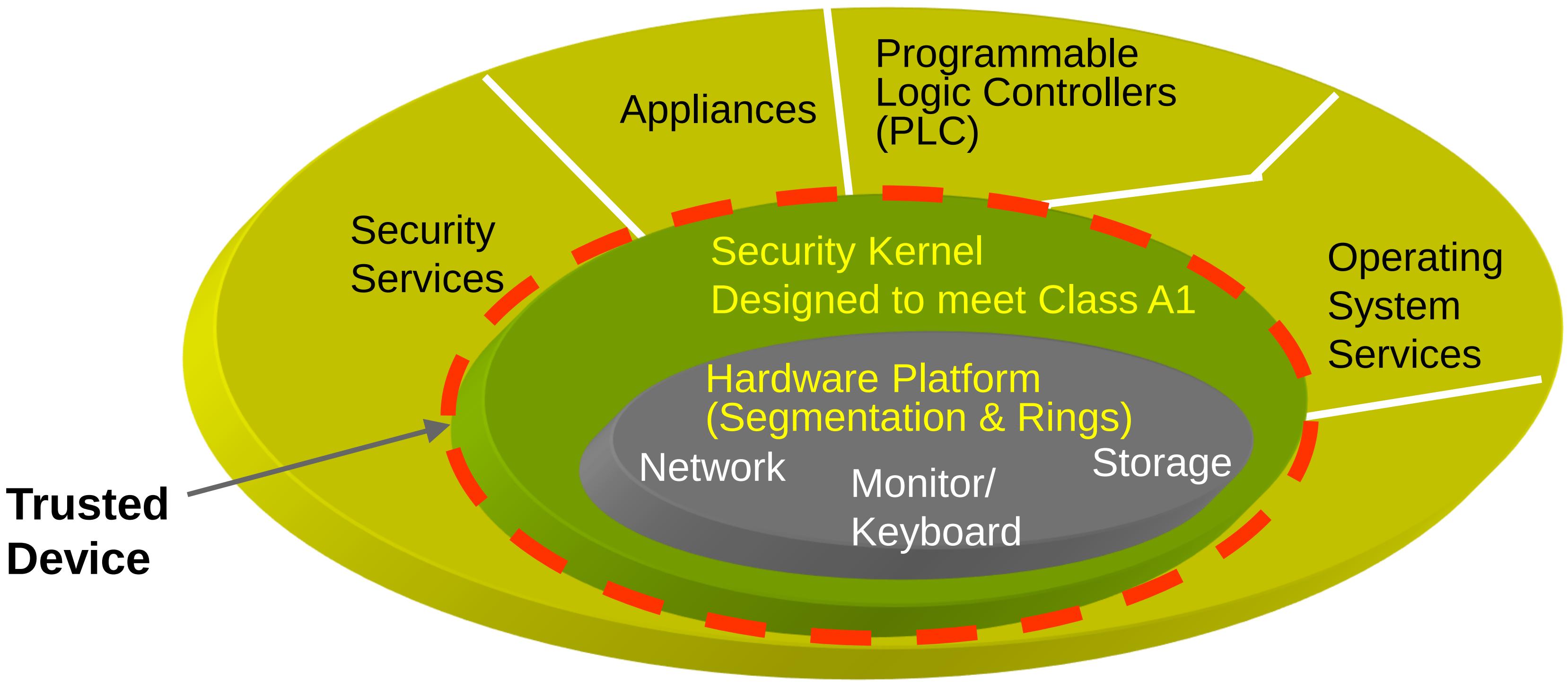

Truly a paradigm shift: no Class A1 security patches for kernel in years of use

Security Kernel Technology
NIST Calls Out Solution Concept

- NIST calls out "kernel" in flagship SP-800-160v1
  - "Electric Grid – Industrial/process control systems"

- PLC typically controls critical physical component

  "*Trustworthy components within ICS, including for example, highly assured,* ***kernel-based*** *operating systems in* ***Programmable Logic Controllers***" [PLC]

- Kernel MAC controls integrity security domains

  "*can help achieve a high degree of system* ***integrity*** *and availability through* ***domain*** *separation with control over cross-domain flows and use of* ***shared*** *resources.* "

Security Kernel Technology
Strategic Approach to Protection

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- Controlled sharing between integrity domains
  - Enforce Mandatory Access Controls (MAC) policies
- Verifiable Design required for MAC enforcement
  - **Add on** security by test and analysis has failed
    - Threat/vulnerability detection & response never finish
  - **Build in** security by Construction is successful
    - Reference Monitor basis of the TCSEC Class A1 approach
- Mitigate subversion, e.g., malware (STUXNET)
  - To protect distribution of software & commands
    - Protect installed code, configuration settings & data
- All three required for Secure Operating System

Security Kernel Technology
Cyber Defense Triad

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- MAC policies required
  - To secure information flows
- Reference Monitor
  - Only known verifiable protection technology
- Deal with Subversion
  - tool of choice for witted adversaries

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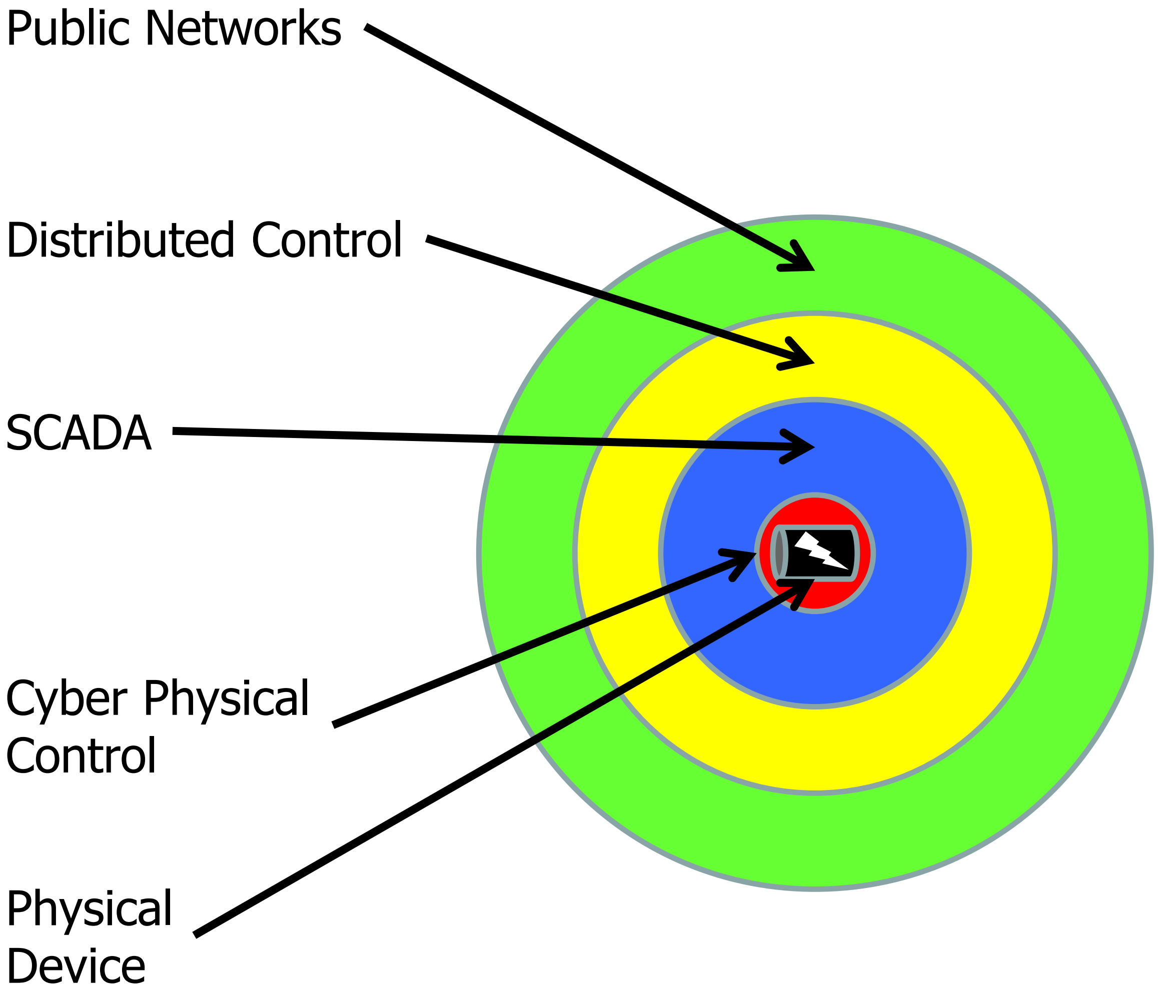
Integrity MAC policy
OpenPLC Prototype Approach

- Four distinct **hierarchical** integrity domains

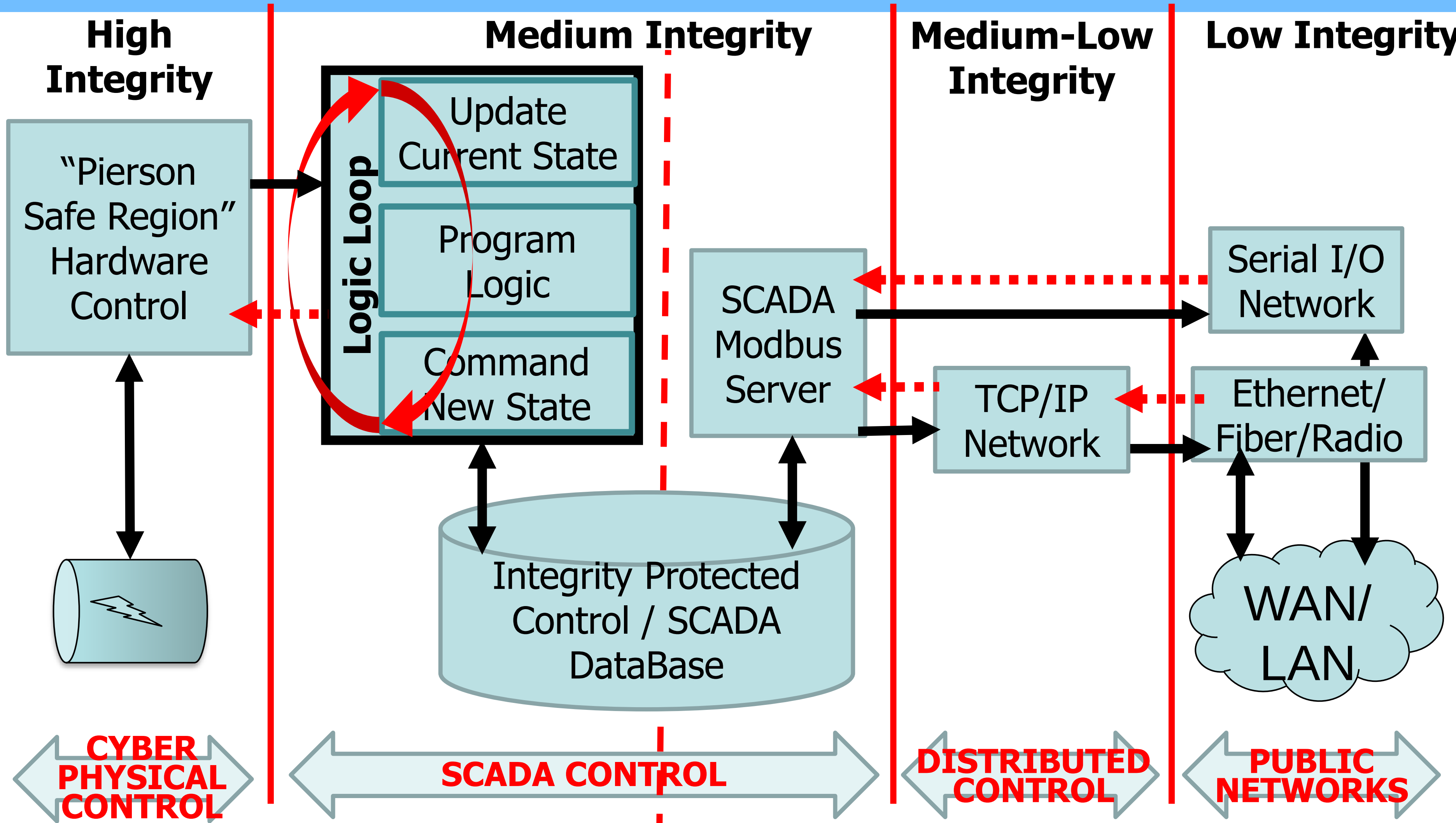
1. Cyber physical system (CPS) control
   - **Only** domain with I/O access to physical hardware
   - Enforces "Pierson Safe Region" for physical device
2. Supervisory Control and Data Acquisition
   - SCADA domain – main PLC "Logic Loop"
3. Distributed control
   - Integrity-protected network interfaces
4. Untrusted public networks (e.g., Internet)

Integrity MAC policy
MAC Reduces Attack Surface



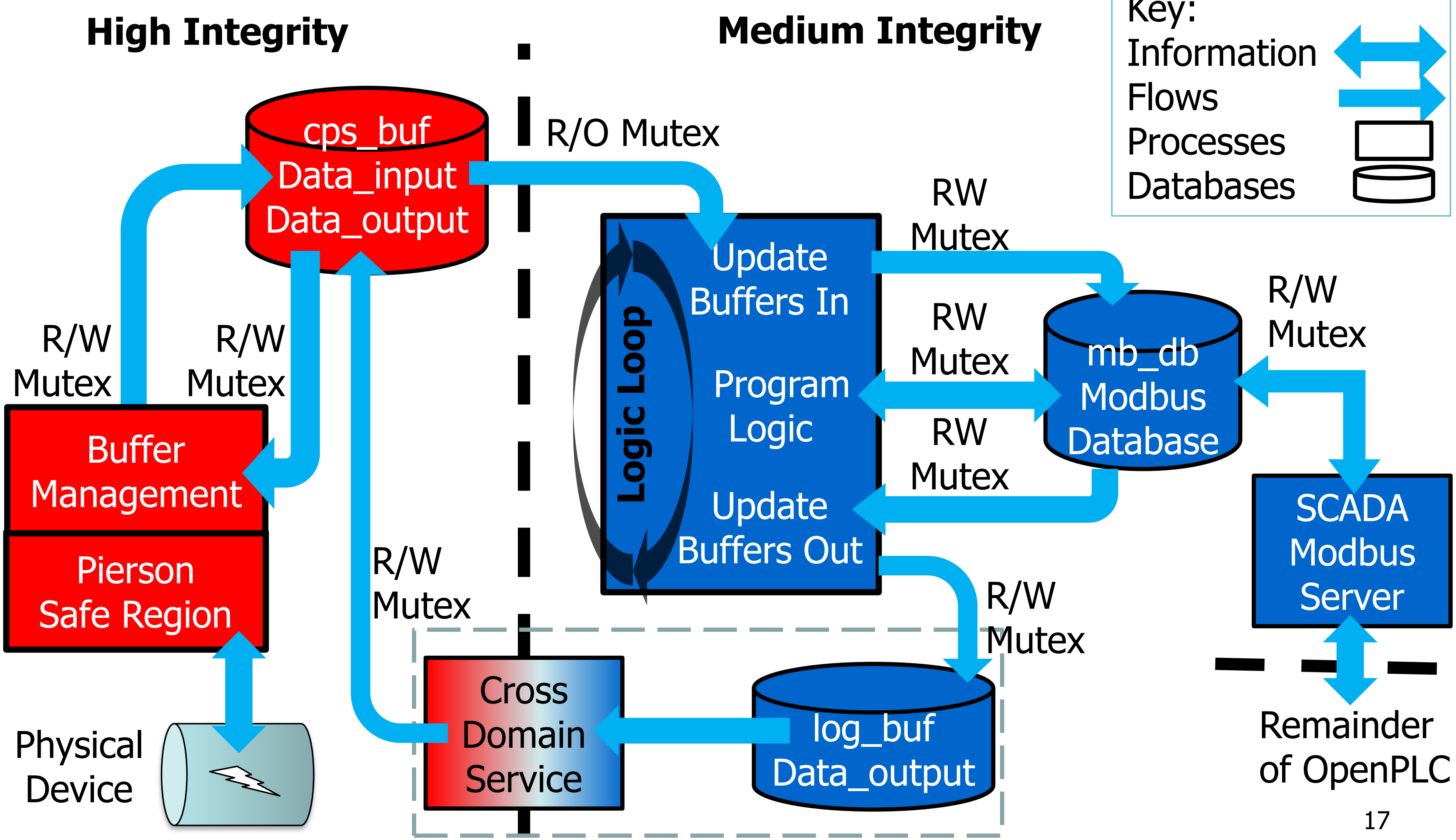
- Network access of any kind gives adversaries a huge attack surface
- Distributed control is vulnerable to insider attack
- SCADA and other adaptable control systems can be sabotaged
- Cyber Physical Control requires protection of Safe Regions that only Mandatory Access Controls provide

Integrity MAC policy
Prototype OPLC Integrity Domains



= Cross-Domain Service (CDS)

Integrity MAC policy
OPLC Physical CPS Device Control



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Verifiable Design for MAC
NIST: Reference Monitor Concept

- NIST highlights in flagship SP-800-160v1
  - "Trustworthy Secure System Development "
- Reference Monitor Concept
  "*provides an abstract security model of the* ***necessary and sufficient*** *properties that must be achieved by any system mechanism claiming to securely enforce* ***access controls****.*"
- Security Kernel **defined** as its implementation
- Integrity-MAC is access control policy

Verifiable Design for MAC
Secure by Construction

Mappings

E.g., Hardware Segmentation

System Specifications

- Security Policy
  - Philosophy and Design of Protection
- Formal Security Policy Model **[linchpin]**
  - (**FSPM**) For Reference Monitor. i.e., security kernel API

Development Specifications

- Formal Top Level Level Spec (FTLS)
  - With hardware properties visible at interface
- Descriptive Top Level Spec

Product Specifications

- Implementation Design Documents
  - Source Code
  - Layering & info hiding
  - Code correspondence
  - Covert channel analysis

Deliverable Product

- Product End Item
  - Trusted Distribution
  - Security Features Users Guide
  - Trusted Facility Manuals

Verifiable Design for MAC
Ineffective Shortcuts

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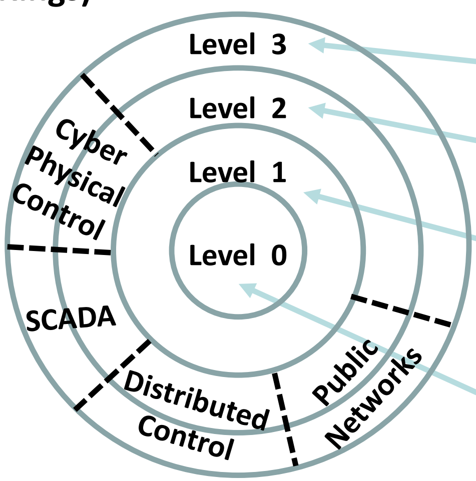
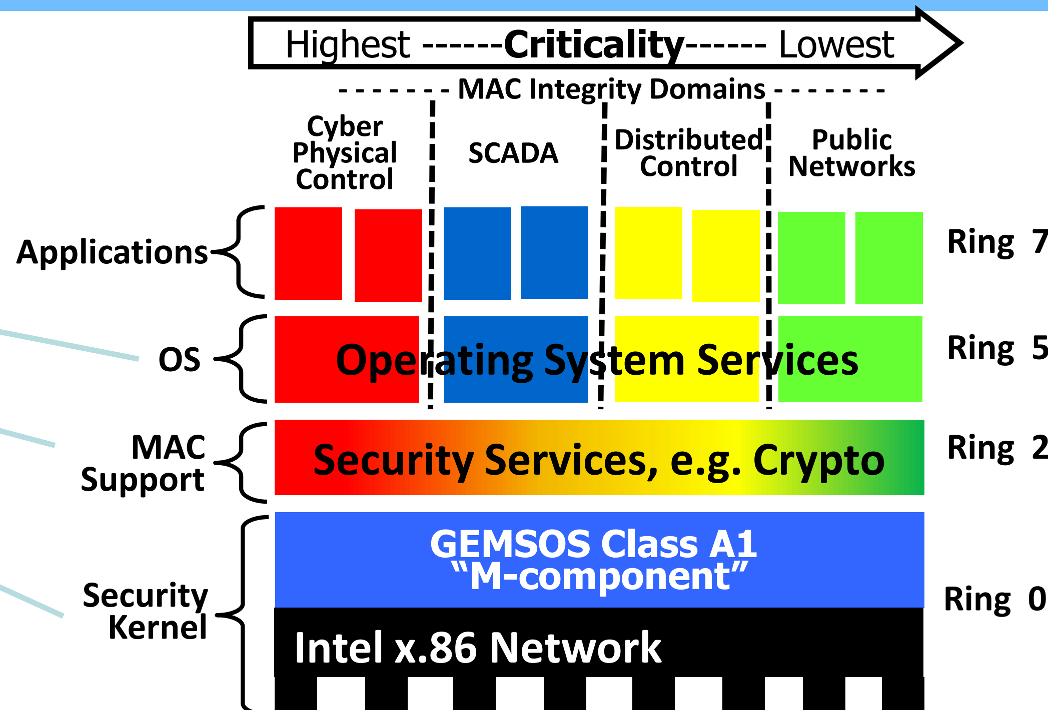
- Reference Monitor & **FSPM** are long, hard work
  - Omitted by unwary/lazy for “plausible” shortcuts
- “Verified OS” – for functionality, not policy FSPM
  - Example: seL4 – need to verify info flow outside OS
- “Partition Kernel” lacks FSPM for kernel API
  - Example: MILS – explicitly excludes from kernel
- “Verified capability hardware” – missing a FSPM
  - Examples: DARPA-sponsored CRASH and CHERI
- Static code analysis – lacks FSPM for API of OS
  - Example: LDRA Testbed
- Shortcuts cannot **enforce** Integrity MAC for PLC

Verifiable Design for MAC
Reproducible Research Setup

Intel x86 Architecture
Hardware Protection Levels
(Protection Rings)





- Essential Hardware Properties
  - Hardware Rings – more than 2
  - Memory Segmentation vs Paging
  - Strong Process Model
- NSA TCSEC/TNI Class A1 – Verified Design

MAC Integrity Domains	Criticality	Attack Surface
Cyber Physical Control	High	Very Small
SCADA	Medium	Small
Distributed Control	Medium-low	Moderate
Public Networks	Low	Very Large

Concentric ring diagram taken from Intel® 64 and IA-32 Architectures Software Development's Manual, Volume 3A: System Programming Guide, Part 1, (order number 253668)

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Mature Subversion Mitigation

NIST: Class A1 for Subversion

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- NIST cites "Class A1" in flagship SP-800-160v1
  - "Application . . . to Commercial Products"

- Products are worked examples and use cases
  "*highly trustworthy components and systems that have been verified to be highly resistant to **penetration** from determined adversaries*"

- TCSEC **Class A1** distinguished
  "*by substantially dealing with the problem of **subversion** of security mechanisms.*"

Mature Subversion Mitigation
Trusted Device Protects Itself

- Trusted Boot for software/configuration settings
- Vet Trusted Devices for unauthorized behavior
- Code Correspondence stop “dead code” malware
- Trusted Distribution avoids supply chain attacks
- Media integrity mitigates “parking lot” attacks

Mature Subversion Mitigation
Stopping Malware Attacks

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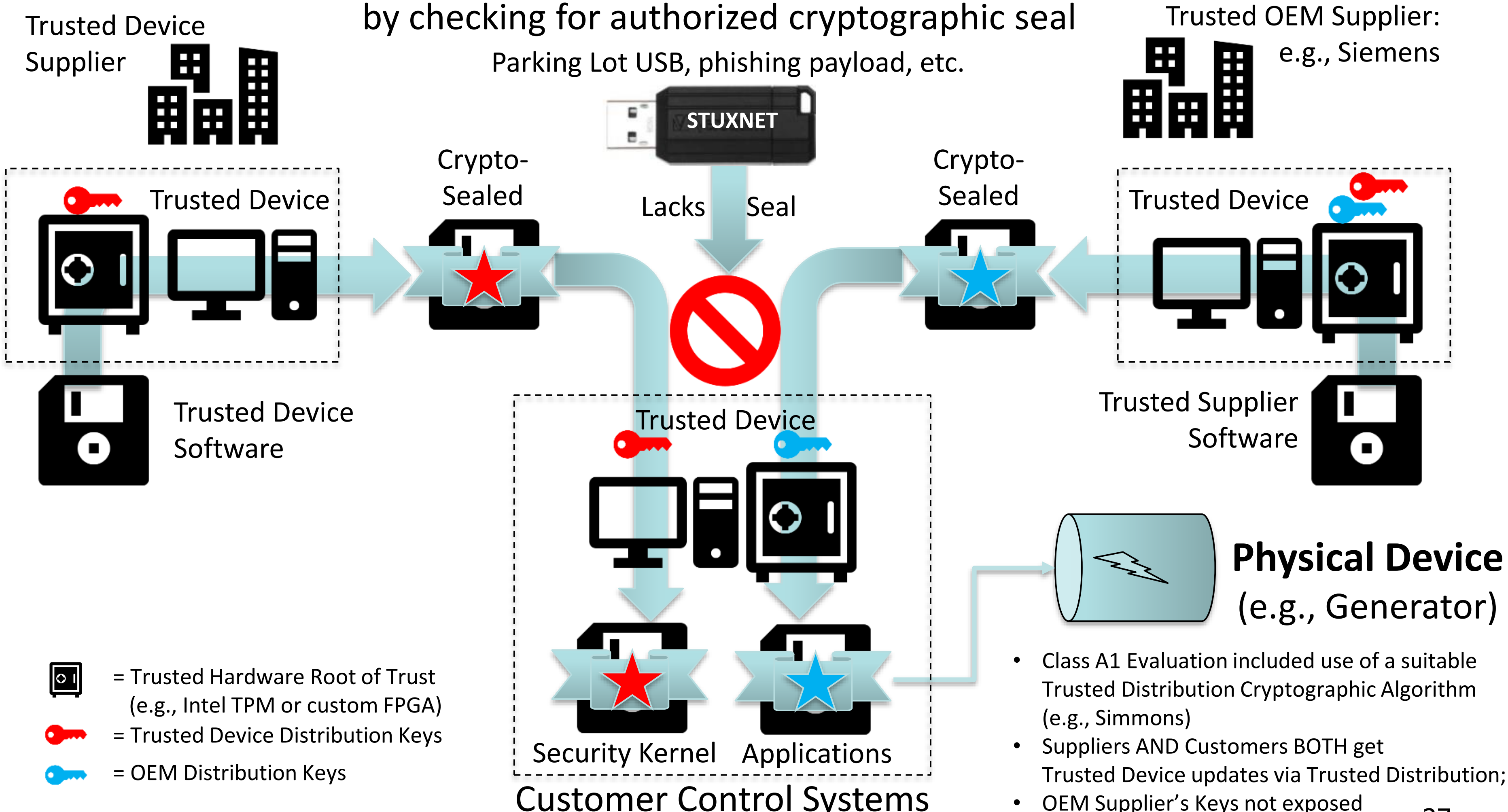
Attack technique	Attempt	Class A1 Stopper	Value Proposition
• Design process • Development process • Industry standards	Subvert the design	• Formal Sec Policy Model • Formal Top-Level Spec • Minimization • Code Correspondence	Verifiable Design substantially mitigates subversion
• Parking lot USB drives • Network attacks • Phishing attacks	Install discovery tools	• Trusted Distribution prevents unauthorized installation of code	Trusted Distribution prevents toe-hold
• Deliver network map • Find OS/RTOS • Tailor attacks	Send data to malware controller	• MAC Secrecy prevents unauthorized data transfers to public networks	MAC Secrecy prevents data exfiltration
• Install tailored attacks • Alter config settings • Bypass safety limits	Install code on device controller	• MAC Integrity prevents unauthorized changes at runtime to code and data	MAC Integrity defeats targeted attacks
• Bypass safety limits • Send damaging commands • Erase audit logs	Trigger attack on physical device	• MAC Integrity prevents unauthorized access to I/O connections to physical devices	MAC Integrity over Composable* domains (hierarchy) prevents damage to physical device

*Composition per TNI Class A1

Mature Subversion Mitigation
Illustrative STUXNET Mitigation

Class A1 Trusted Distribution rejects installation of untrusted software (malware) by checking for authorized cryptographic seal



- Class A1 Evaluation included use of a suitable Trusted Distribution Cryptographic Algorithm (e.g., Simmons)
- Suppliers AND Customers BOTH get Trusted Device updates via Trusted Distribution;
- OEM Supplier’s Keys not exposed

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  - Original Equipment Manufacturer (OEM) model

PLC Technology Transfer
Traditional OEM Model

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- Security kernel vendor offers Trusted Device
  - Hardware & software domain-specific platform, e.g., motherboard, SOC
  - Trusted distribution, system security certification
- OEMs & manufacturers build PLC platforms
  - Trusted Device is part of any hardware product configuration
- VARs, ISVs, appliance vendors
  - Add applications and system services software, use OpenPLC source
- Solution providers and system integrators
  - Customization and integration for customers
  - Deliver complete solutions

PLC Technology Transfer
Previously Evaluations Accelerate

- Former DIRNSA LtGen Linc Faurer note [2007]
- "very high priority problem area"
  - "vulnerability of our network components and
    - electronic credentials to software **subversion**"
  - "convinced that an IC disaster looms"
- "demands that the first set of solutions"
  - "directly leverage the designs, architectures and
    - rating maintenance plans [RAMP] which NSA has
    - previously evaluated at the **Class A1** level of assurance"
  - "this is the **only** practical way to be confident the
    - needed solutions can be operationally deployed in the
    - next **couple of years**."

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Summary

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Verifiable CPS Bottom Line

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- Critical *physical* components need verifiable PLC
  - Limited system risk from remaining components
- Kernel makes CPS attack surface much smaller
  - Each *integrity MAC* domain protected from lower
  - Security kernel *verified design* for unknown attacks
  - Deals with *subversion* of security mechanisms
- PLC performance & functionality retained
  - OEM host PLC on *trusted device* with secure OS
  - PLC manufacturers can use OpenPLC prototype
- Mature OEM business model & support approach
  - Successful security kernel OEM delivery history

CPS Cybersecurity Conclusion

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EDS clear **NEED** for resilient CPS

Commercial **TECHNOLGY** available

Lack PLC manufacturer **ADOPTION**

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