End-to-End Security for the Internet of Things

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Intel/NSF CPS-Security
November 1, 2016

The Internet of Things (IoT)

A Security Disaster

The Economist | World politics | Business & finance | Economics | Science & technology | Culture

Cyber-security

The internet of things (to be hacked)

Hooking up gadgets to the web promises huge benefits. But security must not be an afterthought

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How the Internet of Things Could Kill You

By Fahmida Y. Rashid JULY 18, 2014 7:30 AM - Source: Tom's Guide US | 5 COMMENTS

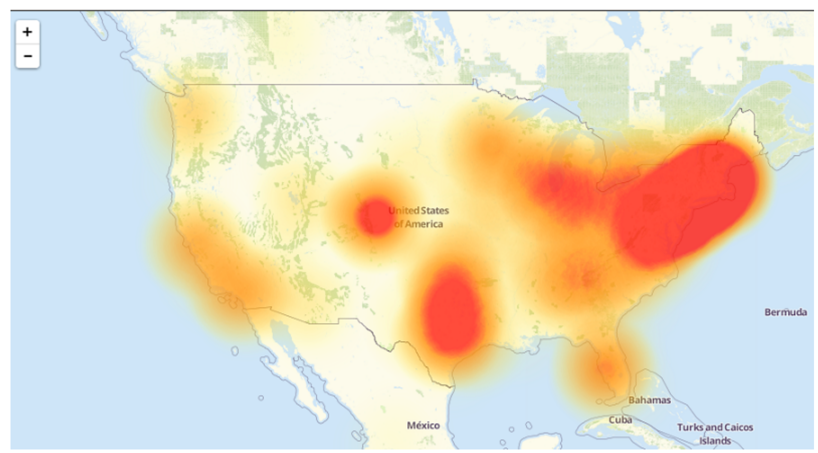
Hacking the Fridge: Internet of Things Has Security Vulnerabilities

JESS SCANLON | MORE ARTICLES
JUNE 28, 2014

Philips Hue LED smart lights hacked, home blacked out by security researcher

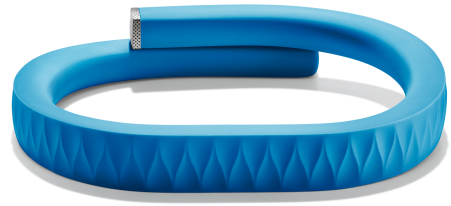
By Sal Cangeloso on August 15, 2013 at 11:45 am | 7 Comments

- HP conducted a security analysis of IoT devices[1]
  - 80% had privacy concerns
  - 80% had poor passwords
  - 70% lacked encryption
  - 60% had vulnerabilities in UI
  - 60% had insecure updates



[1] http://fortifyprotect.com/HP_IoT_Research_Study.pdf

Internet(s) of Things



Industrial Automation

Thousands/person
Controlled Environment
High reliability
Control networks
Industrial requirements

WirelessHART, 802.15.4
6tsch, RPL
IEEE/IIC/IETF

Home Area Networks

Hundreds/person
Uncontrolled Environment
Unlicensed spectrum
Convenience
Consumer requirements

ZigBee, Z-Wave
6lowpan, RPL
IETF/ZigBee/private

Personal Area Networks

Tens/person
Personal environment
Unlicensed spectrum
Instrumentation
Fashion vs. function

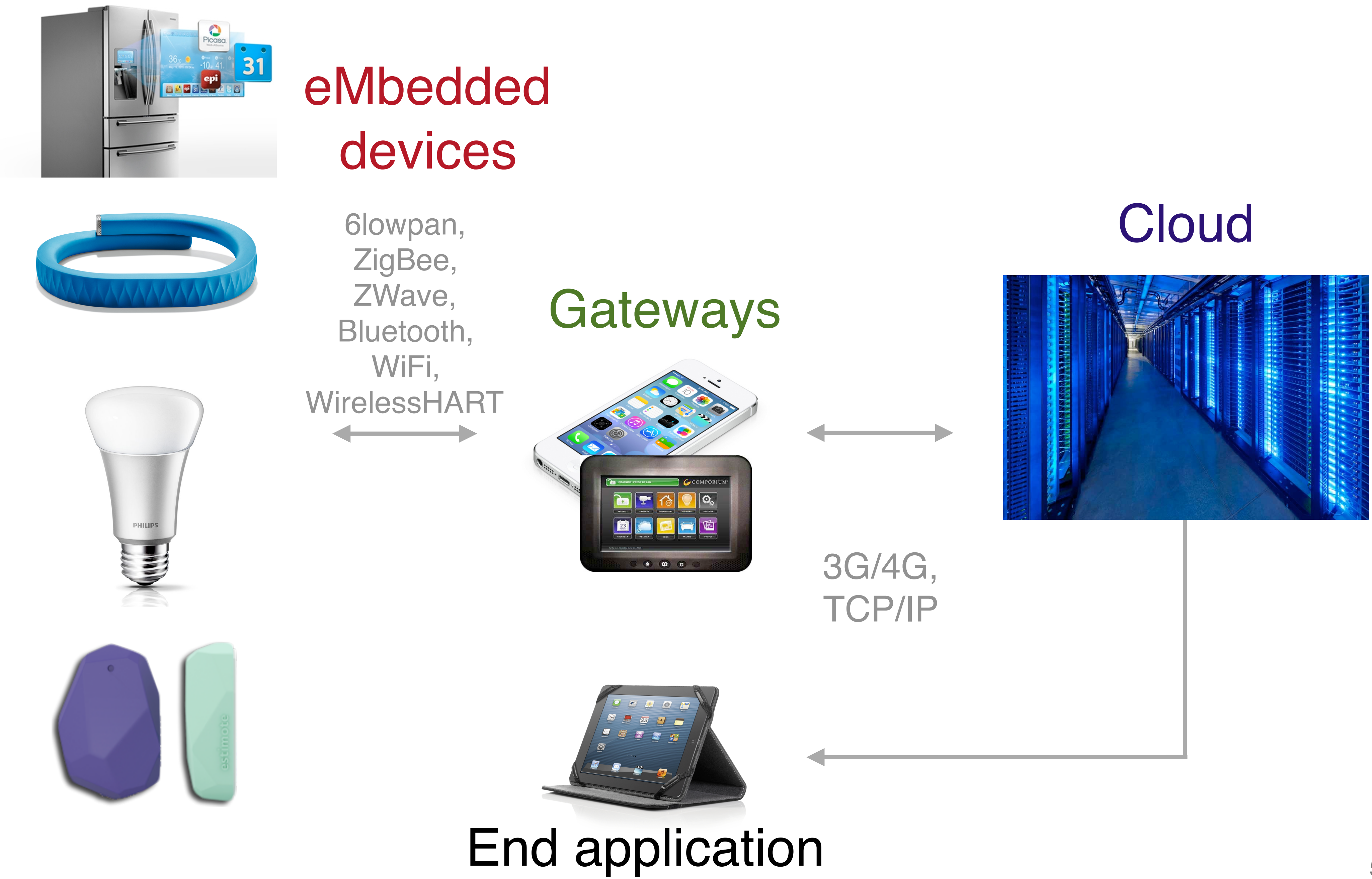
Bluetooth, BLE
3G/LTE
3GPP/IEEE

Networked Devices

Tens/person
Uncontrolled Environment
Unlicensed spectrum
Convenience
Powered

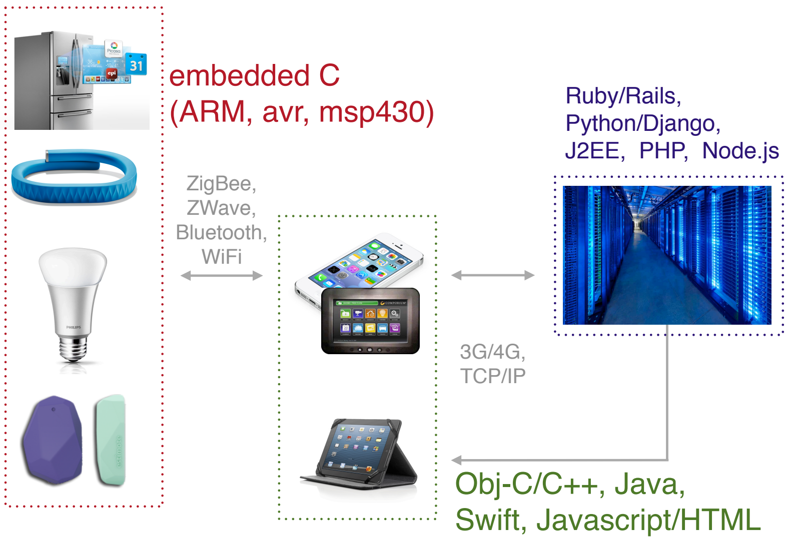
WiFi/802.11
TCP/IP
IEEE/IETF

IoT: MGC Architecture



IoT Security is Hard

- Complex, distributed systems
  - 10^3-10^6 differences in resources across tiers
  - Many languages, OSes, and networks
  - Specialized hardware
- Just *developing* applications is hard
- Securing them is even harder
  - Enormous attack surface
  - Reasoning across hardware, software, languages, devices, etc.
  - What are the threats and attack models?
- Valuable data: personal, location, presence



- Rush to development + hard ➔ avoid, deal later

Architectural Principles

- Longevity: these systems will last for up to 20 years and their security must too.
- Transparency: we must be able to observe what our devices are saying about us.
- End-to-end: consider security holistically, from data generation to end-user display.

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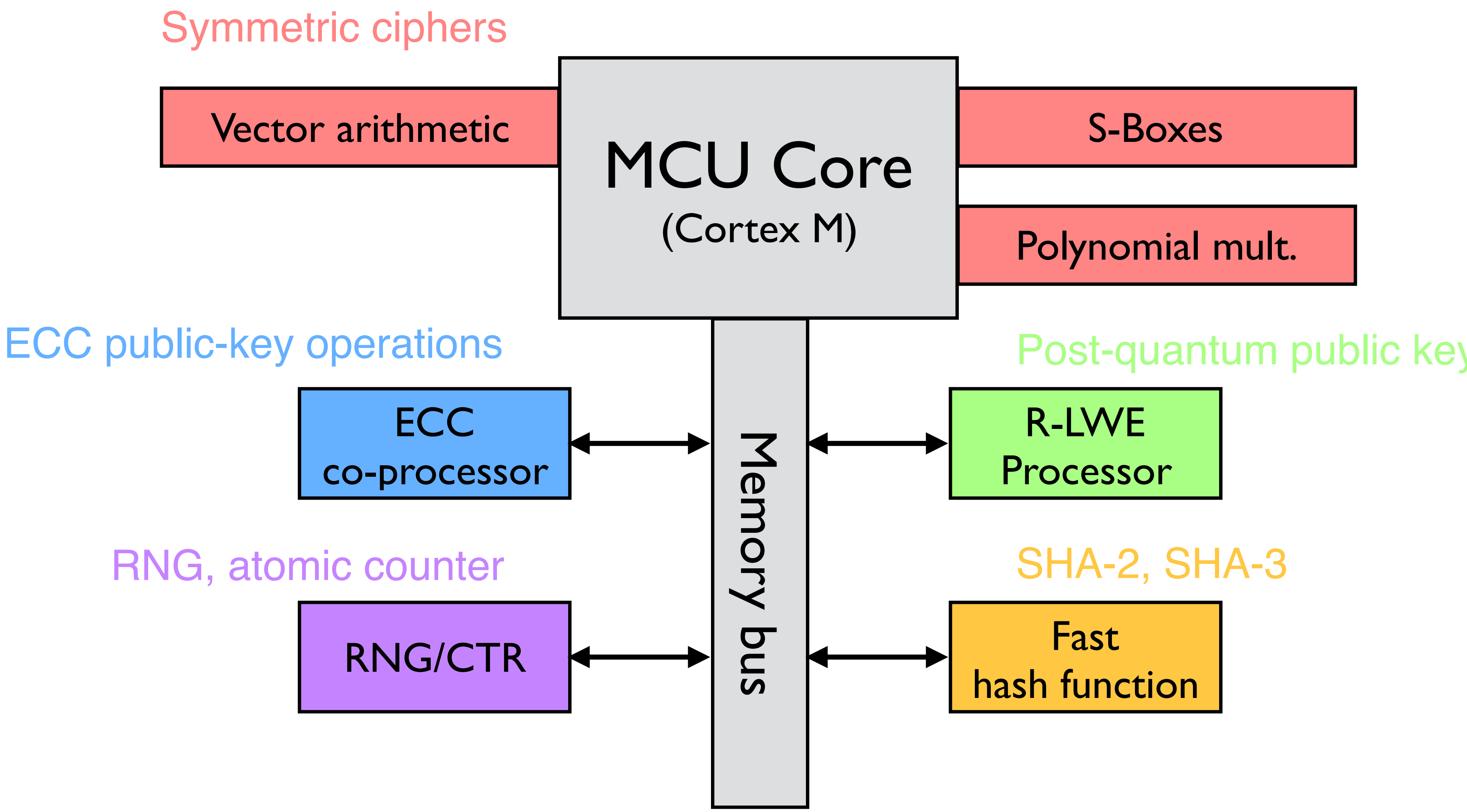
Microsoft
Microsoft
Windows 95

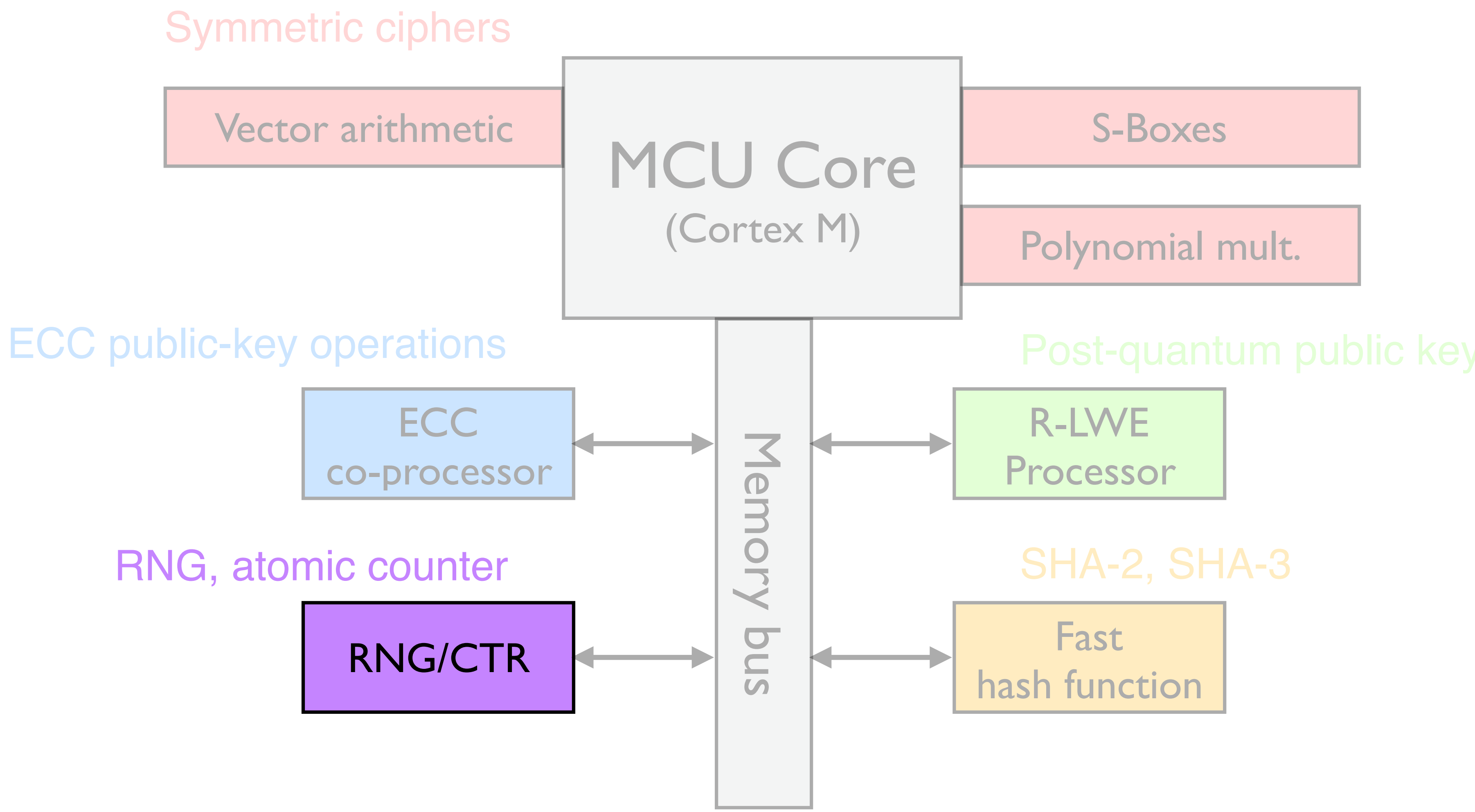
Flexible Crypto Hardware

- Devices need to be able to support ciphers that are used 20 years from now
- Add extensible cryptographic accelerator: silicon is cheap and BLE dominates the SoC
- Designing a 20-year crypto processor
  - Symmetric crypto: S-boxes and vectors, an instruction set
  - Public key crypto: several very different constructions
  - What if quantum computers are real in 20 years?
- There is often unused micro controller die area

CESEL


Symmetric ciphers
Vector arithmetic
MCU Core
(Cortex M)
S-Boxes
Polynomial mult.
ECC public-key operations
Post-quantum public key
ECC
co-processor
Memory bus
R-LWE
Processor
RNG, atomic counter
SHA-2, SHA-3
RNG/CTR
Fast
hash function

CESEL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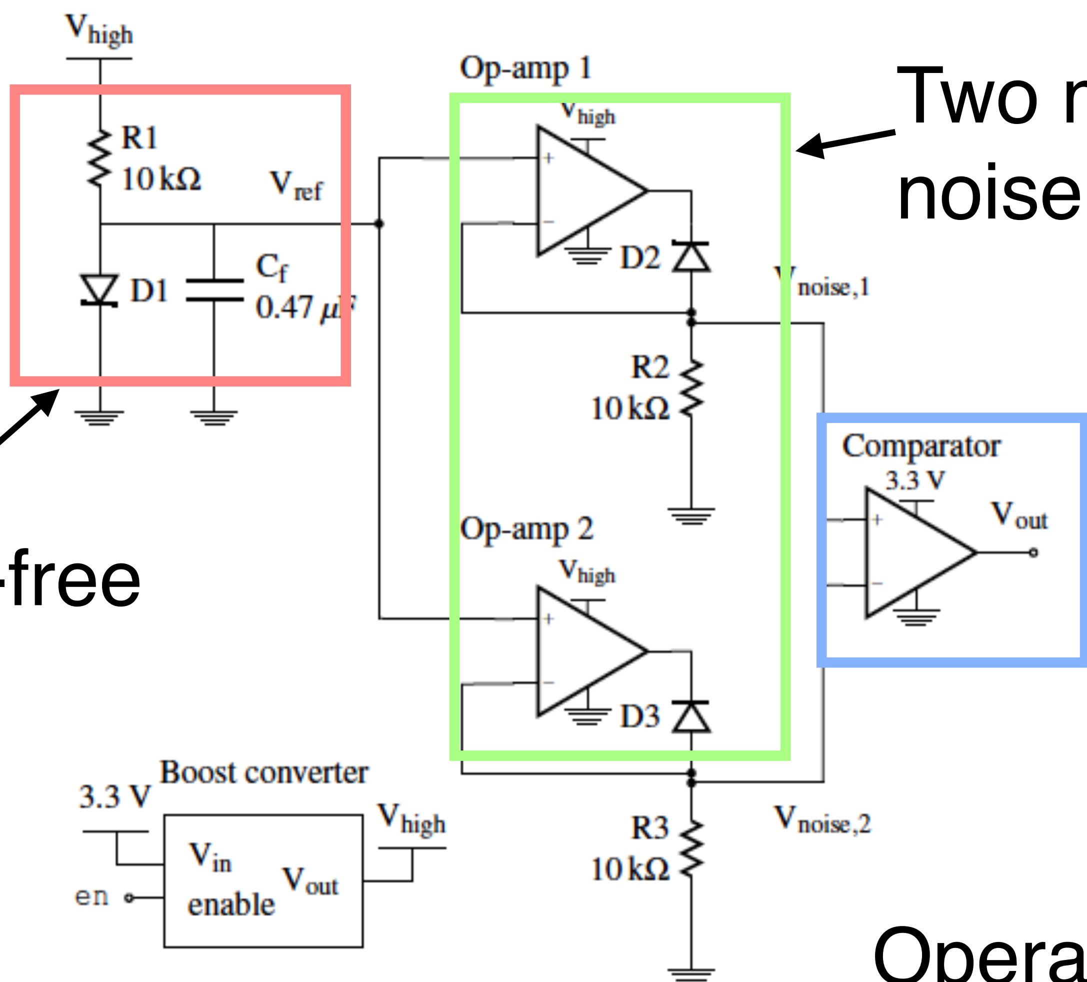
Embedded IoT Security

- Random numbers are foundational to security
  - E.g., key generation, nonces, etc.
- A random number generator needs a seed of entropy — truly random bits
  - Can then expand this entropy seed into a huge stream of unguessable bits, assuming adversary cannot see seed
  - E.g., use entropy to generate AES-128 key, then run AES-128 in counter mode, encrypting 0, 1, 2, … , 2^{128-1}
- Can add *more* entropy, but not needed

Lampert Circuit



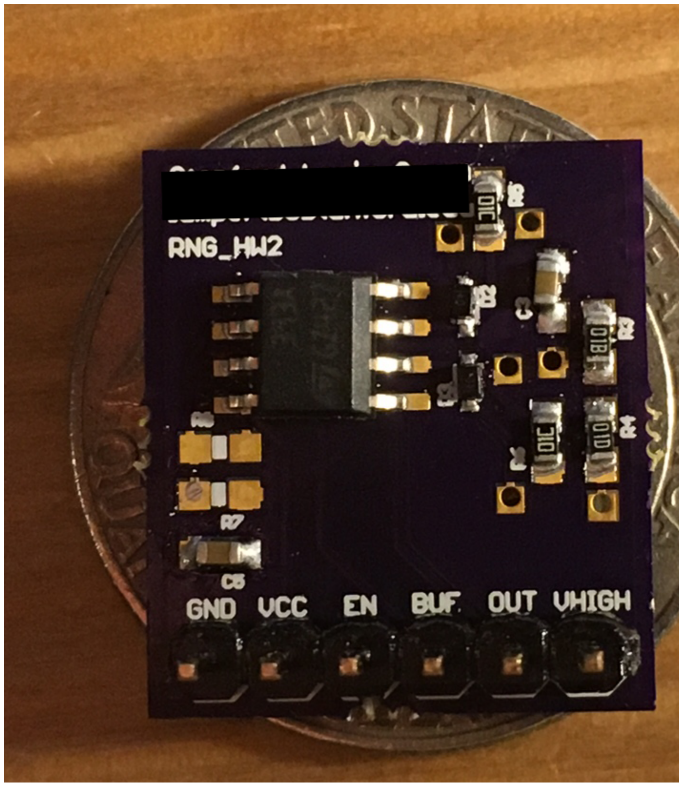
Two matched avalanche noise sources (no bias)

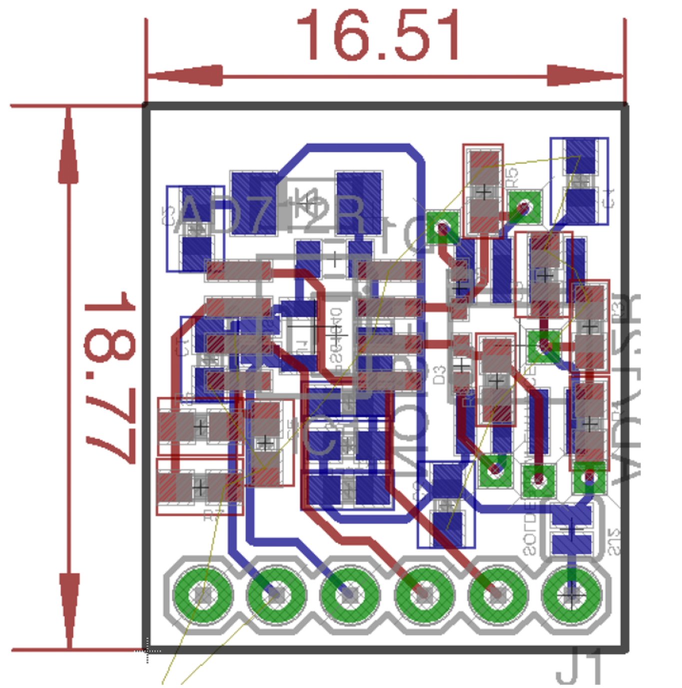
Noise-free power

Comparator

Operating mode: seed hardware AES-128

Lampert Circuit





Going Up the Stack

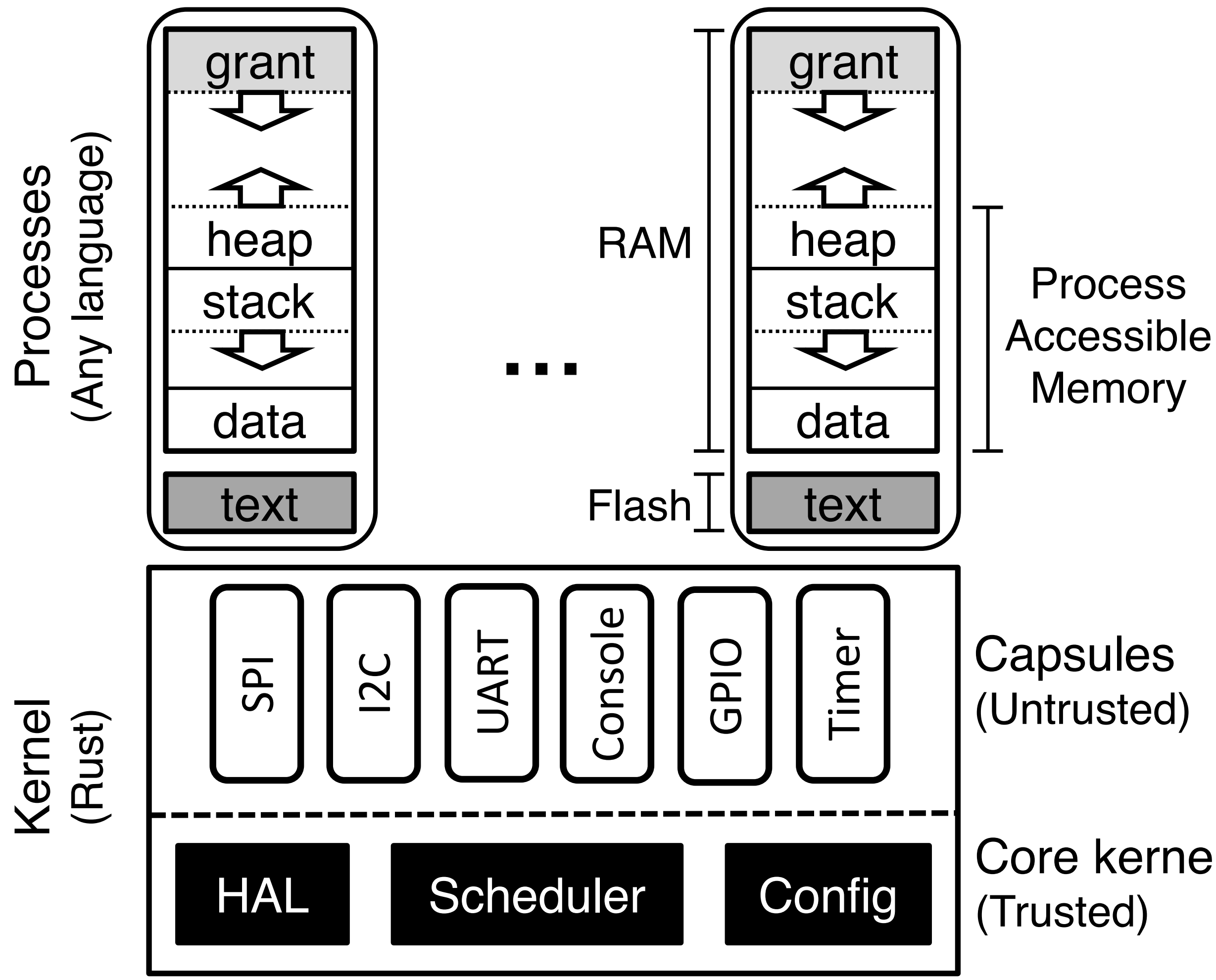
TockOS

CESEL

Tock Operating System

- Safe, multi-tasking operating system for memory-constrained devices
- Core kernel written in Rust, a safe systems language
  - Small amount of trusted code (can do unsafe things)
    - Rust bindings for memory-mapped I/O
    - Core scheduler, context switches
- Core kernel can be extended with *capsules*
  - Safe, written in Rust
  - Run inside kernel
- *Processes* can be written in any language (asm, C)
  - Leverage Cortex-M memory protection unit (MPU)
  - User-level, traps to kernel with system calls

Tock: Secure Embedded OS



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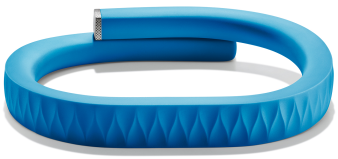
IoT: MGC Architecture

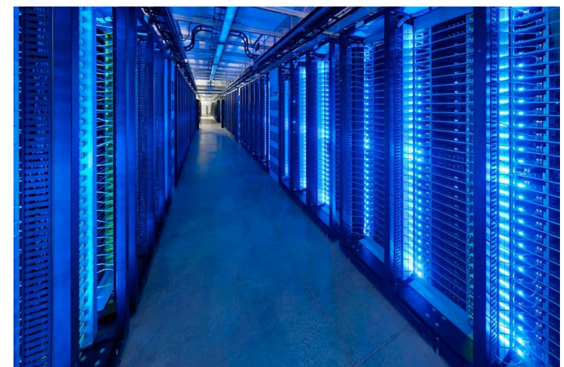
eMbedded devices



6lowpan, ZigBee, ZWave, Bluetooth, WiFi, WirelessHART

Gateways

Cloud

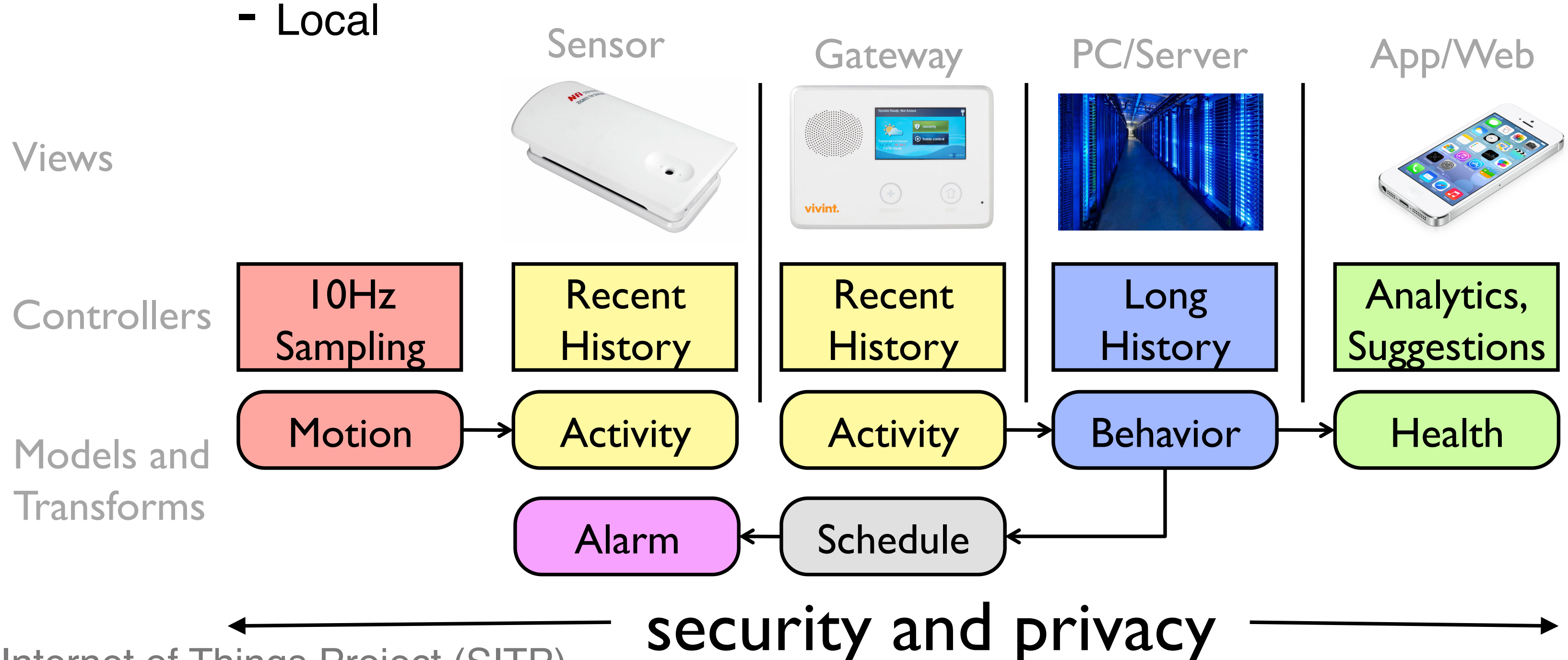


3G/4G, TCP/IP

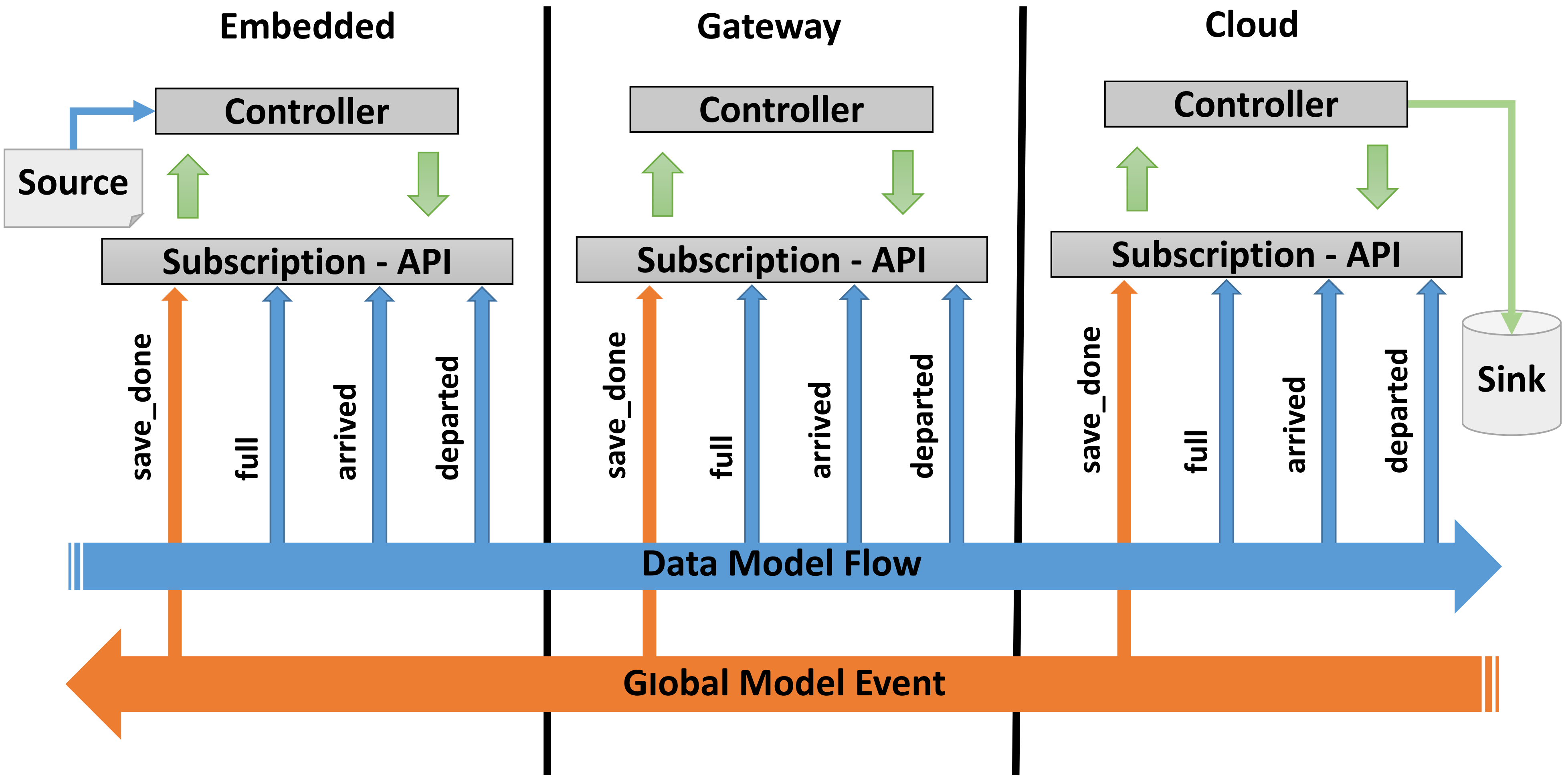
End application

Ravel Framework

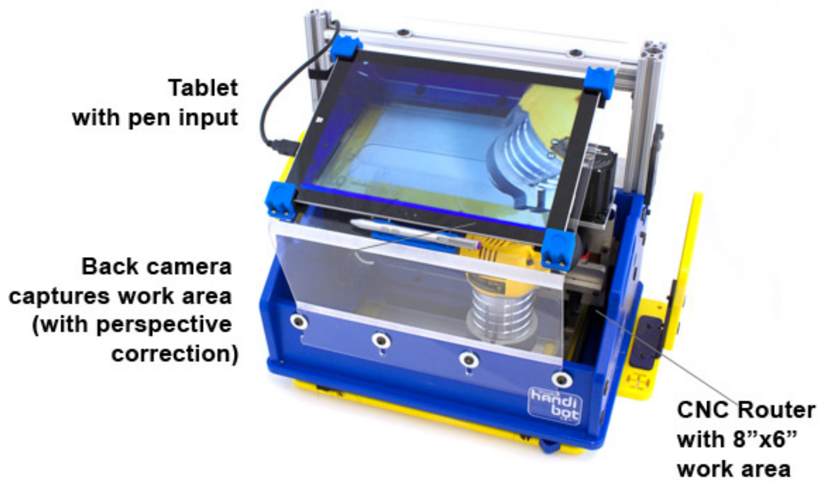
- Write a data processing pipeline
  - Consists of a set of Models, describing data as it is stored
  - Instances of Models are bound to Spaces
  - Three types of models
    - Replicated
    - Streaming
    - Local

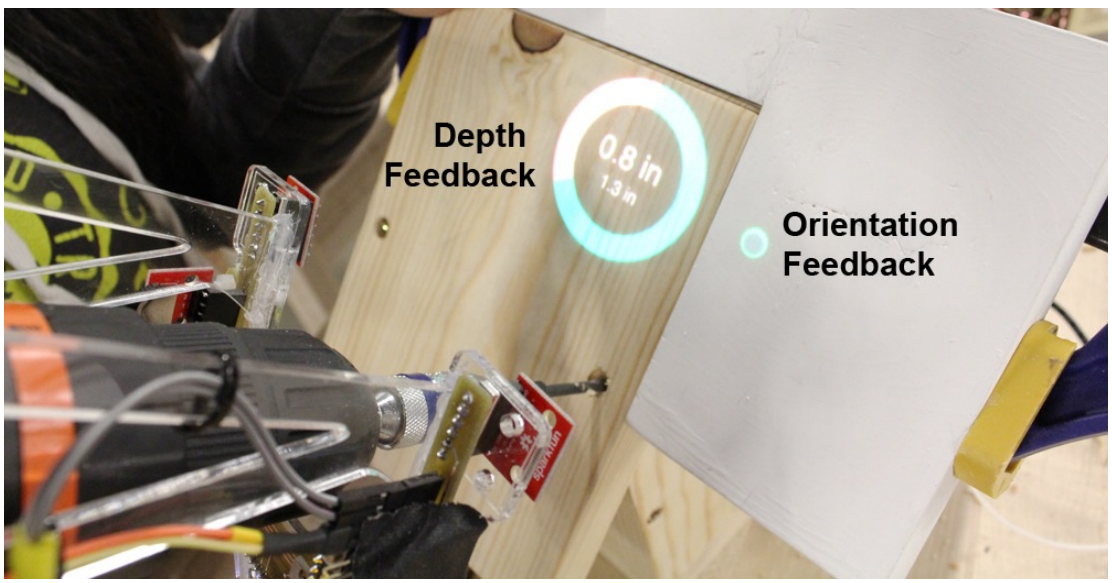


Streaming Model API



Drill Sergeant





Data Security Results

- Arx: A Strongly Encrypted Database System
- Embark: Securely Outsourcing Middleboxes to the Cloud
- BlindBox: Deep Packet Inspection for Encrypted Traffic
- Machine Learning Classification Over Encrypted Data
- Verena: End-to-End Integrity Protection for Web Applications
- Privacy, Discovery, and Authentication for the Internet of Things
- Hosting Services on an Untrusted Cloud
- Semantically Secure Order-Revealing Encryption: Multi-input Functional Encryption Without Obfuscation

System Security Results

- CESEL: Securing a Mote for 20 Years
- Robust, low-cost, auditable random number generation for embedded system security
- Auditing IoT Communications with TLS-RaR
- How to Build Static Checking Systems Using Orders of Magnitude Less Code.
- Ownership is Theft: Experiences Building an Embedded OS in Rust
- Beetle: Flexible Communication for Bluetooth Low Energy.
- Toastboard: Ubiquitous Instrumentation and Automated Checking of Breadboarded Circuits
- Ravel: Programming IoT Applications as Distributed Models, Views, and Controllers
- MBus: An Ultra-Low Power Interconnect Bus for Next Generation Nanopower Systems
- PowerBlade: A Low-Profile, True-Power, Plug-Through Energy Meter
- Cinamin: A Perpetual and Nearly Invisible BLE Beacon

Thank you!

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Dan Boneh
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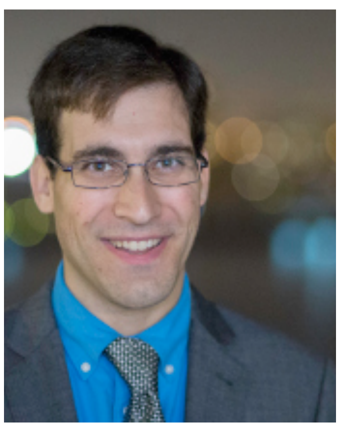
Cryptography

Dawson Engler
Stanford
Software



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