Why *Embedded* and The *Internet of Things* Is Interesting (to 8th Light)

Computing Moved to Mobile

Percentage of U.S. adults with *smartphones*[1]:
- **2011: 35%**
- **2018: 77%**
- **2019: 81%**

— Including cellphones, the total for **2019** is **96%**

[1] https://www.pewinternet.org/fact-sheet/mobile/

Computing Moved to Mobile

- There were about **5 billion** unique mobile subscribers as of 2017
- Forecast to be **75%** of world by 2020.
- Is slowing: It took only **3.5 years** to go from 3 to 4 billion, but took **4 years** to go from 4 to 5 billion

Embedded System

An embedded system is a computerized system that is purpose-built for its application.[2]

[2] Definition taken from *Making Embedded Systems: Design Patterns for Great Software* by Elicia White.

But, This Is Small By Comparison!

- By **2020**, there will be **75 billion** non-mobile phone connected devices
- IoT spending is **$770 billion** in 2018, and is projected to reach **$1 trillion** in 2020.
- Four times larger than **Big Data** and **AI** combined
- Is/will be an in-demand skillset

Computing Is Moving to Microcontrollers

- Extremely small physical size
- Very low energy usage (ESP32: 0.01mA deep sleep, battery life of months)[3]
- Low cost: ~$2
- Capable:
  - e.g. ESP32 is a 160MHz 32-bit processor (think

[3] Calculation for a "datalogger" use case: 2000 mAh battery, 0.01 mA deep sleep, 130 mA active usage, 30 wakeups/hr, 1000 ms wakeup period. See https://www.geekstips.com/battery-life-calculator-sleep-mode/

User Interface: Radically Different

- Displays & radios are key constraint & can break energy budget
- Ideal may be to not be noticed at all
- Focus on "proactive computing"

Consumer Profile

- Less noticeable to end-users: no App Store, no flagship device
- Commercial and industrial spending dominates (by over 5x)
- Timing: industry is replacing PLCs (programmable logic controllers) & PID controllers (proportional, integral, derivative) with MCUs.

Development: Very Different

- Toolchains can be limited: often only a manufacturer-provided C compiler
- Dev cycles can be long (especially with hardware involved)
- Different skill set than web development
- More careful testing and verification (may be in environment where fixes are not feasible)
- Typically no OS (no Linux, Mac, etc.). Sometimes a

Development

- Means there is a lot of room to improve
- We are at a high-leverage point in time w.r.t. tooling and development methodology (we can still build the framework! TDD not widespread)
- Wireless & connectivity options are exploding right now: WiFi, Bluetooth Low Energy, LoRa, Z-Wave, Thread, NFC, RFID, SigFox, and more

Energy, Energy, Energy

- Compute/watt may dominate processing decisions
- If power use is low enough, energy-harvesting, solar & off-grid become feasible
- Trading on-device compute for radio is usually a good choice
- Battery capacity is a major constraint on designs

Work Smarter

- MCU + Deep Learning + Sensors = Solutions
- *Running* a neural net on-device is cheap in energy
- Only *important* data gets sent upstream. Sending is expensive in energy
- Sending all data upstream is too energy-intensive

Work Smarter

- Sending only summaries is also privacy-respecting
- Reduce *Data Liability* exposure
- Cannot leak data that is never stored

TODO

- Widespread GDPR-type regulations may become prevalent in the future
- Need clean-room, non-PII architectures
- *Trust-free* (*trust-less*, *untrusted*, *private*, *privacy-respecting*?) architectures needed

References

- *Mobile Fact Sheet* - Pew Internet
- *Two-thirds of the world's population are now connected by mobile devices* - Business Insider
- *Why the Future of Machine Learning is Tiny* - Pete Warden
- *The Revolution is Coming... You might barely notice* - Bryan Costanich

References

- *The Revolution is Coming… You might barely notice.* - Bryan Costanich
- *The Future is Tiny* - Bryan Costanich
- *The Best Interface is No Interface* - Golden Krishna
- *Understanding the Real Energy Consumption of Embedded Microcontrollers* - Digikey

References

- *Batteries Still Suck, But Researchers Are Working on It -* Wired
- *Making Embedded Systems: Design Patterns for Great Software -* Elicia White