Software Systems for IoT

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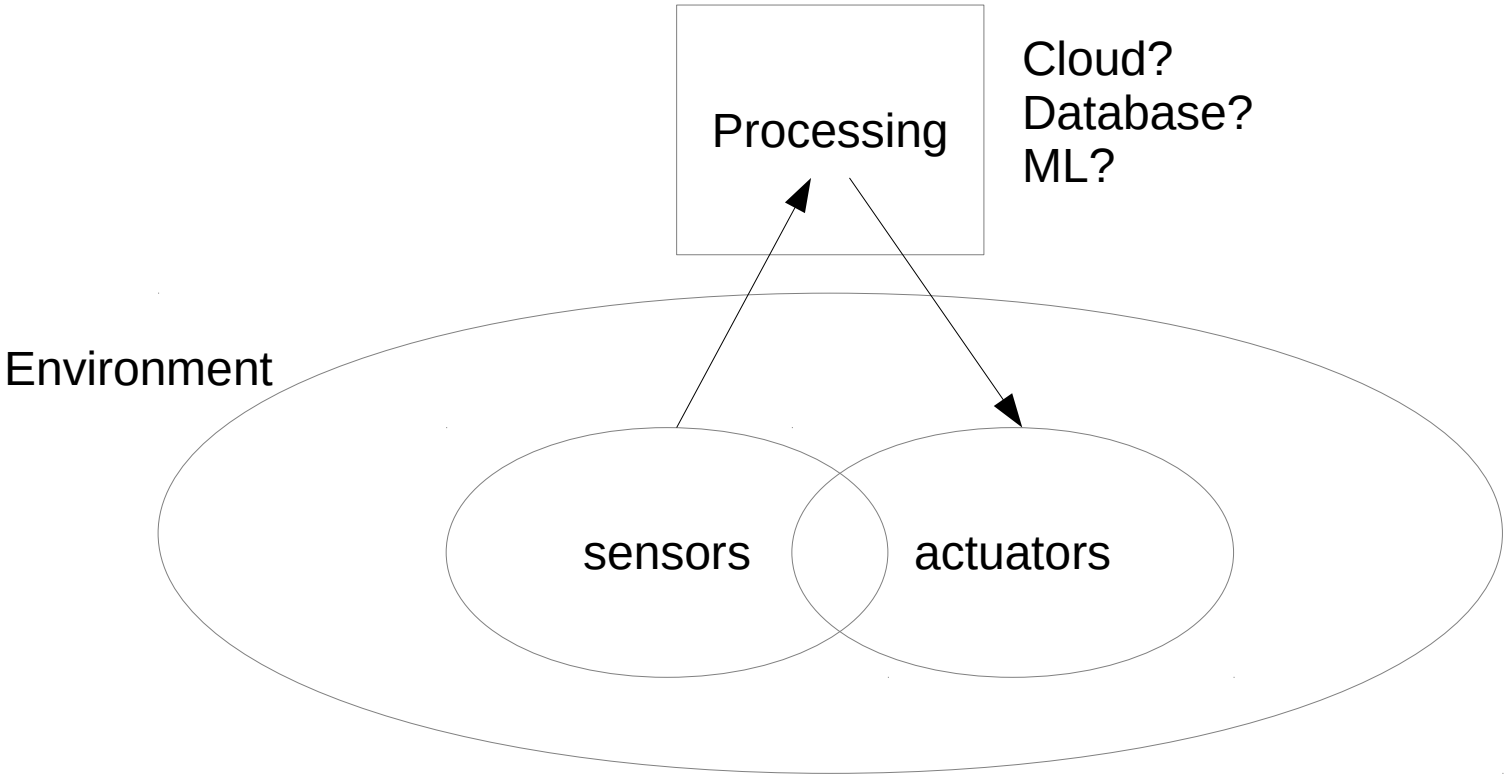
IoT Systems are Embedded

- The “things” or devices are not just computers…
  - Sensors
    - Temperature, humidity, air pressure, magnetic fields, light…
    - Body temperature, blood pressure, heart rate, oxygenation, steps…
    - Acceleration, GPS location...
    - Camera, microphone...

IoT Systems are Embedded

- The “things” or devices are not just computers…
  - Actuators
    - Thermostat, lights, door locks…
    - Drug pumps...
    - Motors...
    - Displays, speakers...

IoT Systems are Embedded



IoT Systems are Embedded

- Wide range of computational capability
  - “Smart dust”
  - Battery operated wireless sensor nodes
  - Single board computers (Arduino, Raspberry Pi, etc.)
  - Large scale computer system
    - Telsa uses full Linux installation with GPUs for image processing

IoT Systems are Embedded

- Lower end systems often highly constrained
  - Slow CPUs (1 MHz clock)
  - Small memory (16 KB ROM, 4 KB RAM)
  - Low power (AA batteries… required to last for months)
  - Limited RF (range 10s or 100s of feet at most)
- Creates new programming challenges

IoT Systems are Embedded

- Low end systems might be disposable
  - Sensing fire information during forest fire
  - Volcanic eruptions
  - Animal tracking
  - Any application with a large number of sensors
- Consequence: sensor devices must be cheap

IoT Systems are Embedded

- Security!
  - Privacy: sensor personal information
    - Microphones pick up conversations
    - Cameras see things
    - Medical devices
  - Data integrity and confidentiality
    - On the way to/from the processing
    - Devices subject to physical attack
  - Cyber-physical systems! **Attacks have physical consequences**

IoT Systems are Embedded

- High integrity & High reliability
  - Safety critical systems
    - Medical devices
    - Autonomous vehicles
    - Infrastructure (power generation, etc.)
  - Software failure can cause major loss of life or other assets

IoT Systems are Networked

- Various protocols
  - Traditional IPv4 and IPv6 (with Wi-Fi, IEEE 802.11)
  - ISM (Industrial, Scientific, Medical) bands
    - 2.4 GHz and also 915 MHz (in the USA)
  - IEEE 802.15.4
    - MAC/PHY layer protocol
    - Low rate WPAN network (Wireless Personal Area Network)
  - Bluetooth (was IEEE 802.15.1, now Bluetooth Special Interest Group)
  - Zigbee (rides over IEEE 802.15.4)
  - 6LoWPAN (IPv6 over IEEE 802.15.4)

IoT Systems are Networked

- Low power devices have limited range
  - Necessitates multi-hop configurations
  - Ad-hoc networks
    - No pre-existing infrastructure
    - Nodes dynamically determine when and where to forward data
- Power saving may require frequent off time
  - Radios tend to consume a lot of energy; **keep them off**
  - Communication challenges when nodes are up/down often

IoT Systems are Networked

- 5G (vs 4G)
  - Higher bandwidth
  - Better resource (bandwidth) utilization
  - Better able to manage crowded areas (many devices)
  - Lower latency
  - Potentially long range communication (compare: Wi-Fi)
    - e. g., Autonomous vehicles

IoT Systems are Networked

- Millimeter wave communication (60-90 GHz)
  - Even more bandwidth
  - BUT…
    - Line of sight only (use multiple antennas to mitigate)
    - More attenuation by the atmosphere
  - Some IoT applications can live with these limitations
  - 5G may use this band, but focus is on lower bands

IoT Systems are Networked

- DTN
  - “Delay/Disruption” Tolerant Networking
  - Useful for super-long latency systems
    - Spacecraft (latencies in minutes/hours!)
  - Useful for extremely unreliable links
    - Spacecraft (planetary blockage)
    - Undersea vehicles/devices (poor propagation through water)
  - **Special protocols required**

IoT Systems are Networked

- DTN example: Europa mission
  - Earth to Europa orbiter (about 45 minutes at the speed of light)
  - Orbiter to lander on surface (sometimes blocked by Europa)
  - Lander to submarine in Europan under-ice ocean
- Data must multi-hop over several nodes with limited availability
  - Telemetry & science data must reach Earth
  - Command and control data must reach submarine
- Other questions:
  - How much behavior can be autonomous?
  - Where is data processing & evaluation done?

IoT Systems can use the Cloud

- Advantages of the Cloud
  - Global access
  - Enormous data storage capacity
    - e. g., 10^5 sensors, taking multiple readings every second
  - Enormous computational capacity
    - Advanced data processing & reduction methods
    - Advanced machine learning algorithms
    - AI-based decision making
  - Broad access

IoT Systems can use the Cloud

- Disadvantages of the Cloud
  - Additional security concerns (privacy, access control)
  - Less local control
  - More expensive (maybe)
- Not all IoT applications need the cloud
  - Many could benefit from it