One Possible Taxonomy

- Small systems (constrained in size)
  - E.g., Cellular phones, pagers, home appliances, toys, smart cards, MP3 players, PDAs, digital cameras and camcorders, sensors, smart badges
  - Key challenge: Deal with stringent resource constraints
- Signal processing systems (input signal → Process → output signal)
  - E.g., Radar, sonar, real-time video, set-top boxes, DVD players, medical equipment, residential gateways
  - Key challenge: Need for high computational power (increase rate of processing)
- Mission critical systems
  - E.g., Avionics, space-craft control, nuclear plant control
  - Key challenge: Need for extreme reliability
- Distributed control (communication system)
  - E.g., Smart grid, mass transit systems, elevators in buildings
  - Key challenge: Need to deal with distributed nature of systems

Typical Characteristics

- HW and SW do application-specific function – not general purpose
  - Application is typically known a priori
- Physically coupled (coupled with physical world)
  - Interact (sense, manipulate) with physical world processes and phenomena
  - Hybrid dynamics (mix of continuous-state (physical world) and discrete-state (digital)) – cyber-physical systems
- Passage of time is extremely important
  - Correctness of results also depends on time at which they are produced
  - Operation is almost always time constrained: latency, throughput
- Inherently concurrent – many things need to happen at the same time (e.g., a system is concurrently sensing movement & temperature)
- Never terminate (ideally) – WiFi Router (keep operating until we turn it off)
  - → loops
- Various constraints: computation, memory, bandwidth, power, size, weight, heat, reliability, cost, etc.

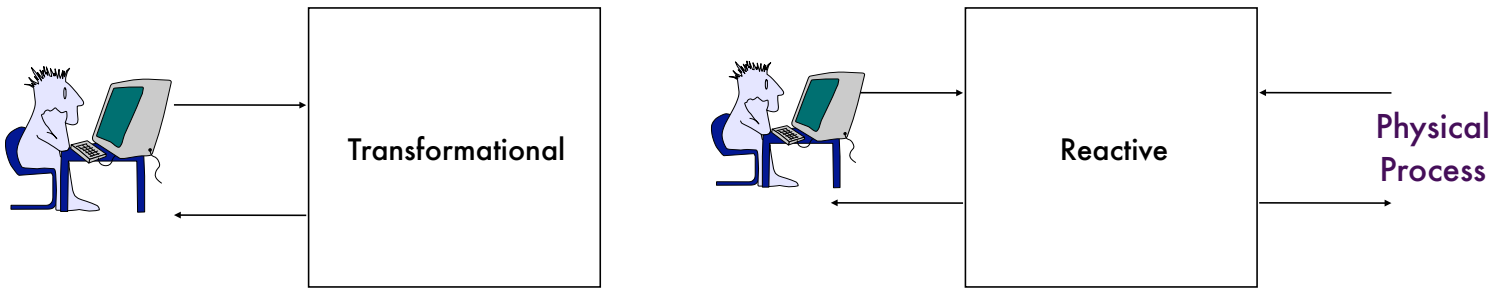
Key Recent Trends

- Increasing computation demands (memory, software architecture)
  - e.g.,HDTV, gaming on mobile phones, machine learning and inference
  - Affects many design metrics (cost, size, battery life, reliability)
    - ↳ I feel this

benefits computation demands

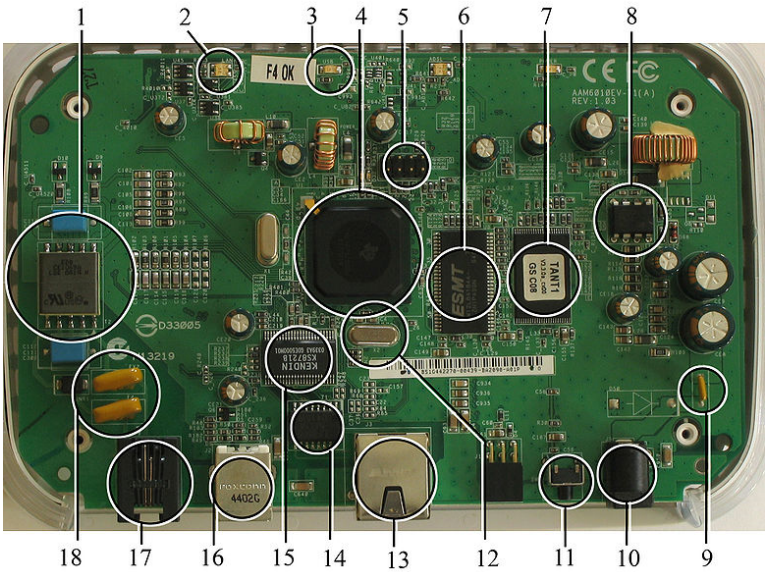
- Increasingly networked (the Internet is everywhere!)
  - e.g., embedded web servers, cameras, disks, etc., that sit directly on networks
  - Enables new and exciting applications, lots of additional challenges
    - issues: security (design for security from early-stages of design)
- Increasing need for flexibility - more programmable systems
  - Time-to-market under ever changing standards! (minimum viable product)
  - Upgrading, bug fixing, product differentiation, customization
  - Implications on design choices and tradeoffs
  - Increasing share of SW development in terms of cost

Reactive Operation



- Computation is in response to external events, as opposed to transformational operation in interactive systems
  - Need to deal with a mix of periodic and aperiodic events
- Interaction with environment causes problems
  - Indeterminacy in execution
    - e.g., waiting for events from multiple sources
  - Physical environment is delay intolerant
    - can't put it on wait with an hour glass icon!
- Handling timing constraints crucial to the design of embedded systems

Example: DSL Modem



Bill of Components:

1. Telephone decoupling electronics (for ADSL).
2. Multicolor LED (displaying network status).
3. Single color LED (displaying USB status).
4. Main processor, a TNETD7300GDU, TI ARM7.
5. JTAG (Joint Test Action Group) port.
6. RAM, a single ESMT M12L64164A 8 MB chip.
7. Flash memory, obscured by sticker.
8. Power supply regulator.
9. Main power supply fuse.
10. Power connector.
11. Reset button.
12. Quartz crystal.
13. Ethernet port.
14. Ethernet transformer, Delta LF8505.
15. KS8721B Ethernet PHY.
16. USB port.
17. Telephone (RJ11) port.
18. Telephone connector fuses.

Embedded HW Considerations

- Processor
  - energy, computation
- Network interface
  - wired, RF, acoustic, optical
  - energy, range, bandwidth, interference-robustness
- Energy supply
  - wired, battery, scavenging
  - lifetime, size
- User interface
  - type, energy, complexity
- Sensing
  - type, energy, range, accuracy, resolution, frequency, fidelity
- Actuation
  - type, energy, range
- Storage
  - energy, capacity, bandwidth
- Packaging
  - form-factor, weight, weather-proof
- Overall cost

Processing Choices

- Microprocessors (general purpose)
- Domain-specific processors (e.g., GPU)
  - DSPs
  - Network processors
  - Microcontrollers (bit level manipulation operations)
- ASIPs : Appl. Specific Instruction-Set Processor
- Reconfigurable SoC - tightly coupled with FFT
- FPGA
- ASIC - Appl Specific Integrated Circuit (custom chip just for that appl.)