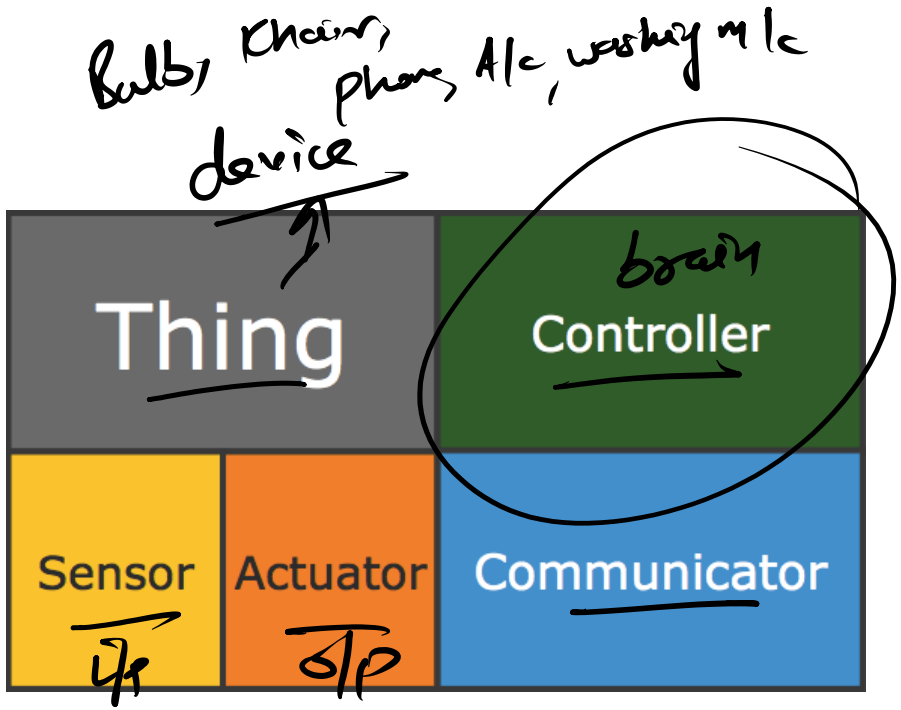
last lecture
Application of IoTs

Components-Embedded Systems

Internet-of-Things

Lecture 5

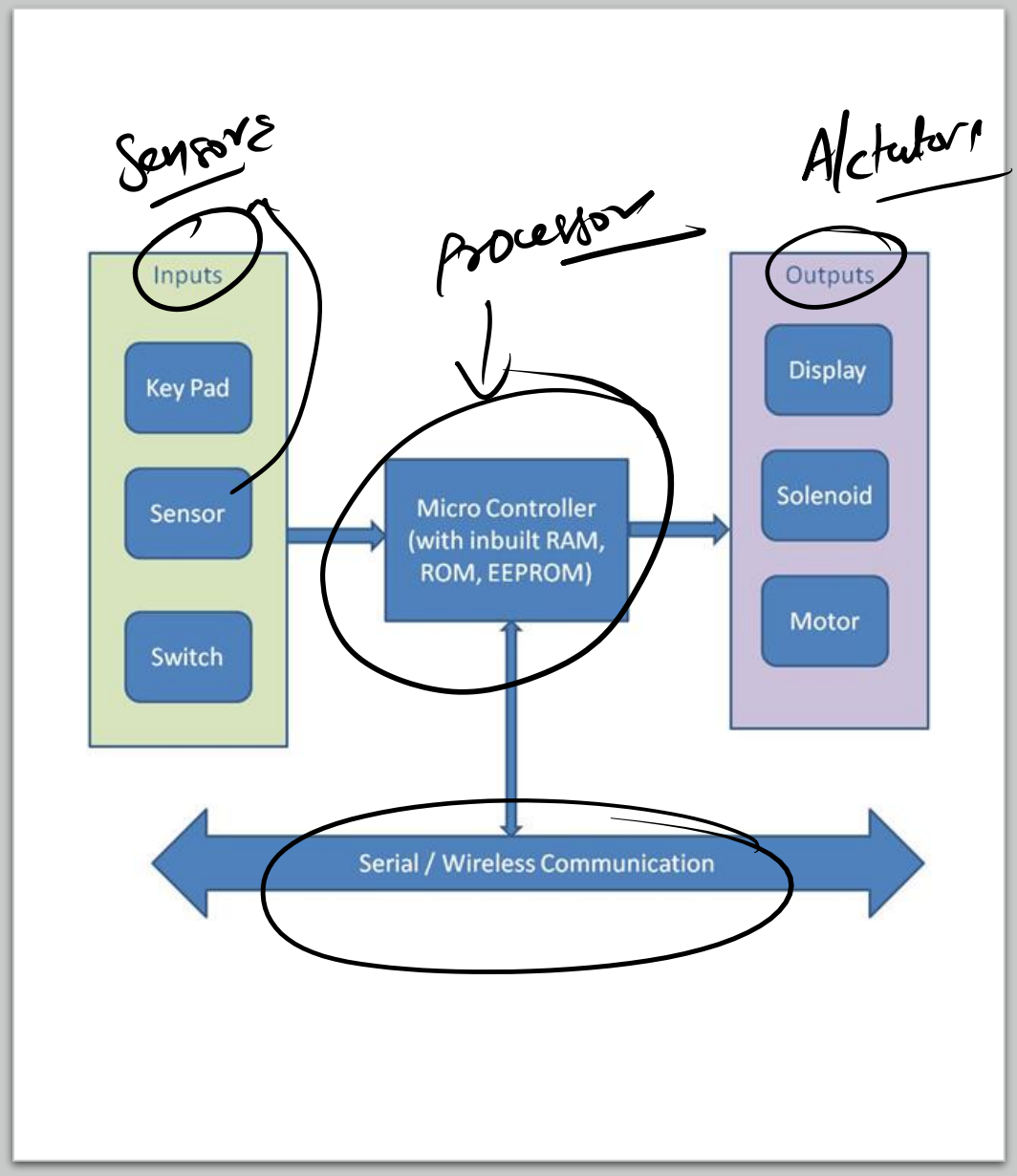
*University of Notre Dame and ARM



Components of an IoT Device

Embedded System/Computer

- "Any sort of device which includes a programmable computer but itself is not intended to be a general-purpose computer" -Wayne Wolf
  - General purpose
  - Dedicated



Embedded systems

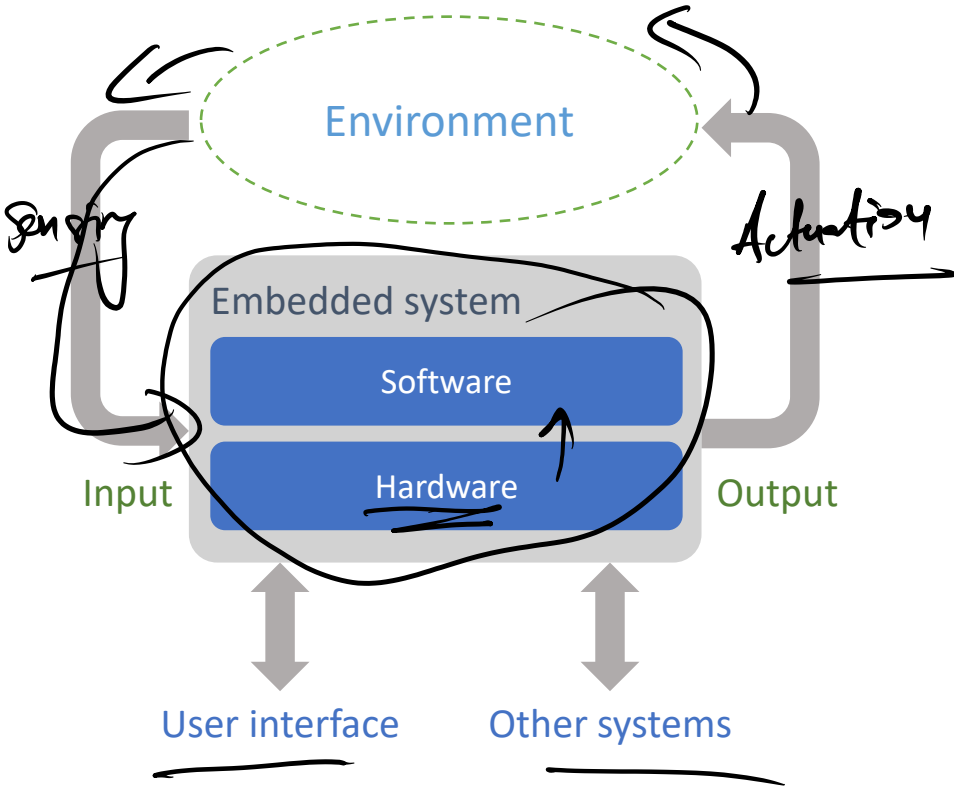
Internet of Things (IoT)

- Application-specific computer system
- Built into a larger system
- Often with real-time computing constraints

Adding embedded systems to larger systems

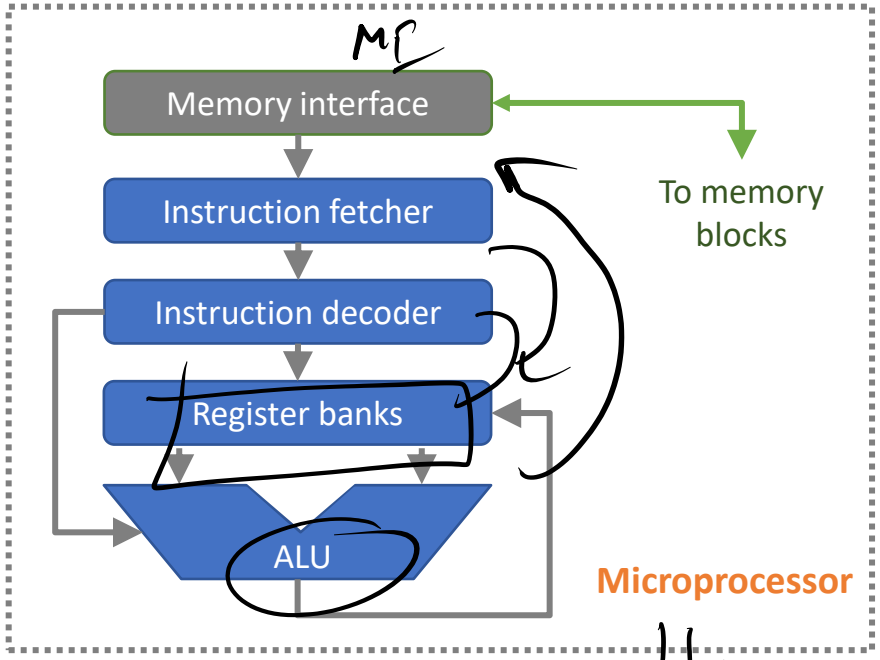
- Better performance
- More functions and features
- Lower cost, for e.g., through automation
- More dependability

Examples: smartphones, smart watches, printers, gaming consoles, wireless routers



CPUs → MCUs → Embedded Systems

Microprocessor or Central Processing unit (CPU)

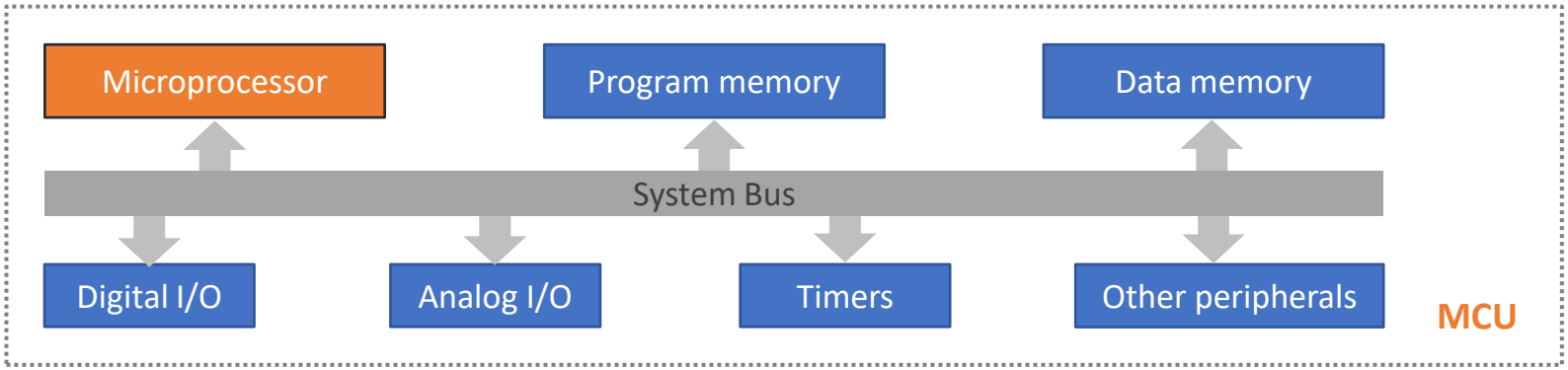


Defined typically as a single processor core that supports at least instruction fetching, decoding, and executing

Used for general purpose computing, but needs to be supported with memory and Input/Output (I/O) interfaces

CPUs ⟶ MCUs ⟶ Embedded Systems

Microcontroller Unit (MCU)

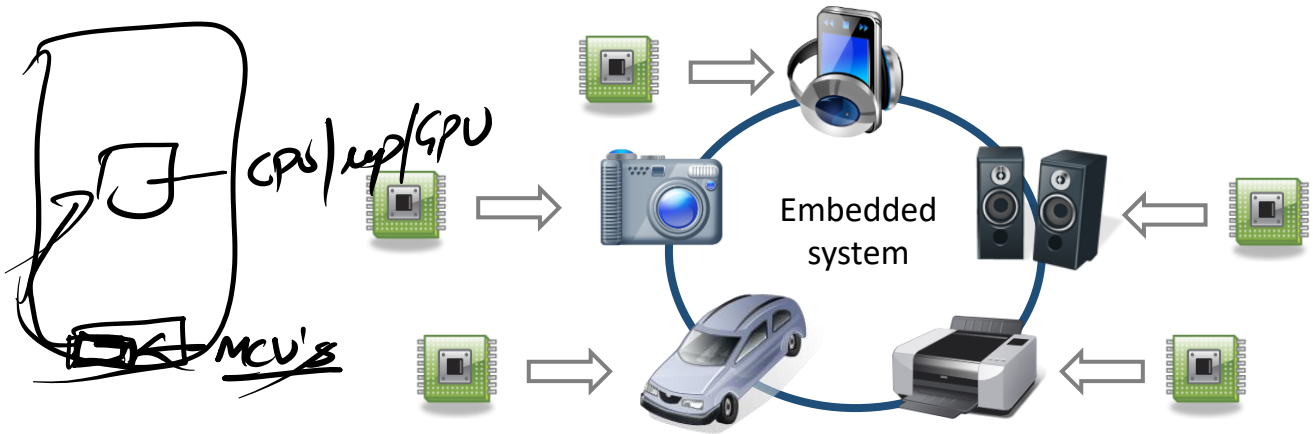


- Typically has a single processor core
- Has memory blocks, digital I/Os, analog I/Os, and other basic peripherals
- Used for basic control purposes, such as embedded applications

CPUs ⟶ MCUs ⟶ Embedded Systems

Embedded system

- Typically implemented using MCUs
- Often integrated into a larger mechanical or electrical system
- Usually has real-time constraints



Embedded system example: Bike computer

- Functions
  - Speed, cadence, distance, heart rate (HR) measurements
- Constraints
  - Size, weight, and cost; power and energy
- Inputs
  - Wheel rotation sensor and mode key
- Output
  - Liquid crystal display (LCD), BLE interface to smartphone
- Uses low performance microcontroller

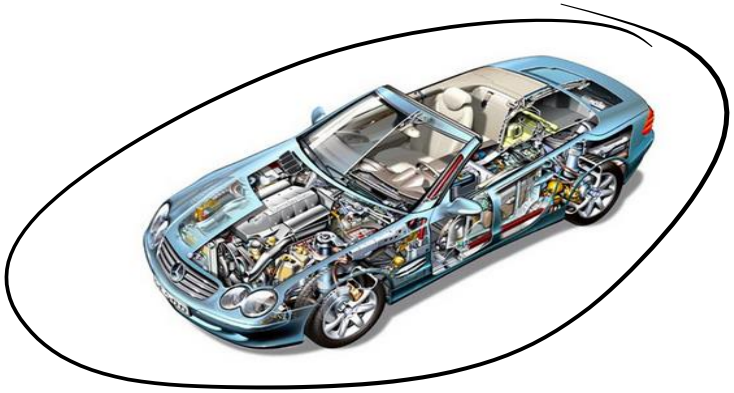
Inputs:
Wheel rotation
Mode key

Outputs:
Display/transmi
t speed, HR, etc.

Embedded system example: Gasoline engine control unit

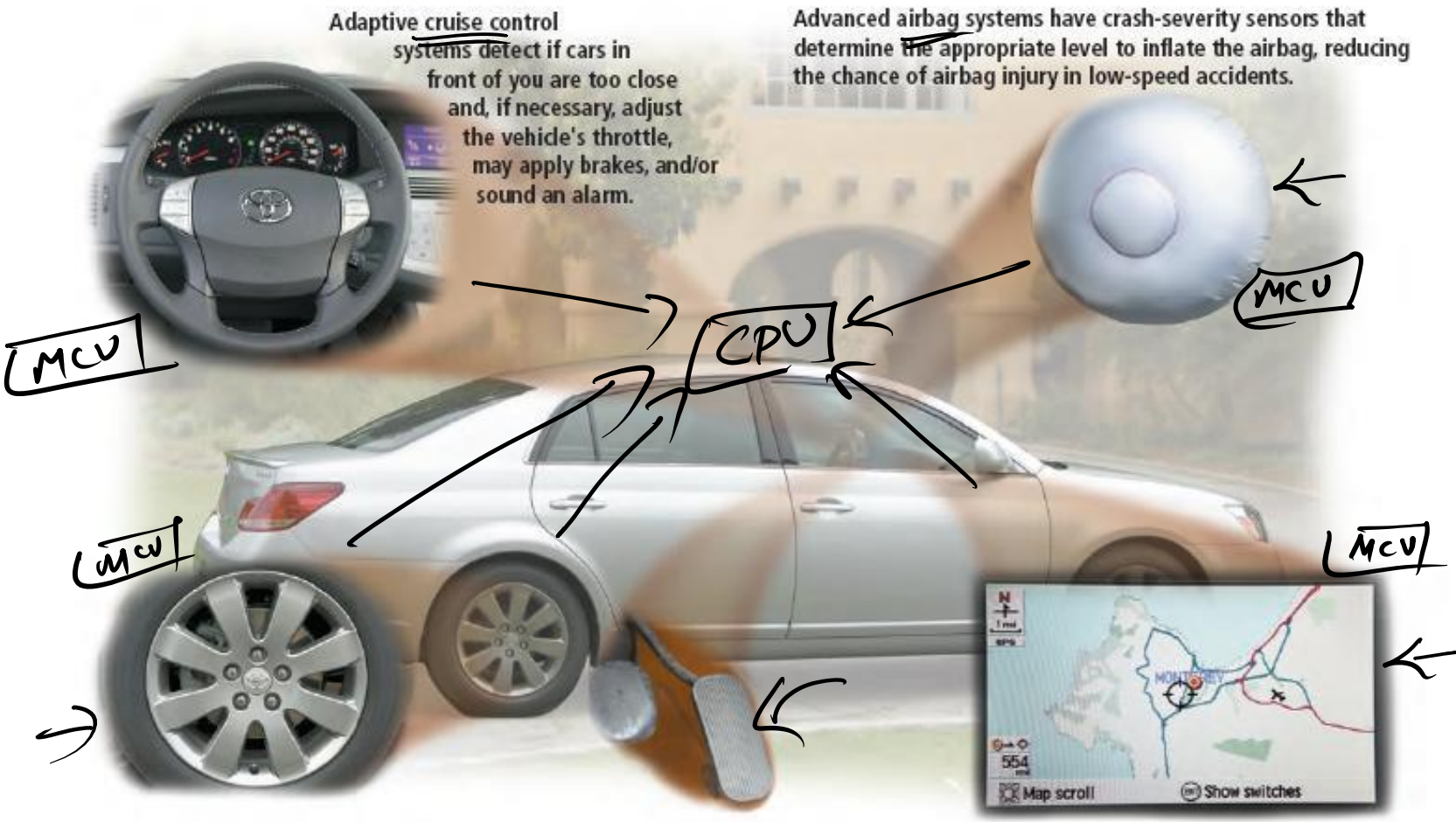
- Functions
  - Fuel injection
  - Air intake setting
  - Spark timing
  - Exhaust gas circulation
  - Electronic throttle control
  - Knock control
- Constraints
  - Reliability in a harsh environment
  - Cost
  - Weight

- Many inputs and outputs
  - Discrete sensors and actuators (MCU)
  - Network interface to rest of the car (MCU)
- Uses high performance microcontroller
  - E.g., 32-bit, 3MB flash memory, 150–300MHz



Automotive Embedded Systems

(Self drive car)



Tire pressure monitoring systems send warning signals if tire pressure is insufficient.

Drive-by-wire systems sense pressure on the gas pedal and communicate electronically to the engine how much and how fast to accelerate.

Cars equipped with wireless communications capabilities, called *telematics*, include such features as navigation systems, remote diagnosis and alerts, and Internet access.

Automotive Embedded Systems

- Today's high-end automobile may have 100+ microprocessors:

  Seat belt; dashboard devices; engine control; ABS; automatic stability control; navigation system; infotainment system; collision avoidance system; tire pressure monitoring; lane warning; adaptive cruise control; climate control; airbag control unit; electric window and central locking; parking aid; automatic wiper control; alarm and immobilizer; power seat; electric power steering; electronic transmission; active suspension

Embedded Processor Market

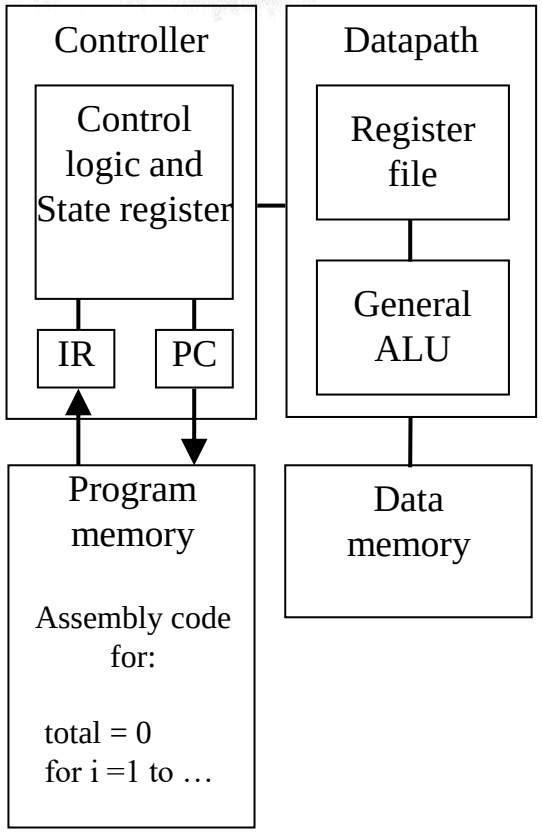
80 million PCs every year

3 billion embedded CPUs every year

Embedded systems market growing, while PC market mostly saturated

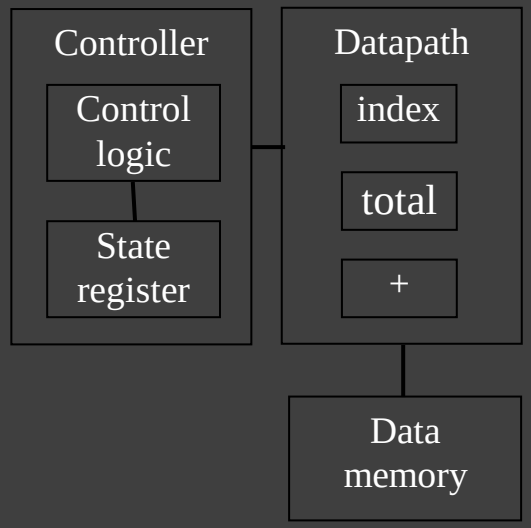
General-Purpose Processor

- Programmable device, “microprocessor”
- Features
  - Program memory
  - General data path with large register file and general ALU
- User benefits
  - Low time-to-market and NRE costs
  - High flexibility
- Examples: Intel Core i7, AMD Ryzen 5, etc.



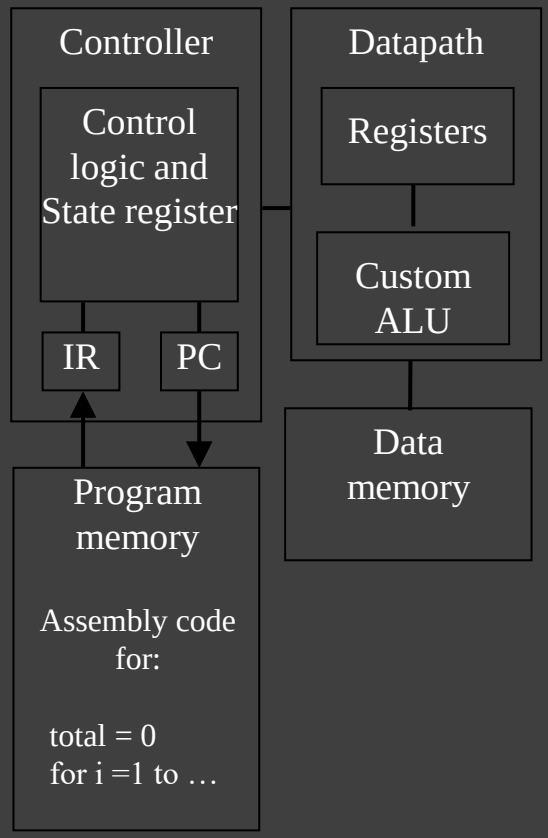
Dedicated Processor

- Digital circuit designed specifically for one purpose
- Features
  - Contains only the components needed to execute a single program
  - No program memory
- Benefits
  - Fast
  - Low power
  - Small size



Application-Specific Processor (ASIC)

- Programmable processor optimized for a particular class of applications that have common characteristics.
- Features
  - Program memory
  - Optimized data path
  - Special functional units
- Benefits
  - Some flexibility, good performance, size, and power, “reusable”



https://en.wikipedia.org/wiki/Application-specific_integrated_circuit

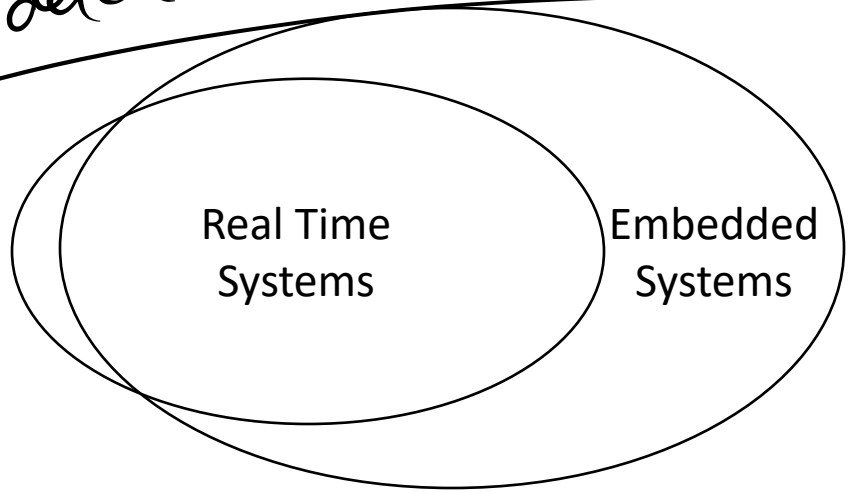
Characteristics of Embedded Systems

- Dedicated functionality
- Real-time operation
- Small size and low weight
- Low power
- Harsh environments
- Safety-critical operation
- Cost sensitive

Embedded vs. Real Time Systems

- Embedded system: is a computer system that performs a limited set of specific functions; it often interacts with its environment
- RTS: Correctness of the system depends not only on the logical results, but also on the **time** in which the results are produced

Tire pressure ⇒ pedestrian detection – in self drive car – RTS



Examples?

Examples

- Real Time Embedded:
  - Nuclear reactor control
  - Flight control
  - Basically, any safety critical system
  - GPS
  - MP3 player
  - Mobile phone
- Real Time, but not Embedded:
  - Stock trading system
  - Skype
  - Pandora, Netflix
- Embedded, but not Real Time:
  - Home temperature control
  - Sprinkler system
  - Washing machine, refrigerator, etc.

Benefits of embedded systems

Greater performance and efficiency

More sophisticated control through software

Lower cost

Cheaper components

Reduced manufacturing costs

Reduced operating and maintenance costs

More features

Many not possible or impractical using other approaches

Better dependability

Adaptive systems that can compensate for failures

Better diagnostics to improve repair time

Constraints specific to embedded devices

Cost

Competitive markets penalize products that do not deliver adequate value for money

Size and weight limits

Mobile (aviation, automotive) and portable (e.g., handheld, wearable) systems

Power and energy limits

Battery capacity, cooling limits

Environment

Temperatures may range from -40 degrees C to 125 degrees C, or even more.

Functions of embedded systems

Closed-loop control system

Monitor a process, adjust an output to maintain the desired set point of operation (temperature, speed, direction, etc.)

Sequencing

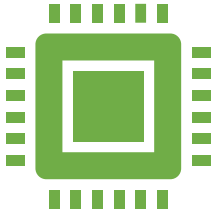
Step through different stages based on environment and system conditions

Signal processing

Remove noise, select desired signal features

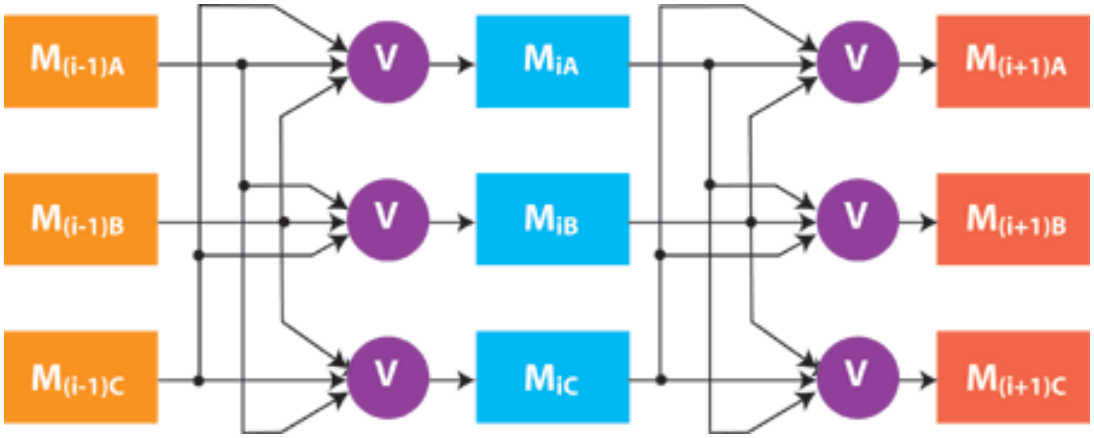
Communications and networking

Exchange information reliably and quickly

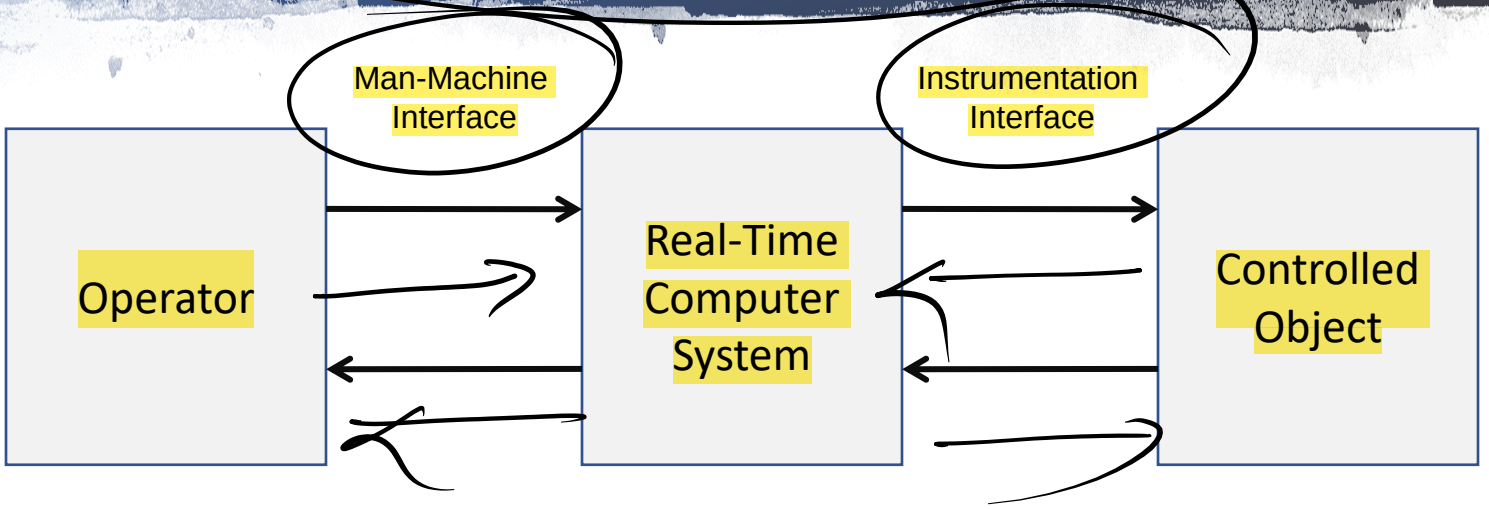


Characteristics of RTS

- Event-driven (reactive) vs. time-driven
- Reliability/fault-tolerance requirements (example: triple modular redundancy)
- Predictability
- Priorities in multi-programmed systems



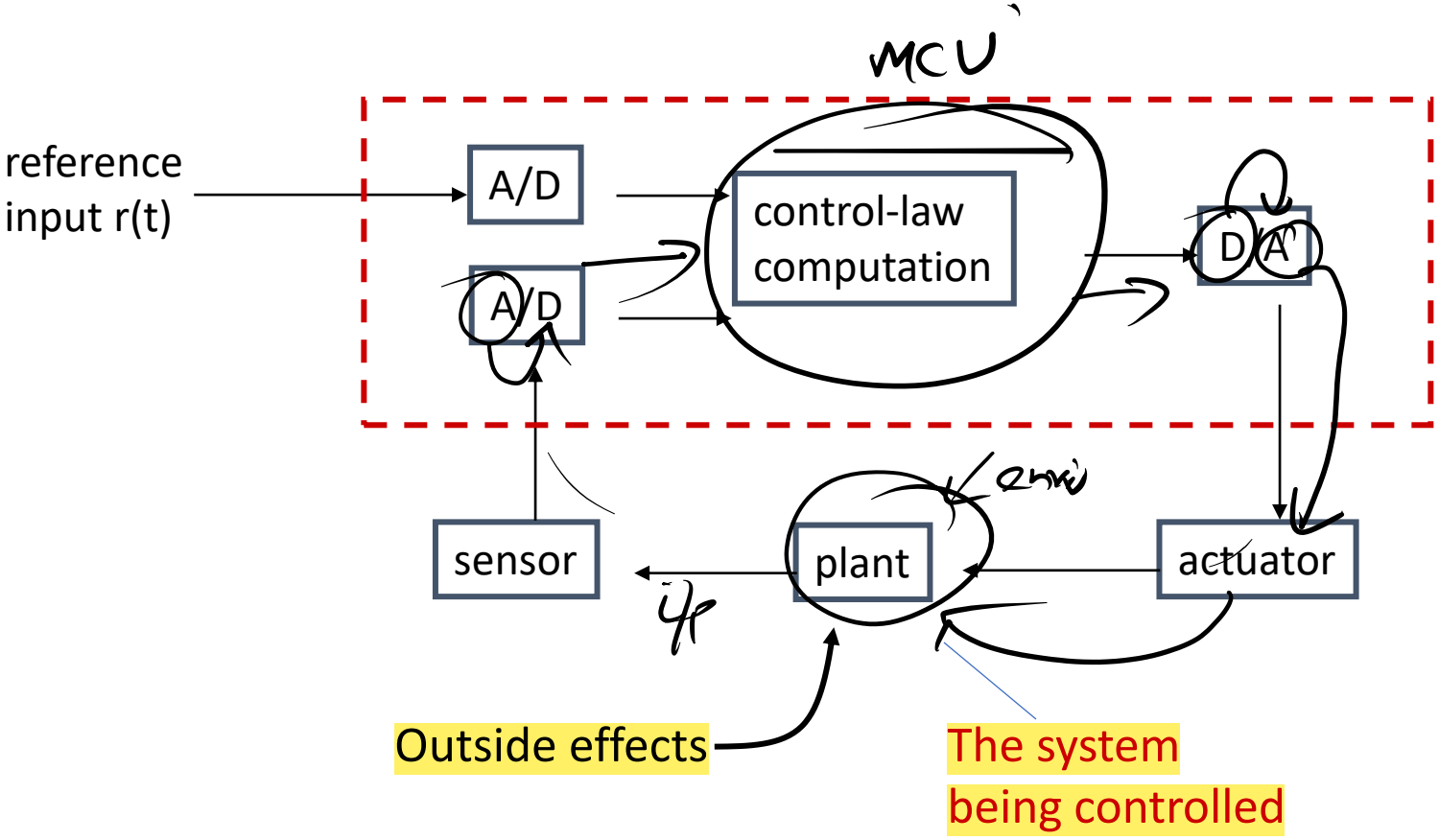
Control Systems



- **Man-machine interface:** input devices, e.g., keyboard and output devices, e.g., display
- **Instrumentation interface**: sensors and actuators that transform between physical signals and digital data.

Control System Example

Example: A simple one-sensor, one-actuator control system.



Control Systems Cont'd.

Pseudo-code for this system:

```
set timer to interrupt periodically with period T;
at each timer interrupt do
        do analog-to-digital conversion to get y;
        compute control output u;
        output u and do digital-to-analog conversion;
end do
```

process it

decode it

T is called the **sampling period**. *T* is a key design choice. *T*ypical range for *T*: seconds to milliseconds.

Sensors and Actuators

Sensors:

- They are mainly input components
- They sense and collect surrounding information

Actuators:

- They are mainly output components
- They alter the surrounding

Communications

- Connects devices with each other & the cloud
- Communication type:
  - Wireline (e.g., copper wires, optical fibers)
  - Wireless (e.g., RF, IR); RF-based communication is the most popular choice
- Popular RF-based communication solutions:
  - IEEE 802.15.4 (LR-WPANs) (Zigbee, 6LoWPAN)
  - IEEE 802.11 (or Wifi)
  - Bluetooth
  - Near Field Communication (NFC), e.g., RFID

Thank You!!

Next Session:

Human Computer Interaction

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