Teaching Assessment (OMET)

- November 22 to December 12

- Your feedback is important
  - What do you like about this course?
  - Suggestions for improvement?

- Incentive
  - 1% of your **final** course grade
  - Send me the screenshot of completion

Recap from last class

- Dynamic power management policy
  - Workload-independent metrics for energy saving calculation
  - Predictive techniques
    - Fixed timeout policy
    - Predictive shutdown and wakeup
- Power manager
  - Advanced Configuration and Power Interface (ACPI)
- Holistic approach
  - Memory system
  - Cache behavior
  - Optimizing operations on I/O devices

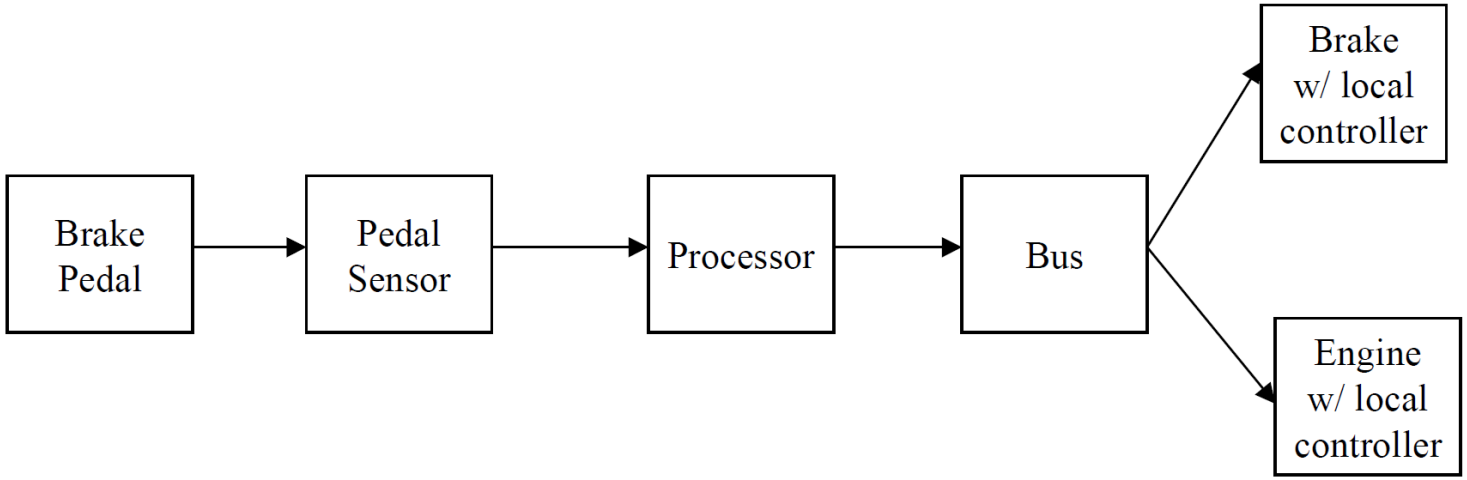
ECE 1175
Embedded System Design

Safety and Reliability

Wei Gao

What is a “Safe” Embedded System?

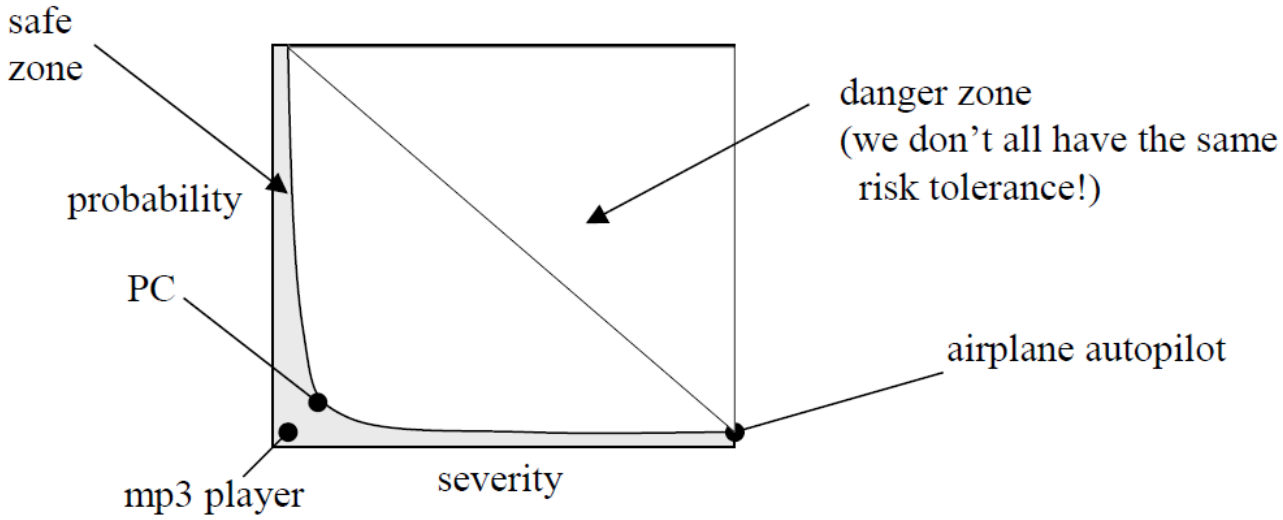
- Again, the ABS system’s case



- Is it safe?
- What does “safe” mean?
- How can we make it safe?
- Add watch dog between brake and bus
- Add mechanical linkage from brake pedal directly to brake
- Add a third mechanical linkage…

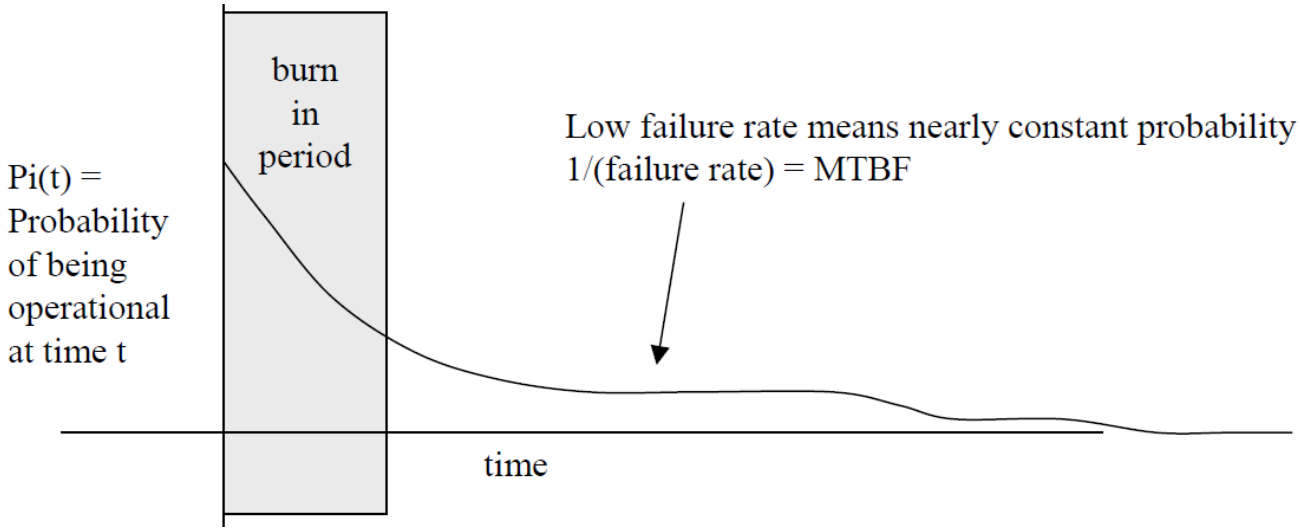
A "Safe" Embedded System

- A system is **safe** if its deployment involves assuming an *acceptable* amount of risk…acceptable to whom?
- Risk factors
  - Probability of something bad happing
  - Consequences of something bad happening (Severity)
- Example
  - Airplane Travel – high severity, low probability
  - Electric shock from battery powered devices – high probability, low severity



A "Reliable" Embedded System

- **Reliability** of component *i* can be expressed as the probability that component *i* is still functioning at some time *t*



- Is the system's reliability $P_s(t) = \prod_i P_i(t)$?
  - Assuming that all components have the same component reliability, Is a system w/ fewer components always more reliable?
  - Does component failure always result in system failure?

Faults

- No problem if there are no faults!
- A **fault** is an “unsatisfactory system condition or state”
- Systematic faults
  - Design Errors (includes process errors such as failure to test or failure to apply a safety design process)
  - Faults due to software bugs are systemic
  - Security breech
- Random faults
  - Random events that can cause permanent or temporary damage to the system. Includes EMI and radiation, component failure, power supply problems, wear and tear.

Component vs. System

- Reliability is a component issue
- **Safety** and **Availability** are system issues
- A system can be safe even if it is unreliable!

- If a system has lots of redundancy the likelihood of a component failure (a fault) increases, but so may increase the safety and availability of that system

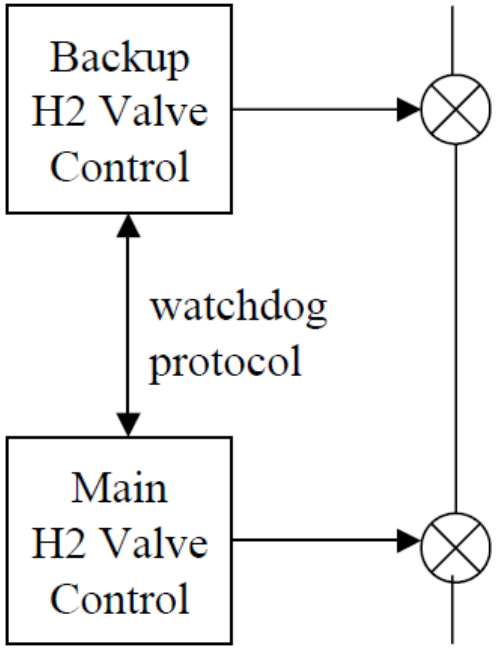
- Safety and Availability are different and sometimes at odds. Safety may require the shutdown of a system that may still be able to perform its function.
  - A backup system that can fully operate a nuclear power plant might always shut it down in the event of failure of the primary system.
  - The plant could remain available, but it is unsafe to continue operation

Terms

- Safety: assuming acceptable risk
- Hazard: dangerous system state that could cause damage
- Fault: conditions that lead to hazards
- Reliability
  - System is functioning if all components are functioning
    - $P_s(t) = \prod_i P_i(t)$
  - System is functioning
    - $P_s(t) = 1 - \prod_i F_i(t)$
    - $F_{i(t)} = 1 - Pi(t)$: probability of component failure

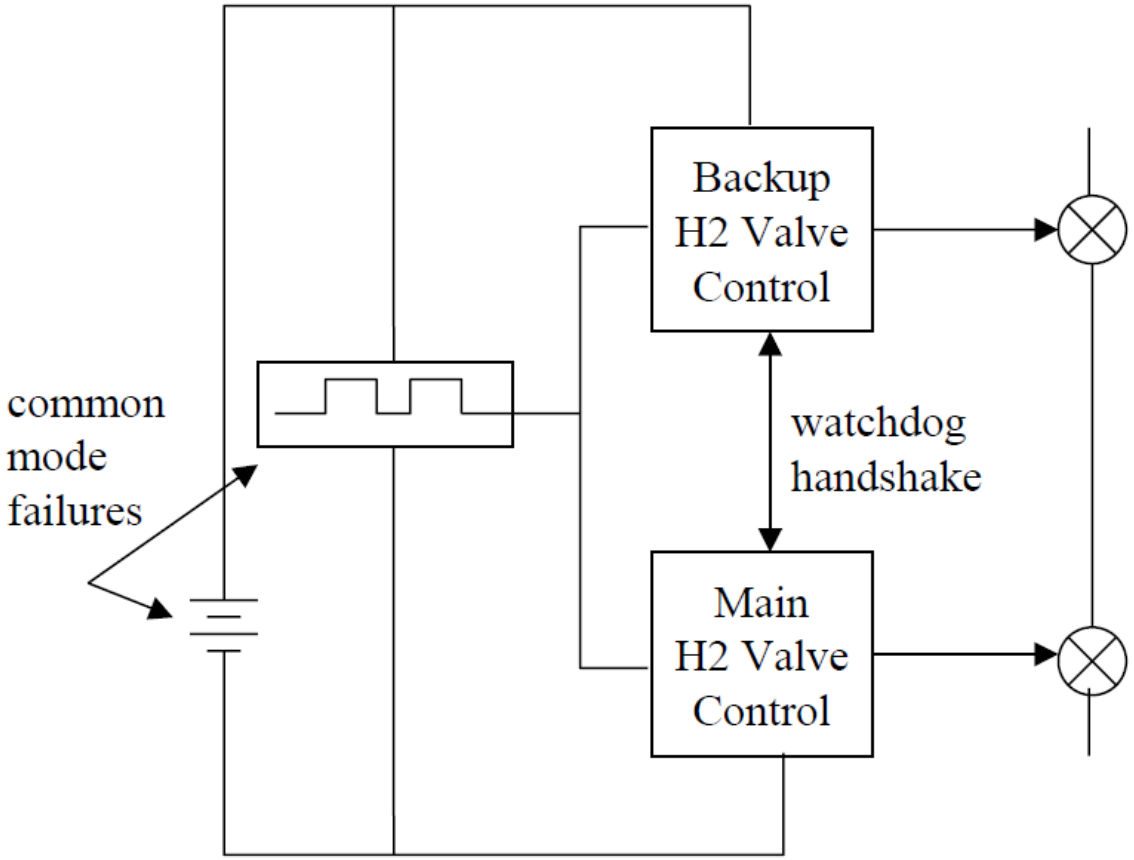
Single Fault Tolerance (for Safety)

- Single fault tolerant systems are generally considered to be safe, but more stringent requirements may apply to high risk cases…airplanes, power plants, etc.

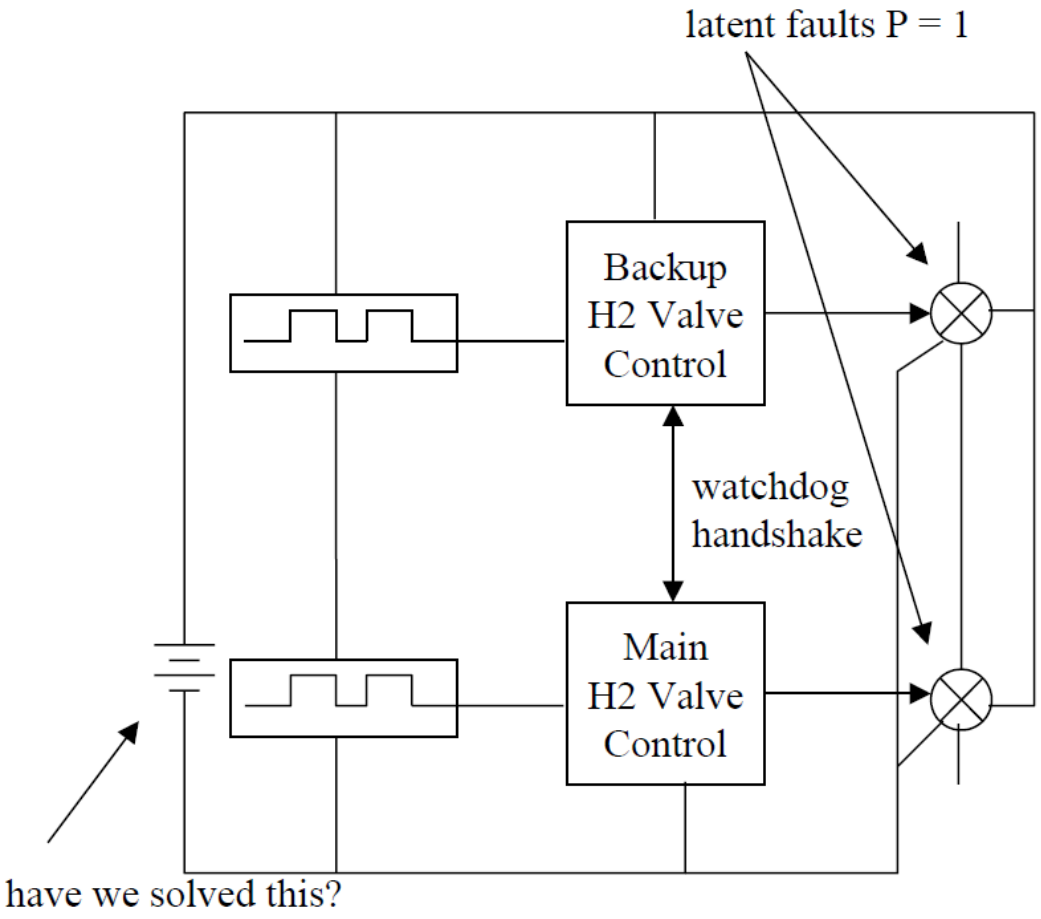


If the handshake fails, then either one or both can shut off the gas supply. Is this a single fault tolerant system?

Is This Safe?


Backup
H2 Valve
Control
common
mode
failures
watchdog
handshake
Main
H2 Valve
Control

Now Safe?



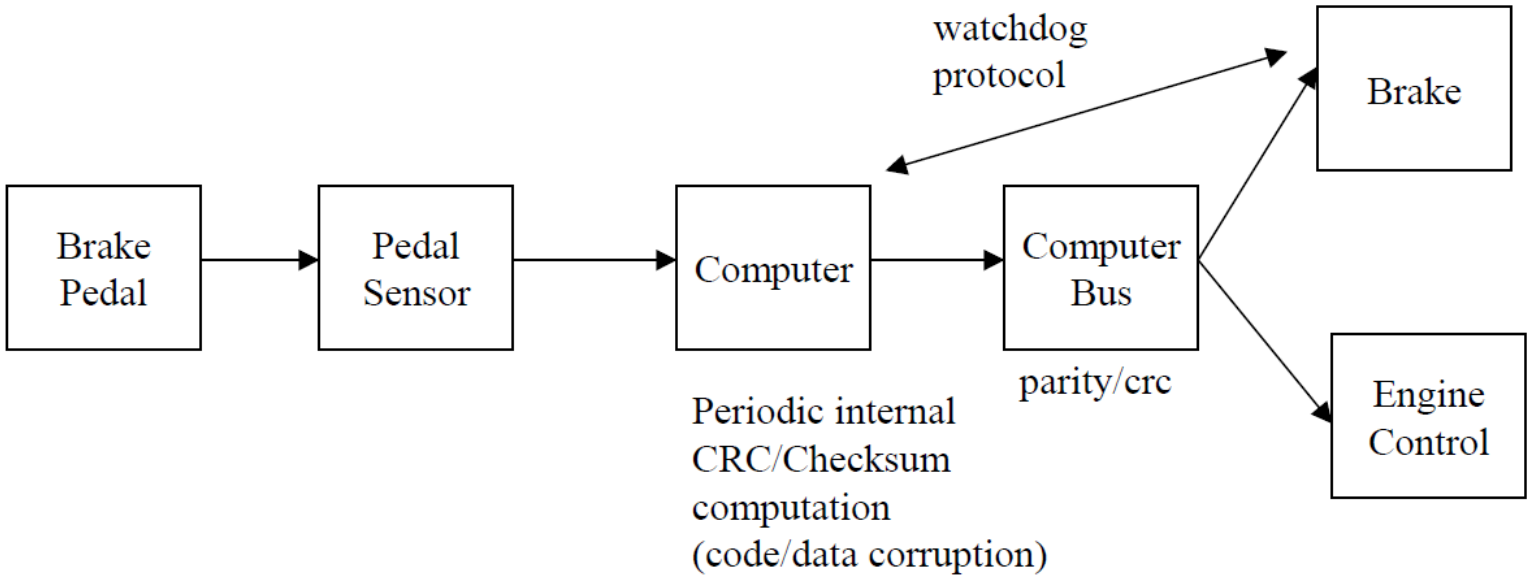
- Separate Clock Source
- Power Fail-Safe (non-latching) Valves

What about power spike that confuses both processors at the same time? Maybe the watchdog can't be software based.

Does it ever end?

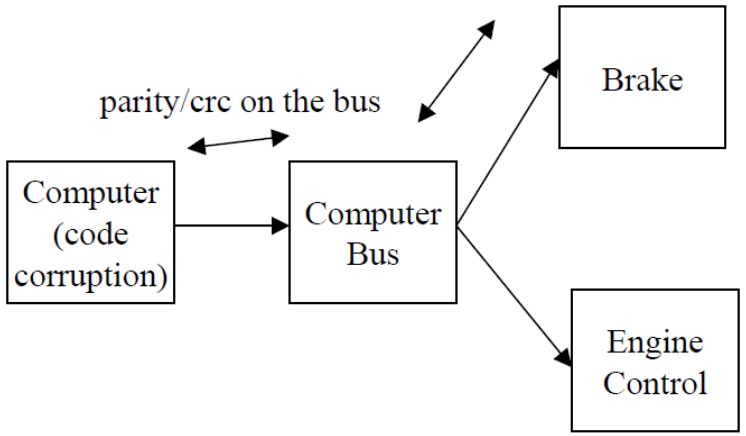
Safety Architectures

- Self checking (single channel protected design)
- Redundancy
- Diversity or Heterogeneity



Single Channel Protection

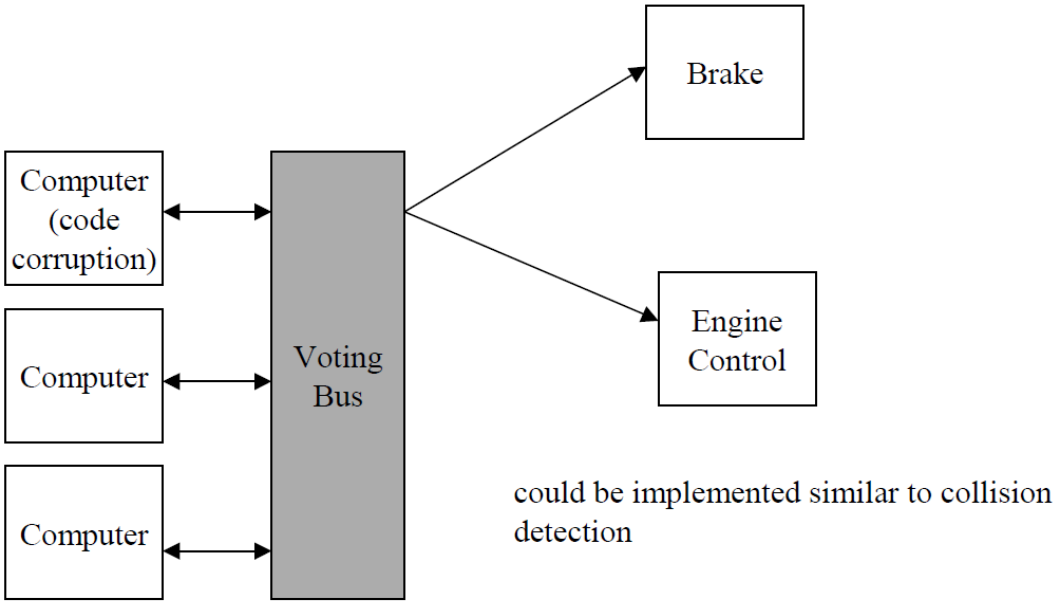
- Self Checking
  - Perform periodic checksums on code and data
  - How long does it take?
  - No protection against systematic faults



- Feasibility of single channel protection
  - Fault tolerance time
  - Processor speed
  - Memory size
  - Special hardware

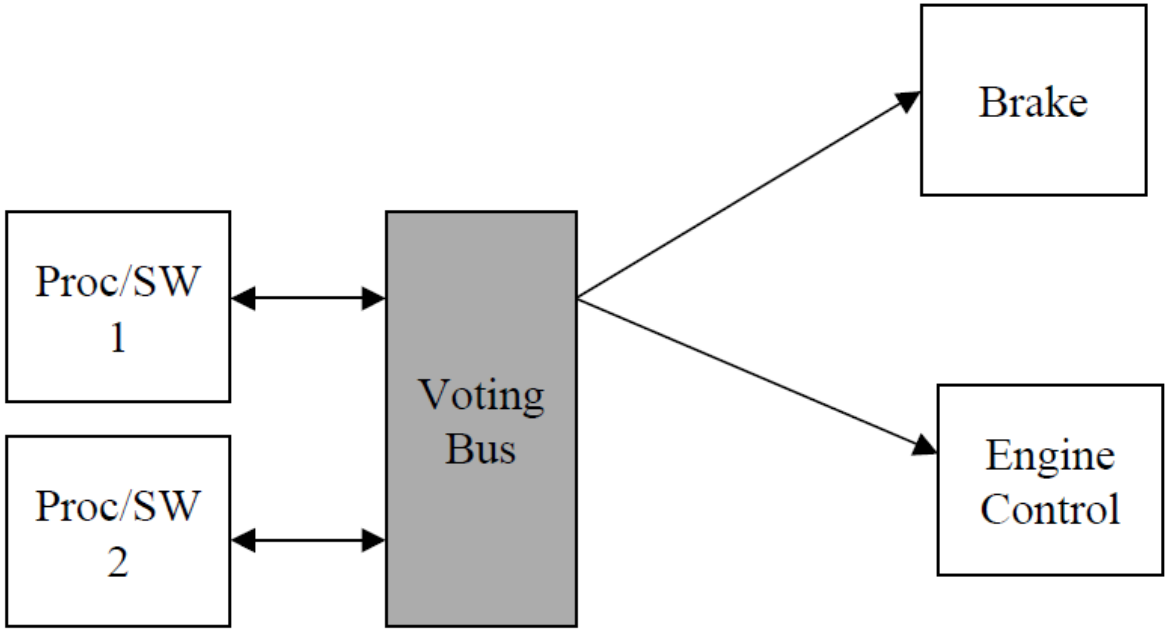
Redundancy

- Homogeneous redundancy
  - Low development cost – just duplicate
  - High recurring cost
  - No protection against systematic faults



Diversity

- Heterogeneous redundancy
  - Protects against random and some systematic faults
- Example: space shuttle – 5 computers, 4 same 1 different



Design Process

1. Hazard identification and fault analysis
2. Risk assessment
3. Define safety measures
4. Create safety requirements
5. Implement safety
6. Test, Test, Test, Test, …

Language Definition

- Static analysis
  - Software: compilation time
  - Hardware: design phase
- Dynamic analysis at run-time
  - Make sure that you never access memory in the wrong way
    - Null pointer access
    - Array out of bounds
    - Type mismatch even when casting
    - Memory management and garbage collection
  - What happens in the event of an exception?

Exception Handling

- It is NOT ok to just let the system crash if some operation fails!
  - You must, at least, get into safe mode
- Language-dependent handling
- Typical C approach:
  - Exception flow is the same as normal flow
  - Use negative numbers for exceptions

```
a = f1(b,c)
if (a) switch (a) {
case 1: handle exception 1
case 2: handle exception 2
…
}
b = f2(e,f)
if (a) switch (a) {
case 1: handle exception 1
case 2: handle exception 2
…
}
```

Exception Handling in Java

- All exceptions must be handled or thrown

```
void myMethod() throws FatalException {
        try {
                a = x.f1(b,c)
                b = x.f2(e,f)
                if (a) … // handle all functional outcomes here!
        } catch (IOException e) {
                recover and continue if that's okay.
        } catch (ArrayOutOfBoundsException e) {
                not recoverable, throw new FatalException("I'm Dead");
        } finally {
                finish up and exit
        }
}
```

Encapsulation: semantic checking

- In C

```
while (item!=tail) {
        process(item);
        if (item->next == null) return –1 // exception ?
        item = item->next;
}
```

- In Java

```
while (item = mylist.next()) { // inside mylist is not my problem
        process (item);
}
class list {
        Object next() throws CorruptListException {
        if (current == tail) return null;
                current = current.next; // private field access okay
        if (current == null) throw new CorruptListException(this.toString());
        return(current.value);
}
```

Java for Embedded Systems

- Why not using Java for embedded systems?
  - It is slower
  - Code bloat
  - Garbage collection may not be interruptible
    - Long latency, low predictability
  - Low time resolution
  - Limited hardware access

Summary

- Safety and reliability
  - Component vs. system
- Techniques to ensure safety/reliability
  - Self checking
  - Redundancy
  - Diversity and heterogeneity
- Language definition
  - Be careful about exception handling and garbage collection