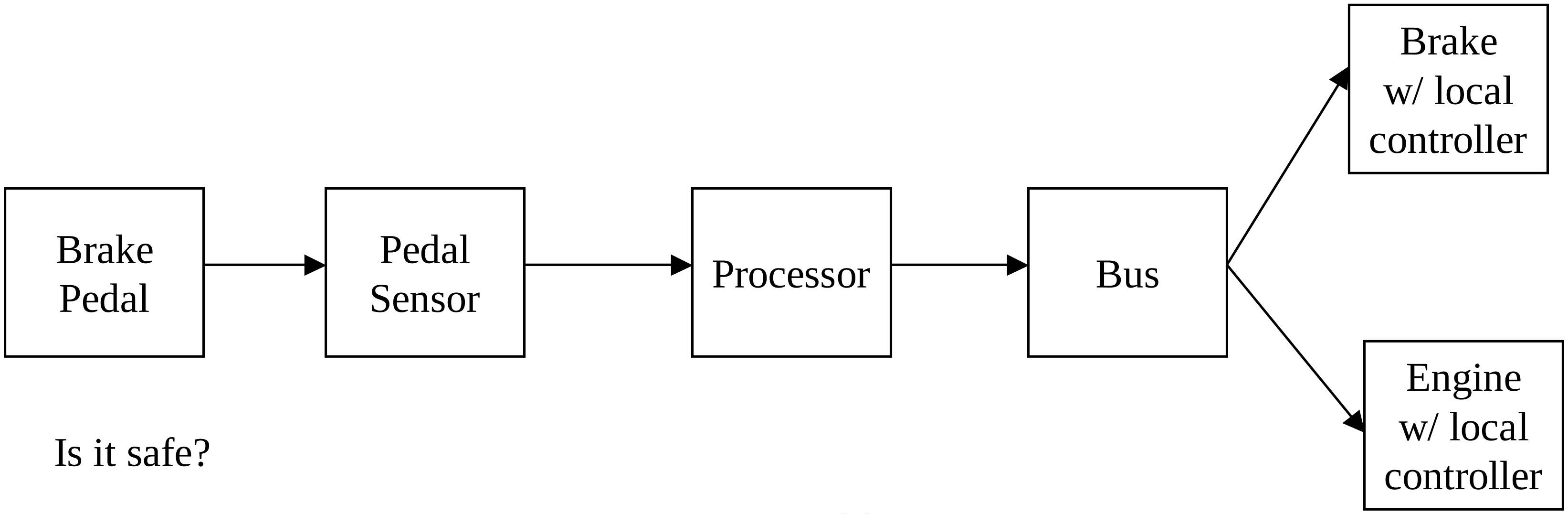
Safety

- Terms and Concepts
- Safety Architectures
- Safe Design Process
- Software Specific Stuff
- Sources

    Hard Time by Bruce Powell Douglass, which references *Safeware* by Nancy Leveson

What is a Safe System?



Is it safe?

What does "safe" mean?

How can we make it safe?

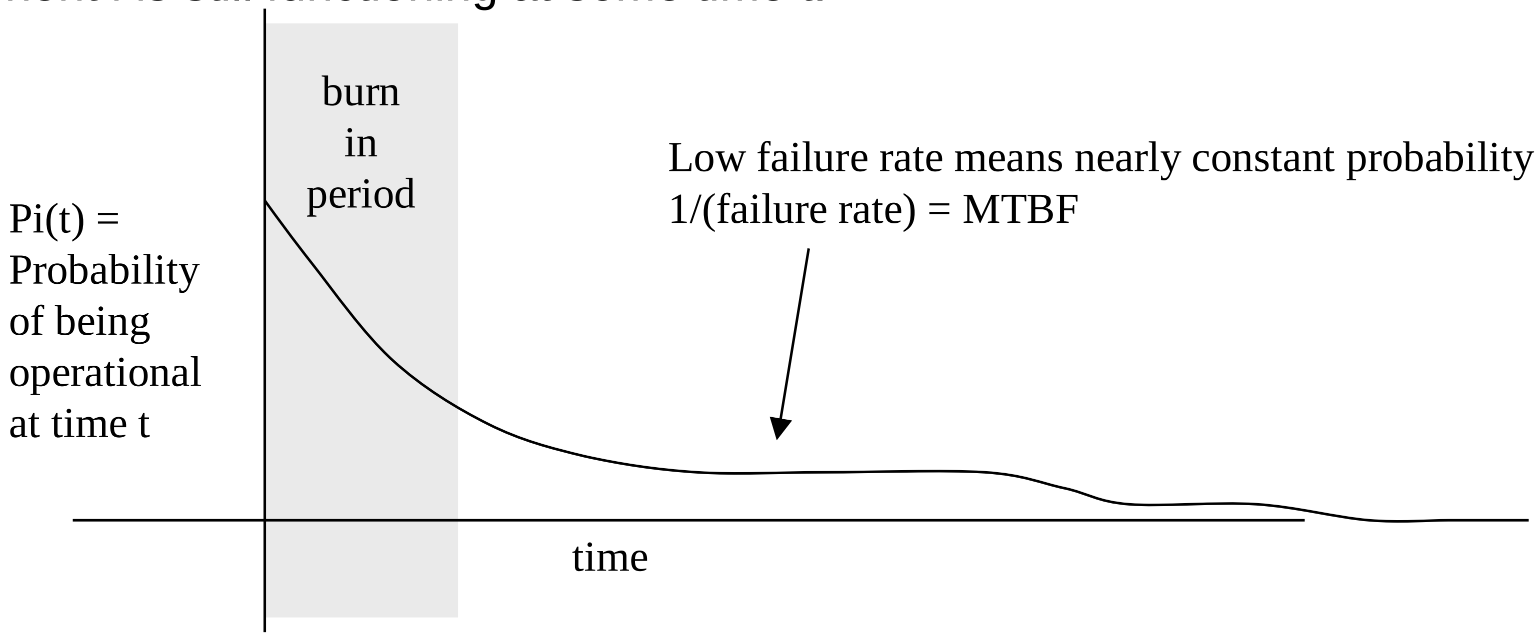
Add
electronic watch dog
between brake and bus

Add mechanical linkage
from separate brake pedal
directly to brake

Add a third mechanical linkage….

Terms and Concepts

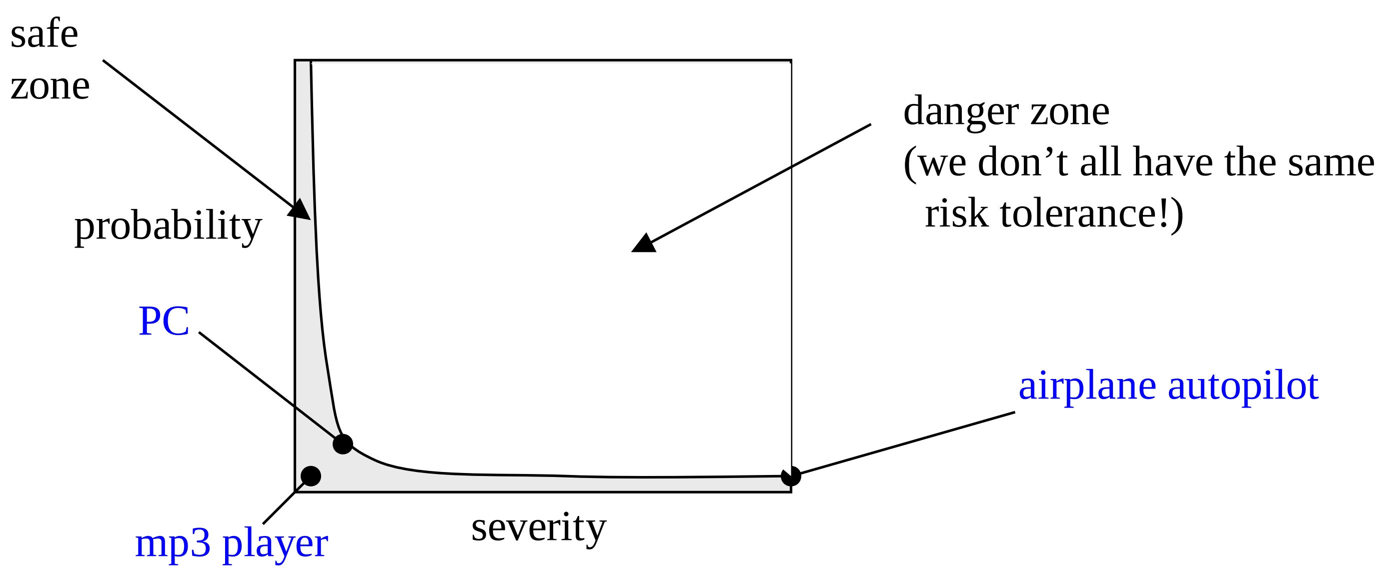
- **Reliability** of component i can be expressed as the probability that component i is still functioning at some time t.



- Is system reliability $P_s(t) = \Pi P_i(t)$?
- Assuming that all components have the same component reliability, Is a system w/ fewer components always more reliable ?
- Does component failure   system failure ?

A Safety System

- A system is **safe** if it's 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 – hi probability, low severity



More Precise Terminology

- **Accident or Mishap**: (unintended) Damage to property or harm to persons. Economic impact of failure to meet warranted performance is outside of the scope of safety.
- **Hazard**: A state of the the system that will inevitably lead to an accident or mishap
  - Release of Energy
  - Release of Toxins
  - Interference with life support functions
  - Supplying misleading information to safety personnel or control systems. This is the desktop PC nightmare scenario. Bad information
  - Failure to alarm when hazardous conditions exist

Faults

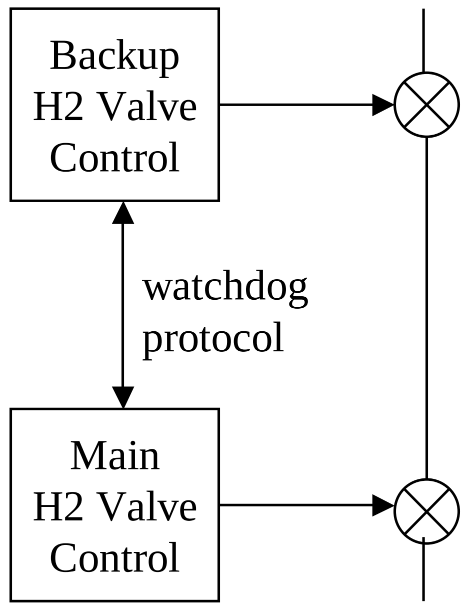
- **A fault** is an “unsatisfactory system condition or state”. A fault is not necessarily a hazard. In fact, assessments of safety are based on the notion of *fault tolerance*.
- **Systemic** faults
  - Design Errors (includes process errors such as failure to test or failure to apply a safety design 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 v. 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

Single Fault Tolerance (for safety)

- The existence of any single fault does not result in a hazard
- 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?

Next Week

- Project Presentations/Demos
  - Wednesday
    - Tiny OS (one day)
    - Structure of the OS, how does it work?
    - Applications, what is it like to write code
      - event handling
      - communications
      - examples
  - Monday demos
    - Lake Analysis (Forget about funding from the new EPA)
    - Modem
    - Gravity Mouse
    - MBOX Alarm

The Final

- Something networking, related to the stack that we built in lecture
  - assumes a working understanding of I2C
- A safety question
- Something from previous sections

Terms

- Safety: Assuming acceptable risk
- Accident: Unintended damage
- Hazard: Dangerous system state: accident is inevitable
- Fault: Conditions that lead to hazards
  - Systemic (design) faults
  - Random faults
- Reliability

  System is functioning if all components are functioning

  $Ps(t) = \Pi Pi(t)$

  System is functioning of any component is functioning (redundancy)

  $Ps(t) = 1- \Pi(Fi(t))$

  probability of component failure $Fi(t) = 1-Pi(t)$

  Example:

  let P1(T) = P2(T) = 0.9

  then F1(T) = F2(T) = 0.1, so Fs(T) = 0.1*0.1 = 0.01

  So Ps(T) = 1-Fs(T) = .99

Term (cont)

- Latent fault: a fault that does not in itself lead to a hazard, but which cannot be detected. Must assume that the probability of this fault = 1
- Safety Architectures
  - Single Channel Protection
  - Redundancy
  - Diversity
- Time equation
  - Time to Eliminate Hazard < Tolerance Time of Hazard < Time to Next Fault

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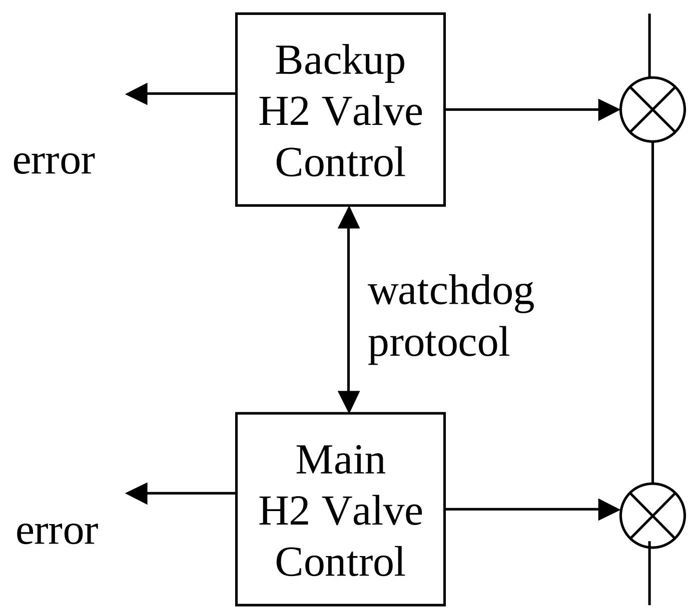

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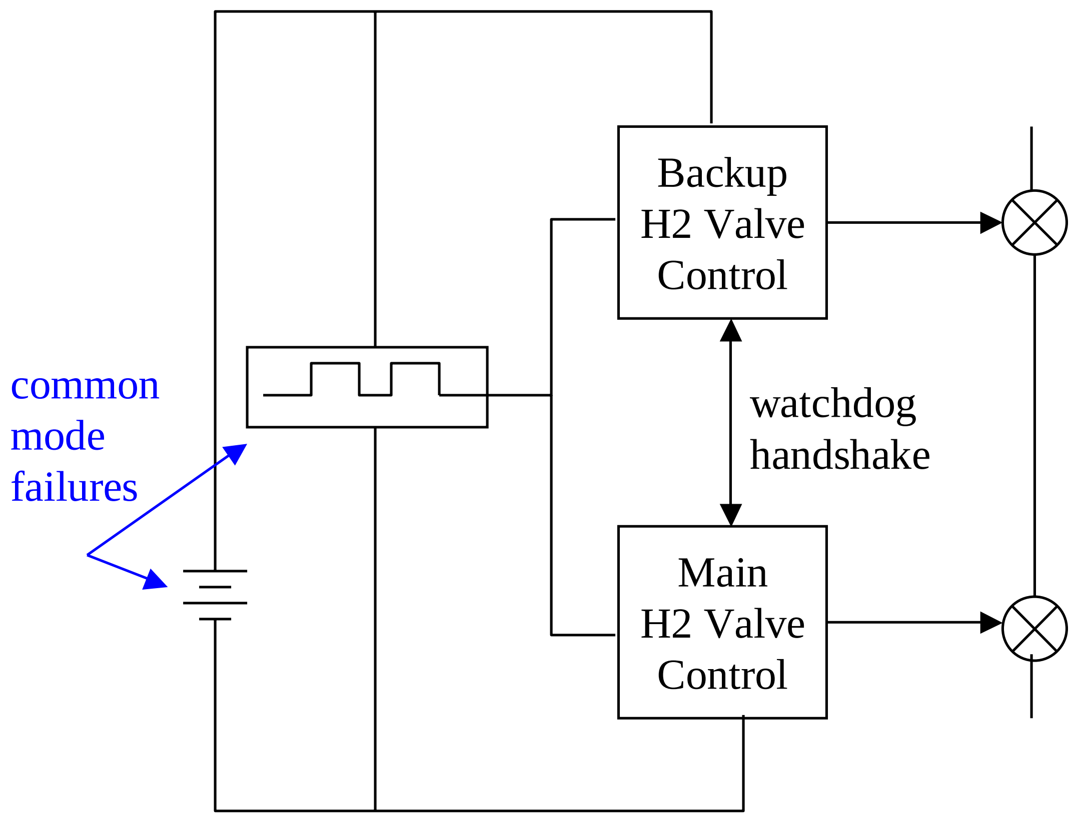
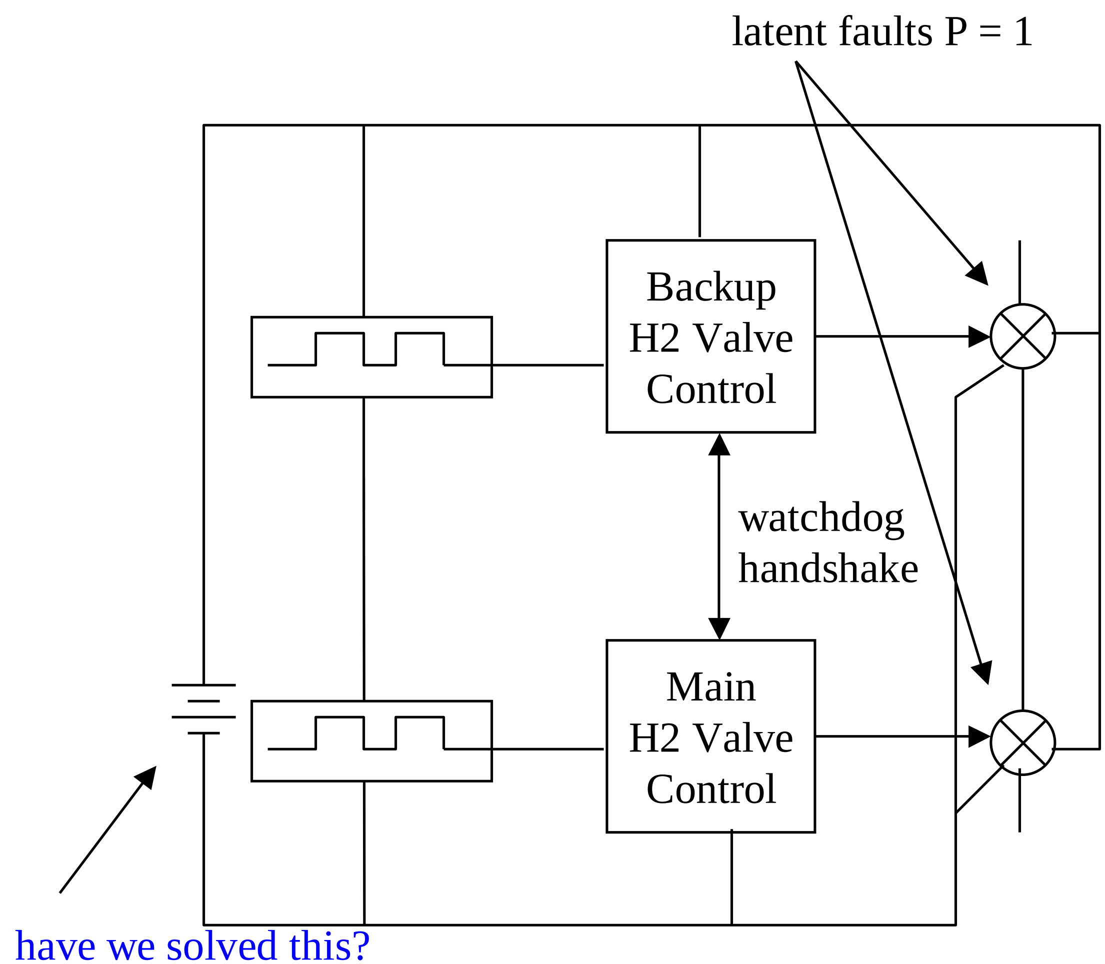
Is This?


common
mode
failures
Backup
H2 Valve
Control
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.

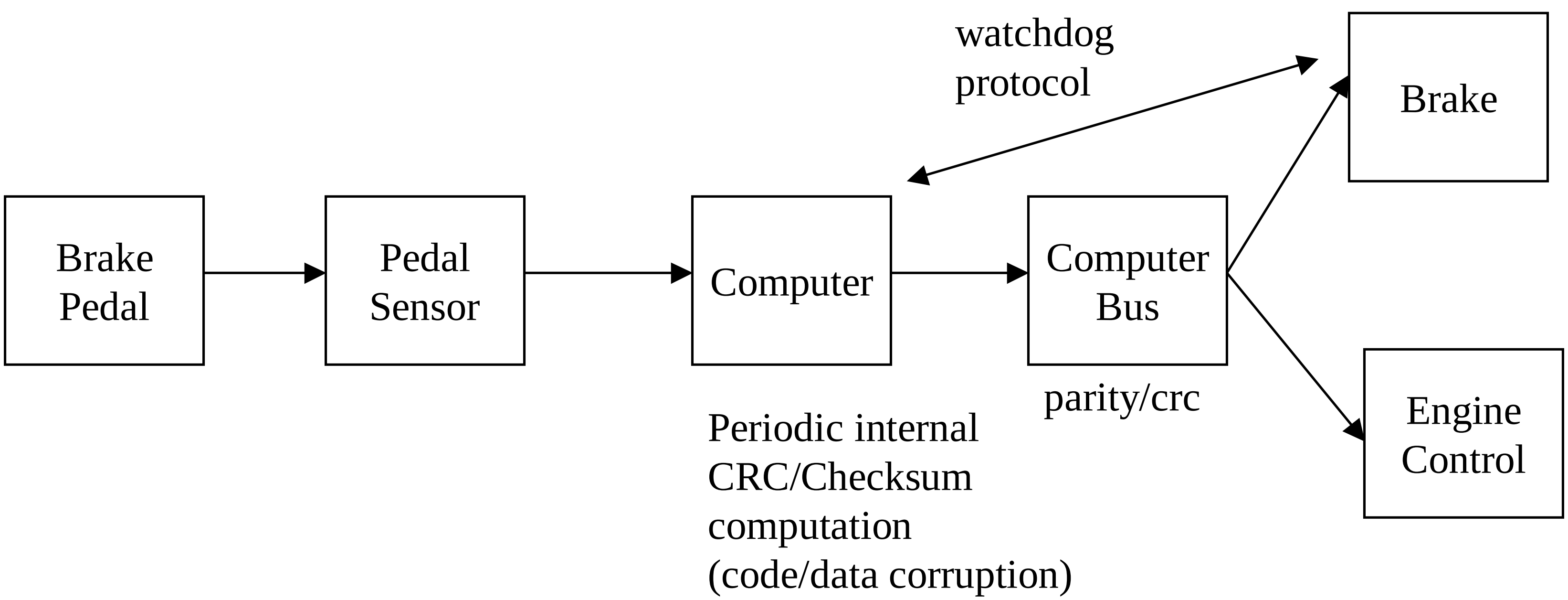
Does it ever end?

$$T_{test} < T_0 < T_1$$

detection time is < than single fault tolerance time < time to second failure

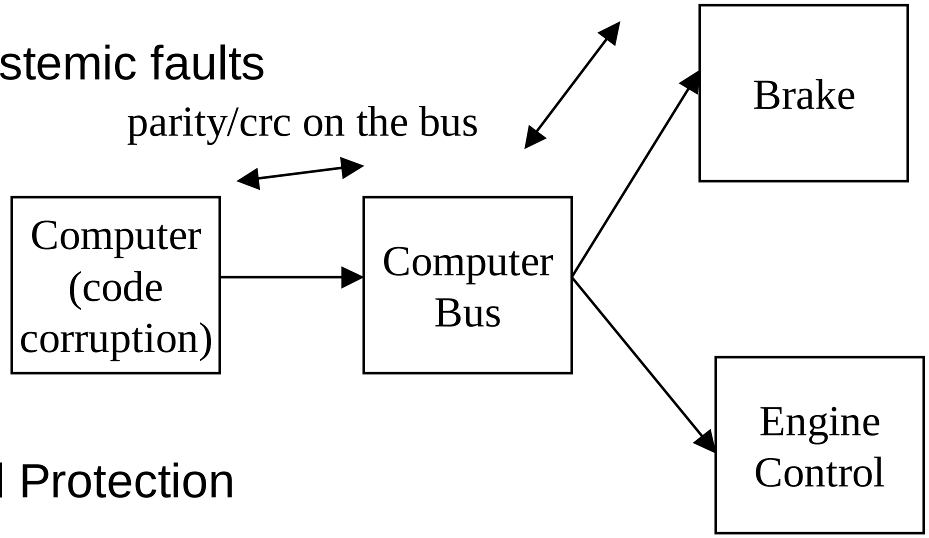
Safety Architectures

- Self Checking (Single Channel Protected Design)
- Redundancy
- Diversity or Heterogeneity



Single Channel Protection

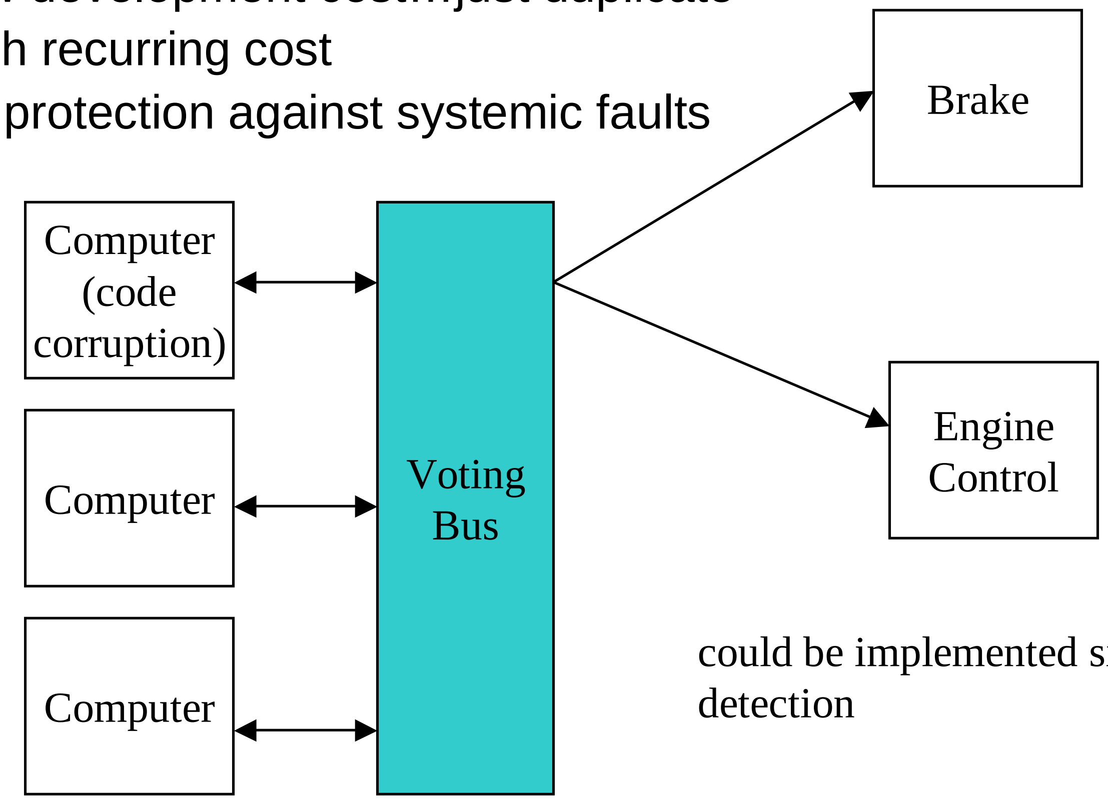
- Self Checking
  - perform periodic checksums on code and data
  - How long does this take?
  - Is $T_{test} < T_0 < T_1$?
  - No protection against systemic faults



- Feasibility of Single Channel Protection
  - Fault Tolerance Time
  - Speed of the processor
  - Amount of ROM/RAM
  - Special Hardware
  - **Recurring cost v. Development cost tradeoff**

Redundancy

- Homogeneous Redundancy
  - Low development cost…just duplicate
  - High recurring cost
  - No protection against systemic faults

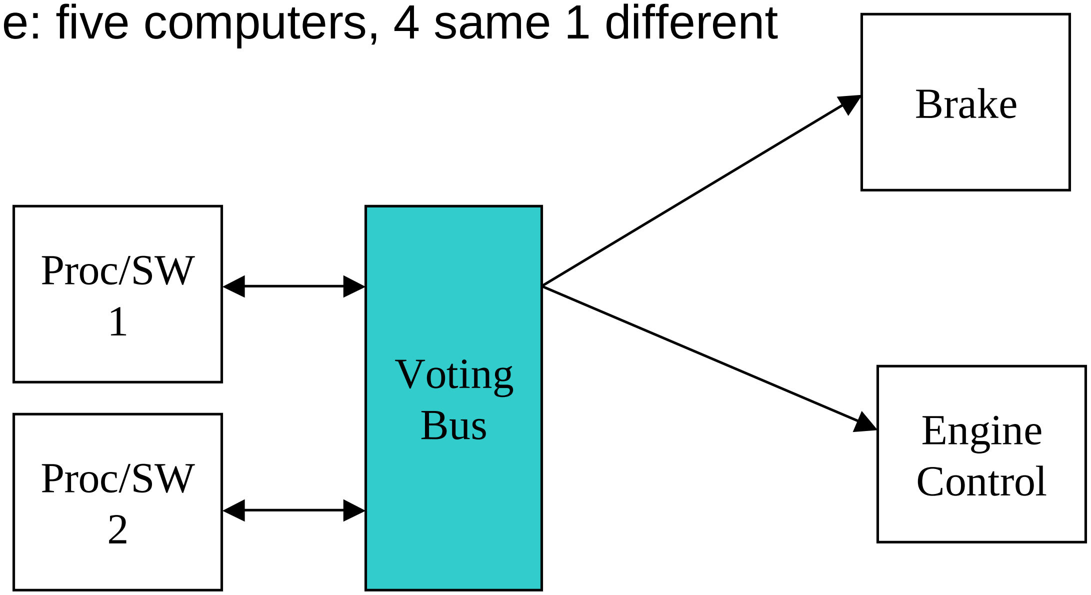


could be implemented similar to collision detection

what happens if you have an even number of computers?

Diversity

- Heterogeneous Redundancy
  - Protects against random and some systemic faults.
  - Best if implementation teams are kept separated
- Space shuttle: five computers, 4 same 1 different



Design Process

1. Hazard Identification and Fault Tree Analysis
2. Risk Assessment
3. Define Safety Measures
4. Create Safe Requirements
5. Implement Safety
6. Test,Test,Test,Test,Test

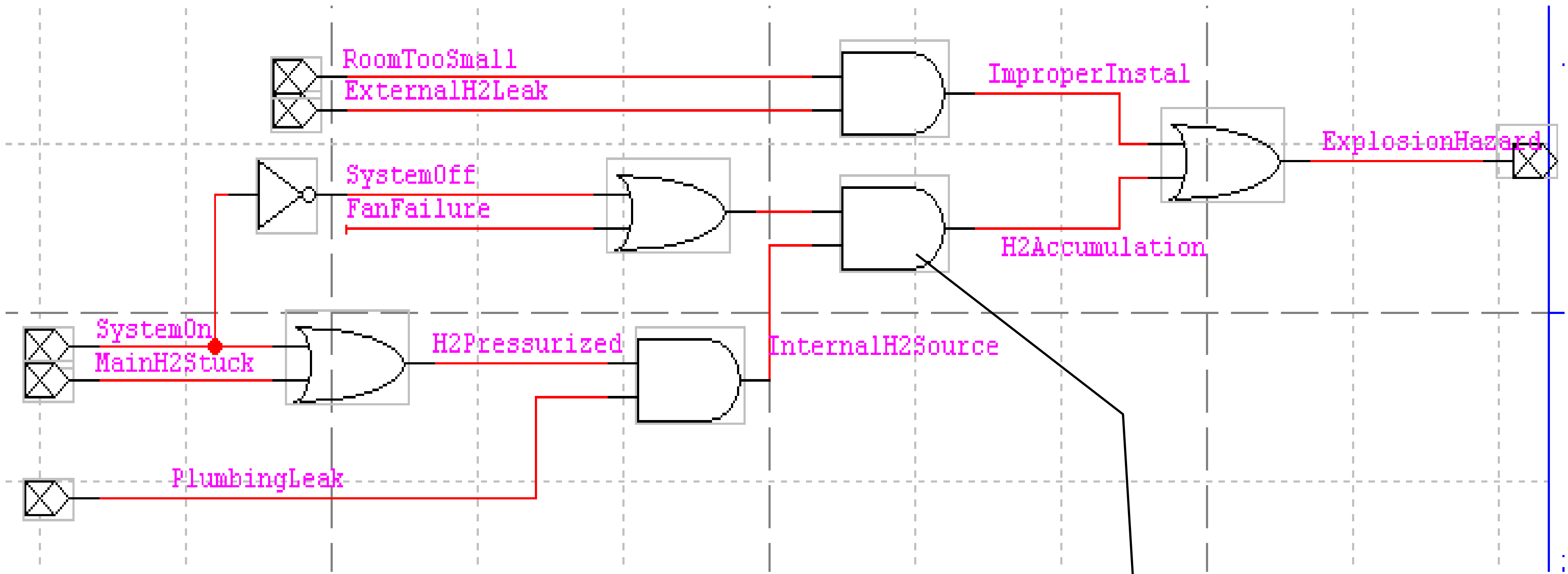
Hazard Analysis – Working forward from hazards

Ventilator Example

Human in Loop

Hazard	Severity	Tolerance Time	Fault Example	Likelihood	Detection Time	Mechanism	Exposure Time
Hypo-ventilation	Severe	5 min.	Motor Too Slow	Rare	30sec	Indep. pressure sensor w/ alarm	40sec
			Esophageal intubation	Medium	30sec	C02 sensor alarm	40sec
			User mis-attaches breathing hoses	never	N/A	Different mechanical fittings for intake and exhaust	N/A
Over-pressurization	Sever	0.05sec	Release valve stuck closed	Rare	0.01sec	Secondary valve opens	0.01sec

Fault Tree Analysis



Satisfiability Analysis: What combinations of inputs produce the hazard

Explosion Hazard: (SystemOn * FanFailure * PlumbingLeak) +
(SystemOff * MainH2Stuck * PlumbingLeak)

Let Plumbing Leak = 1 (there is always some level of leakage
(SystemOn * FanFailure) + (SystemOff * MainH2Stuck)

Let Tdetect(FanFailure < ToleranceTime)
(MainH2Stuck * System is Off) is our biggest concern.

Mitigation: Open an valve from internal H2 plumbing when off?? Why Not?

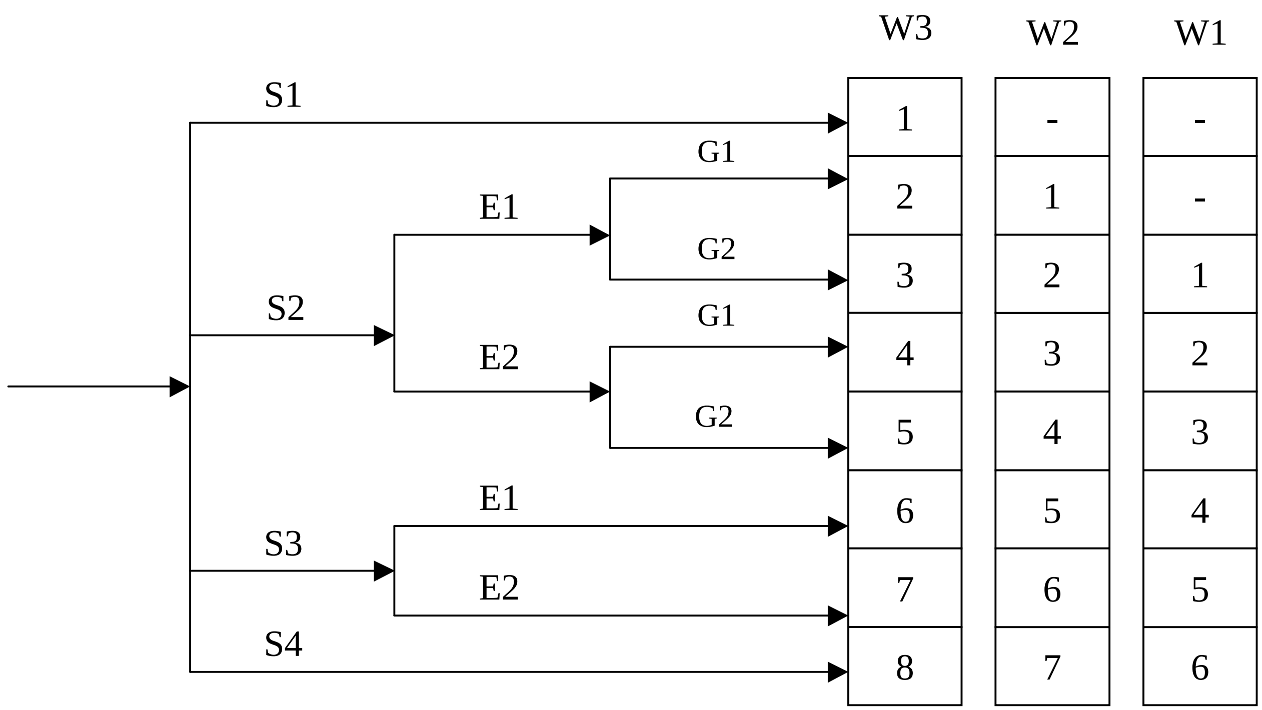
Proper Installation Required!

FMEA: Same as Hazard Analysis, but Start w/ Faults

- Failure Mode: how a device can fail
  - Battery: never voltage spike, only low voltage
  - Valve: Stuck open? Stuck Closed?
  - Motor or Motor Controller: Stuck fast, stuck slow?
  - Hydrogen sensor: Will it be latent or mimic the presence of hydrogen?
- Failure Modes and Effects Analysis
  - Great for single fault tolerant systems
- For each system.
  - Identify all failure modes and likelihoods
  - Identify the hazard that is produced by each failure
  - Determine Time tolerance for each potential hazard
  - Design Considerations
    - Mitigation
    - Detection
  - Response
    - What to do: shutdown, alarm, disable certain features, etc.
- Search space can be quite large

Risk Assessment

- Risk is orthogonal to hazard analysis
- Determine how risky your system is



S: Extent of Damage
- Slight injury
- Single Death
- Several Deaths
- Catastrophe

E: Exposure Time
- infrquent
- continuous

G: Prevenability
- Possible
- Impossible

W: Probability
- low
- medium
- high

Example Risk Assessment

Device	Hazard	Extent of Damage	Exposure Time	Hazard Prevention	Probability	TUV Risk Level
Microwave Oven	Irradiation	S2	E2	G2	W3	5
Pacemaker	Pacing too slowly Pacing too fast	S2	E2	G2	W3	5
Power station burner control	Explosion	S3	E1	--	W3	6
Airliner	Crash	S4	E2	G2	W2	8

Define the Safety Measures

- Obviation: Make it physically impossible (mechanical hookups, etc).
- Education: Educate users to prevent misuse or dangerous use.
- Alarming: Inform the users/operators or higher level automatic monitors of hazardous conditions
- Interlocks: Take steps to eliminate the hazard when conditions exist (shut off power, fuel supply, explode, etc.
- Restrict Access. High voltage sources should be in compartments that require tools to access, w/ proper labels.
- Labeling
- Consider
  - Tolerance time
  - Supervision of the system: constant, occasional, unattended. Airport People movers have to be design to a much higher level of safety than attended trains even if they both have fully automated control

Create Safe Requirements: Specifications

- Document the safety functionality
  - eg. The system shall NOT pass more than 10mA through the ECG lead.
  - Typically the use of NOT implies a much more general requirement about functionality…in ALL CASES
- Create Safe Designs
  - Start w/ a safe architecture
  - Keep hazard/risk analysis up to date.
  - Search for common mode failures
  - Assign responsibility for safe design…**hire a safety engineer.**
  - Design systems that check for latent faults
- Use safe design practices…this is very domain specific, we will talk about **software**

5. Implement Safety – Safe Software

- **Language Features**
  - **Type and Range Safe Systems**
  - **Exception Handling**
- **Re-use, Encapsulation**
  - **Objects**
  - **Operating Systems**
  - **Protocols**
- **Testing**
  - **Regression Testing**
  - **Exception Testing (Fault Seeding)**

What happens if

void* a[SZ]; // Data Structure Definition

a[i] = (void*) x; // Range Violation?

x = (myType *)a[i]; // Range and Data Type Violation?

Ideal Error Checking Hierarchy

Automatic:

Compile Time Checking (Static) better than Run Time Checking (Dynamic)

- data types for assignments
- range
- unitialized
- Out of memory….etc.

Programmer:

Semantic error conditions (e.g array not sorted, too many users, etc)

if (i < SZ) a[i] = (void*) x; else what?? // Range Violation?

if (i < SZ) x = (myType *) a[i]; else what?? // Range and Data Type Violation?

Four Main Problems in C

1. Static analysis not defined by the language: a[5] means *(a+5), not “fifth element of the array a”.
2. There is no run-time checking. OS checks to make sure you stay in your space.
3. Exception flow is indistinquishable from normal flow and exception handling is voluntary
4. Semantic checking onus on user of data structure

Language Definition

- **static analysis is up to the compiler**

  Define the semantics of the language to include all compile time checks that cannot be caught at run time

  - Uninitialized variables
  - type mismatch

- **The run time environment performs dynamic checks** that cannot be caught at compiler time: mainly to make sure that you never access memory the wrong way

  Null pointer access

  Array out of bounds

  Type mismatch even when casting

  Memory Management and Garbage Collection

```
a[i] = (void*) x;                 // raise an exception
x =  (myType *) a[i];             // raise and exception
```

  What happens in the event of an exception?

Exception Handling

- Its NOT okay to just let the system crash if some operation fails! You must, at least, get into safe mode.
- In C it is up to the designer to perform error checking on the value returned by f1 and f2. Easily put off, or ignored. Can't distinguish error handling from normal program flow, no guarantee that all errors are handled gracefully.
- **typical C approach:**

```
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
    …
}
```

In C, the exception flow is the same as the normal flow. Use negative numbers for exceptions?!

Exception Handling in Java

```
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
    }
}
```

Separates
- throwing exceptions
- functional code
- exception handling

All exceptions must be handled or thrown. Exceptions are subclassed so that you can have very general or very specific exception handlers.

Encapsulation: Semantic Checking

- <u>IN C</u>

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

- <u>In Java</u>

```
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);
}
```

More Language Features

- Garbage collection
  - What is this for
  - Is it good or bad for embedded systems
- Inheritance
  - Means that type safe systems can still have functions that operate on generic objects.
  - Means that we can re-use commonalities between objects.
- Re-use
  - Use trusted systems that have been thoroughly tested
  - OS
  - Networking
  - etc.

Java for Embedded Systems

- Why not Java for Embedded Systems
  - Its slower
  - Code bloat
  - Garbage Collection may not be interruptible (Latency, predictability)
  - Time resolution – run time support for multithreading and synchronization must be optimized. Java assumes the existence of a basic operating system.
  - Hardware access – interrupt handlers, event handlers
- TinyOS
  - A Component model that seems to be good for “reactive” systems. Probably does a good job of addressing the four major issues listed here.

Testing

- Regression Test

- Fault Seeding

Safe Design Process

- Mainly, the hazard/risk/FMEA analysis is a process not an event!
- How you do things is as important as what you do.
- Standards for specification, documentation, design, review, and test
  - ISO9000 defines quality process…one quality level is stable and predictable.