Electrical & Computer ENGINEERING

18-642:

Redundancy Management

4/4/2018

I'm not dead!
'Ere, he says he's not dead.
Yes he is.
I'm not.
He isn't.
Well, he will be soon, he's very ill.
I'm getting better!
– Monty Python

These tutorials are a simplified introduction, and are not sufficient on their own to achieve system safety. You are responsible for the safety of your system.

Carnegie Mellon University

Is Your Redundancy Working?

Edge Case Research

- **Anti-Patterns for Redundancy:**
  - **Unsafe because double-spending redundancy**
  - **No between-mission redundancy diagnostics**
  - **Low test coverage on redundant components**
- **Redundant components help reliability**
  - But, what happens when a component breaks?
    - Need to gracefully curtail current mission
    - Prohibit additional missions until repaired
  - Reliability assumes perfection at mission start
    - Untested redundancy undermines reliability

Figure 1. Postaccident aerial view of portion of Whatcom Creek showing fire damage.

Bellingham WA, June 1999: Gasoline spill & fire kills 3 due to improper management of SCADA redundancy

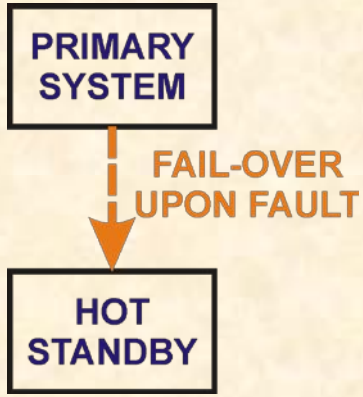
Response To A Component Failure

Edge Case Research

- **Use of Redundancy: Availability**
  - Hot Standby takes over upon failure
  - Assumes somehow you detect failure
    - For low criticality systems, perhaps it's OK to miss some failures; have human trigger failover

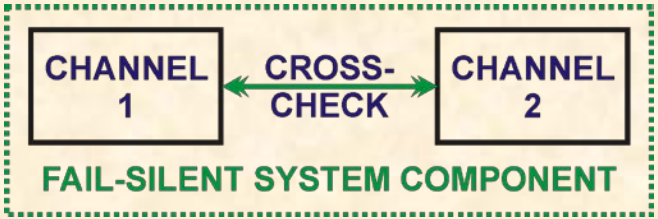
Hot Standby Pattern

Remember Ariane 5 Flight 501?



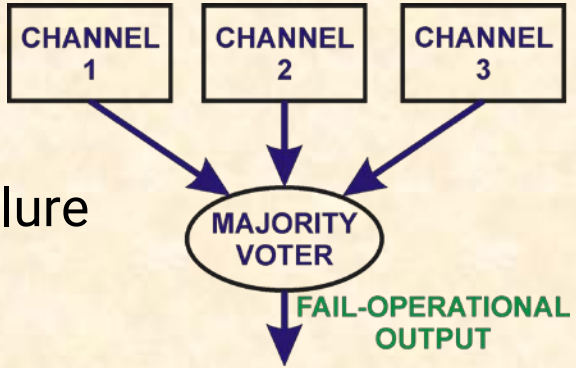
- **Even if only one component breaks at a time…**
  - Single computer can fail "active" (dangerous)
  - Self-test cannot find all faults
  - Single component is unsafe for SIL 3,4
- **Use of Redundancy: Fault Detection**
  - 2-of-2 used for fault detection

2-of-2 Fail Silent Pattern

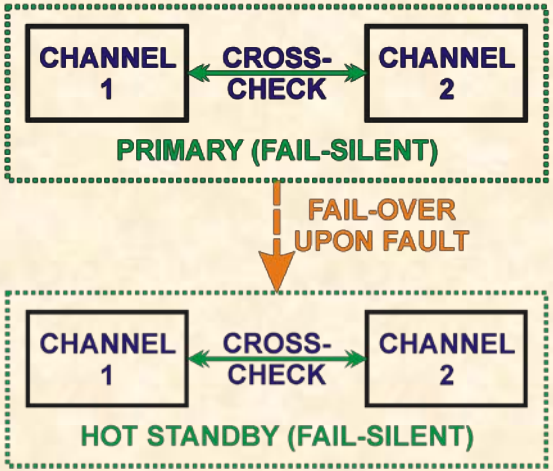


Fail Operational Approaches

- **Can't double-spend redundancy!**
  - Need 2 components to detect a failure
  - ***PLUS*** more components to operate after failure
- **Triplex modular redundancy (2-of-3)**
  - Three copies of subsystem and voter
  - But … voter can be single point of failure!
- **Dual 2-of-2**
  - Two copies of subsystem for availability
  - Each subsystem is 2-of-2 to provide fault detection



2-of-3 Voter Pattern

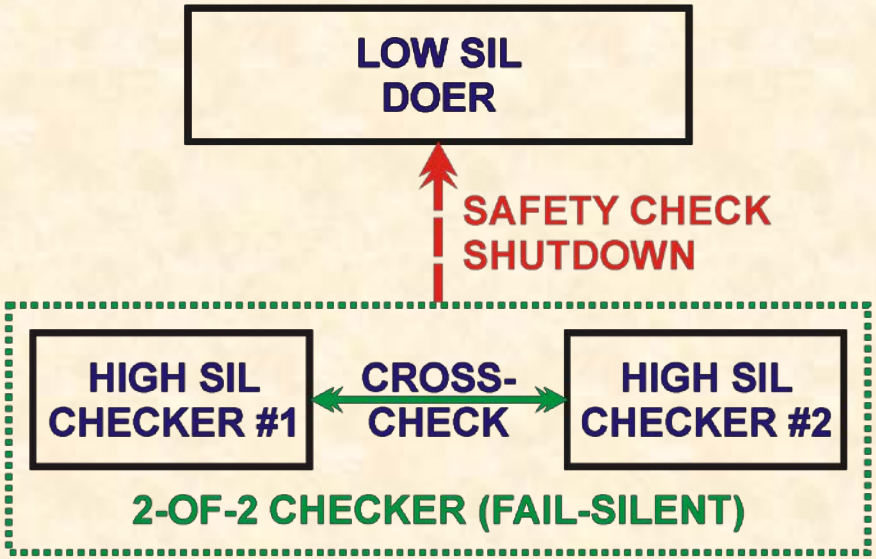


Dual 2-of-2 Pattern

Doer/Checker & Redundancy

Edge Case Research

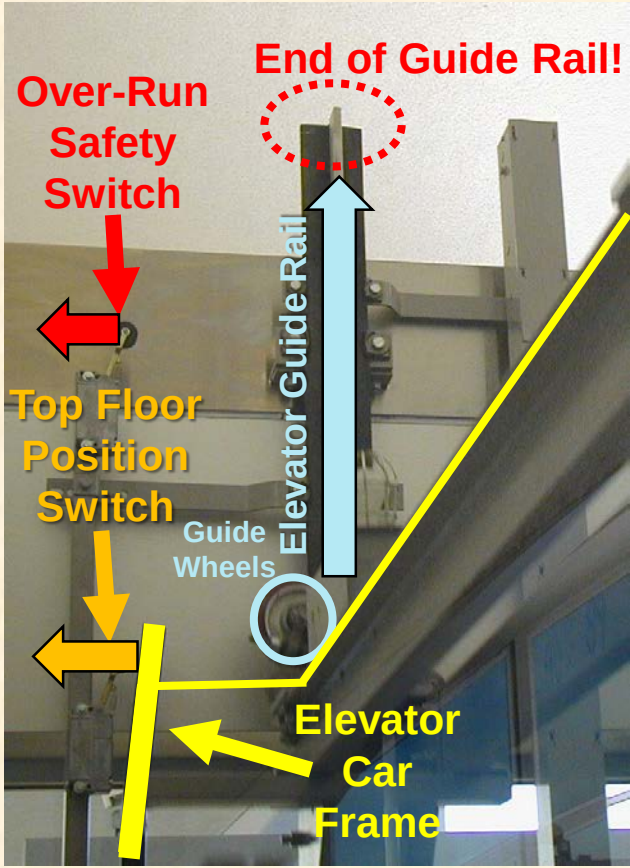
- **Hybrid of Low SIL Doer and High SIL 2-of-2 checker**
  - Single Low SIL primary
    - Provides normal functionality
  - 2-of-2 High SIL checker
    - Shuts down if primary unsafe
    - Shuts down if cross-check fails
- **Common building blocks:**
  - 2-of-2 for fault detection
  - Doer/Checker for fault isolation
  - Hot standby for fail operational



Mixed-SIL
Doer/Checker Pattern

Diagnostic Effectiveness

- **Reliability math assumes *all* redundancy working**
  - On-line diagnostics: self-test at start of mission
    - Example: IEC 60730 self-test library
  - Off-line diagnostics: "Proof test"
    - Example: exercise an elevator safety limit switch
- **Latent undetected faults**
  - Undetectable faults lead to coincident failures
    - 2-of-2 doesn't work if both fail the same way!
  - Run-time detection: frequent health cross-checks
    - Scrub state, e.g., compare RAM values
    - Swap active units periodically to self-test
  - Off-line detection: enforce periodic proof tests
    - Self-test or require diagnostic to resume operation



Best Practices For Redundancy Management

Edge Case Research

- **What happens when component fails?**
  - ***Some*** redundancy is for fault detection
  - ***Other*** redundancy is for availability
  - Plan how to detect & survive failures
- **Diagnostic coverage matters**
  - Pre-mission test; cross-checks; proof tests
  - Minimize potential for latent faults
- **Pitfalls:**
  - Don't double-spend your redundancy (detect & failover are different)
  - Look for common-mode failures (e.g., software updates)

Figure 1. Accident Caused by SIF Failure

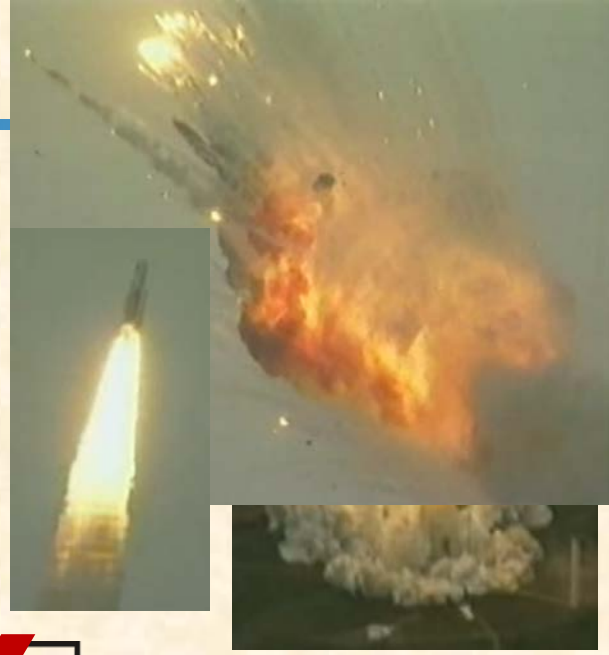
Safety Instrumented Function (SIF) Failure at an Undisclosed Plant

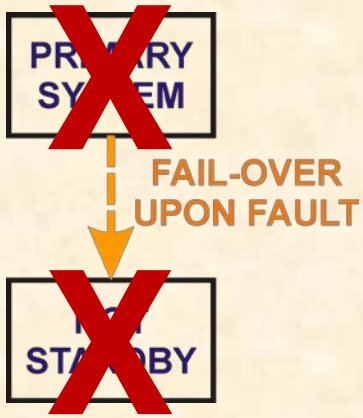
Ariane 5 Flight 501 Failure

- **June, 1996 loss of inaugural flight**
  - Also lost $400 million scientific payload
- **Primary/Backup Inertial Reference System**
  - Reused from Ariane 4
    - But, Ariane 5 had higher horizontal velocity
    - 64-bit float to 16-bit integer overflow in backup

      … followed by …

      The exact same numeric overflow in primary
  - Both processors failed ➔ loss of control
- **Software is a single point of failure**
  - Redundant SW fails the same way
  - Redundancy best for HW failures





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