Electrical & Computer ENGINEERING

18-642:
Critical Systems

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.

ASSC; 22 May 2019

"Never tell me the odds!"
— *Han Solo*

Carnegie Mellon University

Critical Systems

Edge Case Research

- **Anti-Patterns for Critical Systems:**
  - **You haven't characterized worst case failures**
  - **You haven't assigned SILs to system hazards**
  - **Validation plan doesn't match fleet exposure**
- **Critical systems require low failure rates**
  - **SIL = Safety Integrity Level**
    - Higher level of integrity needed for higher risk
  - **Safety critical:**
    Loss of life, injury, environmental damage
    - Special care must be taken to avoid deaths
  - **Mission critical:**
    Brand tarnish, financial loss, company failure
    - Consider a safety critical approach

Knight Capital Says Trading Glitch Cost It $440 Million

By NATHANIEL POPPER AUGUST 2, 2012 9:07 AM 356 Comments

Runaway Trades Spread Turmoil Across Wall St.

Errant trades from the Knight Capital Group began hitting the New York Stock Exchange almost as soon as the opening bell rang on Wednesday. Brendan McDermid/Reuters

The Knight Capital Group announced on Thursday that it lost $440 million when it sold all the stocks it accidentally bought Wednesday morning because a computer glitch.

https://goo.gl/7dHOjO

What Is The Worst Case Failure?

Edge Case Research

- **Worst case might not be obvious**
  - Aircraft – software can cause a crash
  - Thermostats/HVAC – software can freezing plumbing
    - Can – rarely! – also kill small children due to overheating
- **Key thought experiment:**
  - What's the worst that can happen if …

    … your system intentionally tried to cause harm?
  - This identifies system hazards to mitigate
- **Failure consequence varies, typically:**
  - Multiple fatalities (e.g., plane crash)
  - Single fatality (e.g., single-vehicle car crash)
  - Severe injuries
  - Minor injuries
  - Can consider analogies for mission-critical goals

WFAA Channel 8 https://goo.gl/rFd8qW
Takeaway: get a baby monitor with temperature sensor

Safety Integrity Level (SIL)

Edge Case Research

- **SIL represents:**
  - The risk presented by a system-level hazard
  - The engineering rigor applied to mitigate the risk
  - The permissible residual probability after mitigation
- **Example: DO-178 (aviation flight hours)**
  - DAL A (Catastrophic): 10^9 hrs/failure = 114077 years
  - DAL B (Hazardous): 10^7 hrs/failure = 1141 years
  - DAL C (Major): 10^5 hrs/failure = 11 years
  - DAL D (Minor): 10^3 hrs/failure = 42 days
- **Example: IEC 61508 (industrial controls)**
  - SIL 4: 10^8 hrs/dangerous failure = 11408 years
  - SIL 3: 10^7 hrs/dangerous failure = 1141 years
  - SIL 2: 10^6 hrs/dangerous failure = 114 years
  - SIL 1: 10^5 hrs/dangerous failure = 11 years

https://en.wikipedia.org/wiki/Bhopal_disaster

1984: Bophal Chemical Plant
Thousands of deaths
(not software related;
pre-dates IEC 61508)

https://goo.gl/GGHWRn

Higher SIL Invokes More Engineering Rigor

Edge Case Research

- **Example: IEC 61508**
  - HR = Highly Recommended
  - R = Recommended
  - NR = Not Recommended (don't do this)
- **SIL 1: lowest integrity level (low risk)**
- **SIL 4: highest integrity level (unacceptable risk)**

	Technique/Measure*	Ref	SIL1	SIL2	SIL3	SIL4
1	Fault detection and diagnosis	C.3.1	---	R	HR	HR
2	Error detecting and correcting codes	C.3.2	R	R	R	HR
3a	Failure assertion programming	C.3.3	R	R	R	HR
3b	Safety bag techniques	C.3.4	---	R	R	R
3c	Diverse programming	C.3.5	R	R	R	HR
3d	Recovery block	C.3.6	R	R	R	R
3e	Backward recovery	C.3.7	R	R	R	R
3f	Forward recovery	C.3.8	R	R	R	R
3g	Re-try fault recovery mechanisms	C.3.9	R	R	R	HR
3h	Memorising executed cases	C.3.10	---	R	R	HR
4	Graceful degradation	C.3.11	R	R	HR	HR
5	Artificial intelligence - fault correction	C.3.12	---	NR	NR	NR
6	Dynamic reconfiguration	C.3.13	---	NR	NR	NR
7a	Structured methods including for example, JSD, MASCOT, SADT and Yourdon.	C.2.1	HR	HR	HR	HR
7b	Semi-formal methods	Table B.7	R	R	HR	HR
7c	Formal methods including for example, CCS, CSP, HOL, LOTOS, OBJ, temporal logic, VDM and Z	C.2.4	---	R	R	HR
8	Computer-aided specification tools [IEC 61508]	B.2.4	R	R	HR	HR

Fleet Exposure & Probability

Edge Case Research

- **Bigger fleets have increased exposure**
  - 250 Million US vehicles @ 1 hour/day
    = 2.5 * 10^8 hrs/day exposure
  - If "unlikely" failures happen every million hours…
    that's: 2.5 * 10^8 hrs / 10^6 hrs per event
    ➔ 250 events ***every day***
  - This is why 10^8 to 10^{10} hrs is a typical goal

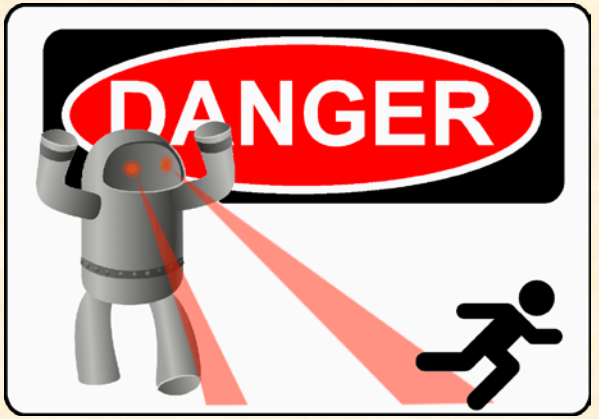
- **Hardware components fail at ~10^5-10^6 hrs**
  - Need two independently failing components to get to 10^9 hours!
    - This motivates redundancy for life-critical applications (SIL 3 & SIL 4)

- **For mission-critical systems, consider:**
  - Fleet exposure = # units * operational hours/unit
  - Number of acceptable failures
  - Compute failure rate = failures / hours; pick an appropriate SIL

Best Practices For Critical Systems

Edge Case Research

- **Characterize worst case failure scenarios**
  - Assign SIL based on relevant safety standard
  - Use engineering rigor for software SIL
  - Use redundancy for ultra-low failure rates
  - Consider fleet exposure, not just single unit



- **Pitfalls:**
  - Software redundancy is difficult, and diversity is usually impracticable
  - Designer's intuition about "realistic" faults usually optimistic
    - At 10^{-9}/hr, random chance is a close approximation of a malicious adversary
  - Going through the motions not enough for SIL-based process