Mechanical Reliability

18-849b Dependable Embedded Systems

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Required Reading: Paper reference

Best Tutorial: Mechanical Applications in Reliability Engineering

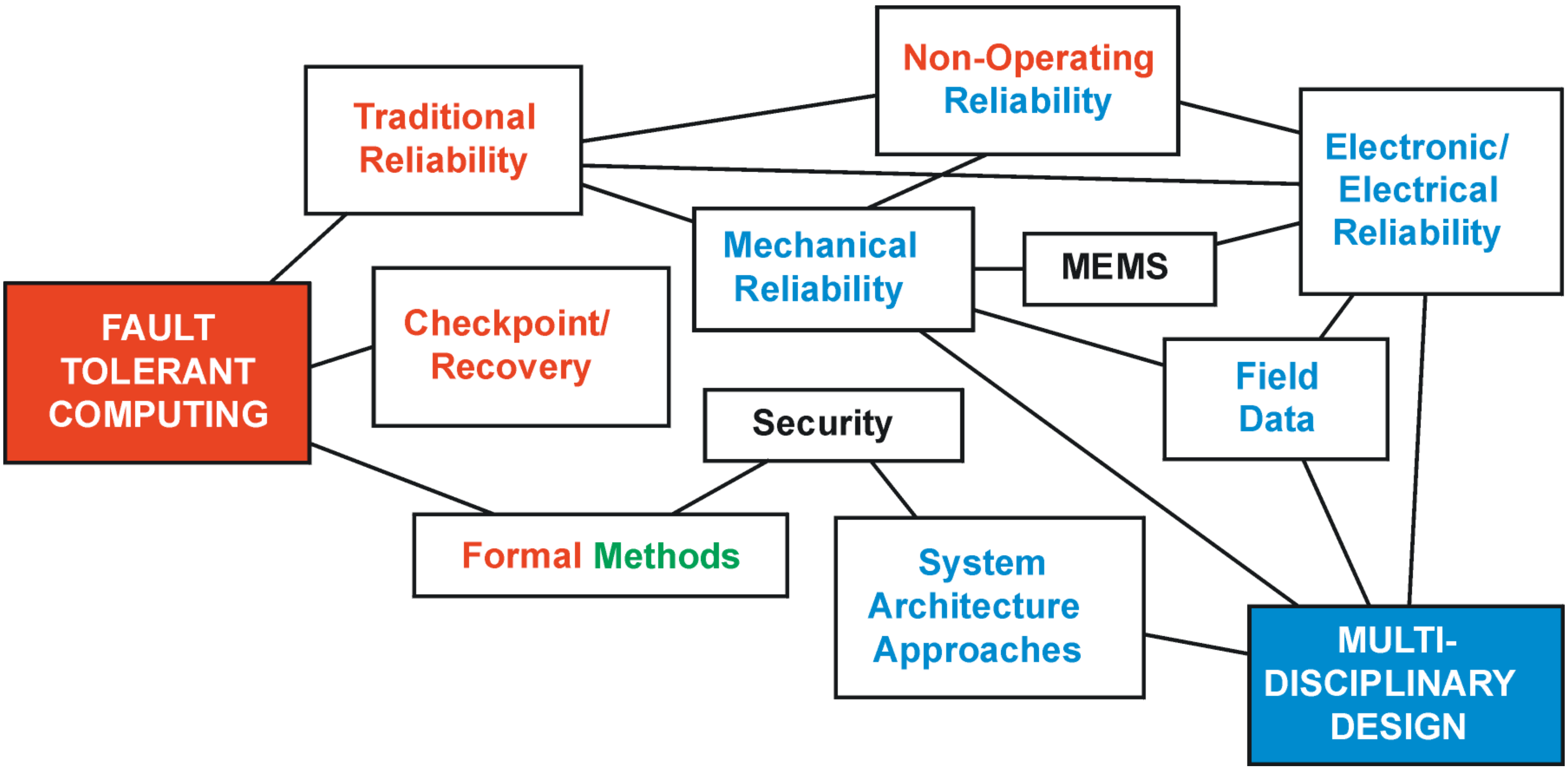
Authoritative Books: Very many, see ref's

Carnegie Mellon

Overview: Mechanical Reliability

- **Introduction**
  - Traditional Reliability
- **Key concepts**
  - Need to know many fields to do original estimations, use historical info instead
  - want to classify failures for use later
  - use estimates and surrogate sources to estimate system reliability
- **Tools / techniques / metrics**
  - The art of mechanical reliability is very advanced
  - Metrics are extremely mature
- **Relationship to other topics**
  - Electronic Reliability, Traditional Reliability
- **Conclusions & future work**

YOU ARE HERE MAP



What is Mechanical Reliability

- **The key to mechanical reliability is estimating the reliability of components**
- **Component reliability**
  - Generic sources
    - AVCO
    - NPRD-3
    - many others
  - Estimating
    - Maximum Normal Stress Theory
    - Distortion Energy theory
  - Historical information
    - This is the best!!!
    - If you have it
- **Figure out what fails and make maintenance schedule for it**

Use Historical Data

- **Historical data is the best**
  - requires that you've built "it" or something like "it" before
  - requires that you have collected data on it
  - much better than other methods
  - takes into account environmental factors
  - includes best knowledge of stresses on the part

Use Generic Sources

◆ Generic Data Sources

- Non-Electronic Parts Reliability Database (NPRD-3)
  - military data
  - based on component usage throughout military hardware
  - military can enforce collection of data much better than most companies
  - military may use their equipment (a lot) harder than commercial
  - all numbers given strictly as number of failures per million hours (λ)
    - » data not as useful for cyclical parts
  - fairly recent data
- AVCO
  - published in 1966 by AVCO
  - gives information about environment and cyclical use
  - BUT, it's getting old
  - material science is still improving the alloys and everything else
  - getting too old to use

Generic Data Sources

- Easy to use generic sources
- can estimate system reliability quickly
- not too accurate, sometimes up to a factor of 10 off
- usually very conservative
- shouldn’t apply it to system critical components

Estimating Component Reliability

- **Two methods recommended by RAC**
- **Maximum Normal Stress Theory**
  - good for brittle materials
  - take a sample of the material to a lab and estimate its strength
    - apply a uniaxial (single dimensional) force to it
    - measure when it breaks
  - determine multi-axial stress on component
    - create normal stress vectors
    - if normal vectors are greater than the maximum tested, the part fails
- **Distortion Energy Theory**
  - "Failure is predicted to occur in the multi-axial state of stress when the distortion energy per unit volume, u_d, becomes equal to or exceeds the distortion energy per unit volume at the time of failure in a simple uniaxial stress test using a specimen of the same material."

More Estimating

- **Distortion Energy Theory**
  - $\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2] >= \sigma_f^2$
    - σ_1 σ_2 σ_3 -> maximum normal stresses
    - σ_f -> uniaxial yield stress
- **Theories based on gaining knowledge from material science and tribology**
  - tribology - study of lubricants and surface wear
    - responsible for many things like replacement joints
    - improving ball bearings significantly
  - material science
    - coming up with new alloys
    - improving the strength of the materials all the time

Tools / Techniques

◆ Failure Mode Classification

- capture the mechanism, cause, and mode
- for example: a rolling bearing race experiences adhesive wear and race pitting fatigue as a result of a loss of lubrication which results in excessive vibration and noise.
  - Mechanism -> adhesive wear
  - Cause -> loss of lubrication
  - Mode -> excessive vibration and noise
- the mechanisms are described methods in which mechanical parts fail
  - RAC macro mechanisms: distortion, fracture, wear, corrosion
- the cause is the reason why the part failed
- the mode is the way in which the system demonstrated the failure
  - useful for later diagnostics if it happens again

More Tools/Techniques

- **Determine system realibility**
  - Fault Tree Analysis (FTA)
    - top down method
    - can be used on mixed systems
    - build a tree of faults in the system
  - Failure Mode, Effects and Criticality Analysis (FMECA)
    - bottom up method
    - can’t be used well in mixed systems
  - useful for classifying failures in fielded systems
  - helps in building maintenance schedules

Metrics

- **Specific metrics exist (en mass) for generic components**
  - unfortunately they vary widely!
  - Very dependent on environment
    - NPRD-3 is not rated for maritime use
    - parts fail much faster at sea in the salt-water air
- **Metrics (nearly) impossible for new random components**
  - building that special lever into a new mechanical design will not have any metrics

Relationship To Other Topic Areas

- **Traditional Reliability**
  - Need to know the math from traditional reliability
  - statistics are all in common
- **Electronic reliability**
  - can use many of the same redundancies to increase reliability
  - electronic parts performance changes over time, but can be recalibrated
  - mechanical parts tend to break and fail

Conclusions & Future Work

- Historical data is the best
- Generic sources are out there and should be used for quick estimates
- Generic sources are wrong, but conservative
- Parts like ball bearings fail the most
- Must develop a maintenance schedule for mechanical parts, they experience mechanical wear
- Very hard to determine when a completely newly designed component will fail
- Methods to estimate component failure are very time intensive
- Need to understand physics, material science, tribology, etc to build better models

More conclusions

- **Better non-destructive testing methods are needed to estimate part reliability for critical components**
- **Non-destructive testing is advancing**
- **Tribology and material science making good strides in making better materials and knowing why the fail**