ECE695: Reliability Physics of Nano-Transistors
Lecture 2: A Brief History of Reliability and Types of Reliability Models

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Outline of lecture 2

1. Reliability as a General Phenomena
2. A Brief History of Reliability
3. Approaches to Reliability Physics
4. Conclusions
Reliability is important

A 4000 year old example:  
*Stone vs. Copper tools*

A modern example: 
*Honda vs. Yugo*

“The car is named Yugo, because it doesn’t …”
Reliability: Physics of how things ‘break’

1. A child breaking a glass, bridges falling apart (e.g. Tacoma Narrows), shuttle exploding (e.g. Challenger).

2. Lighting in a rain-soaked night, volcano, landslides & forest fire

3. Check-out queues, scheduling

A stochastic process terminated by threshold
Reliability: An extreme non-equilibrium problem

One option: create an empirical curve, stay away from yield point …
Outline

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A Brief History of Reliability

Phase 1: Antiquity to 1900 ....
   Based on empirical study and over-design

Phase 2: 1900 onward ...
   Based on system design principles
   Introduction of rigorous statistical principles

Phase 3: 1970 onward ...
   Development on physical principles of reliability & complex/emergent/critical phenomena
Phase 1: Antiquity to 1900 ....

Based on empirical study and over-design

- 3000 years old Pyramid, 2000 years old Pont du Gard stone bridge in Southern France, the 300 year old first Iron Bridge on the Savern River still stand.

- Stone age vs. Cu age (performance vs. reliability @4000 BC)

- Stone to Steel (e.g. Lui Sullivan Monadbuilding in Chicago)

- Power-law for Earthquake, forest fires, attack by insurgents in Iraq

- Invention of Light bulb by Edison
Phase 2: Statistical (Probabilistic) Reliability

Urgency of WWII (50% equipment unserviceable, MTTF 20h for bombers, etc.) forced people to explore reliability issues as a science problems


2. Statistical theories bring discipline to reliability physics (e.g., Von-Neumann theory of fault-tolerant computing). Queuing theory of software and computer systems emerge.

3. Internet protocols (routing through unreliable network)

4. ATT builds trans-Atlantic cable with 40 year lifetime.

5. Response of large crowds under stress – behavior/statistical model (e.g. Presidential inauguration).
Phase 3: Physical Reliability

Pervasive use of physical models to explain reliability

Mechanical/Aeronautical Engineering:
  Theory of Fracture, excellent theory, many books, embedded in software

Software Development:
  Formal methods of verification, embedded in software, courses taught in most universities

Natural Phenomena
  Volcanic eruption: Sandpile models
  Forrest fires: Percolation theory and Firelanes
  Statistical physics of phase transition and emergent phenomena

Electronic Devices:
  Significant work since 1940 at Bell Labs, 1960s in Fairchild, whole industry in 1980s and 1990s.
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Approaches to Statistical Reliability

Empirical approach

Sell a set of computers and observe the frequency of field-returns. Create historical data-base to predict what is likely to happen to your next product.

Statistical Approach/ System Theory:

Assume that each component (blue boxes) has a certain failure rate (e.g. \( \exp(-At) \), need not know the physics of \( A \)) and a certain connectivity. Use the rules of probability to predict overall reliability of the system.

Physical Approach:

Study the physics of individual devices to find the origin of \( A \) as a function of voltage, temperature, etc. and use it in statistical model and compare with empirical results.
Empirical Reliability: Reliability Triangle


Infographics
-- Rose diagram (Nightingle)
-- Many Eyes (IBM)
-- gapminder.com (Rosling)
Empirical reliability and margin of safety

- Stress
- Strain

Ultimate strain

Failure point

Yield point

Ultimate strain

Elastic region

Plastic region

Ultimate stress

Stress

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Statistical Reliability: Series/Parallel Connection

\[ P \quad \text{... Failure probability} \]

A fails \textit{and} B fails, then system fails

\[ P_f = P_A \times P_B \]

A fails \textit{or} B fails, then system fails

\[ 1 - P_f = (1 - P_A) \times (1 - P_B) \]

Analogy of locked doors, failure diagram ....
Computer systems in aircraft, power and computer network
Statistical reliability: An example

\[ P_f = P_A \times P_B \]

E. Henley/Kumamoto, 1981.

Disaster if coolant fails and operator can not shut it down
Impossible to model by Physical Reliability

Sources of data:
- Insurance industry, Sandia studies, accidents, psychological analysis.
- Studies of counter-terrorism in Iraq (Power-laws in size of attacks)

A. Spurgin, Human Risk Assessment, 2010, on Bhopal Gas Disaster

<table>
<thead>
<tr>
<th>Accident Type</th>
<th>Total Number for 1969</th>
<th>Approximate Individual Risk Early Fatality Probability/Yr(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor vehicle</td>
<td>55,791</td>
<td>3 \times 10^{-4}</td>
</tr>
<tr>
<td>Falls</td>
<td>17,827</td>
<td>9 \times 10^{-5}</td>
</tr>
<tr>
<td>Fires and hot substance</td>
<td>7,451</td>
<td>4 \times 10^{-5}</td>
</tr>
<tr>
<td>Drowning</td>
<td>6,181</td>
<td>3 \times 10^{-5}</td>
</tr>
<tr>
<td>Poison</td>
<td>4,516</td>
<td>2 \times 10^{-5}</td>
</tr>
<tr>
<td>Firearms</td>
<td>2,309</td>
<td>1 \times 10^{-5}</td>
</tr>
<tr>
<td>Machinery (1968)</td>
<td>2,054</td>
<td>1 \times 10^{-5}</td>
</tr>
<tr>
<td>Water transport</td>
<td>1,743</td>
<td>9 \times 10^{-6}</td>
</tr>
<tr>
<td>Air travel</td>
<td>1,778</td>
<td>9 \times 10^{-6}</td>
</tr>
<tr>
<td>Falling objects</td>
<td>1,271</td>
<td>6 \times 10^{-6}</td>
</tr>
<tr>
<td>Electrocution</td>
<td>1,148</td>
<td>6 \times 10^{-6}</td>
</tr>
<tr>
<td>Railway</td>
<td>884</td>
<td>4 \times 10^{-6}</td>
</tr>
<tr>
<td>Lightning</td>
<td>160</td>
<td>5 \times 10^{-7}</td>
</tr>
<tr>
<td>Tornadoes</td>
<td>118(^b)</td>
<td>4 \times 10^{-7}</td>
</tr>
<tr>
<td>Hurricanes</td>
<td>90(^c)</td>
<td>4 \times 10^{-7}</td>
</tr>
<tr>
<td>All others</td>
<td>8,695</td>
<td>4 \times 10^{-5}</td>
</tr>
<tr>
<td>All accidents</td>
<td>115,000</td>
<td>6 \times 10^{-4}</td>
</tr>
<tr>
<td>Nuclear accidents</td>
<td>—</td>
<td>2 \times 10^{-10}(^d)</td>
</tr>
</tbody>
</table>

\(^a\) Based on total U. S. population, except as noted.
\(^b\) (1953–1971 avg.).
\(^c\) (1901–1972 avg.).
\(^d\) Based on a population at risk of 15 \times 10^6.
We do not ask why transmission flips a bit, we simply fix it …
Scratch on your CD is fixed by the same way.

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Empirical/Statistical Reliability: Apgar Score

A single empirical test in 1952 that changed infant mortality rate dramatically ….

<table>
<thead>
<tr>
<th>From Wikipedia ….</th>
<th>Score =0</th>
<th>Score =1</th>
<th>Score =2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin Complexion (Appearance)</td>
<td>blue all over</td>
<td>blue at extremities body pink</td>
<td>Body and extremities pink</td>
</tr>
<tr>
<td>Pulse</td>
<td>&lt;60*</td>
<td>&gt;60, &lt;100</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Reflex i (Grimace)</td>
<td>no response</td>
<td>feeble cry when stimulated</td>
<td>sneeze/cough/pulls away when stimulated</td>
</tr>
<tr>
<td>Muscle tone (Activity)</td>
<td>none</td>
<td>some</td>
<td>active movement</td>
</tr>
<tr>
<td>Breathing (Respiration)</td>
<td>absent</td>
<td>weak</td>
<td>strong</td>
</tr>
</tbody>
</table>

7-10 good
4-7 attention
1-3 difficult

\[ P_f (\text{old}) = 1 - \left( P_s^A \times P_s^P \times P_s^G \times P_s^A \times P_s^R \right) \]

Left to die …

\[ P_f (\text{new}) = P_f^A \times P_f^P \times P_f^G \times P_f^A \times P_f^R \]

Neonatal units ..
Two Perspectives on Reliability

Bell Lab’s Jack A. Morton
*Tyranny of numbers:* The more eggs in a basket, the more chances of a bad one (*Uncorrelated defects*)

Fairchild’s Noyce and Moore
*MOSFET has reliability problems, we must find ways to fix them* (*Correlated and predictable defects*)
Conclusions

- History of technology progress parallels advancement in reliability.

- A reliability phenomena can be studied empirically, statistically, or physically, or in combination therefore.

- Although we will focus on physical reliability of transistors, many aspects of IC manufacture (e.g. yield, process control) are informed by statistical models and empirical observations.

- Can not overemphasize the political/social/behavioral aspect of reliability (e.g. Intel’s floating point error, plane vs. car accidents, etc.). Our focus on physical reliability will still be bound by these considerations.
Self Check

- You should be able to name three approaches to reliability physics.

- Combinatorial approach relies on probability theory. You should be able to work out any problem based on ‘failure diagram’ or ‘success diagram’.

- Do you understand clearly the importance of correlated vs. independent events? Most probabilistic calculations assume independence of events.

- Explain why most elements that rely on human elements still rely on combinatorial approaches.
References

- Stress measurement

- Figure of Transatlantic Cables
  [http://gadgets.boingboing.net/gimages/Transatlantic_Cable__TAT_1__under_Construction_1955_200904171301362.jpg](http://gadgets.boingboing.net/gimages/Transatlantic_Cable__TAT_1__under_Construction_1955_200904171301362.jpg)

- A. Spurgin, Human Risk Assessment, 2010, on Bhopal Gas Disaster


- Error correction codes: R. Lucky, Silicon Dreams.

- Measuring the immeasurable – the Apger test for new-borns


- gapminder.com,