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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

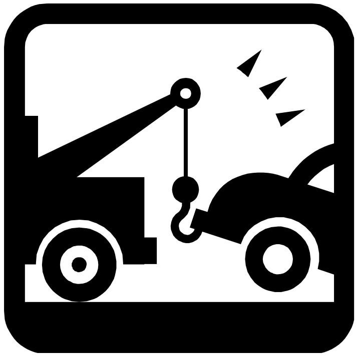
Reliability is important

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'

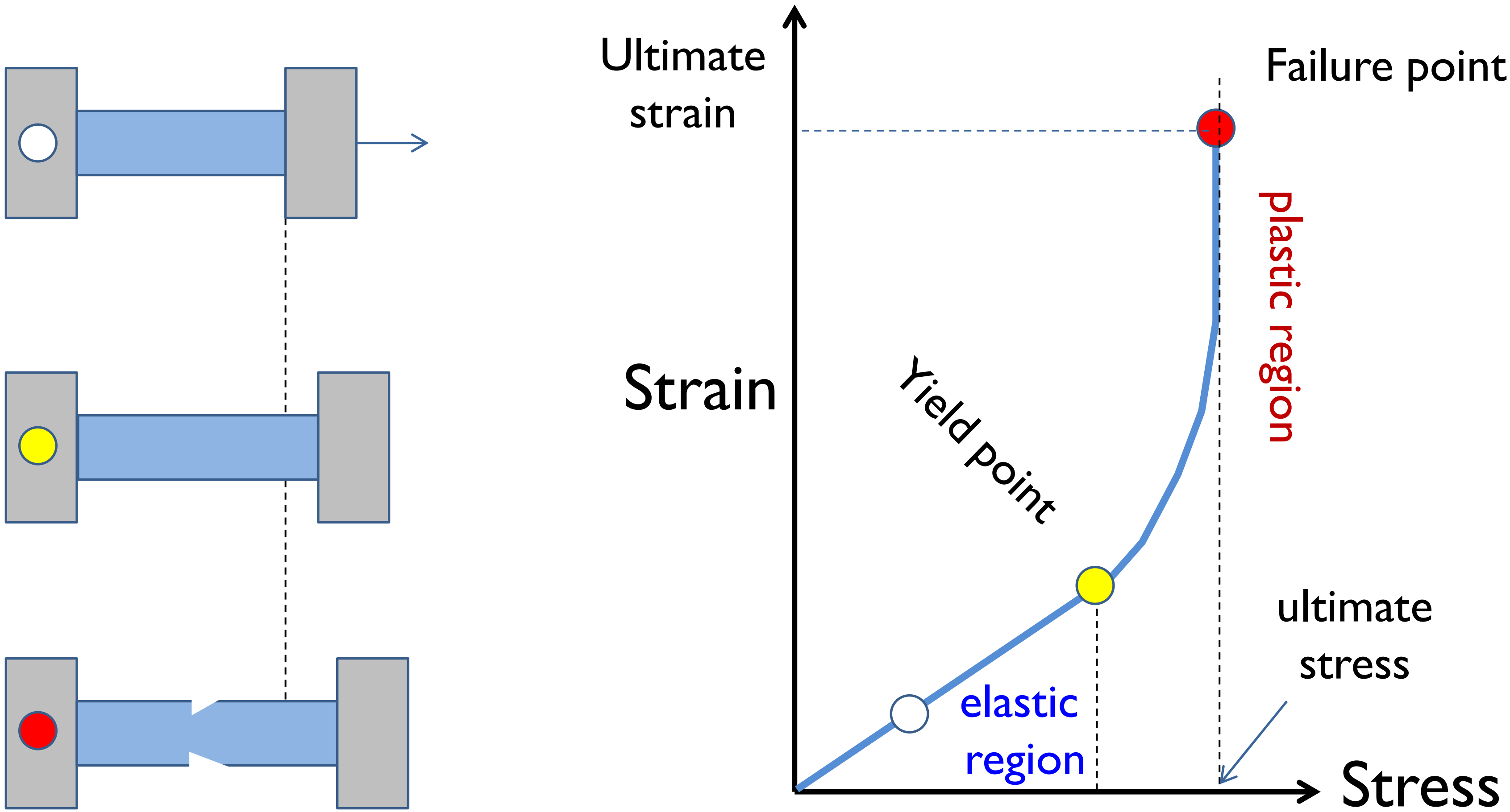
1. A child breaking a glass, bridges falling apart (e.g. Tacoma Narrows), shuttle exploding (e.g. Challenger).

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 …

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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: Empirical Reliability

Phase I: 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

1. DARPA introduces AGREE program (Advisory group of reliability of electronic equipments). Results in MIL-HDBK-217 Handbook. Many books begin to appear in 1960s.

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 inaugation).

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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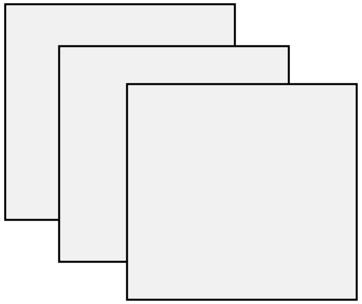
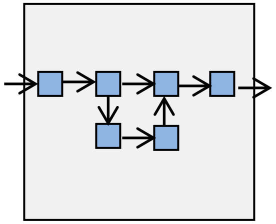
Approaches to Statistical Reliability



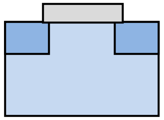
Empirical approach

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.



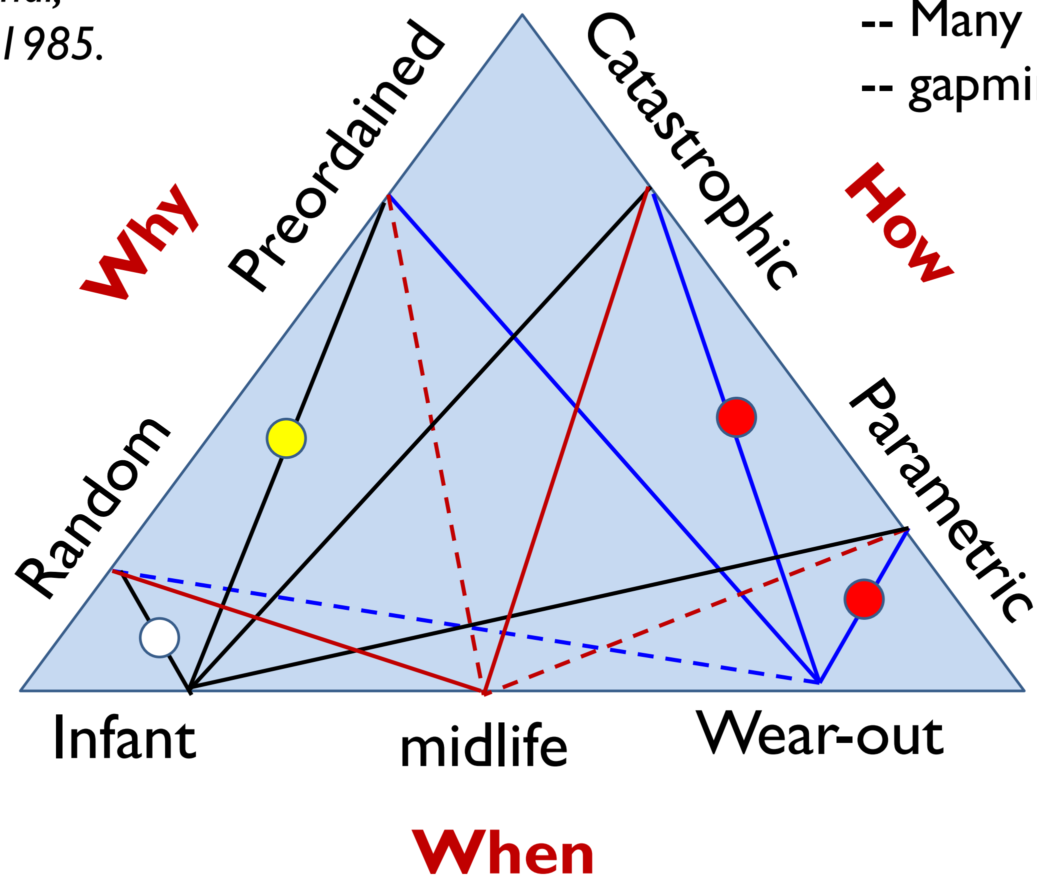
Physical Approach:

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.

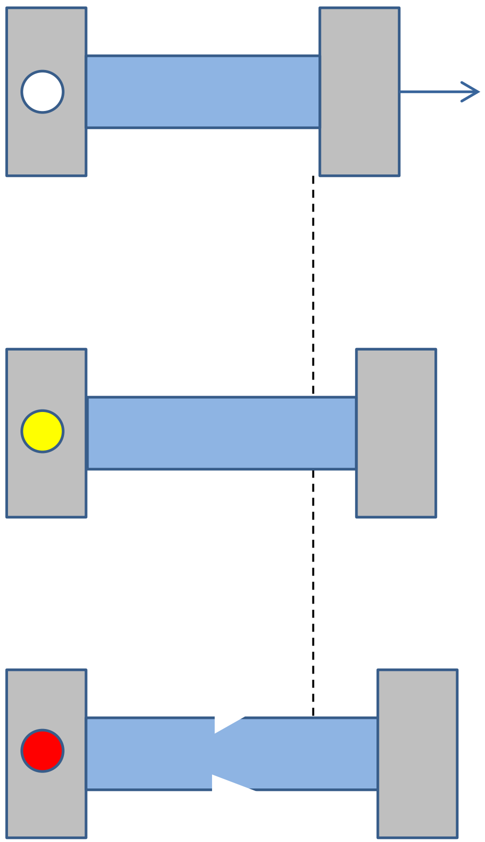
Empirical Reliability: Reliability Triangle

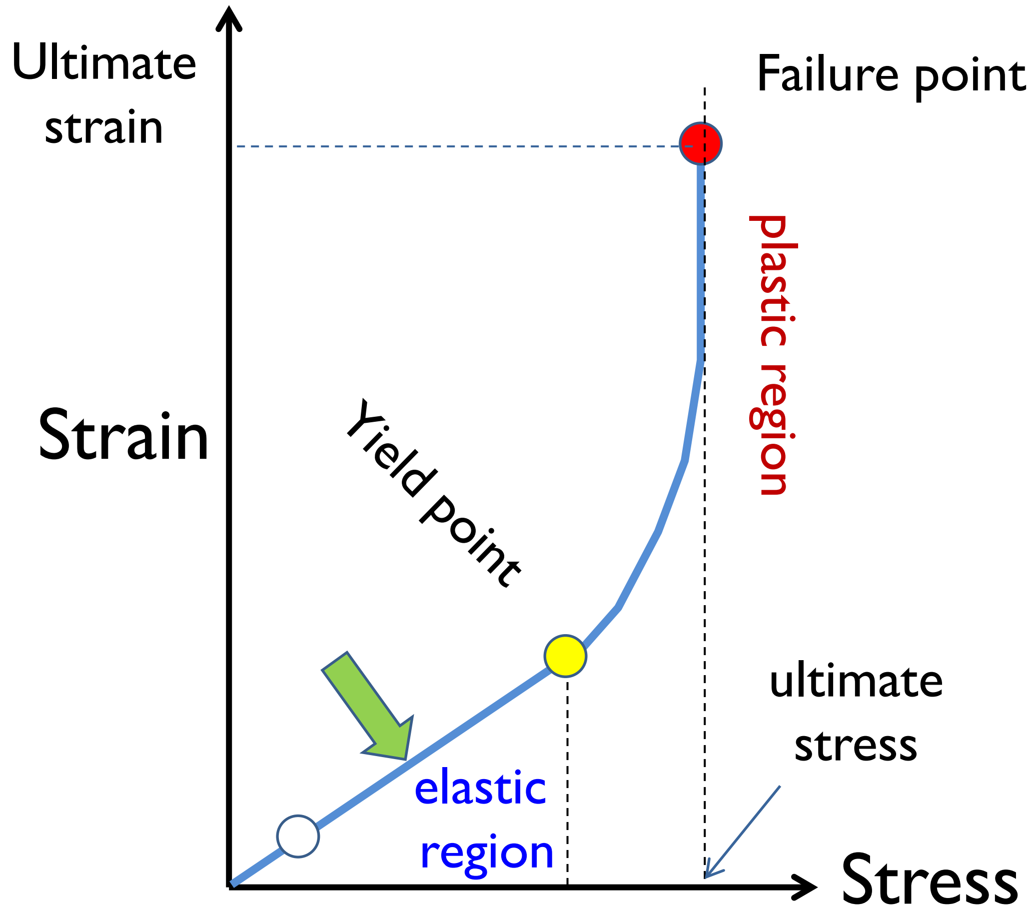
Nash et al. ATT Tech. Journal, 64(3), 671, 1985.

Infographics
-- Rose diagram (Nightingle)
-- Many Eyes (IBM)
-- gapminder.com (Rosling)



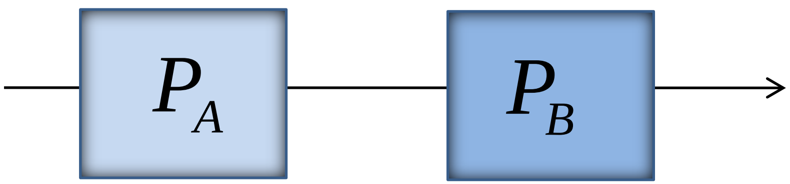
Empirical reliability and margin of safety

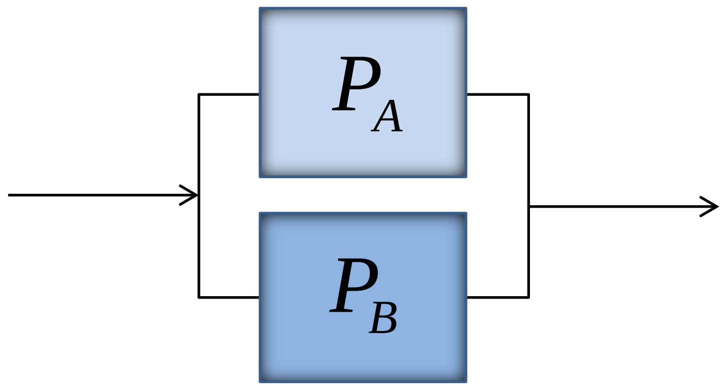




Statistical Reliability: Series/Parallel Connection

P …. Failure probability





A fails *and* B fails, then system fails

A fails *or* B fails, then system fails

$$P_f = P_A \times P_B$$

$$1 - P_f = (1 - P_A) \times (1 - P_B)$$

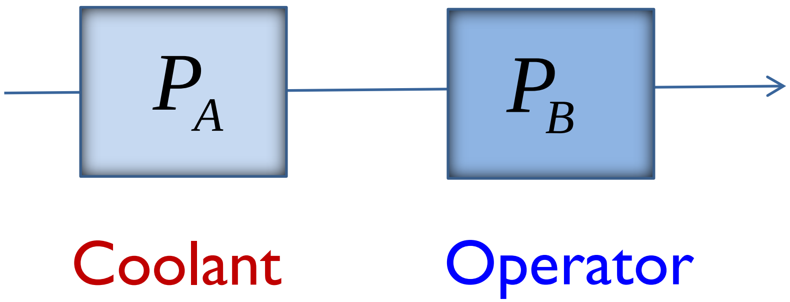
Analogy of locked doors, failure diagram ….

Computer systems in aircraft, power and computer network

Statistical reliability: An example

E. Henley/Kumamoto, 1981.

$$P_f = P_A \times P_B$$



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

TABLE 1.1 INDIVIDUAL RISK OF EARLY FATALITY BY VARIOUS CAUSES

Accident Type	Total Number for 1969	Approximate Individual Risk Early Fatality Probability/Yr[a]
Motor vehicle	55,791	3×10^{-4}
Falls	17,827	9×10^{-5}
Fires and hot substance	7,451	4×10^{-5}
Drowning	6,181	3×10^{-5}
Poison	4,516	2×10^{-5}
Firearms	2,309	1×10^{-5}
Machinery (1968)	2,054	1×10^{-5}
Water transport	1,743	9×10^{-6}
Air travel	1,778	9×10^{-6}
Falling objects	1,271	6×10^{-6}
Electrocution	1,148	6×10^{-6}
Railway	884	4×10^{-6}
Lightning	160	5×10^{-7}
Tornadoes	118[b]	4×10^{-7}
Hurricanes	90[c]	4×10^{-7}
All others	8,695	4×10^{-5}
All accidents	115,000	6×10^{-4}
Nuclear accidents (100 reactors)	—	2×10^{-10}[d]

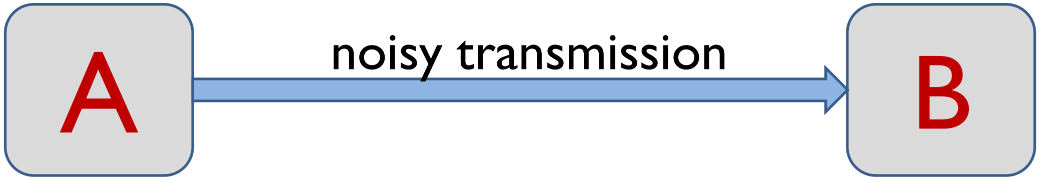
[a]Based on total U. S. population, except as noted.
[b](1953–1971 avg.).
[c](1901–1972 avg.).
[d]Based on a population at risk of 15×10^6.

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

Statistical reliability: Error correction codes



Code 1

0	000
1	001
2	010
3	011
4	100
5	101
6	110
7	111

Code 2

Parity bit ?

0	000	0
1	001	1
2	010	1
3	011	0
4	100	1
5	101	0
6	110	0
7	111	1

Code 3

	bit 1	bit 2	bit 3
0	000	000	000
1	001	000	111
2	010	111	000
3	011	111	111
4	100	000	000
5	101	000	111
6	110	111	000
7	111	111	111

We do not ask why transmission flips a bit, we simply fix it …
Scratch on your CD is fixed by the same way.

Empirical/Statistical Reliability: Apgar Score

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

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

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

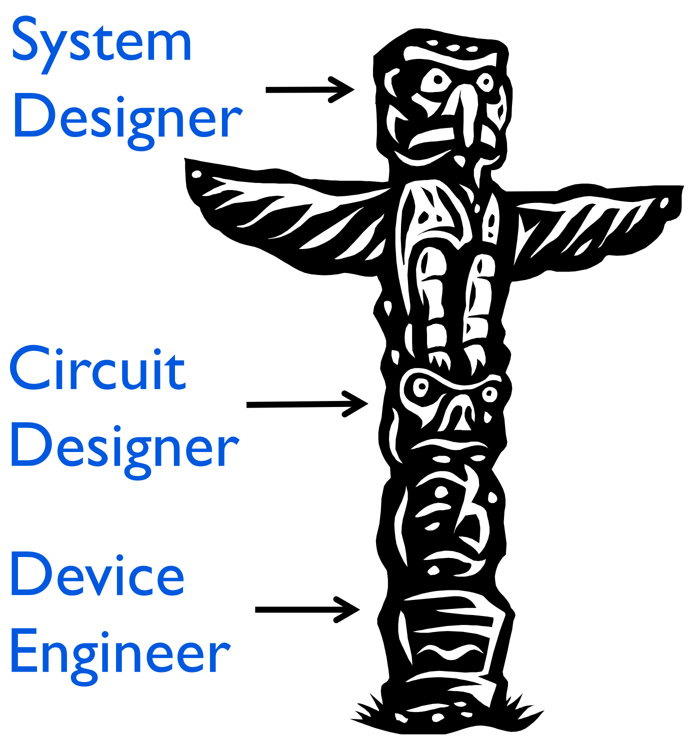
$$P_f\,(\text{old}) = 1 - \left(P_s^A \times P_s^P \times P_s^G \times P_s^A \times P_s^R\right)$$

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 ..

Dangers of Statistical Reliability



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

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