IAF0530 (MSc)
IAF9530 (PhD)

Dependability and fault tolerance

Gert Jervan
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Tallinn University of Technology (TTÜ)

General Information

- Contents:

  Dependability and fault tolerance

  www.pld.ttu.ee/IAF0530

- Lecturer & Examiner:

  Gert Jervan

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  www.pld.ttu.ee/~gerje

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Gert Jervan

- MSc from TTÜ in 1998
  - Exchange student at TIMA Labs (Grenoble, France), Fraunhofer Institute (Dresden, Germany), Linköping University (Sweden)
- PhD from Linköping University (Sweden) in 2005
- Senior research fellow at TTÜ since 2005, professor since 2012
- Vice-Dean for Research at the Faculty of IT (2012), Dean (2013)
- Published more than 80 papers at international conferences and journals
- Organized many international conferences and coordinated several research projects, incl. 7-year project CEBE (Centre for Integrated Electronic Systems and Biomedical Engineering)

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Course Plan

- 16 occasions, á 1,5 hours
  Mondays 10:00-11:30
- Longer sessions during the second half of the semester (will be announced separately)
- 7-10 Lectures with discussion sessions. No meeting on March 27, April 24 (Tentatively). Always check the course homepage!!
- Individual project work
- Oral exam (discussion)

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Individual work

- Reading
- Writing
- Presenting
- The course requires weekly reading and participation in discussions
  - All missing assignments have to be compensated during the exam

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Reading

- **Various papers (on the course homepage)**

  www.pld.ttu.ee/IAF0530

- Textbooks
- Incident/accident reports
- Web pages

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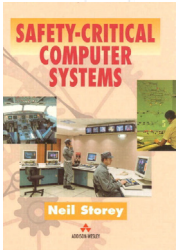
Textbooks

- Safety-Critical Computer Systems
  - Neil Storey
  - Addison Wesley, 1996.
  - An introductory text which provides overview of safety related aspects and methods in computer systems development.
  - Available in the TTÜ library



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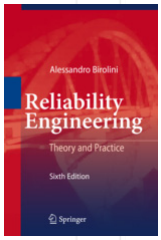
Textbooks



- Reliability Engineering: Theory and Practice.
  - Alessandro Birolini
  - Springer
  - 2014 (7th ed.) 2010 (6th ed.), 2007 (5th ed.)
  - This book shows how to build in, evaluate, and demonstrate reliability & availability of components, equipment, systems. It presents the state-of-the-art of reliability engineering, both in theory and practice
  - TTÜ library has several copies of the latest edition.

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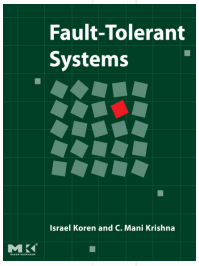
Textbooks

- Fault-Tolerant Systems
  - Israel Koren and C. Mani Krishna
  - Morgan-Kaufman Publishers, 2007



This book covers comprehensively the design of fault-tolerant hardware and software, use of fault-tolerance techniques to improve manufacturing yields and design and analysis of networks. Additionally it includes material on methods to protect against threats to encryption subsystems used for security purposes.

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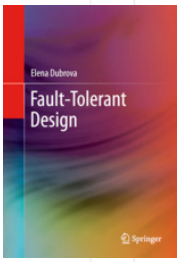
Textbooks

- Fault-Tolerant Design
  - Elena Dubrova
  - Springer, 2013



- This textbook serves as an introduction to fault-tolerance, intended for upper-division undergraduate students, graduate-level students and practicing engineers in need of an overview of the field. Readers will develop skills in modeling and evaluating fault-tolerant architectures in terms of reliability, availability and safety. They will gain a thorough understanding of fault tolerant computers, including both the theory of how to design and evaluate them and the practical knowledge of achieving fault-tolerance in electronic, communication and software systems. Coverage includes fault-tolerance techniques through hardware, software, information and time redundancy. The content is designed to be highly accessible, including numerous examples and exercises.

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Case Studies

- The exact format will be announced during the second lecture (and it depends of the number of students we will have)
- Topic categories:
  - Accident analysis
  - System safety analysis
  - Literature survey
  - Something else (implementation, tool study, etc.)
  - Requires prior ack.

Literature and sample (!) topics on the webpage

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Case Studies

- Some examples (from 2016):
  - Estimating availability of the KSI service.
  - Dependability and Fault Tolerance of PaaS
  - Real-time Transport Protocol security considerations in Source-Specific Multicast topology
  - Fault tolarance on Cryptography
  - Automatic train protection systems
  - Software Fault Injection Methods
  - Safety and reliability of autonomous vehicle technologies
  - Evolution of Fault Tolerance in PostgreSQL
  - Self-checking network-on-chip layout design
  - Verified compilation
  - Fault tolerance in wireless systems
  - Critical Information Infrastructure vulnerability analysis methods

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Course overview

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Course Overview

- Reliability: increasing concern
  - Historical
    - High reliability in computers was needed in critical applications: space missions, telephone switching, process control, medical applications etc.
  - Contemporary
    - Extraordinary dependence on computers: on-line banking, commerce, cars, planes, communications etc. Emergence of internet-of-things.
    - Hardware is increasingly more fault-prone (complexity, technology, environment)
    - Software is increasingly more complex
    - Things simply do not work without special reliability measures

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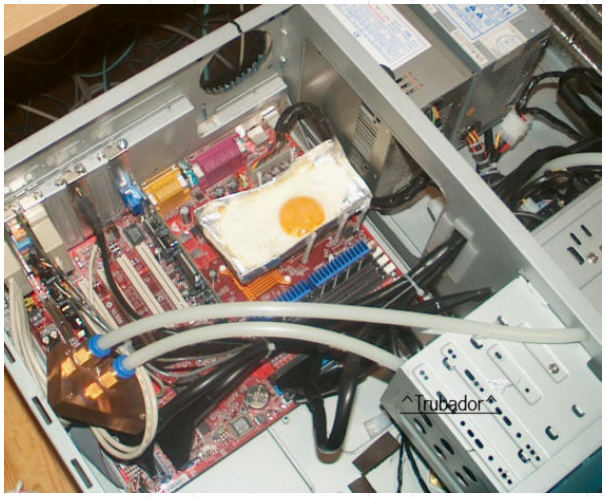
Already yesterday



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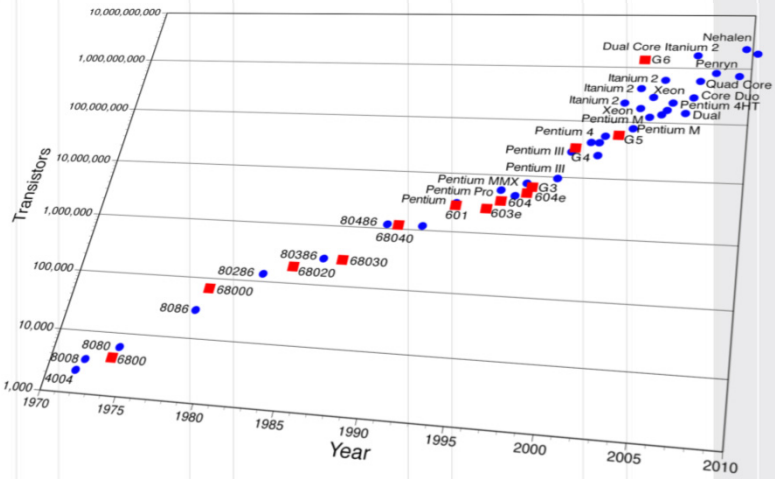
Moore's Law



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Moore's Law

- Growth rate
  - 2x transistors & clock speeds every 2 years over 50 years
  - 10x every 6-7 years

This won't last for long...

- Dramatically more complex algorithms previously not feasible
  - Dramatically more realistic video games and graphics animation (e.g. Playstation 4, Xbox 360 Kinect, Nintendo Wii)
  - 1 Mb/s DSL to 10 Mb/s Cable to 2.4 Gb/s Fiber to Homes.
  - 2G to 3G to 4G to 5G wireless communications
  - MPEG-1 to MPEG-2 to MPEG-4 to H.264 video compression
  - 480 x 270 (0.13 million pixels) NTSC to 1920x1080 (2 megapixels) HDTV resolution to 4K UHD 3840 × 2160 (8.3 megapixels)

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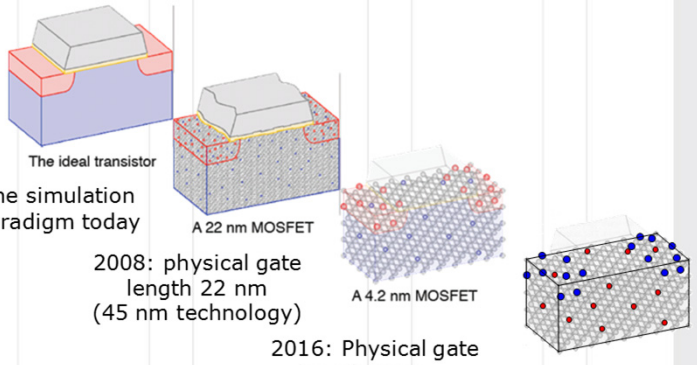
Scaling



The simulation paradigm today

2008: physical gate length 22 nm (45 nm technology)

2016: Physical gate length 9 nm = 30x30x30 atoms (22 nm technology) 50 Si atoms in a channel

2025 (?): 4 nm technology 10 Si atoms in a channel

Courtesy: A. Asenov

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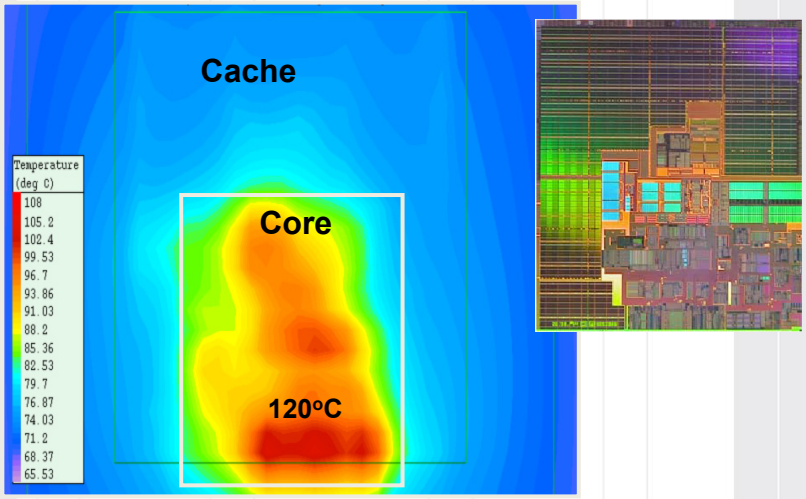
Thermal map: 1.5 GHz Itanium-2



[Source: Intel Corporation and Prof. V. Oklobdzija]

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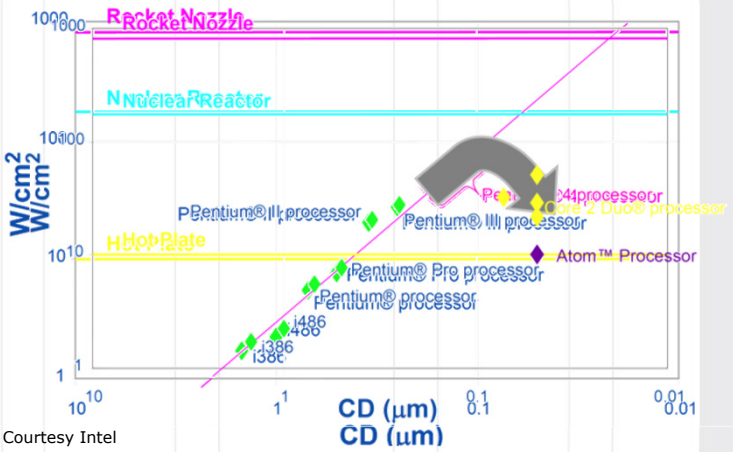
Power Density



Courtesy Intel

Power density too high to keep junctions at low temp

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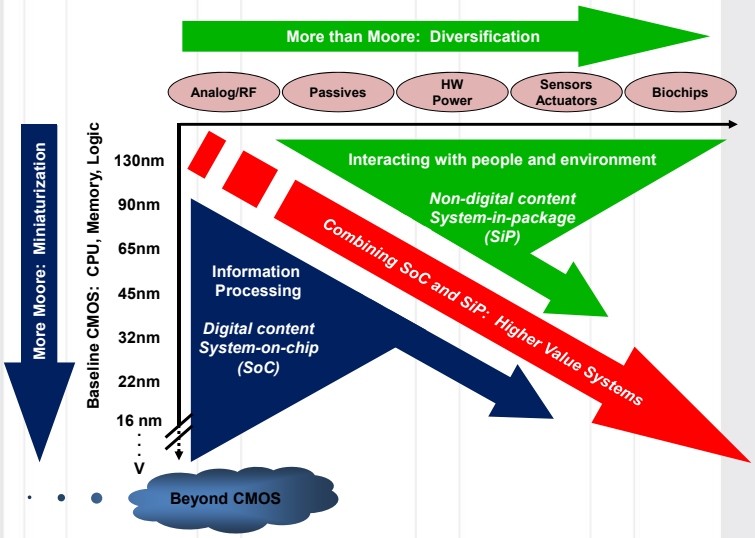
Moore's Law & More



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July 14, 2010 ITRS public conference – San Francisco 21

Hardware - Background

- Chip designers, device engineers and the high-reliability community recognize that reliability concerns ultimately limit the scalability of any generation of microelectronics technology
- Statistical methods and reliability physics provide the foundation for better understanding the next generation of scaled microelectronics
  - Microelectronics device physics
  - Reliability analysis and modeling
  - Experimentation
  - Accelerated testing
  - Failure analysis
- The design, fabrication and implementation of highly aggressive advanced microelectronics requires expert controls, modern reliability approaches and novel qualification strategies

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Scaling Trends & Reliability Considerations

- Dramatic increase in processing steps with each new generation
  - approx. 50 more steps per generation and a new metal level every 2 generations
- Rush to market - Less time to characterize new materials than in the past
  - e.g. reliability issues with new materials not fully understood and potential new failure modes
- Manufacturers' trends to provide 'just enough' lifetime, reliability, and environmental specs for commercial & industrial applications
  - e.g. 3-5 yr product lifetimes, trading off 'excess' reliability margins for performance

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Scaling Trends & Reliability Considerations

- Significant rise in the amount of proprietary technology and data developed by manufacturers, reluctance to share information with hi-relevance customers
  - e.g. process recipes, process controls, process flows, design margins, MTTF
- Next generation microelectronics focus on the performance needs of the commercial customer, with little or no emphasis on the extreme needs
  - e.g. extended life, extreme environments, high reliability
- Increasingly difficult testability challenges due to device complexity

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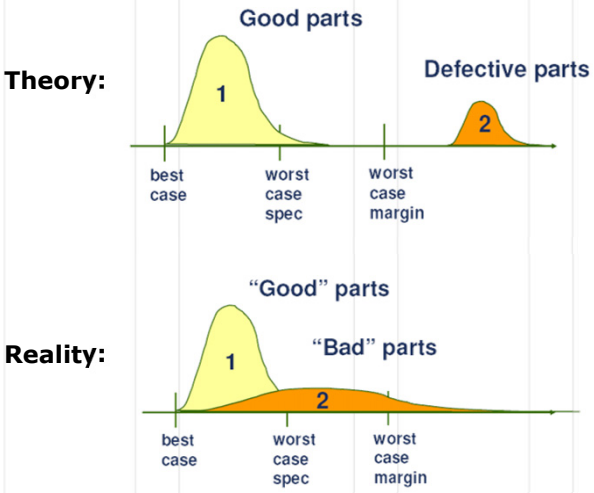
Correct or Defective?



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Product Technical Trends

	1990	2000	2010
Operating temperature, °C	-55 to 125	-40 to +85	0 to 70
Supply voltage	5v	1.5v	0.6v
Max. power (high perf.)	5	100	170
No. of package types	<10	<60	??
Design support life	>10 yrs.	1-5 yrs.	<1yr.
Production life	>10 yrs.	3-5 yrs.	<3yrs.
Service life	*>20 yrs.*	*5-10 yrs.*	*<5yrs.*

*MRQW-2002, Bernstein

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Growing Internet Traffic

Year	Global Internet Traffic
1992	100 GB/Day
1997	100 GB/Hour
2002	100 GB/Sec
2007	2 000 GB/Sec
2012	12 000 GB/Sec
2017	35 000 GB/Sec

Cisco VNI, 2013

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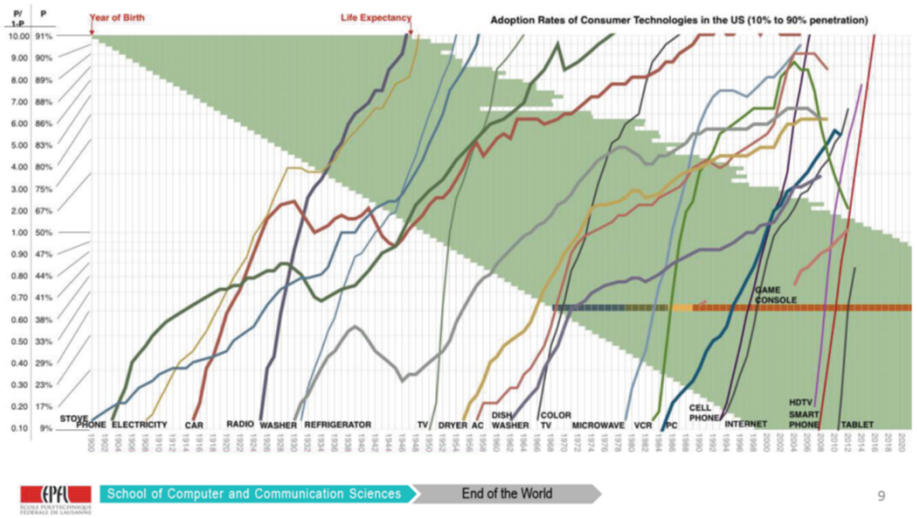
Ubiquitous Computing



James Larus, EPFL

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Software complexity is a challenge

Aviation:

- Boeing 747 → 0.4 M LOC
- Boeing 777 → 4 M LOC
- Technology Review 2002

Software:

- Exponential increase in software complexity
- In some areas code size is doubling every 9 months [ST Microelectronics, Medea Workshop, Fall 2003]
- … > 70% of the development cost for complex systems such as automotive electronics and communication systems are due to software development [A. Sangiovanni-Vincentelli, 1999]

Automotive:

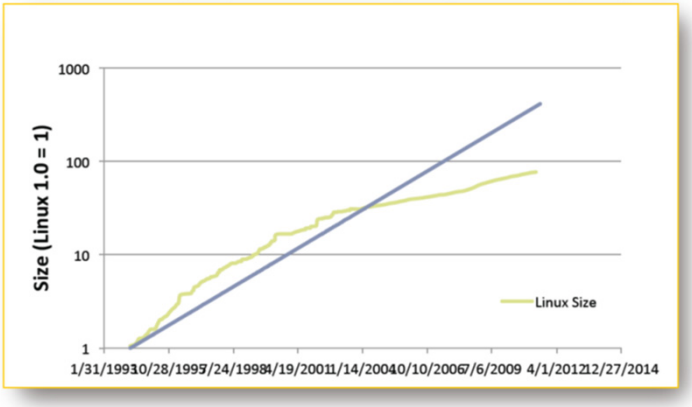
- ✓ 2010 Premium → 100 M LOC
- ✓ 1995 – 2000 → 52%/Year
- ✓ 2001 – 2010 → 35%/Year

  Tony Scott, GM CIO

- ✓ 2011 – BMW is the first manufacturer to break the 1Gb barrier

Rob van Ommering, COPA Tutorial, as cited by: Gerrit Müller: Opportunities and challenges in embedded systems, Eindhoven Embedded Systems Institute, 2004

Linux Growth



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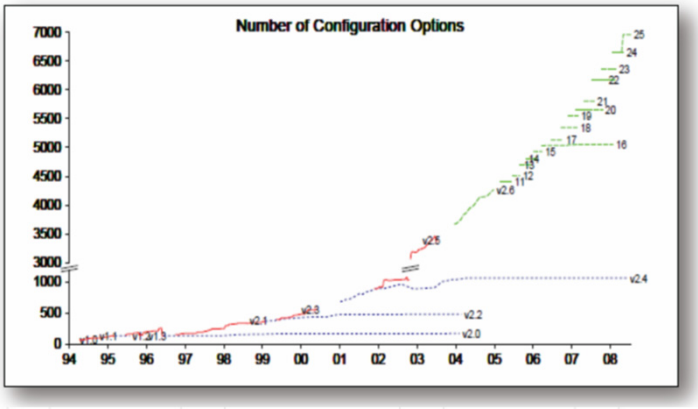
Linux Complexity



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Big Data

- An increasingly sensor-enabled and instrumente business environment generates HUGE volumes of data with MACHINE SPEED characteristics

- 1 Billion lines of code
- EACH engine (A380 has 4 of them) generating 10 TB every 30 minutes!

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Course Overview

- To get an insight into the broad area of system safety
- We cover techniques for high availability, fault tolerance, monitoring, detection, diagnosis, and confinement of failure, ways to improve availability through fast recovery and graceful service degradation, and techniques for using redundancy and replication.
- We also discuss the utopia of flawless software, the impact of scale on availability, ways to cope with human operator error, and metrics for evaluating dependability.

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Contents

- Fault tolerance
- System reliability
- Hardware redundancy
- Error detection techniques
- Coding techniques
- Processor-level detection and recovery
- Disk arrays
- Checkpointing and recovery
- Software fault tolerance
- Testing distributed real-time systems
- ...

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Lecture Outline

- ✓ **Historical perspective and famous incidents/accidents**
- **Basic terminology**

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Murphy's Law

- "If something can go wrong, it will go wrong"

  Major Edward A. Murphy, Jr.

  US Air Force, 1949

- "Every component than can be installed backward, eventually will be"

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Genesis Space Capsule

- $260 million Genesis capsule was collecting samples of the solar wind over 3 years period
- Crashed in Sept 2004 due to the failure of the parachutes
- Reason:
  - the deceleration sensors — the accelerometers — were all installed backwards. The craft's autopilot never got a clue that it had hit an atmosphere and that hard ground was just ahead.

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Mars Orbiter

- One of the Mars Orbiter probes crashed into the planet in 1999.
- It did turn out that engineers who built the Mars Climate Orbiter had provided a data table in "pound-force" rather than newtons, the metric measure of force.
- NASA flight controllers at the Jet Propulsion Laboratory in Pasadena, Calif., had used the faulty table for their navigation calculations during the long coast from Earth to Mars.

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Lockheed Martin Titan 4

- In 1998, a LockMart Titan 4 booster carrying a $1 billion LockMart Vortex-class spy satellite pitched sideways and exploded 40 seconds after liftoff from Cape Canaveral, Fla.
- Reason: frayed wiring that apparently had not been inspected. The guidance systems were without power for a fraction of a second.

A Titan 4 rocket explodes shortly after takeoff in August 1998.

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Therac-25

- Therac-25:
  - the most serious computer-related accidents to date (at least nonmilitary and admitted)
  - machine for radiation therapy (treating cancer)
  - between June 1985 and January 1987 (at least) six patients received severe overdoses (two died shortly afterward, two might have died but died because of cancer, the other two had permanent disabilities)
  - scanning magnets are used to spread the beam and vary the beam energy
  - dual-mode: electron beams for surface tumors, X-ray for deep tumors

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Denver Airport

- Denver International Airport, Colorado: intelligent luggage transportation system with 4000 "Telecars", 35km rails, controlled by a network of 100 computers with 5000 sensors, 400 radio antennas, and 56 barcode readers. Price: $186 million (BAE Automated Systems).
- Due to SW problems about one year delay which costs $1.1 million per day (1993).
- Abondoned in 2005 to save $1 million per month on maintenance
- Today we have the on-going story with the new Berlin Brandenburg Airport
  - Scheduled to open in 2011, the new estimate is 2014

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Boeing 787 Dreamliner

- Program launched in 2003, roll-out in 2007, first delivery in 2011. 114 delivered so far.
- Grounded on January 16, 2013 due to the problems with electrical circuitry
  - Leading to thermal runaway of Li-ion batteries and causing several fires in the battery compartment (several emergency landings, one aircraft (ET) was heavily damaged on ground)
  - Comprehensive review of the 787's critical systems, including the design, manufacture and assembly.
  - Japanese ANA alone lost 1.1 M USD per day (17 aircrafts)

- Grounding lifted on April 26, 2013

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LAX airport ATC software failure

- 2,4 billion USD system (developed by Lockheed Martin) crashed on April 30, 2014.
  - Reason: U-2 spy plane that was Flying „too high"
  - Result: The system attempted to calculate all possible flight paths and run out of memory
- The "new $40 billion air traffic control system, known as NextGen, which encompasses ERAM, including its reliance on Global Positioning System data that could be faked" is "very over-budget and behind schedule," Moss (founder of Def Con) told Reuters. It "doesn't surprise me that it's got some bugs - it's the way it presented itself' that's alarming." You can expect at least two upcoming Def Con talks to delve into exploiting weaknesses in the system.

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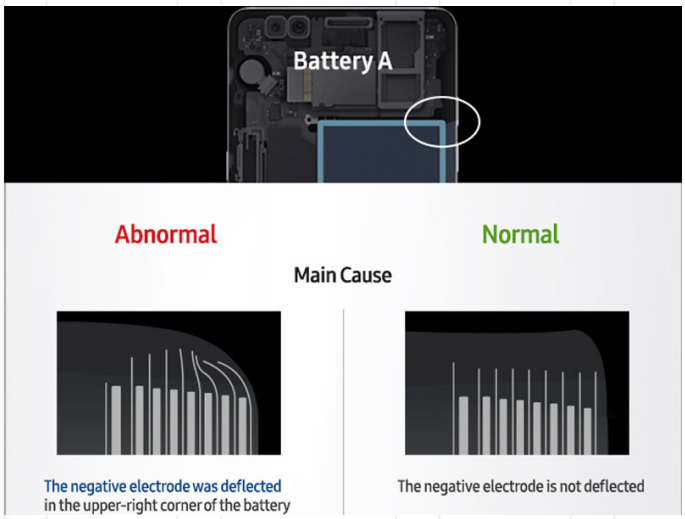
Samsung Galaxy Note 7



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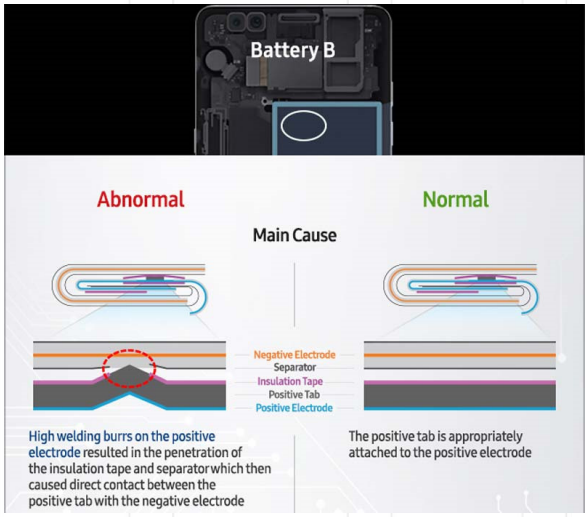
Samsung Galaxy Note 7



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