TECHNISCHE UNIVERSITÄT
KAISERSLAUTERN

0101seda010100
software engineering dependability

Safety and Reliability of Embedded Systems

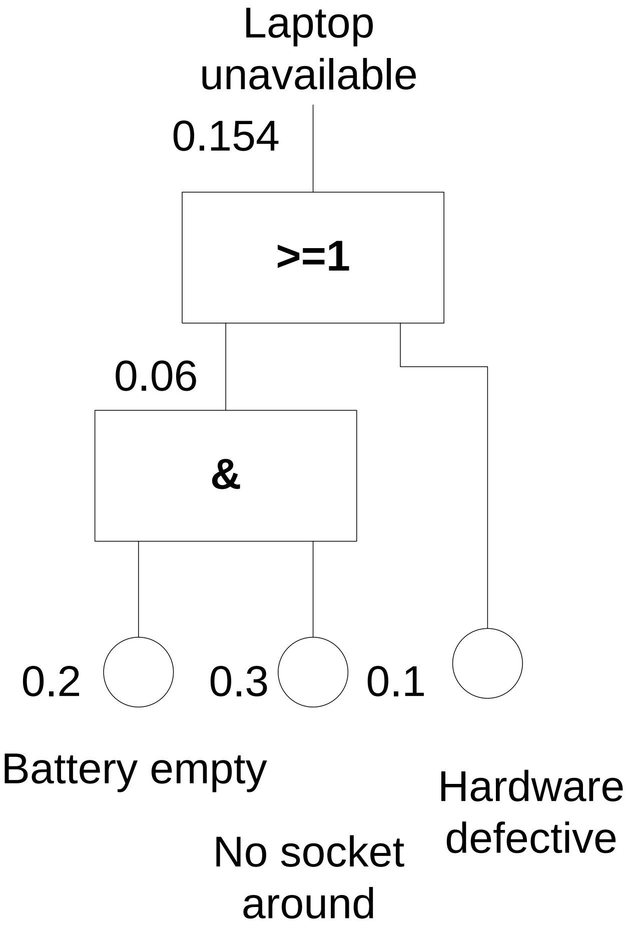
(Sicherheit und Zuverlässigkeit eingebetteter Systeme)

Foundations of Fault Tree Analysis

Content

- Fault Tree Analysis Basics
- Basic Terms
- Gates
- Other Notational Elements
- Informal Use of Fault Trees
- Qualitative Analysis
- Quantitative Analysis
- History
- Standards and Important Literature

What are Fault Trees?



- Fault trees trace back influences to a given hazard or failure
- Help to find all influences
- Graphically explain causal chains leading to the hazard
- Find event combinations that are sufficient to cause hazard (qualitative analysis)
- Calculate hazard probability from influence probabilities (quantitative analysis)

Fault Tree Analysis Basics

- Developed in 1961 by Bell Telephone Laboratories. Later modified by Boeing for computer-aided application
- Analysis method for the qualitative and quantitative evaluation of a specific failure of a system
  - Goal of the qualitative analysis is the systematic identification of all possible failure combinations which lead to a predetermined undesired event
  - Goal of the quantitative analysis is the determination of reliability parameters, e.g. failure rates w.r.t. the undesired event or unavailability of the system
- Causes for the effect can be defective system components
- FTA is applied particularly in complex systems in order to analyze safety-critical effects of failures

Fault Tree Analysis Basics

- Good fault effect model (graphical model of the failure combinations and their effects)
- System evaluation with regard to operation and safety
- Intuitive for engineers due to the familiar logical symbols
- Wide-spread usage in aerospace, nuclear, chemical, and automotive industry
- Fault tree analysis is a standardized method (DIN 25424, IEC 61025, NUREG 0492, Fault Tree Handbook with Aerospace Applications)

Basic Terms

- **Root**: **"Top-Event"** The hazard or failed state (or the accident or failure event)
- **Leaves**: **"Basic Events"** The causes that cannot or shall not be refined any further
- **Gates**: Logical connectives

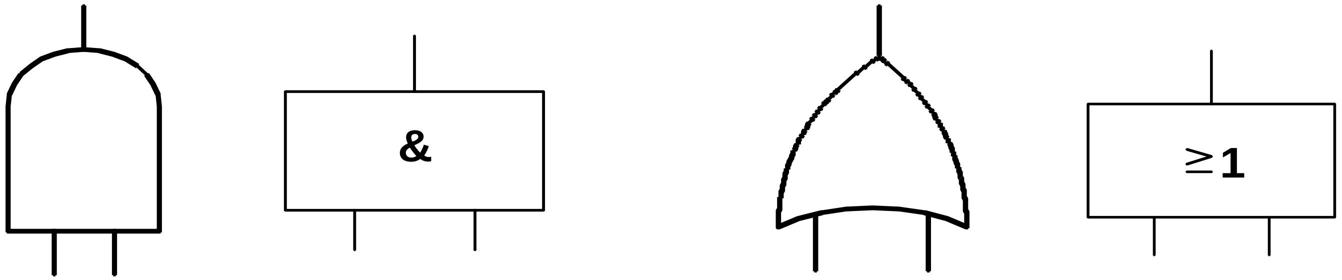
⚠ **Originally only plain Boolean logic!**

? **What about Inhibit, Sequential AND etc? Do FTs express causation?**

? **What is an event? Something happening suddenly? A state of a component? A proposition?**

☝ **In probability theory, "event" means everything that can happen with a given probability**

Gates



AND
(US Style)

AND
(European Style)

OR
(US Style)

OR
(European Style)

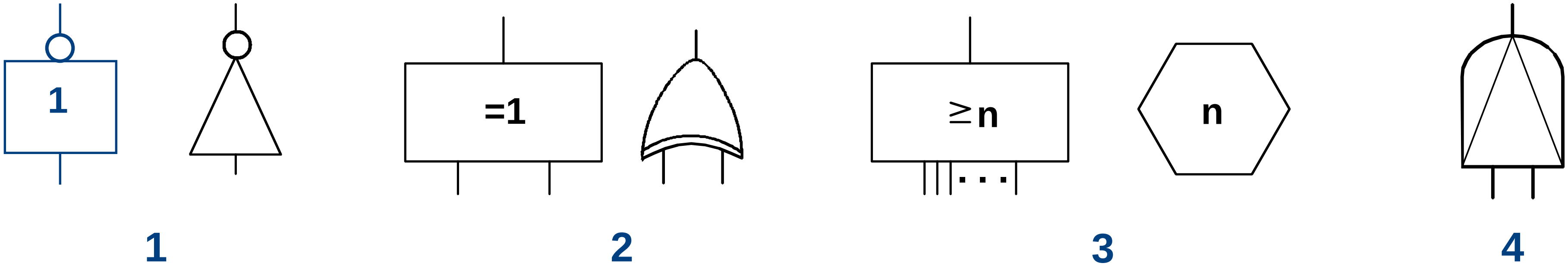
AND: All input events together are necessary to cause the output event

OR: Each one of the input events is sufficient to cause the output event

?

AND-Gate: Can events occur simultaneously?

More Gates (taken from different standards!)

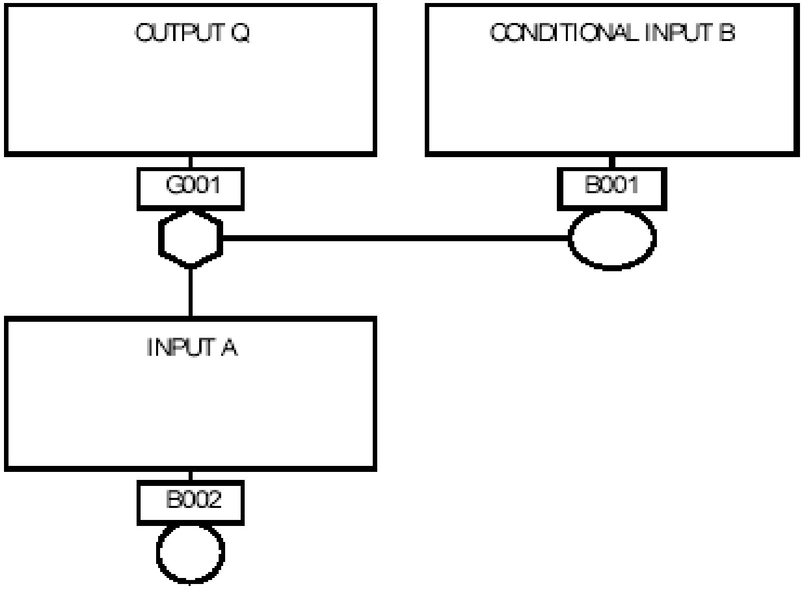


1. **NOT**: Output event is true when input event is false

   ☝ **NOT is not included in all tools**

2. **Exclusive OR (XOR)**: Output occurs when exactly one of the input events is true
3. **N-out-of-M Voter** alias **Combination Gate**: Output occurs if at least n of the m input events occur
4. **Priority AND**: Output occurs when all input events occur in the specified order

More Gates (taken from different standards!)



⚠ Note that B has condition semantics.

- **INHIBIT**: Output event occurs if all of the input events occur in the absence of an inhibiting condition
    - Additional “ingredient” that is necessary for event A to cause output Q
    - Conditional probability that Q occurs given the occurrence of A

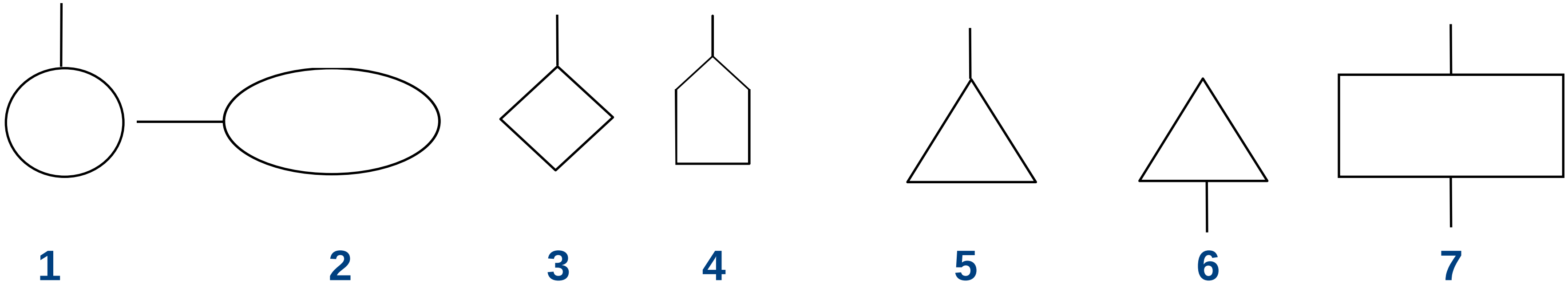
More Gates (taken from different standards!)

- Different spare gates
  - hot / cold / warm spare
  - cf. more complex "Reserveverknüpfung" ("Spare Gate") from German DIN 25424
- Functional dependency
- Sequence enforcing
- Gates modeling different kinds of secondary events

⚠

**There are (even in standards) gates
that are not intuitively clear and informally specified.
Their usage should be considered carefully.**

Other Notational Elements



1.Basic Event

2.Conditioning Event

3.Undeveloped Event / Secondary Fault (DIN 25424)

4.House Event (Event assumed to occur during operation)

5.Transfer In (Continued from another page)

6.Transfer Out (Continue on another page)

7.Comment / Intermediate Event

Informal Use of Fault Trees

- FTs are useful even without any analysis
  - Help understanding the system
  - Reveal problem areas immediately
  - Build up awareness for safety and reliability issues
- Event can be any proposition
  - E.g. “Subsystem is down for more than 5 minutes without this fact being noticed”
- If later analysis is intended, events should be chosen so that
  - they have a semantics that is clear to any person involved
  - they are self-contained and independent
  - a probability can be assigned to them

Qualitative Analysis

- Check, if the top-event is reachable
- Find minimal cut sets
  - e.g. list all cut sets with order 1 or 2
  - e.g. list all cut sets with total probability > 0.01 (requires quantitative analysis)
- Find minimal path sets

Quantitative Analysis

- Quantitative analysis produces numerical results
  - Probability or rate of top-event / of a given cut set
  - Importance of basic events / cut sets
    - How much impact has an event on the total failure probability?
    - By how much is the total failure probability influenced by changes / uncertainties regarding a particular event?

?

What means probability of an event?

History

- 1960s: Foundations
- 1961 Minute Man Launch Control System (Watson, Bell Labs)
- 1966 Computer Application (BACSIM at Boeing)
- Spreads from Aerospace to Nuclear Industry
- 1967 Apollo 1 Launch Pad Fire -> New Safety Programme including FTA
- 1970s: New algorithms, importance measures
- 1977 Three Mile Island Nuclear Power Plant Accident -> Review using FTA
- 1980s: More powerful algorithms (BDDs), much research, FTA becomes a broadly accepted standard technique
- 1986 Challenger Explosion: Review of Space Shuttle using FTA
- 1990s: Increasing PC performance makes mass market tools possible, research work regarding FTA and formal methods

Standards and Important Literature

- DIN 25424
  - Only in German
  - Explanation of minimal-cut-set-based analysis
  - Separate formulas for enduring events (states) and sudden events
- IEC 61025
- NUREG 0492 Fault Tree Handbook (Vesely et al 81)
- FT-Handbook with Aerospace Applications www.hq.nasa.gov/office/codeq/doctree/fthb.pdf

☝ **For algorithms (e.g. BDD) and other details you will probably have to refer to scientific publications**