
Safety and Reliability of Embedded Systems

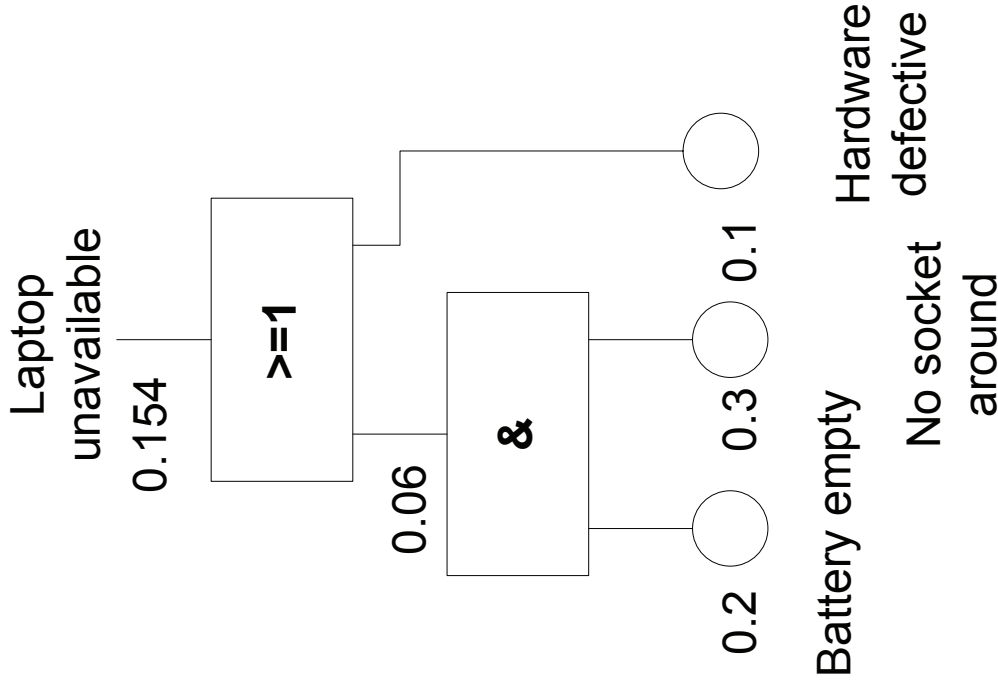
(Sicherheit und Zuverlässigkeit eingebetteter Systeme)

Foundations of Fault Tree Analysis

Content

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- ☐ Gates
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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 is an event?

What about Inhibit, Sequential AND etc?

Do FTs express causation?

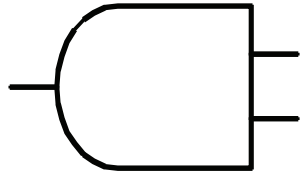
Something happening suddenly?

A state of a component?

A proposition?

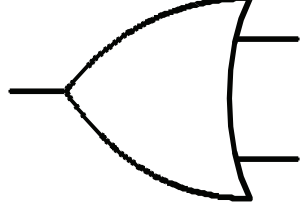
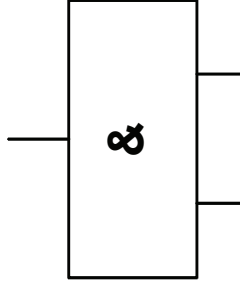
👉 In probability theory, "event" means everything that can happen with a given probability

Gates



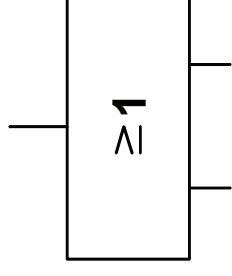
AND

(US Style) **AND** (European Style)



OR

(US Style) **OR** (European Style)



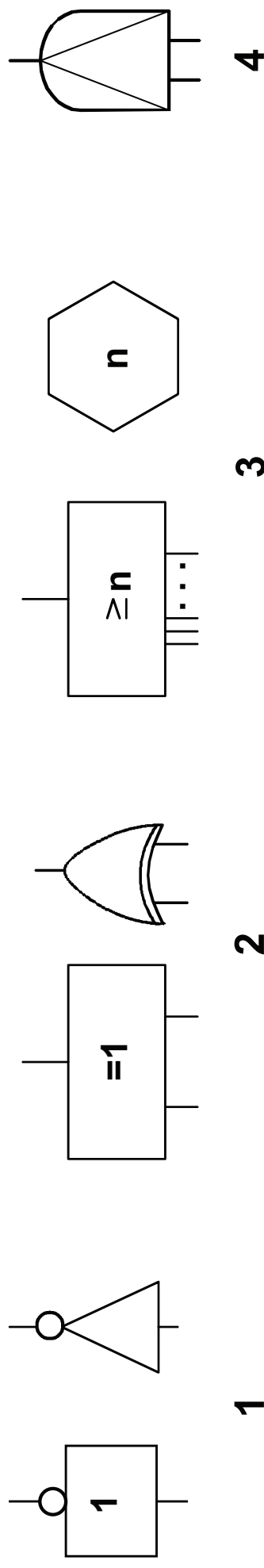
AND: All input events together are necessary to cause the output event

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

?

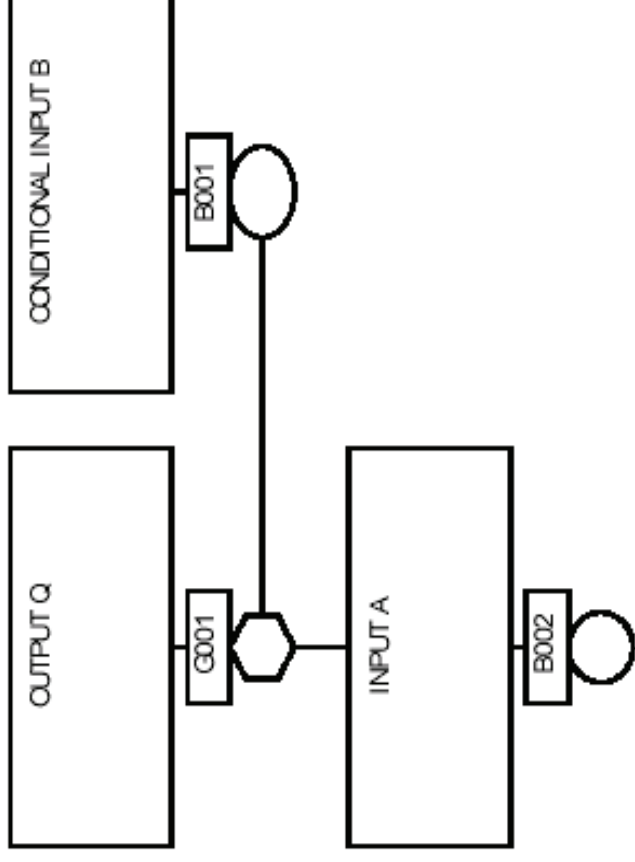
AND-Gate: Can events occur simultaneously?

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

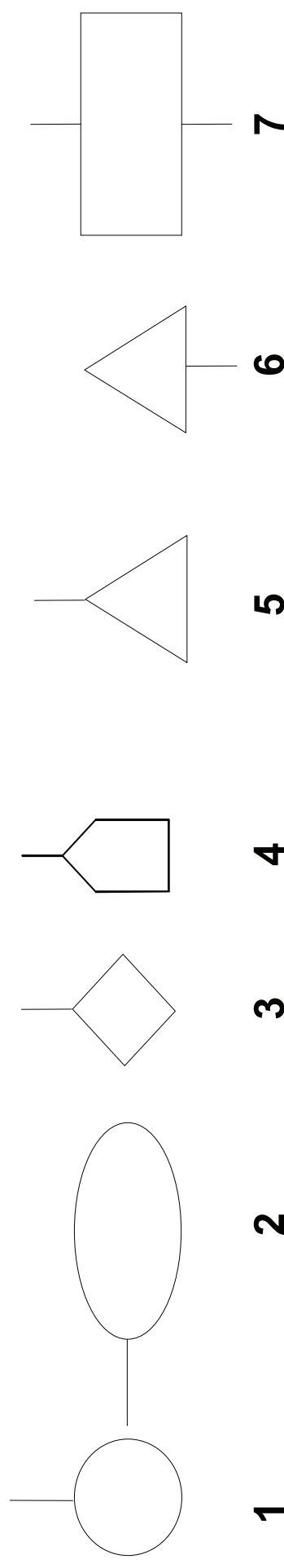
More Gates (taken from different standards!)

- ☐ 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
- ☐ 1977 Three Mile Island Nuclear Power Plant Accident -> Review using FTA
- ☐ 1970s: New algorithms, importance measures
- ☐ 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/ftfb.pdf

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