Fault Models

- Much work has been done on fault models. The discussion is based on the paper:
  - Thambidurai, P., and You-Keun Park, "Interactive Consistency with Multiple Failure Modes”, Reliable Distributed Systems, Volume, Issue, 10-12 Oct 1988 Page(s):93 - 100.
  - There is an interesting follow-up paper "Verification of Hybrid Byzantine Agreement Under Link Faults" by P. Lincoln and J. Rushby that addresses a problem in the algorithm of Thambidurai and Park

Fault Models

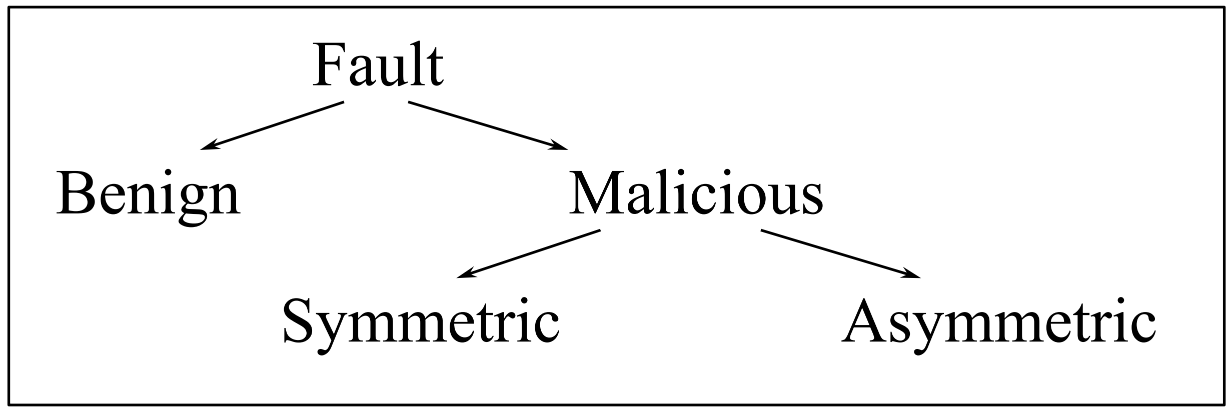
- Benign versus Malicious
  - Benign
    - error is self-evident
    - component does not undergo incorrect state transition during failure
    - examples:
      - omission fault
      - crash fault
      - timing fault
      - data out-of-bound

Fault Models

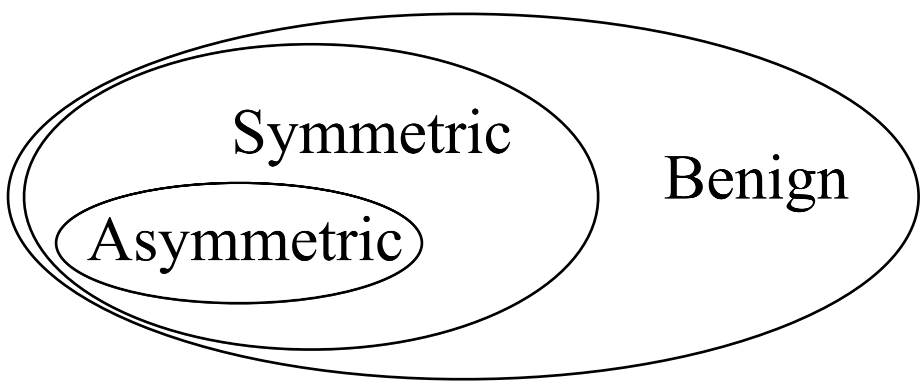
- Malicious
  - not self-evident to all non faulty receivers
  - can behave in two ways
  - symmetric
    - received identically by all processors
  - asymmetric
    - no restrictions of fault => anything goes
- Fault frequency
  - worse case every fault could behave asymmetric
  - best case all faults are benign
  - what is the best assumption for your system?

Fault Models

- Fault Taxonomy



- Relationship & Probability of Occurrence



Fault Models

- Lamport Model
  - assumes that every fault is asymmetric

$$N \geq 3t + 1$$

$$r' \geq t + 1 \quad \text{or} \quad r \geq t \ \text{ rebroadcasts}$$

- Meyer + Pradhan 87
  - differentiates between malicious and benign faults

$$N > 3m + b$$

$$r > m$$

$$m = \text{number of malicious faults}$$

$$b = \text{number of benign faults}$$

Fault Models

- Thambidurai + Park 88
  - difference between malicious faults
    - » symmetric faults
    - » asymmetric faults
    - » result:

$$N > 2a + 2s + b + r$$

$$r \geq a$$

    - » a = asym., s = sym., b = benign, r = rounds
    - » in general $a_{max} < s_{max} < b_{max}$
    - » or $\lambda_a << \lambda_s << \lambda_b$
    - » saves rounds and hardware

Fault Models

- Advantages of multi-fault model
  - 1) more accurate model of the system
    - less "overly conservative"
  - 2) resulting reliabilities are better
    - custom tailor recovery mechanisms
    - Example:
      - consider Byzantine solution using OM() algorithm
      - assume N = 4, 5, 6
      - still, only one fault is covered using the OM algorithm
      - moreover, the system reliability degrades
        - N = 6 results in worse reliability than N = 4
        - one is better off to turn the additional processors off!
    - see paper Tha88, page 98, table 1

Fault Models

Source: Tha88

Model	N	P(Failure)	Faults
BG	4	6.0×10^{-8}	1 arbitrary
BG	5	1.0×10^{-7}	1 arbitrary
BG	6	1.5×10^{-7}	1 arbitrary
UM	4	6.0×10^{-8}	1 arbitrary, $b = 0$, $s = 0$
UM	5	1.0×10^{-11}	1 arbitary, $b = 1$, $s = 0$
UM	6	2.0×10^{-11}	1 arbitary, $b = 0$, $s = 1$
UM	6	1.1×10^{-15}	1 arbitary, $b = 2$, $s = 0$

Table 1: Reliability data for Example 1

Fault Models

Source: Tha88

$r = 1$								
	$a = 0$				$a = 1$			
s	0	1	2	3	0	1	2	3
$b = 0$		4	6	8	4	6	8	10
$b = 1$	3	5	7	9	5	7	9	11
$b = 2$	4	6	8	10	6	8	10	12
$b = 3$	5	7	9	11	7	9	11	13
$b = 4$	6	8	10	12	8	10	12	14
$b = 5$	7	9	11	13	9	11	13	15
$b = 6$	8	10	12	14	10	12	14	16

Table 2: Resiliency of a System based on the Unified Model (minimum number of processors required)

Fault Models

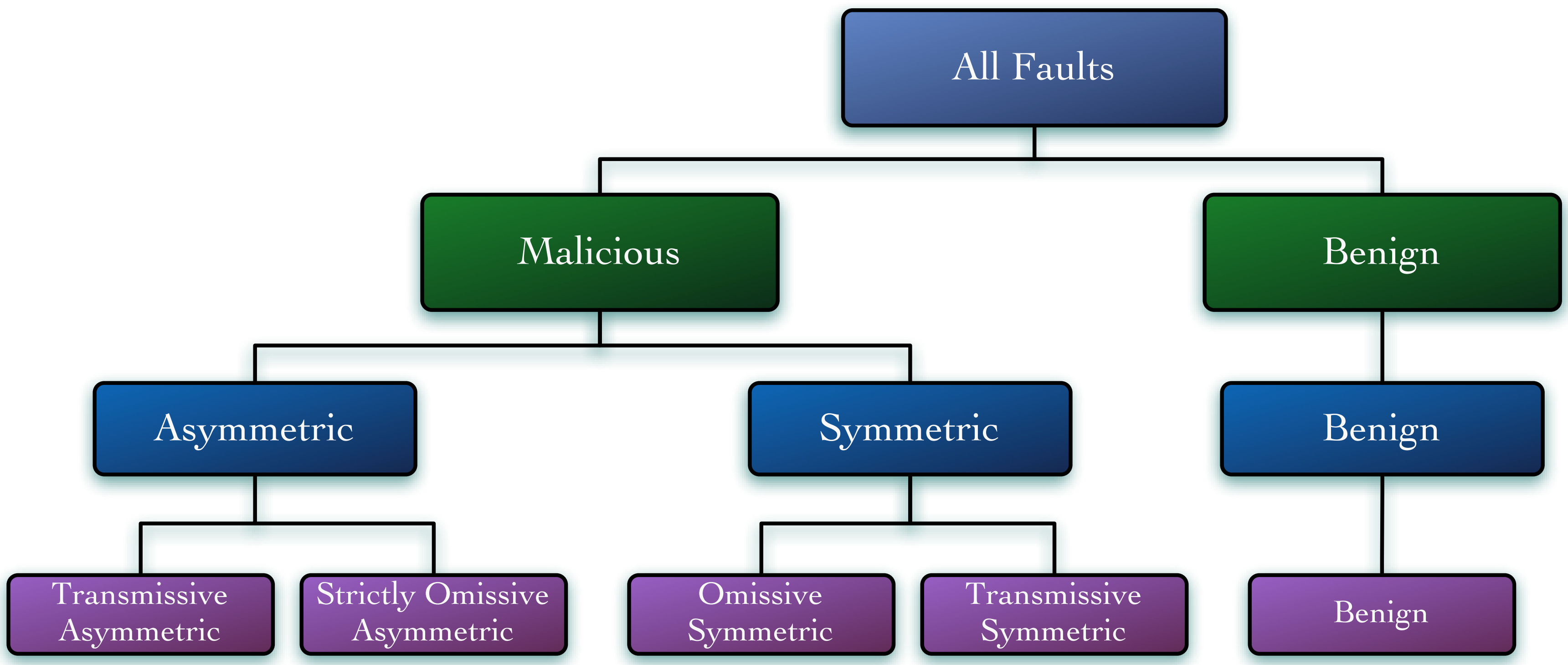
- 3) smarter degradation
  - we can specify the number of rounds
  - example using N = 11
    - let subscript <u>max</u> denote the maximum number of faults covered, assuming this is the <u>only</u> type of fault occurring.
    - if $r = 1$ then $a_{max} = 1$ or $s_{max} = 4$
    - if $r = 2$ then $a_{max} = 2$ or $s_{max} = 4$

      why? $s_{max} = 4 \Rightarrow N > 2\ 4 + 2 = 10$

      $s_{max} = 5 \Rightarrow N \not> 2\ 5 + 2 = 12$
- requirements for success
  - good estimate of fail rates λ_a , λ_s , λ_b
    - typically $\lambda_a << \lambda_s << \lambda_b$
  - good estimate of recovery rates ρ_a , ρ_s , ρ_b
    - typically $\rho_a < \rho_s < \rho_b$

Agreement algorithms

- Azadmanesh & Kieckhafer
  - partitions further into transmissive and omissive cases of malicious faults



Agreement algorithms

- Incomplete Interconnections
  - Lam82, Dol82
  - agreement only if the number of processors is less than 1/2 of the connectivity of the system's network.
- Eventual vs. Immediate Byz. Agreement (EBA,IBA)
  - recall interactive consistency conditions IC1, IC2
  - an agreement is <u>immediate</u> if in addition to IC1 and IC2 all correct processors also agree (during the round) on the round number at which they reach agreement.
  - otherwise the agreement is called <u>eventual</u>
    - each processor has decided on its value, but cannot synchronize its decision with that of the others until some later phase.
    - Thus, agreement may not always need full t+1 rounds

Agreement algorithms

Lamport OM	$N \geq 3m+1$	$r = m+1$
Lamport SM	$N \geq m+2$	$r \geq m+1$
Davis+Wakerly	$N \geq 2t+1$	$S = t+1$
Meyer+Pradhan	$N > 3m+b$	$r \geq m$
Thambidurai+Park	$N > 2a+2s+b+r$	$r \geq a$
Dol82a (EBA)	$N > t^2+3t+4$	$r = \min(f+2, t+1)$