SURVIVING ATTACKS AND INTRUSIONS: WHAT CAN WE LEARN FROM FAULT MODELS

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SURVIVABILITY

- Many Definitions
  - Qualitative
  - Quantitative
  - No single agreed upon definition

SURVIVABILITY

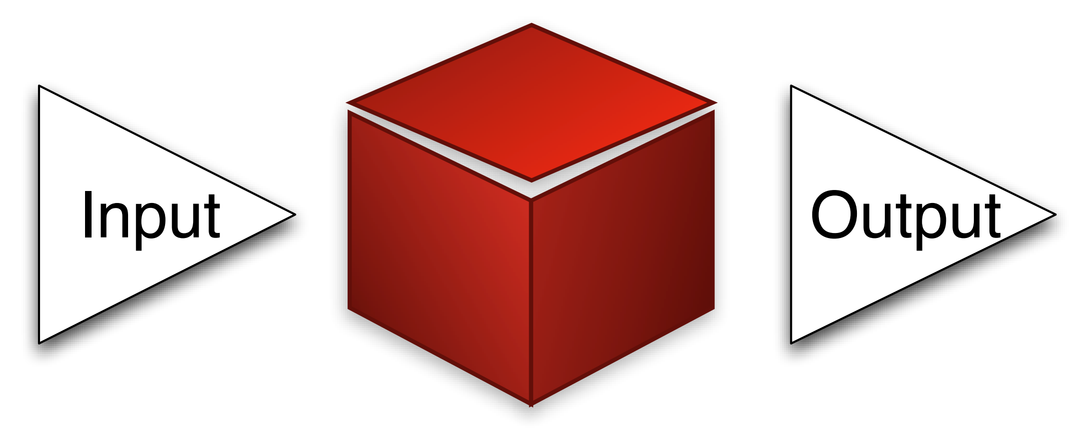
- Closely related Terms
  - Intrusion Tolerance
  - Resilience
- No subscription to specific terms or definitions: for this research survivability, intrusion tolerance, and resilience are interchangeable as their specific differences in the definitions will not really matter.
- Relationship to
  - Fault-tolerance
  - Security

HOW SURVIVABLE/RESILIENT IS MY SYSTEM?

- Lessons learned from Fault-tolerance
    - FT design: the possible and the impossible

DESIGN FOR TESTABILITY

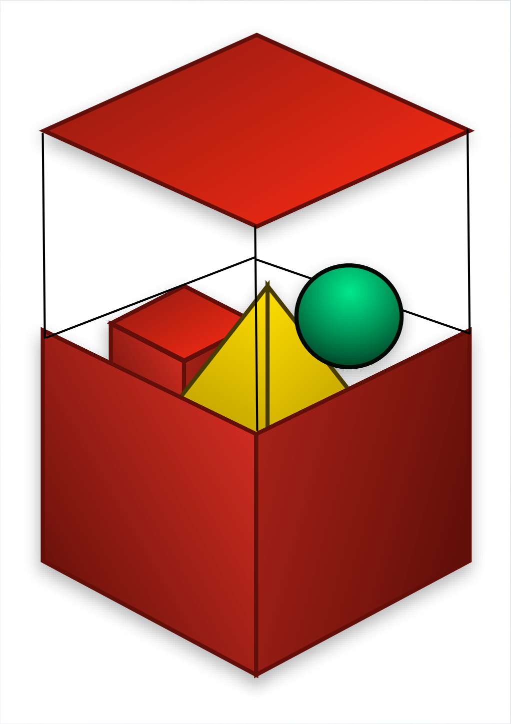
- Testing electronic circuits



- Test pattern generation problem is NP-hard
- Solution: Design for Testability
  - e.g. SCAN, partial SCAN

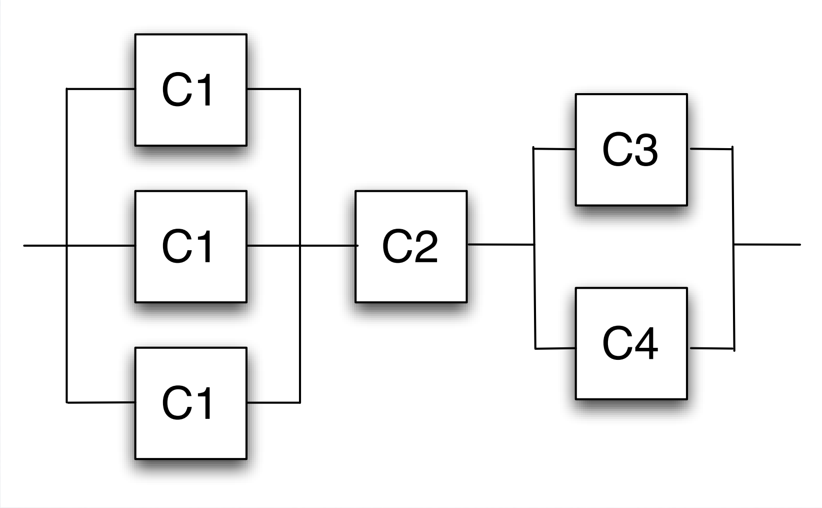
DESIGN FOR SURVIVABILITY

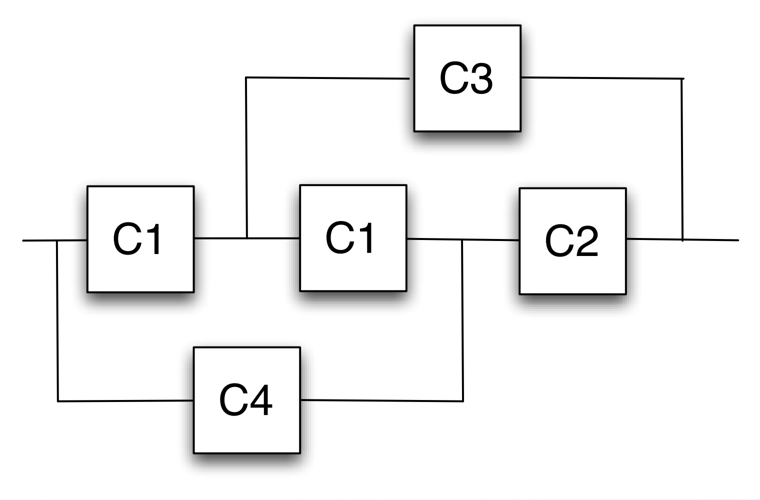
- When Systems become too complex
  - Design by Integration of Survivability mechanisms
  - Build-in *not* add-on
  - Design for Survivability has surfaced in different contexts



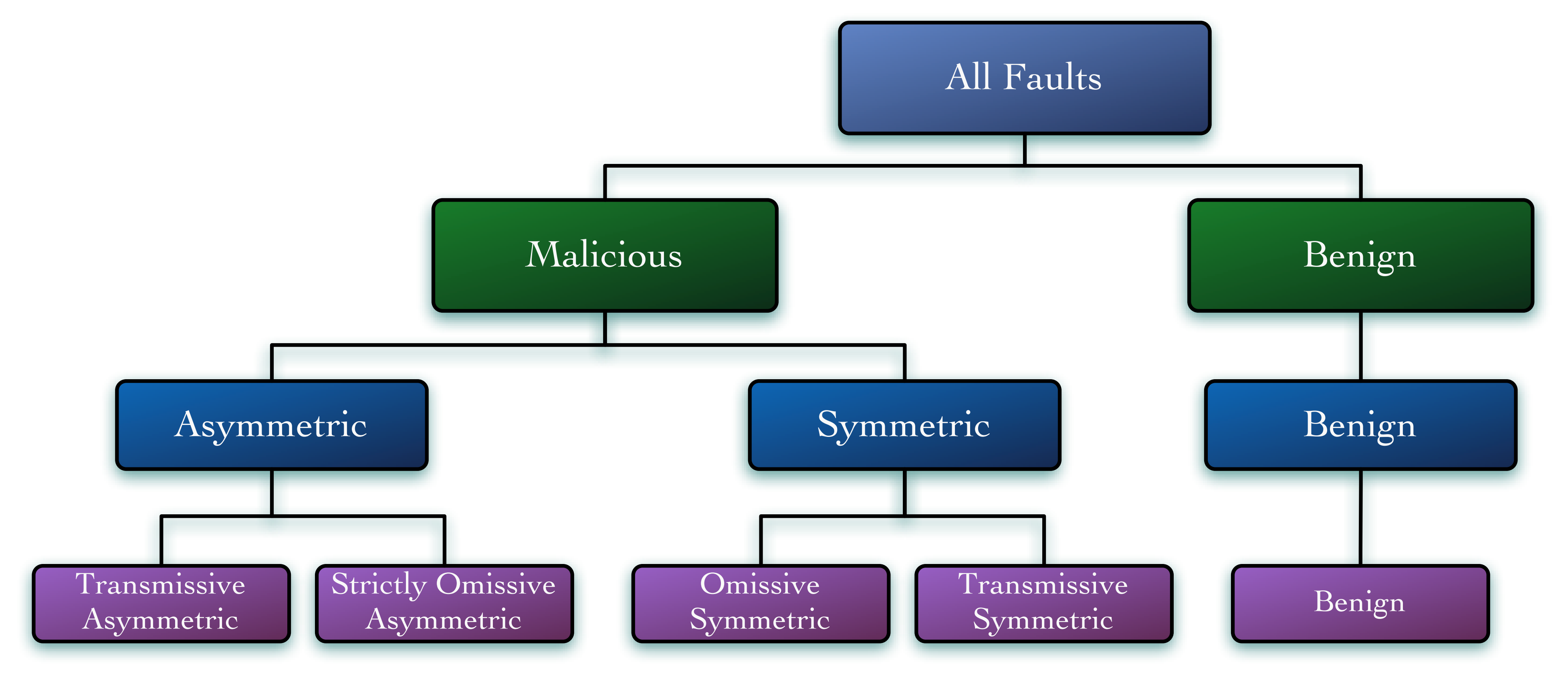
DESIGN FOR ANALYZABILITY

- Not a new concept
- e.g., Series-Parallel RBD
  - Not all systems are Series-Parallel!





FAULT MODELS PLAY CRITICAL ROLE



FAULT ASSUMPTIONS

- Do hybrid fault models apply outside of fault tolerance?
  - Many mechanisms from security & fault-tolerance exist
  - BUT in the end, their impact on the faults they can produce is what really counts

FAULT ASSUMPTIONS

- Example: authentication
  - authentication mechanism reveals fault
    - potentially benign, depends on how many nodes are affected
  - authentication is broken
    - potential for symmetric or asymmetric
- Slight departure from strict definitions of *fault* of the dependability community

SYSTEM DEFINITION

- A collection of Functionalities f_i
  - applications (software modules)
  - system components
- Fault Descriptions F_i
  - defines fault model with respect to functionality f_i
  - defines fault model that f_i is designed to tolerate

$$System = \sum_{i=1}^{k} f_i$$

$$\boxed{System = \bigcup_{i=1}^{k} fi}$$

SYSTEM DEFINITION

- Fault Descriptions F_i
  - example: communication with authentication
    - if authentication is assumed uncompromisable:
      - $F_i = (b)$
    - if authentication is assumed to be compromisable:
      - $F_i = (b,s,a)$

DYNAMIC ENVIRONMENT

- What are the impacts of
  - changes in fault assumptions
  - security feature availability (or their failure)?

- Boils down to the analysis of f_i in the context of F_i and its support infrastructure

IMPORTANT QUESTIONS:

- Given an existing system or application, what is the impact of **adjustments** in the **fault assumptions**?
- Given an existing system or application, what is the impact of **adding** or **subtracting security features**?
- What is the impact of **infrastructure changes** on performance or any of the “-ility” requirements?

SYSTEM ANALYSIS

- Quantification of survivability under assumption of
  - fault model
    - e.g. hybrid fault model
  - fault environment
    - very complex as it addresses statistical assumption about the faults themselves, e.g.
      - fail rates
      - hazard function
      - independence or dependence of faults...

MODEL ANALYSIS

- Reality however is moving towards "UUUR Events"
  - Unpredictable, latent,
  - Unobserved and
  - Unobservable Risks

MODEL ANALYSIS

- Recent introduction of 3-layer survivability analysis architecture [Ma & Krings 2008]
  - tactical, strategic, and operational level
- Key observation: fundamental definition in survival analysis is survivor function $S(t) = Pr(T>t)$, which has same definition as reliability function
  - hazard function $h(t)$ and cumulative hazard function $H(t)$ even use same terminology, besides common mathematical definitions.

SURVIVAL ANALYSIS

- Advantages of survival analysis:

1) more flexible, time-variant or covariates-dependent hazard functions
2) built-in procedures to deal with censored events
3) multivariate failure beyond binary failure
4) more effective modeling for dependent failure events though competing risks and shared frailty modeling

- Our focus is on the hazard functions in 1)

CONSTANT HAZARD FUNCTION

- Simplest model: constant fail rate
  - Failures follow exponential distribution
  - Hazard function $h(t) = \lambda$
    - used in traditional reliability model (with constant fail rate) is not generally suitable

$$R(t) \;=\; e^{-\lambda t}$$

    - strength
    - weakness
    - applications: RBD, FT, Markov Chain, Petri Net

COX PROP. HAZARDS MODEL

- “Fundamental Model of Survival Analysis”
- Hazard Function is a function of time *t* and covariate vector *z*:

$$\lambda(t, z) = \lambda_0(t)e^{Z\beta}$$

- Extensions of PHM: time-dependent covariates
  - unstratified PHM $\lambda[t; z(t)] = \lambda_0(t)e^{Z(t)\beta}$
  - stratified PHM $\lambda_j[t; z(t)] = \lambda_{0j}(t)e^{Z(t)\beta}, \quad j = 1, 2, ..., q$

MODEL AND STATE CHANGES

- Different functionalities can have different fault descriptions
- Different functionalities can utilize different hazard functions
- Each functionality may change its fault description and/or hazard function in time

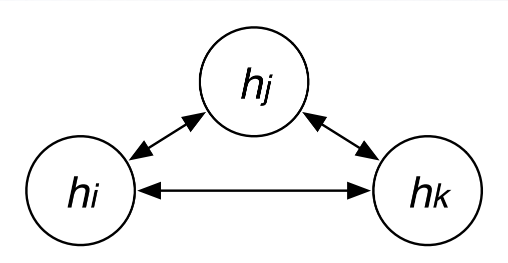


Figure 1. Thread Model State Machine

ADAPTATION

- Integral feature in any design for survivability
- Adaptation addresses
  - dynamics of changing Fault Descriptions F_i
  - different definitions of fault descriptions (active, imposed)

ADAPTATION

- Adaptation may be the result of diverse scenarios
  - The **fault description is no longer valid** due to specific event

    e.g. intelligence suggests that authentication is broken

  - The **fault description of functionality should be strengthened** by design

    e.g. f_i is identified as weakest link

  - **Infrastructure** that f_i depends on **has changed**

    e.g. may not support tolerance to certain fault types anymore

FAULT MODEL ADAPTATION

- **Active** Fault Description: F_i
  - **fault model that system (functionality) currently subscribes to**, i.e.,
    - **the faults that f_i assumes to be able to tolerate or deal with**
  - for f_i fault description F_i represents the active fault description
  - F_i is determined by system designer (designer of f_i)

FAULT MODEL ADAPTATION

- **Imposed** Fault Description: $\hat{F}_i$
  - the **fault model the infrastructure of system imposes on *fᵢ***
  - encompasses those **fault types the system** (or application) **has to explicitly deal with by distinct mechanisms**
  - Example $\hat{F}_i = (b, s)$
    - for given infrastructure benign and symmetric faults are possible and theoretically unavoidable
    - note that no asymmetric faults are listed (there is no "a")
    - infrastructure is assumed to be capable of theoretically eliminating this fault type, e.g., broadcast network

EXAMPLE TCP/IP

- 1) Assume TCP/IP provides reliable transmission
  - W.r.t. infrastructure this leads to $\hat{F}_i = (s, a)$
    - there are no benign (omission) faults
    - value fault (s and a) cannot be resolved without explicit mechanisms
- 2) Now assume that TCP times out
  - Leads to $F_i = (b, s, a)$
    - benign fault was added

EXAMPLE

- Interesting case: authentication is compromised
  - introduced value faults (s,a)
  - explicit mechanisms need to be added
  - symmetric: $N > 2s$
  - asymmetric: $N > 3a$
    - not only requires higher degree of redundancy
    - but agreement algorithm

EXAMPLE

- Authentication example cont.
- System designer choices:
  - live with the risk of authentication compromises
  - pay the cost of module and message overhead
- But how high is that cost?
  - depends on desired *s* and *a*
  - in addition: common mode fault need to be addressed

DESIGN CHANGES

- Imposed fault description gives insight about what infrastructure cannot inherently deal with
  - allows for adaptation
- Authentication example
  - assume authentication may be compromised:

$$F_i = \hat{F}_i = (b, s, a)$$

asymmetric faults are a problem! ⚠

  - changing to broadcast protocol we can avoid asymmetrics

$$\hat{F}_i = (b, s)$$

ADAPTIVE POLICIES

- Select the lowest overhead solution possible under a given threat level
- Similar to the “shifting gear” approaches used in agreement algorithms

INFRASTRUCTURE CHANGES

- What happens if infrastructure used by f_i change?
  - Any changes to the imposed fault description?
  - Carefully analyze the implication of the changes
    - can be good or bad news
    - misjudging fault descriptions may render application non-survivable!

CONCLUSIONS

- System Definition
  - functionalities, active/imposed fault models
- System Analysis
  - Model Analysis (include UUUR)
  - Resilience based on active and imposed fault descriptions
  - Adaptation (functionalities and fault models)
    - different fault description
    - different hazard functions
    - dynamic fault descriptions and/or hazard functions