Chapter 1: Safety-Critical Computer System Design and Evaluation

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EECE 692 System Safety

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1.1 The Safety-Critical Computer System

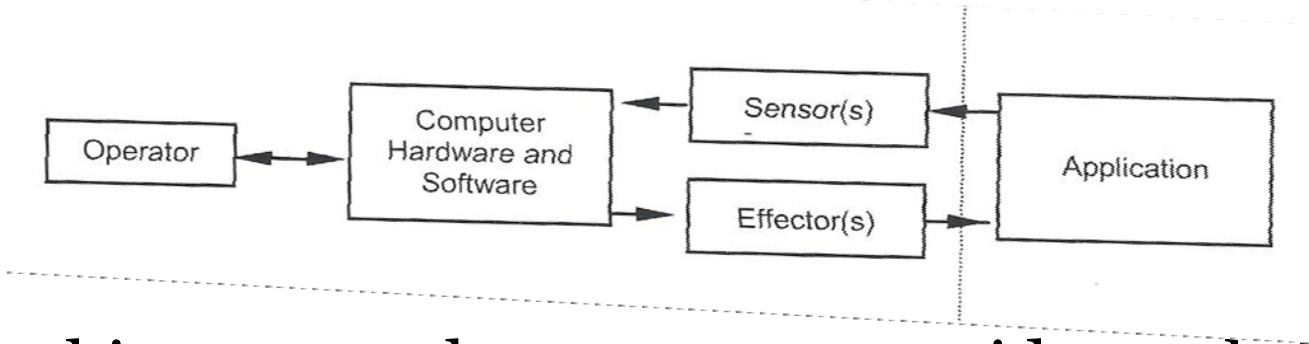
- "Safety-Critical" applies to wide family of applications

- Failure can lead to:
  - Injury
  - Death
  - Property/Environmental Damage

1.1 The Safety-Critical Computer System

- Reasons for Broad Applications:
  - Global Perspective
    - Most safety-related systems don't fall into high-visibility category
  - **Combined losses of these systems far exceed those that command widespread public attention
    - In terms of total human suffering and loss of property)

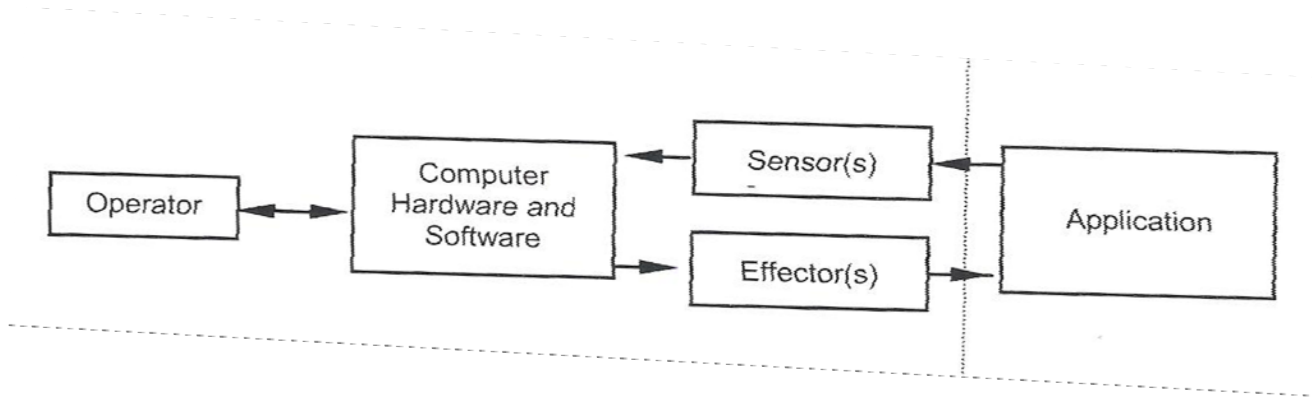
1.1 The Safety-Critical Computer System: The Computer System



- In this system, the computer provides real-time control/monitoring of an application
  - Chemical process
  - Aircraft in flight
  - Automobile anti-skid brake
  - Artificial heart
  - Production assembly line

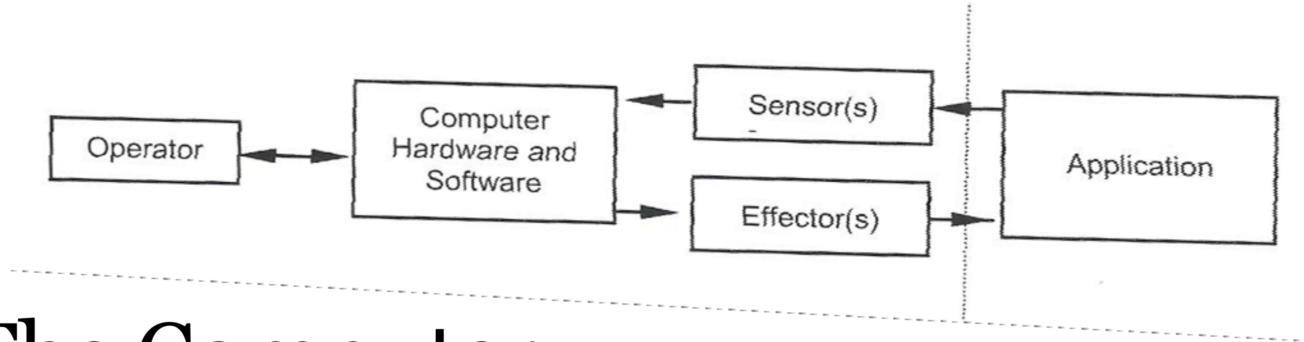
- Application also referred to as "plant" or "process"

1.1 The Computer System, cont'd



- Sensors (Field Instruments)
  - Let computer know what is happening in application
- Effectors (Actuators/Final Elements)
  - Allow computer to control physical parameters in application based on sensed information

1.1 The Computer System, cont'd



- The Computer
  - Single-chip microcontroller
  - Custom microprocessor-based controller
  - PLC (Programmable logic controller)
  - DCS (Distributed control system)
  - Airborne flight computer
  - PC-based controller
  - Other programmable electronic systems
- The Operator

1.1 The Computer System: Two Basic System Types

- Computer Control Systems
  - Operator, computer, sensor, effectors are employed to actively control the application
    - Continuous monitoring, continuously issuing controls

- Computer Safety Systems
  - Same components but used to passively monitor the application
    - Continuous monitoring, controls issued when dangerous state is sensed

1.2 Safety-Critical Computer System Design - Overview

- Partitioning the Design Problem:
  - Functional/Operational requirements not directly safety-related
  - Safety-related requirement
    - System does not fail and produce an unsafe condition

1.2 Safety-Critical Computer System Design: Example

- Industrial Gas Furnace
  - First (non-safety) Requirement?
    - Automatically control gas flow to maintain temperature
  - Second (safety-related) Requirement?
    - System shouldn’t fail
    - Should not produce an over-temperature condition

1.2 Safety-Critical Computer System Design: Safety Requirements

- System Safety
  - Employs distinct set of engineering/management principles, criteria, techniques
  - Help define safety requirements
  - Show how the design process should be structured to realize safe system

- Key Elements
  - Addresses the system life cycle
  - Requires a distinct management effort
  - Is a multidisciplinary effort
  - Is built around safety standards

1.2 Safety-Critical Computer System Design: Safety Requirements

- System Life Cycle
  - All phases of system's life
    - Design
    - Research
    - Development
    - Test and Evaluation
    - Production
    - Deployment (inventory)
    - Operations and Support
    - Disposal

1.2 Safety-Critical Computer System Design: Safety Requirements

- System Safety Management
  - System may change hands (management) many times
    - Normal Employee Turnover
  - Effective Management Will Include
    - Design and documentation standards and practices
    - System configuration management
    - Tracking system for verifying safety issues raised are resolved

1.2 Safety-Critical Computer System Design: Safety Requirements

- Multidisciplinary Effort
  - Systems are made safe through efforts of all responsible: involved in creation, operation, maintenance, and retirement from service
  - Includes
    - HW/SW design engineers
    - Test engineers
    - Reliability and risk analysts
    - Operating Engineers
    - Maintenance Engineers/Technicians
    - Managers

1.2 Safety-Critical Computer System Design: Safety Requirements

- System Safety
  - Governed by Safety Standards
    - Public Law/Government Regulations
    - Documents produced through work by industry committees, professional societies, safety0related institutions
  - Two Important/Common Standards
    - MIL-STD-882D (Military Standard)
    - IEC 61508 (Commercial Standard)

1.2 Safety-Critical Computer System Design: Safety Requirements

- MIL-STD-882D
  - "Standard Practice for System Safety"
  - Issued by DoD in February 2000
  - Presents basic requirements that apply to computer control systems and computer safety systems
  - Contains both *requirements* and *guidance* to aid user in applying standard
  - *Over 300 pages?*

1.2 Safety-Critical Computer System Design: Safety Requirements

- IEC 61508
  - “Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems”
  - Approved by International Electrotechnical Commission (IEC) in 2000
  - Several hundred pages
  - Addresses safety-critical computer control systems and computer safety systems
  - Chapter 6…

1.2 Safety-Critical Computer System Design: Mishaps and Mishap Risk

- Mishap
  - An unplanned event or series of events resulting in death, injury, occupational illness, damage to or loss of equipment or property, or damage to environment (MIL-STD-882D)
    - Airliner crash
    - Nuclear meltdown
    - Refinery fire
    - Toxic gas release
    - Natural gas explosion

1.2 Safety-Critical Computer System Design: Mishaps and Mishap Risk

- Mishap Risk
  - An expression of the impact and possibility of a mishap in terms of potential mishap severity and probability of occurrence (MIL-STD-882D)
    - Possibility of automobile accident
      - Think about not only severity, but also likelihood that the severity could happen

1.2 Safety-Critical Computer System Design: Mishaps and Mishap Risk

- Acceptable Risk?
  - MIL-STD-882D has Four Categories:
    - Negligible
    - Marginal
    - Critical
    - Catastrophic
  - Each level assigned based on degree of
    - Human suffering
    - Amount of dollar loss
    - Extent of damage to the environment

1.2 Safety-Critical Computer System Design: Mishaps and Mishap Risk

- Acceptable Risk for IEC 61508?

Safety Integrity Level	Consequence of Safety-Related System Failure
1	Minor property and production protection.
2	Minor property and production protection. Possible employee injury.
3	Employee and community protection.
4	Catastrophic community impact.

- Safety Integrity
  - The probability of a system satisfactorily performing safety functions under all stated conditions within stated period of time

1.3 The Design Process: Hazards

- Hazard
  - Any real or potential condition that can cause
    - Injury, illness, death to personnel
    - Damage to/loss of system, equipment, or property
    - Damage to environment
  - Examples
    - Loss of flight control
    - Loss of nuclear reactor cooling
    - Use of flammable substances
    - Presence of toxic gases in populated environment
    - Presence of natural gas

1.3 The Design Process: Safety-Critical Computer System Design Approach

- Safety-Critical Approach
  - Identify hazards and mitigate them so acceptable level of mishap risk is achieved
- Design Steps
  - System definition
  - Hazard identification and analysis
  - Mishap risk mitigation
  - Mishap risk assessment and acceptance

1.3 The Design Process: Hazard Identification and Analysis

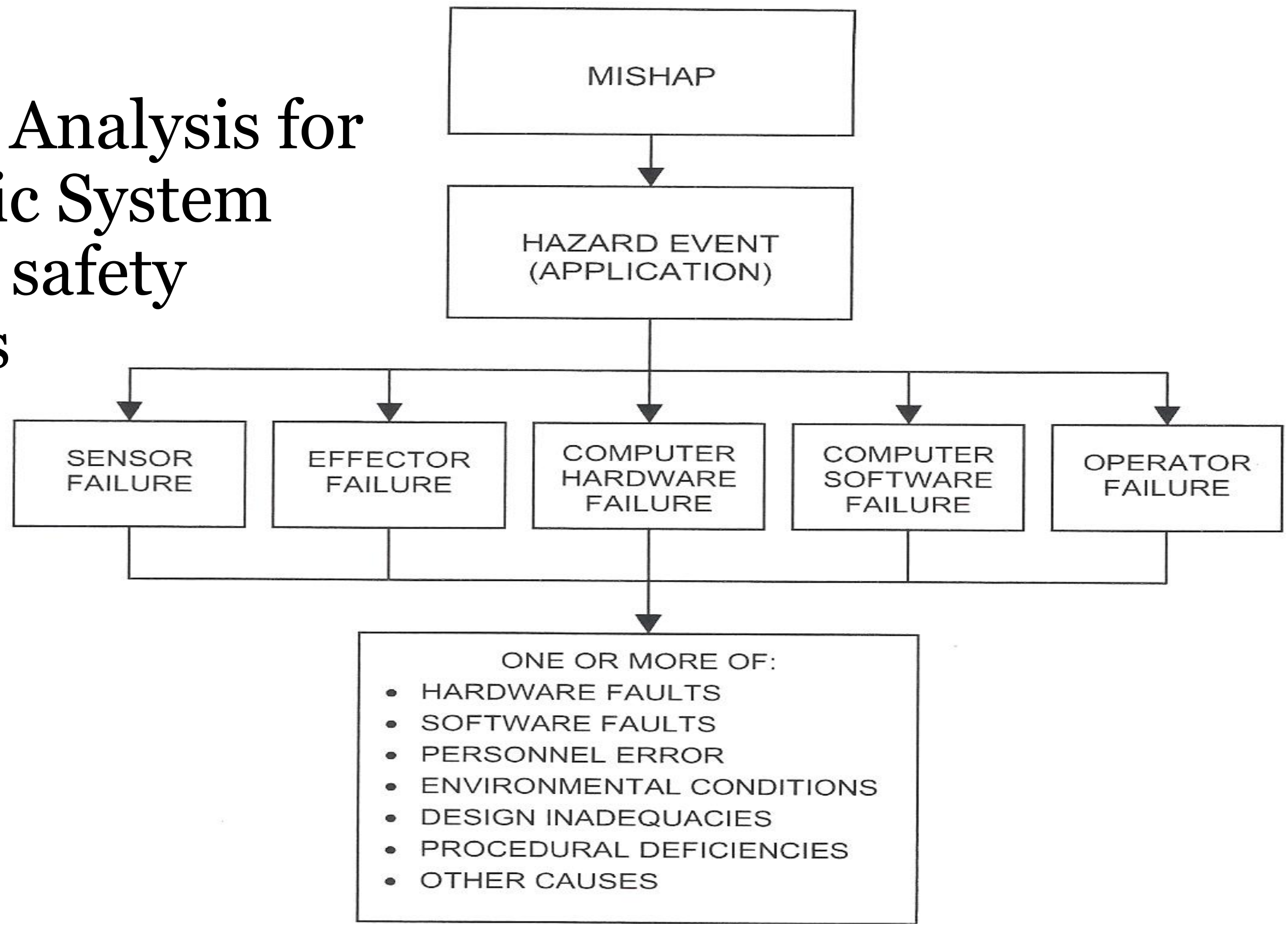
- After system is defined, identify hazards
  - Based on systematic examination of sources of energy and toxicity in application
    - (formal process beyond the scope of this book)
- Once identified, causes must be determined before design proceeds
  - Fault Tree Analysis (Chpt. 5)
  - Failure Modes and Effects Analysis (Chpt. 5)

1.3 The Design Process: Hazard Identification and Analysis

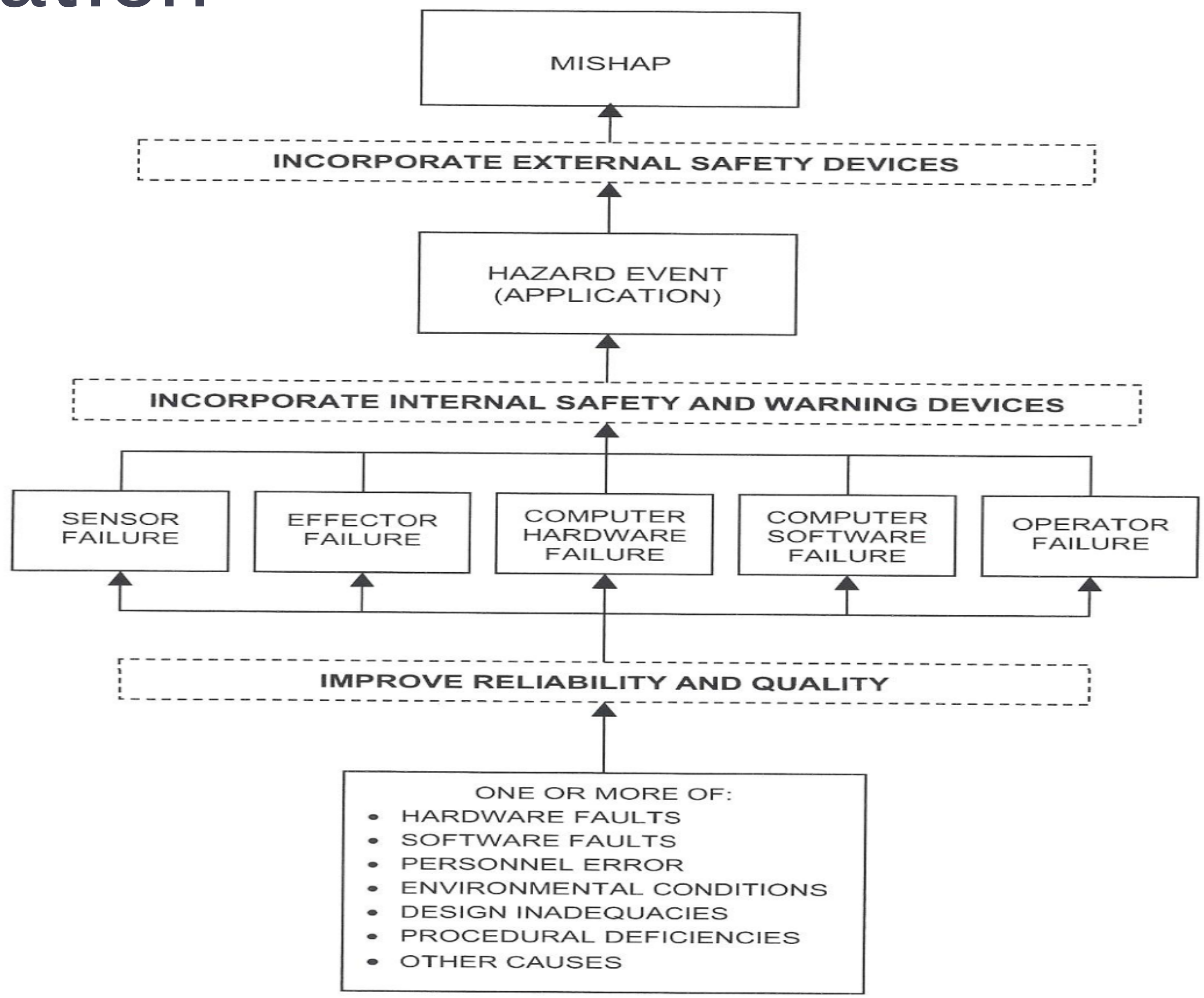
- Failure vs Fault
  - Failure: does not perform a duty or expected action
  - Fault: a defect
- Example: Effector Failure
  - System employs computer-actuated safety valve that closes if computer senses a hazardous event
  - Event occurs, computer senses and signals valve
  - Valve may experience *failure* (may not close) due to *fault* of worn bearing (hardware fault), missing spring (personnel error), or excessive ambient temperature (environmental condition)

1.3 The Design Process: Hazard Identification and Analysis

- Mishap Analysis for the Basic System with no safety features



1.3 The Design Process: Mishap Risk Mitigation



1.3 The Design Process: Mishap Risk Mitigation

- Incorporate Internal/External Safety Devices
  - Internal: placed within the computer system
    - Software patches, additional sensors
  - External: placed outside computer system
    - Change of location, personnel, management

- Layers of Protection
  - Distribute effort across all three risk mitigation measures in balanced manner
    - Produces minimum mishap risk

Review

- 1.1 The Safety-Critical Computer System
- 1.2 Safety-Critical Computer Design
- 1.3 The Design Process