

# Software Reliability and Safety

## CSE 8317 — Fall 2008

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### **SSE.1: SSE Basics and SSP**

- Motivation and Concepts
- Defining Embedded Systems
- Software Safety Program (SSP)

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## Software Safety Engineering

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- SSE.1: SSE basics and SSP
  - ▷ SSE basics: “Safeware” Parts I-III
  - ▷ SSP (software safety program)
    - “Safeware”, Part IV (Ch.11-18)
  
- SSE.2: Hazard analysis and resolution
  - ▷ Focus: accidents and pre-conditions (hazards), not other failures
  - ▷ “Safeware” Ch.13-16 & SQE Ch.16.4
  - ▷ Identification and analysis
  - ▷ Resolution: elimination/reduction/control
  
- Formal verification related:
  - ▷ Main part: SSE.3, SQE Ch.15.
  - ▷ PSC: SSE.4, SQE Ch.16.5

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## Safety: Why?

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- Risk in modern society:
  - ▷ Serious accidents:
    - “Safeware” Appendix A-D
    - medical/aerospace/chemical/nuclear/etc.
  - ▷ IEEE Computer 4/2006: Clinical Sw
  - ▷ Techniques for reducing risks
  
- Risk factors in industrialized society:
  - ▷ new technology  $\Rightarrow$  new hazard
  - ▷ increasing complexity
  - ▷ interdependency  $\Rightarrow$  exposure  $\uparrow$
  - ▷ increasing amount of energy
  - ▷ automation  $\uparrow$  of manual operations
  - ▷ increasing centralization and scale
  - ▷ increasing pace of tech. change

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## Computers and Risk

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- Computer in safety-critical systems
  - ▷ controller/control subsystem:
    - application-specific computer
    - general-purpose computer
  - ▷ functionality and flexibility
  - ▷ fact of life
  - ▷ critical functions (later)
  
- Software safety: difficulties
  - ▷ continuous vs. discrete states
  - ▷ the “curse of flexibility”
    - “Safeware” Fig.2.4 (p.35)
  - ▷ complexity and invisible interface
  - ▷ lack of historical usage information
  - ▷ pure SE approach inadequate ⇒ SSE

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## SSE: Pure SE?

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- Pure SE (S/w Eng.) approach
  - ▷ Safety constraints  $\Rightarrow$  requirements
  - ▷ Carried/verified in development stages
  - ▷ Fig. 18.1 (a)
  - ▷ Basis: myths below.
- Software myths (“Safeware” Ch.2.2):
  - ▷ lower cost than other devices
  - ▷ software is easy to change
  - ▷ computers provide greater reliability
  - ▷ software reliability  $\uparrow \Rightarrow$  safety  $\uparrow$
  - ▷ testing/formal-veri. eliminate defects
  - ▷ reusing software  $\Rightarrow$  safety  $\uparrow$
  - ▷ computers reduce risk over mechanical systems

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## SSE: Problems and Solutions

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- Assumptions and problems
  - ▷ Level of quality (LoQ) required
  - ▷ LoQ provided by existing practice (SRE?)
  - ▷ Fault-tolerant techniques
    - particularly NVP, intrinsic problems
    - LoQ still not enough
  - ▷ Formal verification
    - LoQ/rare-events/scalability problems
  
- Problems and solutions:
  - ▷ Scalability and coverage
  - ▷ Correctness of *everything*
  - ▷ Not focus on safety-related artifacts
  - ⇒ SSE, particularly Leveson's SSP

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## Basic Definitions

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- Accident or mishap:
  - ▷ unplanned (series of) events
  - ▷ leading to unacceptable loss
    - death, injury, illness
    - equip./property/environment damage
  - ▷ excess energy/dangerous substance
  - ▷ computers relatively safe
  - ▷ but computer control  $\Rightarrow$  accidents
  
- Hazard:
  - ▷ a set of conditions leading to accidents under certain environmental conditions
  - ▷ e.g.: guard gates at rail-crossing
  - ▷ safety focus: control factors (vs. env. factors beyond control)
  - ▷ analysis and resolution  $\Rightarrow$  SSE

## Basic Definitions

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- Risk: function of 3 elements
  - ▷ likelihood(hazard)
  - ▷ likelihood(hazard  $\Rightarrow$  accident)
  - ▷ worst possible loss due to accident  
(compare to expected loss)
  
- (System) safety engineering:
  - ▷ ensuring acceptable risk
  - ▷ scientific/management/engineering
  - ▷ reducing risk factors
  - ▷ context for software safety
  - ▷ hazard identification, assessment,  
analysis, and resolution



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## Safety and Embedded Systems

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- *Safety*: The property of being accident-free for (embedded) software systems.
  - ▷ Accident: failures with severe consequences
  - ▷ Hazard: condition for accident
  - ▷ Special case of reliability
  - ▷ Specialized techniques
  - ▷ Focus on prevention and tolerance
  
- Embedded systems
  - ▷ Failure and consequences
  - ▷ Interaction among sub-systems
  - ▷ Safety: software vs. system

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## System/Software Definitions

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- System (general vs embedded):
  - ▷ Physical systems or processes
  - ▷ A set of components
  - ▷ Common purposes/objectives
  - ▷ Description: input/output/time
  - ▷ Self-regulating vs. controlled
  
- Controller/Control subsystem:
  - ▷ Providing control to system
    - order events
    - regulate variable values
  - ▷ Help achieve overall objectives
  - ▷ Example control systems
  - ▷ Use of computers in control

## System Definitions: Control Function

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- Function (mathematical?) to be achieved
  - ▷ input, output and time
  - ▷ dynamic (differential) equation(s)
  - ▷ state variables and matrices
  - ▷ traditional vs. modern analysis
  - ▷ use of computers for system analysis
  
- Traditional analyses
  - ▷ single input, single output
  - ▷ transformations: Fourier & Laplace
  - ▷ stability criteria
  - ▷ performance and other analysis
  - ▷ pre-requisite for safety

## System Definitions: Control Function

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- Modern control system analyses
  - ▷ state variables and set of equations
  - ▷ controllability & observability
  - ▷ other concerns:
    - optimality, robustness, adaptability, etc.
  - ▷ computer controller
  - ▷ continuous vs. discrete system
  - ▷ Z-transformation for discrete systems
  
- Example control systems
  - ▷ traditional feedback control
  - ▷ state variable based
  - ▷ sampling and discrete systems
  - ▷ computer control (examples later)

## Analysis and Constraints

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- Previous analyses unconstrained (provide necessary but not sufficient condition for safety)
  
- Constraints on operating conditions
  - ▷ quality considerations
    - effect of defects in system
    - performance and other measures
  - ▷ equipment capacity
    - time and/or energy constraints
    - volume, rate, etc.
  - ▷ process characteristics
    - above factors fit into process
    - given vs. adjustable aspects
  - ▷ safety constraints (next)  
(derived from analysis of above)

## System Definitions: Safety Constraints

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- Safety constraints:
  - ▷ Derived from safety process
    - particularly hazard id. FTA & ETA
  - ▷ Example: pressure threshold
  - ▷ Integration to other functions?
  - ▷ Discrete vs. continuous functions
  
- Handling of safety constraints:
  - ▷ Constrained optimization
    - feasibility and practicality problems
  - ▷ Usually handled separately:
    - different/conflicting concerns
    - different characteristics
    - feasibility of functional representation?
    - liability and regulatory concern

## System Definitions: Software Safety

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- Software functions in control systems:
  - ▷ data logging
  - ▷ control function implementation
    - direct digital control (via actuators)
    - supervisory control (values/parameters)
  - ▷ maintenance of safety conditions
  - ▷ example: nuclear plant
  
- Relating safety constraints to software:
  - ▷ data logging: no direct impact
  - ▷ other two: possible safety problems
  - ▷ subsequence analysis

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## Software Safety Program (SSP)

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- Leveson's approach
  - ▷ Limited goals
  - ▷ Safety analysis and hazard resolution
  - ▷ Safety verification: Fig. 18.1 (c)
    - few things carried over (dotted line)
  - ▷ Part IV, "Safeware"
    - particularly Chapters 15-18.
  
- Software safety program (SSP)
  - ▷ Formal verification/inspection based
  - ▷ But restricted to safety risks
  - ▷ Based on hazard analyses results



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## SSP in Software Lifecycle

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- Major activities
  - ▷ Hazard identification and analysis
  - ▷ Hazard resolution (design for safety)
  - ▷ Safety verification
  - ▷ Change analysis and operational feedback
  - ▷ Fit in s/w process; Fig. 13.2 (p.293)
  
- Safety constraints and verification
  - ▷ Identify problems early
  - ▷ Carry over as design/code constraints
  - ▷ Distributed verification effort
  - ▷ Cascading:
    - using safety/design/code constraints
    - represented as formal specs
    - verifying req./HLD/LLD/code

## SSP in Software Lifecycle

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- SSP in early (concept formation) phase:
  - ▷ Initial risk assessment: identify
    - critical areas/hazards/design criteria
  - ▷ Preliminary hazard list
  - ▷ Audit trail: tracking/evaluating
  - ▷ Hazard analysis of previous accidents
  
- SSP in requirement stage
  - ▷ SRS (s/w req. specifications)
  - ▷ SRS consistent/satisfy safety constraints
  - ▷ Conflicts and tradeoffs?
  - ▷ SRS in a formal language
    - able to handle timing and failure

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## SSP in Software Lifecycle

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- SSP in High-Level Design (HLD)
  - ▷ Identify safety-critical items
    - based on FTA and ETA
  - ▷ Design for safety: key!
    - isolation/encapsulation
    - protection and security, etc.
  - ▷ Use of safety invariants for modules
  - ▷ Link to pre/post safety verifications
  
- SSP in Low-Level Design (LLD)
  - ▷ Safety invariants/etc. preserved
  - ▷ (dynamic) interconnection properties
  - ▷ Same design for safety issues
    - but finer granularity/less flexibility

## SSP in Software Lifecycle

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- SSP in code analysis
  - ▷ Further refinement
  - ▷ Preserving safety invariants/properties?
  - ▷ Combination of techniques
    - testing/inspection/formal veri., etc.
    - safety-focus: based on FTA&ETA
  - ▷ Yih/Tian approach later
  
- SSP in configuration control/maintenance
  - ▷ Change during verification/operation
  - ▷ Change effect analysis:
    - how does it affect safety
    - problem identification and resolution
    - use FTA and ETA with modifications
  - ▷ Importance of separation/isolation
  - ▷ Above  $\Rightarrow$  informed safety management

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## Perspectives

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- State-of-the-Practice:
  - ▷ Computer used in safety-critical appl.
  - ▷ S/w Eng.: V&V, SRE, FT, FM
  - ▷ Gap between safety goal and QA
  
- SSE: Augment S/w Eng.
  - ▷ Overall framework: Leveson's SSP
  - ▷ Analysis to identify hazard
  - ▷ Design for safety/hazard resolution
  - ▷ Safety constraints and verification
  
- Link to other topics:
  - ▷ In addition to: V&V, SRE
  - ▷ Important elements: FM and FT
  - ▷ New development: prescriptive specs