Hardware/Software Codesign

Embedded Systems – 5

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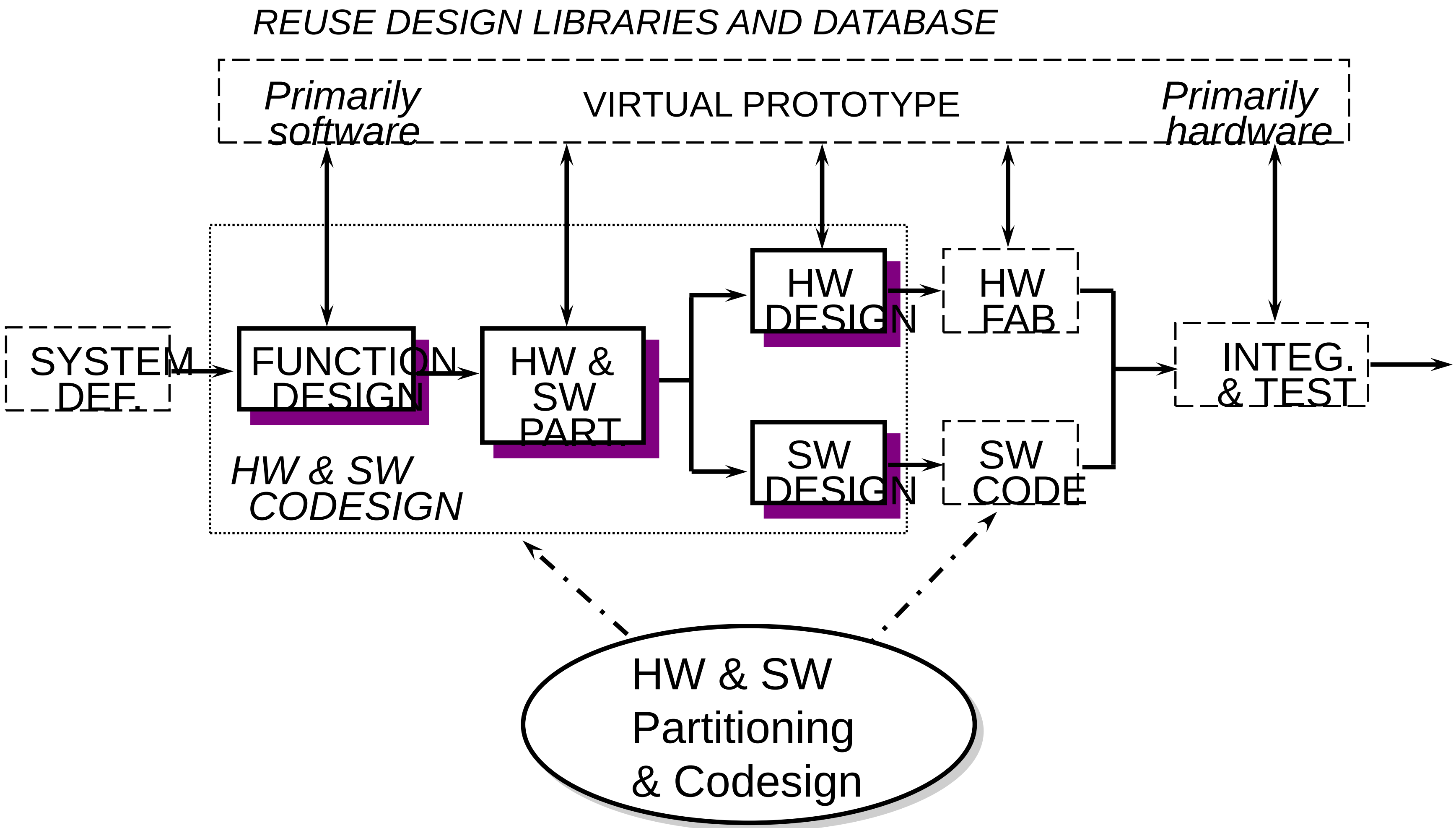
Rapid Prototyping Design Process



Lecture’s Goals

Introduce the fundamentals of HW/SW codesign and partitioning concepts in designing embedded systems

- Discuss the **current trends in the codesign** of embedded systems
- Provide information on the goals of and methodology for **partitioning hardware/software** in systems

Show benefits of the **codesign approach** over current design process

- Provide information on how to incorporate these techniques into a general digital design methodology for embedded systems

Illustrate **how codesign concepts** are being **introduced into design methodologies**

- Several example codesign systems are discussed

Introduction to Embedded Systems and Hardware-Software Codesign

Introduction

Unified HW/SW Representations

HW/SW Partitioning Techniques

Integrated HW/SW Modeling Methodologies

HW and SW Synthesis Methodologies

Industry Approaches to HW/SW Codesign

Hardware/Software Codesign Research

Summary

Codesign Definition and Key Concepts

Codesign

- The meeting of system-level objectives by exploiting the trade-offs between hardware and software in a system through their **concurrent design**

Key concepts

- Concurrent: hardware and software developed at the same time on parallel paths
- Integrated: interaction between hardware and software developments to produce designs that meet performance criteria and functional specifications

Motivations for Codesign

Factors driving codesign (hardware/software systems):

- Instruction Set Processors (ISPs) available as cores in many design kits (386s, DSPs, microcontrollers,etc.)
- Systems on Silicon - many transistors available in typical processes (> 10 million transistors available in IBM ASIC process, etc.)
- Increasing capacity of field programmable devices - some devices even able to be reprogrammed on-the-fly (FPGAs, CPLDs, etc.)
- Efficient C compilers for embedded processors
- Hardware synthesis capabilities

Motivations for Codesign (cont.)

The **importance of codesign** in designing hardware/software systems:

- Improves design **quality, design cycle time, and cost**
  - Reduces integration and test time
- Supports growing complexity of embedded systems

Three Categories for Hardware/Software Systems

Application Domain
- Embedded systems
  - Manufacturing control
  - Consumer electronics
  - Vehicles
  - Telecommunications
  - Defense Systems
- Instruction Set Architectures
- Reconfigurable Systems

Degree of programmability

Implementation Features
- Discrete vs. integrated components
- Fabrication technologies

Categories of Codesign Problems

Codesign of embedded systems

- Usually consist of sensors, controller, and actuators
- Are reactive systems
- Usually have real-time constraints
- Usually have dependability constraints

Codesign of ISAs (Instruction set architecture)

- Application-specific instruction set processors (ASIPs)
- Compiler and hardware optimization and trade-offs

Codesign of Reconfigurable Systems

- Systems that can be personalized after manufacture for a specific application
- Reconfiguration can be accomplished before execution or concurrent with execution (called *evolvable* systems)

Components of the Codesign Problem

Specification of the system

Hardware/Software Partitioning

- Architectural assumptions - type of processor, interface style between hardware and software, etc.
- Partitioning objectives - maximize speedup, latency requirements, minimize size, cost, etc.
- Partitioning strategies - high level partitioning by hand, automated partitioning using various techniques, etc.

Scheduling

- Operation scheduling in hardware
- Instruction scheduling in compilers
- Process scheduling in operating systems

Modeling the hardware/software system during the design process

Embedded Systems: Complexity Issues

Complexity of embedded systems is continually increasing

Number of states in these systems (especially in the software) is very large

Description of a system can be complex, making system analysis extremely hard

Complexity management techniques are necessary to model and analyze these systems

Systems becoming too complex to achieve accurate “first pass” design using conventional techniques

New issues rapidly emerging from new implementation technologies

Techniques to Support Complexity Management

Delayed HW/SW partitioning

- Postpone as many decisions as possible that place constraints on the design

Abstractions and decomposition techniques

Incremental development

- “Growing” software
- Requiring top-down design

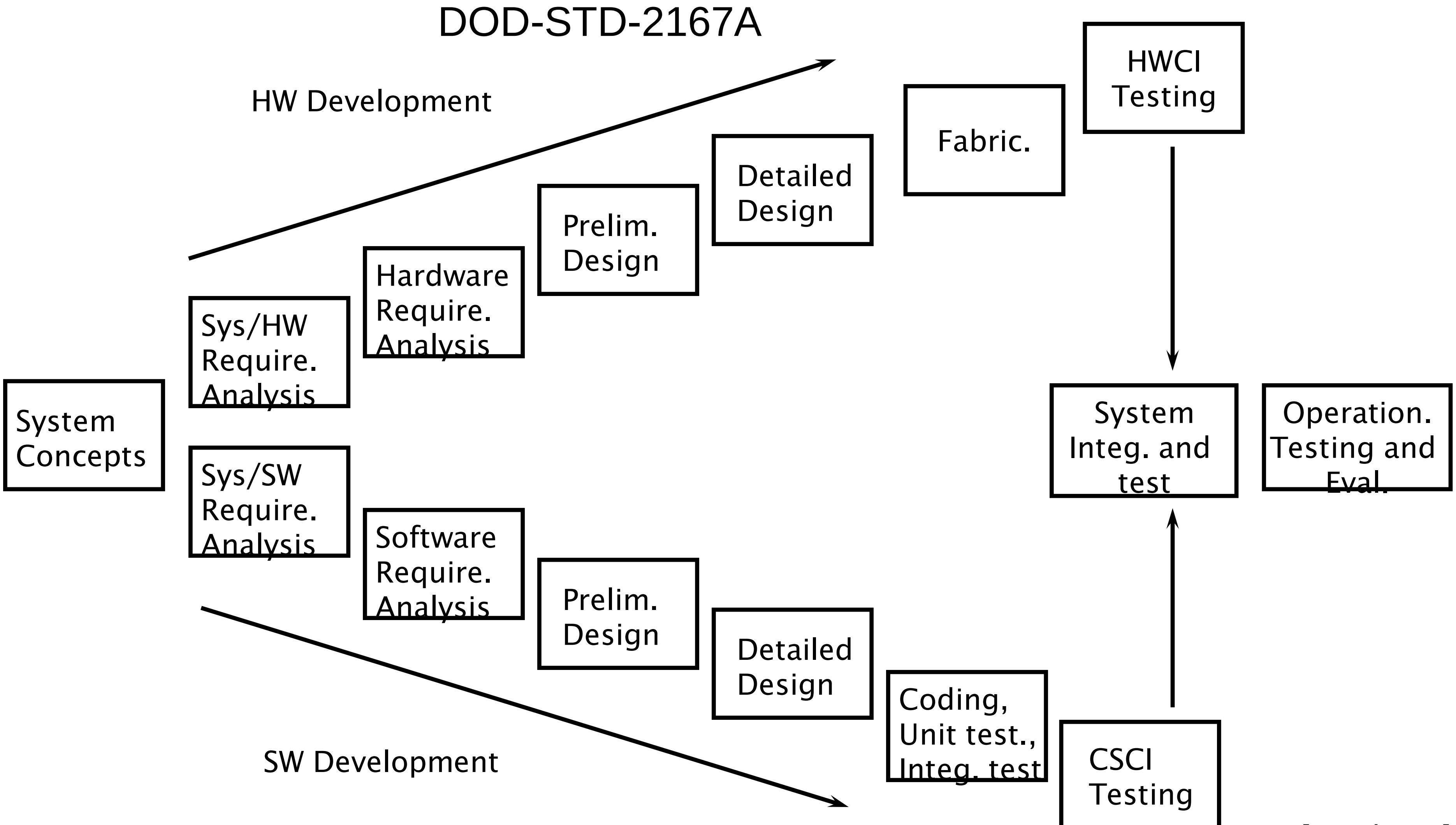
Description languages

Simulation

Standards

Design methodology management framework

A Model of the Current Hardware/Software Design Process



[Franke91]

Current Hardware/Software Design Process

Basic features of current process:

- System immediately partitioned into hardware and software components
- Hardware and software developed separately
- "Hardware first" approach often adopted

Implications of these features:

- HW/SW trade-offs restricted
  - Impact of HW and SW on each other cannot be assessed easily
- Late system integration

Consequences these features:

- Poor quality designs
- Costly modifications
- Schedule slippages

Common Misconceptions in Current Hardware/Software Design Process

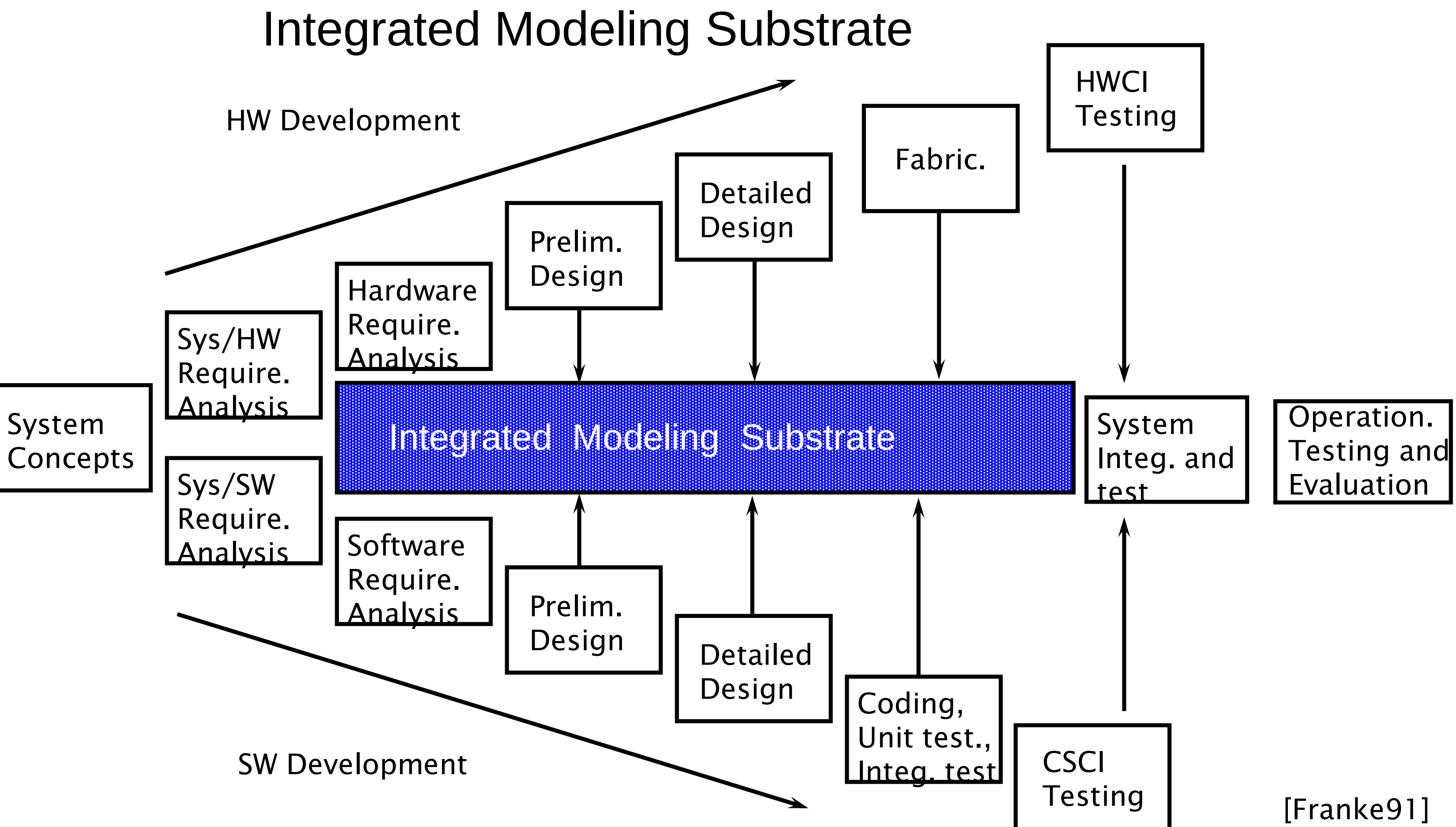
Hardware and software can be acquired separately and independently, with successful and easy integration of the two later

Hardware problems can be fixed with simple software modifications

Once operational, software rarely needs modification or maintenance

Valid and complete software requirements are easy to state and implement in code

Directions of the HW/SW Design Process



Requirements for the Ideal Codesign Environment

Unified, unbiased hardware/software representation

- Supports uniform design and analysis techniques for hardware and software
- Permits system evaluation in an integrated design environment
- Allows easy migration of system tasks to either hardware or software

Iterative partitioning techniques

- Allow several different designs (HW/SW partitions) to be evaluated
- Aid in determining best implementation for a system
- Partitioning applied to modules to best meet design criteria (functionality and performance goals)

Requirements for the Ideal Codesign Environment (cont.)

Integrated modeling substrate

- Supports evaluation at several stages of the design process
- Supports step-wise development and integration of hardware and software

Validation Methodology

- Ensures that system implemented meets initial system requirements

Cross-fertilization Between Hardware and Software Design

Fast growth in both VLSI design and software engineering has raised awareness of similarities between the two

- Hardware synthesis
- Programmable logic
- Description languages

Explicit attempts have been made to “transfer technology” between the domains

Cross-fertilization Between Hardware and Software Design (cont.)

VLSI DESIGN → SOFTWARE ENGINEERING

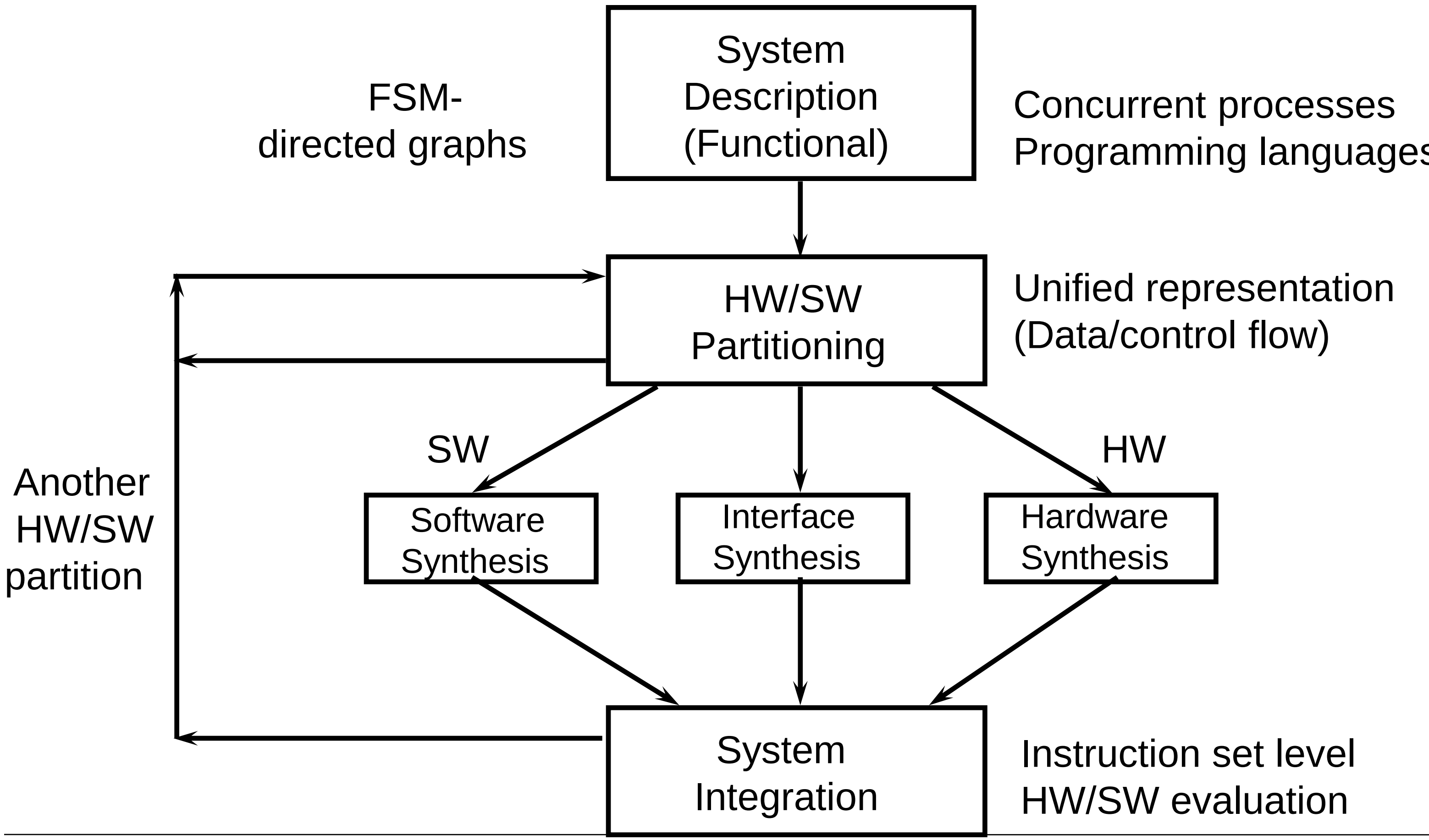
EDA (electronic design automation) *tool technology has been transferred to SW CAD systems*

Cross-fertilization Between Hardware and Software Design (cont.)

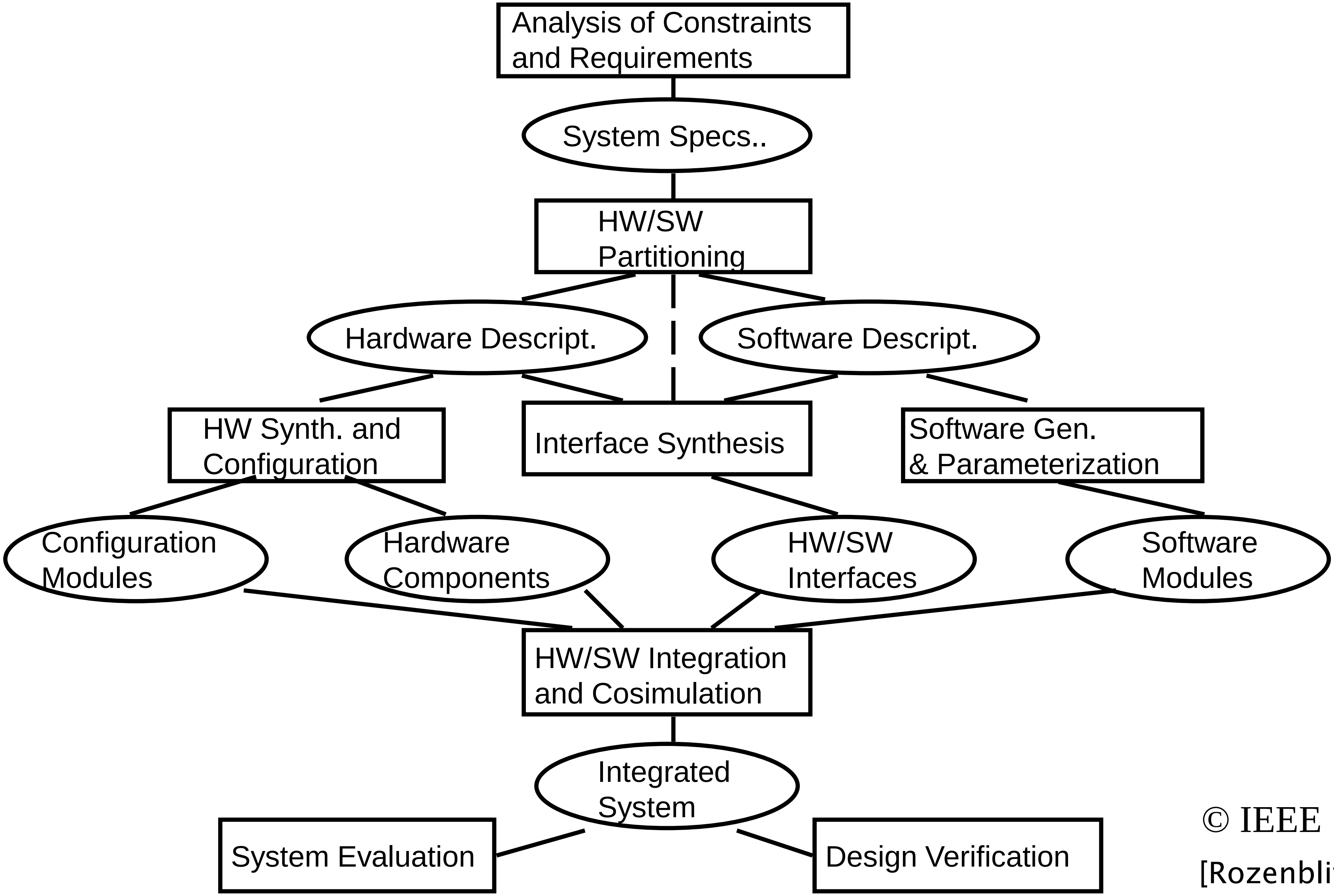
SOFTWARE ENGINEERING → VLSI DESIGN

Software technology has been transferred to EDA tools

Typical Codesign Process



Conventional Codesign Methodology



[Rozenblit94]

Codesign Features

Basic features of a codesign process:

Enables mutual influence of both HW and SW early in the design cycle

- Provides continual verification throughout the design cycle
- Separate HW/SW development paths can lead to costly modifications and schedule slippages

Enables evaluation of larger design space through tool interoperability and automation of codesign at abstract design levels

Advances in key enabling technologies (e.g., logic synthesis and formal methods) make it easier to explore design tradeoffs

State of Codesign Technology

Current use limited by:

- Lack of a standardized representation
- Lack of good validation and evaluation methods

Possible solutions:

- Extend existing hardware/software languages to the use of heterogeneous paradigms
- Extend formal verification techniques to the HW/SW domain

Issues and Problems: Integration

Errors in hardware and software design become much more costly as more commitments are made

"Hardware first" approach often compounds software cost because software must compensate for hardware inadequacies

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