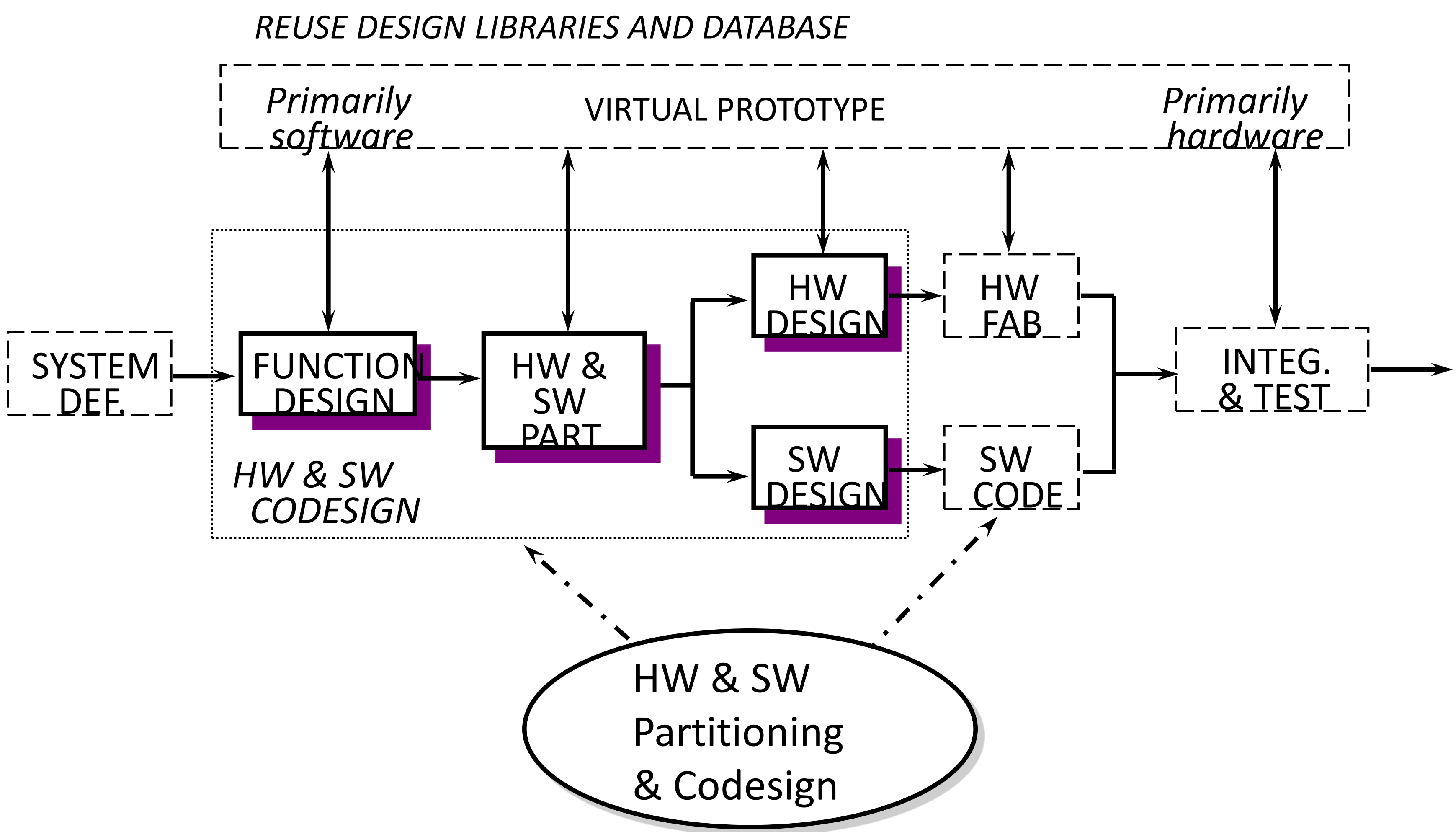
Hardware-Software Codesign

Rapid Prototyping Design Process



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
  - Takes advantage of advances in tools and technologies
    - Processor cores
    - High-level hardware synthesis capabilities
    - ASIC development

Categorizing Hardware/Software Systems

- Application Domain
  - Embedded systems
    - Manufacturing control
    - Consumer electronics
    - Vehicles
    - Telecommunications
    - Defense Systems
  - Instruction Set Architectures
  - Reconfigurable Systems
- Degree of programmability
  - Access to programming
  - Levels of programming
- 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
  - 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

Embedded Systems

Application-specific systems which contain hardware and software tailored for a particular task and are generally part of a larger system (e.g., industrial controllers)

- Characteristics
  - Are dedicated to a particular application
  - Include processors dedicated to specific functions
  - Represent a subset of reactive (responsive to external inputs) systems
  - Contain real-time constraints
  - Include requirements that span:
    - Performance
    - Reliability
    - Form factor

Embedded Systems: Specific Trends

- Use of microprocessors only one or two generations behind state-of-the-art for desktops
  - E.g. *N/2* bit width where *N* is the bit width of current desktop systems
- Contain limited amount of memory
- Must satisfy strict real-time and/or performance constraints
- Must optimize additional design objectives:
  - Cost
  - Reliability
  - Design time
- Increased use of hardware/software codesign principles to meet constraints

Embedded Systems: Examples

- Banking and transaction processing applications
- Automobile engine control units
- Signal processing applications
- Home appliances (microwave ovens)
- Industrial controllers in factories
- Cellular communications

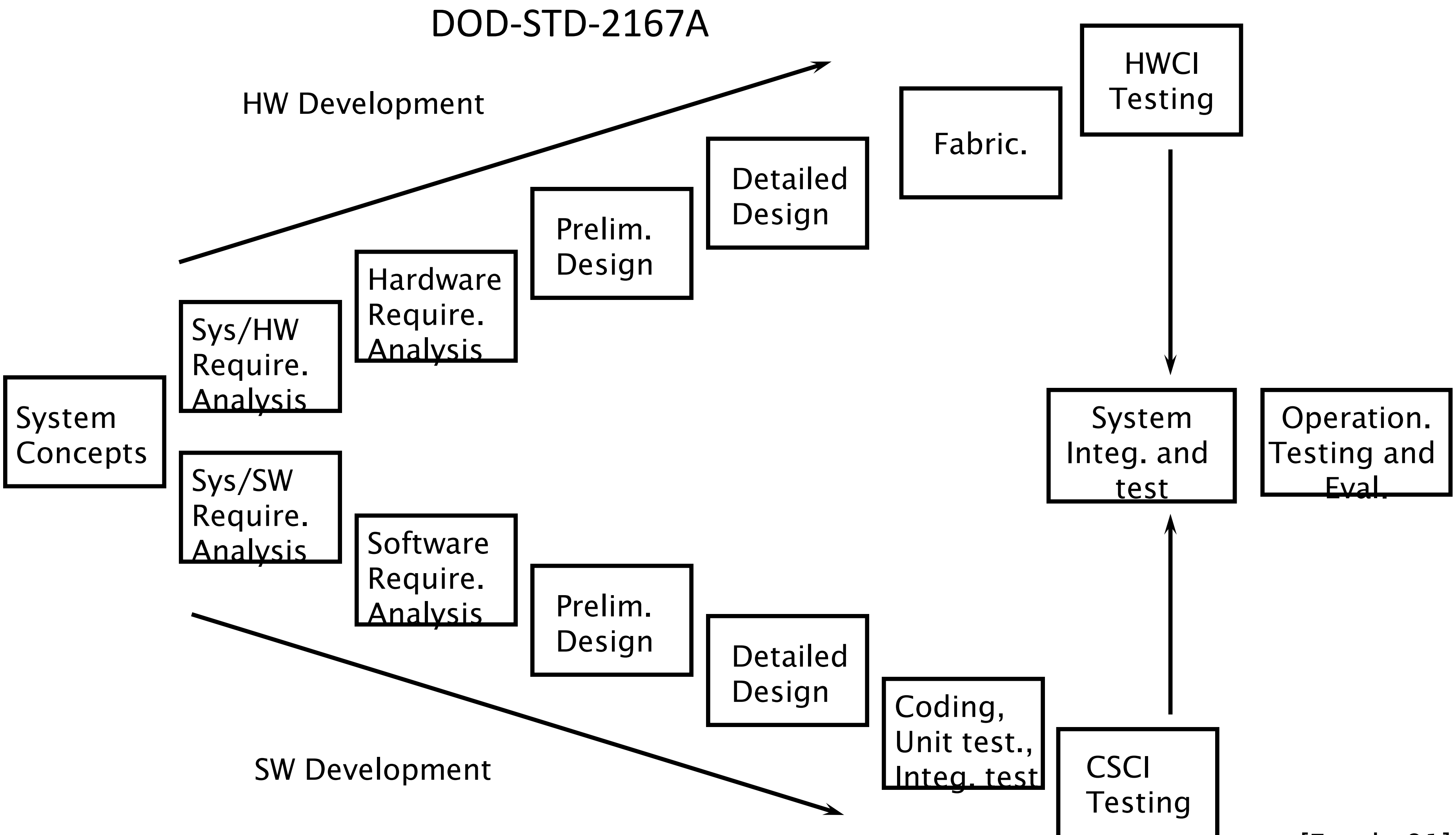
Embedded Systems: Complexity Issues

- 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



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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

Incorrect Assumptions in Current Hardware/Software Design Process

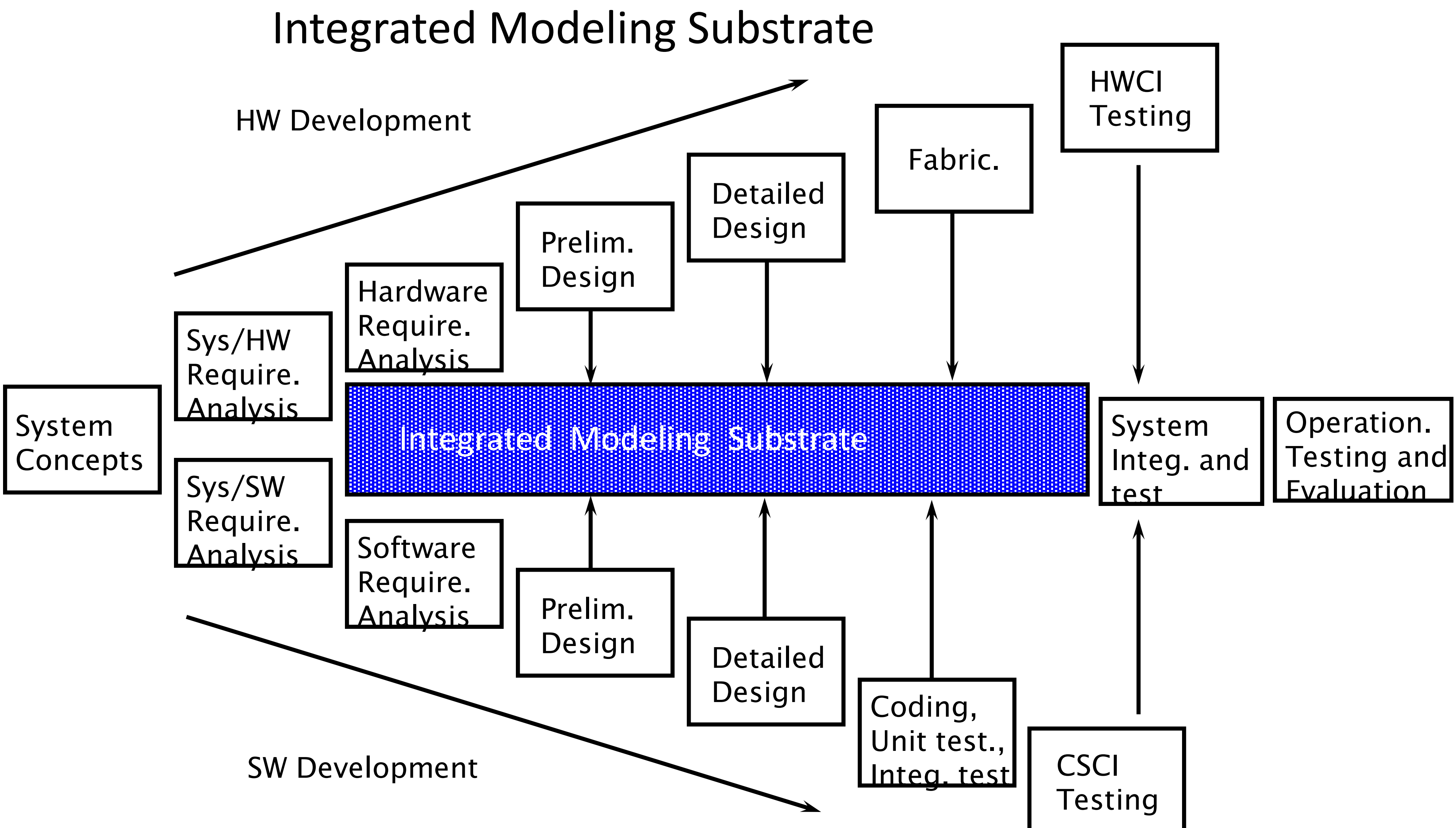
- Hardware and software can be acquired separately and independently, with successful and easy integration of the two later

- 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



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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
  - Insures 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

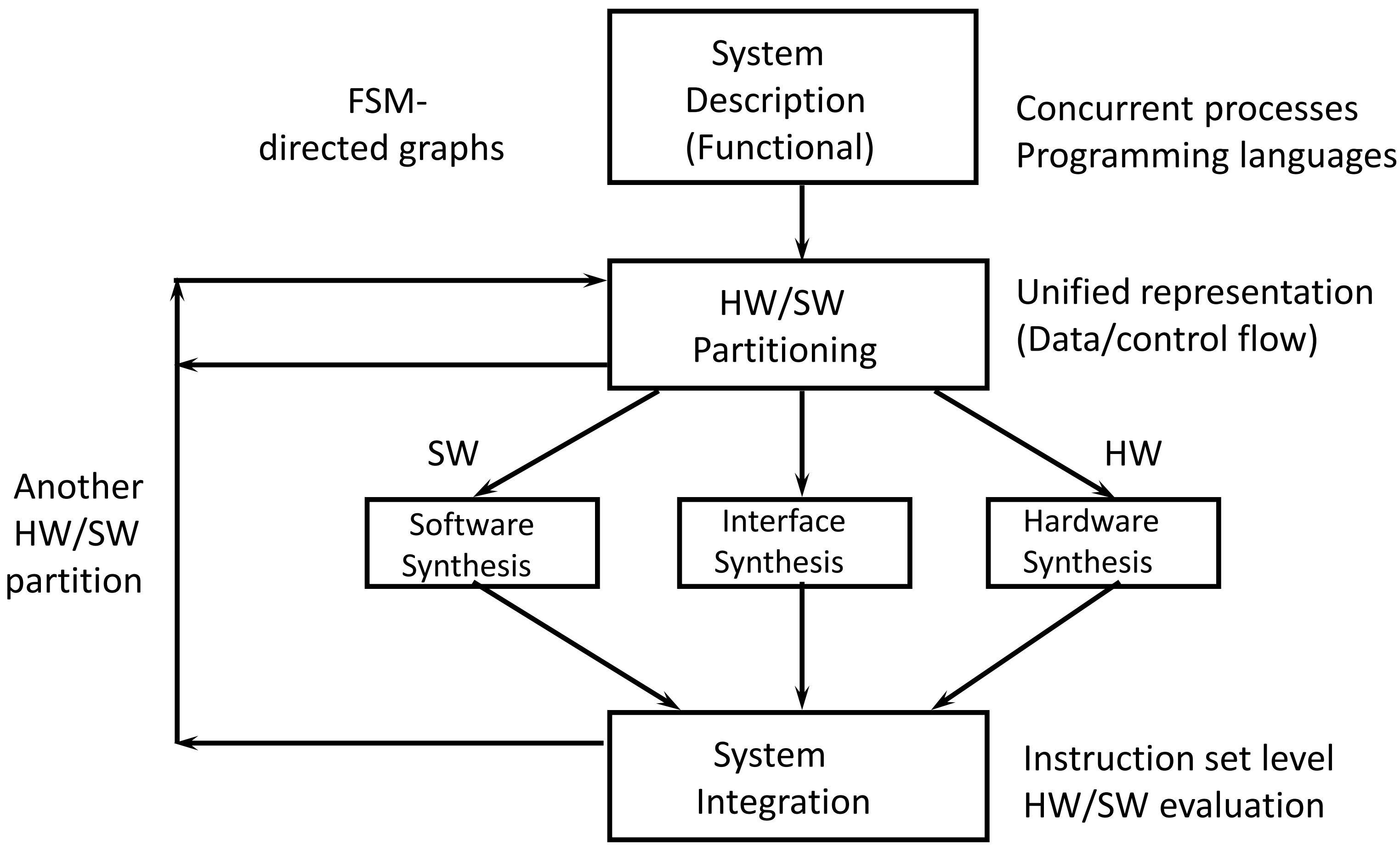
- *EDA tool technology has been transferred to SW CAD systems*
  - Designer support (not automation)
  - Graphics-driven design
  - Central database for design information
  - Tools to check design behavior early in process

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

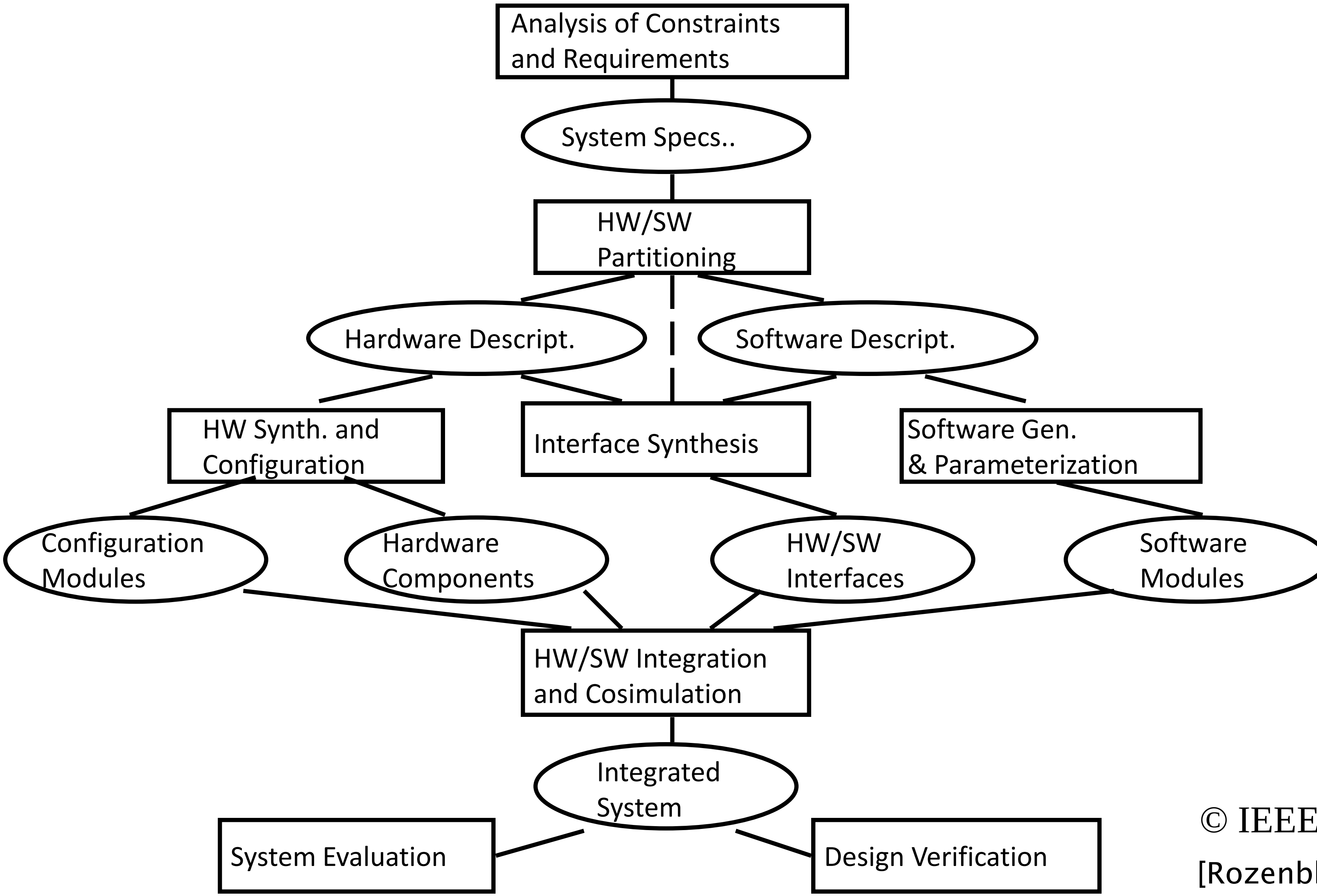
SOFTWARE ENGINEERING → VLSI DESIGN

- *Software technology has been transferred to EDA tools*
  - Single-language design
    - Use of 1 common language for architecture spec. and implementation of a chip
  - Compiler-like transformations and techniques
    - Dead code elimination
    - Loop unrolling
  - Design change management
    - Information hiding
    - Design families

Typical Codesign Process



Conventional Codesign Methodology



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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