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Raising the Level of Abstraction: A Signal Processing System Design Course

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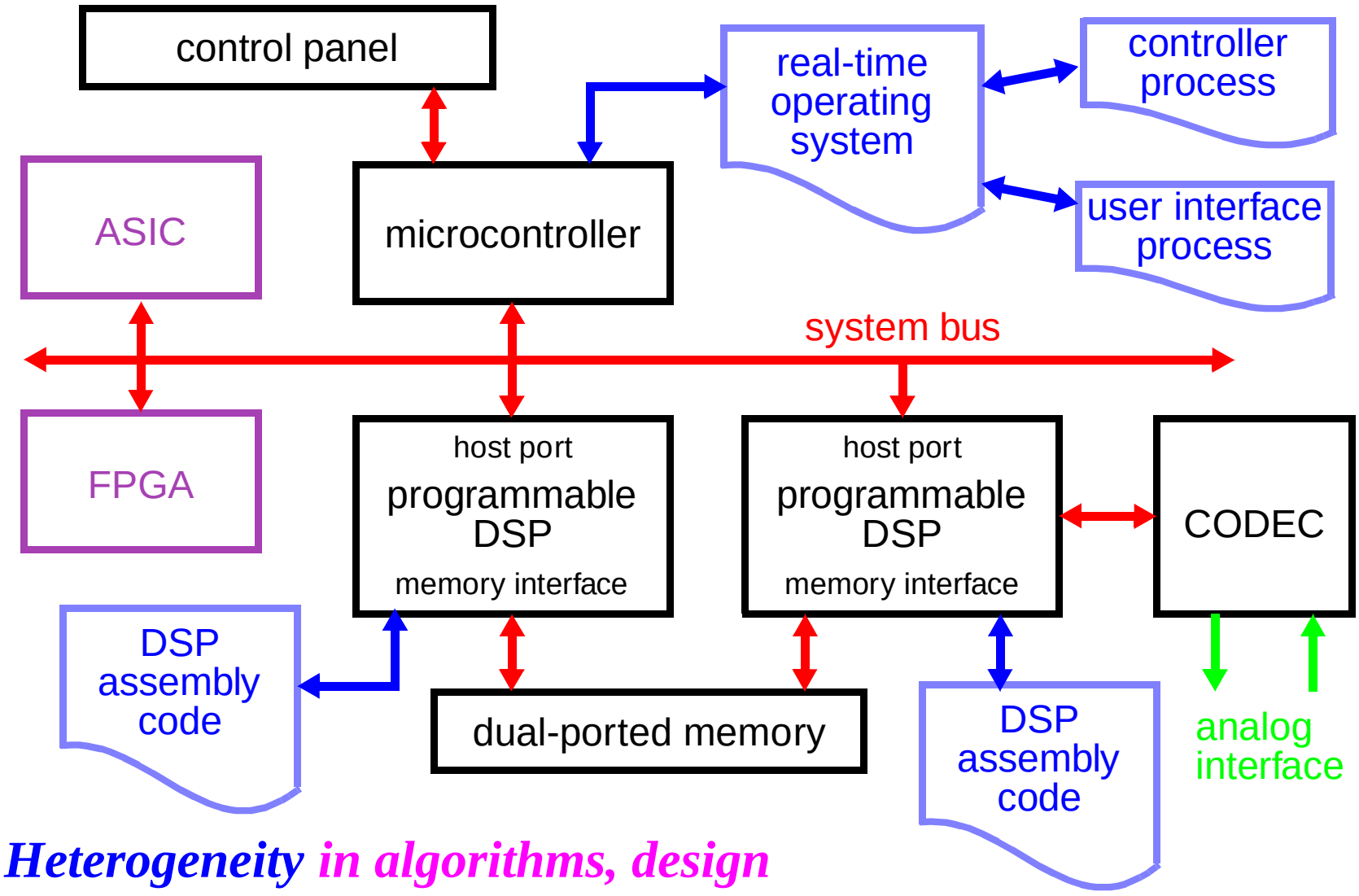
Introduction

- New standard for speech/audio compression, image/video compression and mobile communication each year
- Growth and diversity of implementation technologies
  - Dedicated and configurable hardware
  - Dozens of high-volume programmable processors introduced each year (general-purpose processors, digital signal processors, microcontrollers)
  - Revolution in high-level languages every 10 years (Fortran, C, C++, Java)
- Increasing complexity in implementation technologies
  - Moore's Law: Number of transistors on a chip doubles every 18 months
  - Networked, distributed, and multiprocessor systems
- Signal processing system design course raises abstraction by decoupling system specification from its implementation
  - Enables mapping of the same subsystem onto a variety of implementation technologies
  - Reuse of existing designs

Embedded Signal Processing Systems



***Heterogeneity** in algorithms, design methods, and implementation technologies*

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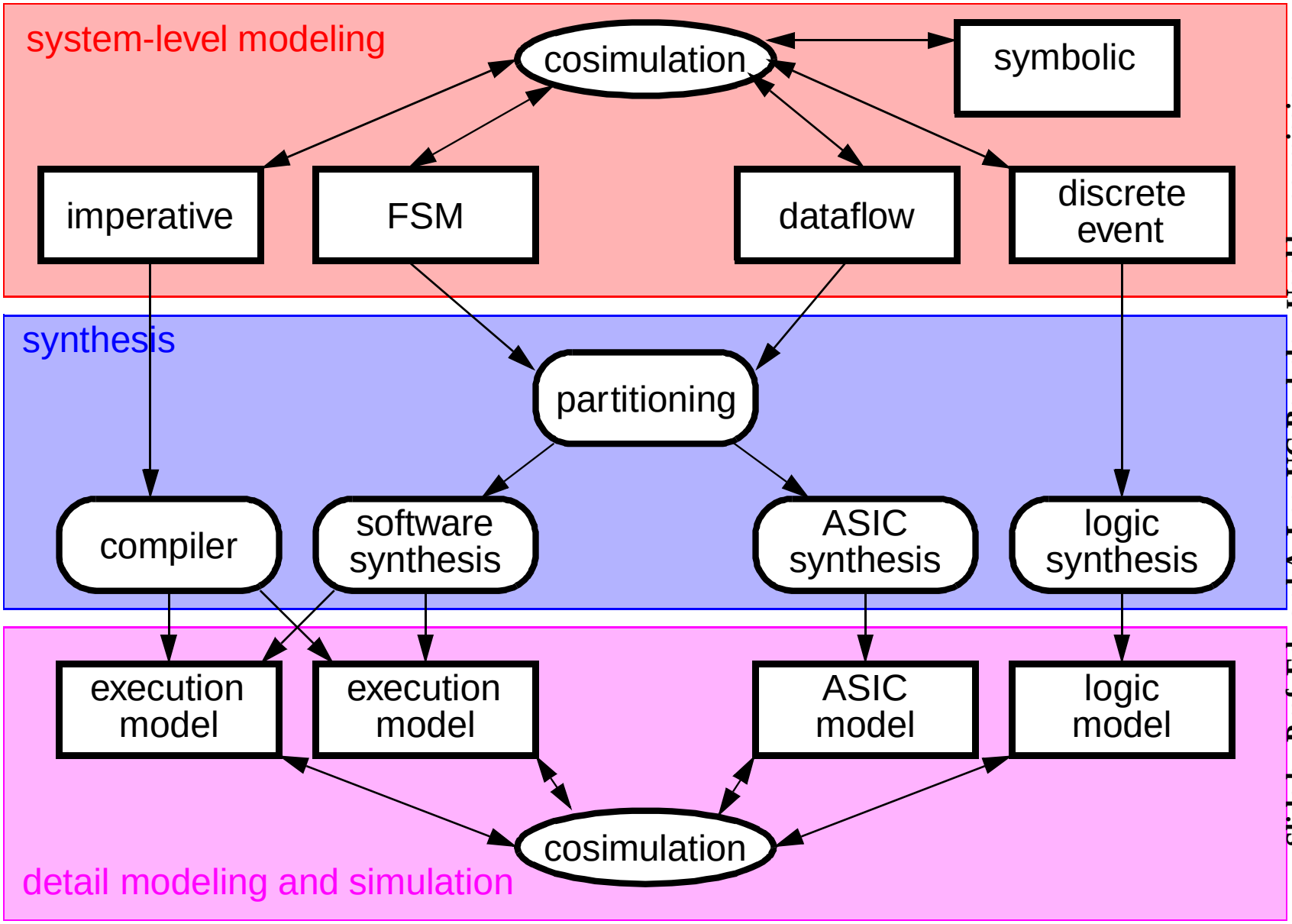
Heterogeneity in a System-Level Design Flow



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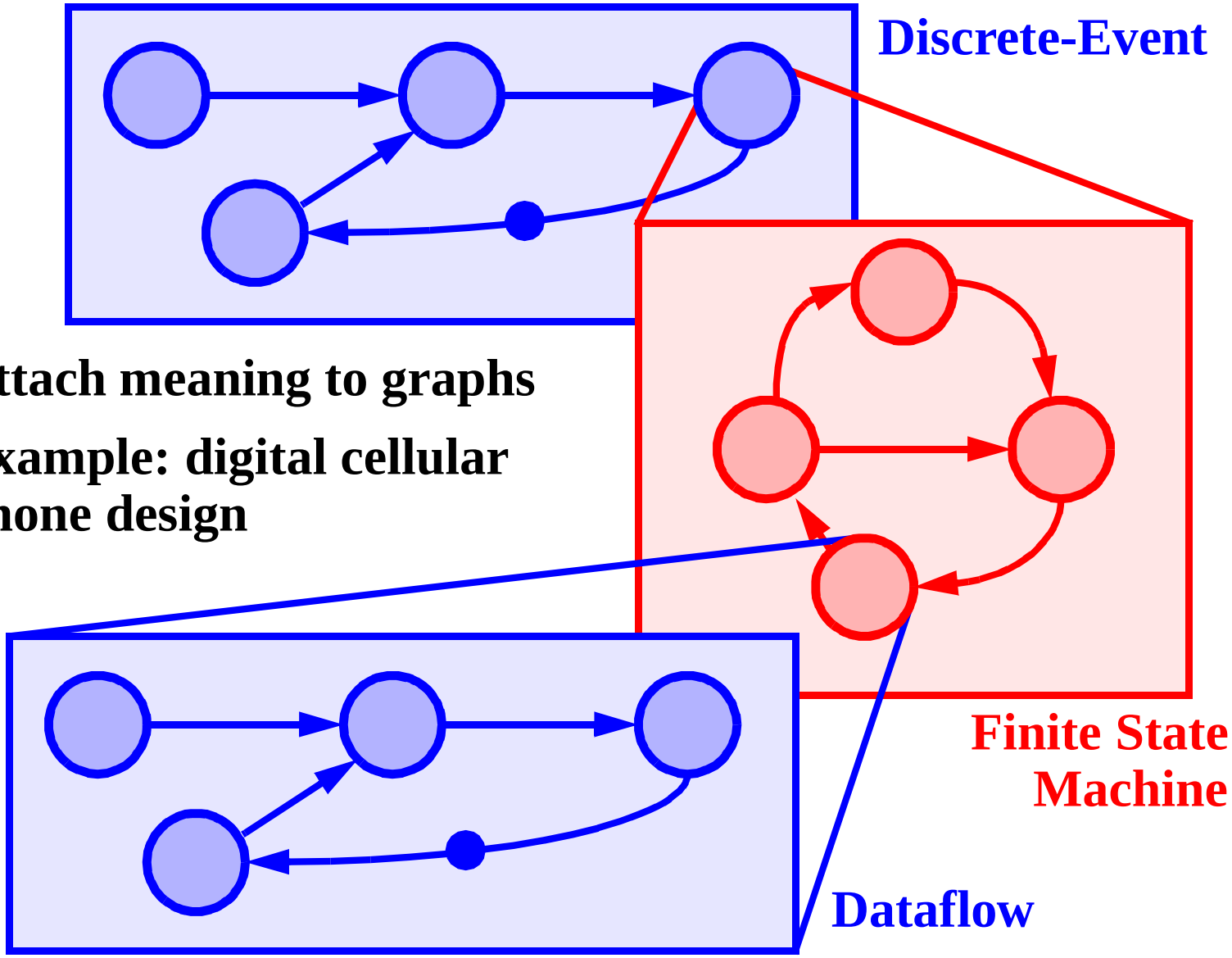
System Modeling

- **Models of computation**
  - **Coordinate computation of and communication between subsystems**
  - **Ideally unbiased towards implementation in software and hardwar**
  - **Map be mapped onto a variety of implementation technologies**
- **Modeling signal processing subsystems**

Subsystem	*Model of Computation*
speech/audio processing	1-D dataflow
image processing	1-D/2-D dataflo
image/video resampling	m-D multirate dataflow
user interface	synchronous/reactive
communication protocols	finite state machine
digital control	dataflow
scalable descriptions	process networks

- **Hierarchical combination forms heterogeneous systems: models must compose with each other**

Specification Using Hierarchical Block Diagrams



- Attach meaning to graphs
- Example: digital cellular phone design

System Simulation and Synthesis

- **Two sides of the same coin**
  - ***Simulation*: scheduling then execution on desktop computer(s)**
  - ***Synthesis*: scheduling then code generation in C++, C, assembly, VHDL, etc.**
- **Validation by simulation important throughout design flow**
- **Models of computation enable**
  - **Global optimization of computation and communication**
  - **Scheduling and communication that is *correct by construction***

Model of Computation	*Global State*	*Type of Comm.*	*Type of Scheduling*	*Optimal Scheduling*	*Simulation Speed*
synchronous dataflow	finite	asynch	static	n^3	fast
Boolean dataflow	infinite	asynch	quasi-static	infinite	fast
process networks	infinite	asynch	dynamic	infinite	fast
finite state machine	finite	either	static	not poly.	fast
synchronous/reactiv	finite	synch	static	n^2	fast
discrete event	infinite	synch	dynamic	infinite	slow

Educational Objectives

- **Design space (global state)**
  - *Finite*, e.g. finite state machine, synchronous dataflow, synchronous/reactive
  - *Infinite*, e.g. imperative programming, Boolean dataflow, process networks
- **Worst-case optimal scheduling time**
  - Finite time if design space is finite, and infinite time if design space is infinite
  - Infinite-time off-line scheduling is impractical: use heuristics (e.g. compilers)
  - Process networks on-line scheduling takes infinite time but bounded memory
- **Use models of computation with finite state when possible**
  - Enables formal analysis (consistency, deadlock, boundedness, verification)
  - Suitable for fixed topologies (VLSI and embedded software implementations)
- **Example: model signal processing in a sonar beamformer**
  - Statically schedule a synchronous dataflow model of the processing onto a fixed number of processors, e.g. on a workstation or embedded processors
  - Dynamically schedule a process networks model for scalable software
  - Both approaches lead to real-time solutions

Conclusion

- **Traditional signal processing course**
  - **One style of algorithm (e.g. speech/audio or image/video)**
  - **One implementation technology (e.g. Matlab, C, or digital signal processor)**
- **Signal processing system design course raises abstraction by decoupling system specification from its implementation**
  - **Implementation-unbiased models of computation**
  - **Compose models to specify complex heterogeneous systems**
  - **Simulate and synthesize heterogeneous systems**
- **Students use and extend system-level CAD tools**
  - ***UC Berkeley Ptolemy*: dataflow, FSM, discrete event, synchronous/reactive models plus synthesis in C, assembly, and VHDL**
  - ***HP EEsof Advanced Design System*: mixed analog, RF, and digital design for wireless communication systems using Spice, harmonic balance, and dataflow modeling**
- **All course notes, handouts, and lectures are on the Web**

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