

Design Methodologies and Tools

- Design styles
 - Full-custom design
 - Standard-cell design
 - Programmable logic
 - Gate arrays and field-programmable gate arrays (FPGAs)
 - Sea of gates
 - System-on-a-chip (embedded cores)
- Design tools

Full-Custom Design

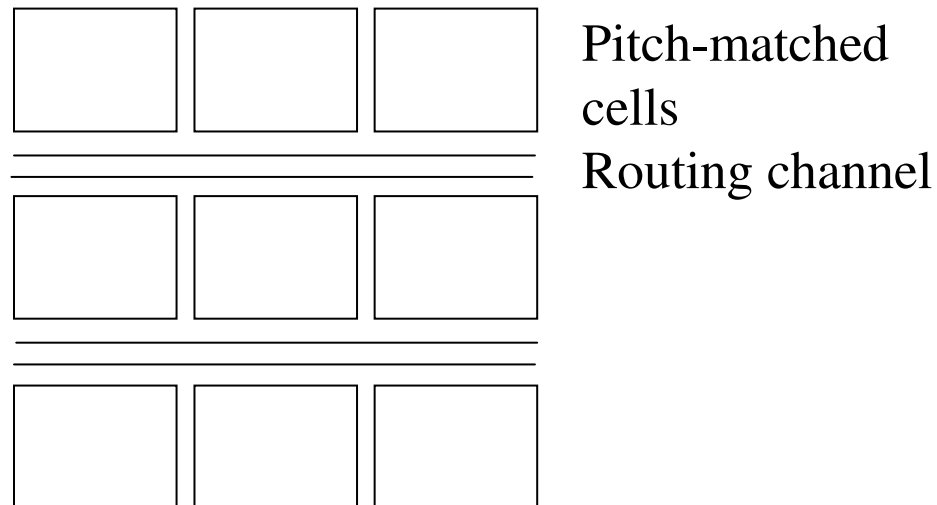
- Every gate is carefully designed and optimized
 - Hierarchical design may be used, place-and-route tools typically used
- Advantages:
 - High density, ideal for high volumes
 - Performance optimization
- Disadvantages:
 - High design time, cumbersome
- Applications: Datapaths in microprocessors
- *High-paying jobs!*

Full-Custom Design (Contd.)

- Simple CAD tools suffice
 - Design entry
 - Schematic editor
 - Layout editor
 - DRC, LVS, Spice
- No need for sophisticated synthesis and design partitioning tools

Standard Cell Design

- Use pre-optimized SSI or MSI library cells
 - NAND gates, multiplexers, adder slices, decoders, comparators, RAM, ROM
- Reduces design time
- Lower density and lower performance
- Standardized at the logic or function level



Standard Cells (Contd)

- CAD tools needed for partitioning design
- Technology mapping
- Design entry, DRC, LVS, simulations tools needed
- Place and route tools
- Good for moderate volumes, as in ASICs, typically used for non-critical portions of a CPU

Programmable Logic

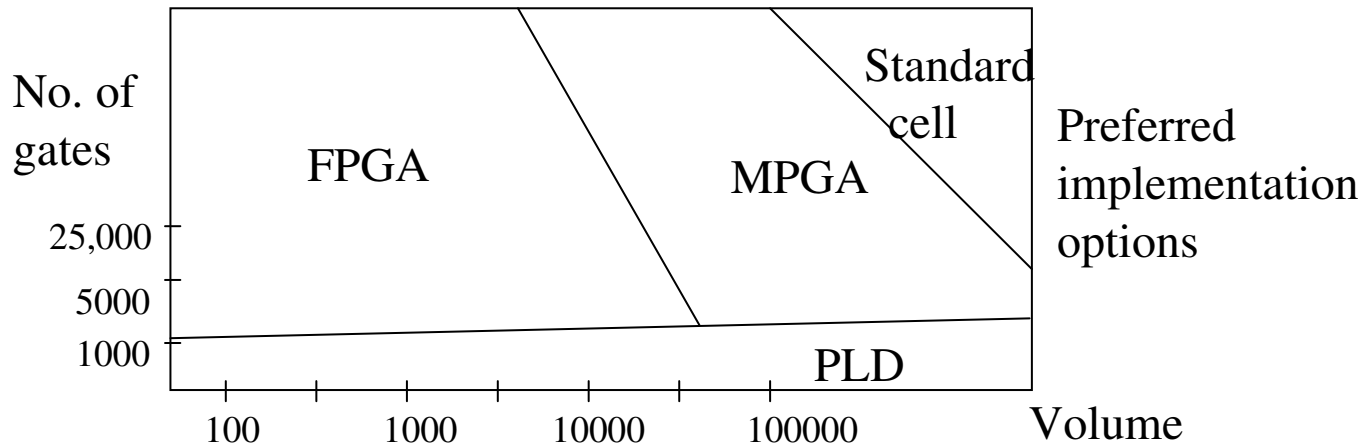
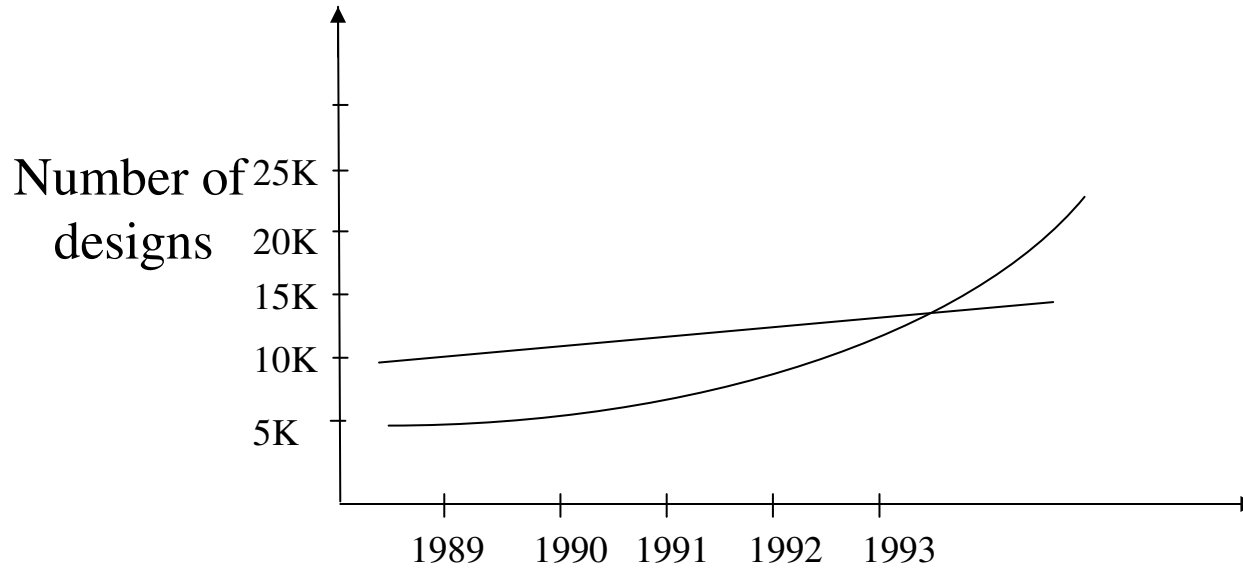
- Programmable logic blocks
 - PLDs, PALs
 - Fusible links (fuses) blown when current is exceeded
- Programmable interconnects
 - Mask-programmed gate-arrays (MPGAs)
 - Field-programmable gate-arrays (FPGAs)
 - Sea of gates

Programmable Logic

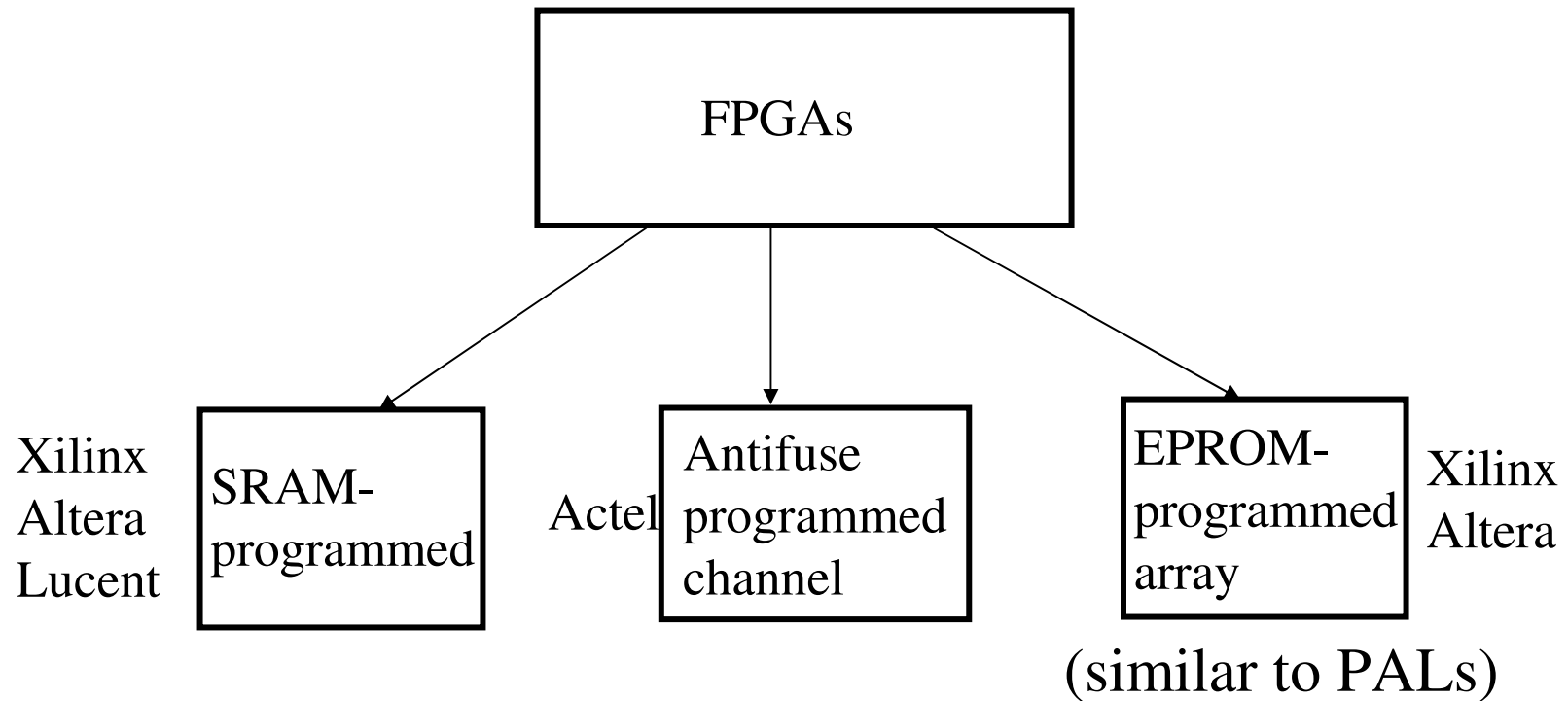
- PLDs
 - Wide fan-in, 2-level SOP, optional flip-flops on output
 - Best known: 22V10 with 22 inputs, 10 outputs, from AMD
 - Programmed by users
 - Fusible links
- MPGAs
 - Also called gate arrays
 - More dense than PLDs
 - Predesigned transistors with customized wiring
 - Wiring done during manufacture (not user)

FPGAs: complex designs, user programmable

MPGAs vs FPGAs



FPGAs



Analog FPGAs (FPAAs) now commercially available

FPGAs

- Advantages

- Low design cost (custom masks not needed)
- Rapid turnaround
- Low risk
- Effective design verification
- Low testing costs-test program same for all designs

- Disadvantages

- Programming circuitry: area penalty, ten times larger for same gate capacity as MPGA
- Speed: 2-3 times slower than MPGA
- Design methodology: “too easy” to use, encourages “try-it-and-see-what-happens” methodology

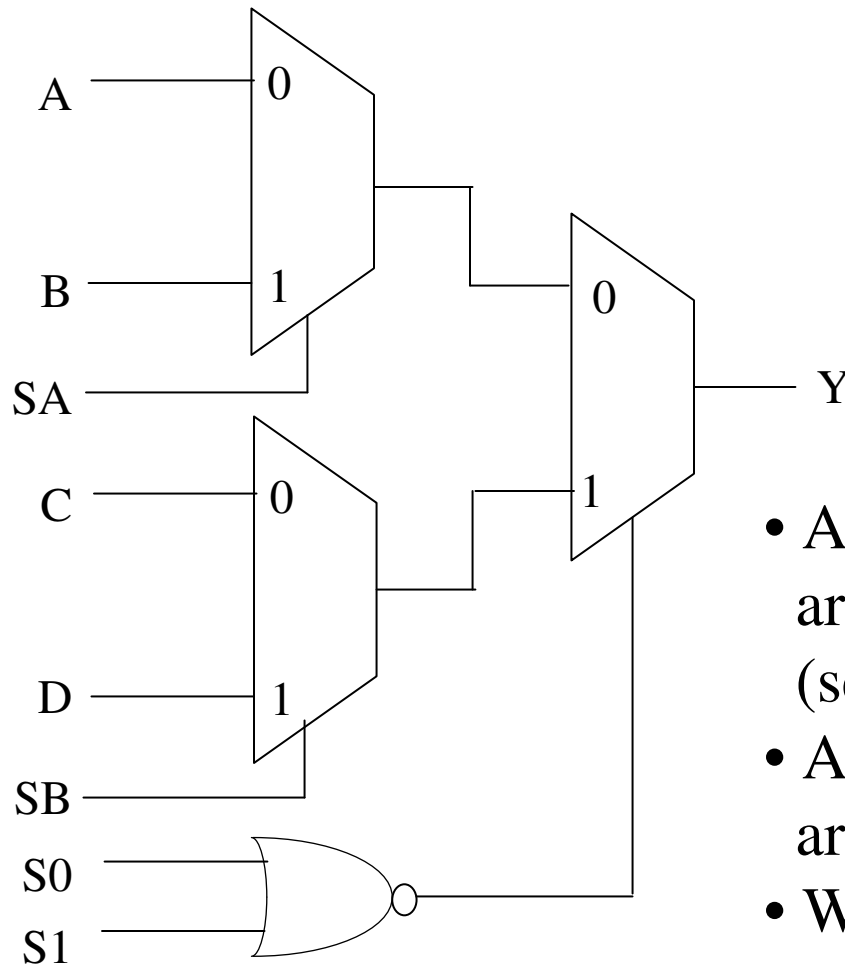
Programmable Interconnects

- Program the routing
- PLICE: Programmable Low-Impedance Circuit Element, “antifuse”
 - Normally high resistance ($> 100\text{M}\Omega$)
 - Antifuse can be permanently changed to a low-resistance ($200\text{-}500\Omega$) structure, i.e. form links
- Low gate utilization
- E.g. 32-bit adder using Actel FPGAs:
 - 160 logic modules, 65 ns for addition
 - 3.5 32-bit adders on an FPGA chip

Comments on Gate Utilization for FPGAs

- 32-bit adder using Actel FPGAs:
 - 160 logic modules, 65 ns for addition
 - 3.5 32-bit adders on an FPGA chip
 - Design time: one afternoon, \$5-\$10 design cost
 - Lot of wasted logic
- 32-bit full-custom adder (1 micron)
 - 1300 adders on one chip, 33 ns addition time
 - Design time: 6 months, \$200,000

Actel Logic Cell



- All 2-input functions are realized (select inputs carefully)
- All 3-input functions are realized (if?)
- Which 4-input functions?
- How to implement a latch?

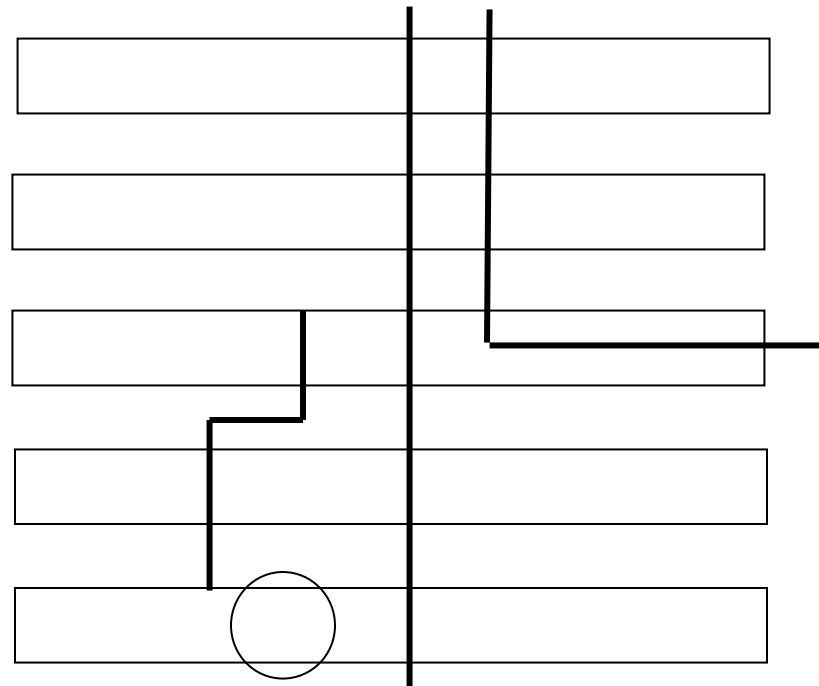
Xilinx FPGAs

- Configurable logic blocks (contain SRAMs), CLBs
- Programmable interconnect
- 500 CLBs on a chip
- 100K bits of RAM per chip
- 32-bit adder example:
 - 62 CLBs, 8 adders per chip
 - Speed: 20-50 MHz

Sea of Gates Design

- Goal: reduce design cost of IC, rapid prototyping, fast turnaround time
 - Not useful for high-volume production (more area per IC)
- Core of chip (base array) contains continuous array of n and p transistors
 - Polysilicon laid a-priori (transistors formed in advance)
- Personalization done by using design-specific metallization and contacts
- Highly automated process: sophisticated CAD tools used

Sea of Gates



Routing possible
over unused
rows

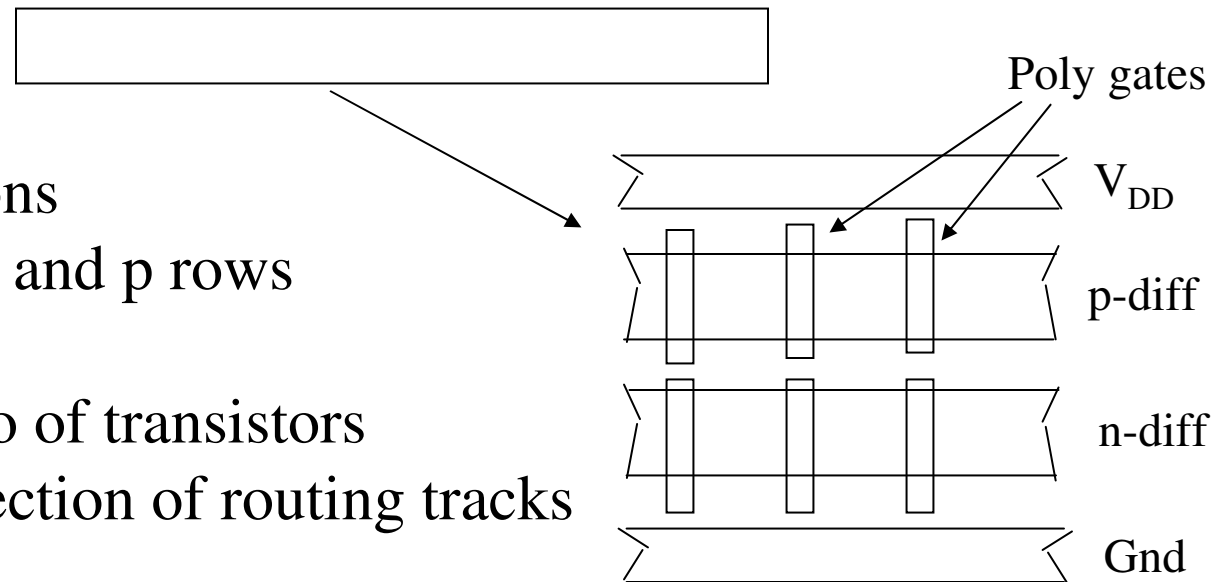
Sea of Gates

- Design Decisions

How many n and p rows
per strip?

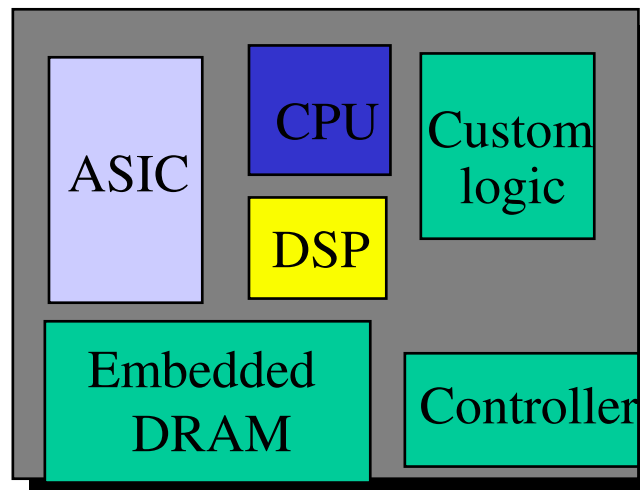
Size and ratio of transistors

Number, direction of routing tracks



Embedded Cores

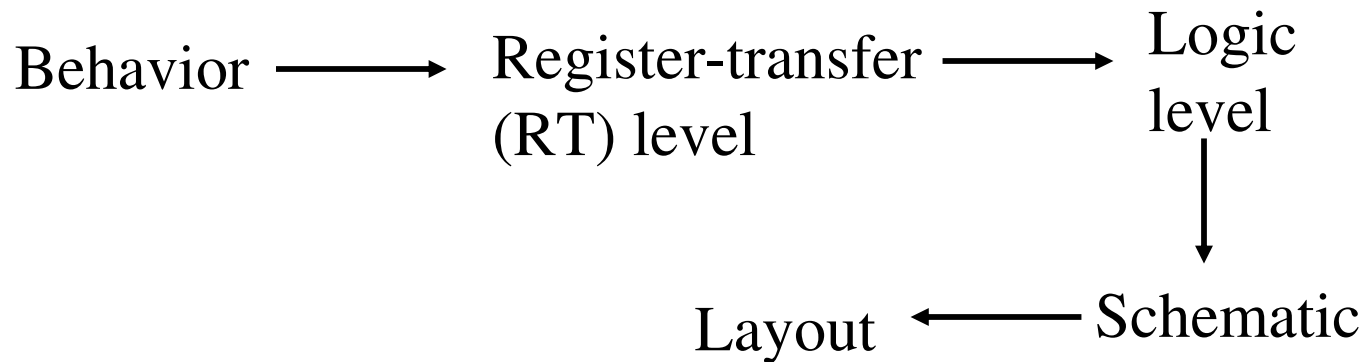
- Complex “off-the-shelf”, optimized, pre-designed circuits: processors, ASICs, memories, controllers
- Used for system-on-a-chip (SOC) designs
- Hot intellectual property (IP)
- IC consists of several embedded cores along with custom-designed blocks



Design Tools

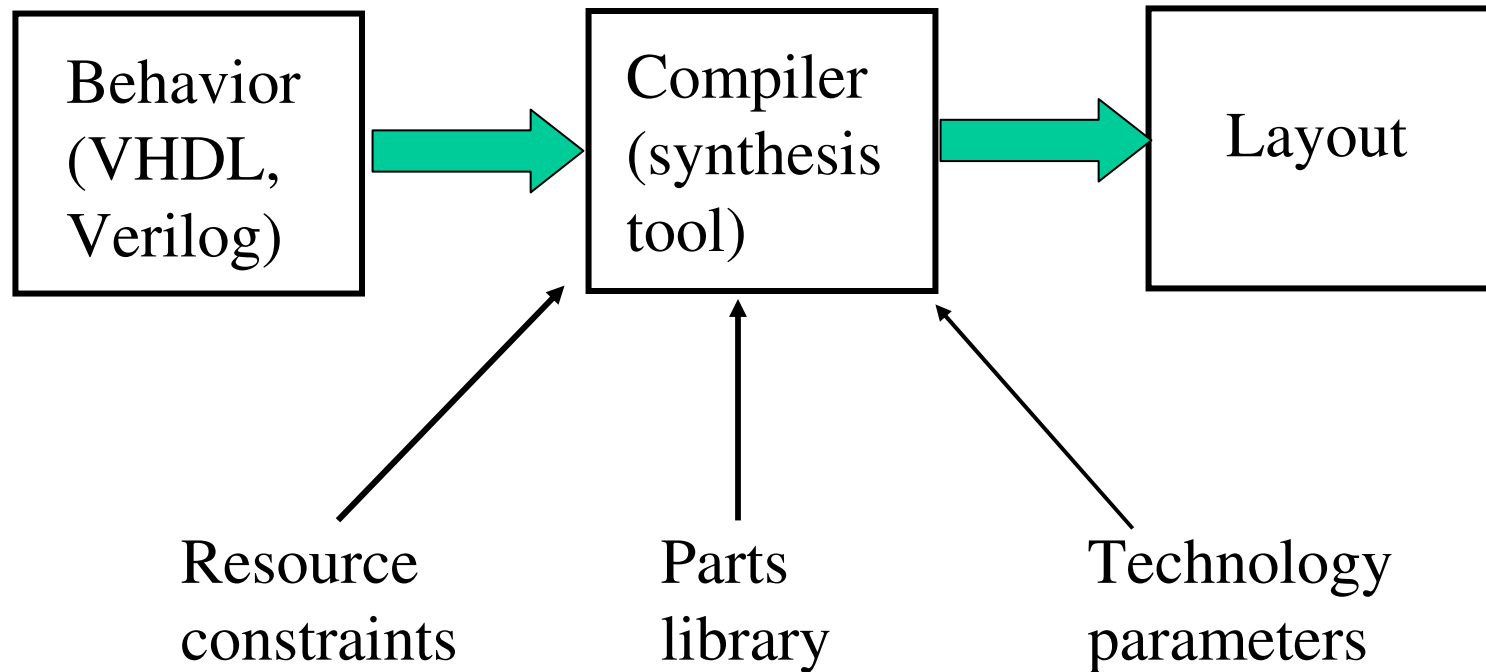
- Synthesis tools
 - Behavioral synthesis
 - Logic synthesis
- Design capture
- Design verification

Synthesis Tools



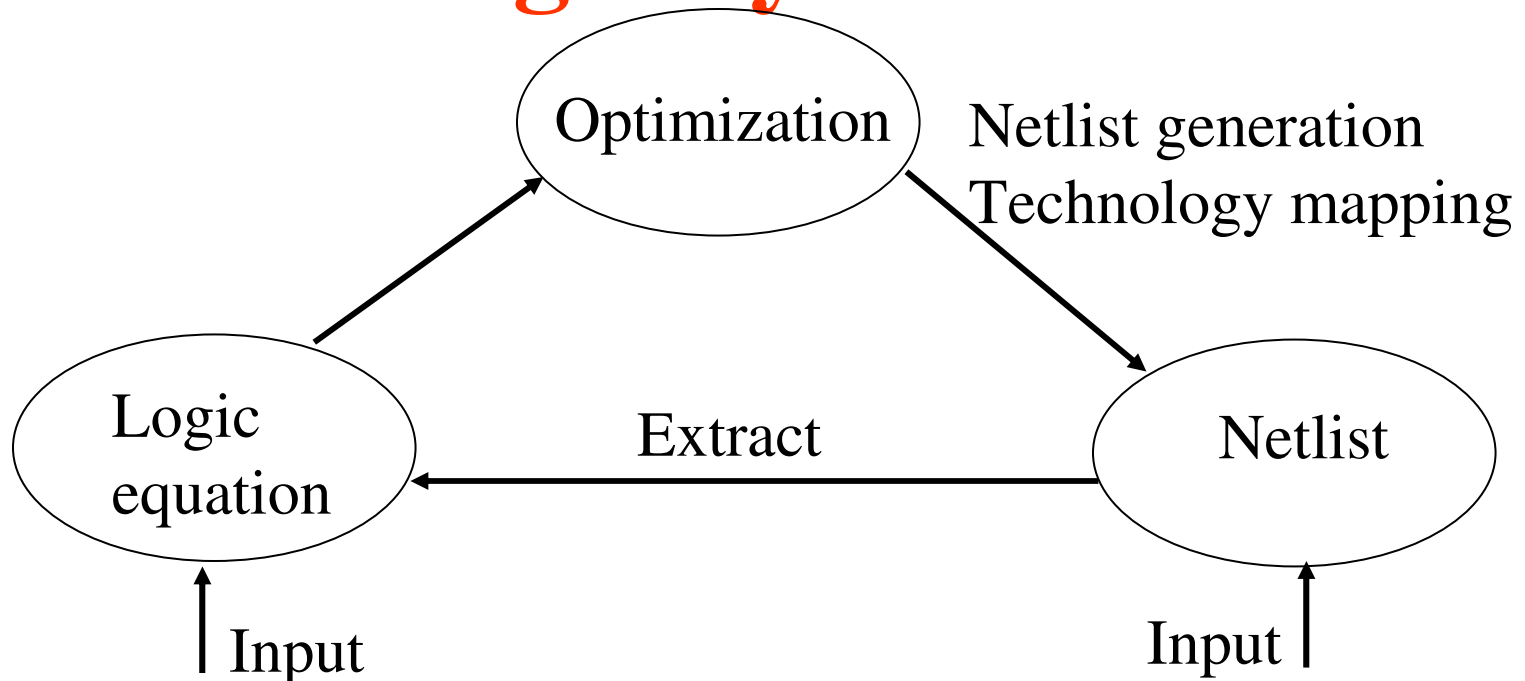
- Specify system behavior without implementation details
- Allows fast simulation/verification
- Technology-independent
- Esp. successful for signal processing architectures
- Silicon compilers

Behavioral Synthesis



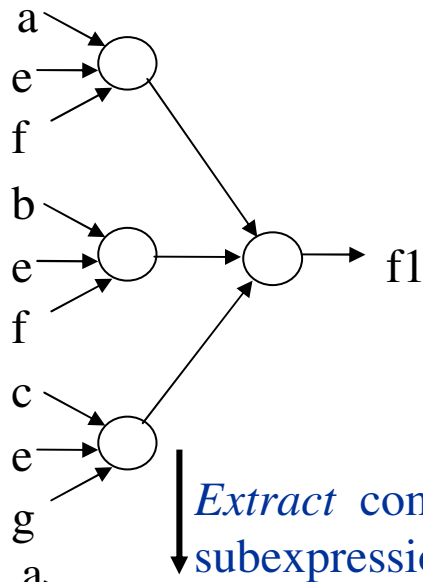
- Decide upon and assign resources (scheduling and binding)
- Insert pipeline registers to meet timing constraints
- Create microcode and control logic

Logic Synthesis

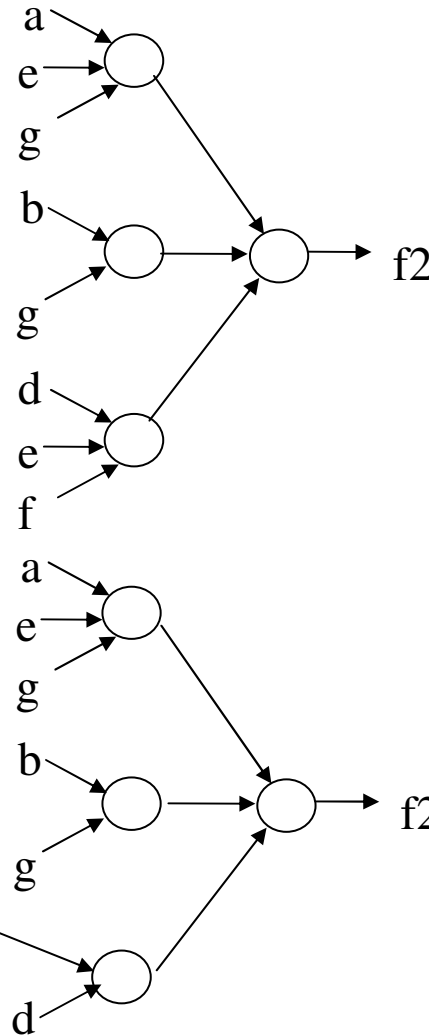
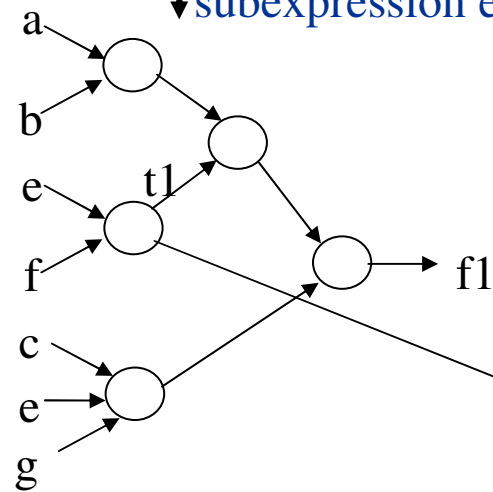


- Technology-independent: use Boolean and/or algebraic techniques
 - Network optimization, two-level and multi-level minimization
- Technology-mapping phase: cell binding

Logic Optimization Example



Extract common subexpression ef



$$f1 = aef + bef + ceg$$

$$f2 = aeg + bg + def$$

Literal count = 17

$$f1 = (a+b)t1 + ceg$$

$$f2 = aeg + bg + dt1$$

Literal count = 15

Design Capture Tools

- How to describe the behavior/structure of a system?
- HDLs: VHDL, Verilog
- High-level languages (HLLs): C, Pascal, Lisp
- HDLs differ from HLLs by catering for hardware concepts: bit vectors, signals, timing
 - Like HLLs, HDLs provide structure, parameterization, conditionals, looping, hierarchy
- Structure specification: HDL, netlist editor
- Behavior specification: HDL, finite-state machines, Petri nets

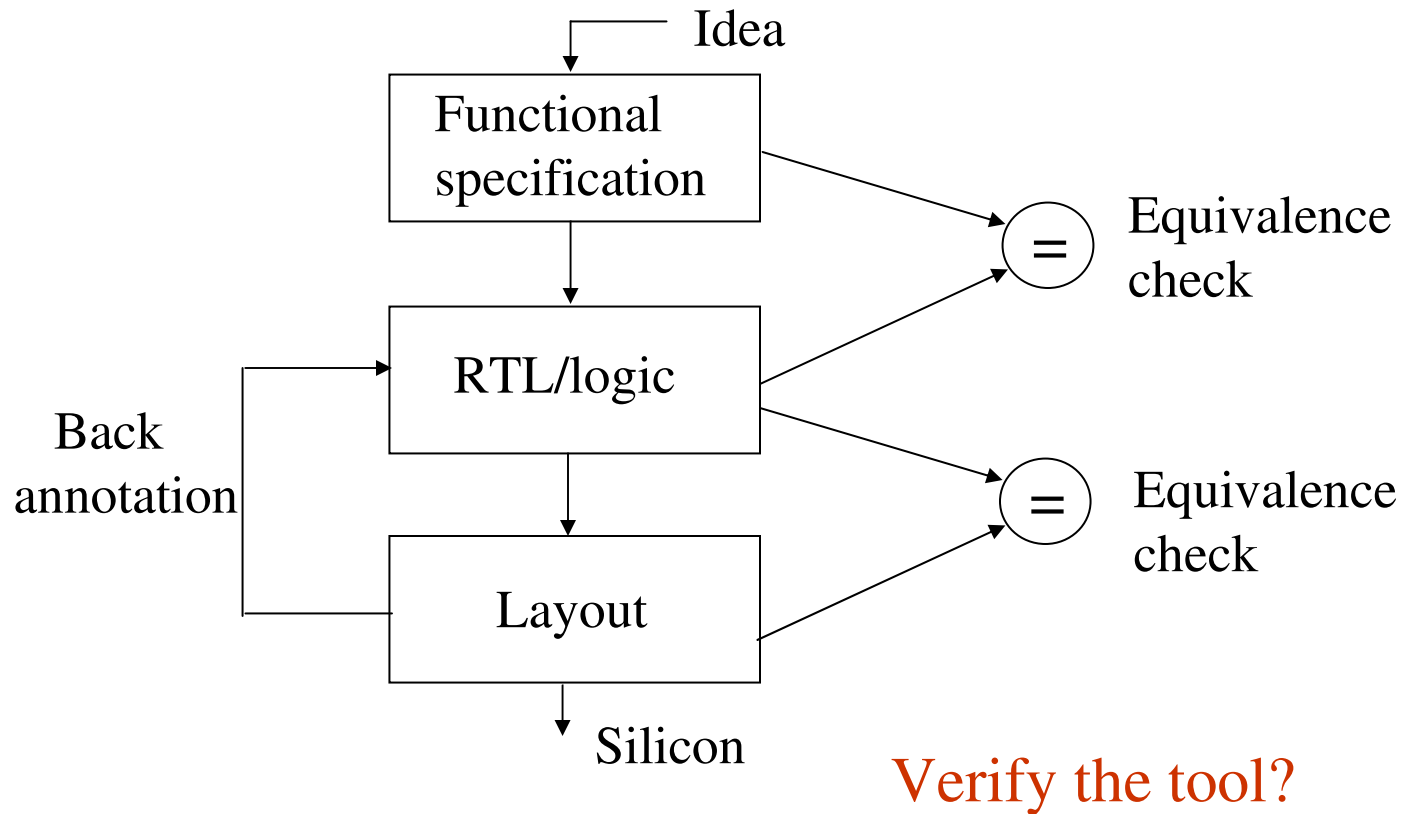
Schematic Entry

- Textual editor
- Easy to modify, make changes
- Suitable for more complex designs
- Interactive graphics editor
- Example: Mentor DA
- Diagrams are easily understood (“A picture is worth a thousand words”)

Layout Editors

- Captured via code: (cell/layout generators), silicon compilation
- Interactive graphics editors (Mentor IC)
- Means for turning off detail or zooming
- Design rule checking programs (DRC)
- Layout extraction programs
 - Determine netlist from layout

Design Verification



Design Verification

Simulation

Gate-level

Transistor, schematic-level (Qsim)

Circuit level (HSpice): high accuracy but high simulation times, $O(N^m)$, N transistors,

$0 < m < 1$

Formal verification: Mathematical models