

Logic Synthesis and Verification

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Course Info

Instructor

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Course webpage

<http://cc.ee.ntu.edu.tw/~jhjiang/instruction/courses/fall11lsv/lsv.html>

Email contact

Your official NTU email addresses will be used for future contact

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Grading Policy

Grading rules

- Homework 30%
- Programming assignments 10%
- Midterm 30%
- Project 30%
 - Presentation 5%
 - Final report 25%

Homework

- discussions encouraged, but write down solutions individually and separately
- due one week from the problem set is out except for programming assignments (due date will be specified)
- 20% off per day for late homework
- 6 homework assignments (peer-review grading)

Midterm

- in-class exam (schedule may/may not differ from the academic calendar)

Project

- oral presentation, final report

Report grading errors within one week after receiving notice.

Plagiarism and cheating are strictly prohibited (no credits for plagiarism).

References

- J.-H. R. Jiang and S. Devadas. *Logic Synthesis in a Nutshell*. (Chapter 6 of *Electronic Design Automation: Synthesis, Verification, and Test*), Elsevier 2009.
 - Downloadable handout
- F. M. Brown. *Boolean Reasoning: The Logic of Boolean Equations*. Dover, 2003.
 - Used in the introduction to Boolean algebra
- S. Hassoun and T. Sasao. *Logic Synthesis and Verification*. Springer, 2001.
- G. D. Hachtel and F. Somenzi. *Logic Synthesis and Verification Algorithms*. Springer, 2006.
- W. Kunz and D. Stoffel. *Reasoning in Boolean Networks: Logic Synthesis and Verification Using Testing Techniques*. Springer, 1997.

References (cont'd)

- Papers on course webpage

- Conference Proceedings

- ACM/IEEE Design Automation Conference (DAC)
- IEEE/ACM Int'l Conf. Computer-Aided Design (ICCAD)
- DATE, ASP-DAC
- Computer-Aided Verification (CAV)
- TACAS, FMCAD

- Journals

- IEEE Trans. on Computer-Aided Design
- IEEE Trans. on Computers

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Introduction

Reading:

Logic Synthesis in a Nutshell

Section 1

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Evolving Information Technology

□ The Industrial Revolution

- Application of power-driven machinery to manufacturing (1750 – 1830)

□ IT Revolution

- Application of electronic devices to information processing (1950 – present)

□ Electronic systems evolve in a fascinating speed

- Design challenges emerge and design paradigms shift in this evolution
- EDA tools change along the evolution

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Electronic Design Automation

- EDA tools aim at automating electronic system design and optimizing *most* design instances (not just some specific design)

- EDA is a field with rich applications from electrical engineering, computer science, and mathematics

- Electronics, circuit theory, communication, DSP, device physics, ...
- Algorithms, complexity theory, automata theory, logics, games, ...
- Probability, statistics, algebra, numerical analysis, matrix computation, ...

- EDA is one of the most advanced areas in practical computer science

- Many problems require sophisticated mathematical modeling
- Many algorithms are computationally hard, and require advanced heuristics to work on realistic problem sizes

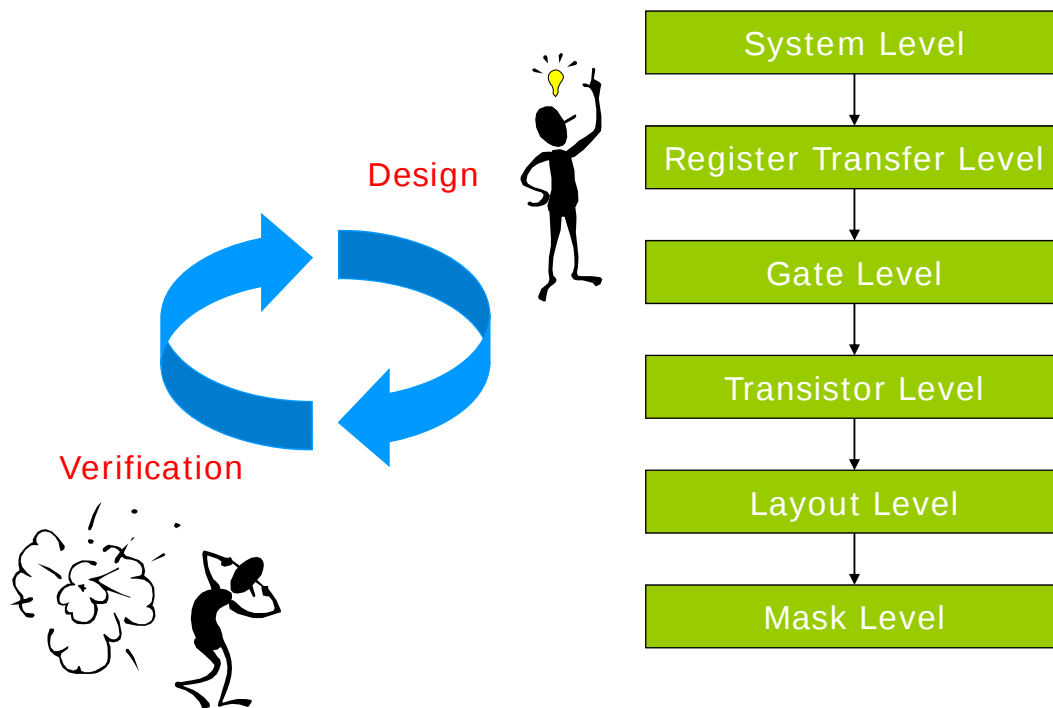
- EDA is a very good workplace for software engineers

- E.g., modern SAT solvers (GRASP, Chaff, BerkMin, MiniSAT) are developed in the field of EDA



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VLSI Design Flow & Abstraction Levels



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System Level

□ Abstract algorithmic description of high-level behavior

■ E.g., C-programming language

```
Port*
compute_optimal_route_for_packet(Packet_t *packet,
                                Channel_t *channel)
{
    static Queue_t *packet_queue;

    packet_queue = add_packet(packet_queue, packet);
    ...
}
```

- abstract because it does not contain any implementation details for timing or data
- efficient to get a compact execution model as first design draft
- difficult to maintain throughout project because no link to implementation

Register Transfer Level

- Cycle accurate model “close” to the hardware implementation
 - bit-vector data types and operations as abstraction from bit-level implementation
 - sequential constructs (e.g. if - then - else, while loops) to support modeling of complex control flow

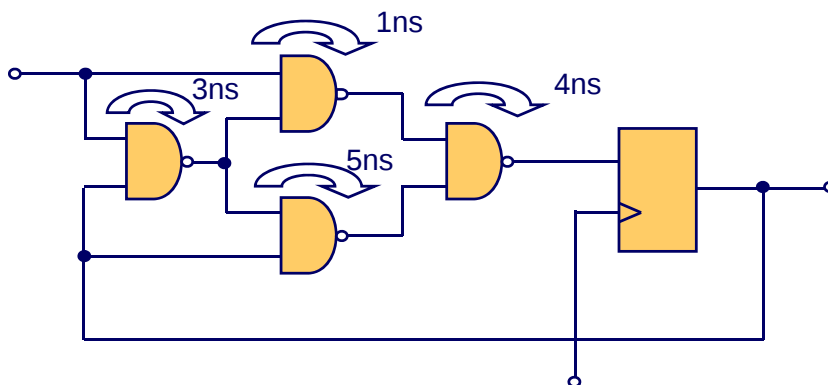
```
module mark1;  
  reg [31:0] m[0:8192];  
  reg [12:0] pc;  
  reg [31:0] acc;  
  reg[15:0] ir;  
  always  
  begin  
    ir = m[pc];  
    if(ir[15:13] == 3b'000)  
      pc = m[ir[12:0]];  
    else if (ir[15:13] == 3'b010)  
      acc = -m[ir[12:0]];  
    ...  
  end  
endmodule
```

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Gate Level

- Model on finite-state machine level
 - models function in Boolean logic using registers and gates
 - various delay models for gates and wires

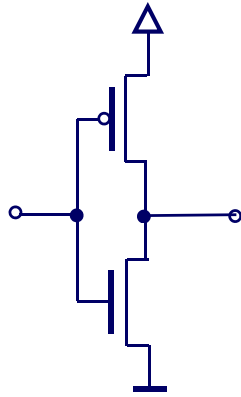


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Transistor Level

- Model on CMOS transistor level
 - Binary switches used for function modeling
 - E.g., in functional equivalence checking
 - Differential equations used for circuit simulation
 - E.g., in timing/waveform analysis

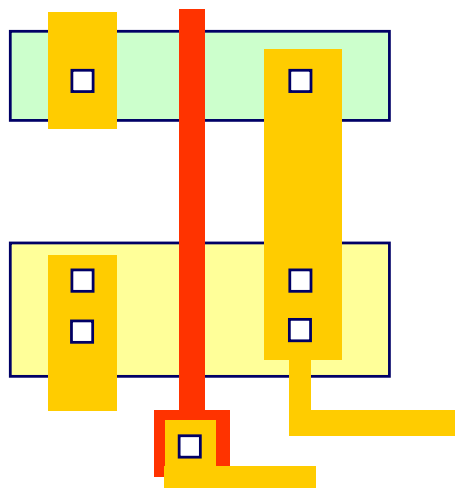


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Layout Level

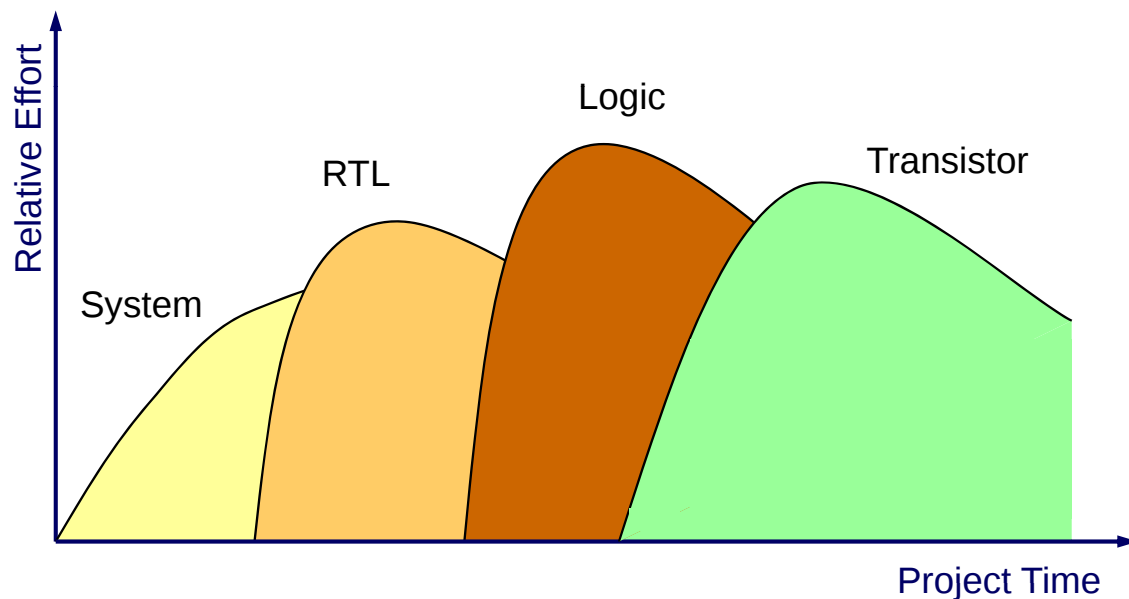
- Transistors and wires are laid out as polygons in different technology layers such as diffusion, poly-silicon, metal, etc.



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Integrated System Design



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General Design Approaches

□ Divide and conquer !

- partition design problem into many sub-problems which are manageable
- define mathematical model for sub-problem and find an algorithmic solution
 - beware of model limitations and check them !
- implement algorithm in individual design tools, define and implement general interfaces between the tools
- implement checking tools for boundary conditions
- concatenate design tools to general design flows which can be managed
- see what doesn't work and start over

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Full Custom Design Flow

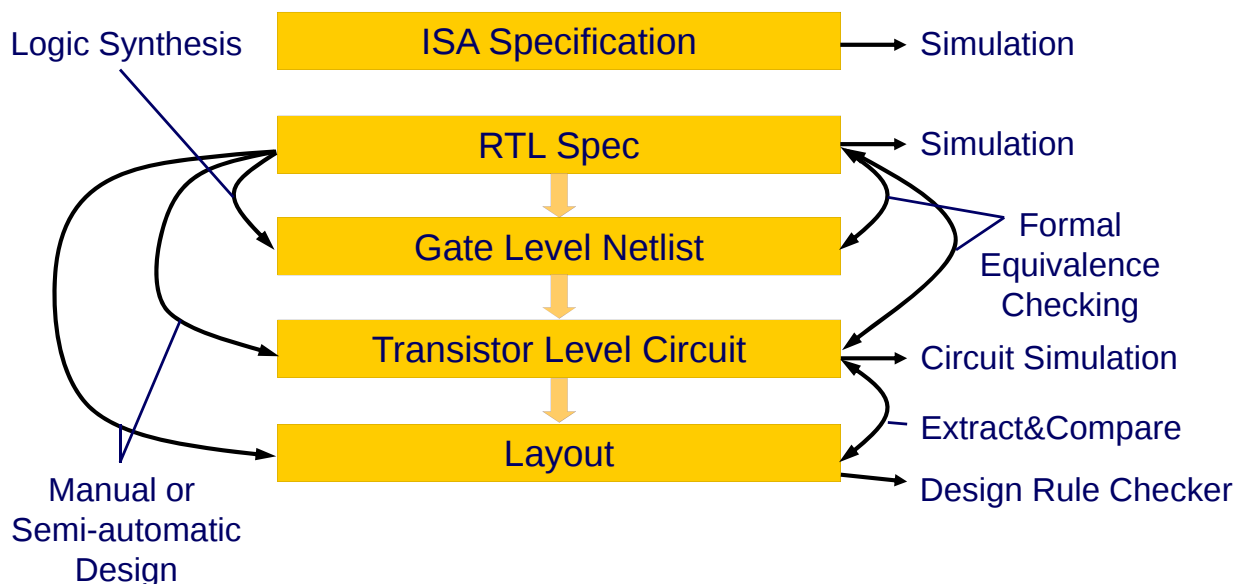
- ❑ Application: ultra-high performance designs
 - general-purpose processors, DSPs, graphic chips, internet routers, game processors, etc.
- ❑ Target: very large markets with high profit margins
 - e.g. PC business
- ❑ Complexity: very complex and labor intense
 - involving large teams
 - high up-front investments and relatively high risks
- ❑ Role of logic synthesis:
 - limited to components that are not performance critical or that might change late in design cycle (due to design bugs found late)
 - ❑ control logic
 - ❑ non-critical data-path logic
 - bulk of data-path components and fast control logic are manually crafted for optimal performance

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Full Custom Design Flow

(incomplete picture)



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ASIC Design Flow

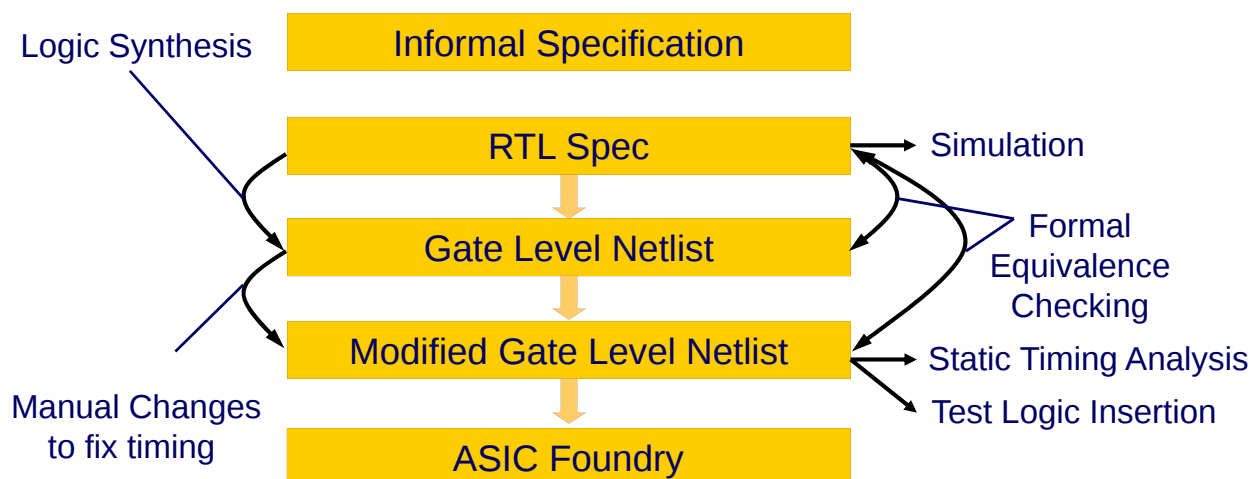
- ❑ Application: general IC market
 - peripheral chips in PCs, toys, handheld devices, etc.
- ❑ Target: small to medium markets, tight design schedules
 - e.g. consumer electronics
- ❑ Complexity of design: standard design style, quite predictable
 - standard flows, standard off-the-shelf tools
- ❑ Role of logic synthesis:
 - used on large fraction of design except for special blocks such as RAM's, ROM's, analog components

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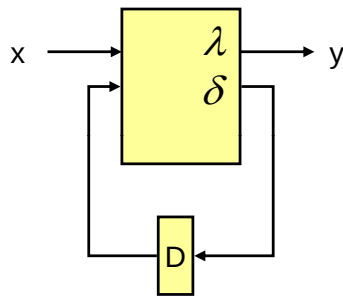
ASIC Design Flow

(incomplete picture)



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What Is Logic Synthesis About?



Given: Finite-State Machine $F(Q, X, Y, \delta, \lambda)$ where:

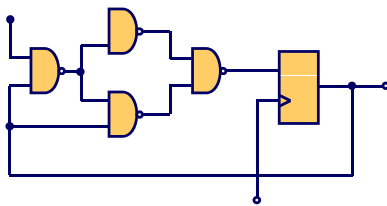
Q : Set of states

X : Input alphabet

Y : Output alphabet

$\delta: X \times Q \rightarrow Q$ (next-state function)

$\lambda: X \times Q \rightarrow Y$ (output function)



Target: Circuit $C(G, W)$ where:

G : set of circuit components $g \in \{\text{Boolean gates, flip-flops, etc.}\}$

W : set of wires connecting G

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Why Is Logic Synthesis Useful?

- ❑ Core logic optimization technique in today's EDA flows for IC and system design
- ❑ Broad applications in hardware model checking, software verification, program synthesis, and other areas besides circuit optimization
 - Synthesis and verification are two sides of the same coin
- ❑ Good subject to get acquainted to Boolean reasoning

Brief History

- ❑ 1847: Boole's "algebra of logic"
- ❑ 1937: Shannon's M.S. thesis, *A Symbolic Analysis of Relay and Switching Circuits*
- ❑ 1950s: Quine's minimization theory of Boolean formulas
- ❑ 1958: Kilby's invention of IC
- ❑ 1960s: ATPG D-Algorithm for Boolean reasoning
- ❑ 1970s: two-level logic minimization for PLA,
 - IBM introduced formal equivalence checking in computer design in 1978 and logic synthesis for gate array based design in 1979
- ❑ 1980s: multi-level logic minimization, FSM optimization, technology mapping, BDD, symbolic equivalence checking
 - Synopsys founded in 1986
 - ❑ first product "remapper" between standard cell libraries
- ❑ 1990s: sequential circuit optimization, don't care computation, FPGA synthesis, SAT, low-power synthesis, physical-aware logic synthesis, hardware property checking
 - More companies founded including Ambit, Compass, Synplicity, Magma, Monterey, ...
- ❑ 2000s: large-scale logic synthesis, synthesis for reliability, synthesis for emerging technologies, statistical analysis and optimization

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Course Outline

- ❑ Representation of Boolean functions and basic algorithms
 - Boolean functions, formulas, circuits, SOP and POS representations, BDDs
 - Efficient data structures and algorithms for Boolean reasoning
- ❑ Combinational circuit optimization
 - Technology-independent two-level/multi-level logic optimization
 - Technology mapping
- ❑ Timing analysis and optimization
- ❑ Sequential circuit optimization
 - Clock skewing, retiming and resynthesis
- ❑ Formal verification
 - Reachability analysis
 - Formal equivalence checking
 - Safety property checking
- ❑ Logic synthesis and verification tool
 - ABC

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