Lecture 1.
Course Overview

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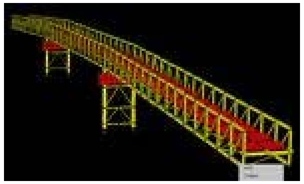
Outline

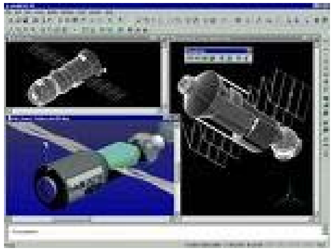
- **Course overview**
- **CAD basics**
- **Project-based learning and teamwork**
- **What is EDA?**
- **Top 10 algorithms in 20th century**

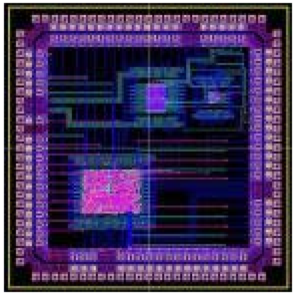
What to learn in this course?

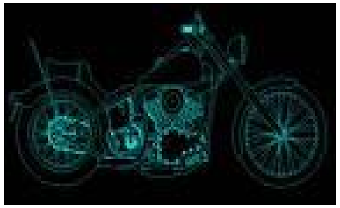
- **Learn software skills for Design Automation**
- **Get familiar with Linus OS or CYGWIN**
- **Learn GUI programming toolkits**
  - **GTK, Qt, or others**
- **Learn compiler tools**
  - **Yacc and Bison**
  - **PCCTS**
- **Learn principles of circuit simulation**
  - **to construction methods and sovling algorithms**

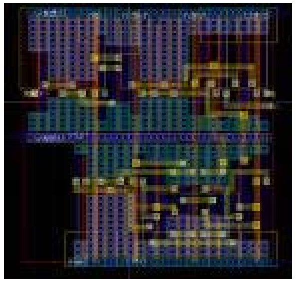
Computer-Aided Design (CAD)



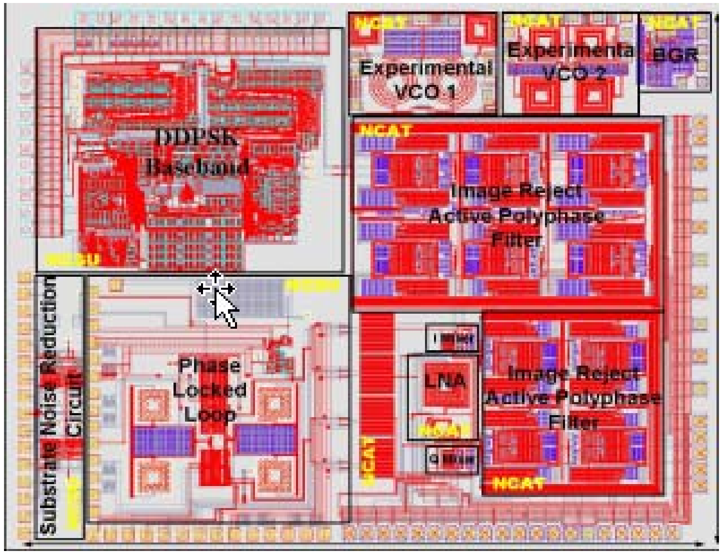


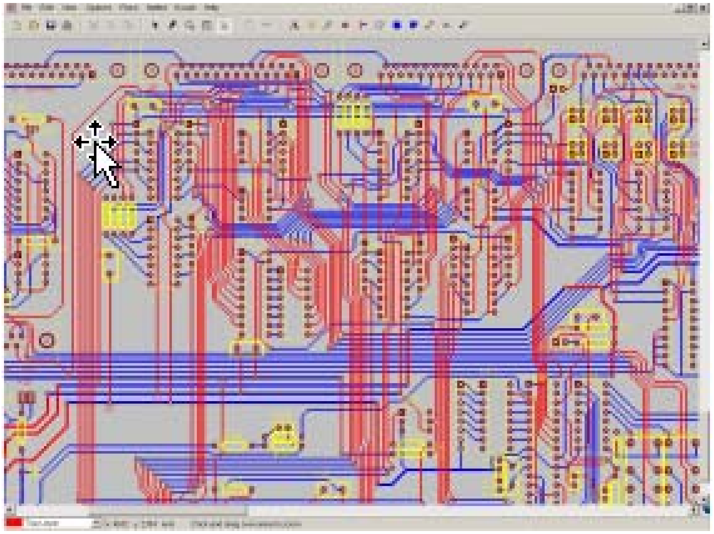


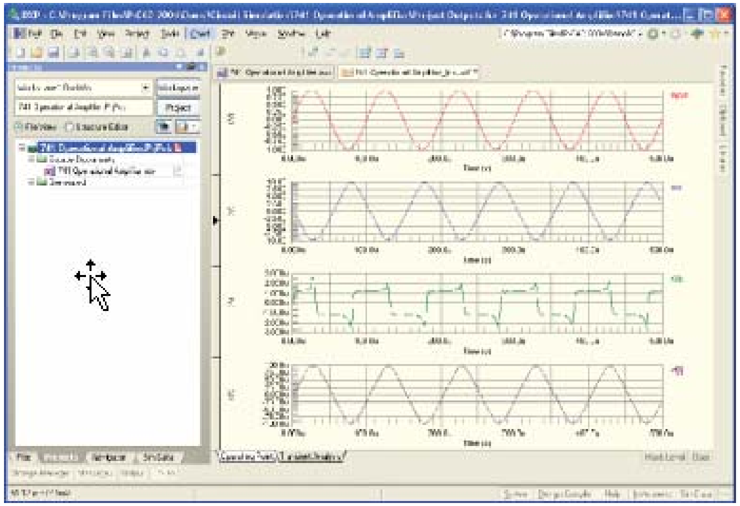


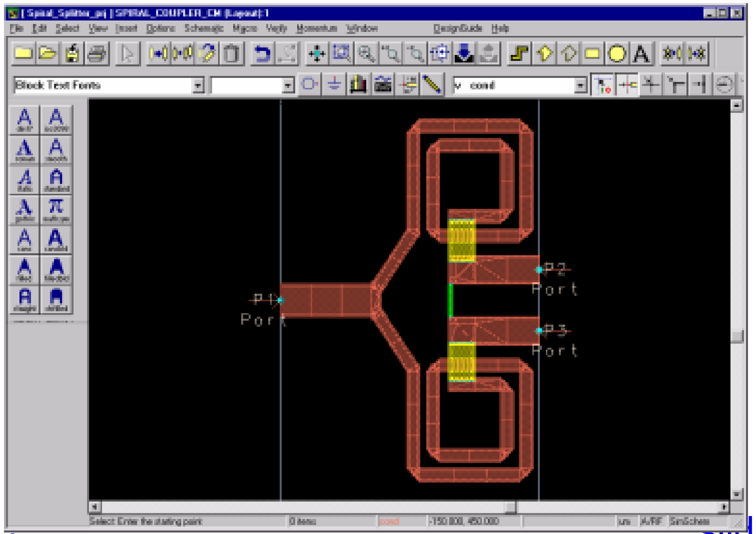


CAD for Integrated Circuits (IC)

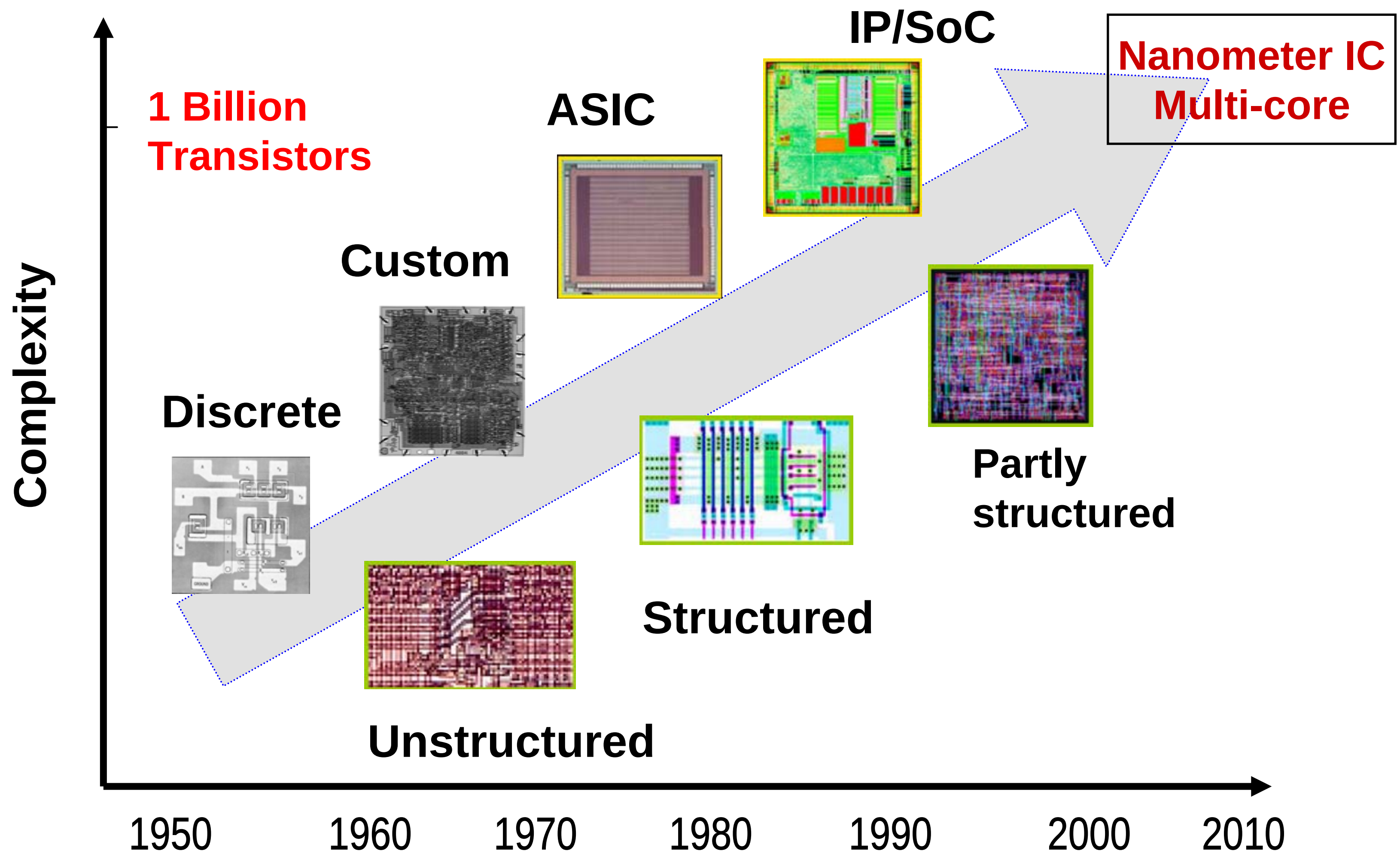








The VLSI Roadmap



EDA = VLSI CAD

- **EDA = Electronic Design Automation**
- **EDA is another name for Computer-Aided Integrated Circuit Design**

- **EDA as an area born with the IC industry.**
- **EDA is application science and technology.**
- **EDA is part of the software industry**

What this course is and is not

- **This course does <u>not</u> teach how to use EDA tools**
  - **you learn them in IC design courses**

- **This course teaches the basic principles on how to develop EDA software.**
  - **You mainly learn how a SPICE simulator is developed.**

Who should learn this course

Those who are interested in

- **challenging software programming.**
- **circuit simulation.**
- **analog/RF circuit design.**
- **a career in EDA industry**

Textbook & Webpage

- **Textbook**
  - **No official textbook is used**
  - **You must come to attend all lectures!**

- **Course webpage**
  - **http://edalab.sjtu.edu.cn/moodle/**
  - 集成电路设计/**EDA**引论
  - **password: ugradeda**

  - **For downloading course materials**
  - **For uploading finished homework, etc.**

Good Reference Books

1. **T.L. Pillage, R.A. Rohrer, C. Visweswariah, *Electronic Circuit and System Simulation Methods*, McGraw-Hill, Inc., 1995.**
2. **C.K. Cheng, J. Lillis, S. Lin and N. Chang, *Interconnect Analysis and Synthesis*, John Wiley & Sons, Inc., 2000.**

... but are not required.

Instructor & TA

- **Instructor**
  - 施国勇 教授
  - **shiguoyong@ic.sjtu.edu.cn**

- **TA:** 徐辉 （**master student**）
  - **xuhui@ic.sjtu.edu.cn**

Instructor Office Hours

- **Tuesday: 1:00-2:00pm**
- **Thursday: 1:00-2:00pm**
- **Or appointment by email**

- **Office: School Building, Room 415**

- **TA office hours will be posted on the course webpage**

Course Structure & Grading

- **3 hours x 17 weeks = 51 hours**
- **Lectures + Projects + HW + Final Exam**

- **Grading policy (for reference)**
  - **(30%) Lecture-based assignments (HW);**
  - **(40%) A Spice simulator (team work)**
    - **Midterm seminar;**
    - **Term seminar -- team presentation & simulator demo;**
    - **Final report (individual)**
  - **(30%) Final Exam (based on lectures)**

Course Goals

- **Learn to develop "large" C/C++ programs.**
  - **Upgrade your programming skills**
- **Learn how to make your programs "visible" (GUI programming).**
- **Learn to formulate circuit problems for programming.**
- **Learn to solve circuit problems by efficient algorithms.**

- **Long-term goal –**
  - **To improve your software skills for a successful career.**
  - **Software techniques for EDA are equally useful in other technical areas.**

Programming Assignments

You have to finish **a series of programming assignments** in this course

- **Start from GUI programming;**
  - **Write "visible programs"**
- **Work out a small SPICE simulator step-by-step**
  - **Write the building blocks by assignments;**
- **From individual programming to team-based collaborative programming.**

Project-based Learning

- **Emphasized in this course!**
- **The project components:**
  - **Develop a GUI for your simulator**
  - **Develop a mini-SPICE simulator capable of simulating**
    - **R, C, L, Controlled Sources, (Diodes, MOSFETs)**
    - **DC analysis; AC analysis; Transient analysis; Error control; ...**
- **Teamwork**
  - **About 4 students in each team**
- **Learn to present your work well**
  - **Every student must present at least once**

Student Achievements Last Year

Students of year 2009

- **The best simulators could simulate *diodes, MOS transistors*;**
- **could do *DC, AC* + *Noise, Transient analysis, and error control*.**
  - **much better than the students of the year 2008.**

- **Reason:**
  - **The class-scale was reduced (about 20 students)**

Teamwork

- **Teamwork is emphasized in this course.**
- **Teams are set up in the first two weeks.**
- **Each team elects a team leader.**
- **The team leaders should**
  - **Coordinate job assignments inside team**
  - **Monitor project progress**
  - **Encourage innovative implementations**
  - **Regulate team member presentations**
    - **Every student should present at least once**

How to form teams?

- **Num of teams depending on registration**
  - **4 members in each team (recommended)**
- **Rough work-load divisions:**
  - **One for GUI**
  - **One for Parser**
  - **One for Solver**
  - **One for Analysis Tasks (DC/AC/Tran)**
- **Teams are not advised to change thru out the course.**
- **Teams are encouraged to compete by presentations and demos!**

Final Term Report

- **Every student should submit an individual final project report.**
  - **Should emphasize your own work in the team**
  - **Should include:**
    - **implementation details;**
    - **explanation of the code design; and**
    - **experimental results.**
  - **Attach the source code.**

- **Learn to write your final report like a technical paper.**

Your Individual Grade

- **The final grade of each student will be based upon**
  1. **Weekly assignments (have to turn in before due and get graded)**
  2. **The overall team performance**
  3. **Your individual contribution (seen from presentation, demo, and report)**
  4. **The final exam (everyone must take)**

Target of the Class Project

- **Develop a small circuit simulator**
  - **with GUI (for netlist input & waveform output)**
  - **with Netlist parser**
  - **with linear solver (for solving circuits)**
  - **capable of simulating basic circuit elements; including transistors**
  - **capable of DC/AC/Tran analyses and error control, etc.**

Assignments Policy

- **All assignments are due in one week (exceptions will be noted)**
  - **Turn in no later than a week after the assignment lecture is finished.**
- **Submit all finished assignment *electronically* to MOODLE.**
- **Without permission, no late turn-in will be graded.**
  - **So, be aware of the due!**

Academic Integrity

- **No tolerance to cheating!**
- **Any cheating in exams will lead to a Fail grade.**
- **Typical cheating behavior:**
  - **copy other student's assignments;**
  - **copy other student's code;**
  - **use earlier-year student's work;**
  - **cheating in exams.**

- **Students are encouraged to exchange ideas.**

A Brief Introduction to EDA

History of EDA

- **1960's for layout and routing tools**
- **1970's for circuit simulation – UC Berkeley SPICE**
- **1980's major EDA companies were founded in US**
- **1990's Verilog/VHDL languages pushed to market**
- **2000's Mainstream EDA companies stablized**

- **Future: New EDA tools for emerging design needs; ...**

Leading EDA Companies

- **Synopsys, Inc. (co-founded by Aart J. de Geus in 1986)**
  - **www.synopsys.com**
  - **Mountain View, California**
  - **Now has operation in Shanghai (over 400 employees)**
- **Cadence Design Systems, Inc. (founded 1987)**
  - **www.cadence.com**
  - **San Jose, California**
  - **Now has office in Shanghai (over 200 employees)**
- **Mentor Graphics Corp. (founded in 1981)**
  - **www.mentor.com**
  - **Wilsonville, Oregon**
  - **Mainly digital design and verification tools**
- **Magma Design Automation, Inc. (founded in 1997)**
  - **www.magma-da.com**
  - **Santa Clara, CA**

Leading EDA Companies (cont'd)

- **Ansoft Corporation**
  - **founded by Dr. Zoltan Cendes in 1984**
  - **www.ansoft.com**
  - **Pittsburgh, Pennsylvania (PA)**
  - **mainly on EM/RF design tools**
- **Taiwan SpringSoft (growing quickly)**
  - **www.springsoft.com**

EDA Research Publications

World-leading EDA journals

- **IEEE TCAD (started 1982)**
  - **IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems**
- **The following journals also publish CAD papers**
  - **IEEE Transactions on Circuits and Systems**
  - **IEEE Transactions on VLSI Systems**
  - **IEEE Transactions on Computers**
- **ACM TODAES (started 1996)**
  - **ACM Transactions on Design Automation of Electronic Systems**

Leading EDA Conferences

- DAC (1st in 1964; mainly in Silicon Valley, CA)
  - IEEE/ACM Design Automation Conference
  - www.dac.com
- ICCAD (1st in 1983; mainly in Silicon Valley, CA)
  - International Conference on Computer-Aided Design
  - www.iccad.com
- ASPDAC (1st 1995, mainly in Yokohama/Japan)
  - Asia-South Pacific Design Automation Conference
  - Top EDA conference in Asia
- DATE – Design, Automation and Test in Europe
  - www.data-conference.com
  - Top EDA conference in Europe (started 1989)

International EDA Organizations

- CEDA – Council on Electronic Design Automation
  - An organization of IEEE formed in 2005
  - To unify EDA-related IEEE activities among
    - Antennas and Propagation Society
    - Circuits and Systems Society
    - Computer Society
    - Electron Devices Society
    - Solid State Circuits Society
- The EDA Consortium
  - The trade association for electronic design companies
  - www.edac.org
- The European Design and Automation Association

EDA is a comprehensive area

- **EDA is "interdisciplinary"**
  - **Using knowledge from many technical areas**
- **EDA is important in that the whole IC industry relies on it!**
  - **From device to manufacturing to circuit design**
  - **to verification, ...**
- **EDA is comprehensive in the sense of**
  - **Knowledge; Research; Industry revenue;**
  - **Investment and global competition**
- **US universities and companies lead the whole EDA technology.**

EDA covers many subjects

- **Simulation (a big part)**
  - **Circuit simulation (HSpice, Spectre, ADS, ...)**
    - **Companies are developing faster simulators**
  - **Mixed-technology simulation (electrical/mechanical/thermal...)**
- **Device Modeling**
  - **Modeling new devices for commercial simulators**
- **Synthesis**
  - **Logic synthesis**
    - **From language description to gate-level synthesis to placement and route**
  - **High-level (system-level) synthesis**
    - **Use high-level languages (C/C++; MATLAB) for IC design.**

EDA sub-areas (cont'd)

- **Physical Design Automation**
  - Placement and Routing
  - Timing analysis
  - Signal integrity / power analysis
  - Clock tree / mesh synthesis
- **Electromagnetic (EM) Simulation**
  - HFSS (Ansoft)
  - FEMLAB
  - EEsof (Agilent)

EDA sub-areas (cont'd)

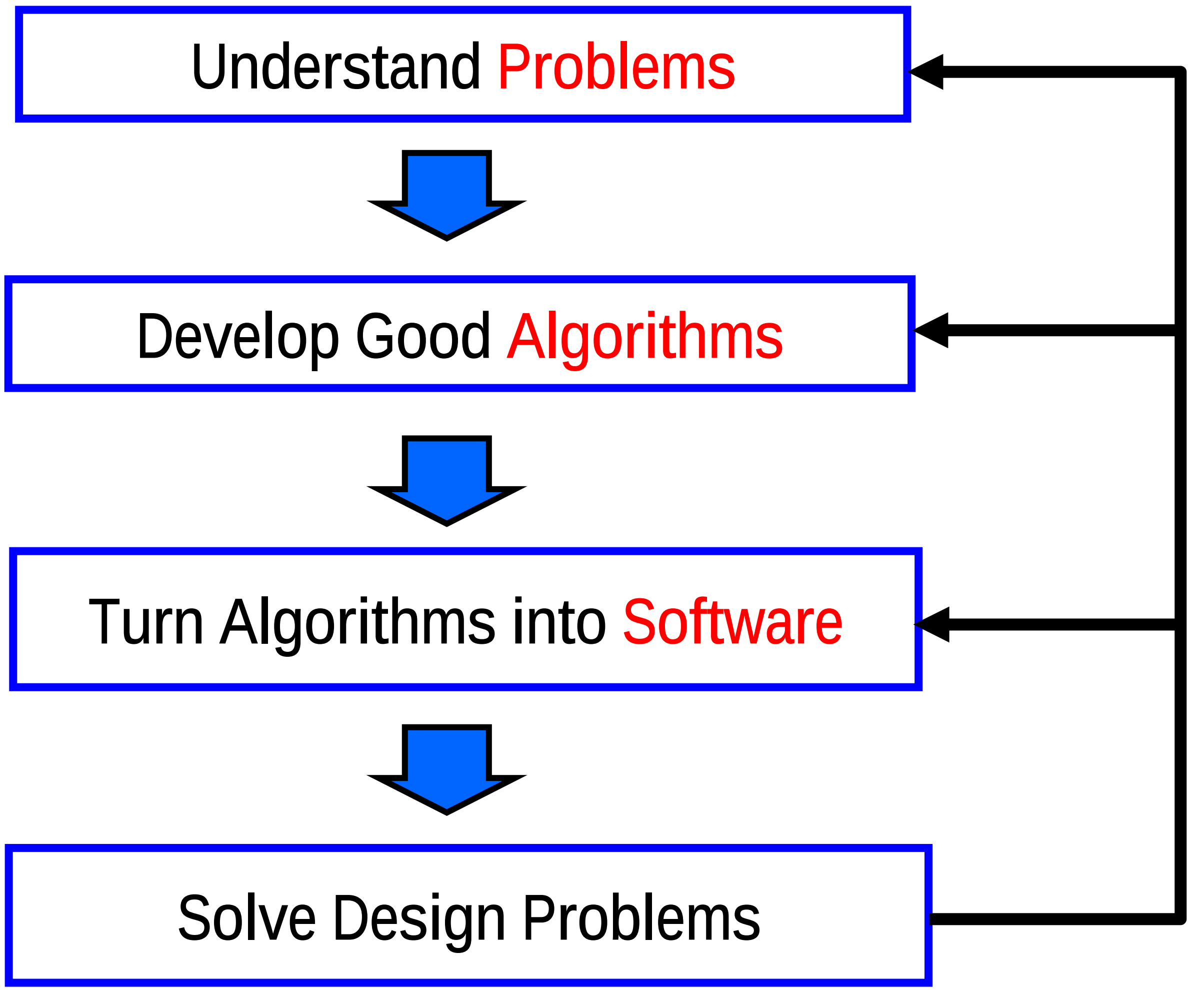
- **Verification and Testing Tools**
  - **Demanding innovations**

- **Design automation tools for embedded systems**
  - **FPGA design tools**
  - **DSP design tools**
  - **ESL**
  - **Algorithmic Synthesis**
- **...**

Knowledge Base for EDA

- **Microelectronics**
  - **Device physics; circuit design; tools experience**
- **Electrical engineering in general**
  - **Signal theory and transforms; linear system theory; circuit analysis;**
- **Mathematics**
  - **Linear algebra; differential equations; numerical methods; graph theory; optimization theory; ...**
- **Computer Science**
  - **C/C++ programming; compiler; parallel computing; software engineering; ...**

Typical Practice in EDA



Circuit Simulation

- The focus of this course.
- Necessary Components for Circuit Simulation
  - Description of circuit (Netlist)
  - Internal representation of circuit in simulator
    - Lots of data structures
  - Models for all possible circuit elements
    - R, C, L, Sources (dependent, independent)
    - Diodes; Transistors
    - Transmission Lines
    - Switches Transformer
    - ...
  - Simulation engine for analysis (cont’d next)

Circuit Simulation (cont'd)

- Simulation engine for analysis
  - Linear solver
  - Nonlinear iteration
  - Time-domain analysis (transient)
  - Frequency-domain analysis (frequency response)
  - Harmonic Balance Analysis (in RF design)
  - Noise analysis
  - Sensitivity analysis
- Presenting waveforms to the user
  - Graphical plots; Text files
  - Scripts
  - Large amount of data !

A Brief History of SPICE

- SPICE
  - Simulation Program with Integrated Circuit Emphasis
- Originally developed at UC Berkeley as a course project in the 1970's
- Once called CANCER:
  - Computer Analysis of Nonlinear Circuits Excluding Radiation (by Prof. Ronald Rohrer)
- PSpice = PC version
- HSpice = Industry Standard
  - Shawn & Kim Hailey, founders of Meta Software

http://en.wikipedia.org/wiki/SPICE

Types of Analysis

- **DC Analysis (single point)**
- **DC Transfer Analysis (DC sweep)**
- **AC Analysis (frequency-domain)**
- **Transient Analysis (time-domain)**
- **Noise Analysis (analog/RF)**
- **Distortion Analysis (analog/RF)**
- **Sensitivity Analysis (analog/RF)**
- **...**

Flow of Circuit Simulation

Input

Netlist

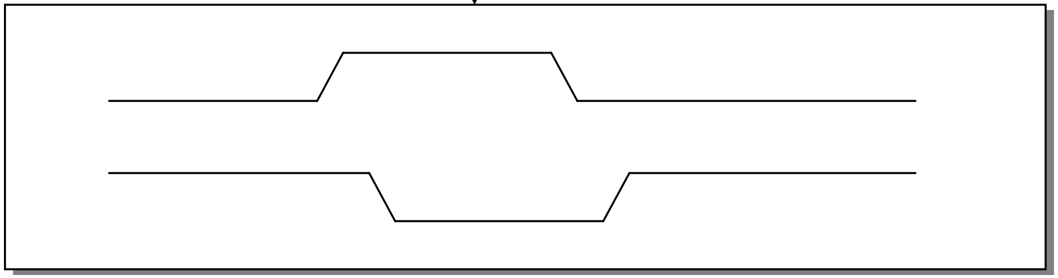
C3 3000 0 .. 0010P
C4 3000 0 .. 0010P
.. .. ..

M1 1 1000 1000 0 DMOS W=2u L=2U

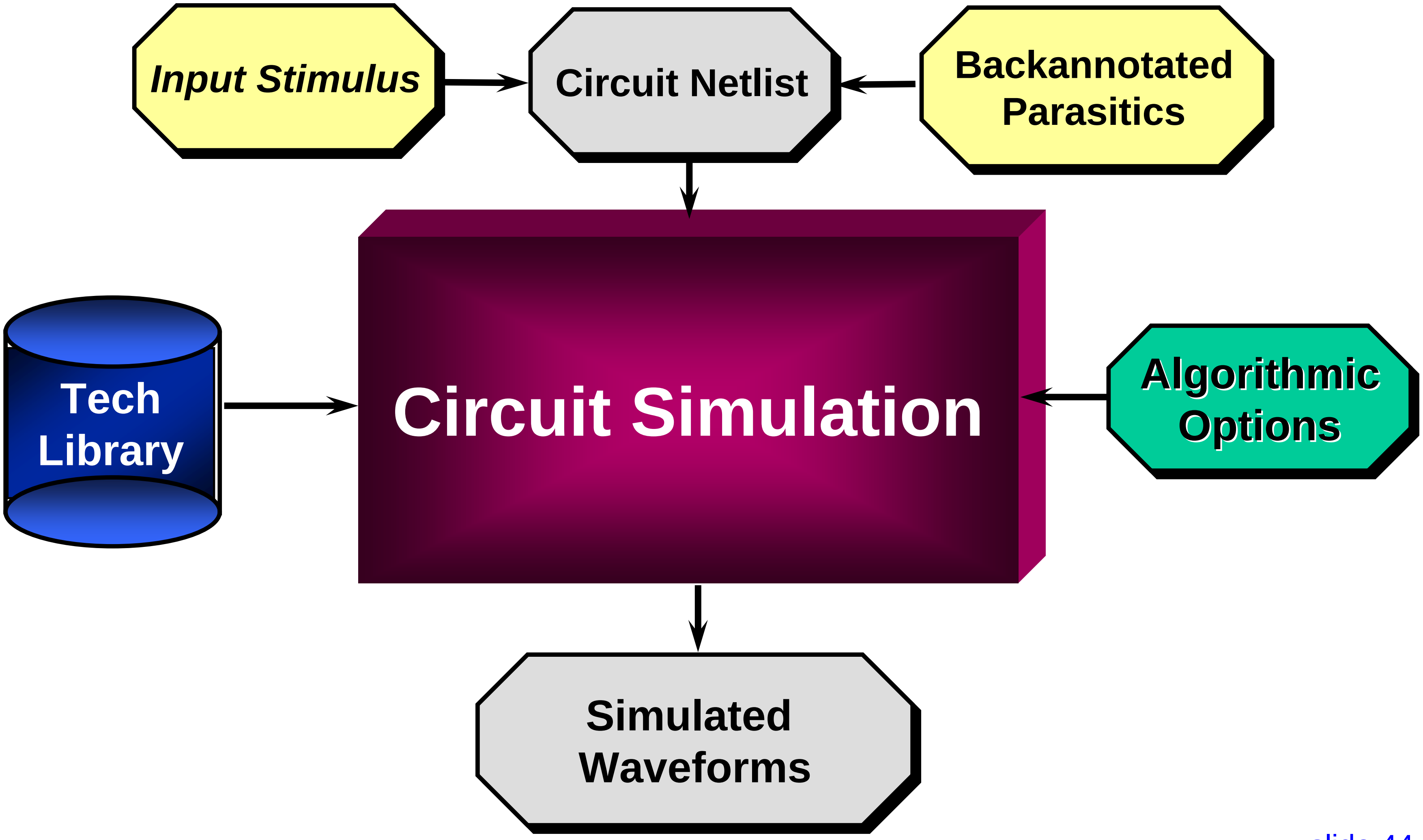
Simulation Engine

Solve
$dx / dt = f(x)$

Output Waveform



Circuit Simulator Components

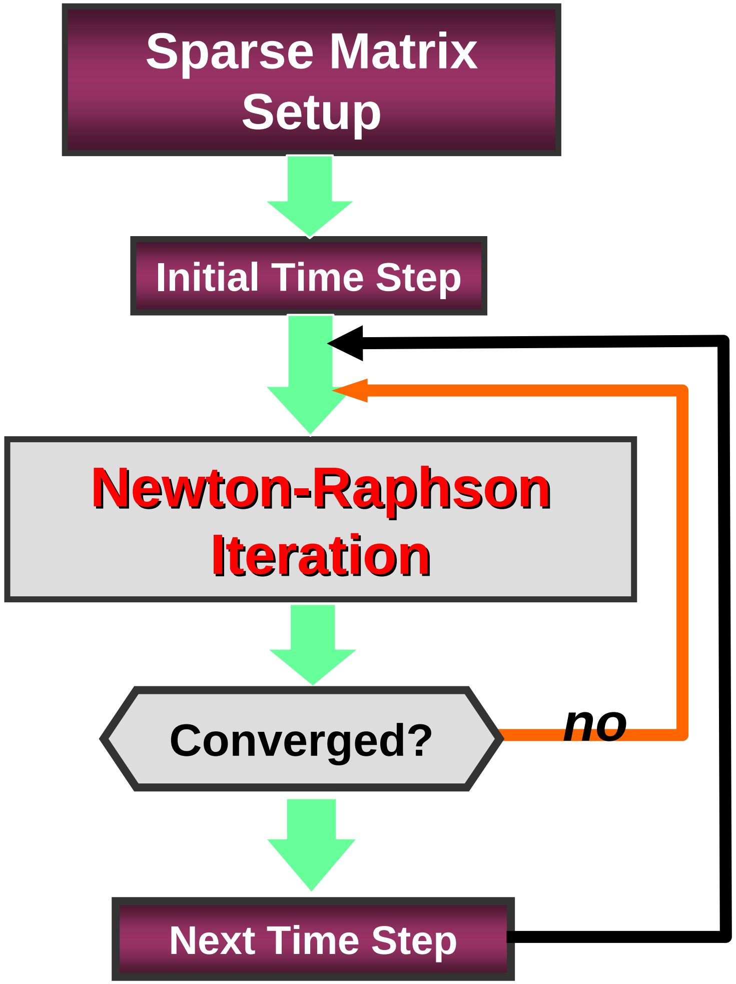


The Simulation Engine

- **Solving a "sparse" nonlinear system.**
- **Simulation speed depends on model and solver efficiency and simulator architecture.**

$$C(x)\frac{dx}{dt}+G(x)=B(u)$$

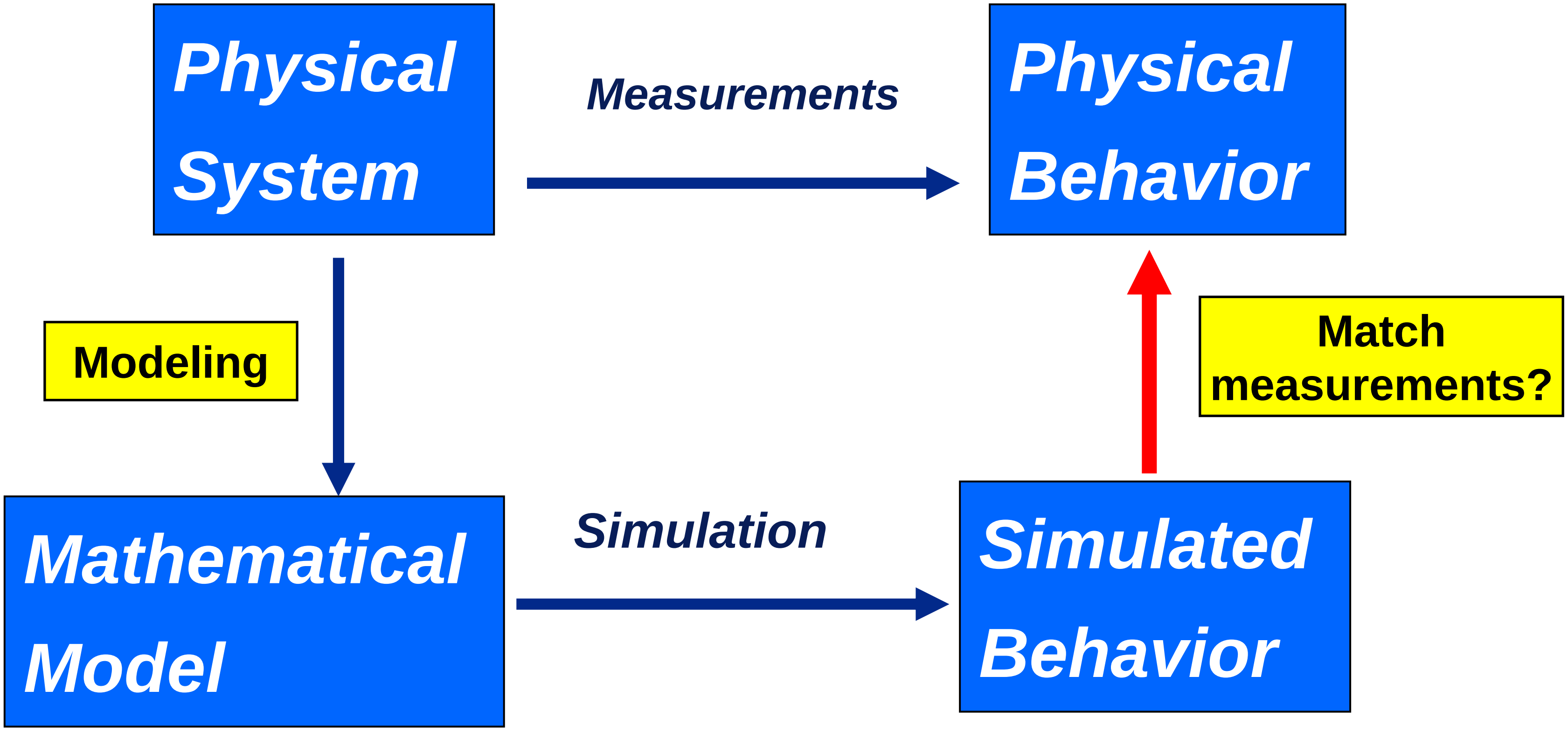
$\Leftrightarrow$



Modeling vs Simulation

- **Modeling is a big part of simulation.**
- **Spice simulation requires *accurate* but *efficient* models.**
- **IC devices (and interconnects) are getting increasingly complicated**
  - **in numbers and structure**
- **Simulation speed will never be "too fast"!**

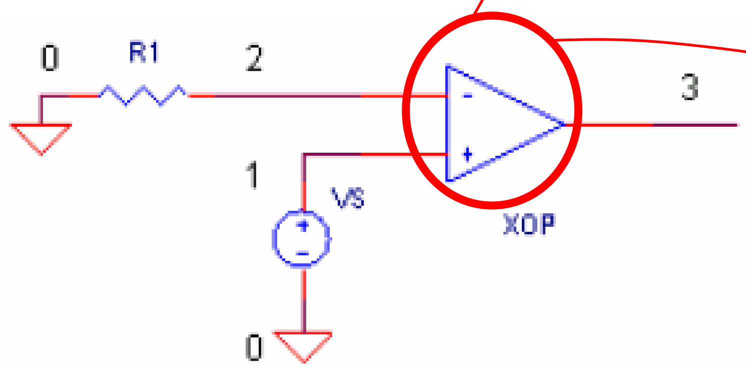
The Practice of Modeling

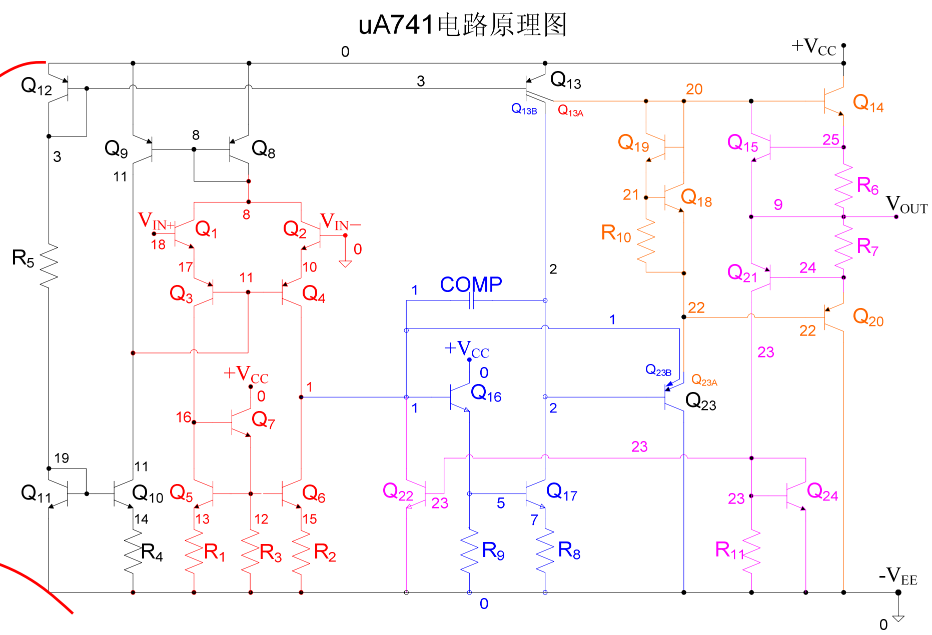


Design also needs modeling

- **Models are not just for simulation.**
- **Designers use lots of simplified macro-models to speed up analysis and prediction.**
- **Models in simulators are hard-coded; designers cannot simply change.**
- **Designers need skills and knowledge to develop good macro models.**

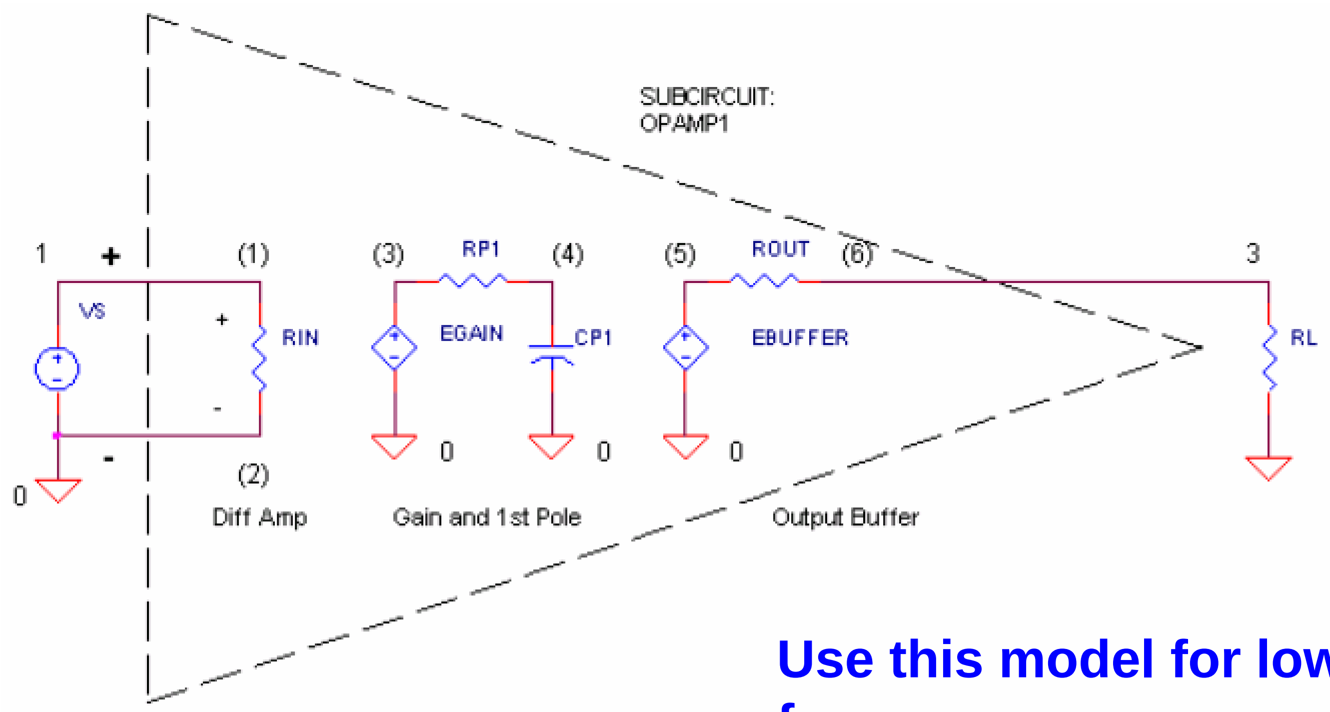
An Op-amp Modeling Example





Transistor-level bipolar op-amp circuit

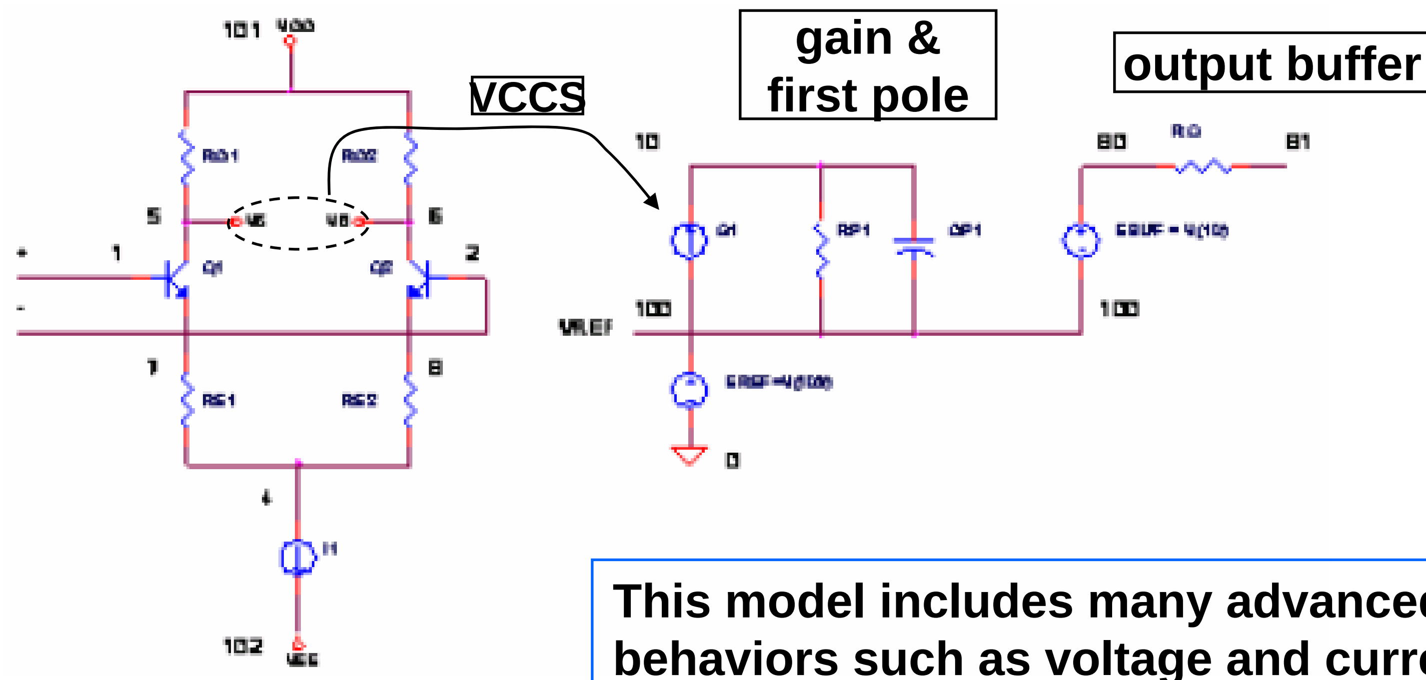
Basic Op-amp Model



Use this model for low-frequency response and DC.

http://www.ecircuitcenter.com/OpModels/OpampModels.htm

Intermediate Level Model

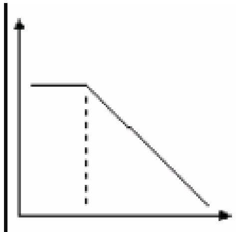
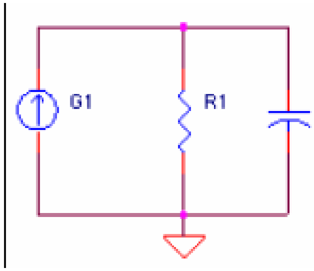
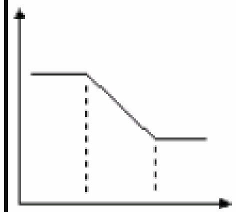
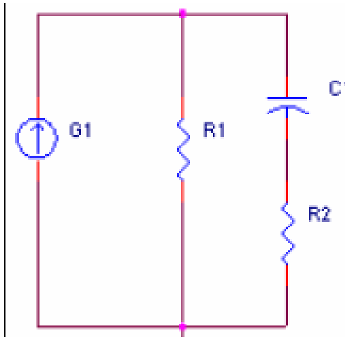
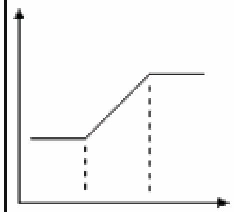
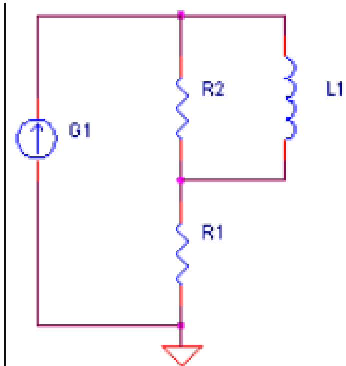


differential amplifier

This model includes many advanced behaviors such as voltage and current limit, CMR behavior, and poles and zeros.

Can be used for slew rate simulation,

Frequency Shaping Stages

POLE STAGE			$C1 = \frac{1}{2 \cdot \pi \cdot R1 \cdot fp}$
POLE / ZERO STAGE fp < fz			$R2 = \frac{R1}{\left(\frac{fz}{fp} - 1\right)}$ $C1 = \frac{1}{2 \cdot \pi \cdot R2 \cdot fz}$
ZERO / POLE STAGE fz < fp			$R2 = \left(\frac{fp}{fz} - 1\right) \cdot R1$ $L1 = \frac{R2}{2 \cdot \pi \cdot fp}$

Can be used for modeling freq response of op-amps.

More Advanced Modeling Needs

Interconnect modeling for

-- Timing;

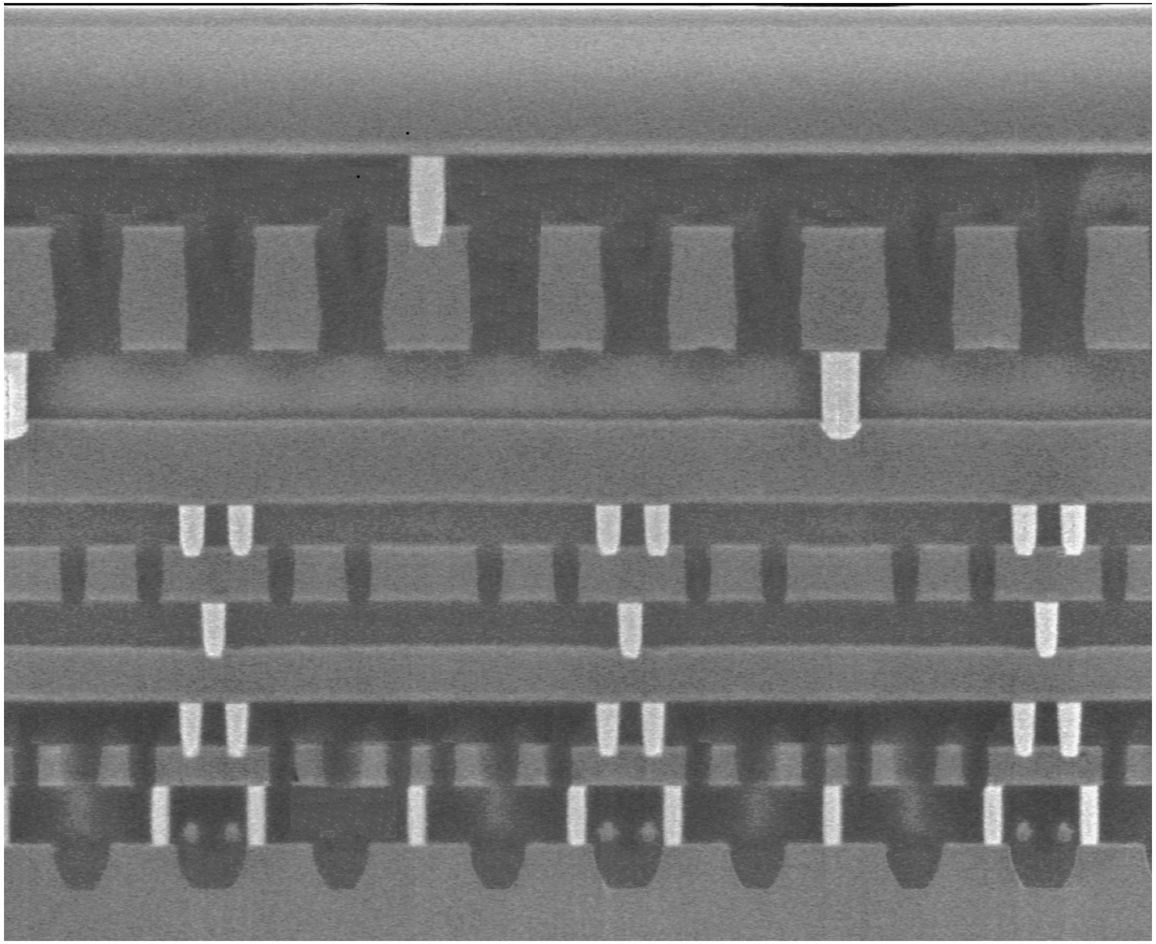
-- Signal integrity;

-- Power delivery; ...

Main challenges:

-- Complexity

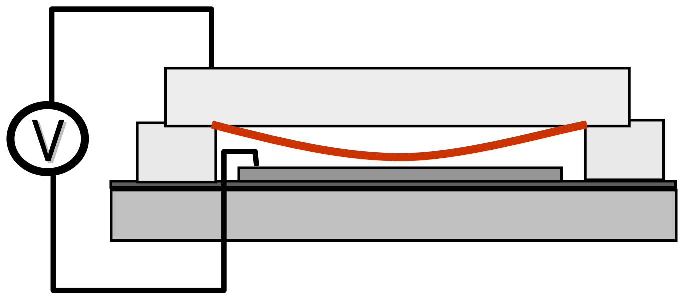
-- Huge scale



0.18 Micron, 6 Layer Technology

Complicated Device Modeling

- **MEMS devices fabricated with semiconductor devices.**
- **Accurate modeling uses partial differential equations (PDEs)**
- **Must use macromodels for fast simulation.**
- **May focus on the** input-output behavior**.**



$$u(t,x) = \sum_{i=0}^{q} \alpha_i(t)\phi_i(x)$$

$$p(t,x,y) = \sum_{i=0}^{q} \beta_i(t)\psi_i(x,y)$$

$$EI\frac{\partial^4 u}{\partial x^4} - S\frac{\partial^2 u}{\partial x^2} = F_e + \int_0^w (p - p_a)dz - \rho\frac{\partial^2 u}{\partial t^2}$$

$$\nabla \cdot (u^3 p \nabla p) = \frac{12\mu}{1+6K}\frac{\partial(pu)}{\partial t}$$

Original Model

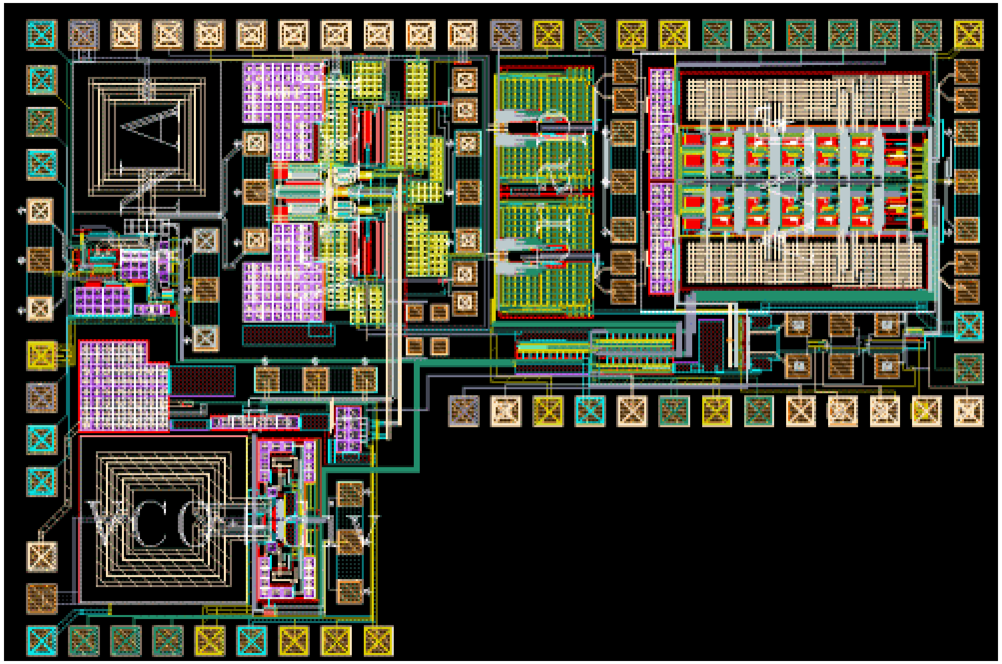
$$\frac{d\alpha_i}{dt} = \cdots$$

$$\frac{d\beta_i}{dt} = \cdots$$

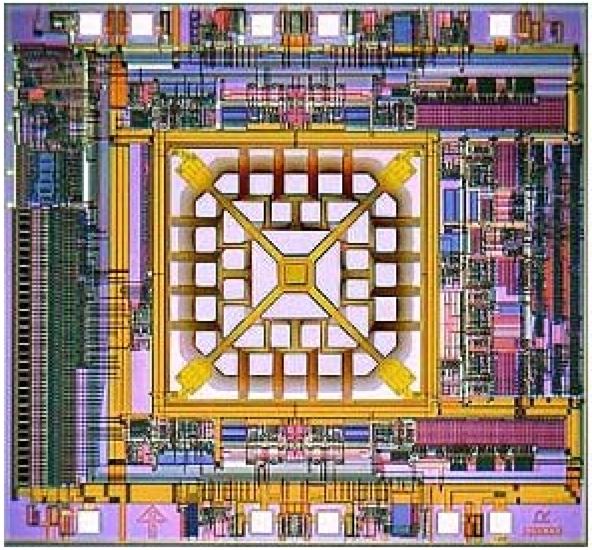
Low order

Macromodel

Multiple-Technology Integration



A single-chip receiver



A MEMS Chip

The existing design and fabrication problems that challenge the CAD engineers!

Emerging Challenges

- **Multiple-technology integration is the future of the IC industry,**
- **which brings huge challenges for simulation**
  - **Modeling multiple physics devices (electrical, mechanical; optical; fluidic; biological; ...)**
  - **Model creation is much harder than semiconductor devices**
  - **Lumped element simulation not adequate**
  - **have to consider field-effect simulation**
  - **Modeling language from description to simulation code.**
  - **Macromodeling and soliving technology**

Top 10 Algorithms in 20th Century

1. 1946: The Metropolis Algorithm for Monte Carlo.
2. 1947: Simplex Method for Linear Programming.
3. 1950: Krylov Subspace Iteration Method.
4. 1951: The Decompositional Approach to Matrix Computations.
5. 1957: The Fortran Optimizing Compiler. Turns high-level code into efficient computer-readable code.
6. 1959: QR Algorithm for Computing Eigenvalues.
7. 1962: Quicksort Algorithms for Sorting.
8. 1965: Fast Fourier Transform.
9. 1977: Integer Relation Detection.
   - A fast method for spotting simple equations satisfied by collections of seemingly unrelated numbers.
10. 1987: Fast Multipole Method.
    - A breakthrough in dealing with the complexity of n-body calculations, applied in problems ranging from celestial mechanics to protein folding.

From *Random Samples*, Science page 799, February 4, 2000.

Summary

- **Course focus and skill set**
- **Course feature:**
  - ***Team work*** **and** ***project-based*** **learning**
- **Some basics on the EDA technology**
- **EDA is a good place to practice your past knowledge**
  - **From** ***math*** **to** ***algorithms*** **to** ***software*** **to** ***IC design problems*** **...**
- **Prepare for your career**
  - **Graduate study or a job position ...**