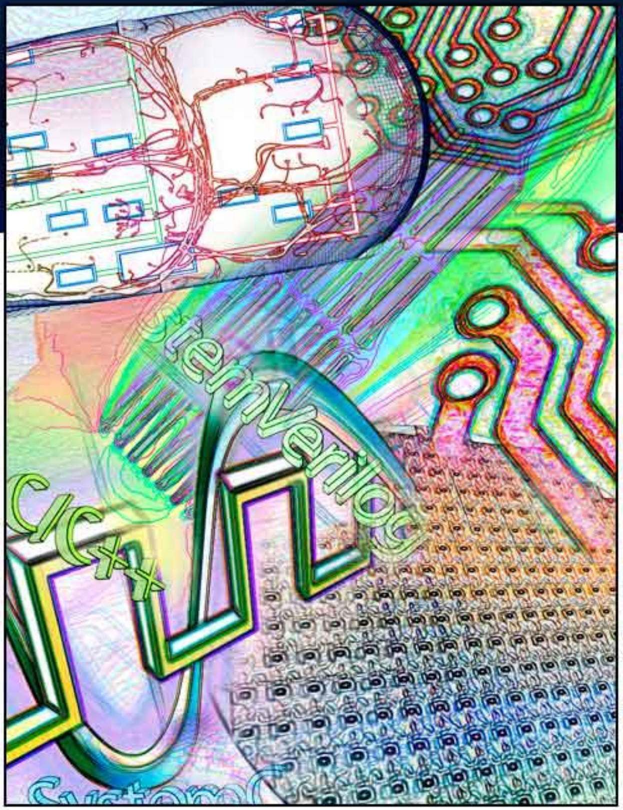

Using range arithmetic in evaluation of compact models

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Outline

- Introduction
- Interval based Simulation flow
- Simulator design
- Simulator models library
- Testing strategy
- Conclusion
- Future work

Process Variations

- For electronic circuit design we can define 3 variable quantities related to the circuit behavior:
  - Design parameters: are related to circuit structure, it is designer responsibility to change them to get optimum performance.
  - Range parameters: usually define the range of operation for the circuit, like supply voltage or temperature range.
  - Statistical parameters: describes the random variations which occur during the manufacturing process, they are modeled in form of probability density functions.
- Process variations become particularly important at smaller process nodes (< 65 nm) as the variation becomes a larger percentage of the device geometry.
- It causes measurable and predictable variance in the output performance of all circuits.

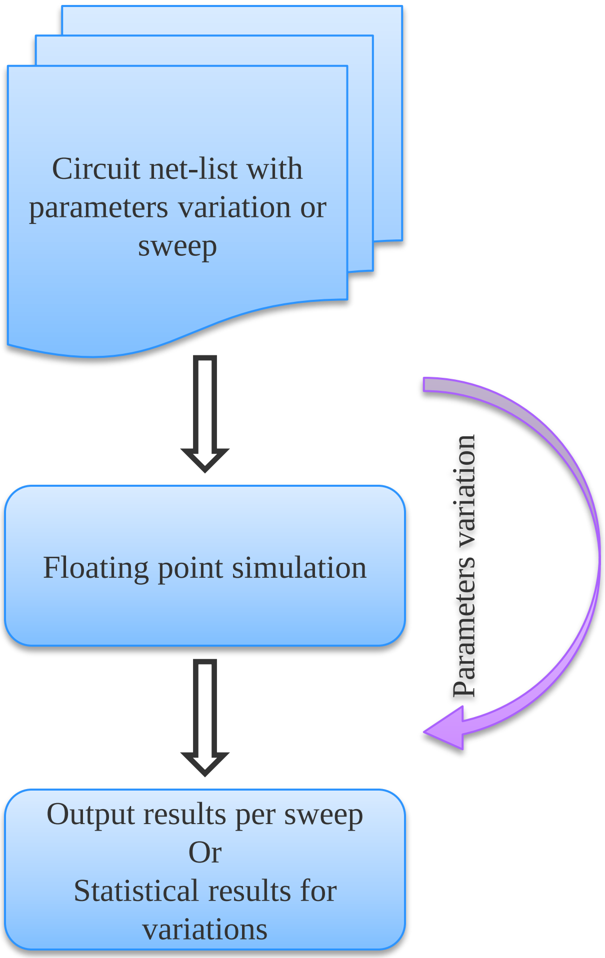
Account for Process Variations

- Circuit simulations is used to expect the behavior of electronic circuits before doing manufacturing.
- Monte-Carlo is a computational algorithm that rely on repeated random sampling to obtain numerical results for difficult or impossible to obtain a closed-form expression, or infeasible to apply a deterministic algorithm.
- Monte-Carlo simulation is used to account for process variations in the design stage.
- Many runs needed to obtain the distribution of an unknown probabilistic entity.
- For big circuits this takes long time, may be weeks.
- We need to replace MC simulation with interval based simulation.

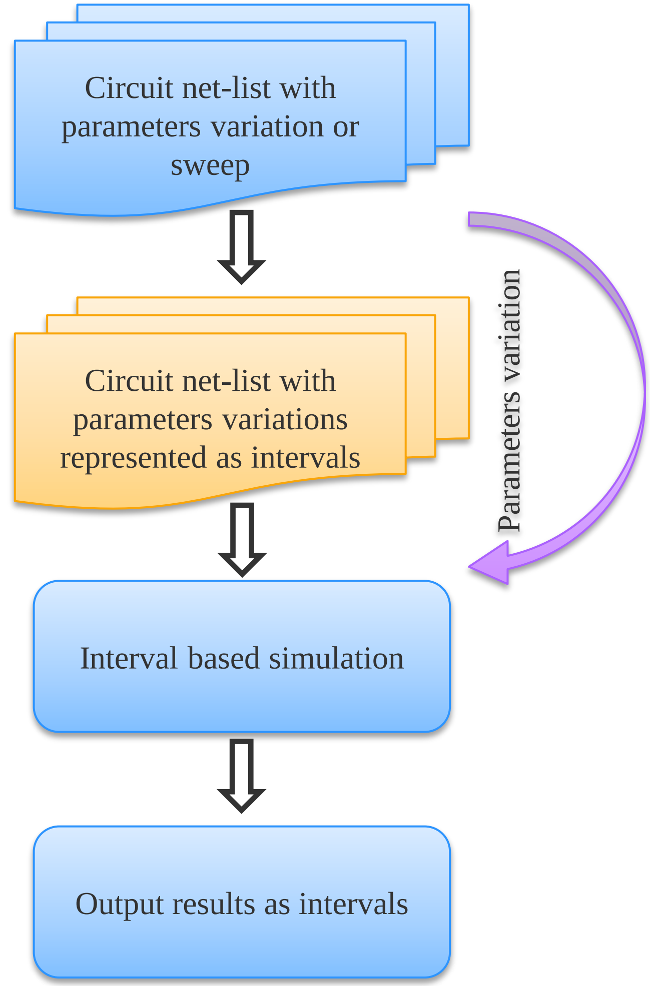
Modal Arithmetic

- In modal arithmetic the following two operators are defined for interval X=[a,b] where b>a
  - dual(X) = [b,a]
  - opp(X) = [-a,-b]
- We use modal arithmetic in our work to bound output results.

Interval Based Simulation flow



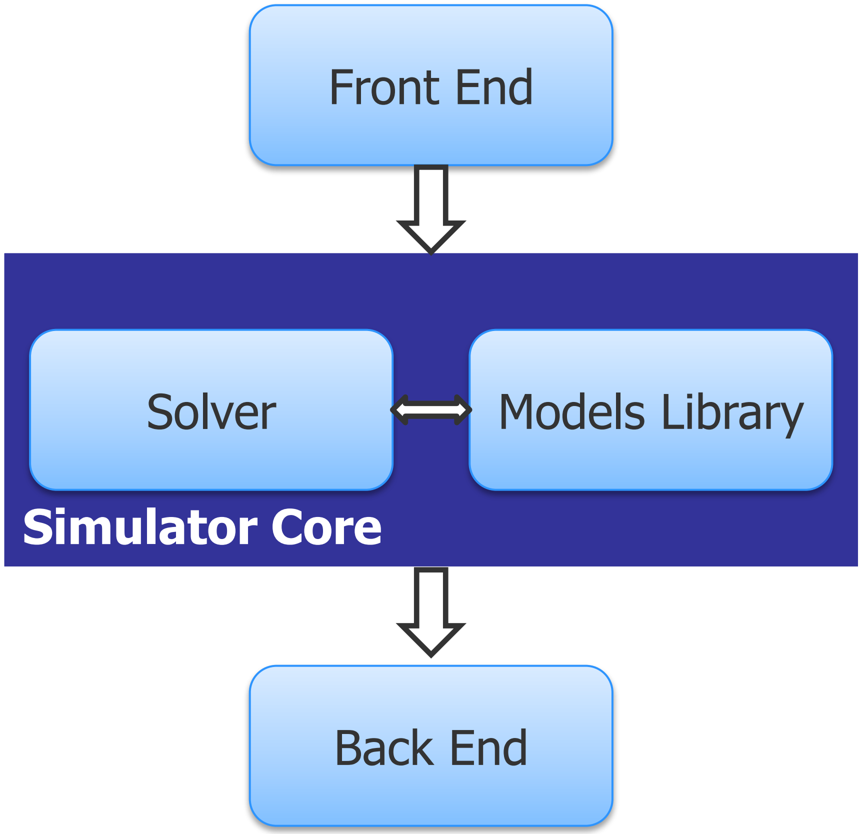
Traditional simulation flow



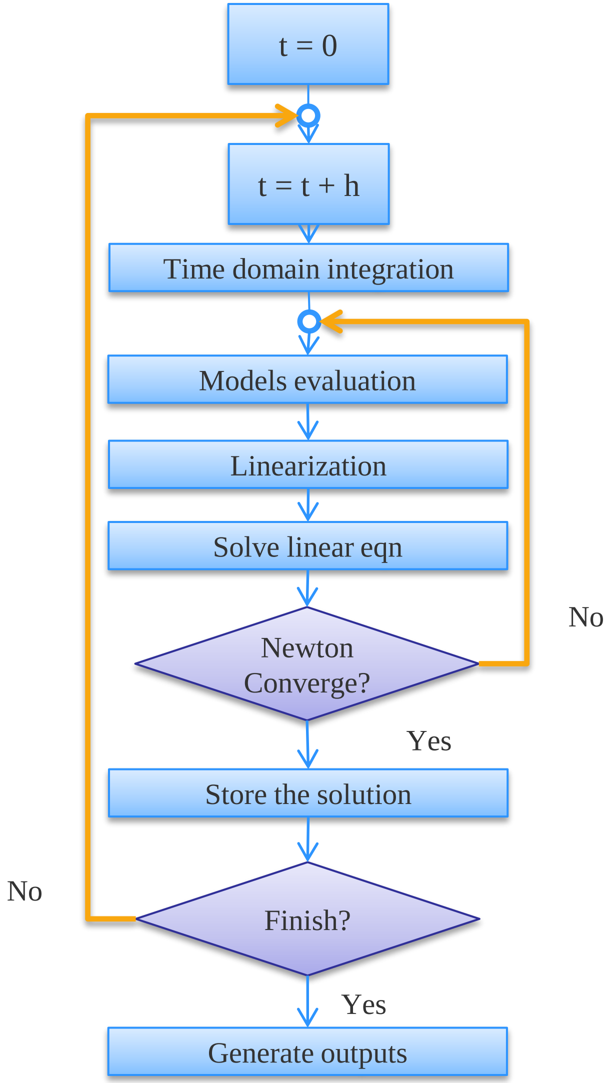
Proposed interval based simulation flow

Simulator Parts

- Front end process the design to get interval parameters.
- The solver formulate and solve the equations which describe the design.
- Models library contains mathematical equations define characteristic of each component in the design.
- Back end process the results and display it in a proper way.



Solver flow



- Flow for steady state and transient simulation
- Use Newton's method for interval system of non-linear equations.
- Interval Gauss-Seidel used to solve the system of interval linear equations.

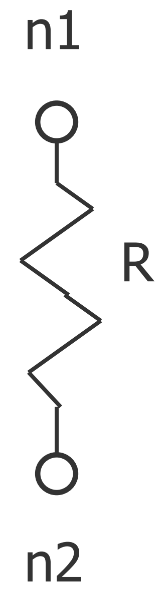
Models Library

- Sources
  - Independent current source
  - Independent voltage source
- Passive elements
  - Resistor
  - Capacitor
  - Inductor
- Active elements
  - Simple diode model
  - Simple MOSFET transistor model
  - Advanced MOSFET transistor model

Resistor Model

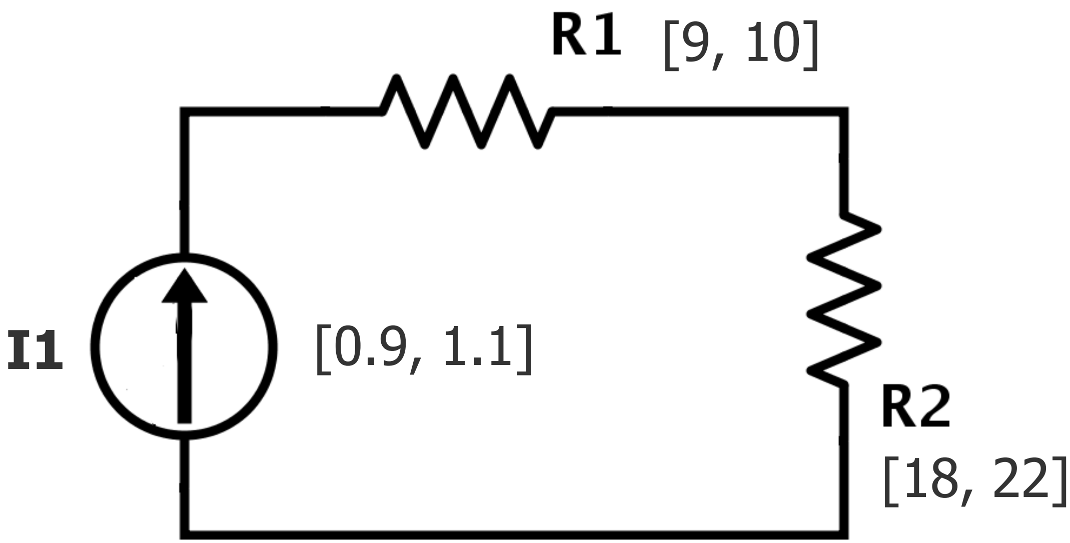
- Voltage difference across Ohmic resistor is:

$$(v1 - v2) = I.R$$



Resistor Model

- This example show how modal arithmetic enhance the results



Resistor Model

- This simple circuit is represented using modified nodal analysis as follow:

$$\begin{bmatrix} G1 & -G1 \\ -G1 & G1+G2 \end{bmatrix} \begin{bmatrix} v1 \\ v2 \end{bmatrix} = \begin{bmatrix} I1 \\ [0,0] \end{bmatrix}$$

Where G = 1 / R

- Classical results

V1 = [21.354545, 41.677778]

V2 = [11.647933, 33.959671]

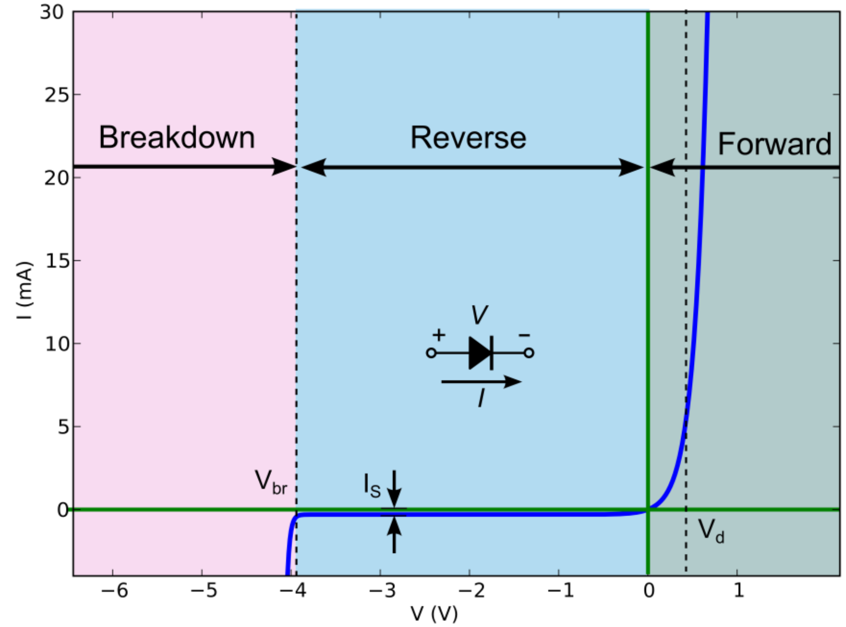
- Modal results by replacing –G1 with opp(G1)

V1 = [24.300000, 36.300001]

V2 = [16.199999, 24.200001]

Simple diode model

- Diode is a two-terminal electronic component with asymmetric conductance.
- Model is defined on regions.
- If regions boundaries (Vbr, Vd) are defined as intervals, we can use monotonic behavior, then we compute output current twice (using end points).
  - Minimum input with the minimum edge of the region, and maximum input with the maximum edge of the region
- Results are the union of the two outputs.

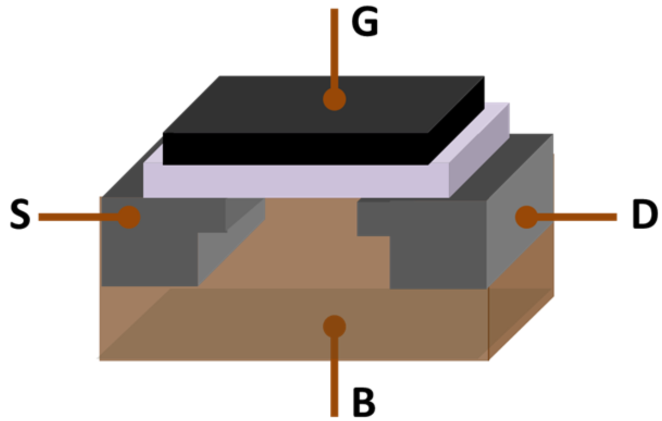


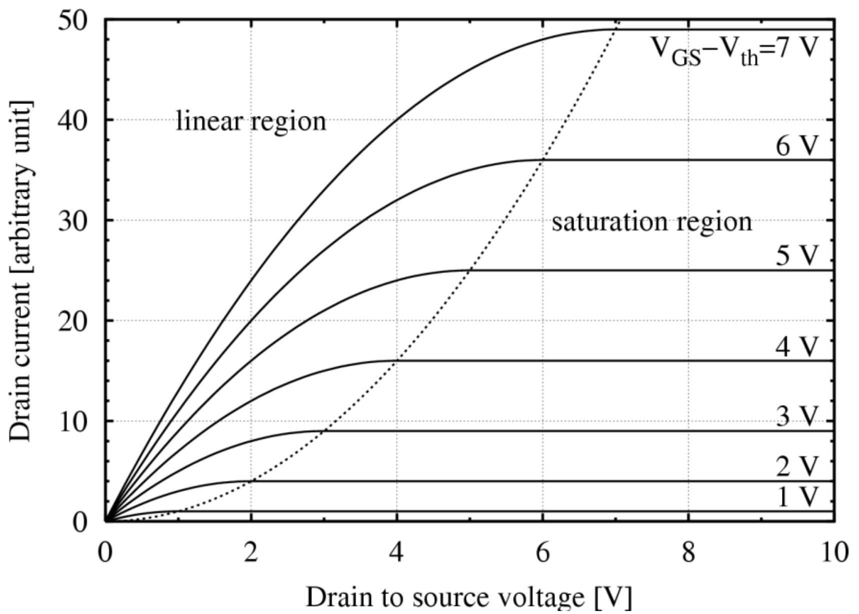
characteristics of a p–n junction diode

* Picture from Wikipedia

Simple MOSFET model

- MOSFET is a type of transistors.
- It is a four terminal electronic device and used for amplifying or switching electronic signals.
- We use a simple model to describe the MOSFET basic characteristics.
- The simple MOSFET model is defined on regions, with one equation for the output current in each region.
- The voltage on the terminals defines the region of operation.
- In case we have interval threshold (boundary), we compute twice and use the same technique used to calculate diode output.





* Picture from Wikipedia

BSIM4 MOSFET Model

- BSIM4 is an accurate compact model for MOSFET transistors.
- It is widely used by electronic circuit industry.
- It has more than 900 model parameters, and 7500 lines of code.
- Results obtained so far from the interval model is not good.
- The model still need more work and investigation to probe the problem.

Testing

- Unit testing: tests interval results for each element or model alone and compare it versus single point results with sweeps.
- RLC network testing: tests simulator behavior with linear elements only.
  - This mainly tests functionality of interval matrix solver.
- Simple circuits: this test show how each component is integrated within the simulator, and how much Newton's algorithm can handle non-linear elements.
- Big circuit: this test show how much our simulator is reliable (capacity and speed).

Conclusion

- We have introduce simulation flow that uses interval computations.
- Basic models library is created.
- Modal arithmetic is used to enhance results.

Future work

- Work to enhance BSIM4 results
- Begin circuit testing with the simulator.
- Support small signal analysis along with steady state and transient analysis.
- Compare affine arithmetic results to modal interval arithmetic results.

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