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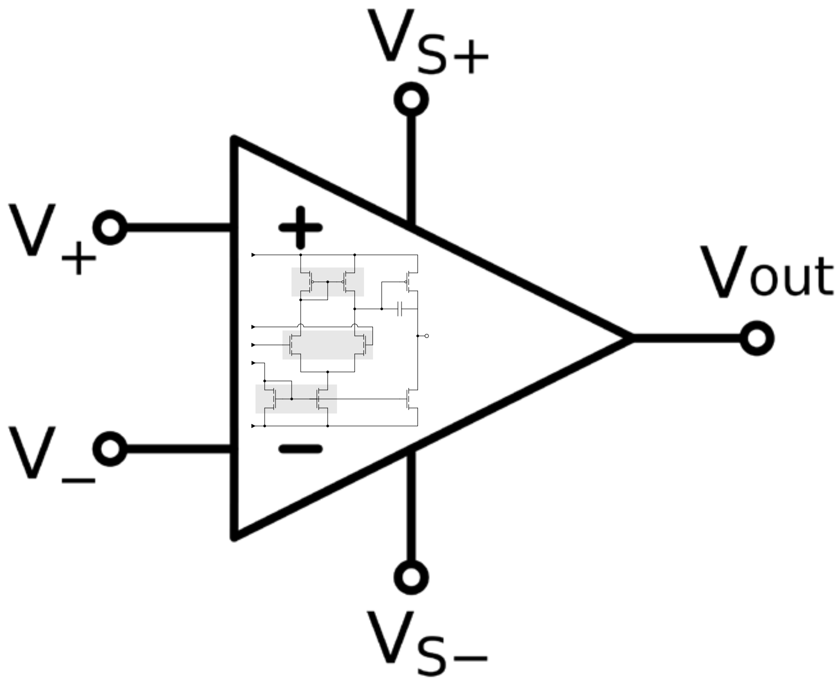
Verification of Mixed-Signal Systems with Range Based Signal Representations



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Contents

Verification of Mixed-Signal Systems

- Problems
  - Slow
  - Rarely used
  - Fast enough only on system-level
    - Too abstract for analog systems
    - Missing variation due to degradation or manufacturing
- Gain
  - Find design errors
  - Is every error really critical for the function of a system?
    - Reduce overdesign of modules
    - Smaller design

Mixed-Signal Systems: Parameter Variations

Analog Systems	Digital Systems
Monte Carlo / Corner Case	Monte Carlo, e.g. using Spice
Sensitivity analysis	Bit errors
Interval / range / distribution arithmetic	Delay errors
Symbolic analysis	Statistical gate-level simulation
	(S)STA
Integration in electric model	Integration in LUTs of libraries
Resulting wave forms	Resulting values, slew or clock rates

Affine Forms

- Mathematical model for error tracking
  - Origin in numerical applications, first used by Stolfi et al.
- Guaranteed save inclusion of the result

Central value | Linear partial deviations | Deviation symbol

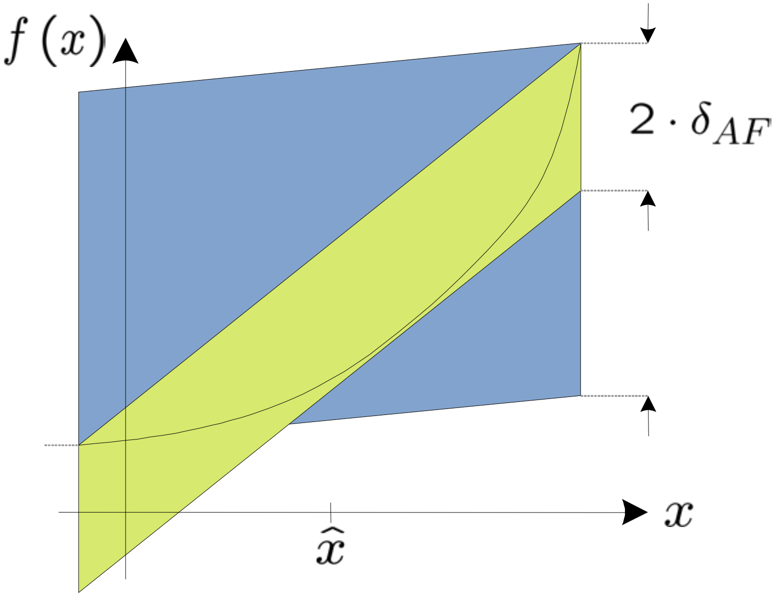
$$\tilde{x} := x_0 + \sum_{i \in \mathcal{N}_{\tilde{x}}} x_i \epsilon_i \qquad \epsilon_i \in [-1, 1]$$

- One unique symbol for each parameter deviation
- Exact affine operations
  - Linear operations: +,−
  - Multiplication with constant

$$c \cdot (\tilde{x} \pm \tilde{y}) := c \cdot (x_0 \pm y_0) + \sum c \cdot (x_i \pm y_i)\epsilon_i$$

Non-affine Operations

- Approximations of the result of each operation
  - Linear correlation preserved
  - One new deviation generated for each operation
  - Guaranteed safe inclusion



- Conversion to interval arithmetic using radius-function

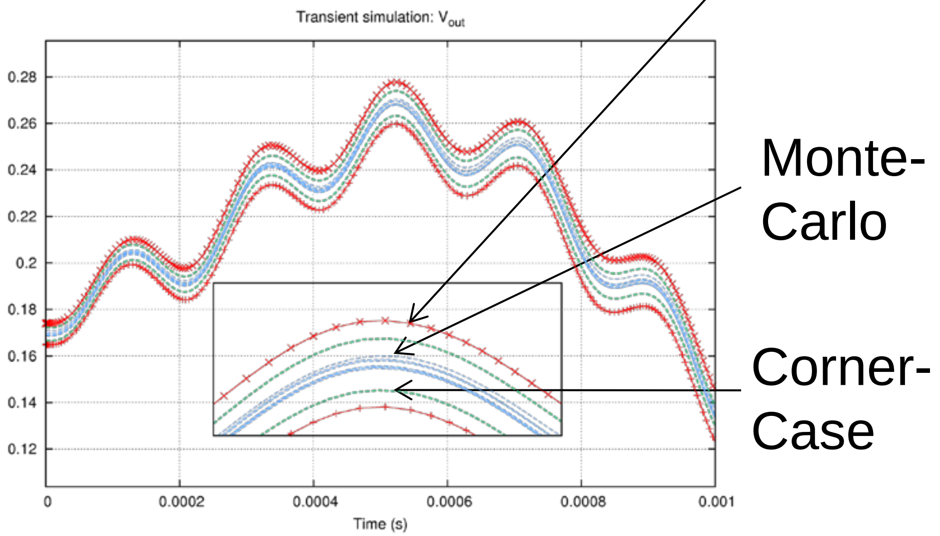
$$\mathrm{rad}(\tilde{x}) := \sum_{i \in \mathcal{N}_{\tilde{x}}} |x_i|$$

- C++-Library licensed under GPL
  - http://aaflib.sourceforge.net/

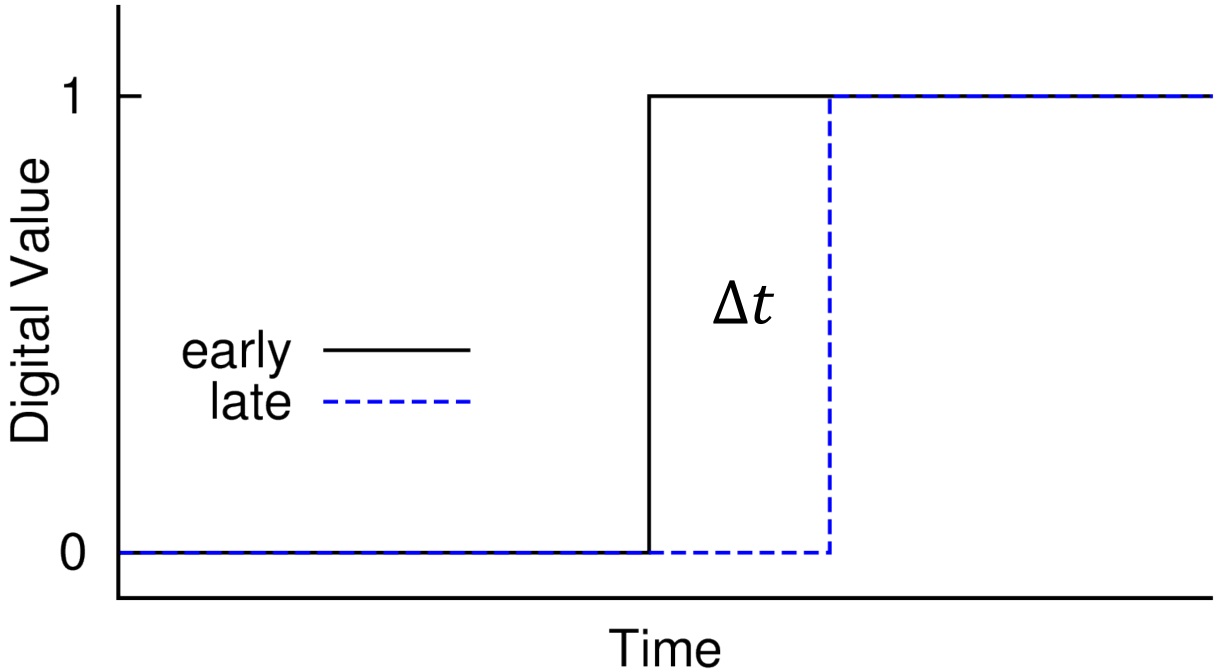
Affine Circuit Simulation

- DC/AC/Transient simulation methods implemented
  - SPICE-like approach
  - Newton-Raphson based solving

- Include all deviation in a single simulation run
  - Speed up verification
  - Tracing of deviations from output back to inputs and parameter



Delay Modeling in Digital Circuits (I)

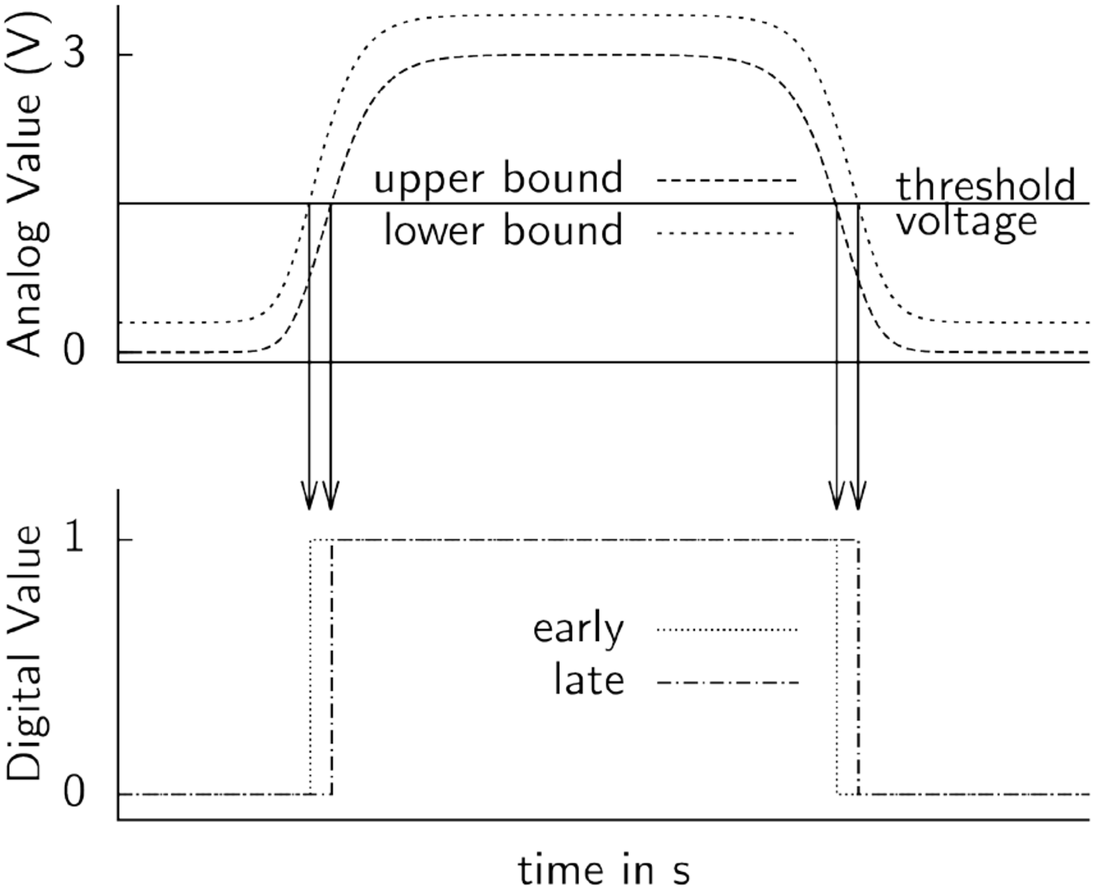


- $\Delta t \ = \ f(slew, cap, V_{th,i}, \ldots)$

Delay Modeling in Digital Circuits (II)

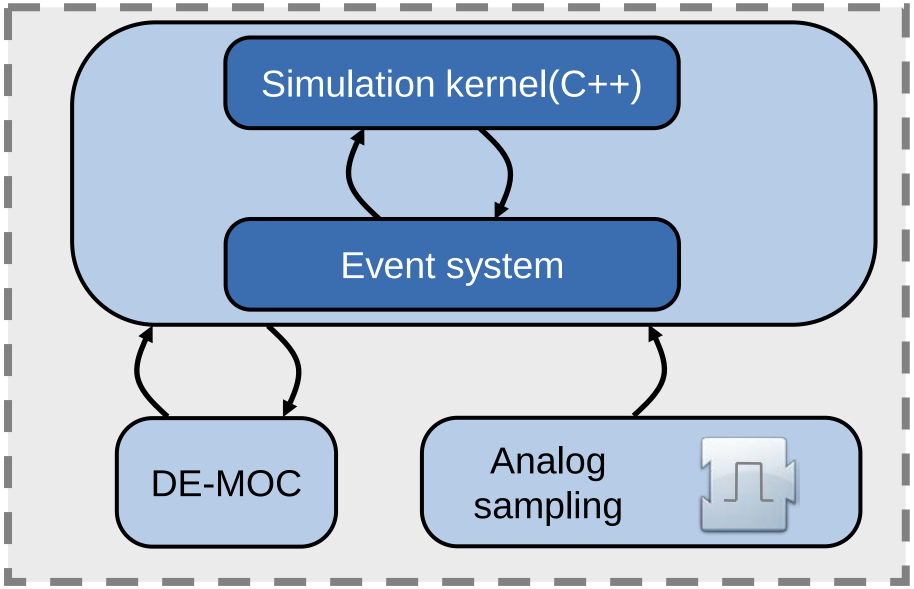
- Delay models consider
  - Signal variations (Slew rate)
  - Process parameter variations (Capacitance, ...)
- Delay models do not represent
  - Permanent bit errors
  - Logic value errors on system level
- Delay values
  - Fast and slow corners (inter die variation)
  - SSTA (intra die variation)
  - Stored in device library

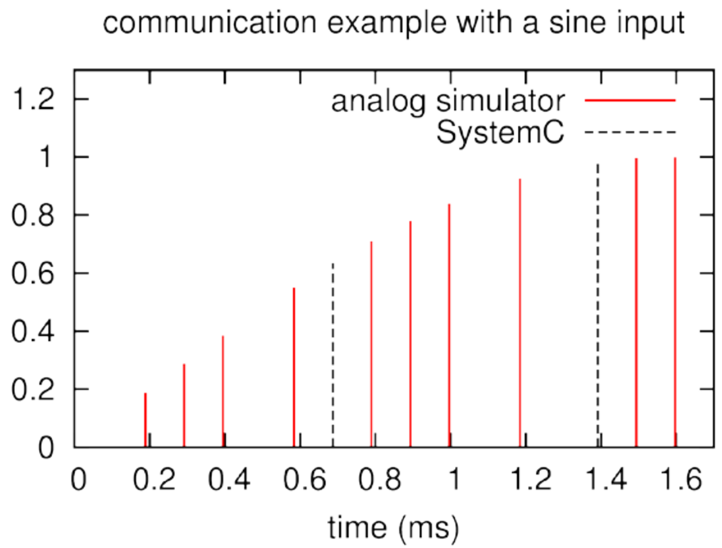
Conversion between Affine and Delay Signals



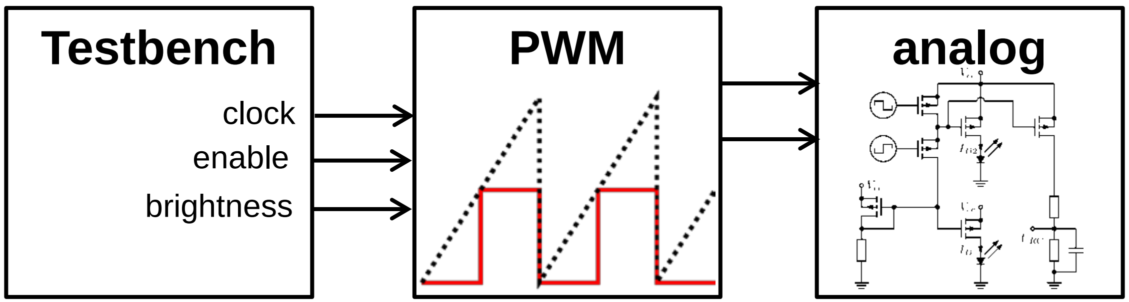
Event Driven SystemC Interface

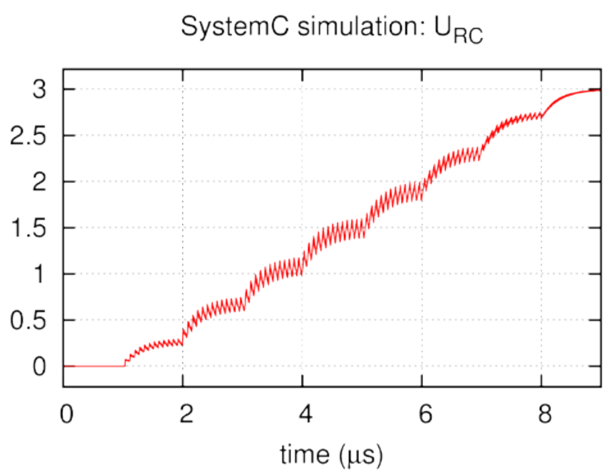
- Analog simulator using affine arithmetic
  - Integration of events between SystemC and the simulator
  - Reduce interpolation errors
  - Analog sampling as fallback solution

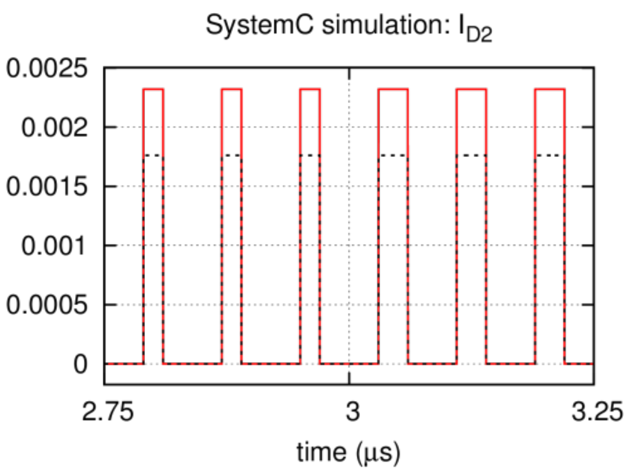




Example: SystemC PWM brightness control

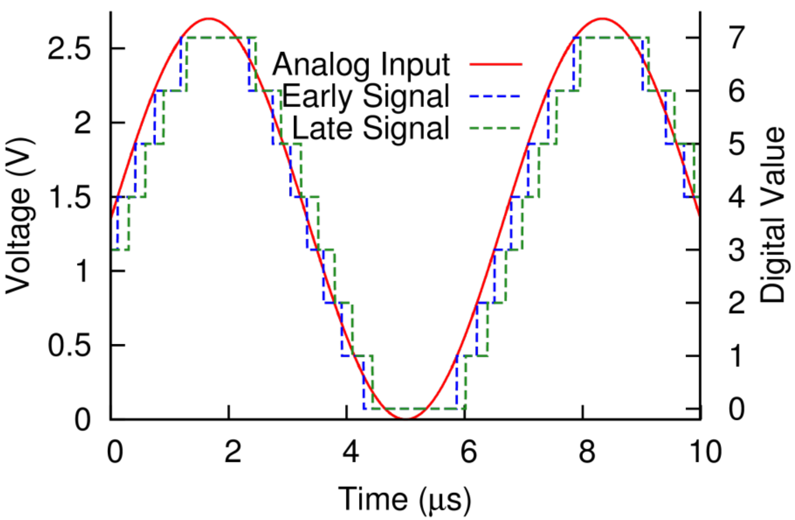


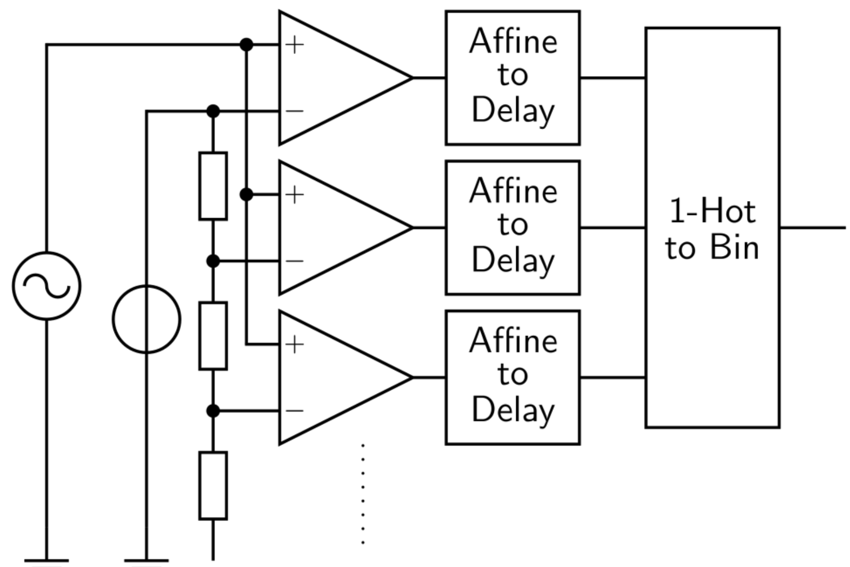




Example: 3 Bit Flash ADC

- Reference voltage + resistor ladder
- Deviation in OPA parameters as well as in reference
- Digital models with delays
- Functional modeling





Future Work

- Preserve correlation in both domains
  - Requires transformation between values and time of deviation symbols and delays
  - Enables more complex examples, e.g. Sigma Delta Converter
  - Special comparator models or converter units
- Modeling of memories and registers
- Modeling of functionality changing errors

Conclusion

- Modeling of variation effects in mixed signal circuits
- Affine arithmetic
- Analog circuit simulation using affine arithmetic
- Delay model for digital circuits
- Mixed signal simulation with variation