Rapid and Accurate Latch Characterization via Direct Newton Solutions of Setup/Hold Times

Shweta Srivastava, Jaijeet Roychowdhury

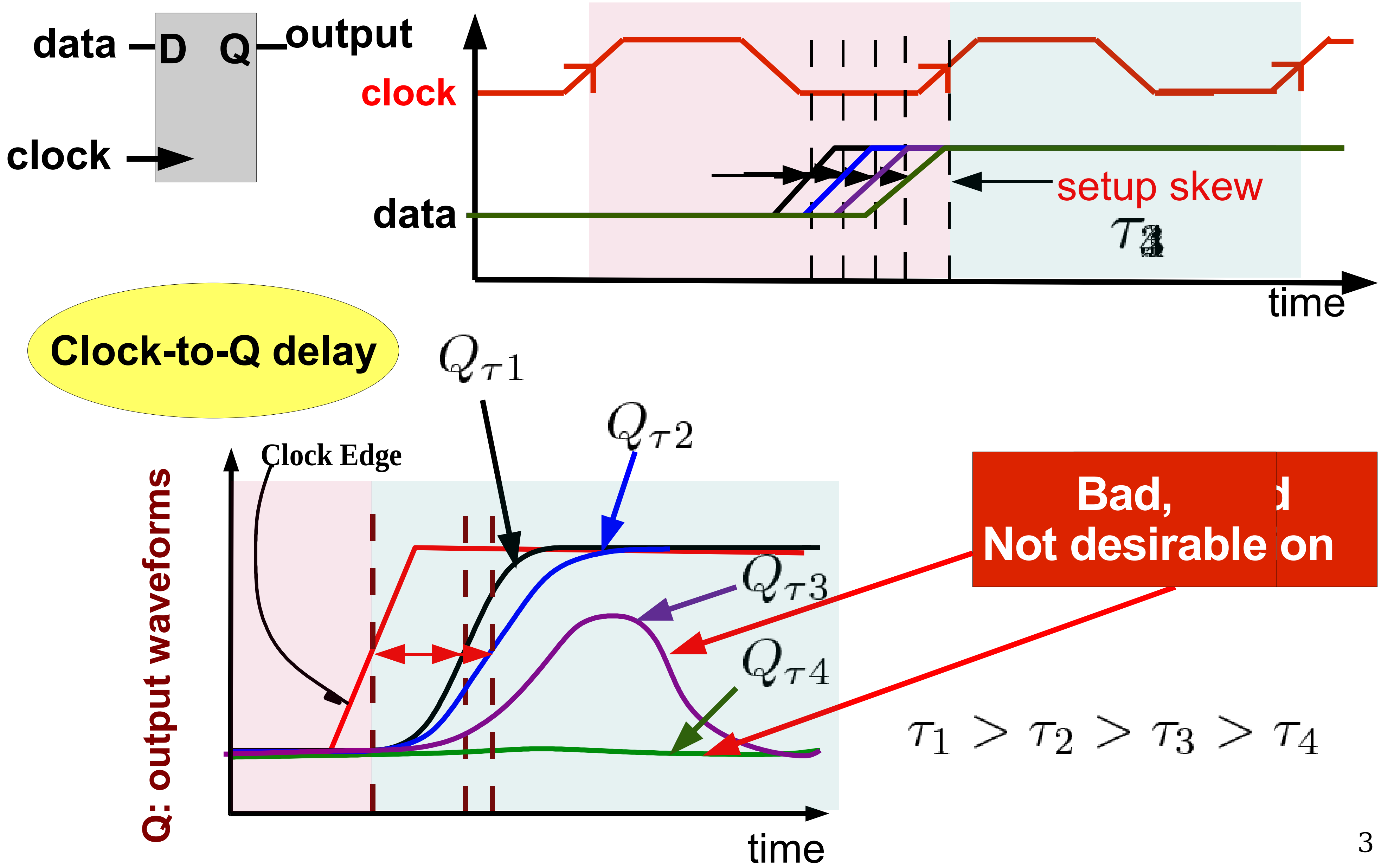
Dept of ECE, University of Minnesota, Twin Cities

shwetas@umn.edu

Outline

- Current method for finding setup and hold times
- Motivation and basic idea
- Contribution:
  - Development of fast characterization method.
    - Problem formulation as a scalar nonlinear algebraic equation.
    - Solving the formulated problem via Newton-Raphson.
- Results and conclusion

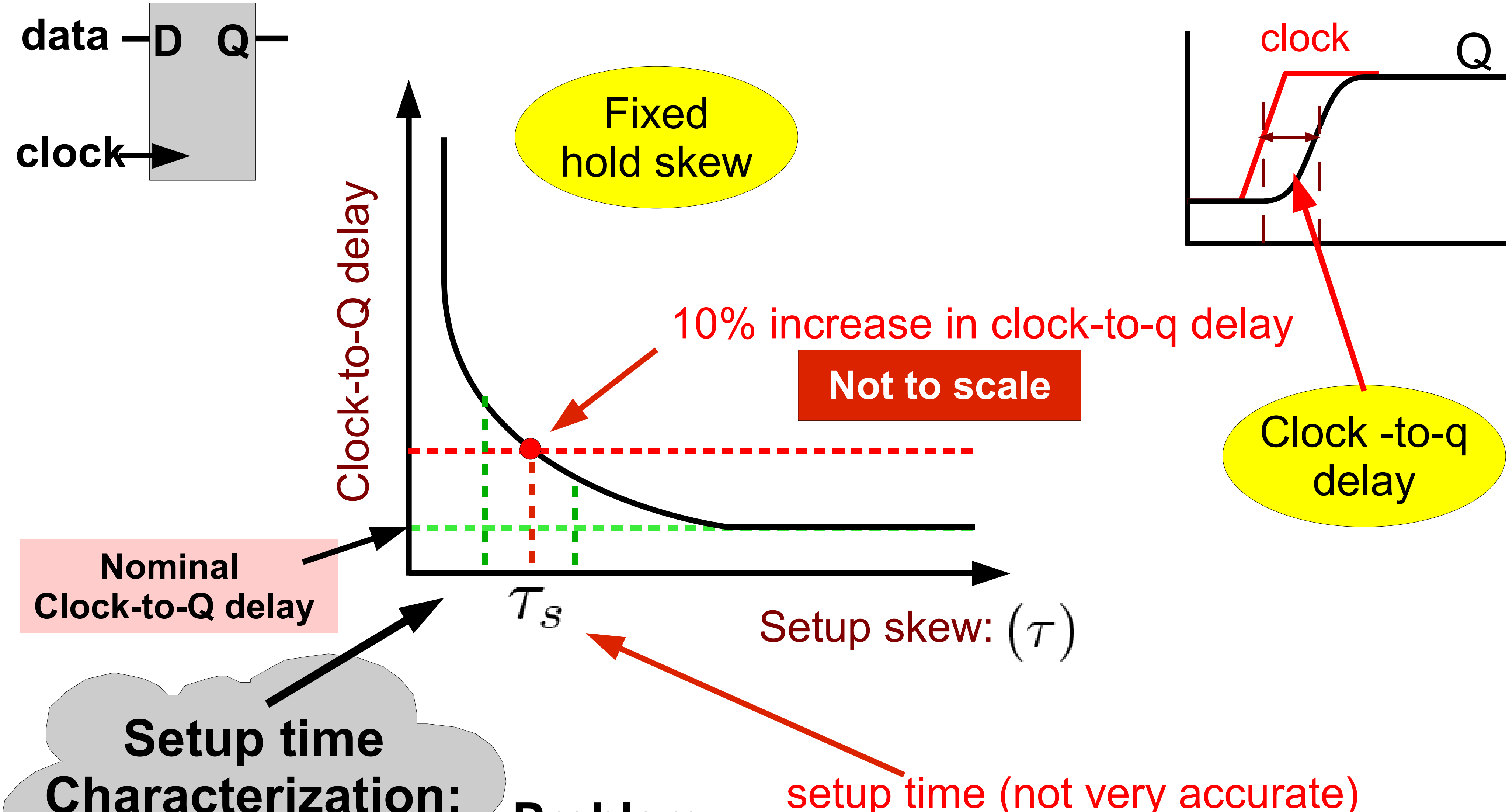
Register And Its Behavior



Definition of Setup Time

Setup Time: **Value of setup skew (delay from data transition edge to clock transition edge) for which clock-to-q delay increases by a certain amount (typically 10%) from the nominal clock-to-q delay.**

Finding setup time via Bisection method



Setup time Characterization:
Bisection method

Problem

Large number of transient simulation: Expensive

Current Characterization Method: Expensive

Characterization of standard cell library takes **months**.

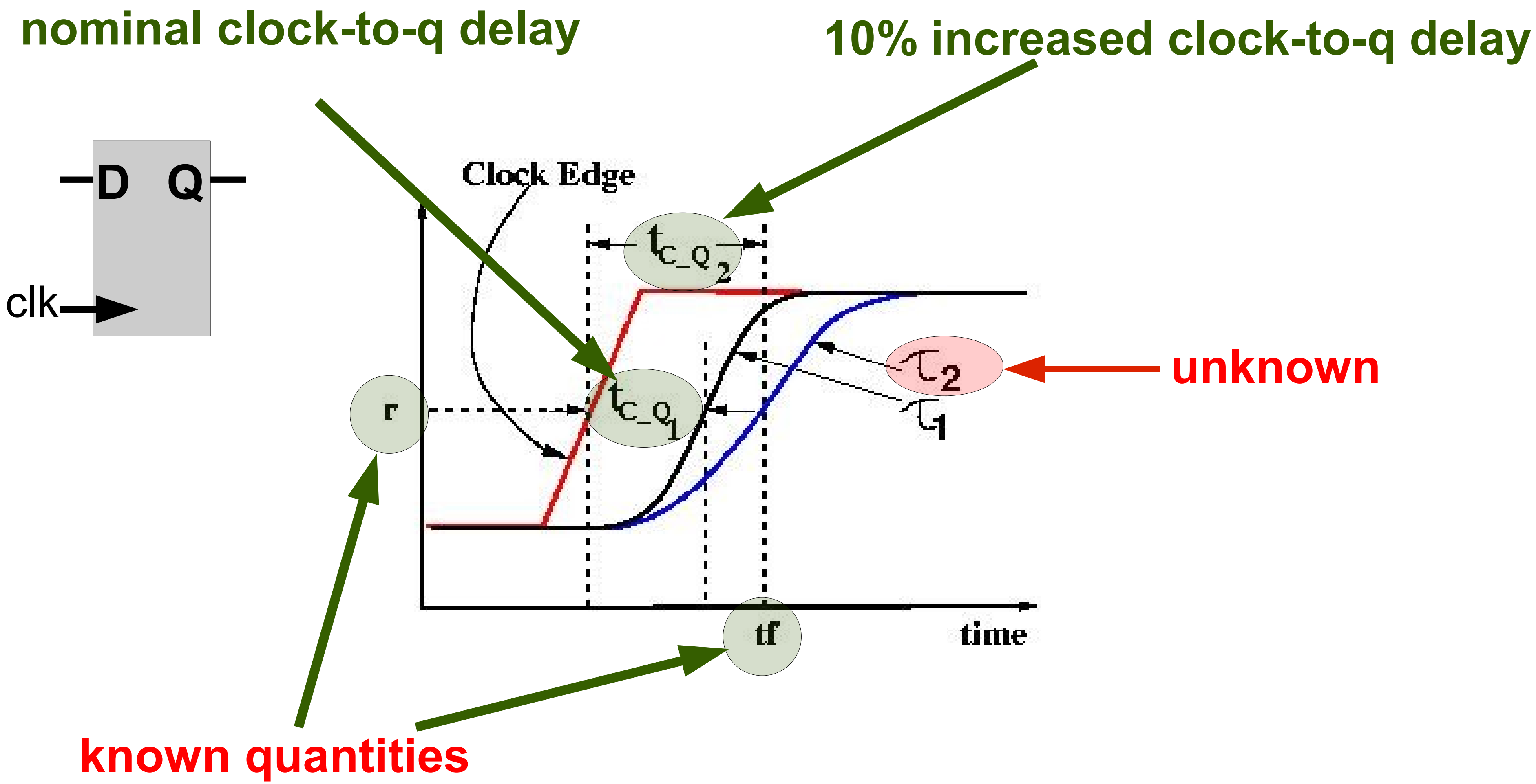
Motivation and Basic Idea

- Setup and Hold times: prerequisite for timing analysis.
- Characterization of standard cell library takes months.
- Need to reduce the characterization time.
  - without losing accuracy.
  - Solution
    - employ Newton-Raphson based solution.
- A moderate reduction in computation time (i.e less number of transient simulations) can be significant.

Contribution

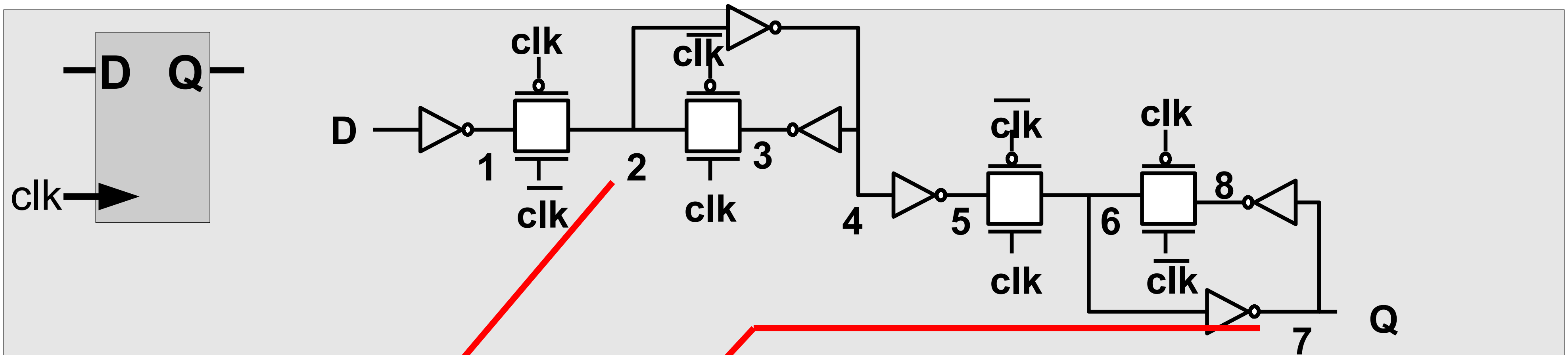
- Formulate the problem of characterization as a scalar nonlinear algebraic equation
- A scalar equation with one unknown: setup time
- Solve the equation via Newton-Raphson method
- Can hope to converge to solution faster

Problem Formulation: Finding Setup Time



Q output waveform for different setup skews

Selection of Output (Q) Waveform



Positive-edge triggered master-slave register

$$\vec{x} = \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \\ x_8 \end{pmatrix} \qquad \vec{c} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \end{pmatrix}$$

Q output

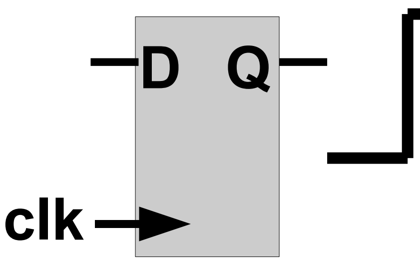
$$\vec{c}^T \vec{x} = x_7$$

Selection of Q output node

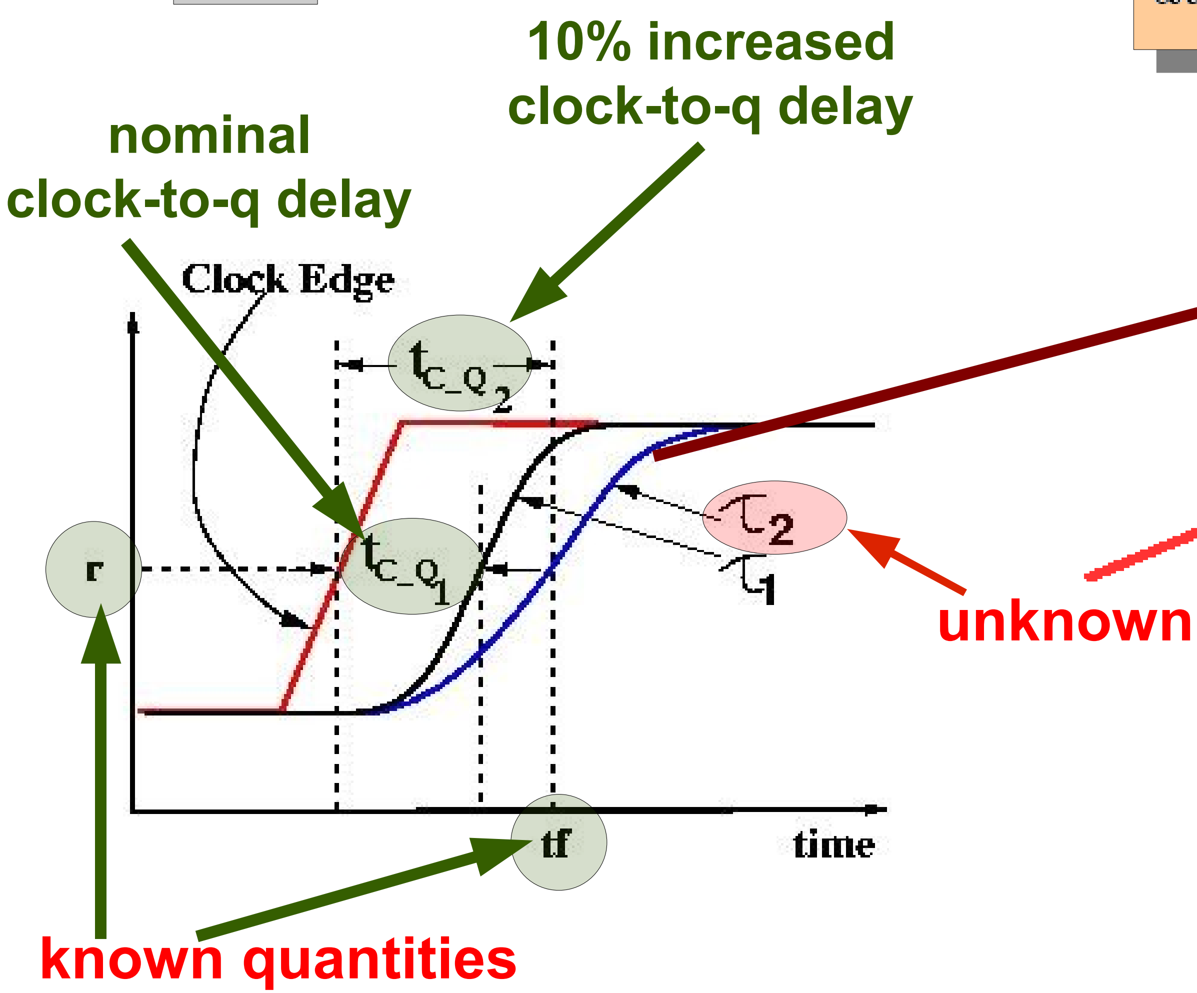
Vector of unknown voltages

Unit vector

Problem Formulation: continued



$$\frac{d}{dt}\vec{q}(\vec{x}) + \vec{f}(\vec{x}) + \vec{b}u(t) = 0$$



Q output waveform

$$\vec{c}^T \vec{x}(t_f, \tau_2) = r$$

This is the condition we are trying to solve.

Problem Formulation: continued

unknown

Q output waveform

$$\vec{c}^T \vec{x}(t_f, \tau) - r = 0$$

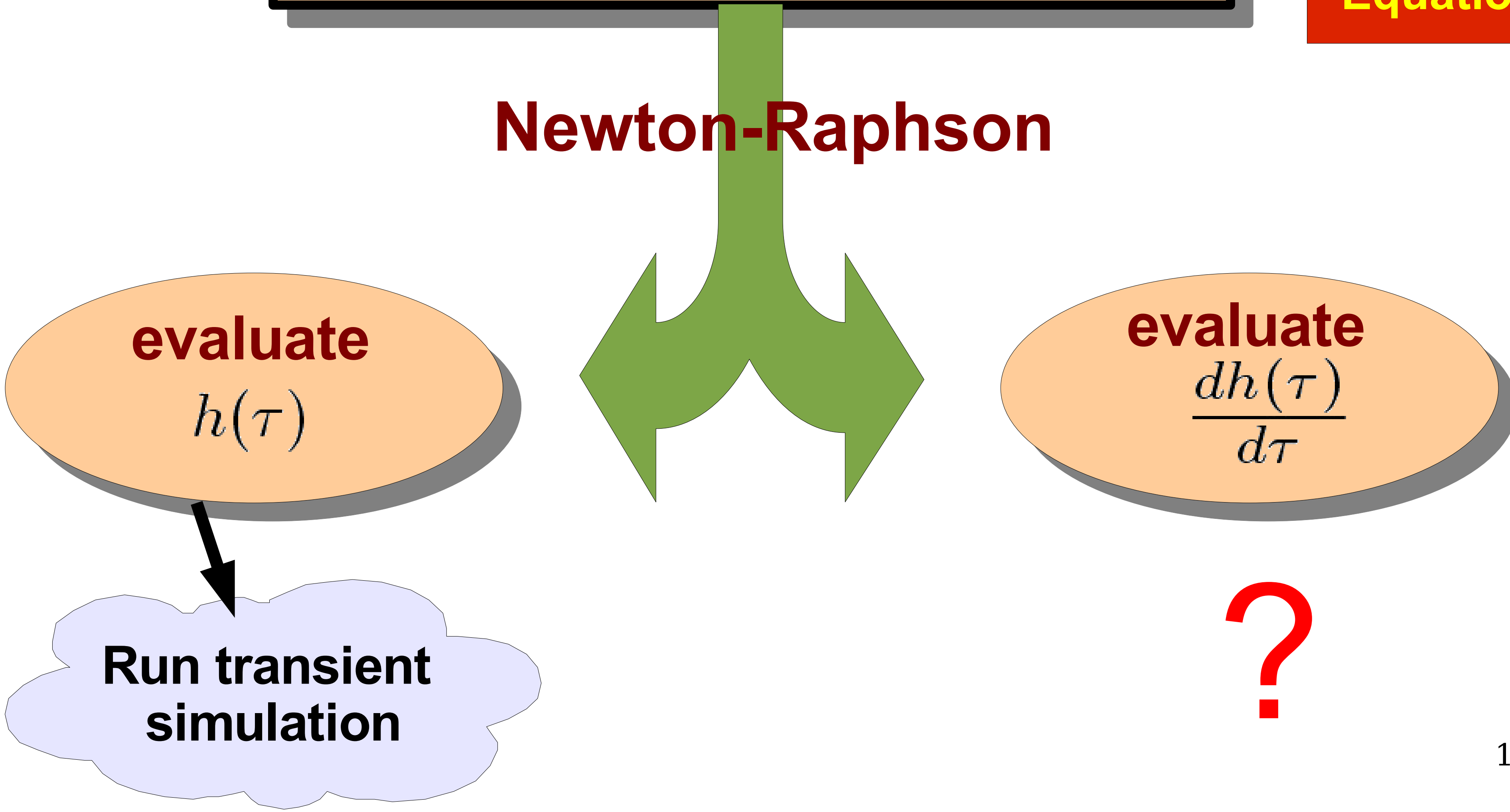
$$h(\tau) \equiv \vec{c}^T \vec{x}(t_f, \tau) - r = 0$$

- **A scalar nonlinear equation with one unknown.**
- **Solution of the equation gives optimal value of tau, i.e. setup time.**
- **This 'formulated problem' is very similar to the shooting equation.**

Solving $h(\tau) = 0$ By Newton Raphson

$$h(\tau) \equiv \vec{c}^T \vec{x}(t_f, \tau) - r = 0$$

Nonlinear Equation



Computing The Jacobian

$$h(\tau) \equiv \vec{c}^T \vec{x}(t_f, \tau) - r = 0$$

$$\frac{dh(\tau)}{d\tau} = \vec{c}^T \left(\frac{d\vec{x}(t,\tau)}{d\tau} \right)$$

Register equation

$$\frac{d}{dt}\vec{q}(\vec{x}(t,\tau)) + \vec{f}(\vec{x}(t,\tau)) + \vec{b}u(t,\tau) = 0$$

Differentiate w.r.t τ

Computing The Jacobian: continued..

$$\frac{d}{dt}\vec{q}(\vec{x}(t,\tau)) + \vec{f}(\vec{x}(t,\tau)) + \vec{b}u(t,\tau) = 0$$

Differentiate above equation w.r.t τ

$$\frac{d}{dt}\left[\frac{d}{d\tau}\vec{q}(\vec{x}(t,\tau))\right] + \frac{d}{d\tau}\vec{f}(\vec{x}(t,\tau)) + \vec{b}u'(t,\tau) = 0$$

$$\frac{d}{dt}\left[\frac{d\vec{q}(t,\tau)}{d\vec{x}}\frac{d\vec{x}}{d\tau}\right] + \frac{d\vec{f}(t,\tau)}{d\vec{x}}\frac{d\vec{x}}{d\tau} + \vec{b}u'(t,\tau) = 0$$

$$C^{\dagger}(t) = \left.\frac{d\vec{q}(t,\tau)}{d\vec{x}}\right|_{\tau^*} \quad G^{\dagger}(t) = \left.\frac{d\vec{f}(t,\tau)}{d\vec{x}}\right|_{\tau^*} \quad \vec{m}^{\dagger}(t) = \left.\frac{d\vec{x}(t,\tau)}{d\tau}\right|_{\tau^*}$$

$$\frac{d}{dt}\left(C^{\dagger}(t)\vec{m}^{\dagger}(t)\right) + G^{\dagger}(t)\vec{m}^{\dagger}(t) + \vec{b}u'(t,\tau) = 0$$

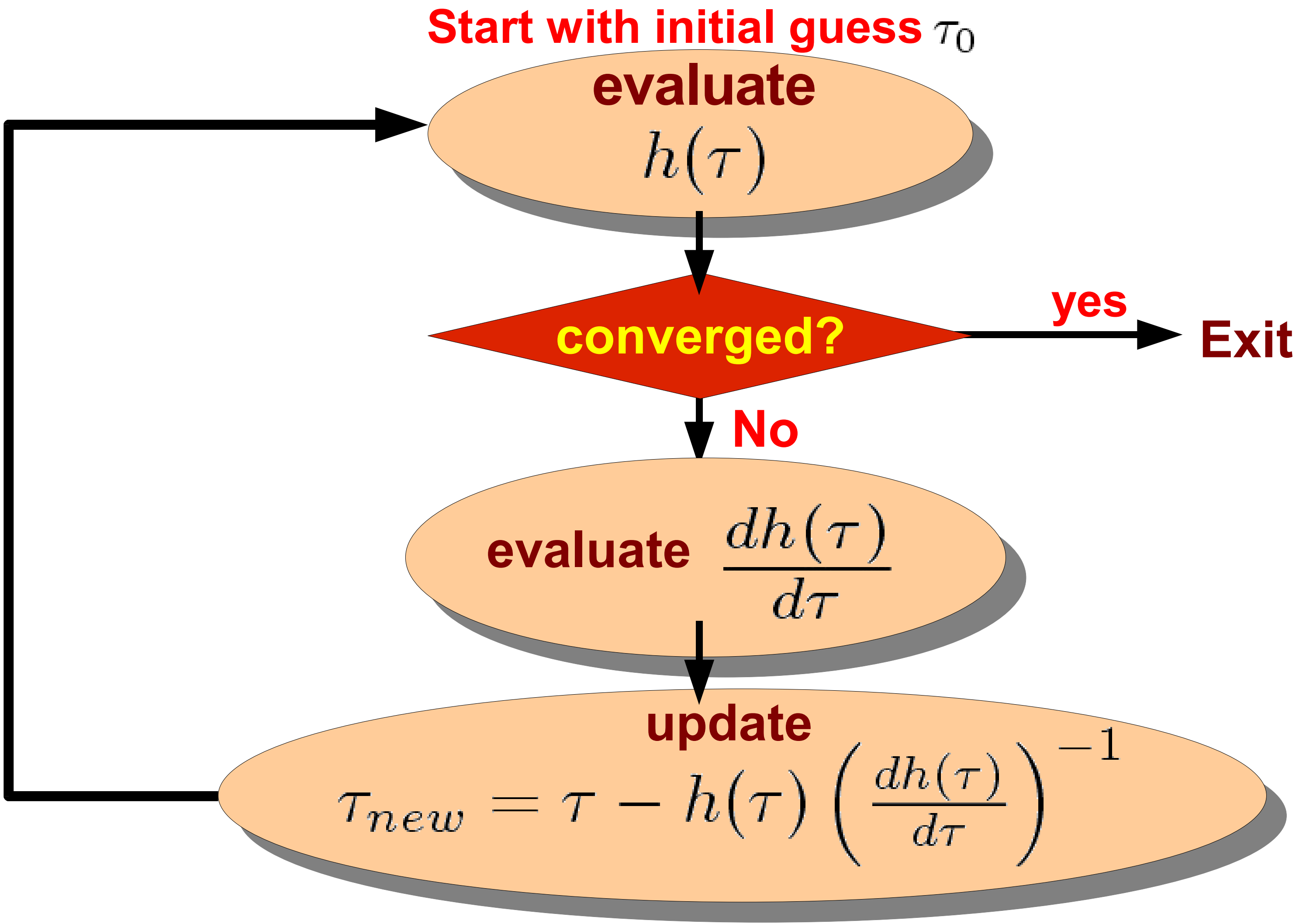
Can be solved using any integration method: BE, TRAP etc..

$\frac{dh(\tau)}{d\tau}$ **is obtained.**

Putting It All Together..

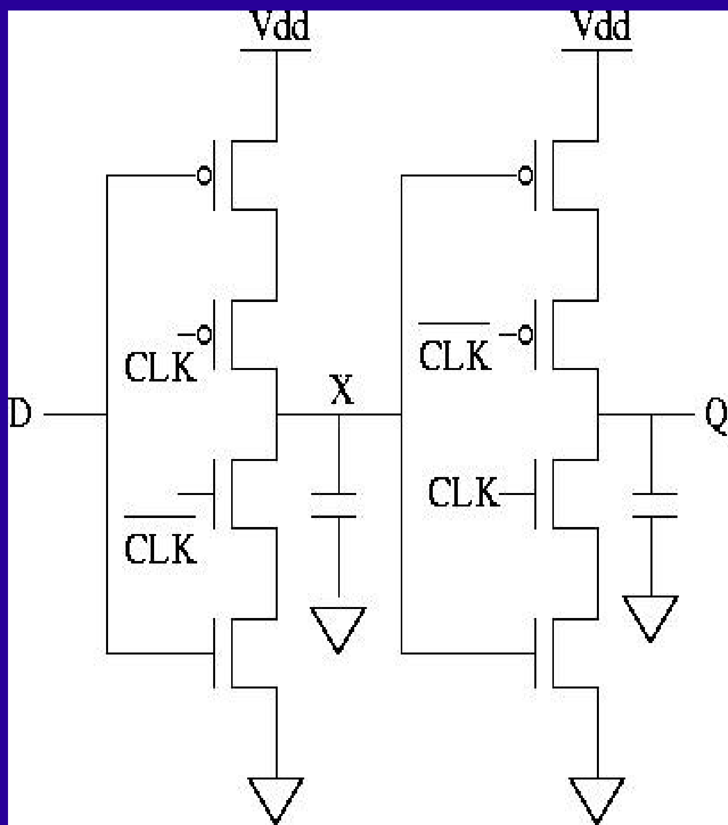
$$h(\tau) \equiv \vec{c}^T \vec{x}(t_f, \tau) - r = 0$$

Scalar equation that needs to be solved.



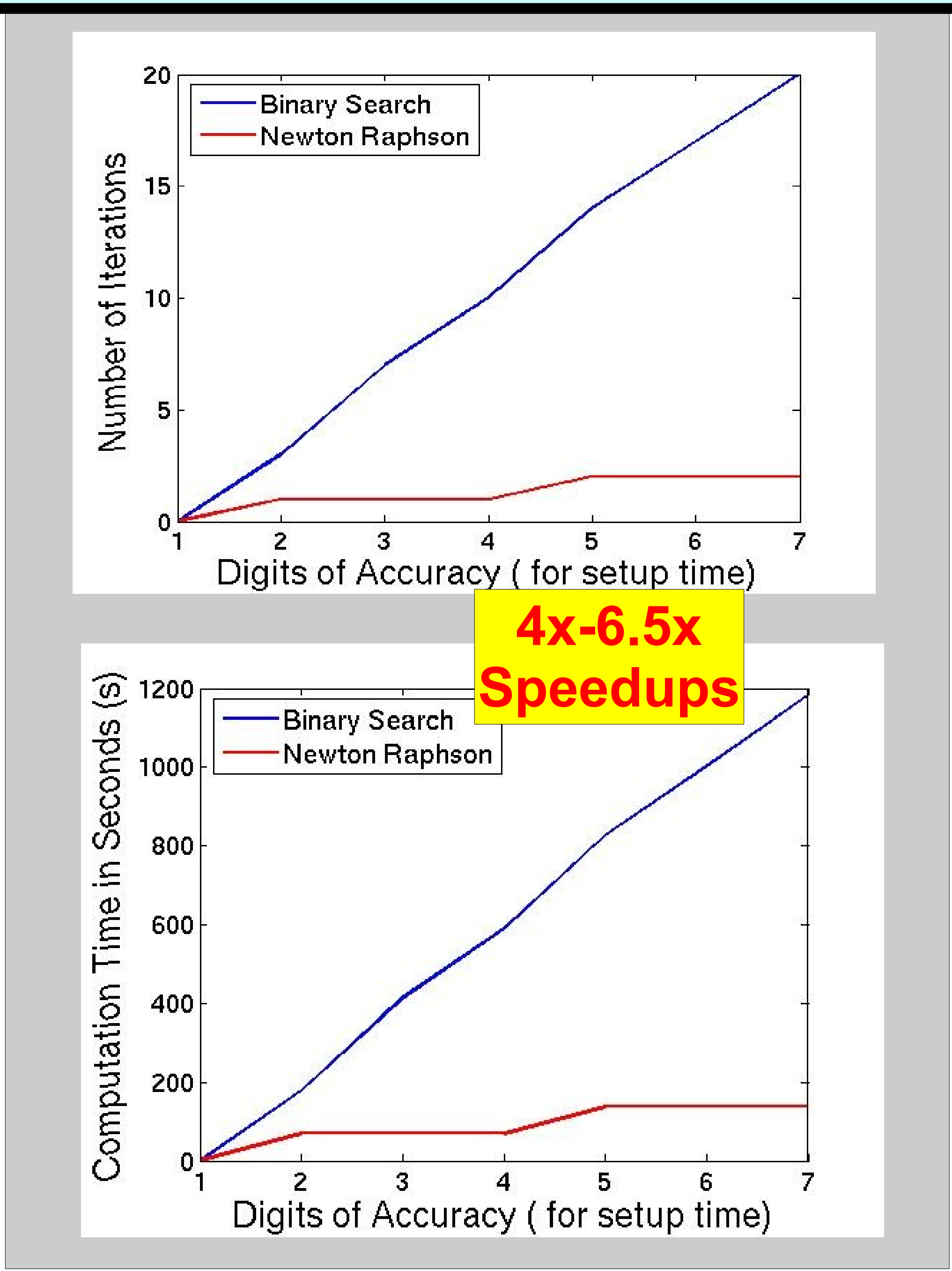
Results

Results: C^2MOS master-slave register

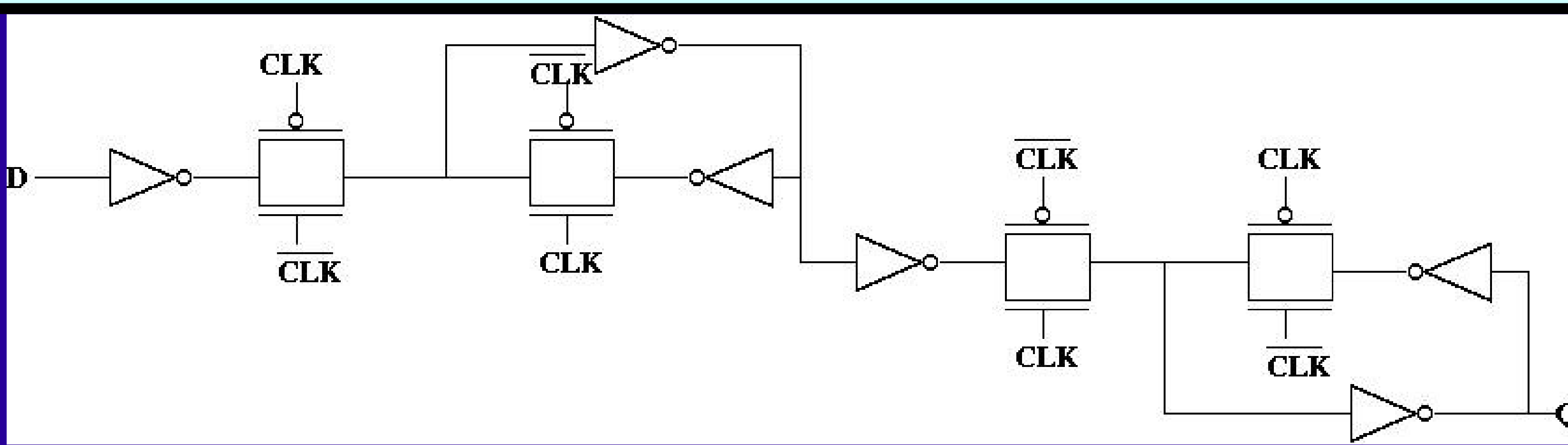


Positive-edge triggered register

Initial guess for setup time was accurate up to 1 digit of accuracy.

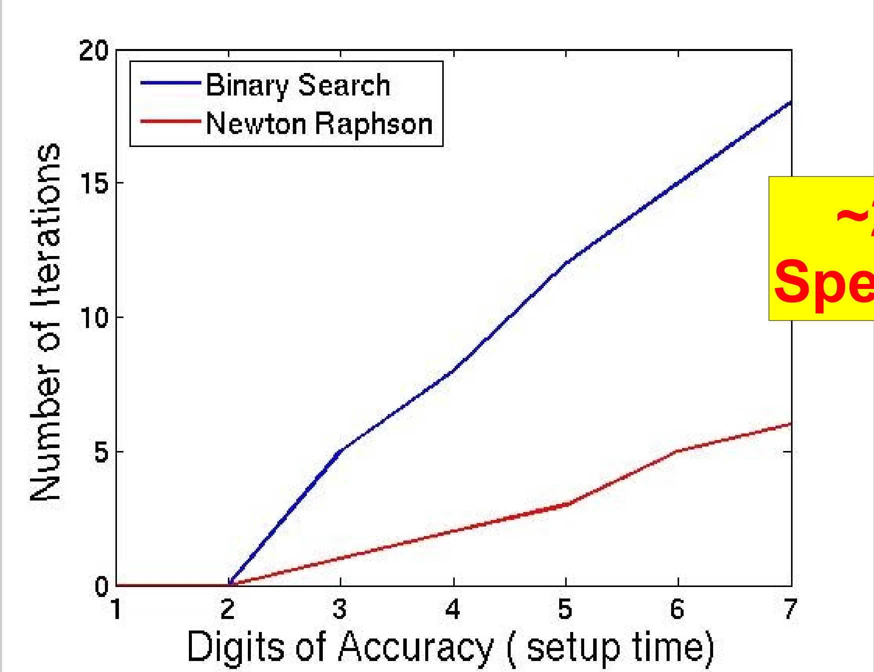


Results: Transmisson gate based register

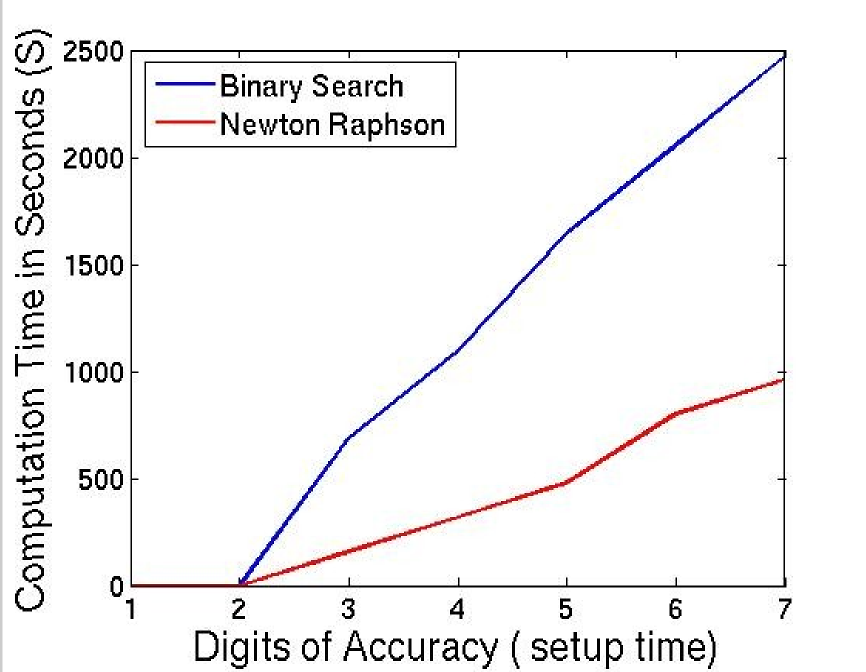


Positive-edge triggered master-slave register

Initial guess of setup time was accurate up to 2 digit of accuracy.



~2.5X Speedups



Conclusion

- Formulation of finding setup/hold times problem as an equation and its solution via Newton-Raphson.
- Newton-Raphson based method:
  - Speedup: 2.5x-7.5x
- Can reduce significant amount of time in characterization?
  - Up to 2 digits of accuracy: Not very useful
  - For 3-7 digits of accuracy:

Months → 11- 4 days

- Faster design cycle.
- NR: Good for multivariate unknowns.