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Runtime Accuracy-Configurable Approximate Hardware Synthesis Using Logic Gating and Relaxation

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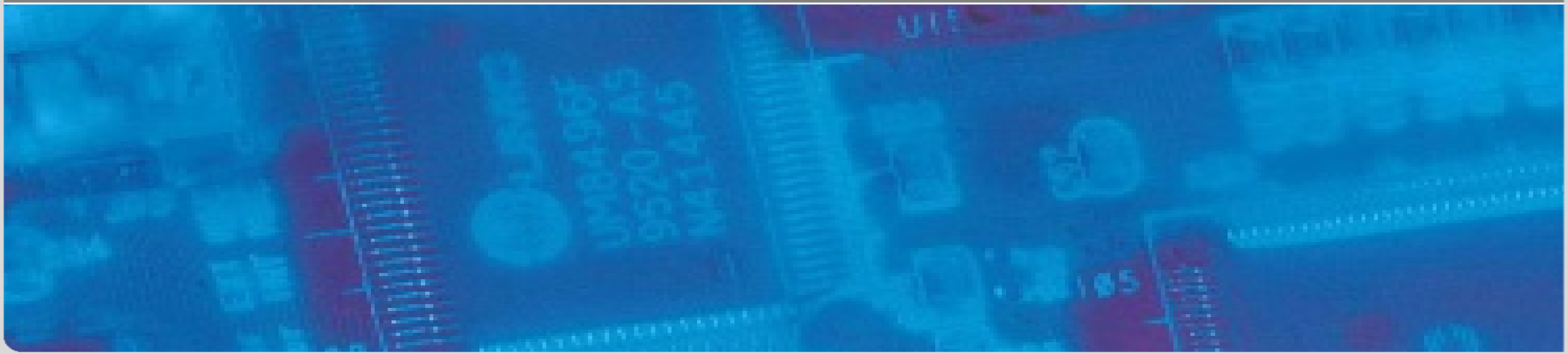
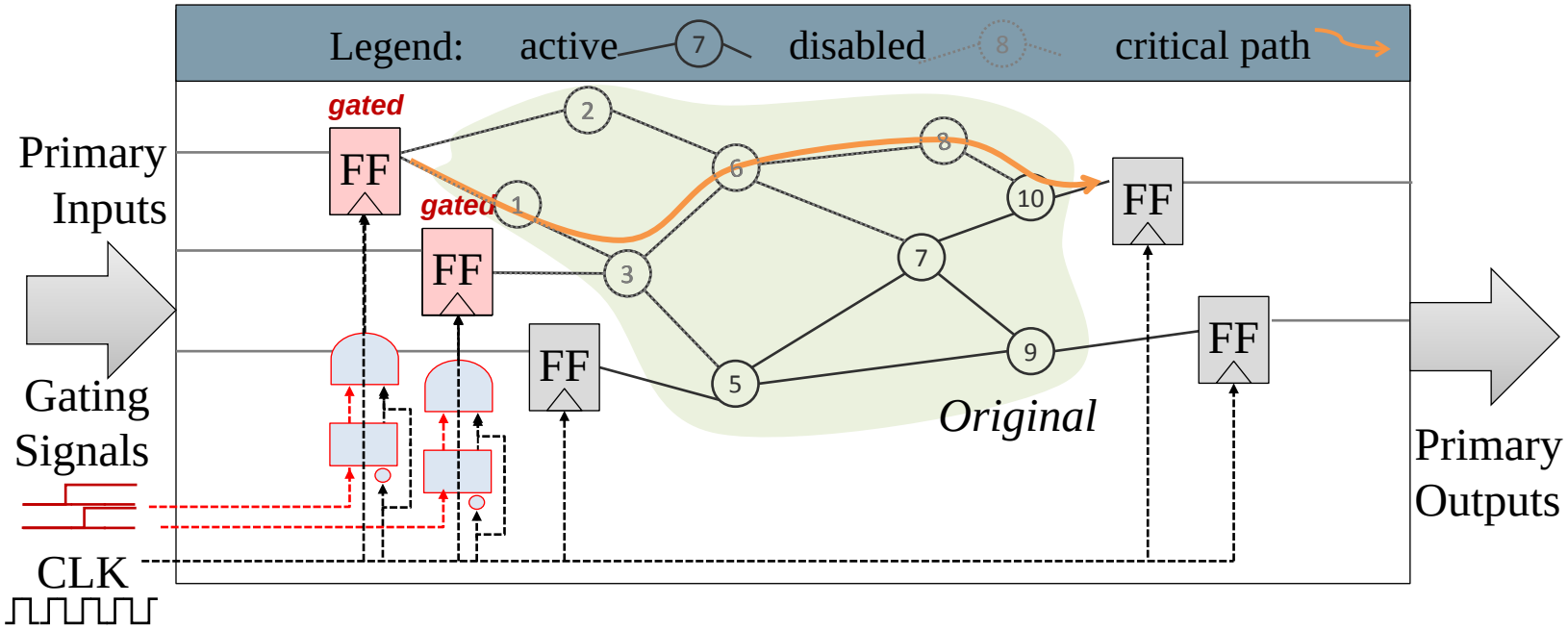
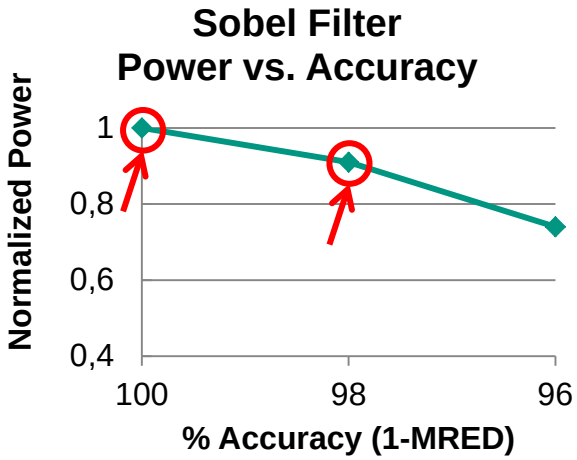


Motivation – Accuracy Configurability

- Approximate Computing
  - Utilizes algorithmic tolerance to inaccuracies
  - Trades accuracy against energy efficiency
- Accuracy:
  - Output quality strongly depends on its inputs
  - Workload tolerance depends on context and environment
- Required accuracy changes at runtime
  - Accuracy configurability is essential!

Background: Accuracy Configuration Using Clock Gating*

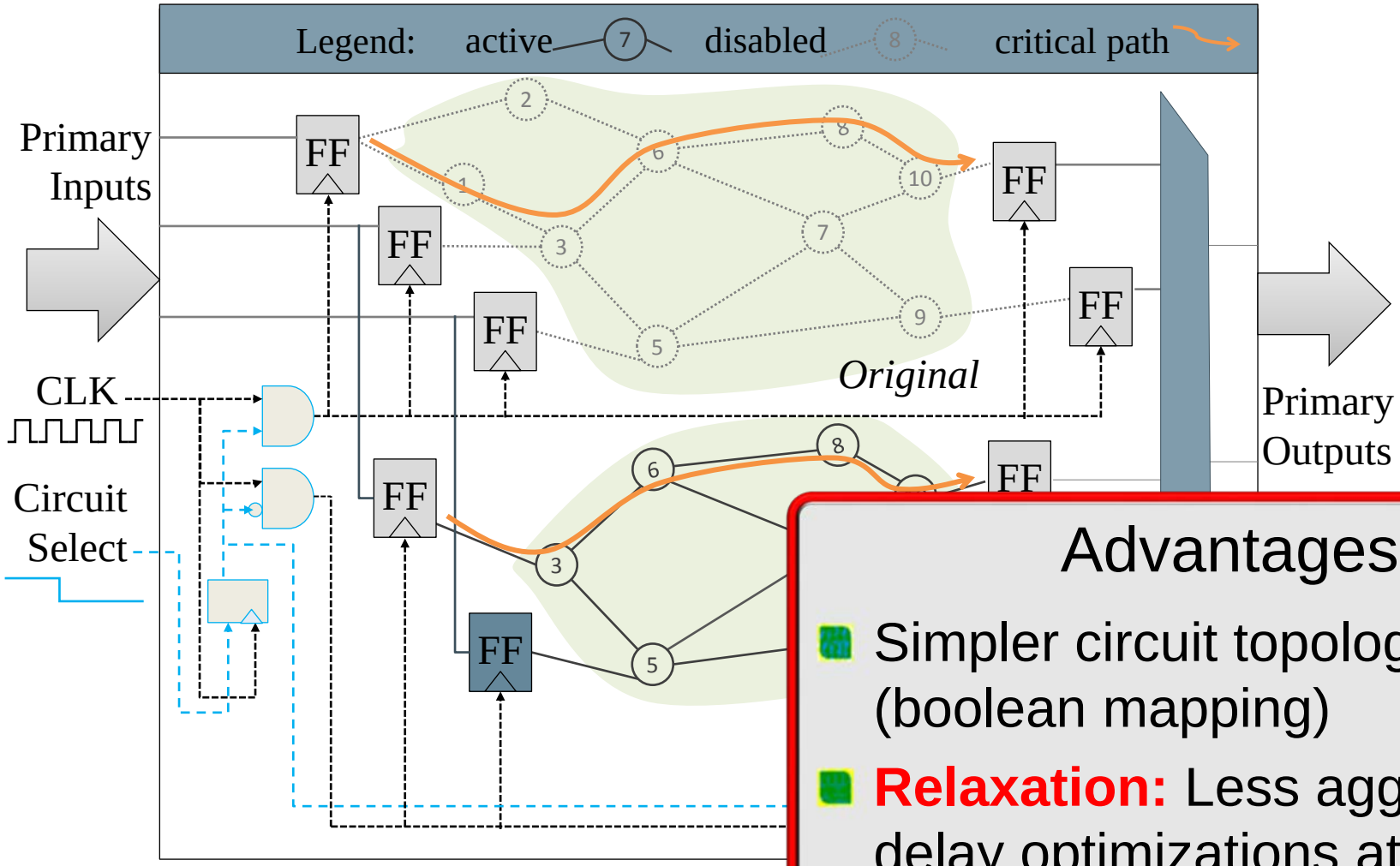


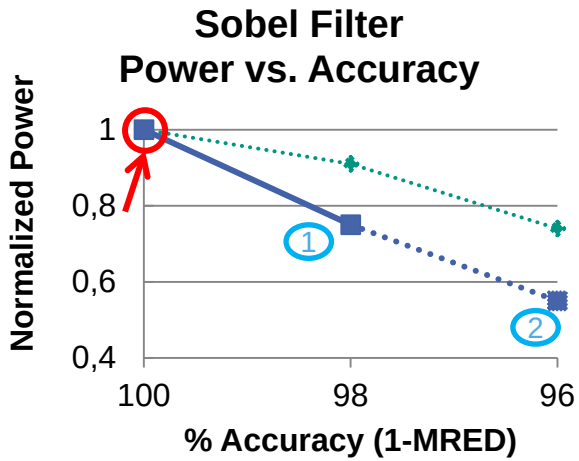


- Same critical path
- Reduced toggling activity

*Kim, Y., Venkataramani, S., Roy, K., & Raghunathan, A. “Designing approximate circuits using clock overgating” DAC 2016

Proposed: Accuracy Configuration Using Logic Relaxation





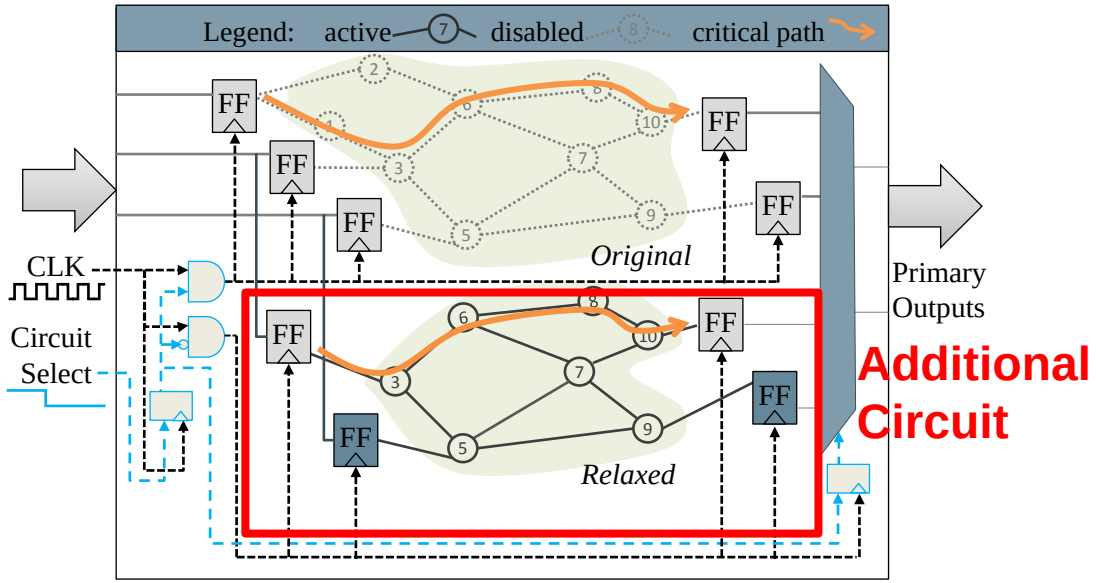
Normalized area cost of
Additional Circuit 1 : 0.79x
Additional Circuit 2 : 0.59x

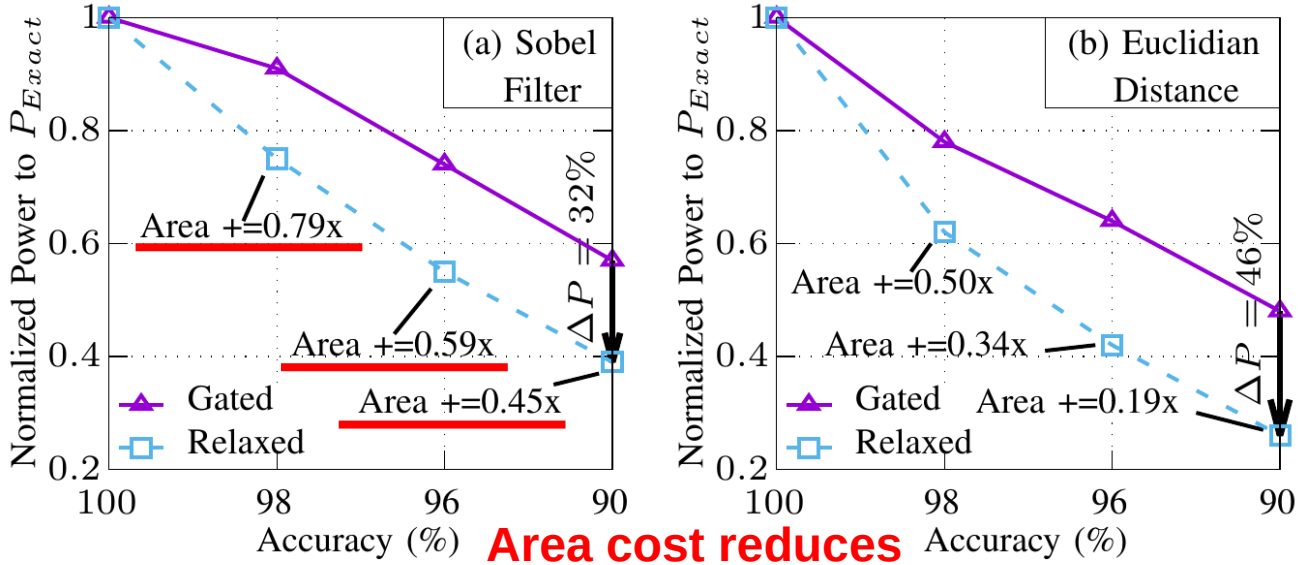
Advantages:

- Simpler circuit topology (boolean mapping)
- **Relaxation:** Less aggressive delay optimizations at synthesis

Instantiation for Accuracy Configurability

- An additional method to gating
- Reduce power at area cost
  - + Smaller, more efficient circuits
  - - Area and leakage cost of new circuits

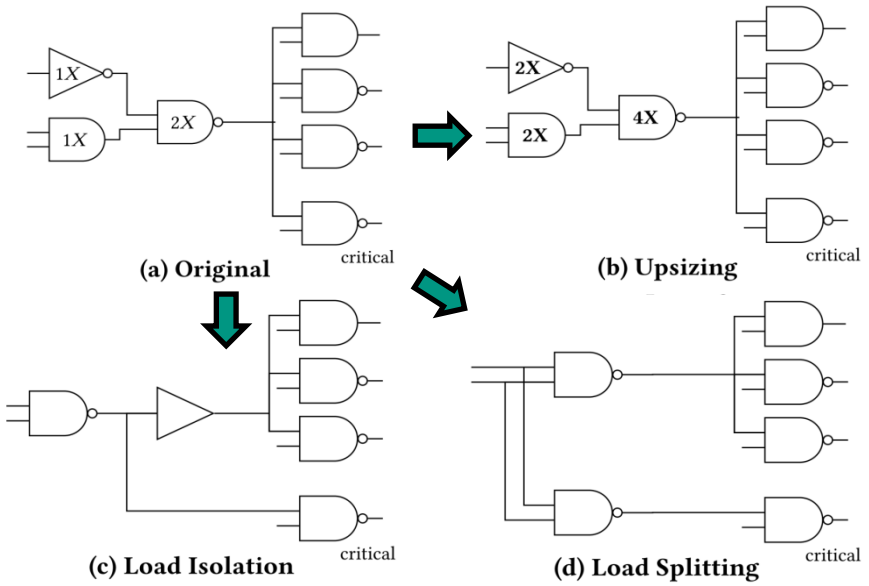




Area cost reduces with accuracy

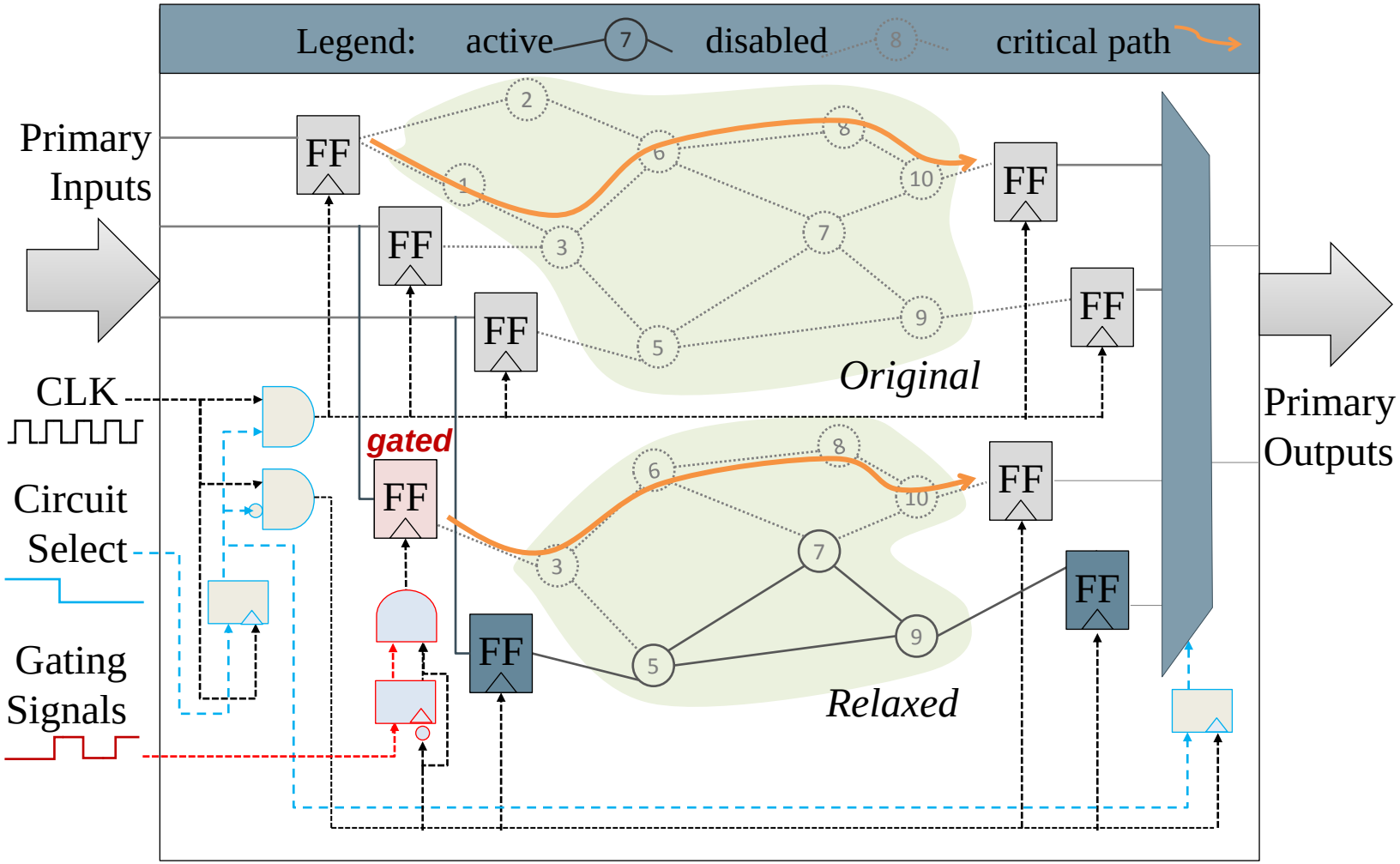
Synthesis Relaxations

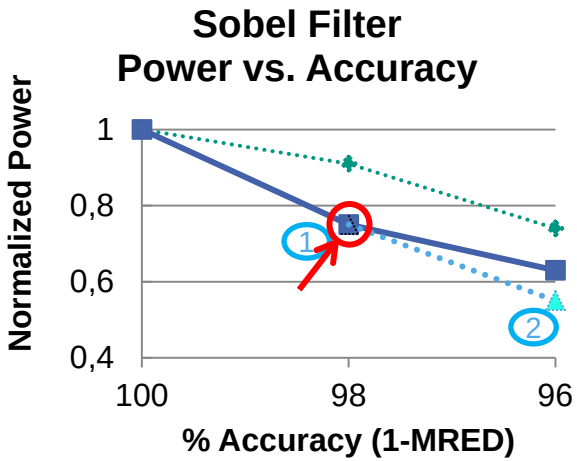
- Given the same clock cycle, approximation allows:
  - Functional simplifications (e.g. precision scaling)
  - Boolean remapping
    - Parallel to sequential structures
      (e.g. Parallel Prefix Adder to Ripple Carry Chain)
  - Undoing Gate-level delay optimizations



Relaxed circuits are more power efficient and require less area than the original

Hybrid: Logic Gating and Relaxation





Normalized area cost of
Additional Circuit 1 : 0.79x
Additional Circuit 2 : 0.59x

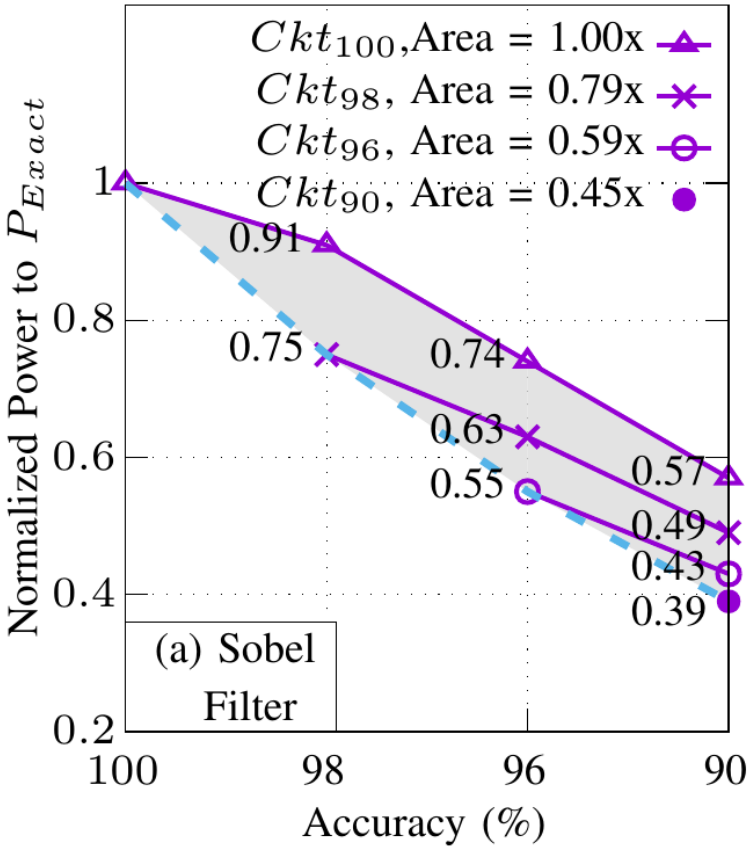
Experimental Setup

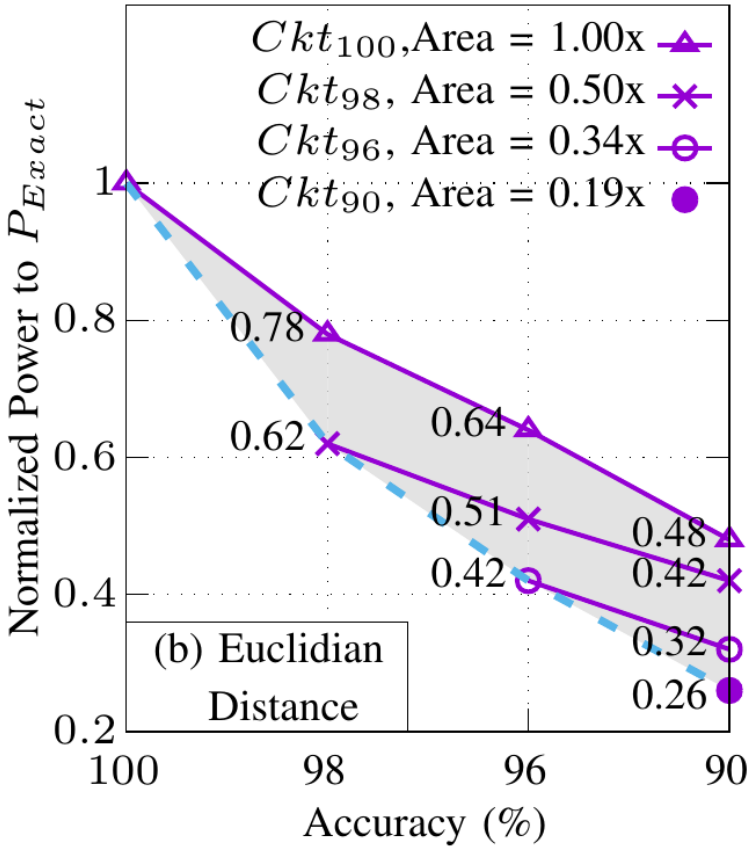
- Accuracy: 1 – MRED (Mean Relative Error Distance)
  -

Gating + Instantiating: A New Design Space

- Gating (only) – top line
- Instantiating – blue line
- Hybrid - gray zone

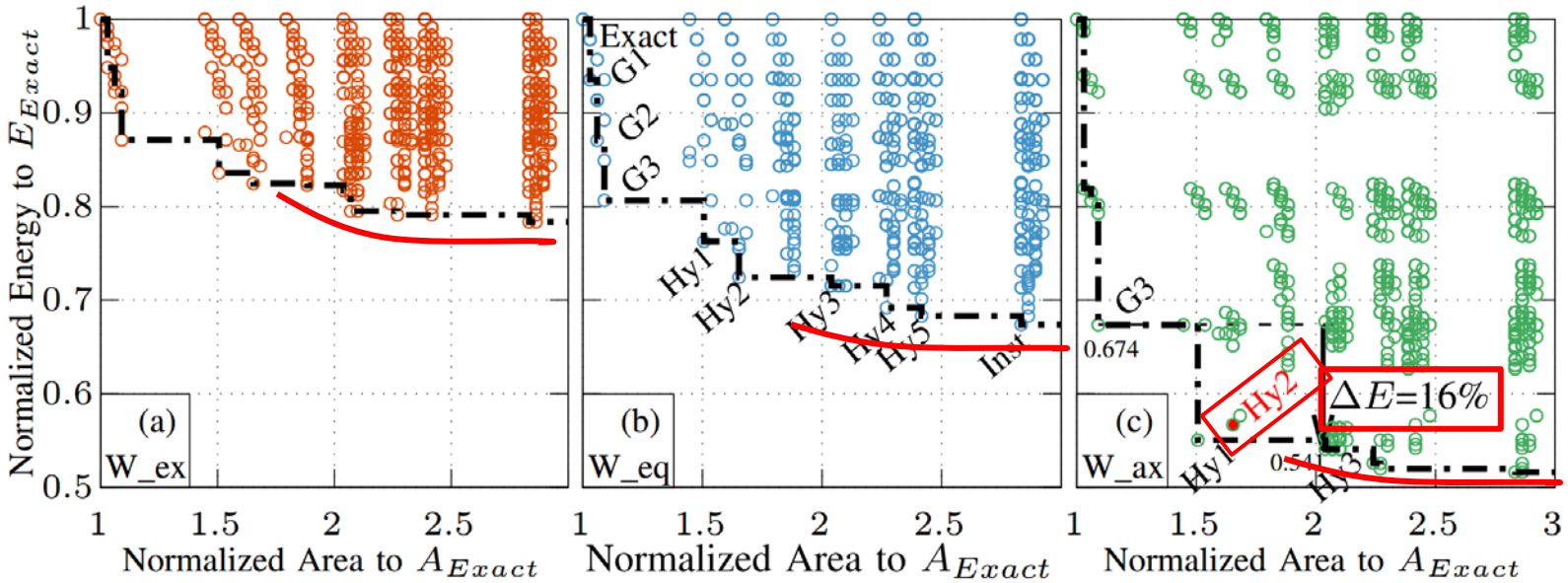
- How to combine?
  - Workload (utilizations)
  - Dynamic power savings
  - Additional leakage power





Results – Workloads with Multiple Accuracy Requirements

- Pareto optimal solutions are workload dependent
- Energy savings diminish at excess area
- Up to 16% energy reduction over gating at 2x area cost
  (dynamic + leakage)



Design Space of a Sobel Filter

Utilization Distributions	Accuracy			
Workload	100%	98%	96%	90%
W_eq - *even distribution*	0.25	0.25	0.25	0.25
W_ex - *mostly exact*	0.5	0.2	0.2	0.1
W_ax - *mostly approximate*	0.1	0.15	0.05	0.7
Corresponds to PSNR:		*45dB*	*38dB*	*31dB*

Conclusion

- Instantiating is an additional method to gating for accuracy-configurable approximate circuits
  - Can reduce energy requirement at area cost
- We propose a novel, hybrid design approach:
  - Combines gating and instantiating
  - Benefits from synthesis relaxations **and** reduced toggling activity
- Our work demonstrates a larger design space of accuracy-configurable hardware