

# Making Cyclic Circuits Acyclic

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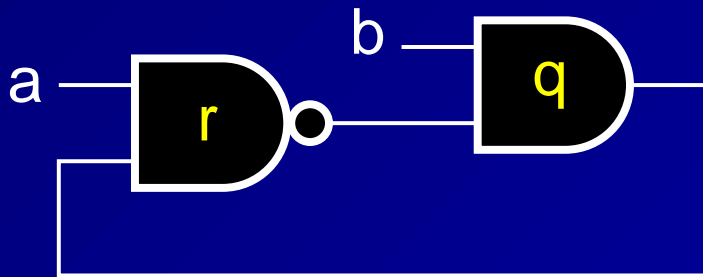
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# What is a Combinational Circuit?

Malik [ICCAD 1993]: “A circuit is combinational *for an input pattern* if three-valued simulation starting from Xs converges to 0s and 1s.”

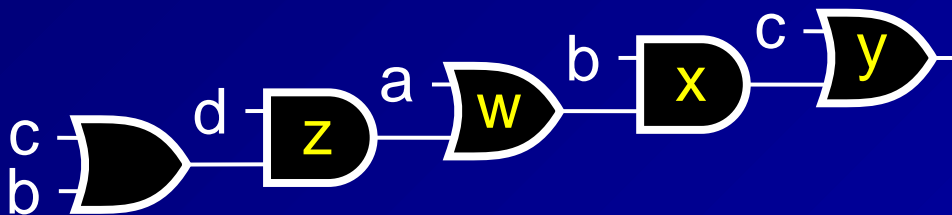
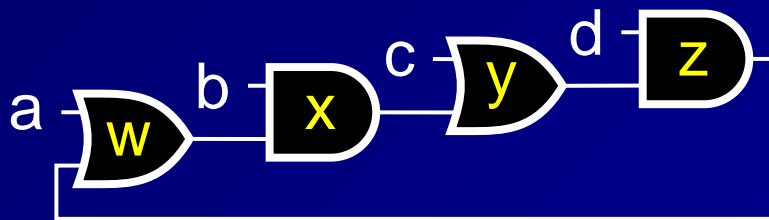
Shiple [1996]: “This is equivalent to stability in Brzozowski and Seger’s [1995] asynchronous model.”



a	b	q	r
0	0	0	1
0	1	1	1
1	0	0	0
1	1	X	X

# Goal

Given a cyclic circuit that is combinational for some inputs, create a similarly-structured acyclic circuit that computes the same combinational function.



Circuit after Rivest [1977]

abcd	wxyz
0000	0000
0001	0000
0010	0010
0011	1011
0100	0000
0101	
0110	0010
0111	1111
1000	1000
1001	1000
1010	1010
1011	1011
1100	1110
1101	1111
1110	1110
1111	1111

this input not  
combinational



# Applications

*Fixing cyclic circuits produced by high-level synthesis*

Stok [ICCAD 92]: resource sharing creates false cycles

Cycles arise naturally in Esterel programs [Berry 1992]

Acyclic circuits easier to simulate efficiently

The next speaker [Riedel] will show how to synthesize cyclic circuits. *He puts 'em together, I take 'em apart.*

# Result

1. Exact algorithm for finding all combinational behavior

*Applies a controlling value to each SCC*

Produces set of acyclic circuit fragments

2. Heuristic algorithm for building equivalent acyclic circuit

Merges fragments while duplicating few gates

Result: A practical algorithm that builds acyclic circuits from cyclic combinational ones.

# Conceptually

1. Compute the circuit's truth table under three-valued simulation.
2. Build a small circuit that computes this function.

Treat inputs for which three-valued simulation produces Xs as don't-cares.

# Conceptually and Concretely

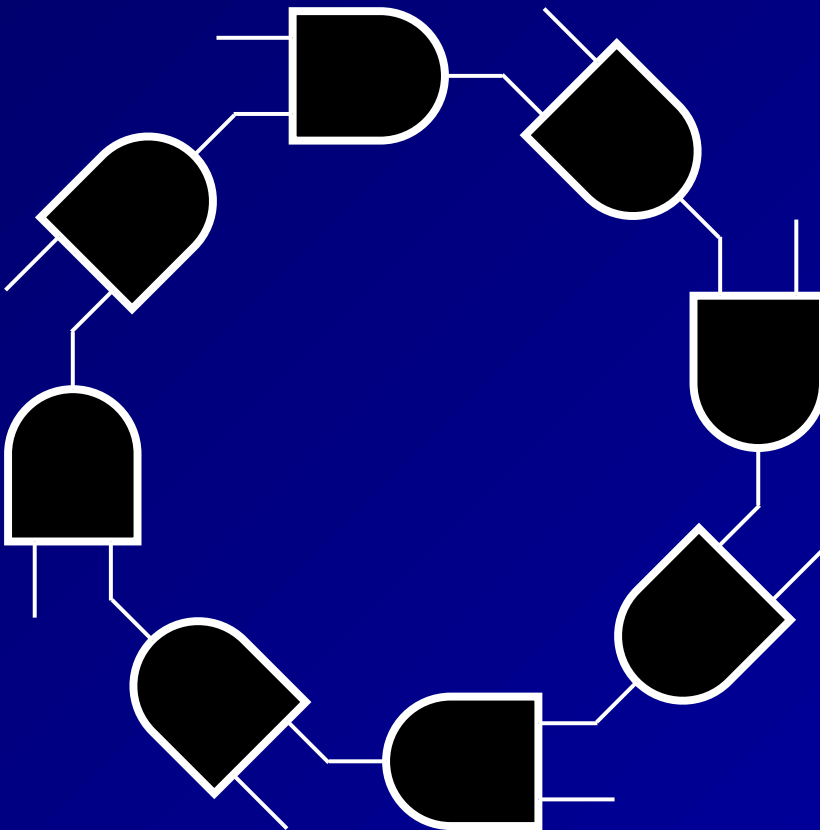
1. Compute the circuit's truth table under three-valued simulation.
2. Build a small circuit that computes this function.

Treat inputs for which three-valued simulation produces Xs as don't-cares.

1. Find input patterns that apply values that break all cycles in the cyclic circuit.
2. Assemble the acyclic circuit fragments these patterns imply into a small acyclic circuit.

# Key Insight

*For an input pattern to be combinational, at least one input coming from outside each strongly-connected component must have a controlling value.*

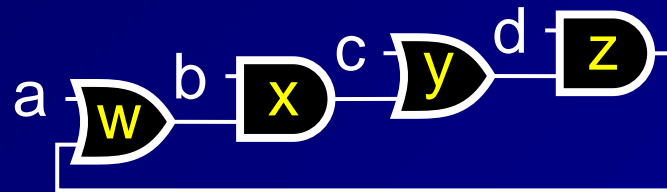


If all external inputs were non-controlling, the gates in the SCC would stay at X.

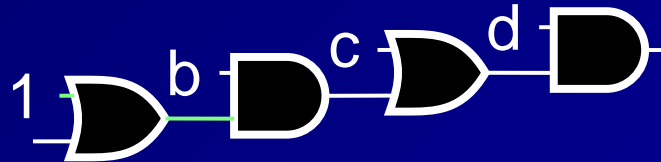


# Applying Controlling Values

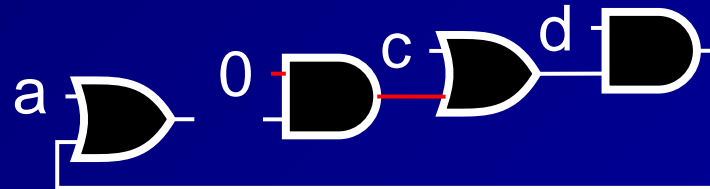
Original circuit



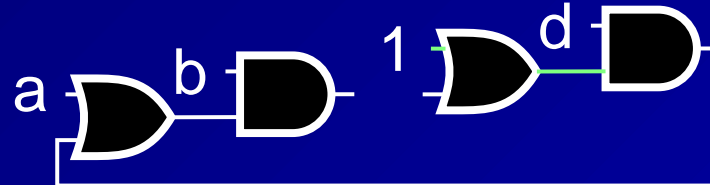
$a = 1$



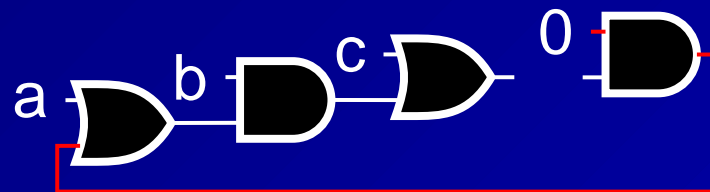
$b = 0$



$c = 1$



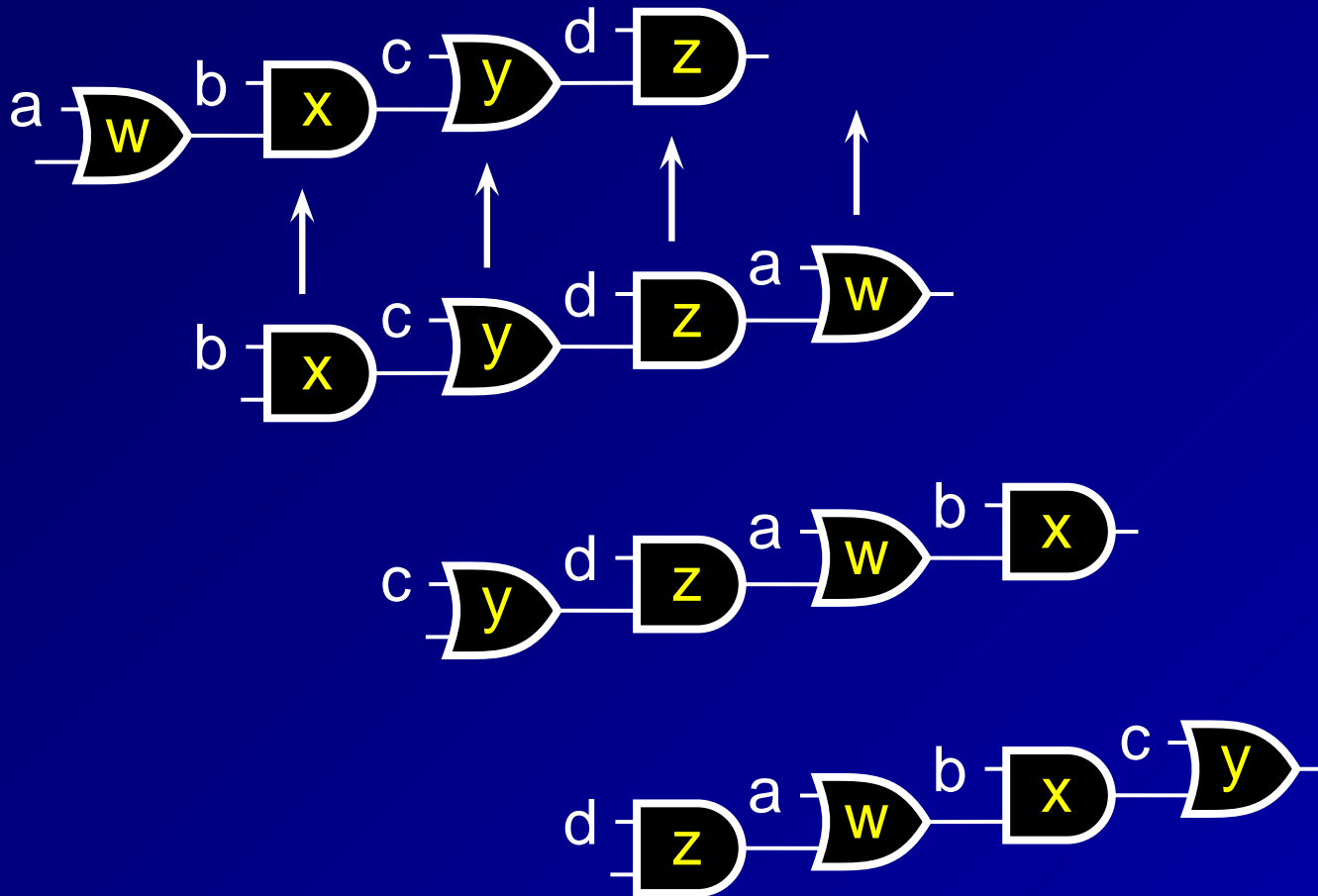
$d = 0$



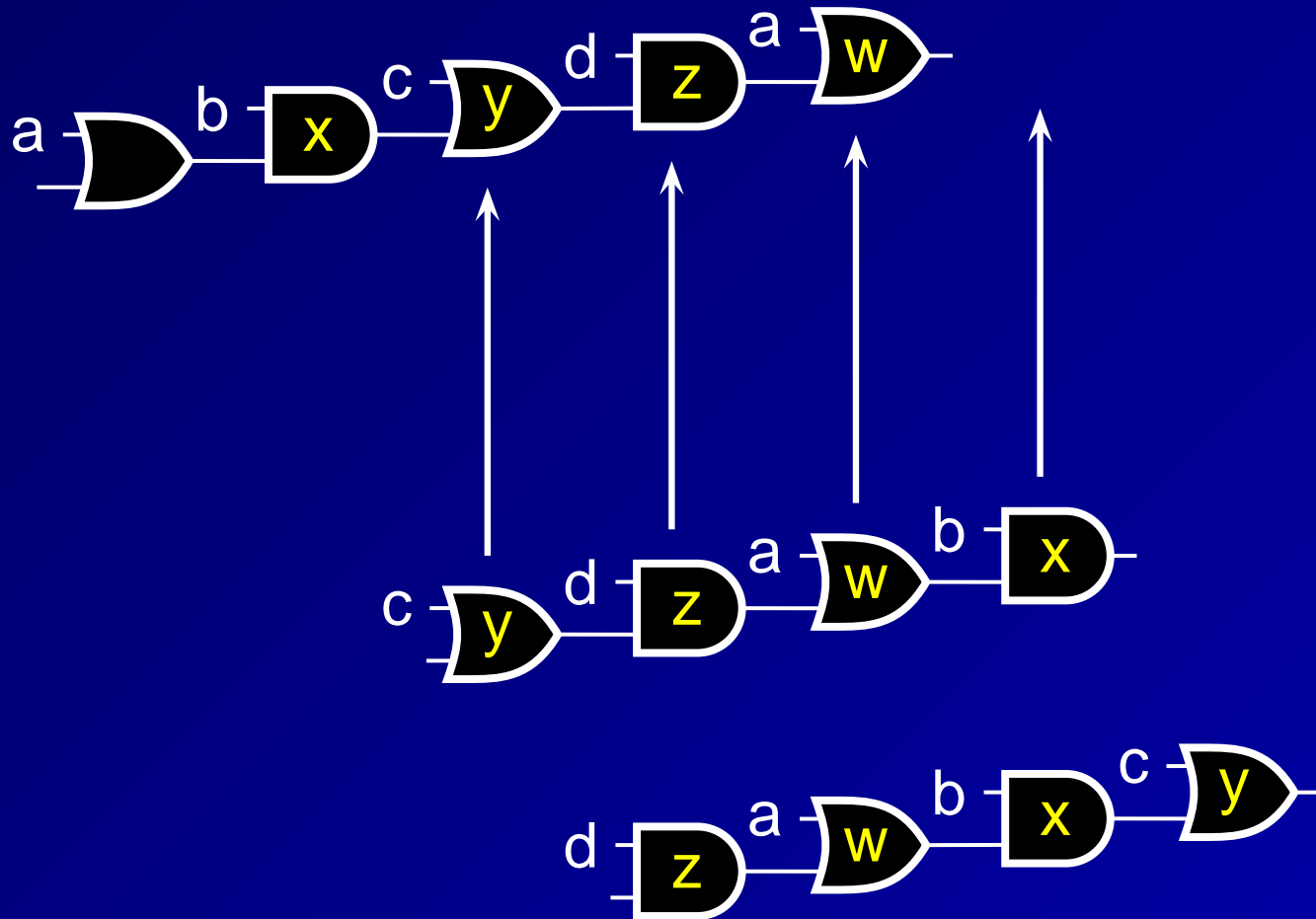
Each of these four fragments covers part of the domain.

Merging these fragments gives the final acyclic circuit.

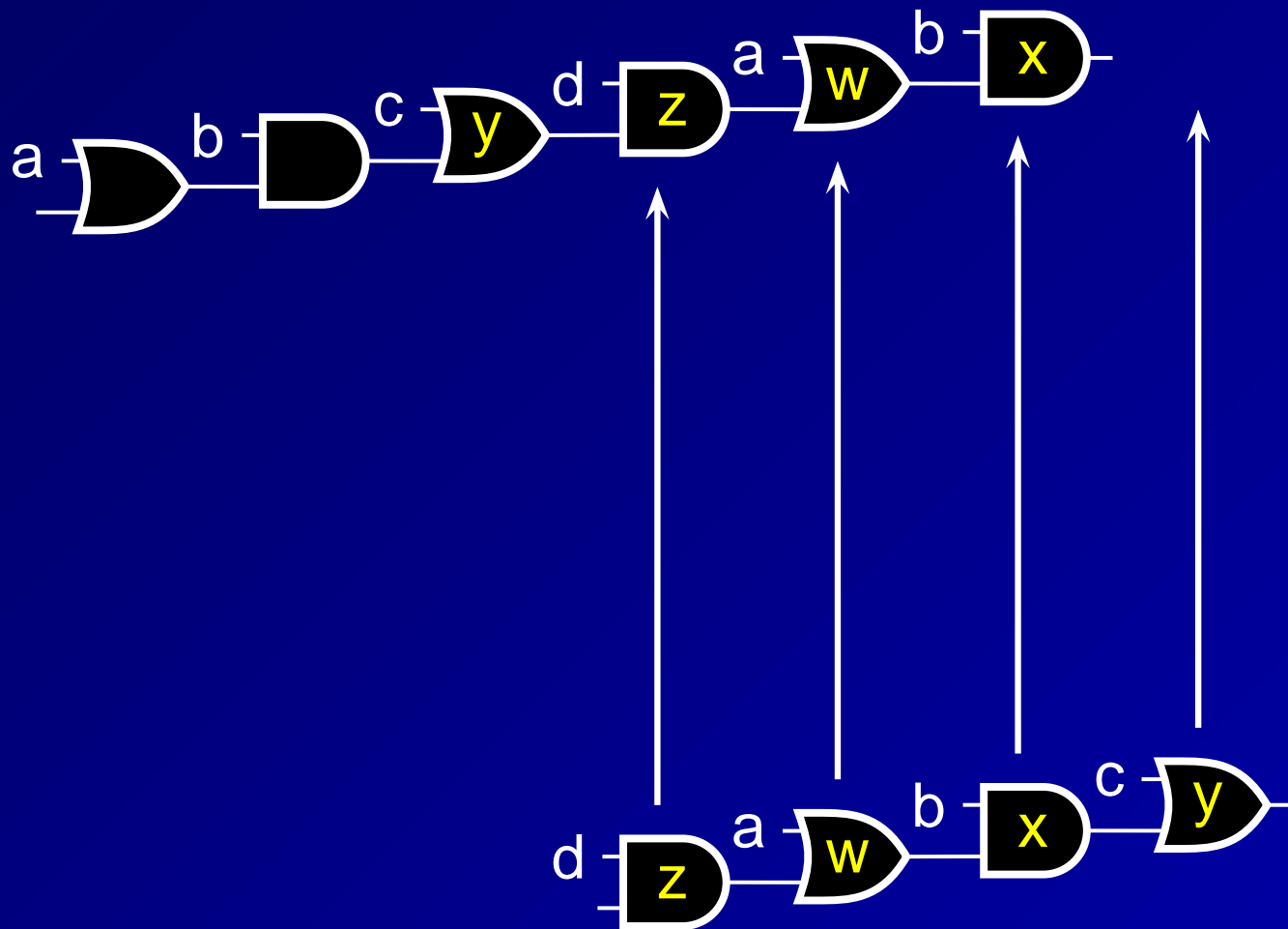
# Merging Fragments



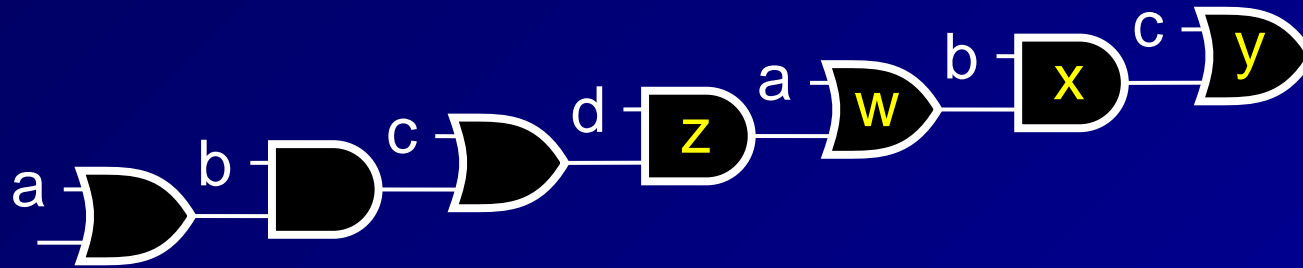
# Merging Fragments



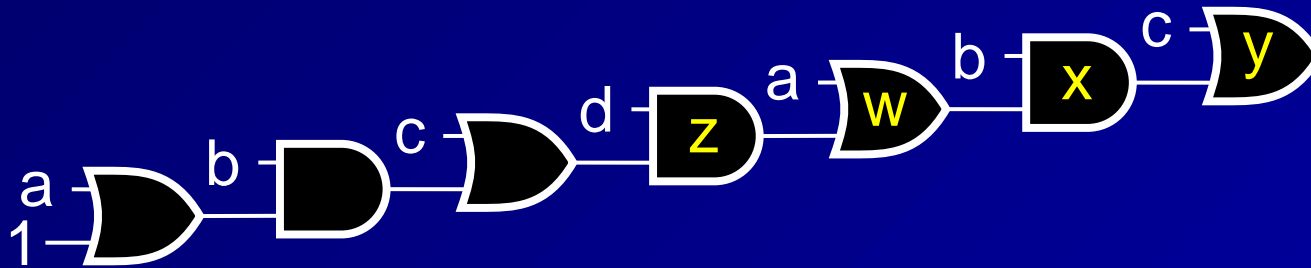
# Merging Fragments



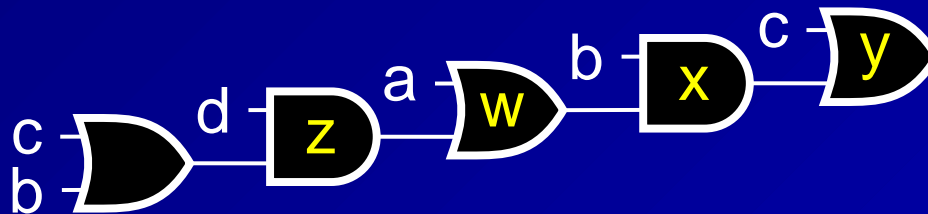
# Merging Fragments



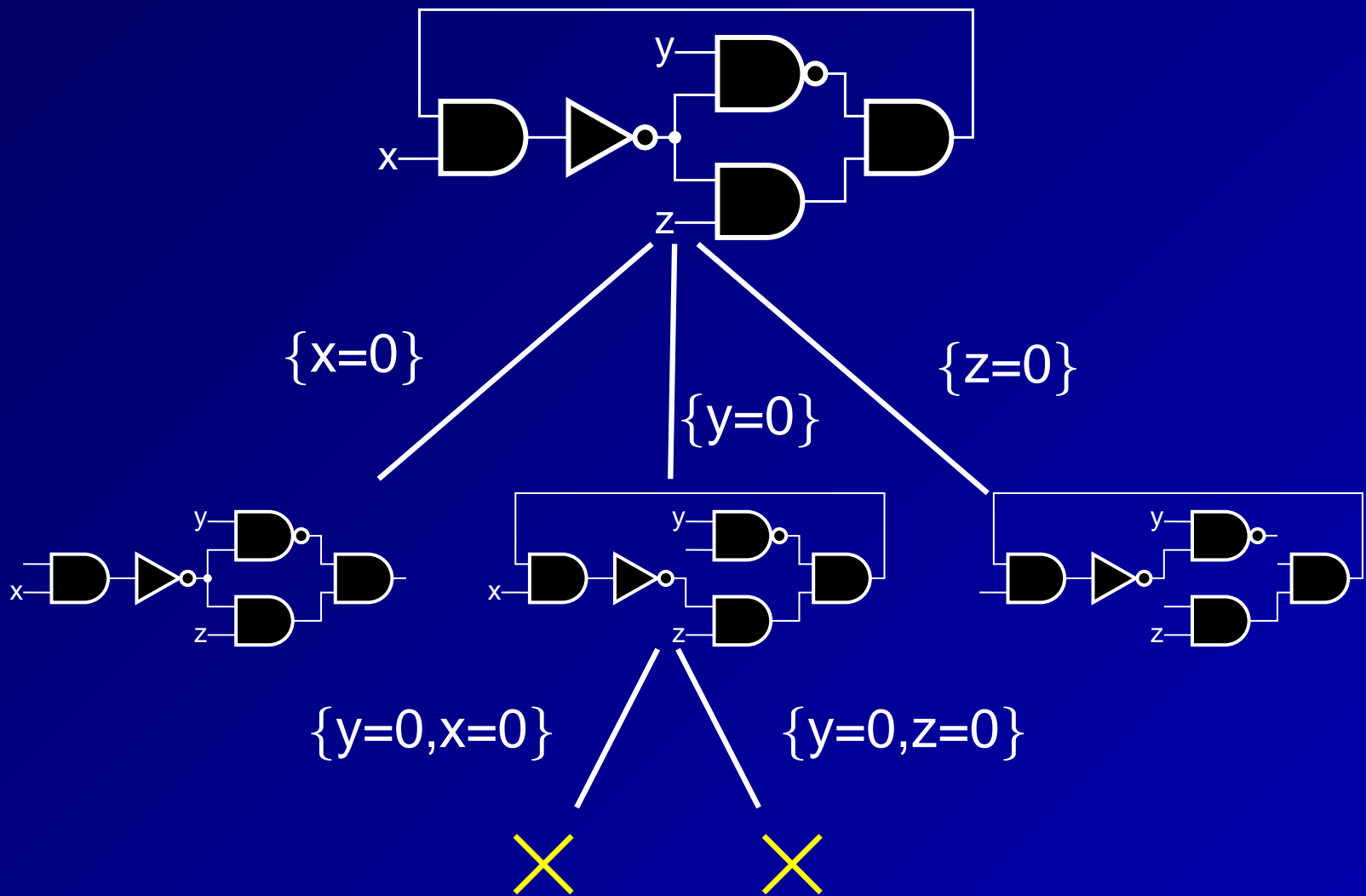
Apply constant 1 to the don't-care input



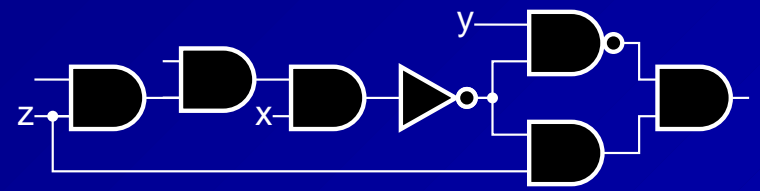
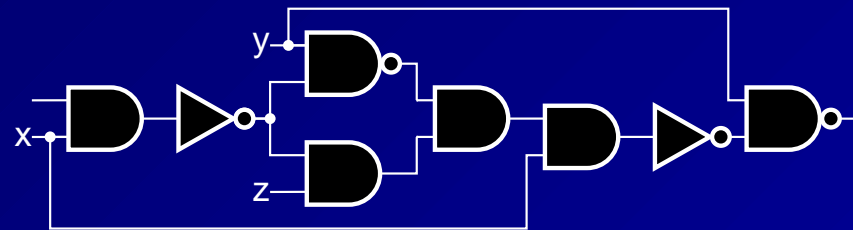
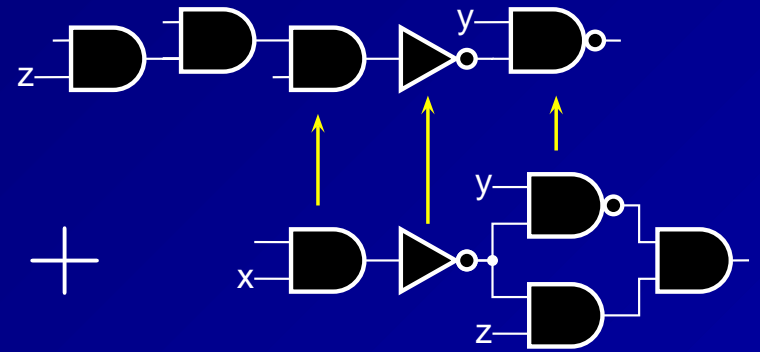
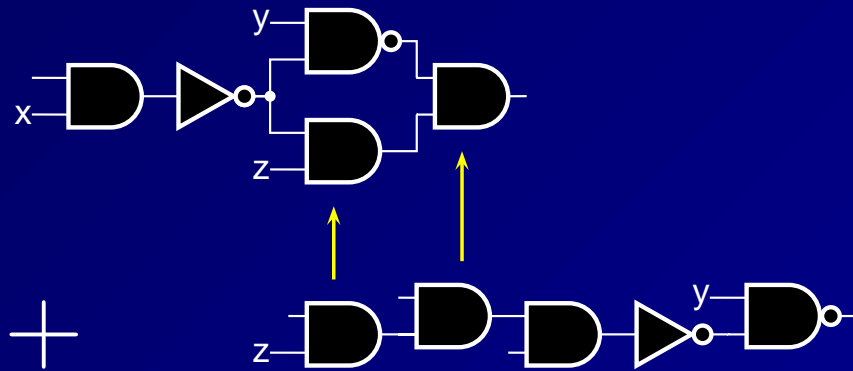
Simplify



# Another Example: Searching

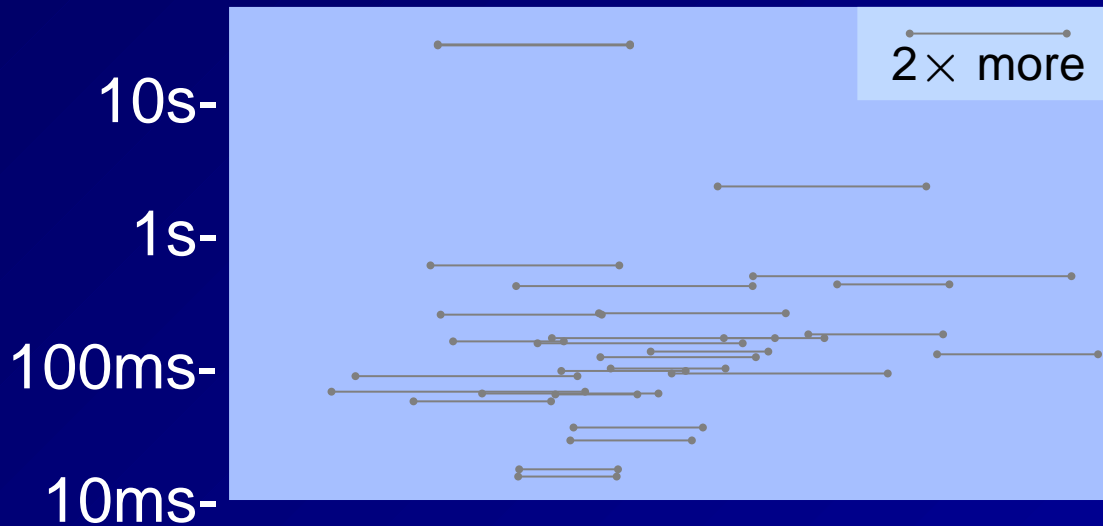


# Another Example: Merging

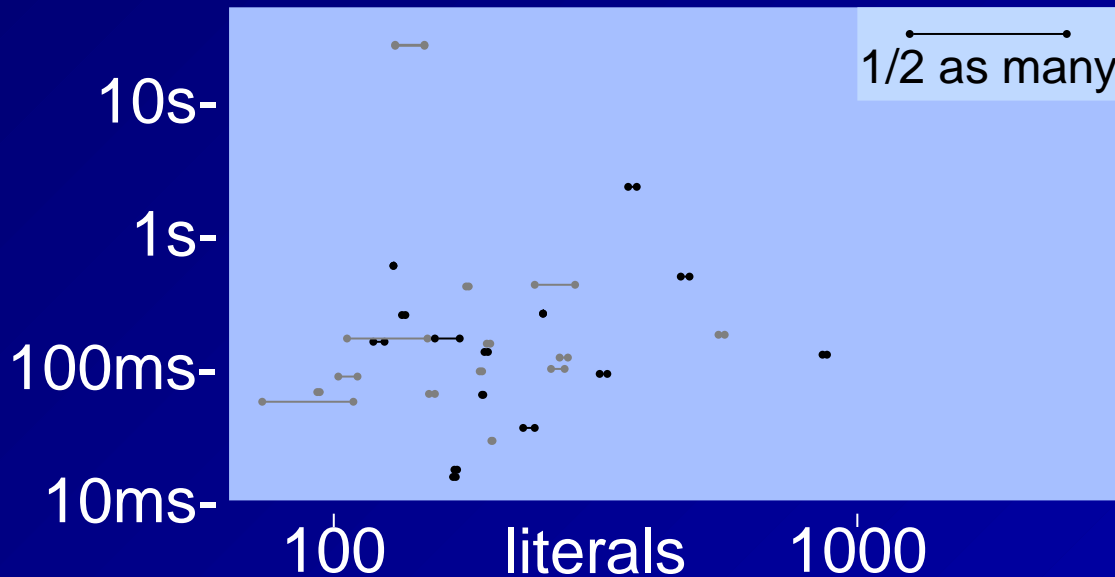


↑  
This is smaller

# Experimental Results



Average  
increase  
before SIS:  
113%



Average  
increase  
after SIS:  
4%



# Conclusions Redux

Algorithm for building an equivalent acyclic circuit from a cyclic combinational circuit

Key idea: apply controlling value to a gate in each SCC

Algorithm finds acyclic fragments, then merges them.

Finding fragments may be exponentially costly

Merging is done with a heuristic

Appears practical for small examples