Advanced Digital Logic Design – EECS 303

http://ziyang.eecs.northwestern.edu/eecs303/

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Outline

Minimization of incompletely specified FSMs

CS	NS(0)	NS(1)	OUT
A	A	X	1
B	B	C	1
C	C	A	X
D	A	D	0

Reason for prime compatibles

Consider the following maximal compatibles

AB

BC

CD

BE $\longrightarrow$ BC

Minimization stages

- State table
- Implication chart
- Maximal cliques (for larger problems)
  - Largest fully connected subgraphs
- Maximal compatibles
- Prime compatibles
- Binate covering

Outline

Registers and counters

- Once you understand flip-flops and FSM design, registers and counters are easy
- Shift registers can shift contents left or right
- Registers
  - Commonly a group of D flip-flops written and read simultaneously
- Counters
  - FSMs that have only a clock input
  - Can count up or down in some binary number system
  - Can also cyclicly shift a one through flip-flops (ring counter)

Multiple-output pseudo-NFAs

- Similar to standard NFAs
- Have multiple accept states
- Simple translation to Moore machines
- Going from DFAs to Mealy machines is more complicated

Outline

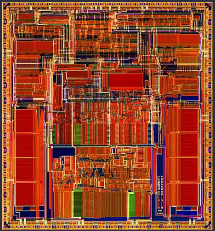
1. Review of state minimization
2. Registers and counters
3. Asynchronous finite state machines

Section outline

Synchronous vs. asynchronous design

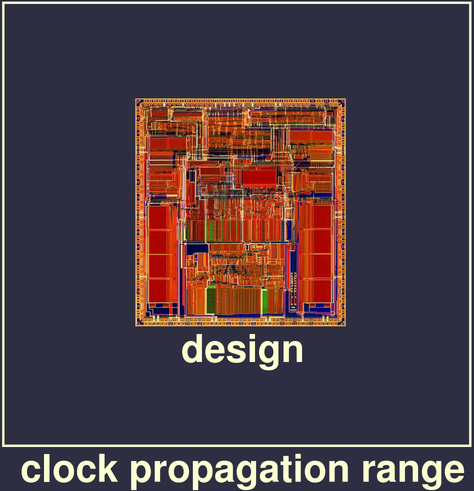
- Synchronous design makes a lot of problems disappear
- Glitches not fatal
- FSM design easier
- However, things are likely to change soon

Current SOC clocking and communication

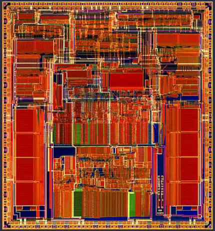


design

Future SOC clocking and communication



Future SOC clocking and communication



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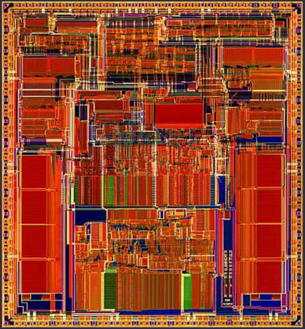
Future SOC clocking and communication



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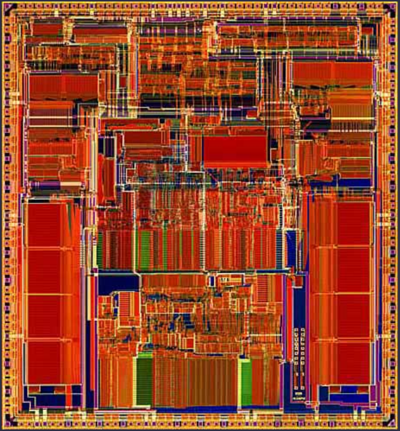
Future SOC clocking and communication



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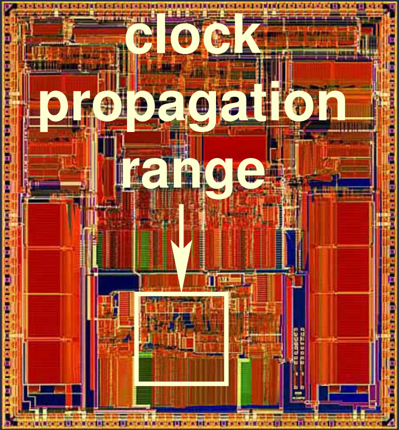
Future SOC clocking and communication

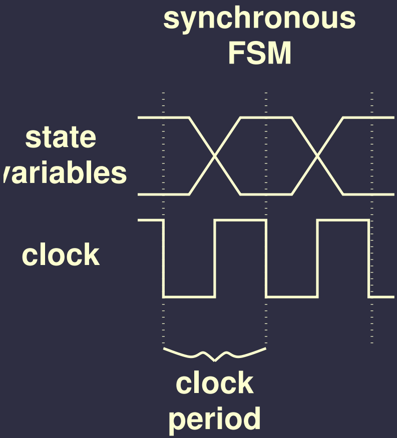


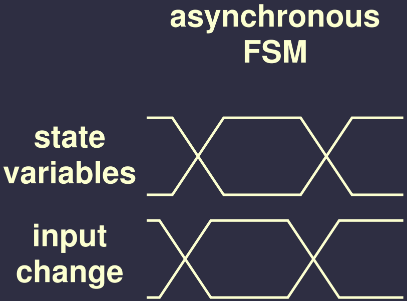
design

Globally asynchronous, locally synchronous (GALS)

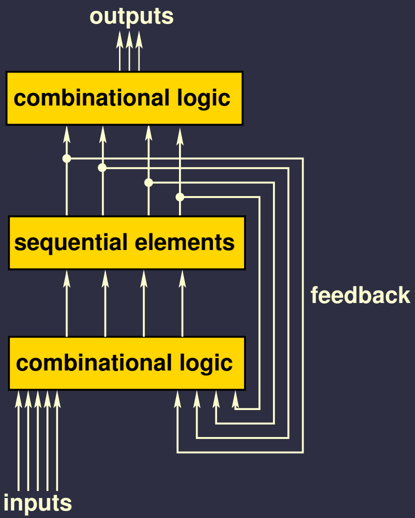
- Complete flexibility in region frequencies
- Reputation for inefficient communication
- However, results always improving
- Asynchronous circuits traditionally skipped
- However, you will encounter them in interface circuits and are likely to encounter them more and more frequently
- Asynchronous design likely to become increasingly important

Synchronous vs. asynchronous FSMs





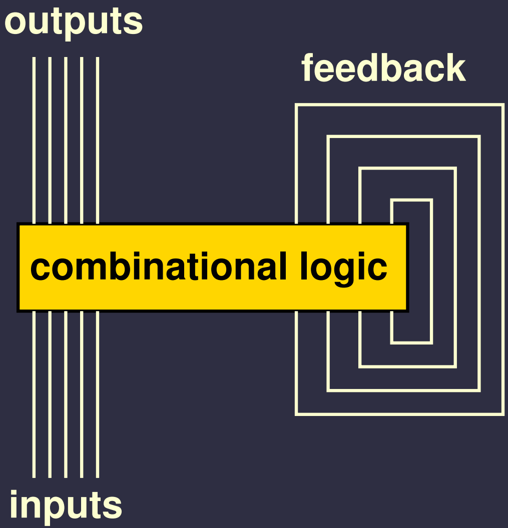
Synchronous system



Differences from synchronous circuits

- Avoid critical races (more later)
- Avoid glitches
- State can be a function of input as well as state variables
- May need to do state splitting

Asynchronous machine block diagram

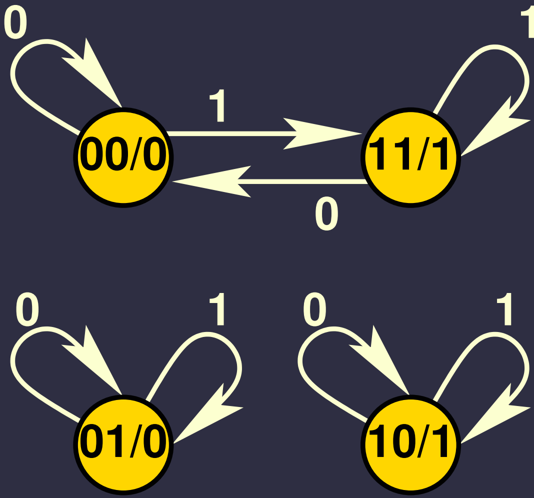


Section outline

Asynchronous FSM state assignment

- For synchronous FSMs, state assignment impacts area and power consumption
- For asynchronous FSMs, incorrect state assignment results in incorrect behavior
- A *race* is a condition in which the behavior of the circuit is decided by the relative switching speeds of two state variables
- An asynchronous FSM with races will not behave predictably
- Avoid *critical races*, races which result in different end states depending on variable change order

Incorrect asynchronous assignment



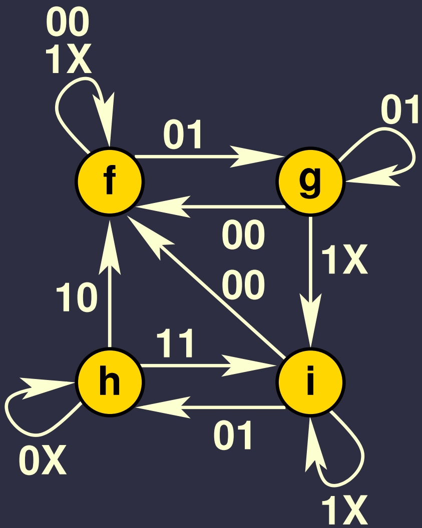
Asynchronous FSM state assignment

	s^+		
s	0	1	Q
00	00	11	0
01	01	01	0
10	10	10	1
11	00	11	1

Consider 00 $\longrightarrow$ 11 transition

- Becomes trapped in 01 or 10
- Which one?
  - Random

Asynchronous FSM adjacency



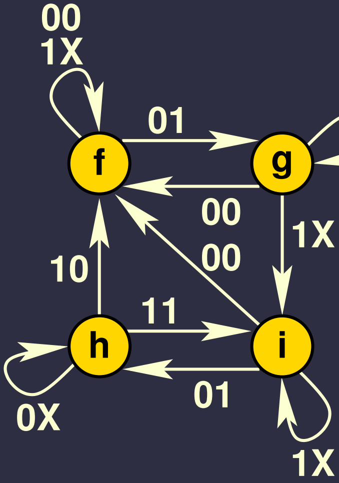
Asynchronous FSM adjacency

- Two input bits
- When a particular input leads to a state, maintaining that input should generally keep one in the state
  - E.g., 01 for g
- Will show exception later

Asynchronous FSM adjacency

- f adjacent to g, h, and i
- g adjacent to f and i
- h adjacent to f and i
- i adjacent to f, g, and h
- Four states $\rightarrow \lceil \lg(4) \rceil = 2$ state variables
- However, in 2D space, each point is adjacent to only two others
- Need at least 3D

Asynchronous FSM adjacency



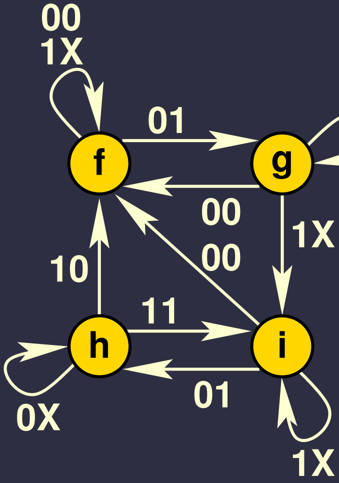
$$\begin{tikzcd}
f \arrow[r, bend left, "01"] \arrow[loop above, "00\ 1X"] & g \arrow[l, bend left, "00"] \arrow[d, "1X"] \arrow[loop right, "01"] \\
h \arrow[u, "10"] \arrow[r, bend left, "11"] \arrow[loop left, "0X"] & i \arrow[ul, "00"] \arrow[l, bend left, "01"] \arrow[loop below, "1X"]
\end{tikzcd}$$

		a	
		0	1
b	0	f	g
	1	h	i

Asynchronous FSM adjacency

- Need all adjacent states in AFSM to be adjacent
- i to f transition could be trapped in g!
- What to do for a graph with too many connections?
- Split states and hop through some states to reach others

Asynchronous FSM adjacency



b \ a	0	1
0	f	g
1	h	i

c \ ab	00	01	11	10
0	g	f	i2	i2
1	X	h1	h2	X

Asynchronous FSM adjacency

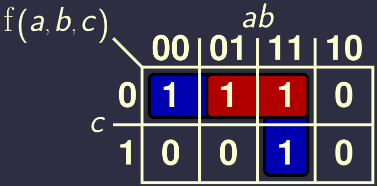
current state	next state 00	01	10	11
f	f	g	f	f
g	f	g	i_2	i_2
h_1	h_1	h_1	f	h_2
h_2	h_2	h_2	h_1	i_1
i_1	f	h_2	i_1	i_1
i_2	i_1	i_1	i_2	i_2

AFSM synthesis redundancy

- Even if AFSM has a fully connected adjacent state assignment there are still additional complications
- State variables must have stable transitions
- E.g., for a SOP implementation, every state pair that is connected in the state transition graph must me covered by at least one cube
- Hazards may cause incorrect operation for AFSMs

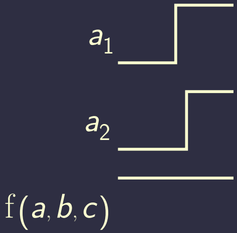
AFSM transition stability

Given that f(a, b, c) is a state variable



$$\overline{a}\ \overline{c} + a\ b + b\ \overline{c}$$

$$\overline{a}\ b\ \overline{c} \rightarrow a\ b\overline{c}$$



AFSM design summary

- AFSMs immediately react to input changes
- No need to worry about clock
- However, design more complicated
- Stability
- Unstable states must have appropriate (no glitches) outputs
- Adjacent states must have adjacent assignments
- Glitches on state variables may be fatal

Section outline

Debouncing

- Recall previous method of debouncing switch
- Consider SPDT (single pole, double throw) switch
- Pull-up/Pull-down resistors?
- Latches?

Glitches on state variables in AFSMs

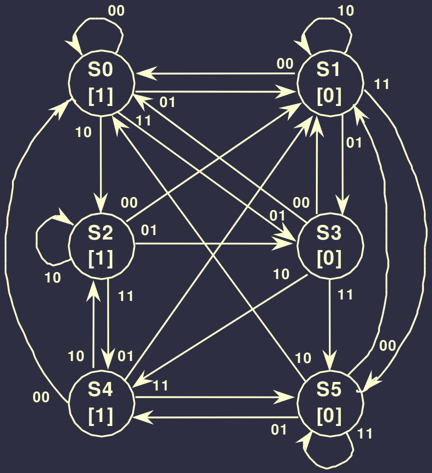
- Can uses latches in similar way
- Additional advantage: Separate sequential and combinational logic. feedback requirements reduced
- Disadvantage: May require more logic
- Consider the example

AFSM design example

- Design a two–input machine (LM)
    - Output 1 iff L is low and M was high at some time during most recent L high period
    - Output 0 otherwise
    - Let's build two AFSMs to solve this problem
    - One will use global feedback
    - One will use RS latches

Multiple input example

Initial multiple input FSM state diagram

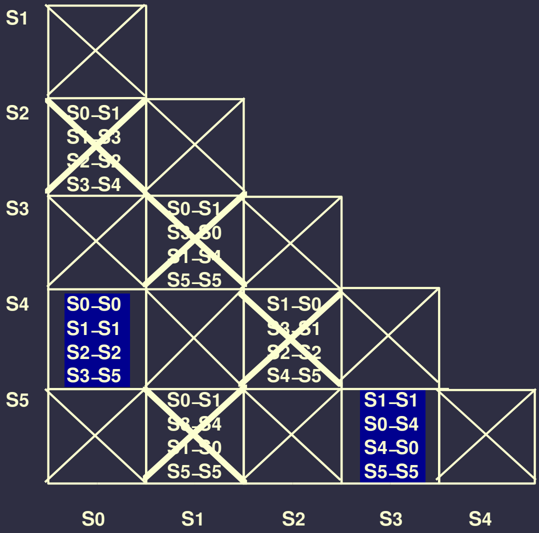


State Diagram

State table

Present State	Next State 00	01	10	11	Output
S_0	S_0	S_1	S_2	S_3	1
S_1	S_0	S_3	S_1	S_5	0
S_2	S_1	S_3	S_2	S_4	1
S_3	S_1	S_0	S_4	S_5	0
S_4	S_0	S_1	S_2	S_5	1
S_5	S_1	S_4	S_0	S_5	0

Implication chart



Simplified state table

Present State	Next State 00	01	10	11	Output
S_6	S_6	S_1	S_2	S_7	1
S_1	S_6	S_7	S_1	S_7	0
S_2	S_1	S_7	S_2	S_6	1
S_7	S_1	S_6	S_6	S_7	0