CS150 Spring 1998

Components and Design Techniques for Digital Systems

Prof. Richard Newton
563 Cory Hall
rnewton@ic.eecs

Prof. Kris Pister
512 Cory Hall
pister@eecs

- **Understand Components of Digital Systems**
  - ➜ Emphasis on **integrated circuit** implementations (CMOS)
  - ➜ Especially **programmable devices** (FPGA, PLD, ROM, RAM)
- **Translation of Design Problems into Hardware Representation**
- **Design of Hardware Logic Systems**
  - ➜ Combinational Logic
  - ➜ Sequential Logic: Synchronous & Asynchronous
- **Implementation of designs in modern, programmable technologies.**

CS150 Newton/Pister 1.1.1

CS150 Spring 1998

Components and Design Techniques for Digital Systems

Prof. Richard Newton
563 Cory Hall
rnewton@ic.eecs

Prof. Kris Pister
512 Cory Hall
pister@eecs

- **Architecture of Digital Systems**
  - ➜ **Microcomputers**
  - ➜ **Digital Signal Processors (DSP)**
- **Arithmetic Circuits and Number Systems**
- **Introduction to Microprogramming**
- **Testing of Digital Systems**
- **Introduction to Analog Interfaces**
- **Interacting with the Real World: *Entire Systems***

CS150 Newton/Pister 1.1.2

Organizational Matters

- **Required Text:**
  - ✰ Randy H. Katz, *Contemporary Logic Design*, Benjamin Cummings: Redwood City, CA., 1994, ISBN 0-13-212838-1
- **Reference:**
  - ✰ John F. Wakerly, *Digital Design: Principles and Practices*, Prentice Hall: Englewood Cliffs, N.J., 2nd Edition, 1994, ISBN 0-13-211459-3
  - → William I. Fletcher, *An Engineering Approach to Digital Design,* Prentice Hall:Englewood Cliffs,N.J., 1980, ISBN 0-13-277699-5
  - → Franklin P. Prosser & David E. Winkel, *The Art of Digital Design*, 2nd Ed., Prentice Hall: Englewood Cliffs, N.J., 1987, ISBN 0-13-046780-4
  - → James L. Adams, *Conceptual Blockbusting*, 3rd Edition, Addison - Wesley: Reading, MA, 1992, ISBN 0-201-55086-5
  - → Donald A. Norman, *The Design of Everyday Things*, Doubleday: New York, NY, 1990, ISBN 0-385-26774-6

CS150 Newton/Pister 1.1.3

Organizational Matters

- Required Laboratory Reference:
  - ✰ *The Programmable Logic Data Book*, Xilinx, San Jose CA, 2nd Edition, #0401253
  - ✰ *XACT Libraries Guide*, Xilinx, San Jose CA, #0401098-01
  - ✰ *XACT Hardware & Peripherals Guide*, Xilinx, San Jose CA, #0401132-01
- Much of this Xilinx documentation is now available on-line via the Web and we will provide the appropriate pointers as needed. Essential sections of these books will be made available at Copy Central on Hearst Ave.
- The laboratory notes themselves will be available via the Web. *Laboratories & discussions start in the second week. You MUST attend the lab lecture on Friday, 23rd!!*
- Homeworks and solutions will also be made available via the Web.

CS150 Newton/Pister 1.1.4

Organizational Matters

- All handouts will be available **on the Web only**
  - http://www-inst.EECS.Berkeley.EDU/~cs150/
  - Please limit your use of the printers! Try to use them for review online only.
- Most lectures will be videotaped and tapes are available for review in McLaughlin Hall.
- All students are required to check the cs150 news group:

  cory.eecs.berkeley.edu

  within 24 hours of any announcement.

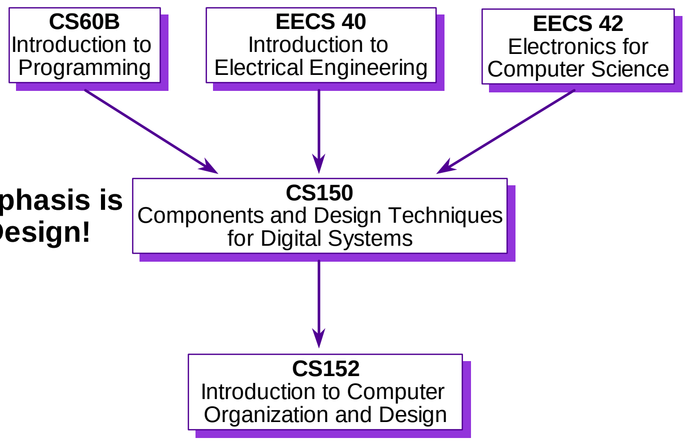
CS150 Newton/Pister 1.1.5

Overview

- This Lecture:
  - **What is the course all about & why is it important?**
  - **What is a digital system? What is a binary digital system?**
  - **Boolean Algebra, Truth tables**
  - **Operators: inversion, and, or, xor, xnor (eq)**
  - **Design Example: Translating a word problem to a combinational logic function**
  - **Multiplexers**
  - **Implementing the example using a multiplexer**

CS150 Newton/Pister 1.1.6

Where CS150 Fits



Emphasis is Design!

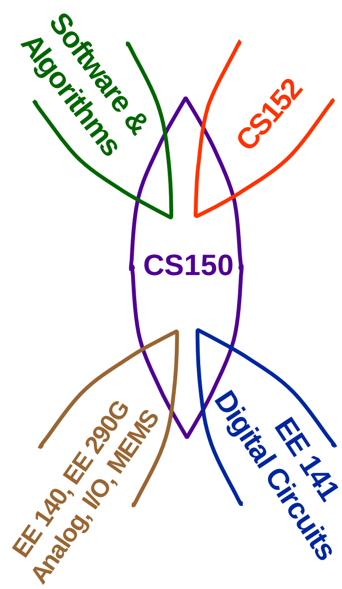
CS150 Newton/Pister 1.1.7

Where CS150 Leads

High-Level Digital Abstractions
Formulations, Algorithms and Ideas

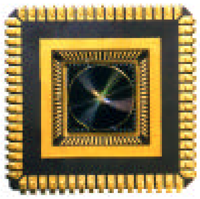
DESIGN

Physics & The Real World
Making it Work Well
Interacting with People

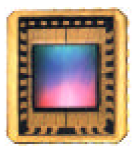


CS150 Newton/Pister 1.1.8

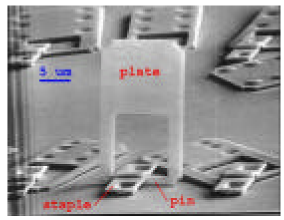
Cameras Everywhere!



CMOS Camera



CCD Camera



Source: Dr. K. Pister, UC Berkeley

Chips that Fly?

SmartPen

The New Peripherals

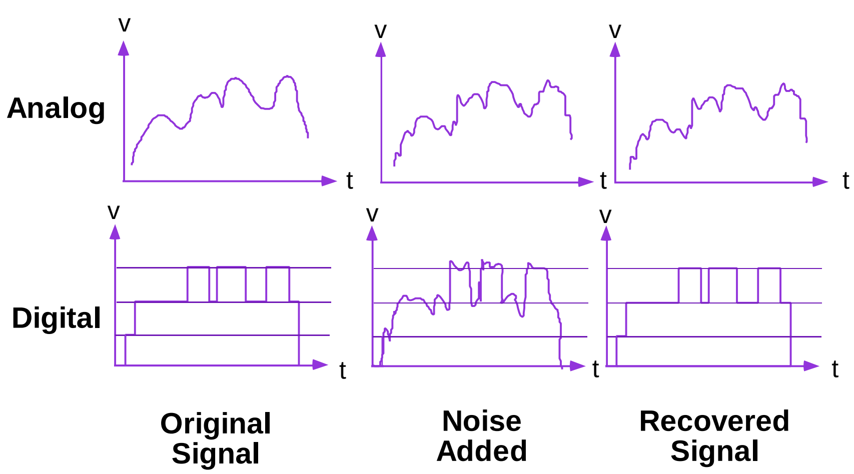
- In a computer-centric world-view, screens, keyboards, mice, pens, disc drives, etc. are peripherals.
- In a consumer-oriented world view, what are the appropriate peripheral (input/output) devices?

What is a Digital Circuit?

- Defined by the *interpretation* of the signals (waveforms, if in time) in the circuit.
  - ***Analog***
    - **Continuous Values**
    - **Fast, economical, low accuracy**
    - **Susceptible to noise & distortion**
  - DIGITAL
    - **Discrete Levels**
    - **Accuracy related to cost (no. of "bits")**
    - **Less susceptible to noise**
- *Binary* - 2 Levels or States
- *Multi-valued* - More than two Levels

CS150 Newton/Pister 1.1.11

Signal Recovery from Noise



<u>Remember</u>: All digital circuits are implemented using analog signals.
Their analog characteristics are often important!

CS150 Newton/Pister 1.1.12

Simplified Model of Design Representation

changing role of time ↑

Clocked, Synchronous Sequential Logic Circuits & Systems
As below, but the output depends only on the previous input values
at times determined by the value(s) of a special "clock" signal.
e.g. Microcomputers, DSPs, controllers, some I/O devices.

Asynchronous Sequential Logic Circuits & Systems
As below, but output depends on previous inputs and the order
in which they changed - from the moment the power was turned on!
e.g.. Latches, many I/O systems, some high-speed circuits.

Combinational Logic Circuits & Systems
Digital: Binary, output is independent of previous inputs
and is always the same if you wait long enough (no storage).
e.g. Decoders/Encoders, format converters, full adder

Physical Design
Analog (Voltages & Currents): Noise, power, heat, wires, size, etc.
e.g. ICs, Boards, Modules, Boxes, Systems

Classification of Designs

- **COMBINATIONAL**

  Output *only* depends on the instantaneous input values.

  IDEAL: Output responds instantly.

  REALITY: Propagation delay, spurious outputs ("glitches") that *must* eventually settle.

  => No feedback path exists from the outputs to the inputs.*

- **SEQUENTIAL**

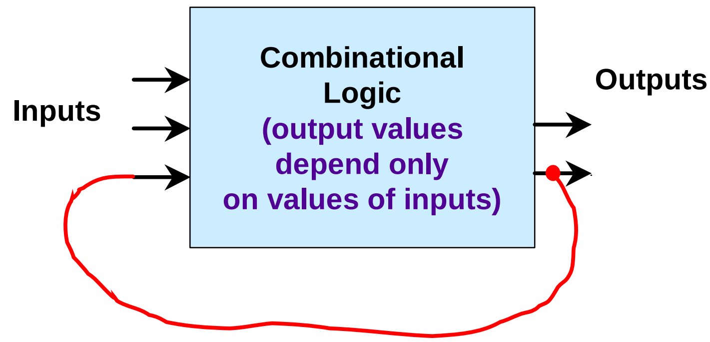
  Circuit contains "memory" (store) so the output *may* depend on the sequence of previous inputs (since power-up!)

  REALITY: Output depends on the *duration* of the inputs.

  => There must be at least one feedback path from the outputs to the inputs.

* Is this *really* true? Why?

Combinational and Sequential Systems



CS150 Newton/Pister 1.1.15

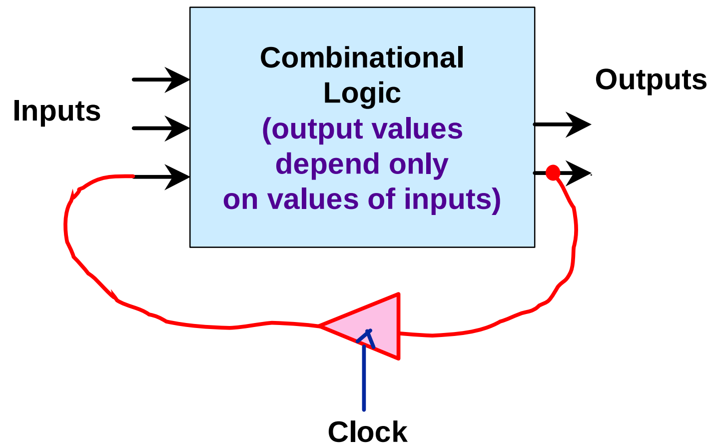
Classification of Designs

- **SYNCHRONOUS**
  - All feedback occurs at the same time, as defined by a special signal called a clock.
- **ASYNCHRONOUS**
  - Feedback occurs whenever values change. No special clock signals.

Remember: Avoid asynchronous design if you can! Try to identify the unavoidable asynchronous interfaces and convert them to synchronous form as reliably and with as few gates as possible.

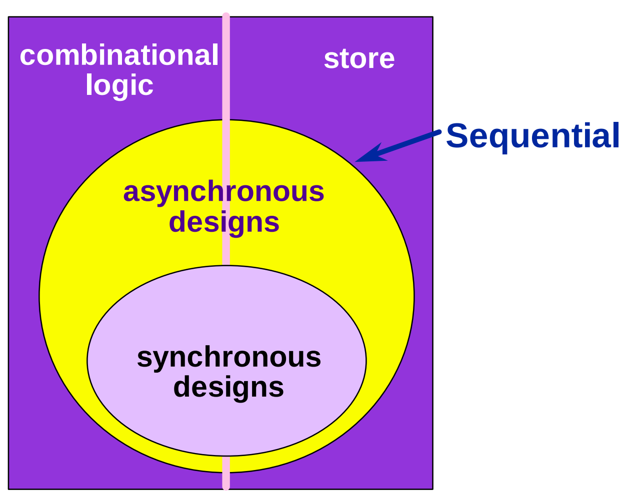
CS150 Newton/Pister 1.1.16

Combinational and Sequential Systems



CS150 Newton/Pister 1.1.17

Representing the Digital Design Problem: Basic Classification of Designs



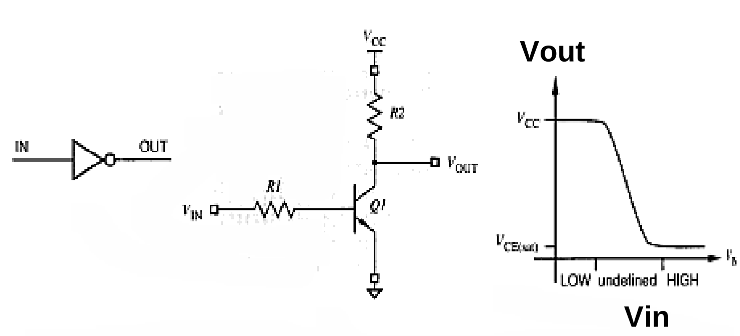
CS150 Newton/Pister 1.1.18

Boolean Algebra

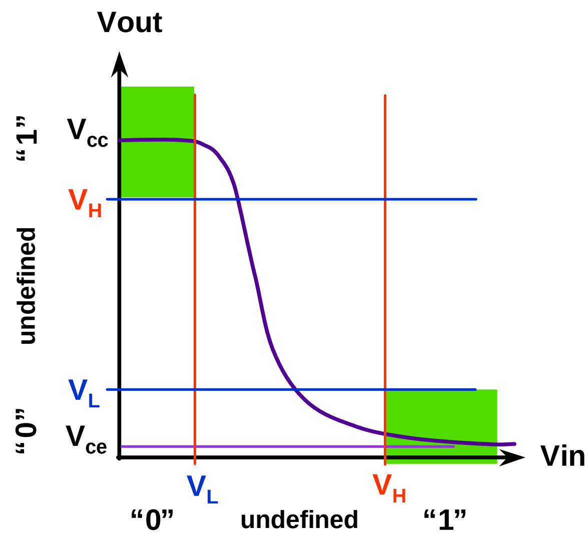
George Boole **1854** **Invented multi-valued discrete algebra**
E. V. Huntington **1904** **Postulates & Theorems**
Claude E. Shannon **1938** **Applied to relay circuits**

	TRUE (logic1)	**FALSE (logic 0)**
Relays:	Contacts closed	Contacts open
MOS logic:	High voltage (>4.8V)	Low voltage (<0.2V)
Magnetic core:	Magnetized up	Magnetized down
Fluids:	Fluid flowing	Not flowing

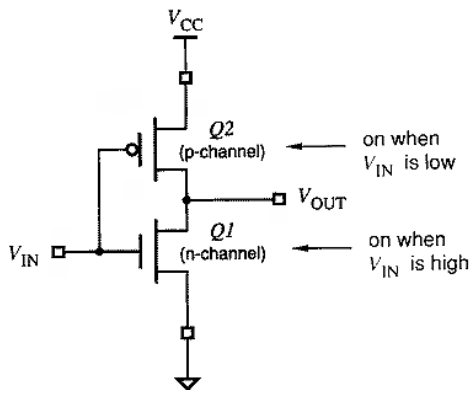
Resistor-Transistor Inverter



Inverter Characteristics



CMOS Inverter



Fundamental Operations

POSITIVE LOGIC ("Active High"):

True = Logic1 (high V), False = Logic0 (low V)

NOTATION:

NOT (Negation, complementation, inversion)

$Z = \overline{X}$, $Z = X'$, $Z = \sim X$

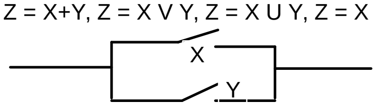
AND: Switches in series, "product"

$Z = X \bullet Y$, $Z = X \wedge Y$, $Z = X \cap Y$, $X = X \& Y$

(note: Z = XY should be avoided - is it X•Y or a signal named "XY"?)

OR: Switches in parallel, "sum"

$Z = X+Y$, $Z = X \vee Y$, $Z = X \cup Y$, $Z = X \mid Y$



XOR: Exclusive OR - either X or Y but not both

$Z = X \oplus Y$; (XNOR or EQ: $Z = X \odot Y = \overline{X \oplus Y}$)

Design Example: Word Problem

A car will not start when the ignition is on iff:

(a) Doors are closed & the seat belts are unbuckled
(b) The seat belts are buckled & the parking break is on
(c) The parking break is off and the doors are not closed

When can the car start if the switch is on?

Truth Tables

- A **Truth Table** is a tabular notation for representing the logic value of a function for *all possible combinations* of the values of its arguments.

NOT

X	Z
0	**1**
1	**0**

AND

X	Y	Z
0	**0**	**0**
0	**1**	**0**
1	**0**	**0**
1	**1**	**1**

OR

X	Y	Z
0	**0**	**0**
0	**1**	**1**
1	**0**	**1**
1	**1**	**1**

XOR

X	Y	Z
0	**0**	
0	**1**	
1	**0**	
1	**1**	

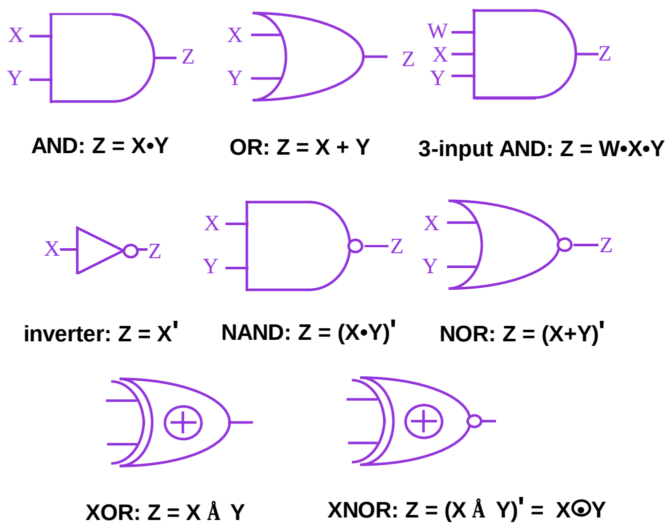
Design Example: Translation to Truth Table

Define variables TRUE as follows:
S = car starts, B = belts are buckled, D = door is closed, P = brake is on

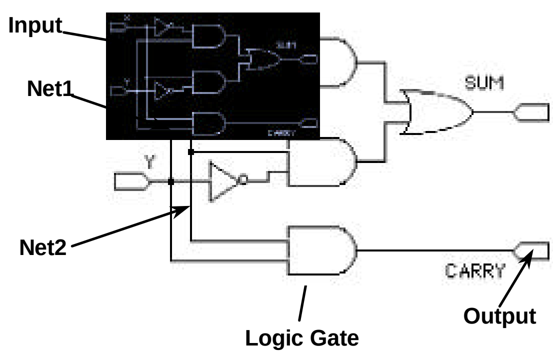
	B	D	P	S'	S
0	0	0	0	1	0
1	0	0	1	0	1
2	0	1	0	1	0
3	0	1	1	1	0
4	1	0	0	1	0
5	1	0	1	1	0
6	1	1	0	0	1
7	1	1	1	1	0

$$S = BD\overline{P} + \overline{B}\,\overline{D}P$$

Schematic Symbols



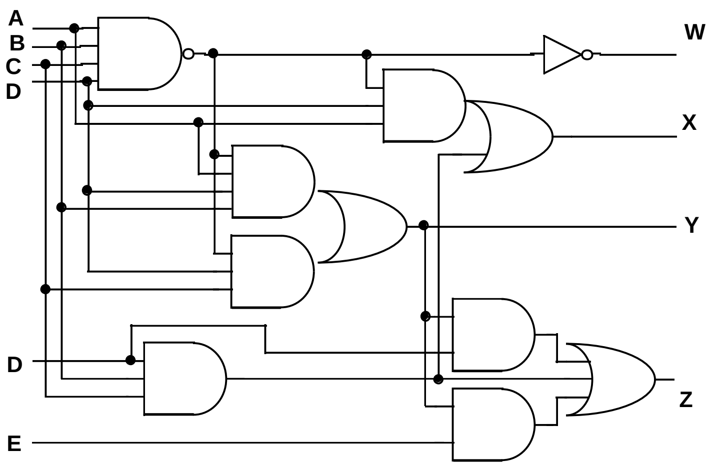
Schematic Diagram Representation



Net: an electrically-connected collection of wires.

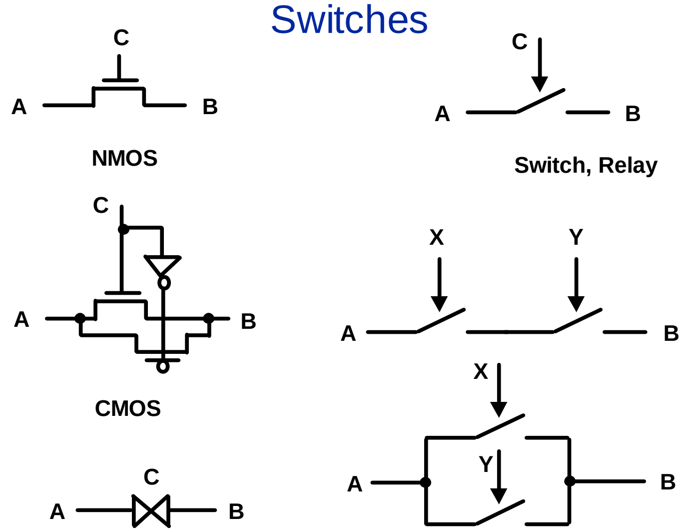
Netlist: a tabulation of gate inputs & outputs and the nets they are connected to.

`Complex´ Schematic Diagram



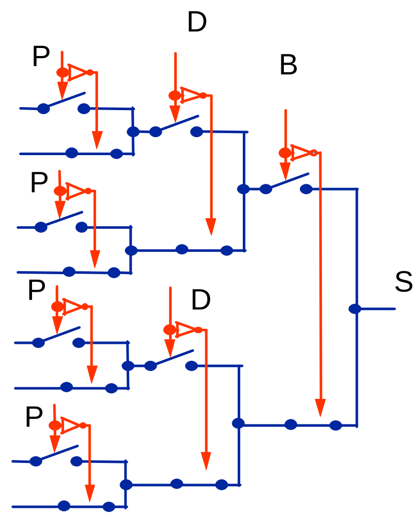
Design Example: Schematic Diagram

Implementation of Logic Using Switches



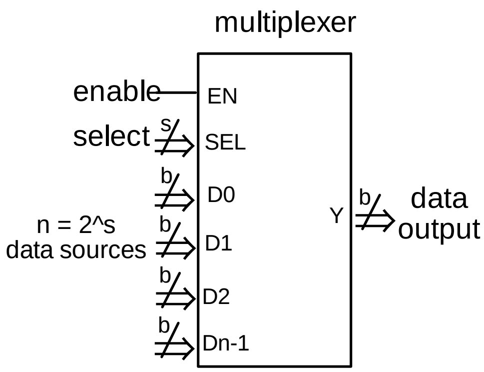
CS150 Newton/Pister 1.1.31

Multiplexer Trees Using Switches



CS150 Newton/Pister 1.1.32

Multiplexer



Consider b=1, s=1

Consider b=2, s=2

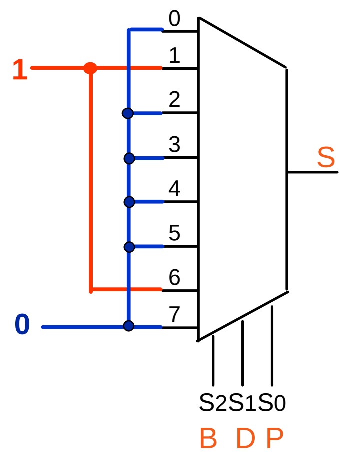
CS150 Newton/Pister 1.1.33

Design Using Multiplexers

$S = BD\overline{P} + \overline{B}\,\overline{D}P$

110 001

6 1



CS150 Newton/Pister 1.1.34

Exercise For Friday

- List the **five things that bug you the most** right now - that you would like to see a better solution to and where technology might be able to help.
- Examples:
  - → Food that goes bad in the refrigerator
  - → Trying to find an empty space in a crowded parking lot
  - → The increase in volume associated with advertising on TV
  - → Remote controls for consumer products
- To be **submitted via e-mail to:**

  newton@eecs.berkeley.edu
  - → **Include the word BUG in all caps in the message subject field**
  - → **Include your full name: Lastname, Firstname as the first line of the file.**

by Friday 23rd, 5pm.

Top Complaints, Spring 1997

Tally	**Concern**
28	traffic, transportation problems, tailgaters, slow drivers in the fast lane
19	alarm clocks: setting them, waking up, loud noises, failure
19	financial problems
17	forgetting: lights, fan, locks
17	waiting, in line or otherwise
15	commercials: long, annoying, false advertising, loud, phone solicitations
15	telebears, voicemail, phone menus
12	cooking problems, washing dishes
12	keys: not working, looking for them in the dark, damaging clothes, locking them in car
11	computer: slow, crashing, screen freezing
11	school problems: scheduling, registration, overcrowded, requirements, bureaucracy
11	television: bad reception, broken, poor design
10	forgetting names, passwords, phone numbers, meetings, dates
10	homework
10	losing books, keys, or personal items
10	poor design of consumer electronics

Top Complaints, Spring 1997

Tally	Concern
9	not getting enough sleep, having to wake up early, early classes, being woken up
8	falling asleep: in class, while driving, with lights and heater on, oversleeping
8	grades: bad grades, being judged on grades
8	parking problems
8	pollution, litter
8	public transportation-slow, off schedule, missing bus, waiting
8	rain
8	tobacco smoke
7	aggressive, insecure, arrogant, intolerant, obnoxious, ignorant, lazy people
7	answering machine, "empty messages"
7	bathroom: putting the seat down, dirty, no paper, etc.
7	busy signal on phone, when using modem, call waiting
7	love, ex girlfriends, ex-boyfriends, friendship or lack of