Digital Logic Combo Cube Design

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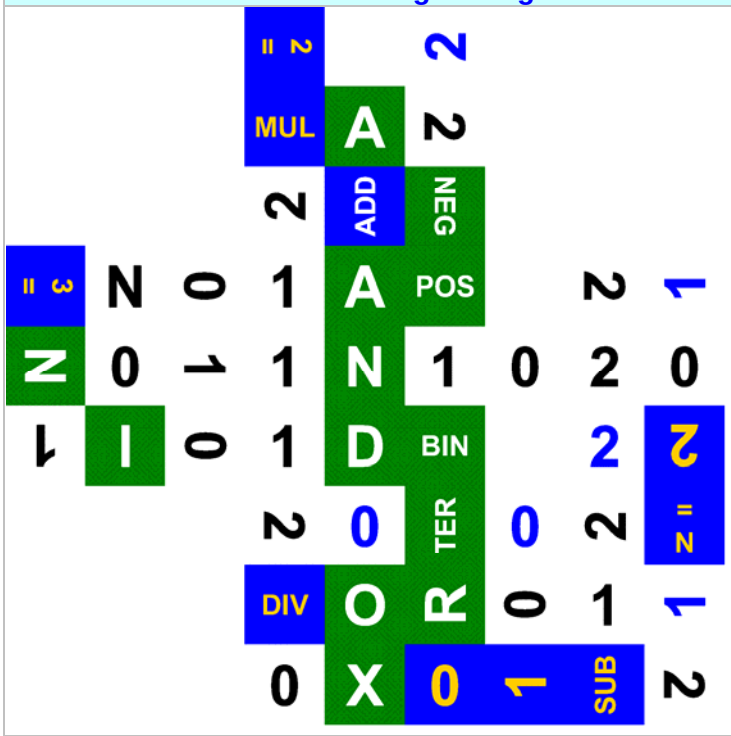
Introduction

A **Digital Logic Combo Cube** is a 3x3x3 **Rubik's Cube** used to display n-ary operations. This is a **Combo** Cube because it is capable of displaying *either* operations on logic gates *or* arithmetic operations (see the **Arithmetic Operations Cube Design** document). Operations can be carried out either on binary or ternary numbers.

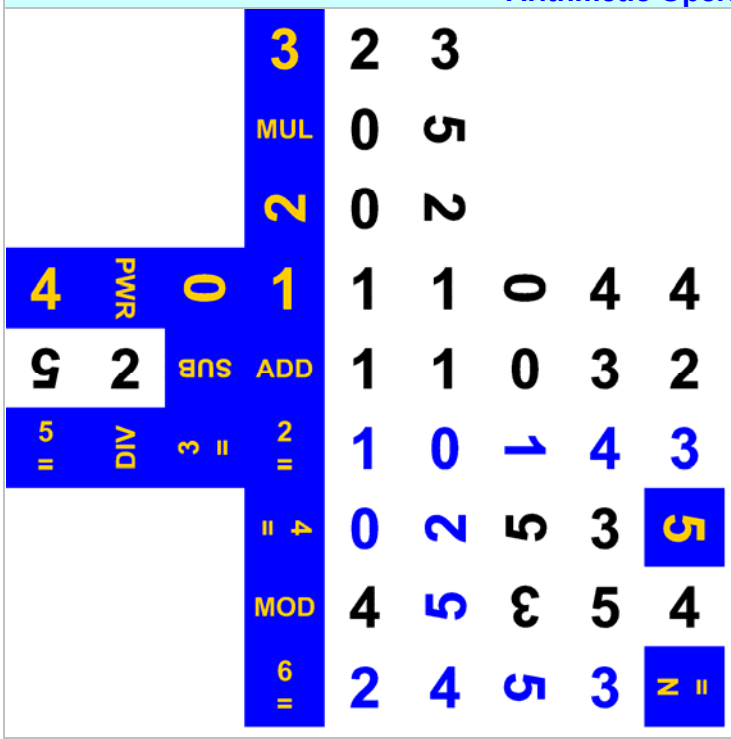
Digital Logic + Arithmetic Operations Combo Cube



Digital Logic Combo Cube Texture

Digital Logic Combo Cube – NAND Gate

Arithmetic Operations Only Cube



Arithmetic Operations Only Cube Texture

Arithmetic Operations Only Cube

Download **CubeTwister** from: http://www.randelshofer.ch/

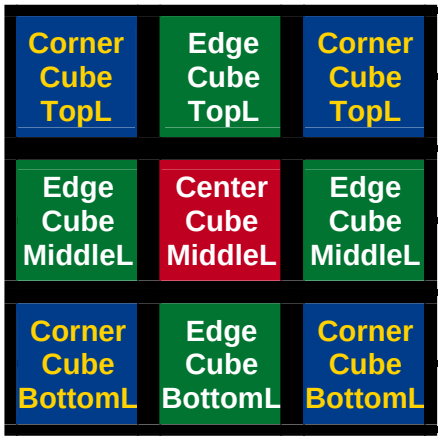
Numeral Systems and Digital Logic– Useful Links	
http://en.wikipedia.org/wiki/Binary_numeral_system	http://en.wikipedia.org/wiki/Boolean_logic
http://en.wikipedia.org/wiki/Logic_gate	http://en.wikipedia.org/wiki/Ternary_numeral_system
http://en.wikipedia.org/wiki/Arity	http://en.wikipedia.org/wiki/Ternary_logic

There are **Virtual Cubes** that can be *virtually* rotated and twisted on a computer screen and **Real Cubes** that can only be *physically* rotated and twisted by hand. A **Texture** is laid down on a Virtual Cube whereas real **Stickers** are stuck down on a Real Cube. A Digital Logic Combo Cube is designed by placing letters and numbers on a texture which is then laid down on a Virtual Cube (see http://www.randelshofer.ch/ for more details).

Designing a Digital Logic Combo Cube that *works* is definitely not a trivial task but **Design Rules** exist that should be applied. Because it is nearly impossible to test all configurations, the placement of numbers and letters on a texture should be carefully checked at *the end* of the design process. This is carried out by applying a **Design Rules Check** (**DRC**) in the final design stage.

Terminology

In a 3x3x3 **Rubik's Cube**, there are 8 *Corner Cubes*, 12 *Edge Cubes*, 6 *Center Cubes* and 6 *Cube Faces*. There are also 4 Corner Cube faces, 4 Edge Cube faces and 1 Center Cube face *per Cube Face*, as shown below.



There are 1 face per Center Cube, 2 faces per Edge Cube and 3 faces per Corner Cube.

There are also 3 horizontal *Layers* called *Top*, *Middle* and *Bottom Layers*.

Cube Lexicon		
English	**Français**	**Deutsch**
Cube	Cube	Würfel
cubie, cube	cube, petit cube	Würfelteil, Teil des Würfels
face	face	Seite, Seitenfläche
front face	face avant	vordere Seite, vorne
back face	face arrière	hintere Seite, hinten
left face	face gauche	linke Seite, links
right face	face droite	rechte Seite, rechts
top face	face supérieure	obere Seite, oben
bottom face	face inférieure	untere Seite, unten
sticker	étiquette (autocollante), plaquette	Kleber, Farbkleber
tile	tuile, plaquette	Plättchen, Farbplättchen
center cube, center	cube central, centre	Mittelwürfel, Mittelstein, Mitte
edge cube, edge	cube-arête, arête	Kantenwürfel, Kantenstein, Kante
corner cube, corner	cube de coin, coin	Eckwürfel, Eckstein, Ecke
layer	couronne	Schicht, Scheibe
top layer	couronne supérieure	obere Schicht, obere Scheibe
middle layer	couronne intermédiaire	mittlere Schicht, mittlere Scheibe, Mittelschicht, Mittelscheibe
bottom layer	couronne inférieure	untere Schicht, untere Scheibe
orientation, direction	orientation	Orientierung
to solve	résoudre	lösen, zusammen drehen
to twist	pivoter	drehen
to rotate	tourner, effectuer une rotation	drehen
clockwise	dans le sens horaire	im Uhrzeigersinn
anticlockwise, counter-clockwise	dans le sens anti-horaire	im Gegenuhrzeigersinn

Digital Logic Combo Cube Layout

Logic Gates

There are 6 types of Logic Gates that are implemented on the Cube:
AND, NAN (NAND), IOR (Inclusive OR), XOR (eXclusive OR), NOR, XNR (XNOR eXclusive NOR).

The logic can be positive (POS) or negative (NEG). The logic system can be displayed either as BIN (binary) or TER (ternary).

Letters are displayed *vertically* on the center column of a solved face. They are sorted out as follows:

1- 4 **T**op **C**enter letters: A,I,N,X
2- 3 **M**iddle **C**enter letters: A,N,O
3- 3 **B**ottom **C**enter letters: D,N,R

Arithmetic Operations

There are also 4 Arithmetic operations that can be carried on 2 numbers:
ADD, SUB, MUL, DIV. A Carry digit is also implemented.

Numbers can be binary (0,1), ternary (0,1,2), or n-ary numbers, with n>3, but with a reduced range of values in that case.

Center Cubes Layout

3 letters (A,N,O) and 3 numbers (0,1,2) are laid on the 6 center cubes.

Corner Cubes Layout

Numbers, letters and symbols are *logically* grouped on each of the 8 corner cubes, because they are *mutually exclusive* (on a solved cube face).

1- 2 corner cubes: **Top Left**: (0,1,2) Logic, (0,1,2) Arithmetic
2- 2 corner cubes: **Bottom Left**: (0,1,2) Logic, ($=^2$,$=^3$,$=^N$) Arithmetic
3- 2 corner cubes: **Top Right**: (0,1,2) Arithmetic, (POS,NEG,white) Logic
4- 2 corner cubes: **Bottom Right**: (0,1,2) Arithmetic, (BIN,TER,white) Logic

Edge Cubes Layout

DRC rules: Arithmetic letters and numbers can be grouped with Logic letters on a same edge cube and on 2 differents faces if they are *mutually exclusive*. But they can share the *same* edge cube face if they are in common.

1- 4 edge cubes (**TC** Logic,**ML** Arithmetic): (A **TC**,ADD **ML**), (I **TC**,DIV **ML**), (N **TC**,MUL **ML**), (X **TC**,SUB **ML**)
2- 3 edge cubes (**BC** Logic,**BC** Arithmetic): (D **BC**,0 **BC**), (N **BC**,1 **BC**), (R **BC**,2 **BC**)
3- 3 edge cubes (**ML** Logic,**TC** Arithmetic): (0 **ML**,0 **TC**), (1 **ML**,1 **TC**), (2 **ML**,2 **TC**)
4- 2 edge cubes (**MR** Logic or **MR** Arithmetic): (0 **MR**,1 **MR**), (2 **MR**,white/**Logo***)

*In this design, there is only one (blank) cube face that is *never* used on a *solved* front face. This edge cube face could then be used for a **Logo**. Then, this would make this Cube a **Fully-Loaded Cube**, ie. with *all* 54 faces loaded.

Some Operations on Logic Gates – Positive Binary Logic

TL	TC	TR
ML	MC	MR
BL	BC	BR

1	A	POS
1	N	1
1	D	BIN

1	A	
0	N	0
1	D	

1	N	
1	A	0
1	N	

1	N	
0	A	1
1	N	

1	I	
0	O	1
0	R	

0	I	
0	O	0
0	R	

0	N	
0	O	1
0	R	

1	N	
0	O	0
0	R	

0	X	
0	O	0
0	R	

0	X	
1	O	1
0	R	

1	X	
1	O	0
1	R	

0	X	
0	N	1
0	R	

0	X	
1	N	0
0	R	

1	X	
1	N	1
1	R	

TL	TC	TR
ML	MC	MR
BL	BC	BR

0	0	1
ADD	1	0
2 =	1	1

1	1	1
ADD	1	0
2 =	0	1

0	1	1
SUB	0	1
2 =	1	0

1	1	0
MUL	1	0
2 =	0	0

0	1	1
DIV	1	0
2 =	0	1

1	2	1
ADD	0	2
3 =	0	0

1	2	1
ADD	1	2
3 =	1	0

0	1	0
ADD	0	2
3 =	1	2

0	2	2
SUB	0	2
3 =	1	2

1	1	2
MUL	0	2
3 =	0	1

0	2	2
DIV	1	0
3 =	0	2

0	1	1
ADD	0	1
8 =	1	2

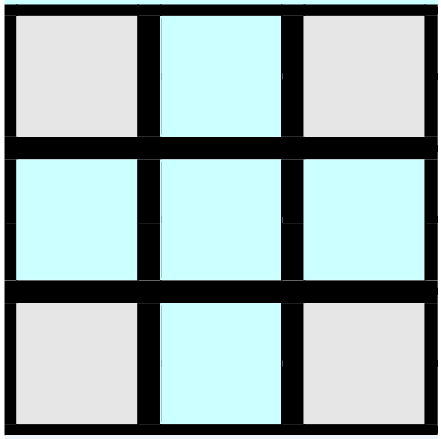
0	1	1
ADD	0	1
10 =	1	2

0	1	1
ADD	0	1
16 =	1	2

Solving a Digital Logic Combo Cube Step by Step

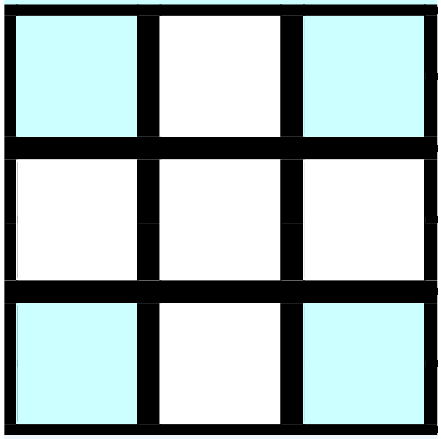
In this example, a step by step solving process is applied to the Digital Logic Combo Cube, just described before. Note that we only need to solve a *single* Face out of six. We will solve a Face for an AND gate.

Solve the Cross First



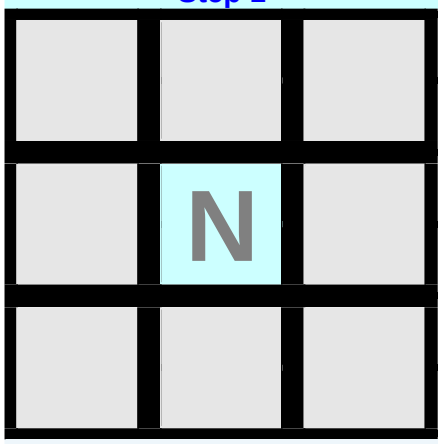
Standard Rubik's Cube Solving

Then Solve the Corner Cubes



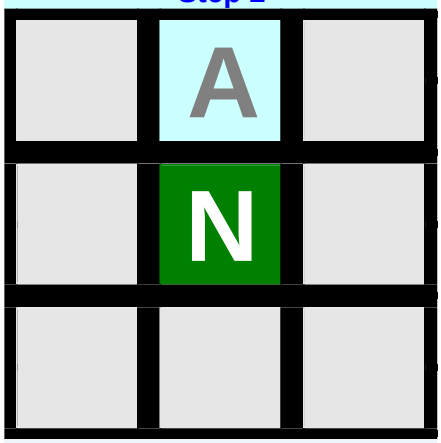
Standard Rubik's Cube Solving

Step 1



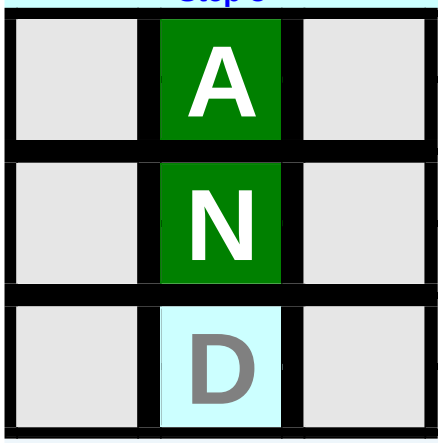
Center Cube **N** on Front Face

Step 2



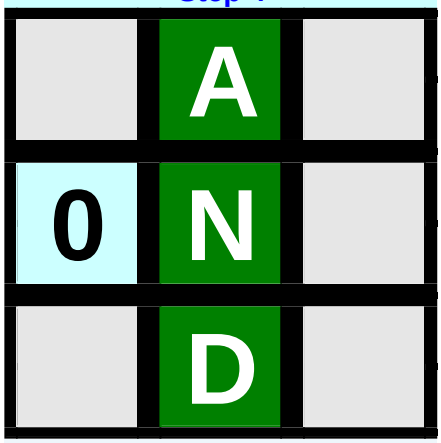
Top Layer: Edge Cube **A**

Step 3



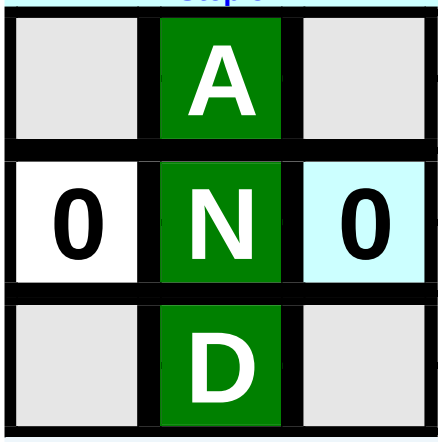
Bottom Layer: Edge Cube **D**

Step 4



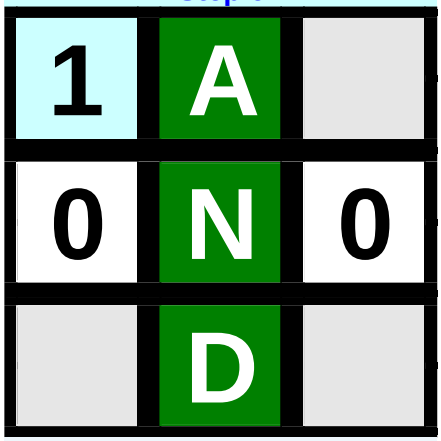
Middle Layer: Edge Cube **0**

Step 5



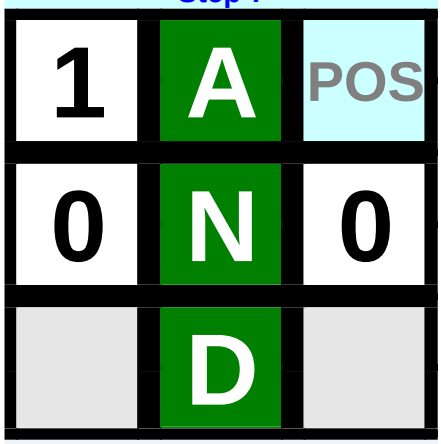
Middle Layer: Edge Cube **0**

Step 6



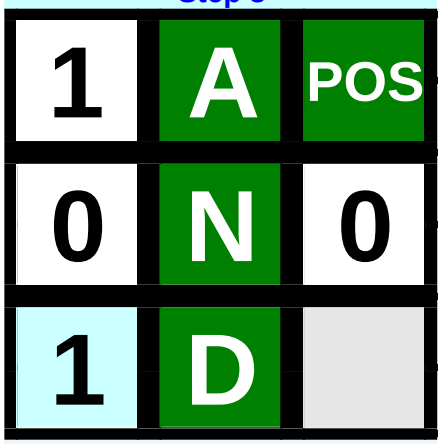
Top Layer: Corner Cube **1**

Step 7



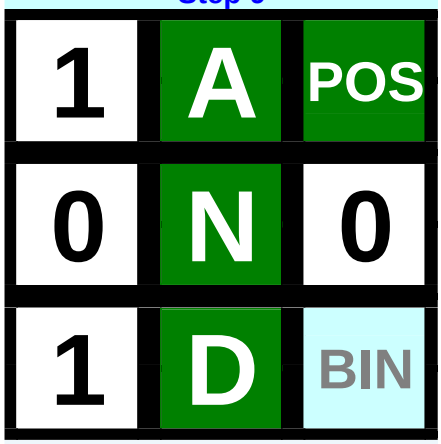
Top Layer: Corner Cube **POS**

Step 8



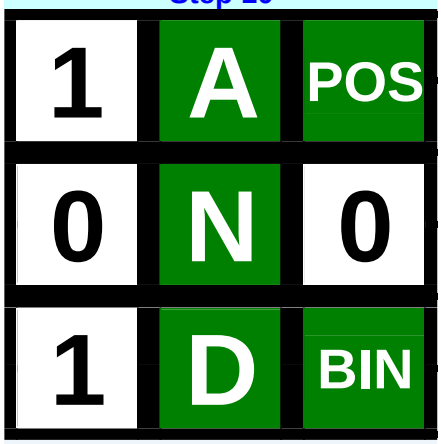
Bottom Layer: Corner Cube **1**

Step 9



Bottom Layer: Corner **BIN**

Step 10



That's it !

Print out this page and fill in the blank faces with *your* data. Then try to design your *own* Cube.

TL	TC	TR
ML	MC	MR
BL	BC	BR

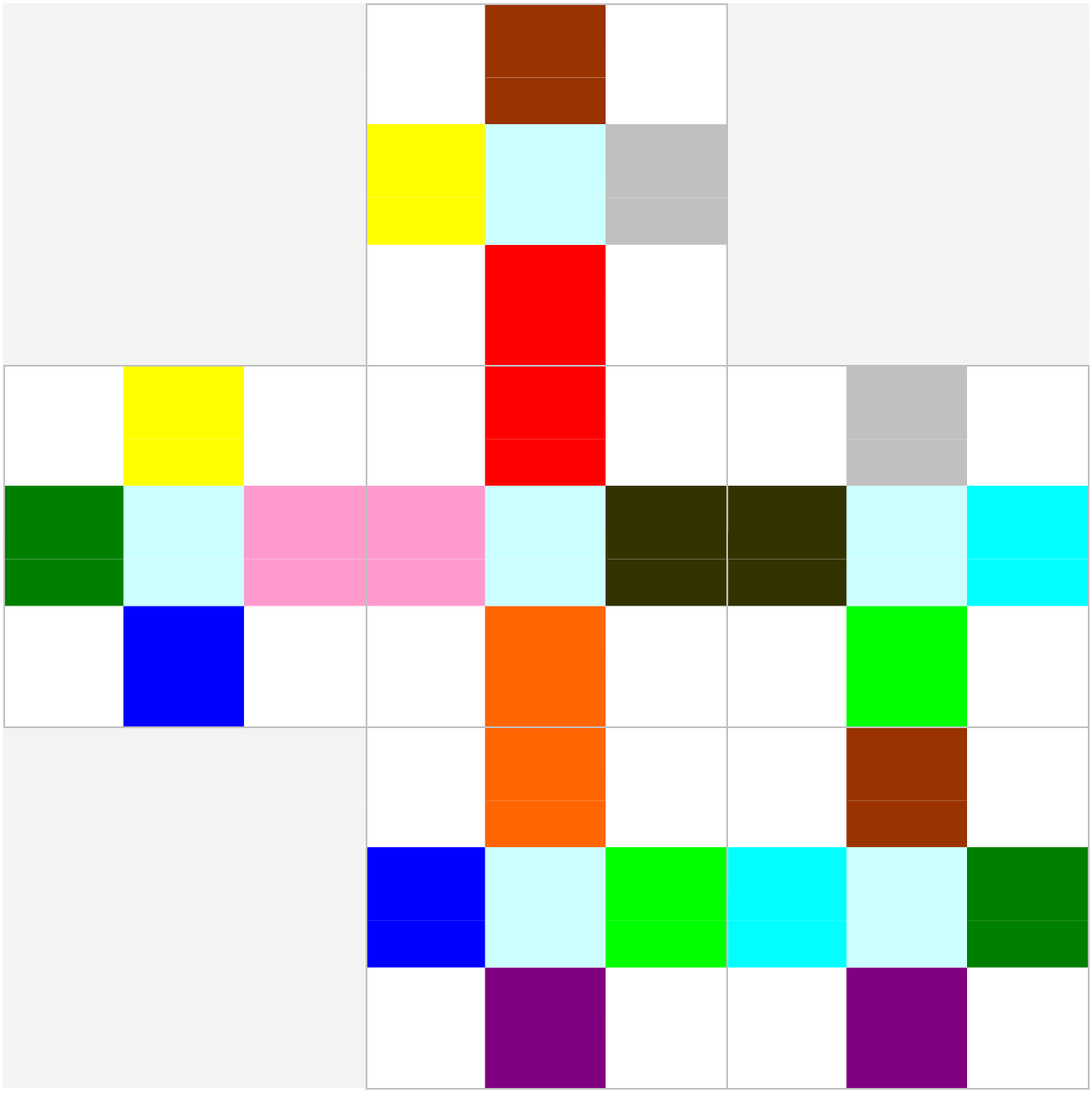
Corner Cubes Final Check

There are 8 Corner Cubes and 3 faces per Corner Cube. In the diagram below, each Corner Cube is displayed in 8 different colors and with the same color applied to each of its 3 faces. This diagram can be used as a convenient *visual aid* to check Design Rules (DRC).

	Up		
Left	**F**ront	**R**ight	**B**ack
	Down	**B**ack	

Edge Cubes Final Check

There are 12 Edge Cubes and 2 faces per Edge Cube. In the diagram below, each Edge Cube is displayed in 12 different colors and with the same color applied to each of its 2 faces. This diagram can be used as a convenient *visual aid* to check Design Rules (DRC).



	Up		
Left	**F**ront	**R**ight	**B**ack
	Down	**B**ack	

Texture Template

This is a texture template that can be printed out and used for writing down numbers and letters by hand *prior to* texture design. All is needed are pencil, rubber…and time.