

$$\frac{1}{1+\sqrt{5}+3} + \frac{\sqrt{5}}{1+\sqrt{5}+3} + \frac{3}{1+\sqrt{5}+3} = \frac{1+\sqrt{5}+3}{1+\sqrt{5}+3} = 1$$

$\downarrow$                        $\downarrow$                        $\downarrow$   
 0.48107      0.35857      0.16035

$$\bar{R} = a_1 \cdot \bar{R}_1 + a_2 \cdot \bar{R}_2 + a_3 \cdot \bar{R}_3$$

$$R^* = \bar{a}_1 \cdot R_1 + \bar{a}_2 \cdot R_2 + \bar{a}_3 \cdot R_3$$

R \* reads as R dual

$$R = 0.48107 \cdot (r_7^1 \cdot 2^7 + \dots + r_0^1 \cdot 2^0) + 0.35857 \cdot (r_7^3 \cdot 2^7 + \dots + r_0^3 \cdot 2^0) + 0.16035 \cdot (r_7^2 \cdot 2^7 + \dots + r_0^2 \cdot 2^0)$$

$$\bar{R} = 0.48107 \cdot \begin{pmatrix} r_7^1 \\ r_6^1 \\ r_5^1 \\ r_4^1 \\ r_3^1 \\ r_2^1 \\ r_1^1 \\ r_0^1 \end{pmatrix} + 0.35857 \cdot \begin{pmatrix} r_7^3 \\ r_6^3 \\ r_5^3 \\ r_4^3 \\ r_3^3 \\ r_2^3 \\ r_1^3 \\ r_0^3 \end{pmatrix} + 0.16035 \cdot \begin{pmatrix} r_7^2 \\ r_6^2 \\ r_5^2 \\ r_4^2 \\ r_3^2 \\ r_2^2 \\ r_1^2 \\ r_0^2 \end{pmatrix}$$

$$R^* = r_7^1 r_6^1 r_5^1 r_4^1 r_3^1 r_2^1 r_1^1 r_0^1 r_7^3 r_6^3 r_5^3 r_4^3 r_3^3 r_2^3 r_1^3 r_0^3 r_7^2 r_6^2 r_5^2 r_4^2 r_3^2 r_2^2 r_1^2 r_0^2 \quad \text{call it } R_{BIG}$$

Ex1

Px0, three surrounding red pixels

$$R_1 = 128_{10} = 10000000_2$$

$$R_2 = 53_{10} = 00110101_2$$

$$R_3 = 127_{10} = 01111111_2$$

$$R_{BIG} = R_1 R_3 R_2 = \underbrace{100000000111111100110101}_{24\text{bit}}, \quad R = 10000100_2 = 132 \quad \text{not good approx.}$$

24bit

Ex2

Px0, three surrounding red pixels

$$R_1 = 128_{10} = 10000000_2$$

$$R_2 = 53_{10} = 00110101_2$$

$$R_3 = 127_{10} = 01111111_2$$

$$\begin{aligned} R_{IDEAL} &= 0.48 \cdot 128 + 0.36 \cdot 127 + 0.16 \cdot 53 \\ &= 115.64 \\ &= 01110011_2 \end{aligned}$$

$$\text{Let } R_{12} = \overline{(R_1 \ggg_1 2)} \oplus \overline{(R_2 \lll_1 1)} = 01110100_2,$$

where  $\ggg_1$  and  $\lll_1$  - logical shift with '1' fill

$\oplus$  - XNOR boolean operator

- better approx. ■

$$\text{Let } R = r_7 r_6 r_5 r_4 r_3 r_2 r_1 r_0$$

$$\text{Define } \mathcal{R} \text{ as: } \mathcal{R} = r_4 r_5 r_6 r_7 r_0 r_1 r_2 r_3 \quad \text{And define reversal operator } \mathcal{R} \text{ as: } \mathcal{R}(R) = \mathcal{R}$$

Ex3

$$\text{From Ex2 } R_{12} = 01110100_2$$

$$\text{Let } \mathcal{R}_{12} = 11100010_2$$

$$\overline{\mathcal{R}_{12} \oplus (R_3 \lll_1 1)} = 11100010_2$$

$$\mathcal{R}(\overline{\mathcal{R}_{12} \oplus (R_3 \lll_1 1)}) = 01110100_2 = R_{12} \quad \text{- identity operator} \quad \blacksquare$$

reverser\_8b.vhd

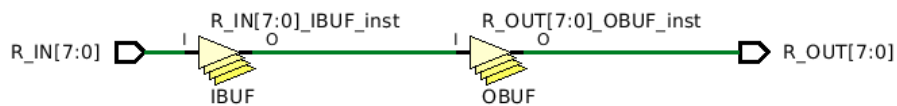
```
entity reverser_8b is
  Port ( R_IN : in std_logic_vector(7 downto 0);
        R_OUT : out std_logic_vector(7 downto 0));
end reverser_8b;
```

```
architecture Dataflow of reverser_8b is
```

```
begin
```

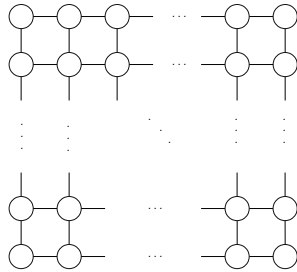
```
  R_OUT(7) <= R_IN(4);
  R_OUT(6) <= R_IN(5);
  R_OUT(5) <= R_IN(6);
  R_OUT(4) <= R_IN(7);
  R_OUT(3) <= R_IN(0);
  R_OUT(2) <= R_IN(1);
  R_OUT(1) <= R_IN(2);
  R_OUT(0) <= R_IN(3);
```

```
end Dataflow;
```



Recall  $R^* = r_7^1 r_6^1 r_5^1 r_4^1 r_3^1 r_2^1 r_1^1 r_0^1 r_7^3 r_6^3 r_5^3 r_4^3 r_3^3 r_2^3 r_1^3 r_0^3 r_7^2 r_6^2 r_5^2 r_4^2 r_3^2 r_2^2 r_1^2 r_0^2$  call it  $R_{BIG}$

Therefore  $R_{BIG}$  is a finite space and dual space  $R^*$  can be viewed as a rectangle or a plane consisting of  $2^{24}$  elements in it arranged in a lattice pattern.



Thus we can define our binary operations such as AND, OR, etc as two different things:

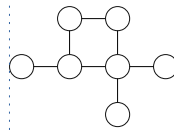
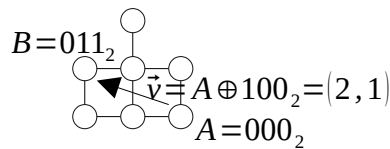
1) Means of traversing the grid by flipping some of the bits

2) vectors

We choose one boolean operator to measure similarity and go from there. Let it be XNOR.

Other operations will have to do with adjusting weights as we arrived here from the weighted sum and the end goal is weighted average.

Ex4



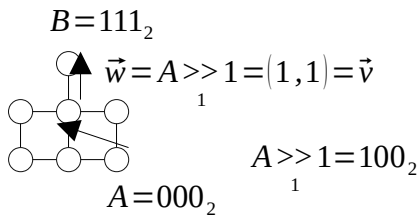
Can try different geometries/origin also.

Actual notion of distance in this space may depend on the amount of such binary operations required to arrive from origin to any other point.

Remember that we are looking for a point in this grid, that surely does exist, that is the closest approximation to the weighted average.

Also remember once we contrived this space to be linear and dual by assuming 0.48 0.36 and 0.16 real numbers are independent (orthogonal) thus their products are equal to 0, all normal algebra went out the window.

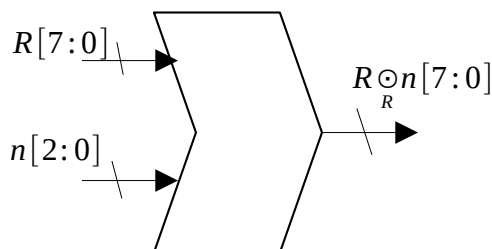
Ex5



Therefore  $\vec{v}, \vec{w}$  are orthogonal (hint from linear algebra) and these two operations (right shift with '1' fill and XNOR) span the entire lattice. ■

Let  $R = r_7 r_6 r_5 r_4 r_3 r_2 r_1 r_0$

Define RPUSH operator as:



where  $n$  – control signal choosing which bit to push to the top position

## rpush\_8b.vhd

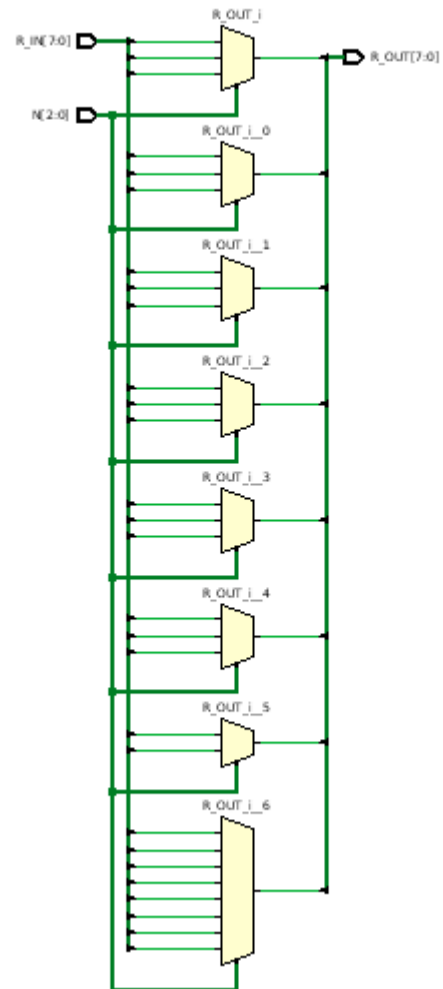
```

entity rpushn_8b is
  Port ( R_IN : in std_logic_vector(7 downto 0);
        N : in std_logic_vector(2 downto 0);
        R_OUT : out std_logic_vector(7 downto 0));
end rpushn_8b;

architecture Dataflow of rpushn_8b is

begin
  with N select
    R_OUT(7) <= R_IN(0) when "000",
    R_IN(1) when "001",
    R_IN(2) when "010",
    R_IN(3) when "011",
    R_IN(4) when "100",
    R_IN(5) when "101",
    R_IN(6) when "110",
    R_IN(7) when others;
  with N select
    R_OUT(6) <= R_IN(6) when "111",
    R_IN(7) when others;
  with N select
    R_OUT(5) <= R_IN(5) when "111",
    R_IN(5) when "110",
    R_IN(6) when others;
  with N select
    R_OUT(4) <= R_IN(4) when "111",
    R_IN(4) when "101",
    R_IN(5) when others;
  with N select
    R_OUT(3) <= R_IN(3) when "111",
    R_IN(3) when "100",
    R_IN(4) when others;
  with N select
    R_OUT(2) <= R_IN(2) when "111",
    R_IN(2) when "011",
    R_IN(3) when others;
  with N select
    R_OUT(1) <= R_IN(1) when "111",
    R_IN(1) when "010",
    R_IN(2) when others;
  with N select
    R_OUT(0) <= R_IN(0) when "111",
    R_IN(0) when "001",
    R_IN(1) when others;
end Dataflow;

```

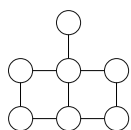


Ex6

Let  $R = r_7 r_6 r_5 r_4 r_3 r_2 r_1 r_0$

$$R \odot_R 3 = r_3 r_7 r_6 r_5 r_4 r_2 r_1 r_0 \blacksquare$$

Ex7



$$\vec{u} = A \odot_R 0 = \vec{0}$$

$$A = 000_2$$

RPUSH operator clearly doesn't do anything for the origin  $\blacksquare$

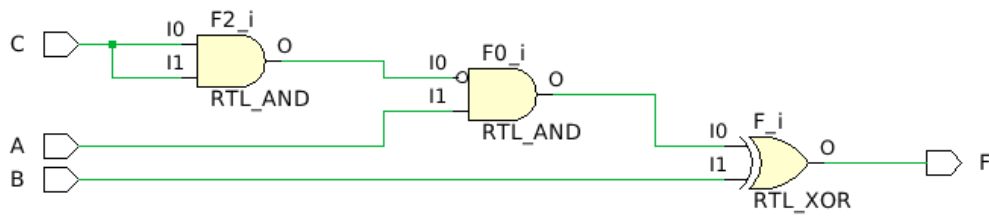
dim\_1b.vhd

```
entity dim_1b is
  Port ( A : in std_logic;
        B : in std_logic;
        C : in std_logic;
        F: out std_logic);
end dim_1b;

architecture Dataflow of dim_1b is

begin
  F <= ((C NAND C) AND A) XOR B;

end Dataflow;
```



## diode\_8b.vhd

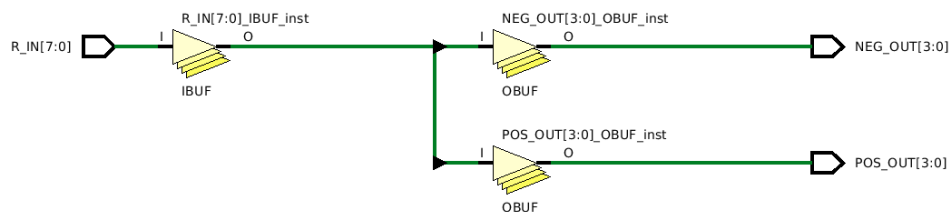
```
entity diode_8b is
  Port ( R_IN : in std_logic_vector(7 downto 0);
        POS_OUT : out std_logic_vector(3 downto 0);
        NEG_OUT : out std_logic_vector(3 downto 0));
end diode_8b;
```

```
architecture Dataflow of diode_8b is
```

```
begin
```

```
  POS_OUT(3) <= R_IN(7);
  POS_OUT(2) <= R_IN(6);
  POS_OUT(1) <= R_IN(1);
  POS_OUT(0) <= R_IN(0);
  NEG_OUT(3) <= R_IN(5);
  NEG_OUT(2) <= R_IN(4);
  NEG_OUT(1) <= R_IN(3);
  NEG_OUT(0) <= R_IN(2);
```

```
end Dataflow;
```





## triode\_8b.vhd

```
entity triode_8b is
  Port ( R1_IN : in std_logic_vector(7 downto 0);
        R2_IN : in std_logic_vector(7 downto 0);
        R3_IN : in std_logic_vector(7 downto 0);
        T1_OUT : out std_logic_vector(7 downto 0);
        T2_OUT : out std_logic_vector(7 downto 0);
        T3_OUT : out std_logic_vector(7 downto 0);
        T4_OUT : out std_logic_vector(7 downto 0));
end triode_8b;
```

```
architecture Dataflow of triode_8b is
```

```
begin
```

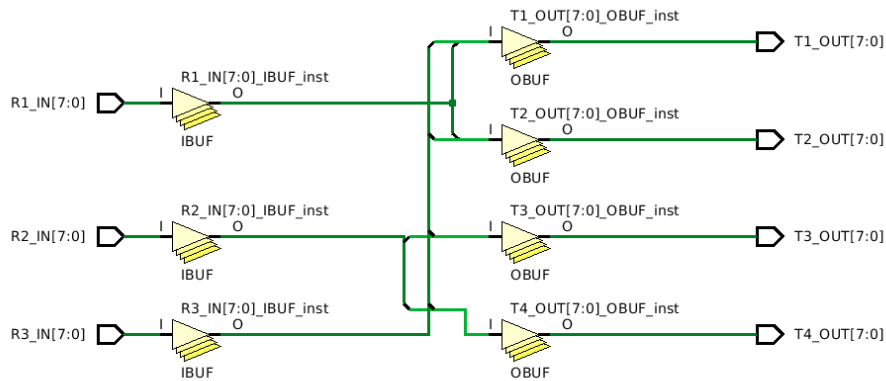
```
  T1_OUT(7) <= R1_IN(7);
  T1_OUT(6) <= R1_IN(6);
  T1_OUT(5) <= R3_IN(3);
  T1_OUT(4) <= R3_IN(4);
  T1_OUT(3) <= R3_IN(7);
  T1_OUT(2) <= R3_IN(0);
  T1_OUT(1) <= R1_IN(1);
  T1_OUT(0) <= R1_IN(0);
```

```
  T2_OUT(7) <= R1_IN(5);
  T2_OUT(6) <= R1_IN(4);
  T2_OUT(5) <= R3_IN(2);
  T2_OUT(4) <= R3_IN(5);
  T2_OUT(3) <= R3_IN(6);
  T2_OUT(2) <= R3_IN(1);
  T2_OUT(1) <= R1_IN(3);
  T2_OUT(0) <= R1_IN(2);
```

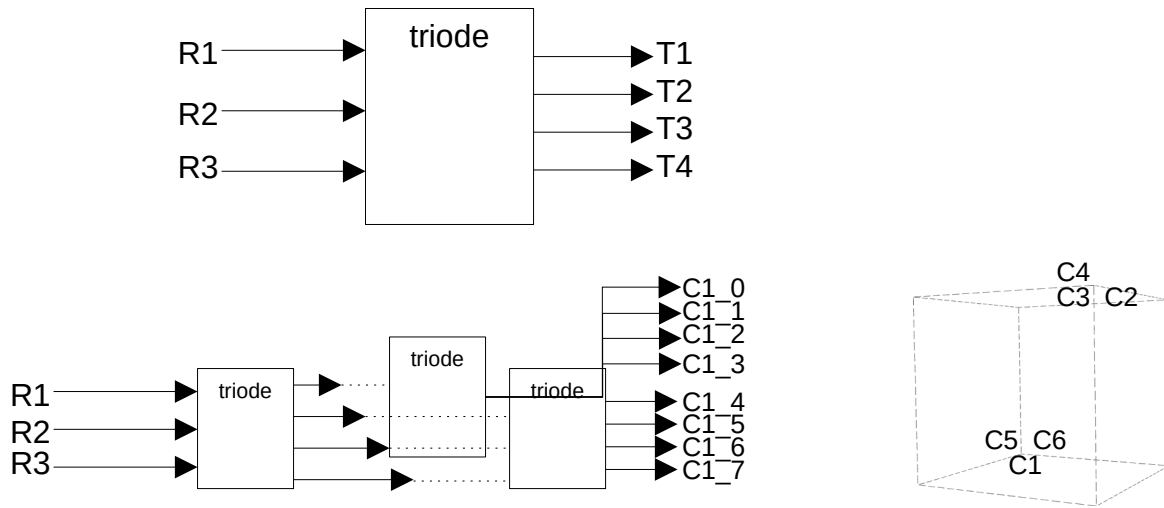
```
  T3_OUT(7) <= R2_IN(5);
  T3_OUT(6) <= R2_IN(4);
  T3_OUT(5) <= R3_IN(1);
  T3_OUT(4) <= R3_IN(6);
  T3_OUT(3) <= R3_IN(5);
  T3_OUT(2) <= R3_IN(2);
  T3_OUT(1) <= R2_IN(3);
  T3_OUT(0) <= R2_IN(2);
```

```
  T4_OUT(7) <= R2_IN(7);
  T4_OUT(6) <= R2_IN(6);
  T4_OUT(5) <= R3_IN(0);
  T4_OUT(4) <= R3_IN(7);
  T4_OUT(3) <= R3_IN(4);
  T4_OUT(2) <= R3_IN(3);
  T4_OUT(1) <= R2_IN(1);
  T4_OUT(0) <= R2_IN(0);
```

```
end Dataflow;
```

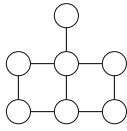


Series triodes. 8X6 matrices. Cubes.



Six possible permutations of R1,R2,R3 fed into series triodes in the arrangement shown above give us a cube – unit of a three-dimensional lattice

Ex8



$A=000_2$

1-bit triode:

$$Triode(R_1, R_2, R_3) = \begin{matrix} r_0^3 \\ r_0^1 \\ r_0^2 \\ r_0^3 \end{matrix}$$

$$Triode(R_1, R_3, R_2) = \begin{matrix} r_0^2 \\ r_0^1 \\ r_0^3 \\ r_0^2 \end{matrix}$$

$$R_1 = r_0^1 \quad R_2 = r_0^2 \quad R_3 = r_0^3$$

$$Triode(R_2, R_1, R_3) = \begin{matrix} r_0^3 \\ r_0^2 \\ r_0^1 \\ r_0^3 \end{matrix}$$

$$Triode(R_2, R_3, R_1) = \begin{matrix} r_0^1 \\ r_0^2 \\ r_0^3 \\ r_0^1 \end{matrix}$$

$$Triode(R_3, R_1, R_2) = \begin{matrix} r_0^2 \\ r_0^3 \\ r_0^1 \\ r_0^2 \end{matrix}$$

$$Triode(R_3, R_2, R_1) = \begin{matrix} r_0^1 \\ r_0^3 \\ r_0^2 \\ r_0^1 \end{matrix}$$

=> 1-bit cube is

$$Cube(R_1, R_2, R_3) = \begin{matrix} r_0^2 & r_0^3 & r_0^1 & r_0^3 & r_0^1 & r_0^2 \\ r_0^3 & r_0^2 & r_0^3 & r_0^1 & r_0^2 & r_0^1 \\ r_0^1 & r_0^1 & r_0^2 & r_0^2 & r_0^3 & r_0^3 \\ r_0^2 & r_0^3 & r_0^1 & r_0^3 & r_0^1 & r_0^2 \\ r_0^3 & r_0^2 & r_0^3 & r_0^1 & r_0^2 & r_0^1 \\ r_0^1 & r_0^1 & r_0^2 & r_0^2 & r_0^3 & r_0^3 \\ r_0^2 & r_0^3 & r_0^1 & r_0^3 & r_0^1 & r_0^2 \\ r_0^3 & r_0^2 & r_0^3 & r_0^1 & r_0^2 & r_0^1 \end{matrix}$$

■

Denoise. Piecewise linear functions.

Recall  $\bar{R} = a_1 \cdot \bar{R}_1 + a_2 \cdot \bar{R}_2 + a_3 \cdot \bar{R}_3$  is the value of the red component in the Bayer color filter array.

Introduce noise as a constant in our linear equation:

$$\bar{R} = a_1 \cdot \bar{R}_1 + a_2 \cdot \bar{R}_2 + a_3 \cdot \bar{R}_3 + \bar{C} \quad , \text{where } C \text{ is noise}$$

$$\bar{R} = 0.48107 \cdot \begin{pmatrix} r_7^1 \\ r_6^1 \\ r_5^1 \\ r_5^1 \\ r_4^1 \\ r_3^1 \\ r_2^1 \\ r_1^1 \\ r_0^1 \end{pmatrix} + 0.35857 \cdot \begin{pmatrix} r_7^3 \\ r_6^3 \\ r_5^3 \\ r_5^3 \\ r_4^3 \\ r_3^3 \\ r_2^3 \\ r_1^3 \\ r_0^3 \end{pmatrix} + 0.16035 \cdot \begin{pmatrix} r_7^2 \\ r_6^2 \\ r_5^2 \\ r_5^2 \\ r_4^2 \\ r_3^2 \\ r_2^2 \\ r_1^2 \\ r_0^2 \end{pmatrix} + \begin{pmatrix} c_7 \\ c_6 \\ c_5 \\ c_5 \\ c_4 \\ c_3 \\ c_2 \\ c_1 \\ c_0 \end{pmatrix}$$

Therefore now our Rbig looks like:

$$R^* = r_7^1 r_6^1 r_5^1 r_4^1 r_3^1 r_2^1 r_1^1 r_0^1 r_7^3 r_6^3 r_5^3 r_4^3 r_3^3 r_2^3 r_1^3 r_0^3 r_7^2 r_6^2 r_5^2 r_4^2 r_3^2 r_2^2 r_1^2 r_0^2 c_7 c_6 c_5 c_4 c_3 c_2 c_1 c_0 \quad \text{call it } R_{BIG}$$

Now, taking it back to the inherent orthogonality of flips and shifts and keeping in mind their vector nature. As this is our new basis, and it is clear that the order of operations is strict, i.e.

$$f \circ g \neq g \circ f$$

Interpret our red component vectors as:

$$i = \begin{cases} 0 & \text{induce shift} \\ 1 & \text{induce flip} \end{cases}$$

Ex9

Px0, three surrounding red pixels

$$\begin{aligned} R_1 &= 128_{10} = 10000000_2 & R_1^* &= F(S(S(S(S(S(S(x))))))) \\ R_2 &= 53_{10} = 00110101_2 & R_2^* &= S(S(F(F(S(F(S(F(x))))))) \\ R_3 &= 127_{10} = 01111111_2 & R_3^* &= S(F(F(F(F(F(F(F(x))))))) \end{aligned}$$

Notion of most and least significance of bits comes to help here.

Therefore our digital circuit core has to contain  $2^8 = 256$  dual vectors. ■

So what we really meant with  $R^*$  and Rbig is:

$$R^* = r_7^1 r_6^1 r_5^1 r_4^1 r_3^1 r_2^1 r_1^1 r_0^1 \wedge r_7^3 r_6^3 r_5^3 r_4^3 r_3^3 r_2^3 r_1^3 r_0^3 \wedge r_7^2 r_6^2 r_5^2 r_4^2 r_3^2 r_2^2 r_1^2 r_0^2 \quad \text{call it } R_{BIG} \text{ - wedge product of linear functionals.}$$

