Gamut Mapping for Tone Mapping Operations

EECE 541 W2019
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AGENDA

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04 WORKFLOW

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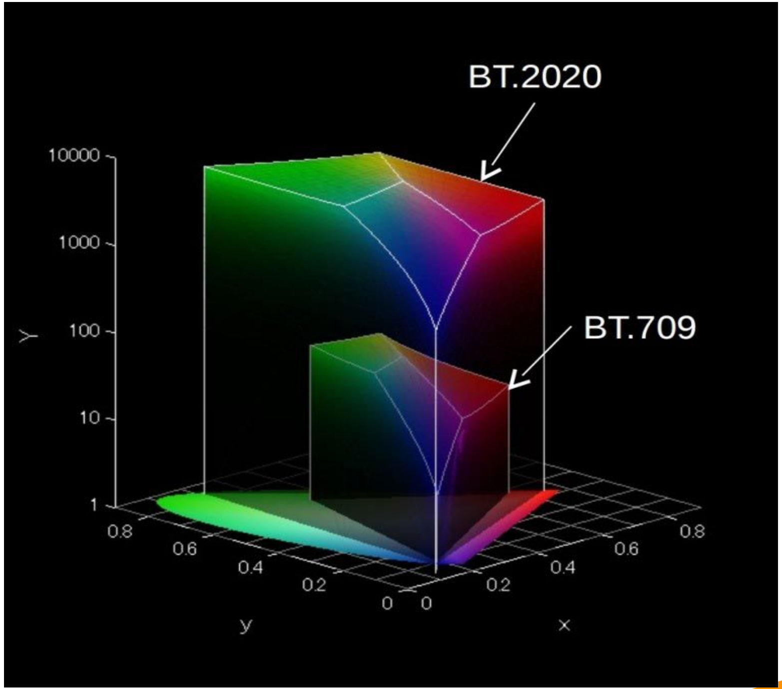
1. Introduction

Introduction

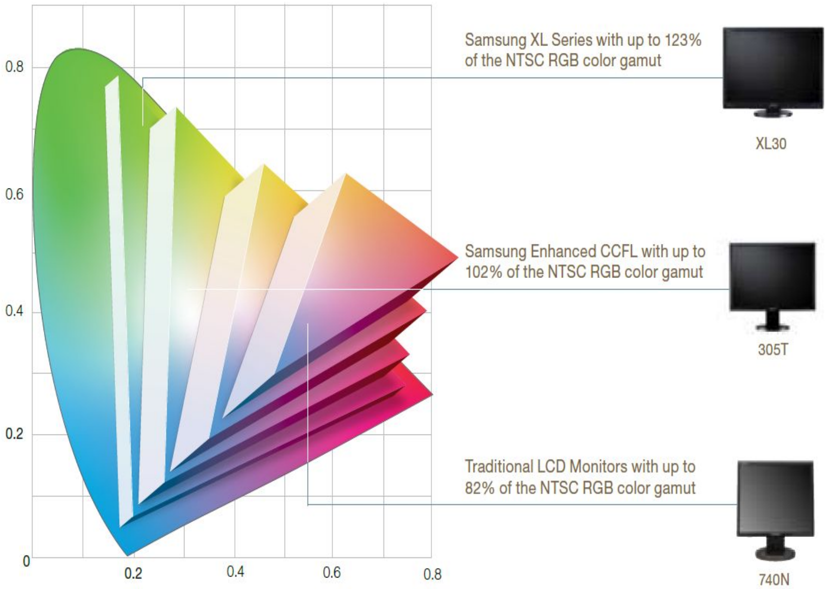
- To map each color from the BT.2020 gamut to BT.709 gamut
- To find the best combination of color space and projection technique that yields the minimum possible color error and improve the QOE



Introduction

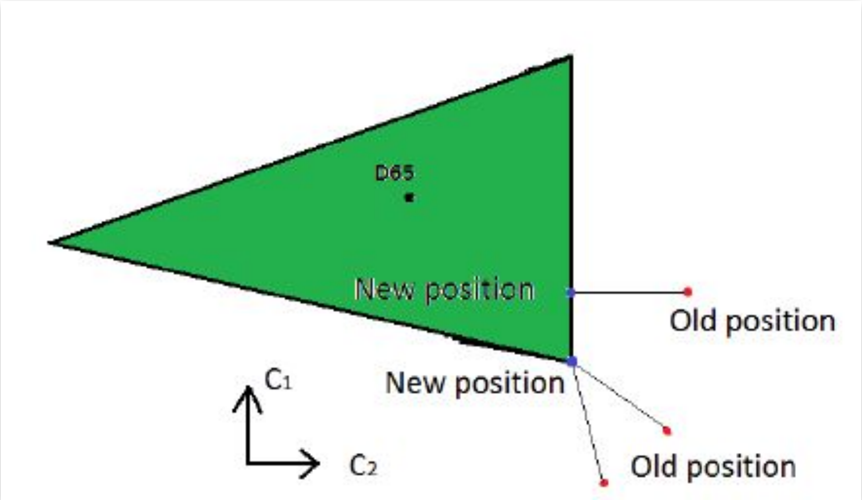
- **To ensure that the colors shown by a TV are as close as possible to original colors, we use a Gamut Mapping approach.**

- **To guarantee global compatibility between the content and display, it is essential to convert the content from wide gamut to smaller gamut.**

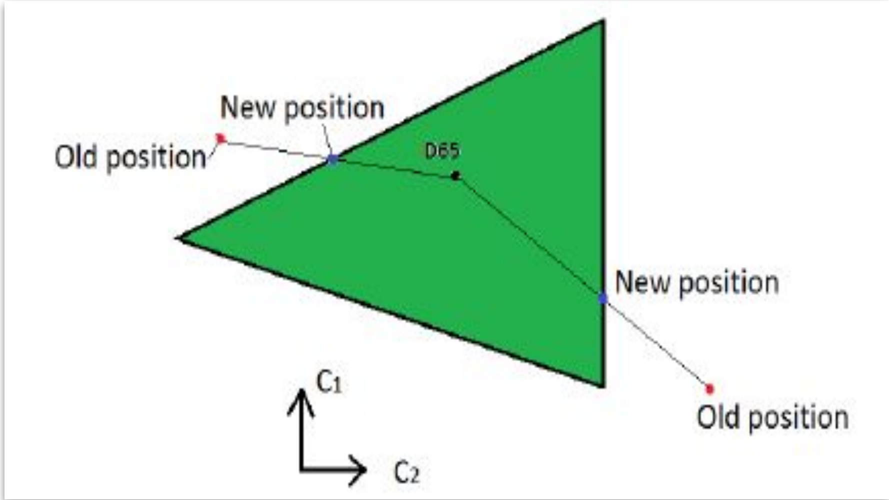


2. Existing Techniques

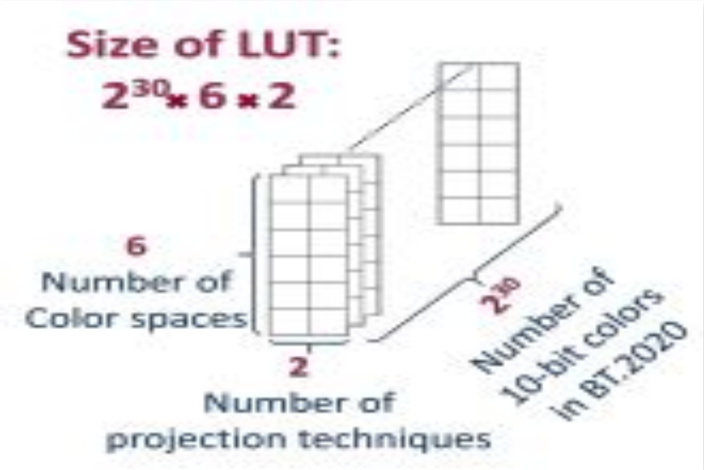
Closest Point



Towards White Point



The existing method finds the combination of color space and projection technique results in the least perceptual difference. Each color being mapped in different color space and projection method.



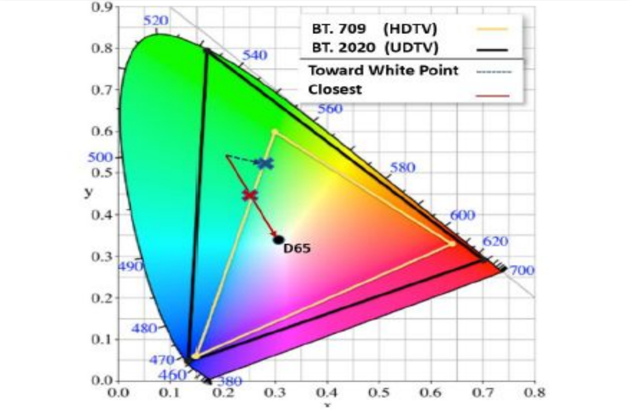


Fig. 1. CIE 1921 xy chromaticity diagram with the BT. 709 and BT. 2020 color gamuts, arrows illustrates Toward White point (TWP) and Closest projection techniques.

Gamut Mapping Method	Mean Error (CIE ΔE2000)	Number of pixels with error < 1
TWP-CIELAB	3.80	8388395
Proposed hybrid approach	2.93	8481814

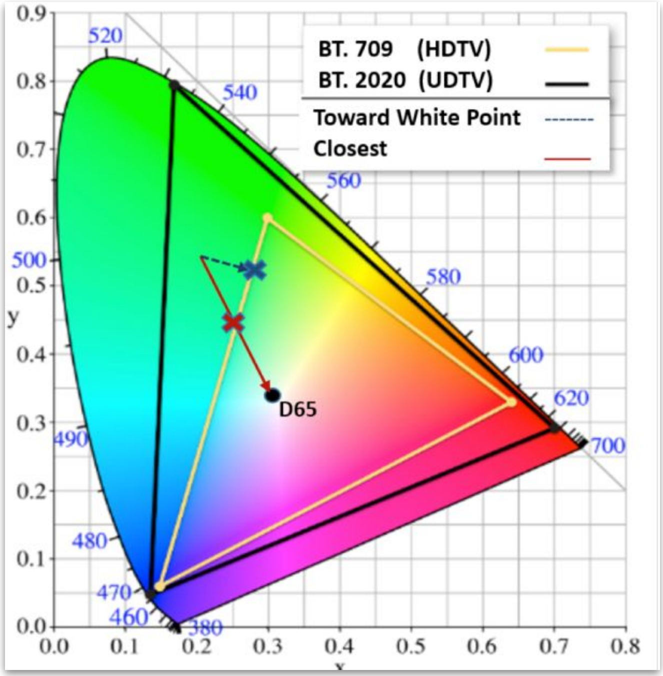
Algorithm	Color Space	Mean Error	STD Error	Time taken [s]
TWP	Yxy	4.283	2.731	209
TWP	$Yu'v'$	4.272	2.719	190
TWP	Yuv	4.264	2.706	167
TWP	$L^*u^*v^*$	4.279	2.716	151
TWP	$L^*a^*b^*$	4.135	2.622	4890
TWP	$LCH_{u^*v^*}$	4.277	2.740	34
TWP	$LCH_{a^*b^*}$	4.158	2.647	2838
TWP	LCH_{xy}	4.244	2.725	29
TWP	LCH_{uv}	4.289	2.745	30
TWP	IC_aC_b	4.18	2.671	14808
Closest	IC_aC_b	4.15	2.63	76298
Closest	Yxy	4.406	2.786	180
Closest	$Yu'v'$	4.407	2.786	168
Closest	Yuv	4.753	3.188	146
Closest	$L^*u^*v^*$	4.407	2.791	136
Closest	$L^*a^*b^*$	4.506	3.061	7249

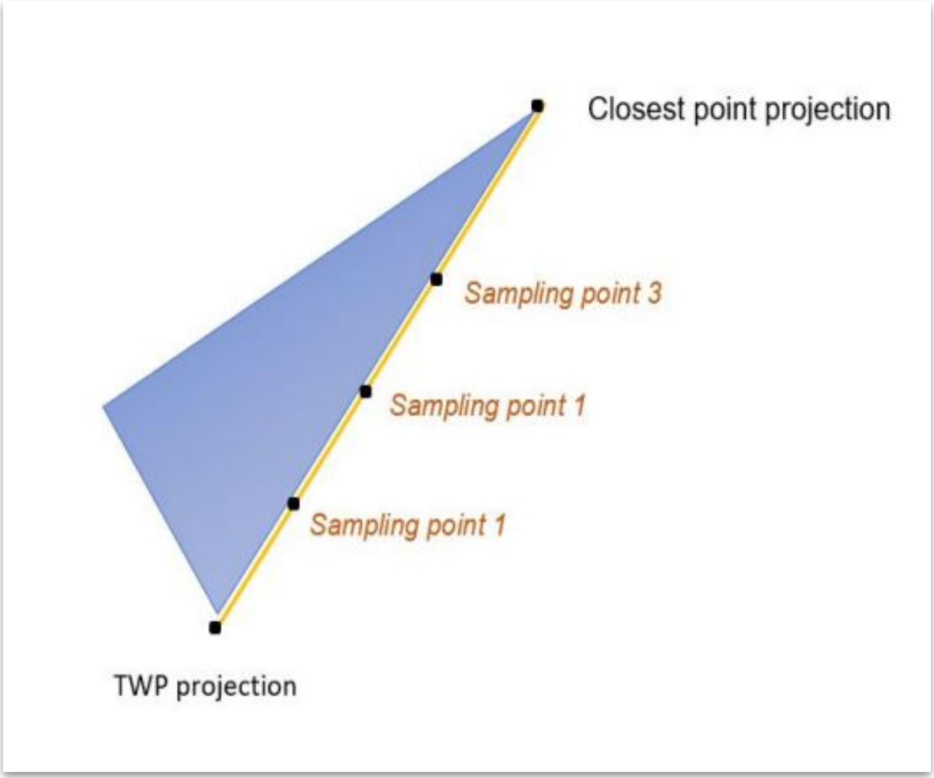
3. Proposed Method

PROPOSED METHOD

- Instead of using 6 color spaces, Compute points on one color space and take more samples
- Compute error for both Closest point and Towards White Point and assign the lower error as lower bound and more error one as upper bound
- Calculate error of median on the line joining Closest Point and TWP.
- Subsequently calculate error of three points between median and lower bound and error for points between median and upper bound.
- Make a Lookup Table for lowest error points.

Mapping a pixel using TWP and CP projection





- Calculate Mid-Point between TWP and CP
- Calculate Mid-Point between TWP and Mid-point
- Calculate Mid-Point between Mid-Point and Closest Point

4. Performance Metrics

Performance Metrics

- DeltaE is a metric to understand how human eyes perceives color
- There are three standard DeltaE Algorithms.
- DeltaE76 is a simple approach of taking Euclidean distance in the 3D space. But its biggest fault is it doesn't take hue into account while calculating the error
- DeltaE94 will take into account certain weighting factors for each lightness, chroma, and hue value. It also introduced the ability to add a modifier according to the use case: either textile, or graphic arts. But it still falls short when calculating the perceived lightness of two colors.
- DeltaE00 is currently the most complicated yet most accurate CIE color difference algorithm.Although the most accurate we have today, dE00 is not without fault. The most significant discontinuity occurs when compared hues are 180° from each other.
- For our proposed method we need the most accurate color difference algorithm so we have used DeltaE00 as our preferred performance matrix.

5. Workflow

WORKFLOW

1. Evaluation of the 10 bit color space and mapping of each point in BT.2020 to BT.709 using various projection techniques in **Lab** color space

2. Projection to lower gamut using Towards White Point, Closest Point, Mid-Point, Midpoint-CP and Midpoint-TWP techniques

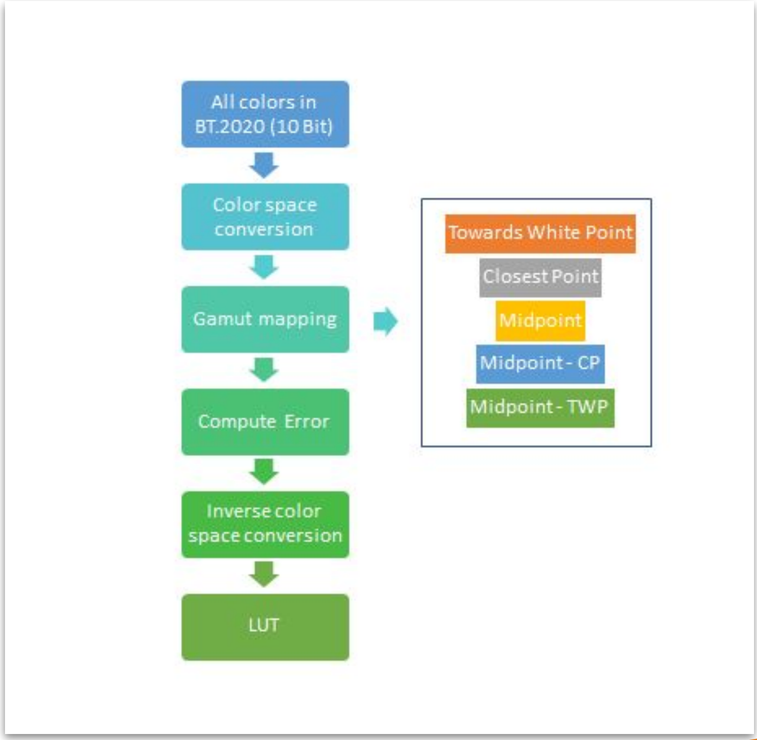
3. Calculation of CIE ΔE2000 metric for each projection technique

4. Create LUT for all colors in BT.2020 along with projected points and their CIE ΔE2000

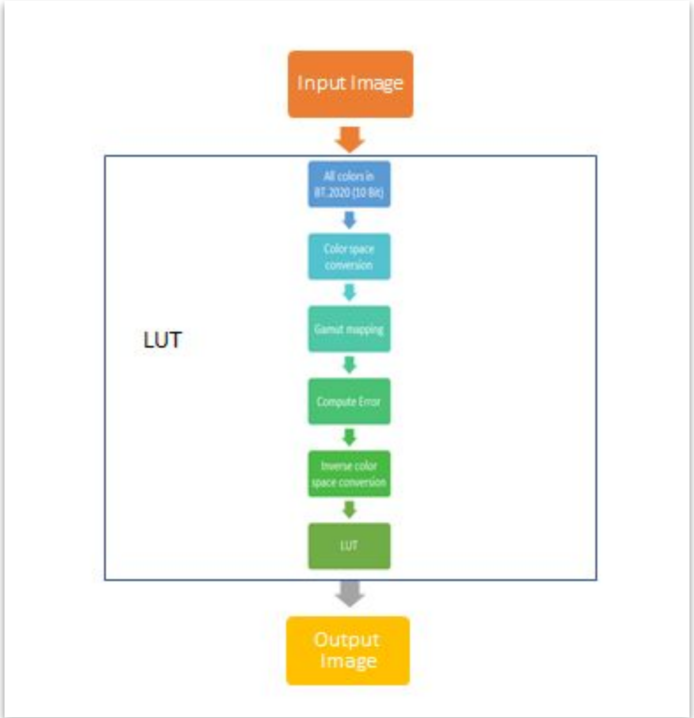
5. Compare the pixels of Input image with the LUT and get projected point with least CIE ΔE2000

6. The output of the algorithm is the image in BT.709 gamut with least color error

WORKFLOW

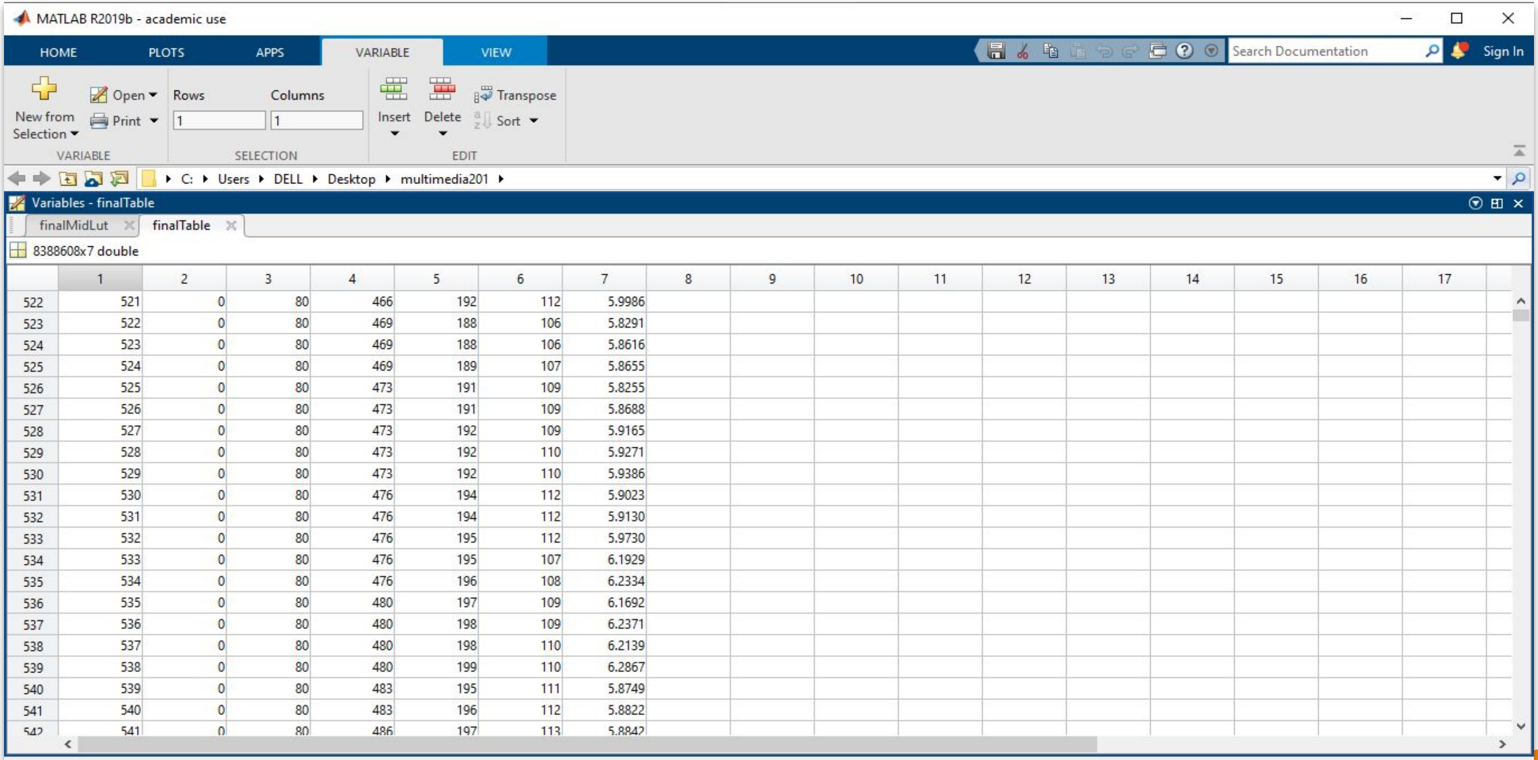

All colors in BT.2020 (10 Bit)
Color space conversion
Gamut mapping
Compute Error
Inverse color space conversion
LUT
Towards White Point
Closest Point
Midpoint
Midpoint - CP
Midpoint - TWP

WORKFLOW


Input Image
All colors in
BT.2020 (10 Bit)
Color space
conversion
Gamut mapping
Compute Error
Inverse color
space conversion
LUT
LUT
Output
Image

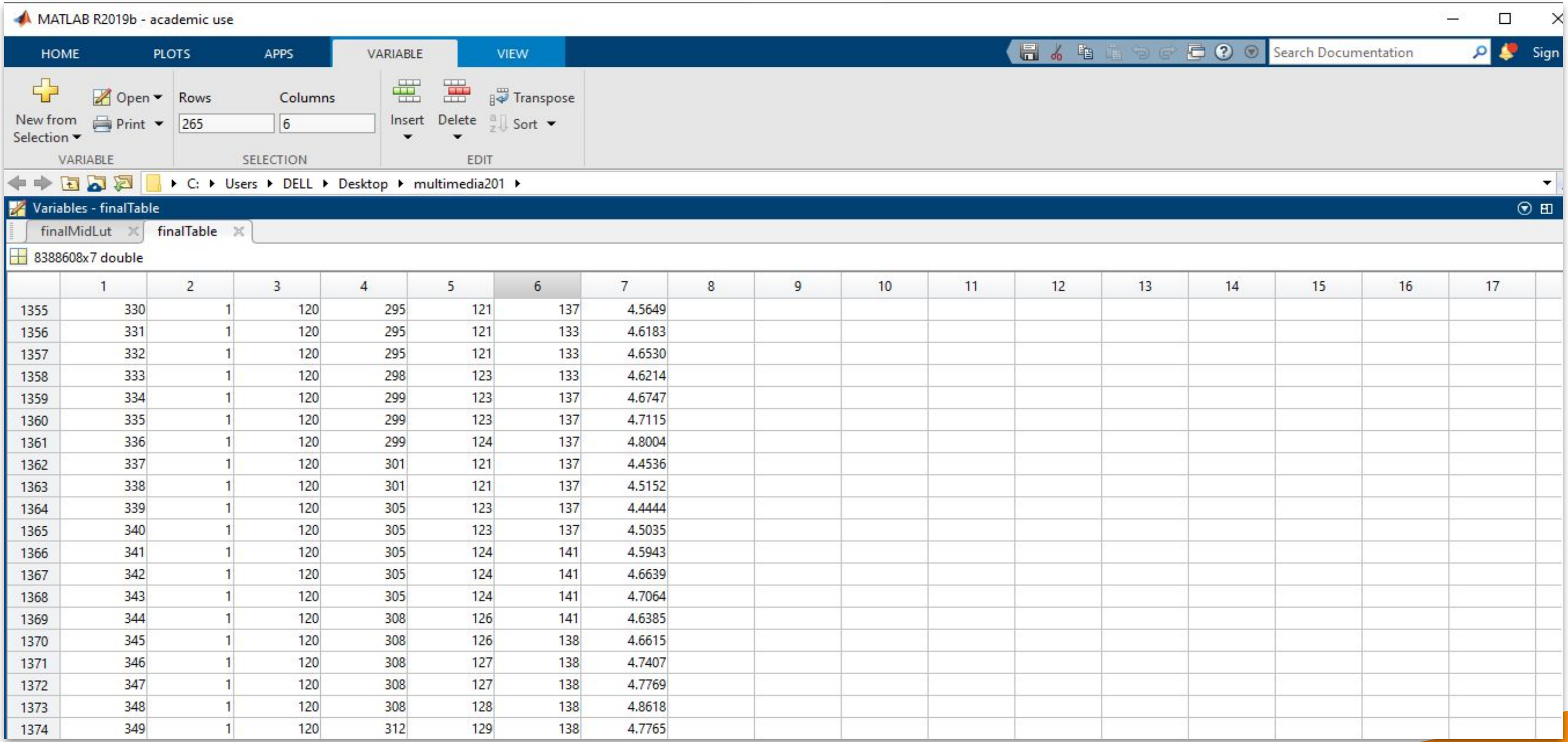
6. Results

CLOSEST POINT LUT



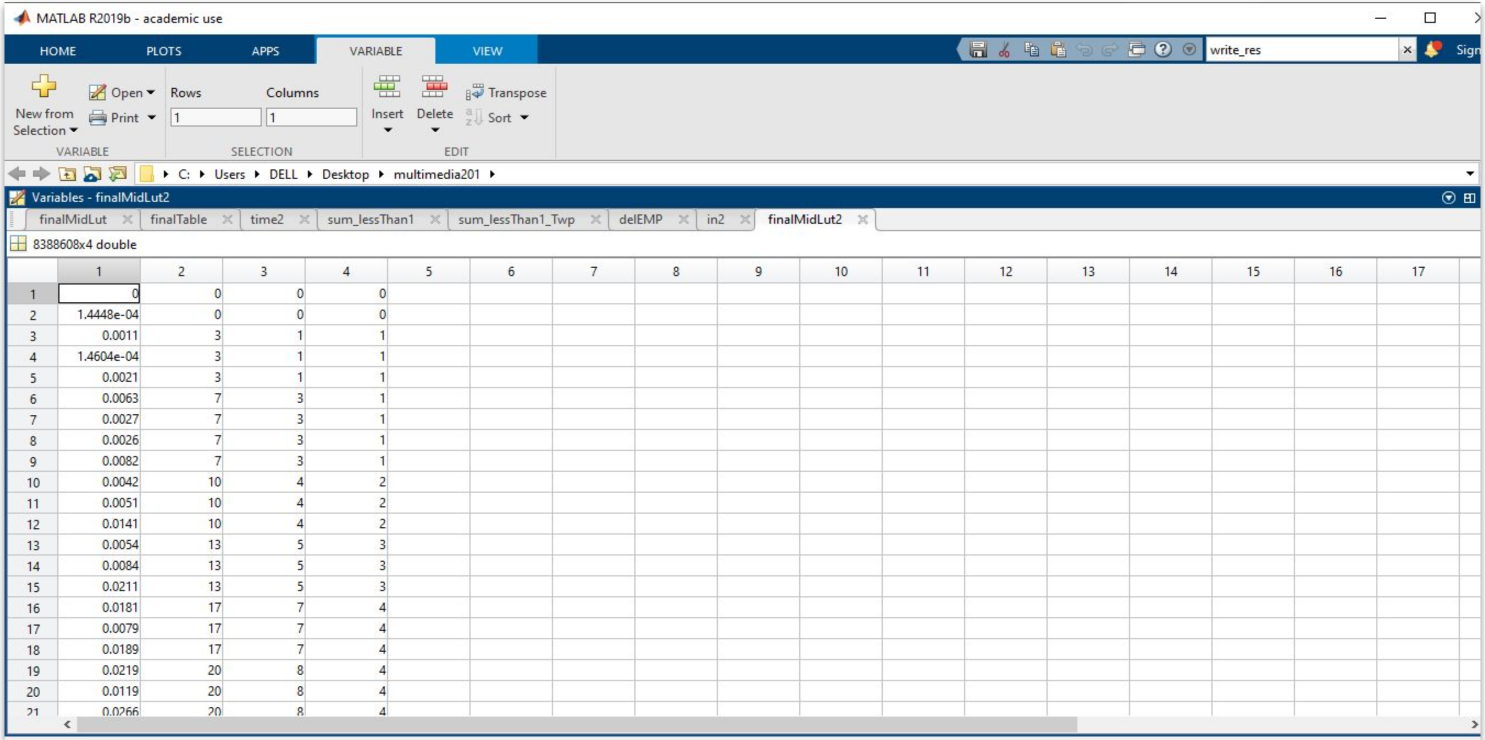
	1	2	3	4	5	6	7
522	521	0	80	466	192	112	5.9986
523	522	0	80	469	188	106	5.8291
524	523	0	80	469	188	106	5.8616
525	524	0	80	469	189	107	5.8655
526	525	0	80	473	191	109	5.8255
527	526	0	80	473	191	109	5.8688
528	527	0	80	473	192	109	5.9165
529	528	0	80	473	192	110	5.9271
530	529	0	80	473	192	110	5.9386
531	530	0	80	476	194	112	5.9023
532	531	0	80	476	194	112	5.9130
533	532	0	80	476	195	112	5.9730
534	533	0	80	476	195	107	6.1929
535	534	0	80	476	196	108	6.2334
536	535	0	80	480	197	109	6.1692
537	536	0	80	480	198	109	6.2371
538	537	0	80	480	198	110	6.2139
539	538	0	80	480	199	110	6.2867
540	539	0	80	483	195	111	5.8749
541	540	0	80	483	196	112	5.8822
542	541	0	80	486	197	113	5.8842

TOWARDS WHITE POINT LUT



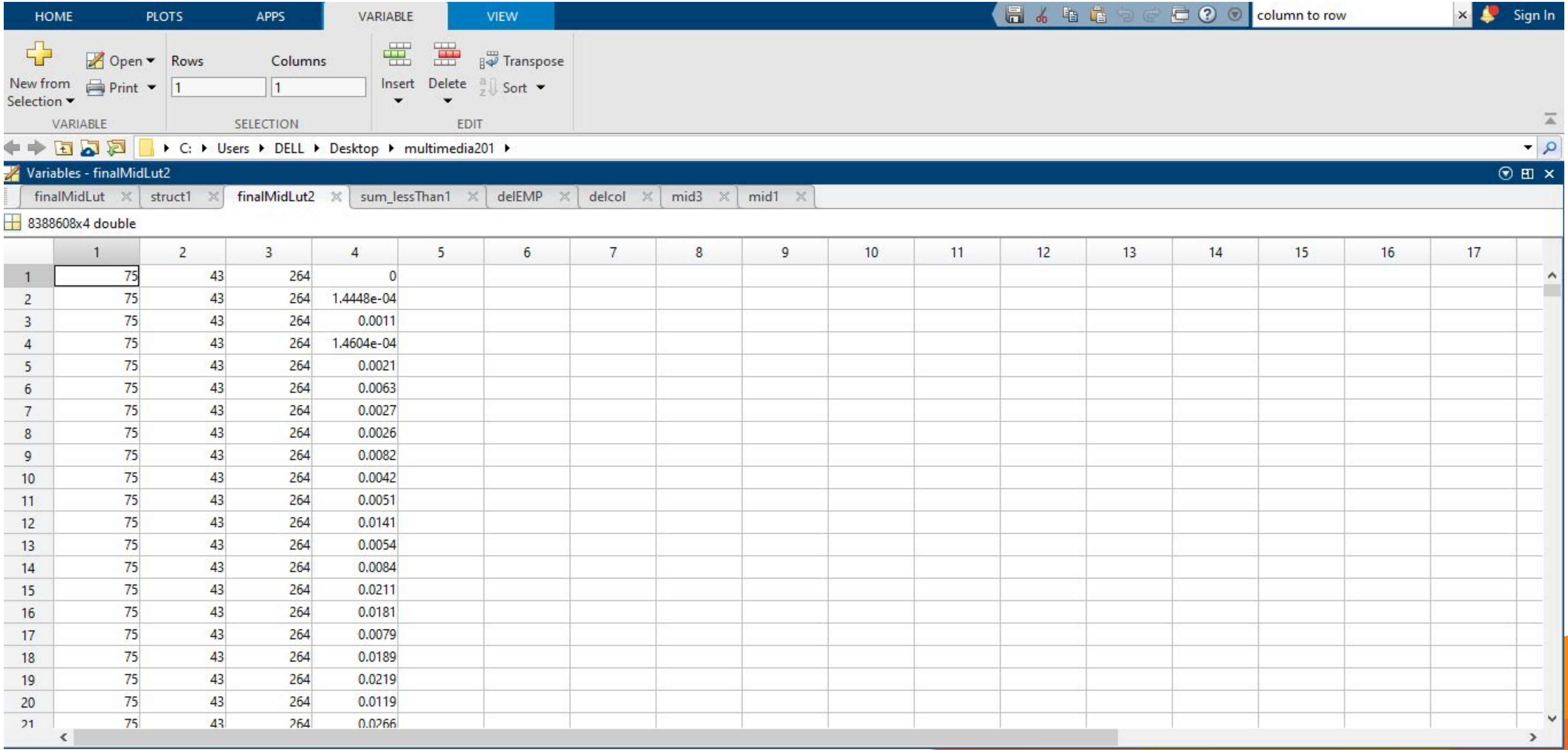
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1355	330	1	120	295	121	137	4.5649										
1356	331	1	120	295	121	133	4.6183										
1357	332	1	120	295	121	133	4.6530										
1358	333	1	120	298	123	133	4.6214										
1359	334	1	120	299	123	137	4.6747										
1360	335	1	120	299	123	137	4.7115										
1361	336	1	120	299	124	137	4.8004										
1362	337	1	120	301	121	137	4.4536										
1363	338	1	120	301	121	137	4.5152										
1364	339	1	120	305	123	137	4.4444										
1365	340	1	120	305	123	137	4.5035										
1366	341	1	120	305	124	141	4.5943										
1367	342	1	120	305	124	141	4.6639										
1368	343	1	120	305	124	141	4.7064										
1369	344	1	120	308	126	141	4.6385										
1370	345	1	120	308	126	138	4.6615										
1371	346	1	120	308	127	138	4.7407										
1372	347	1	120	308	127	138	4.7769										
1373	348	1	120	308	128	138	4.8618										
1374	349	1	120	312	129	138	4.7765										

MID-POINT LUT



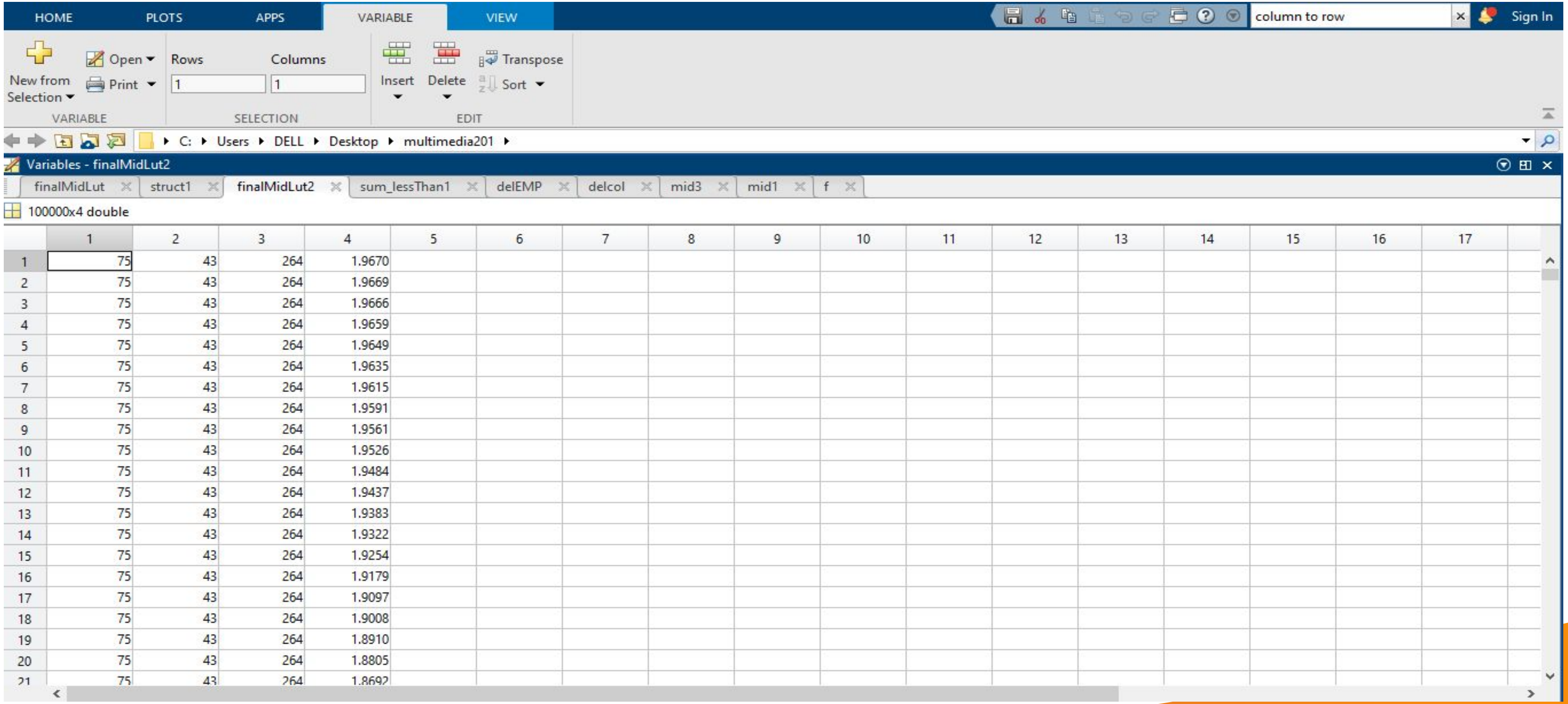
	1	2	3	4
1	0	0	0	0
2	1.4448e-04	0	0	0
3	0.0011	3	1	1
4	1.4604e-04	3	1	1
5	0.0021	3	1	1
6	0.0063	7	3	1
7	0.0027	7	3	1
8	0.0026	7	3	1
9	0.0082	7	3	1
10	0.0042	10	4	2
11	0.0051	10	4	2
12	0.0141	10	4	2
13	0.0054	13	5	3
14	0.0084	13	5	3
15	0.0211	13	5	3
16	0.0181	17	7	4
17	0.0079	17	7	4
18	0.0189	17	7	4
19	0.0219	20	8	4
20	0.0119	20	8	4
21	0.0266	20	8	4

MID-POINT LUT-CP

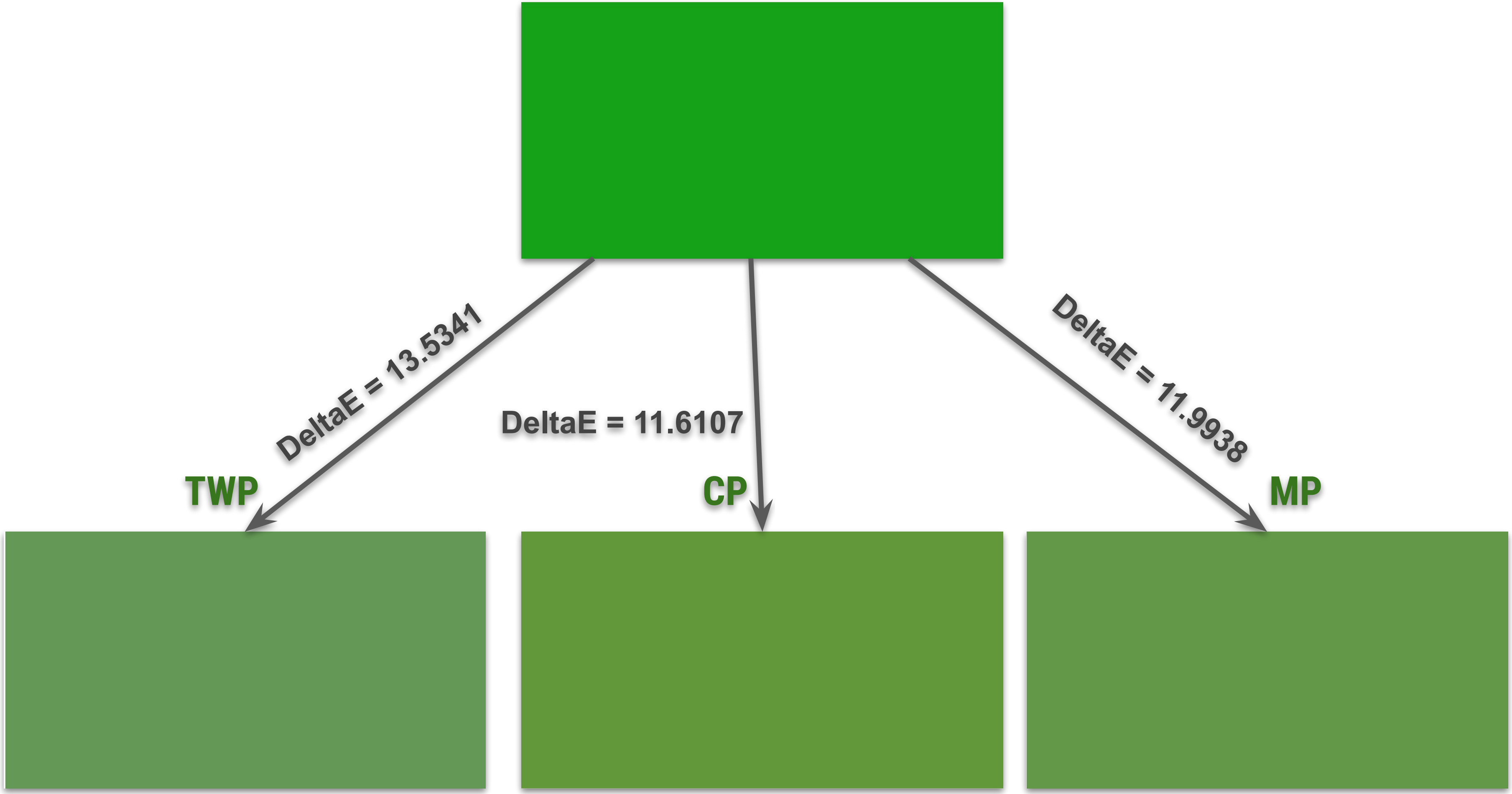


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	75	43	264	0													
2	75	43	264	1.4448e-04													
3	75	43	264	0.0011													
4	75	43	264	1.4604e-04													
5	75	43	264	0.0021													
6	75	43	264	0.0063													
7	75	43	264	0.0027													
8	75	43	264	0.0026													
9	75	43	264	0.0082													
10	75	43	264	0.0042													
11	75	43	264	0.0051													
12	75	43	264	0.0141													
13	75	43	264	0.0054													
14	75	43	264	0.0084													
15	75	43	264	0.0211													
16	75	43	264	0.0181													
17	75	43	264	0.0079													
18	75	43	264	0.0189													
19	75	43	264	0.0219													
20	75	43	264	0.0119													
21	75	43	264	0.0266													

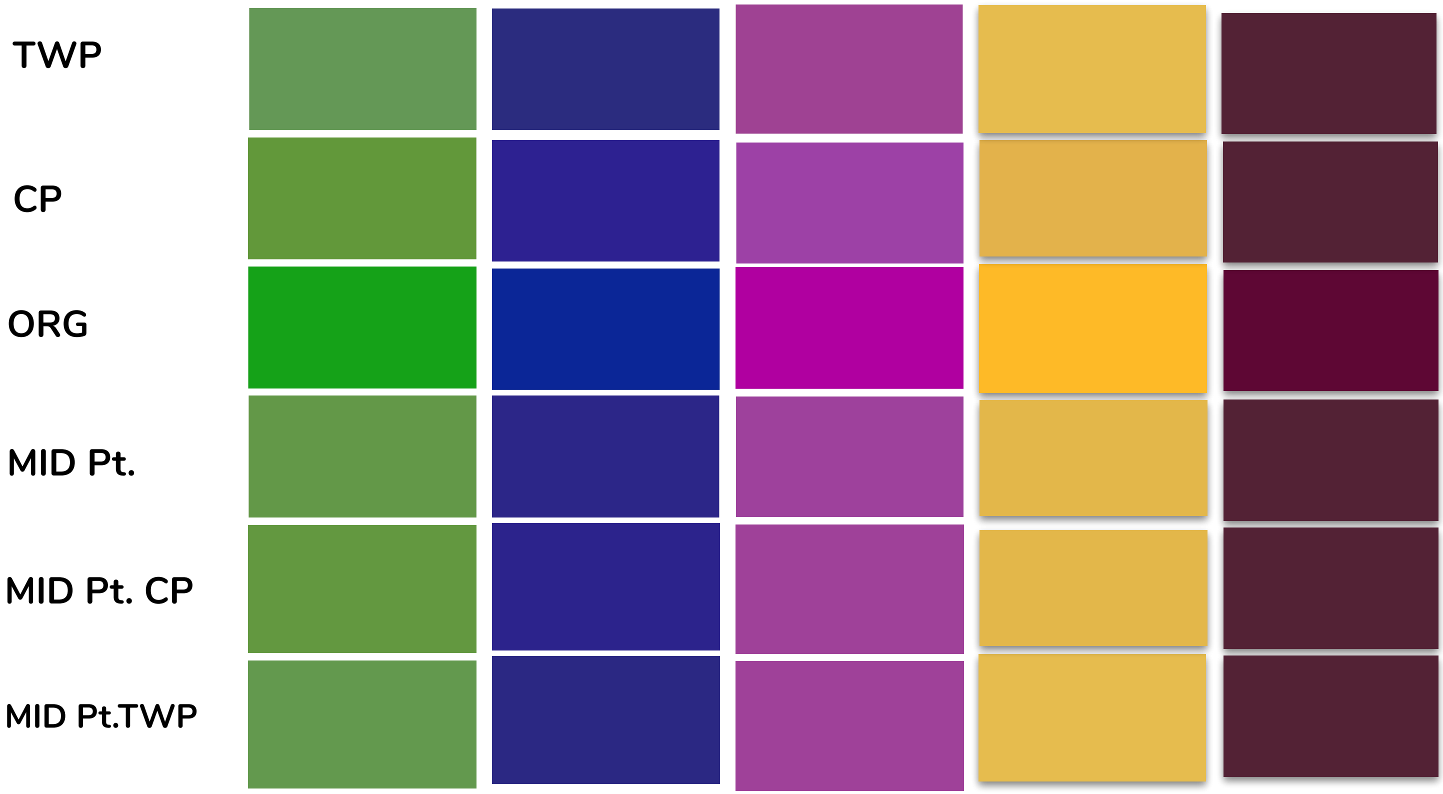
MID-POINT LUT-TWP

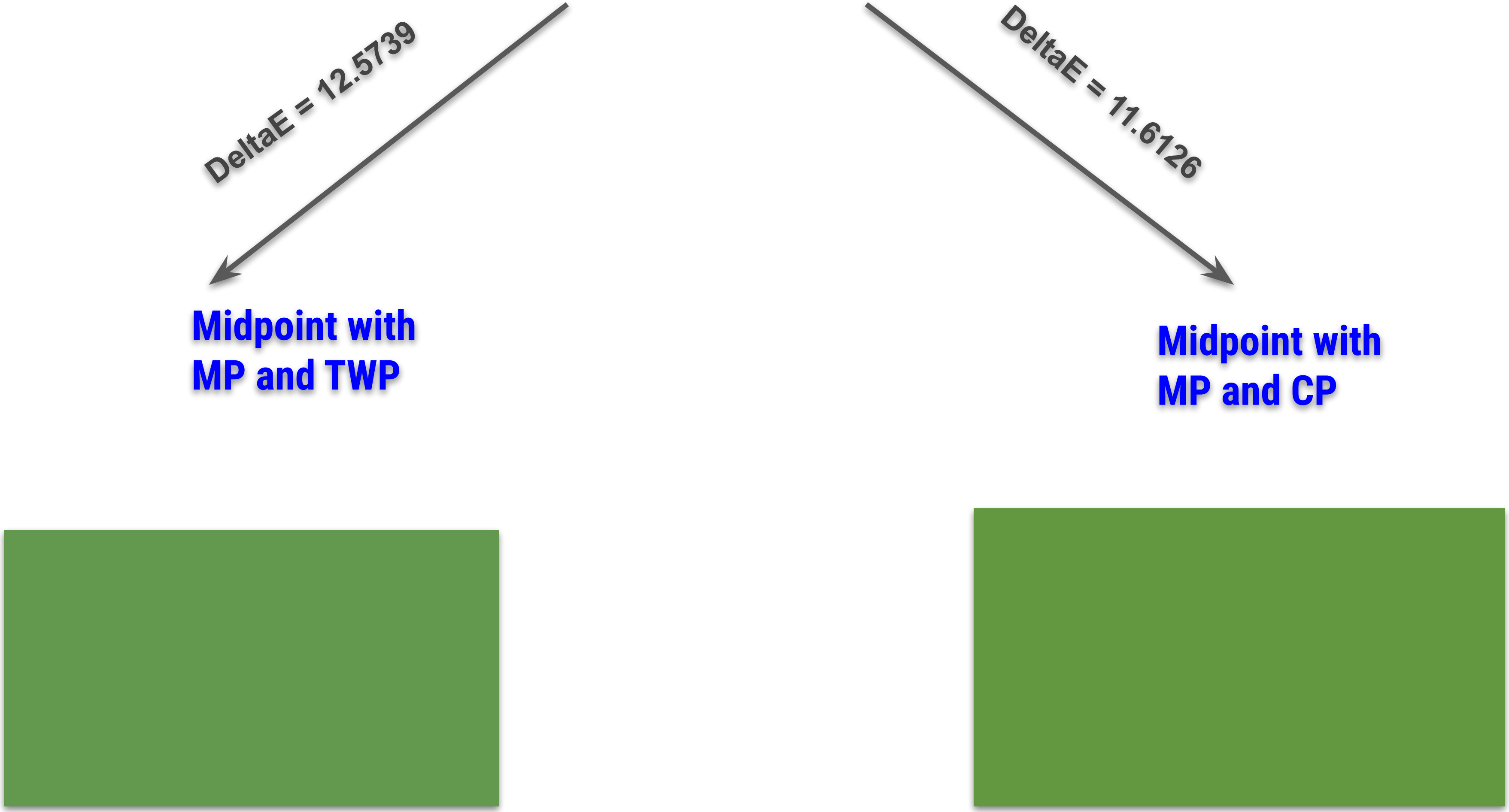


	1	2	3	4
1	75	43	264	1.9670
2	75	43	264	1.9669
3	75	43	264	1.9666
4	75	43	264	1.9659
5	75	43	264	1.9649
6	75	43	264	1.9635
7	75	43	264	1.9615
8	75	43	264	1.9591
9	75	43	264	1.9561
10	75	43	264	1.9526
11	75	43	264	1.9484
12	75	43	264	1.9437
13	75	43	264	1.9383
14	75	43	264	1.9322
15	75	43	264	1.9254
16	75	43	264	1.9179
17	75	43	264	1.9097
18	75	43	264	1.9008
19	75	43	264	1.8910
20	75	43	264	1.8805
21	75	43	264	1.8692

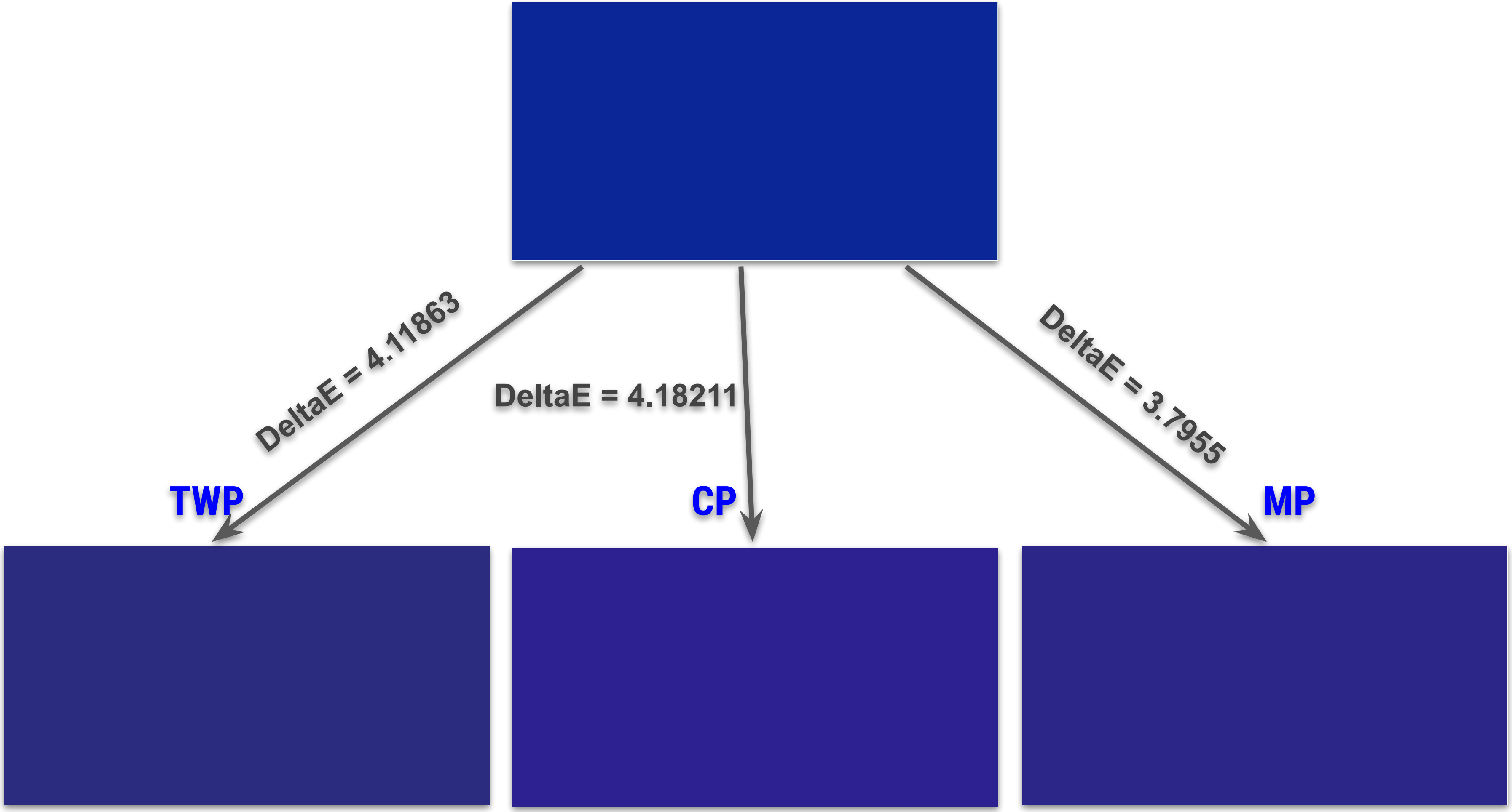


CP - Best Results; Mid point gives better results than TWP


TWP
CP
ORG
MID Pt.
MID Pt. CP
MID Pt.TWP



Mid-point with MP and CP better than MP near to CP



Mid-Point -Best Results ; TWP better than CP

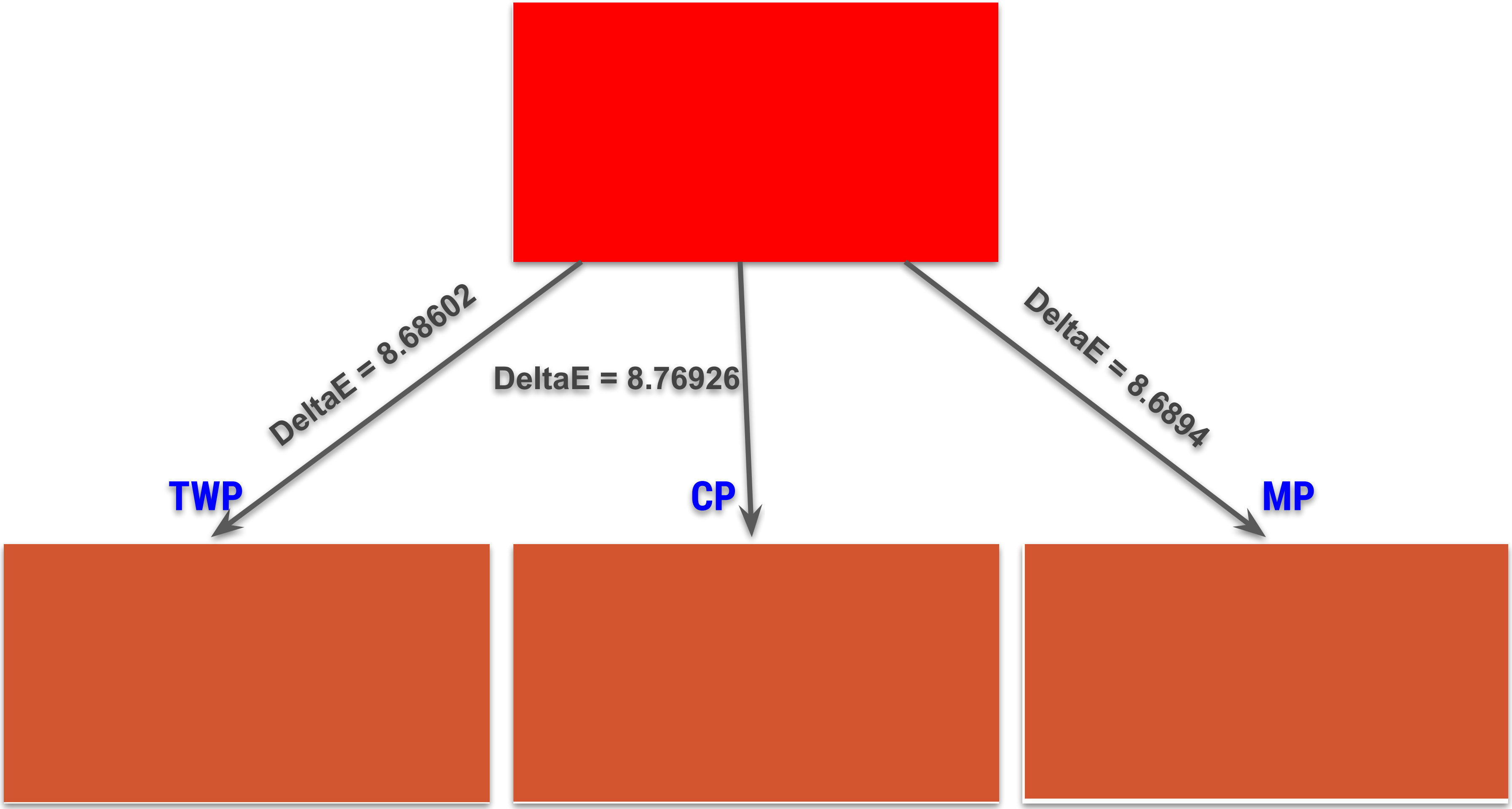
DeltaE = 3.9458

DeltaE = 3.9977

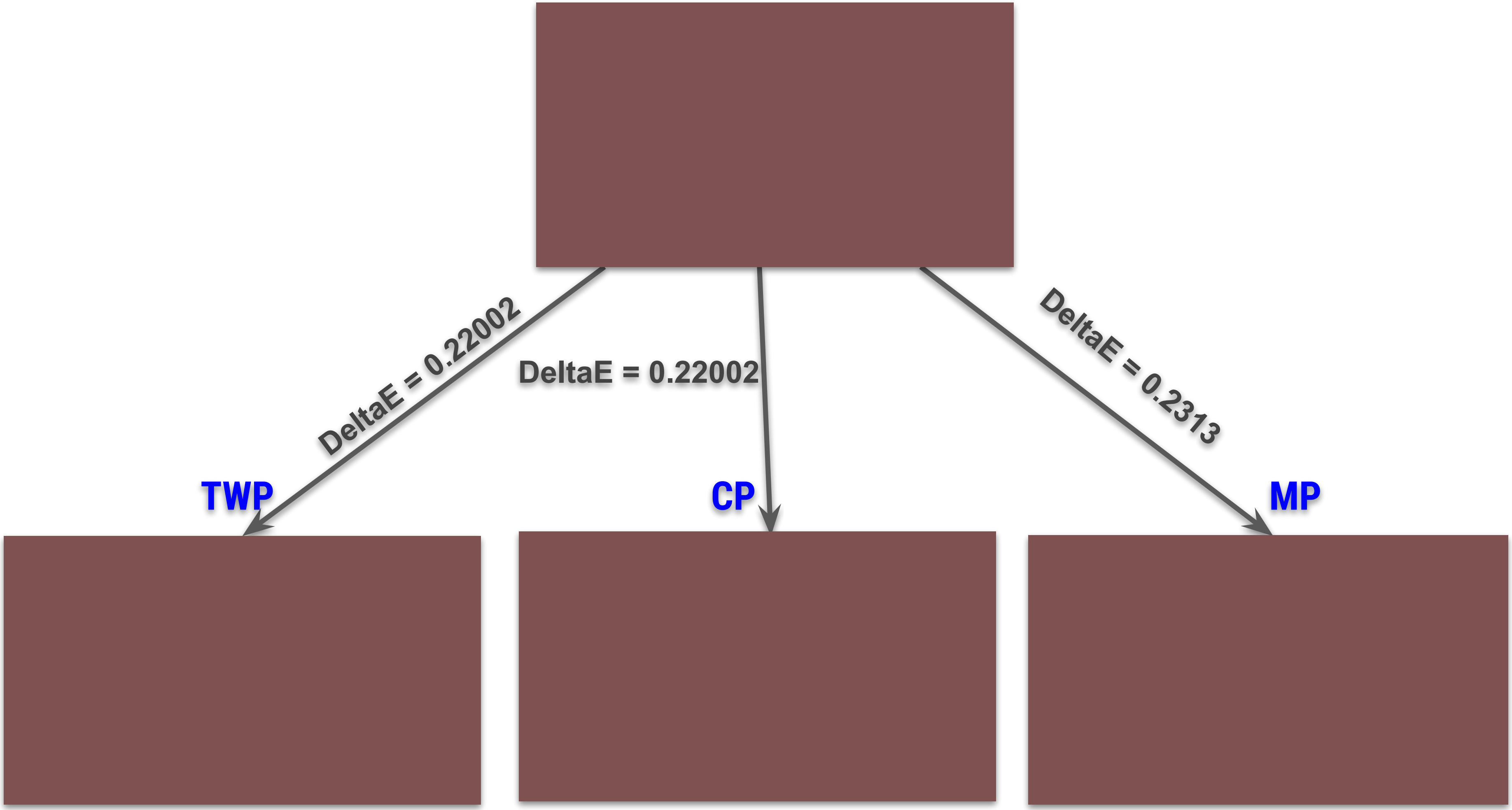
Midpoint with MP and TWP

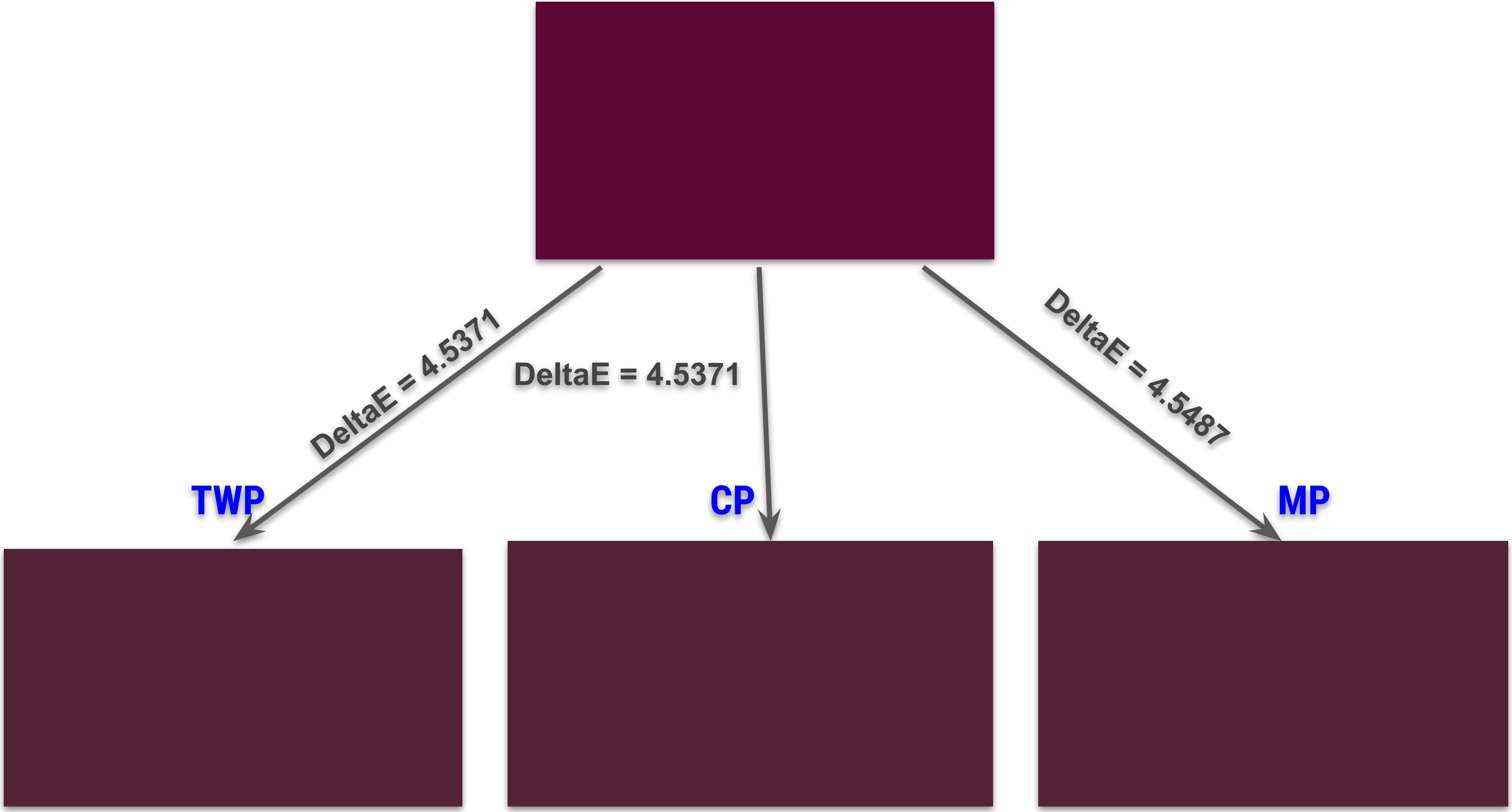
Midpoint with MP and CP

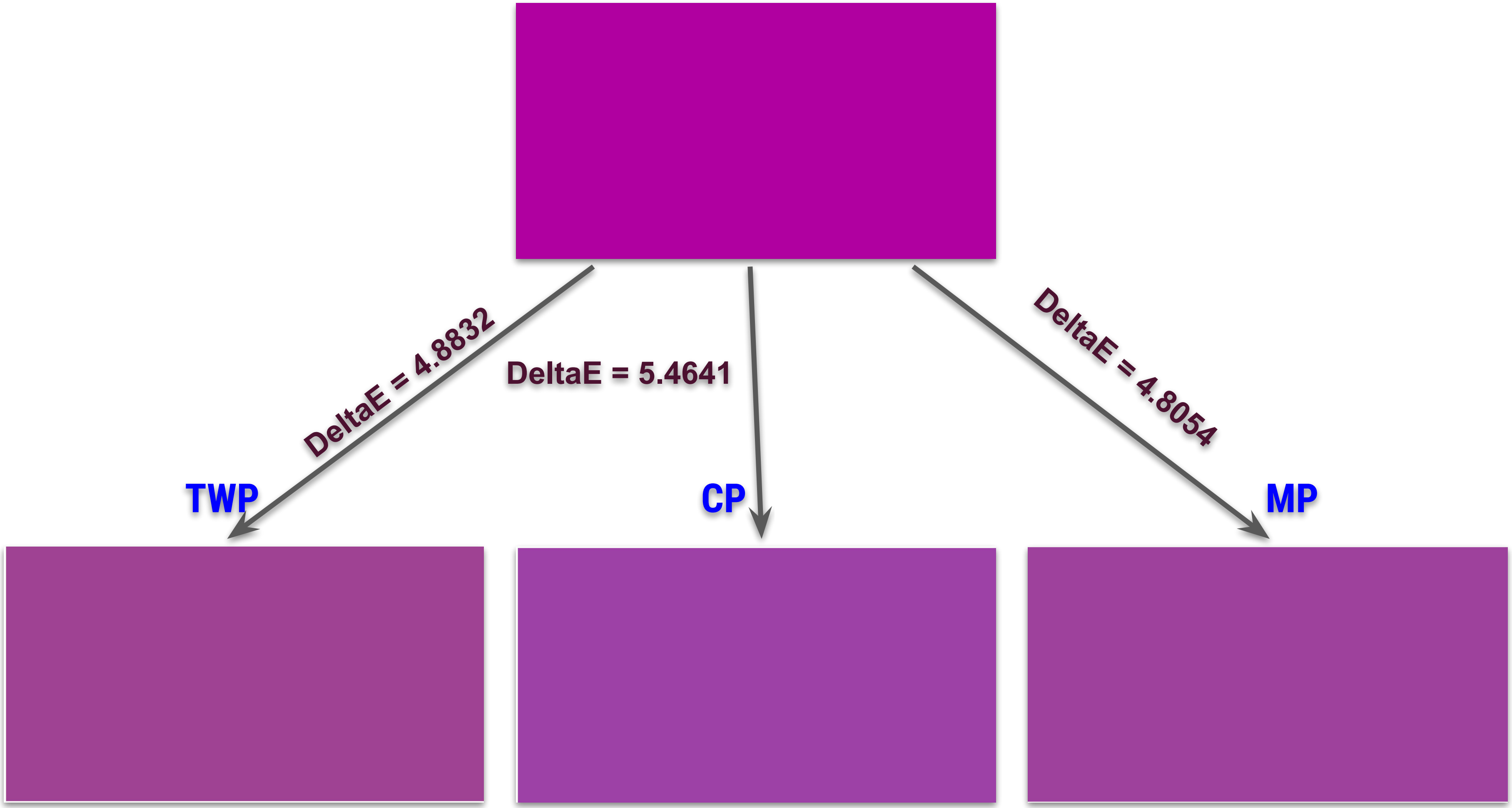
Both Mid-Points worse than MP



Very close Results; though QOE decreases


DeltaE = 0.22002
DeltaE = 0.22002
DeltaE = 0.2313
TWP
CP
MP


DeltaE = 4.5371
DeltaE = 4.5371
DeltaE = 4.5487
TWP
CP
MP



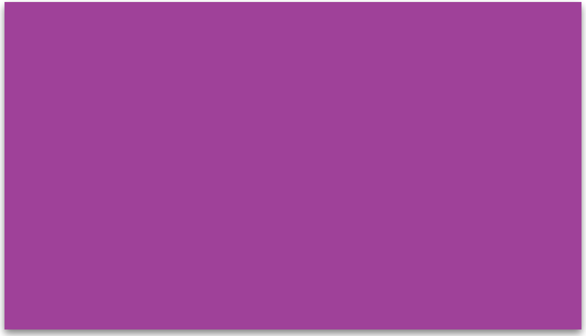
Mid-Point is better than TWP and CP

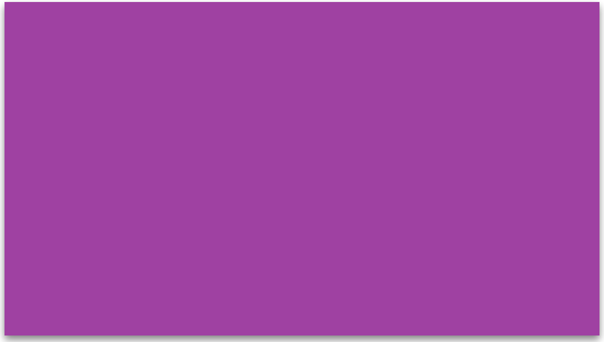
DeltaE = 4.5165

DeltaE = 5.005

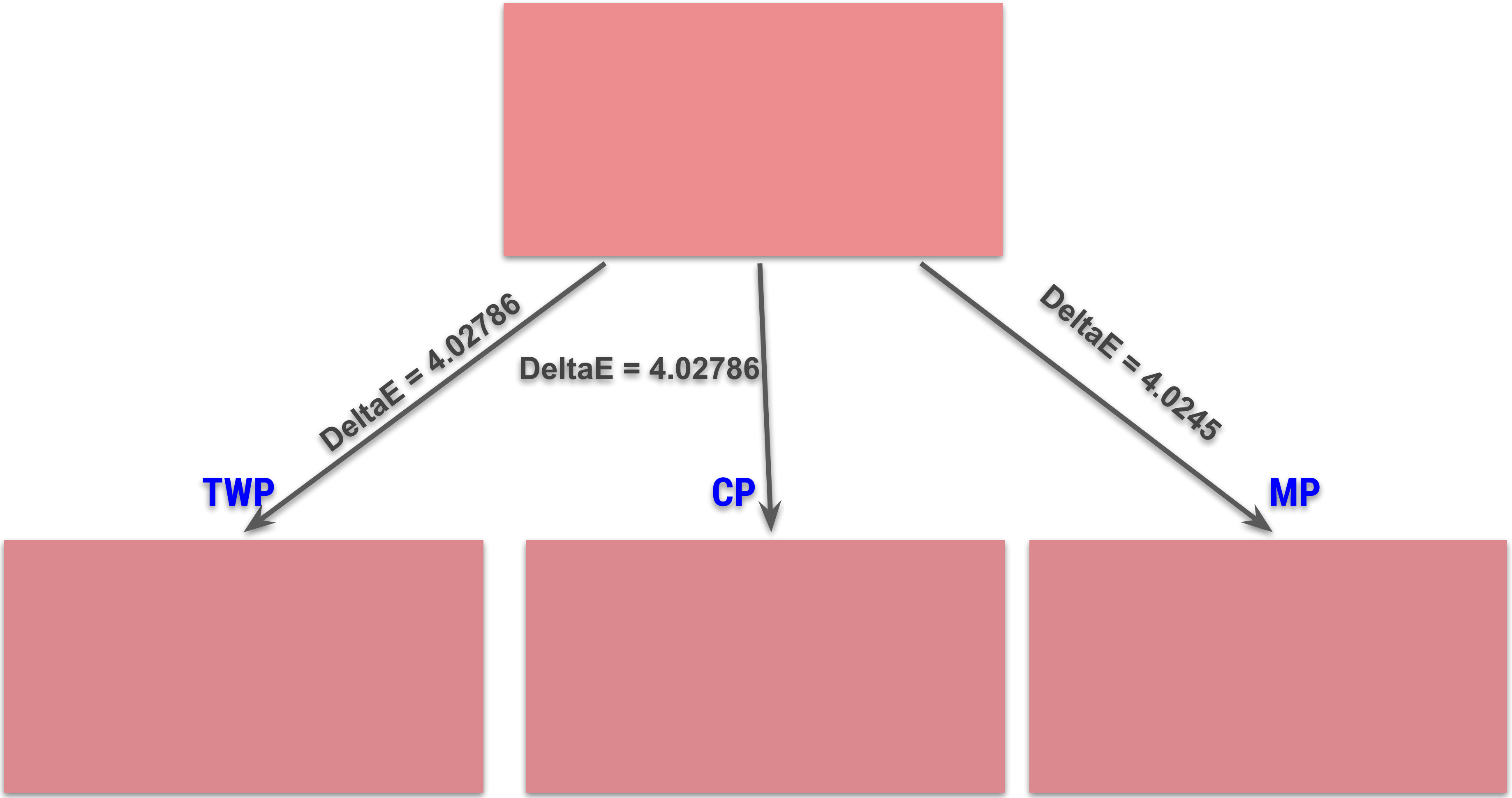
Midpoint with MP and TWP

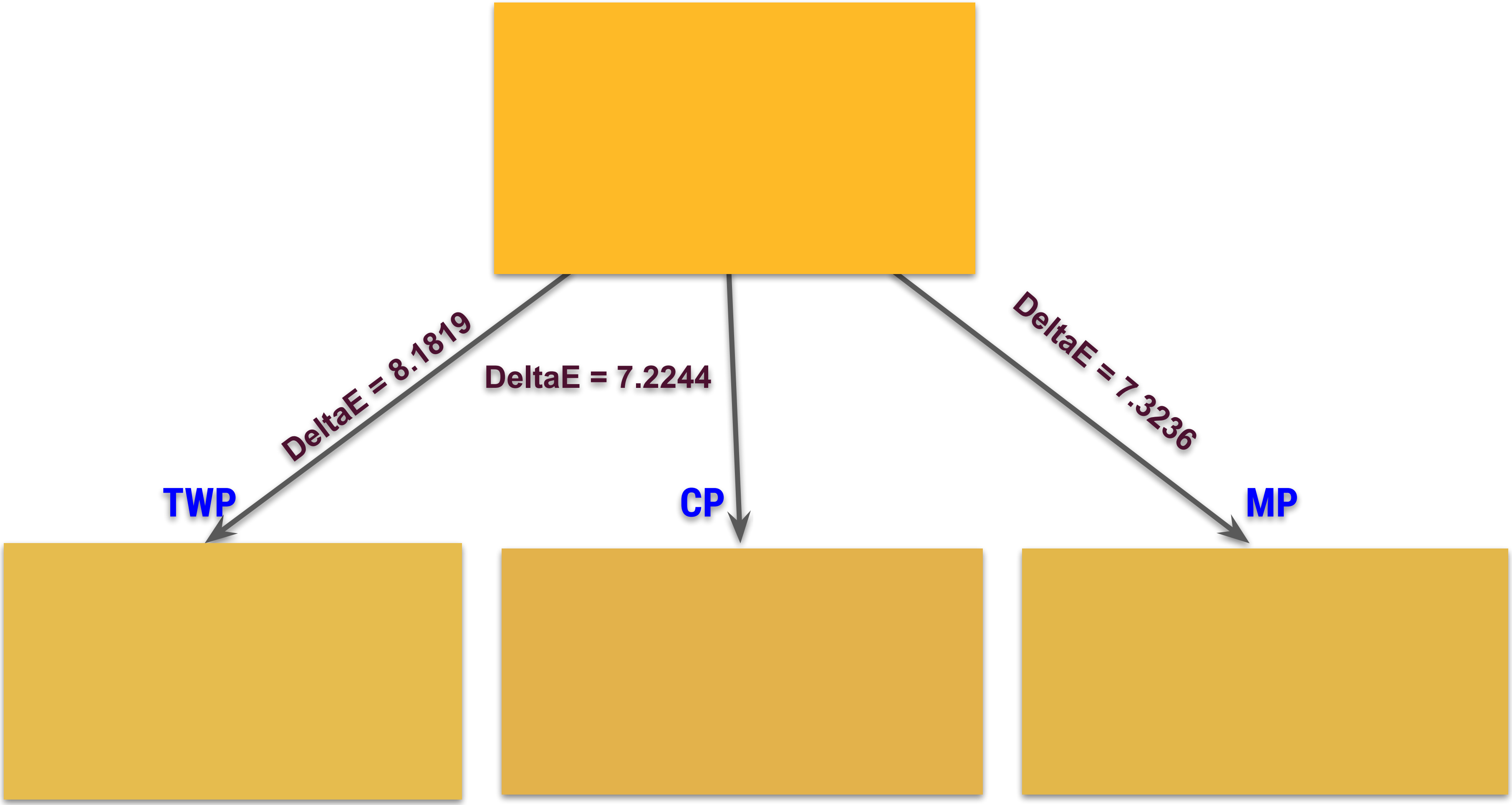
Midpoint with MP and CP





Mid-point with MP and TWP gives best result


DeltaE = 4.02786
DeltaE = 4.02786
DeltaE = 4.0245
TWP
CP
MP



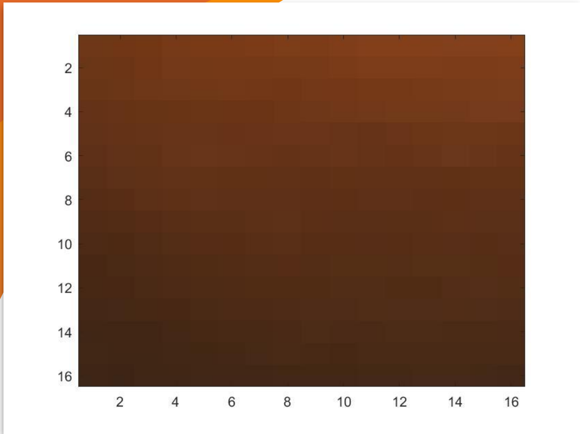
Cp -Best results , MP better than TWP

Results

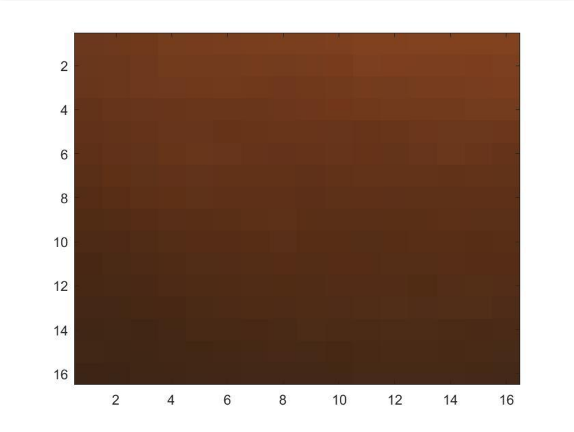
Original Image			Towards White Point				Closest Point				MidPoint				TWP_MP_MidPoint				CP_MP_MidPoint			
R	G	B	R	G	B	Delta E	R	G	B	Delta E	R	G	B	Delta E	R	G	B	Delta E	R	G	B	DeltaE
1017	747	156	920	756	308	8.181	909	714	296	7.2244	915	735	302	7.3236	918	746	305	7.6768	912	725	299	7.1928
949	566	572	878	550	568	4.027	878	550	568	4.0278	878	550	568	4.0245	878	550	568	4.0245	878	550	568	4.0245
41	153	606	171	172	511	4.446	181	129	579	4.339	176	151	545	3.7995	174	162	528	3.9458	179	140	562	3.9977
707	707	640	639	264	594	4.883	629	260	665	5.4641	634	262	630	4.8054	637	256	612	4.5165	632	259	648	5.005
85	644	95	399	608	344	13.53	394	608	232	11.6107	397	608	288	11.9938	398	608	316	12.5739	396	608	260	11.6126
1017	747	156	920	756	308	8.1819	909	714	296	7.2244	915	735	302	7.3236	918	746	305	7.6768	912	725	299	7.1928
508	326	330	508	327	329	0.22	508	327	329	0.22	508	327	329	0.2313	508	327	329	0.2313	508	327	329	0.2313
1023	0	0	844	348	192	8.686	843	342	191	8.7692	844	345	191	8.6894	844	347	192	8.6905	844	344	192	8.724

Results

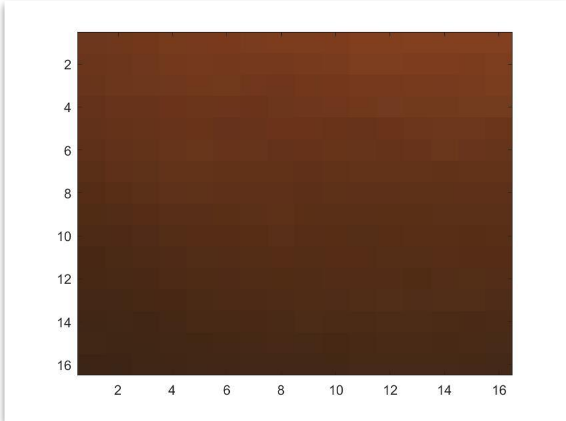
16X16 Patch



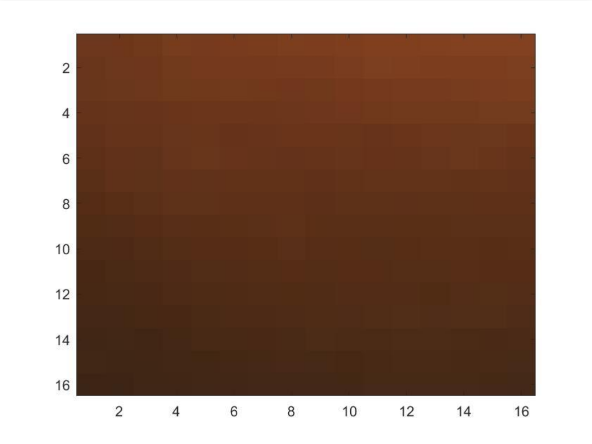
Original



TWP

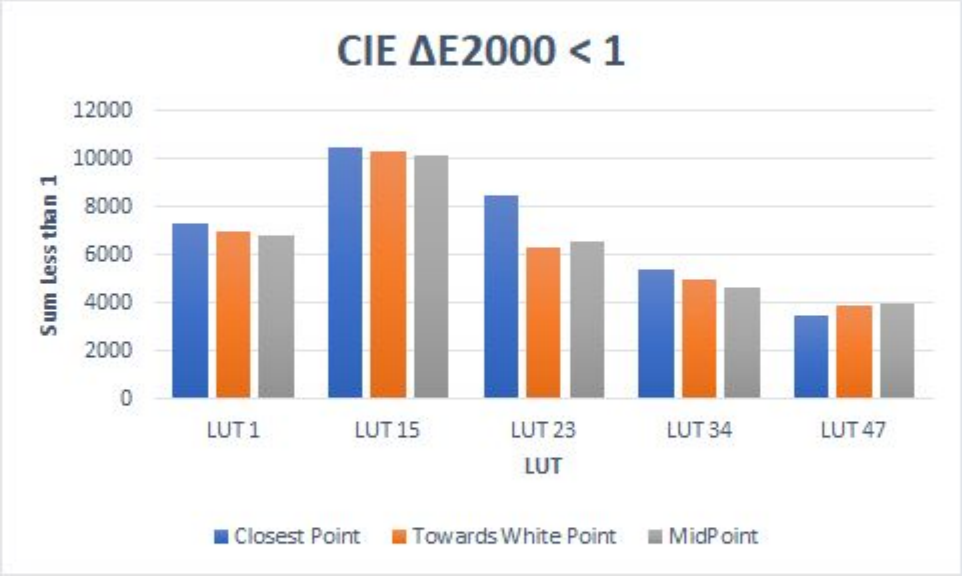


Closest Point

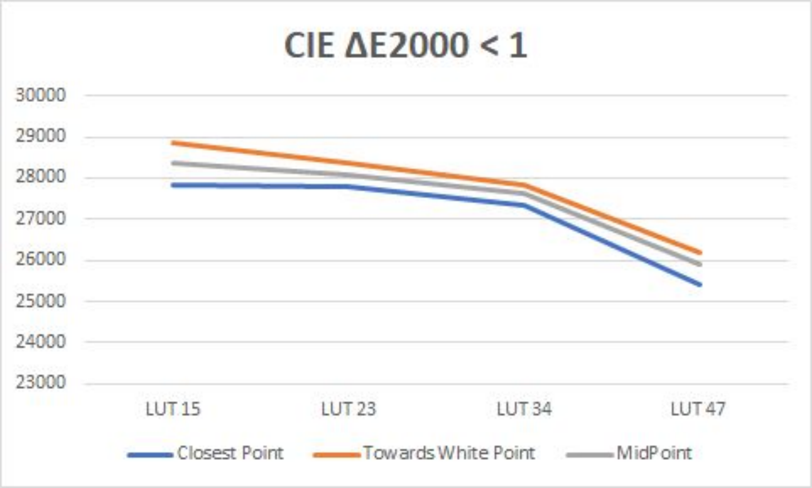


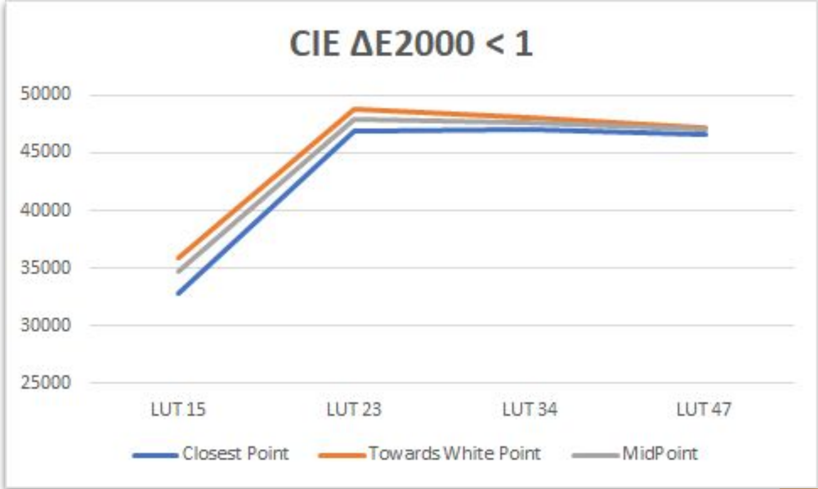
Mid Point

Comparison of Projection Method

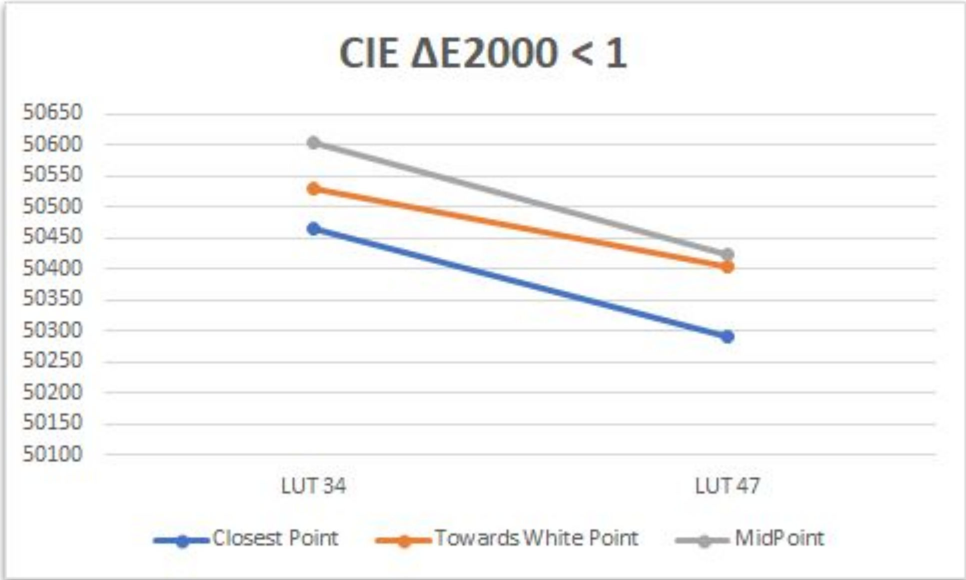


Comparison of Projection Method

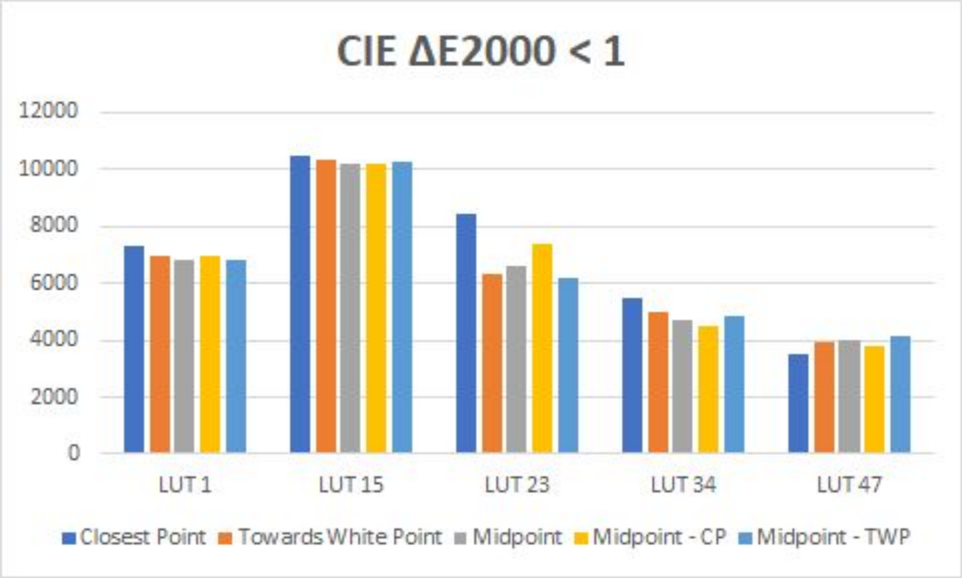




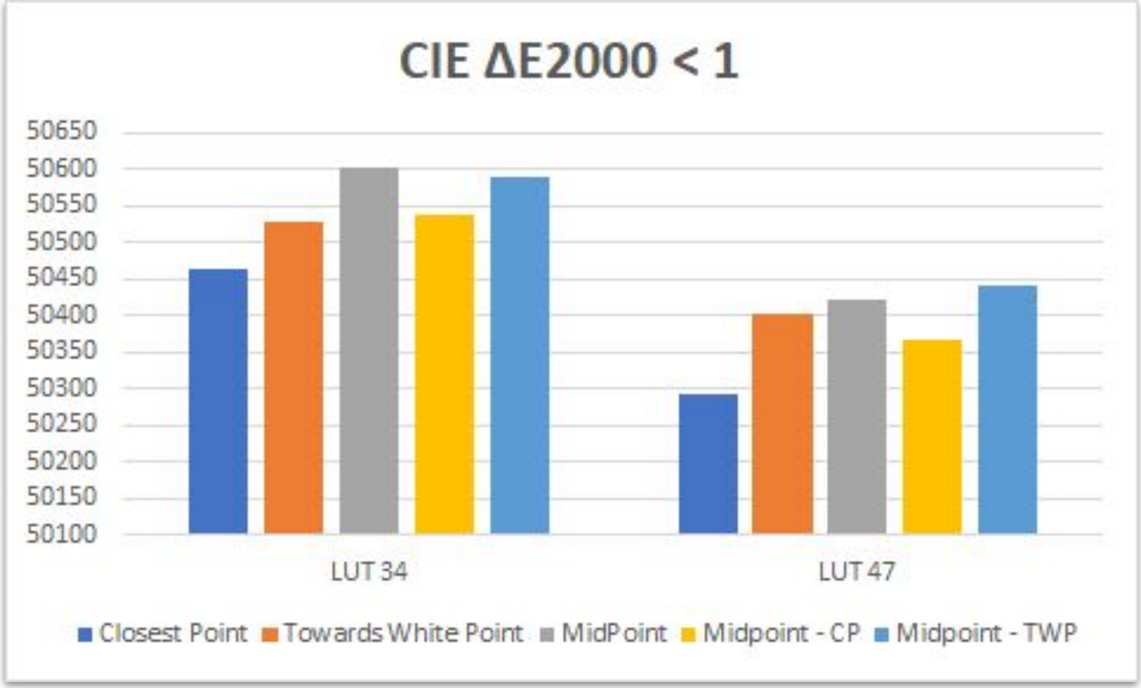
Better results with Midpoint Projection



Better results with Midpoint Projection



Better results with Midpoint - TWP Projection



7. Conclusion

Conclusion

- The proposed method of using 3 more sampling points between TWP and CP has showed that there is **no one best projection method**.

- Our study shows that for some colors Closest Point projection performs better, for some TWP and for some Mid-Points outperforms them

Orignal Image			Towards White Point				Closest Point				MidPoint				TWP_MP_MidPoint				CP_MP_MidPoint			
R	G	B	R	G	B	DeltaE	R	G	B	DeltaE	R	G	B	DeltaE	R	G	B	DeltaE	R	G	B	DeltaE
1017	747	156	920	756	308	8.1819	909	714	296	7.2244	915	735	302	7.3236	918	746	305	7.6768	912	725	299	7.1928
949	566	572	878	550	568	4.0278	878	550	568	4.0278	878	550	568	4.0245	878	550	568	4.0245	878	550	568	4.0245
41	153	606	171	172	511	4.446	181	129	579	4.339	176	151	545	3.7995	174	162	528	3.9458	179	140	562	3.9977
707	707	640	639	264	594	4.8832	629	260	665	5.4641	634	262	630	4.8054	637	256	612	4.5165	632	259	648	5.005

Conclusion

- The results from trials indicate that as error increases, Mid-Point projection tends to perform better than Towards White Point and Closest Point.

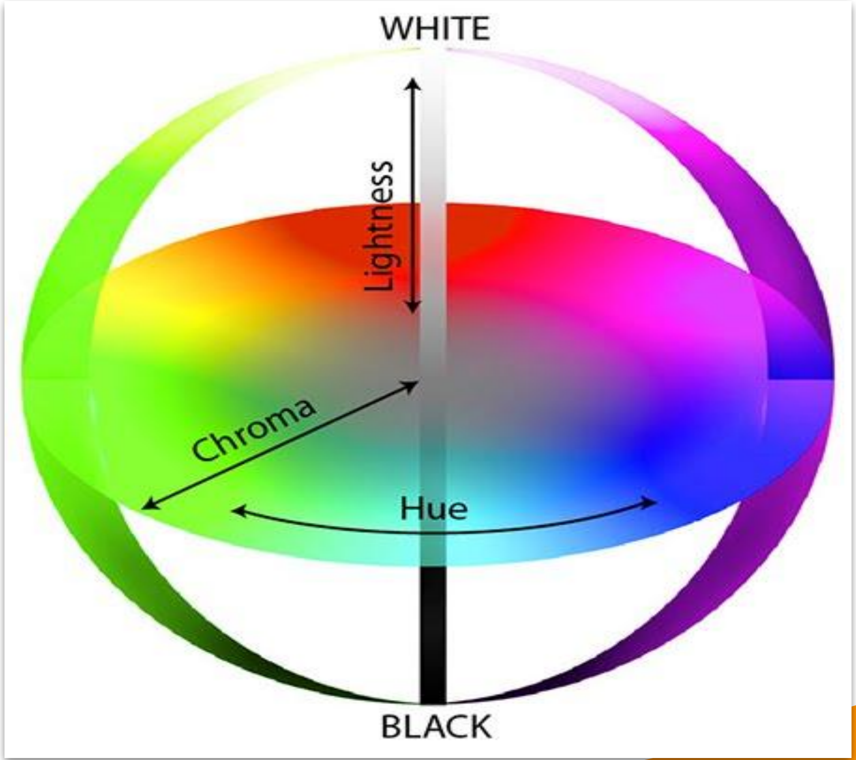
- A major trend is the Mid-Point towards TWP performs better as compared to all other approaches.

- Though the size of LUT makes our method computationally infeasible with the currently commonly available computational resources. Hence our method is not suitable currently for videos.

- Although with categorizing color codes with B-values, the amount of computation required can be decreased and the time required can be reduced.

FUTURE SCOPE

1. Decreasing the LUT size
2. Usage of LCH space for HUE correction



Thanks!

Does anyone have any questions?