Content-Aware Automated Parameter Tuning for Approximate Color Transforms

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Abstract

We present a content-aware, computationally-efficient method for calculating a lower bound for the optimal transform parameters for approximate color transforms. We conducted a user study with 62 participants and 6,400 image pair comparisons to derive the proposed solution. We can predict the parameter lower bound, robustly, with a 1.6% mean squared error by using the user study results and simple image-color-based heuristics. We show that these heuristics are highly correlated with the perceptual score and that our model generalizes beyond the data from the user study. The user study results also show that the color transform is able to achieve up to 50% power saving with most users reporting negligible visual impairment.

① Idea

- Conduct a user study to *quantify the perceptual quality* of transformed images.
- Extract image features that are correlated with an image's *sensitivity to the transform parameters*.
- Learn a model from the features to *predict optimal parameters* given the image and the required perceptual quality score.

② Formulation of the approximate color transform

OLED display power can be modelled as a sum of quadratic functions with parameters $[\alpha, \beta, \gamma]$ for each channel [1]. The power of an image x, with $x^c[i]$ the channel c intensity of pixel i, is given by,

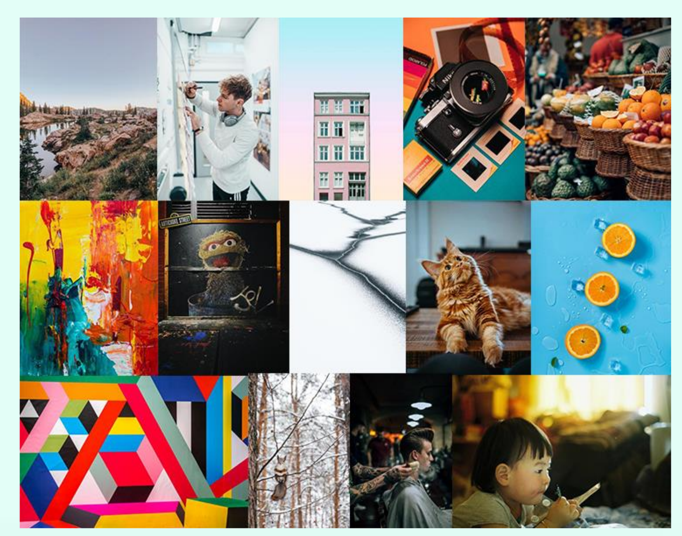
$$\mathrm{P(x)} = \sum_{C \in \{r,g,b\}} \sum_{i=1}^{N} \frac{1}{2} \alpha_c x^c[i]^2 + \beta_c x^c[i] + \gamma_c$$

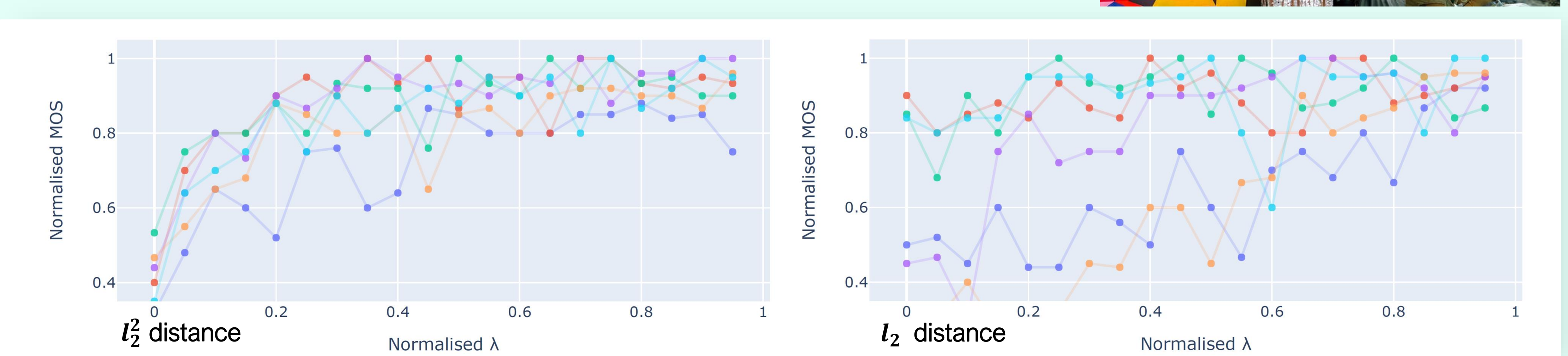
An *energy optimised image* y is found through constrained minimisation, with least-squares (l_2^2) and Euclidean (l_2) distances as $\phi(y-x)$, and the *scalar, λ, controlling the aggressiveness of the approximation*.

$$\min_{y} P(y) + \lambda \phi(y-x)$$

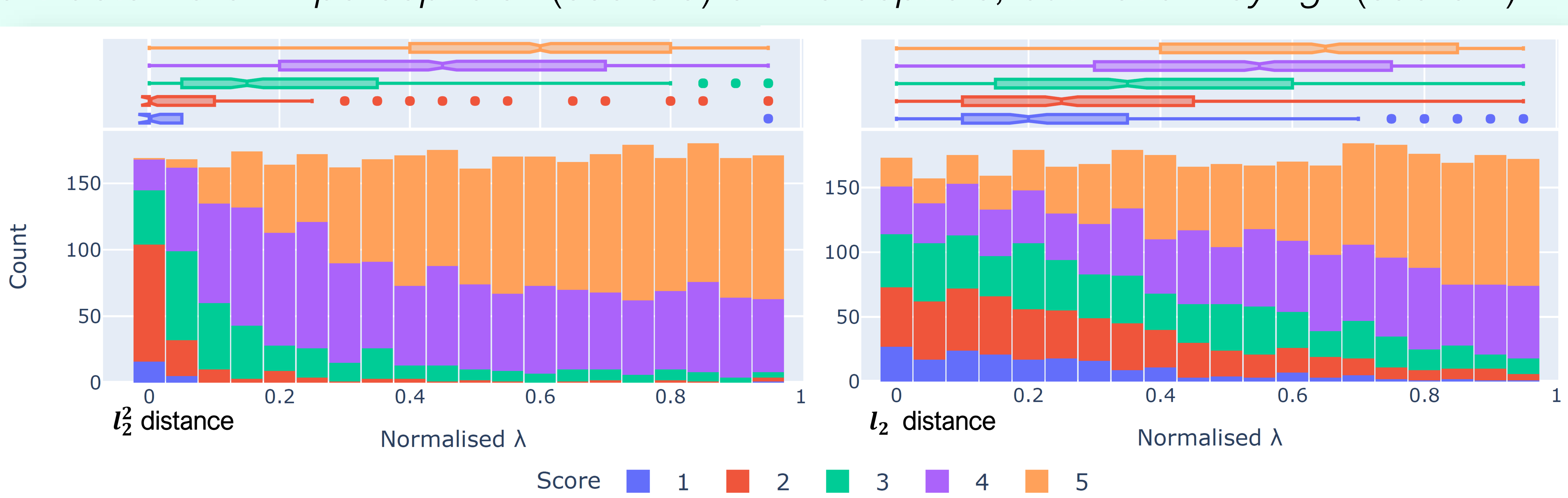
③ User Study

Mean opinion score (MOS) variation against λ, when using the l_2^2 distance (below left) show a consistent trend shape between the images, contrary to the scores with the l_2 distance (below right).





We can achieve **~50% power saving**, ($\lambda = 0.1$) with most observers reporting that the artifacts were *"Imperceptible"* (score 5) or *"Perceptible, but not annoying"* (score 4).



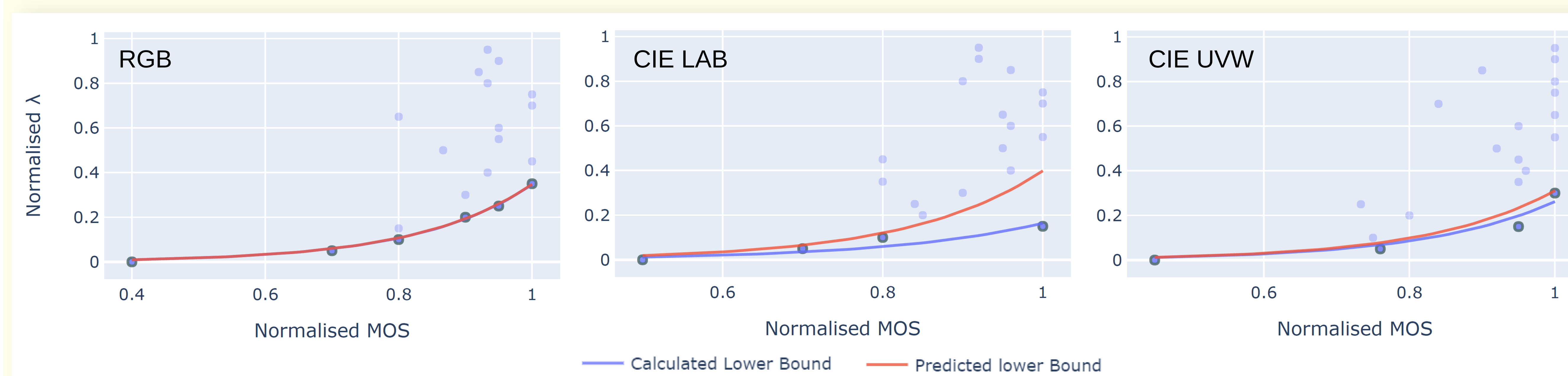
④ Parameter Lower Bound Prediction

- The minimum λ given MOS follows an exponential shape.
- We found that mean luminance, and standard deviation of the luminance, saturation, and hue across the image were correlated with the parameter k with Pearson and Spearman rank **correlation coefficients up to 0.7** (p<0.01).
- We can predict the lower bound shape from the 4 heuristic values, **down to a 7% error** (5-fold cross-validation average, see table right).
- The **error reduces to 1.6%**, with leave-one-out training.
- Our model is also **robust against outliers**, showing it has generalised well (see middle figure below).

$$\lambda_{LB}(s) = \frac{e^{ks} - 1}{1000}$$

Color Space	Model	MSE	Variance	% error
RGB	Linear	0.74988	0.36193	38.325
	Cubic	0.57005	0.19253	29.134
	SVM	**0.29892**	**0.07820**	**15.277**
CIE LAB	**Linear**	**0.14359**	**0.00469**	**7.114**
	Cubic	1.82583	4.45206	90.457
	SVM	0.17525	0.01067	8.6824
CIE UVW	**Linear**	**0.18351**	**0.01352**	**9.955**
	Cubic	0.36907	0.06915	20.020
	SVM	0.28552	0.01677	15.488

Color Space	Model	MSE	% error
RGB	SVM	0.08008	4.091
CIE LAB	SVM	0.17532	8.686
CIE UVW	SVM	0.02951	1.601



Contributions:
1. A method for automated, content-aware, parameter selection for approximate color transforms.
2. A user study of the effect of small color approximations on perceptual quality of images with more than 6000 perceptual quality scores from 62 participants.

References: [1] Phillip Stanley-Marbell, Virginia Estellers, and Martin Rinard. 2016. Crayon: Saving Power through Shape and Color Approximation on next-Generation Displays. In Proceedings of the Eleventh European Conference on Computer Systems (London, United Kingdom) (EuroSys '16). Association for Computing Machinery, New York, NY, USA, Article 11, 17 pages.

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