



ColorfulCurves: Palette-Aware Lightness Control and Color Editing via Sparse Optimization

Cheng-Kang Ted Chao

George Mason University

Jason Klein

Cornell University

Jianchao Tan

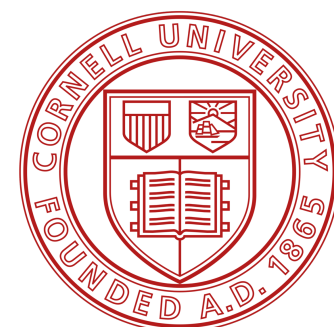
Kuaishou Technology

Jose Echevarria

Adobe Research

Yotam Gingold

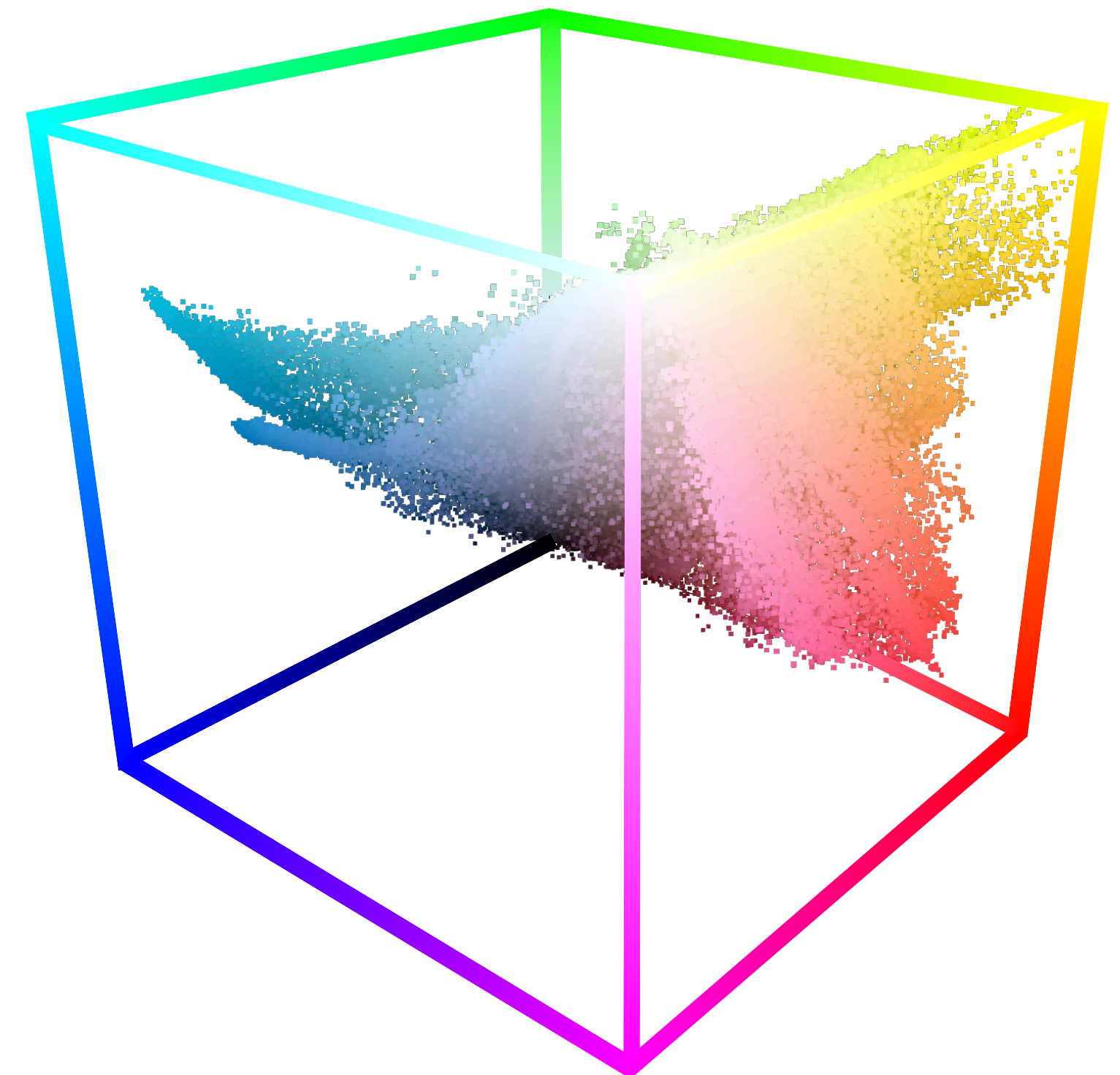
George Mason University



Palette-based editing

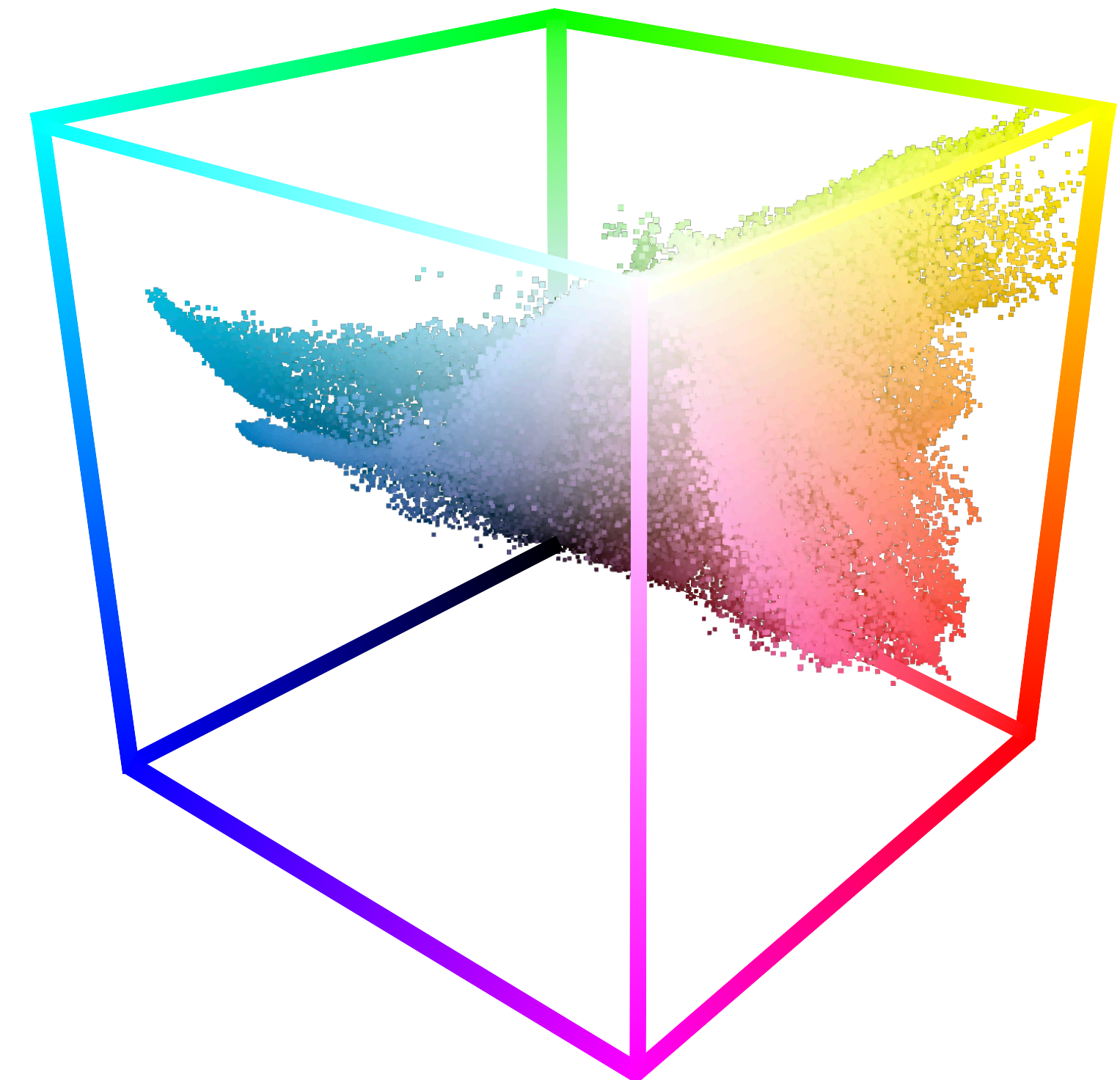


Palette-based editing



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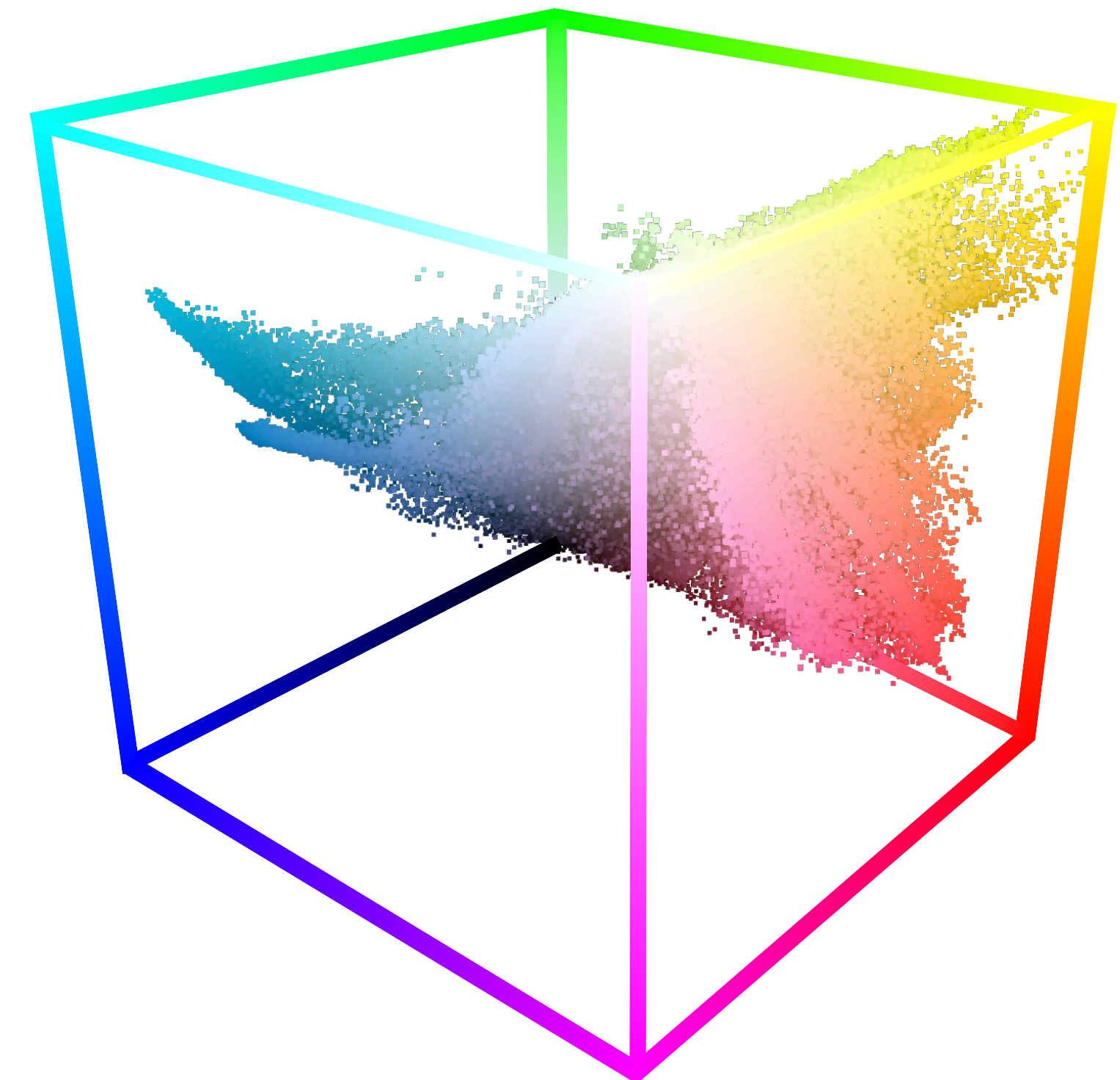
Clustering-based: [Chang et al. 2015; Nguyen et al. 2017; Zhang et al. 2017]



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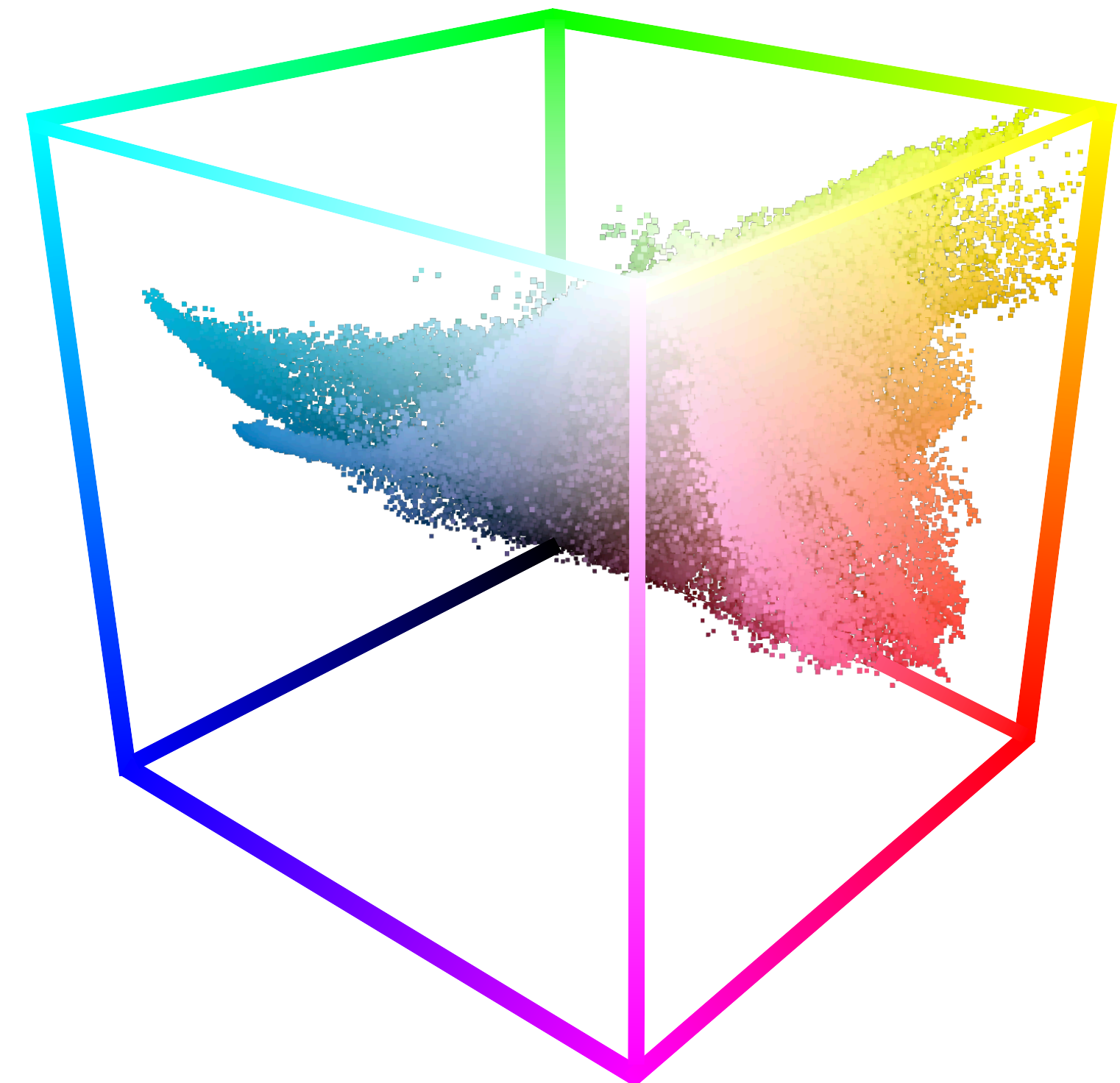
Palette-based editing



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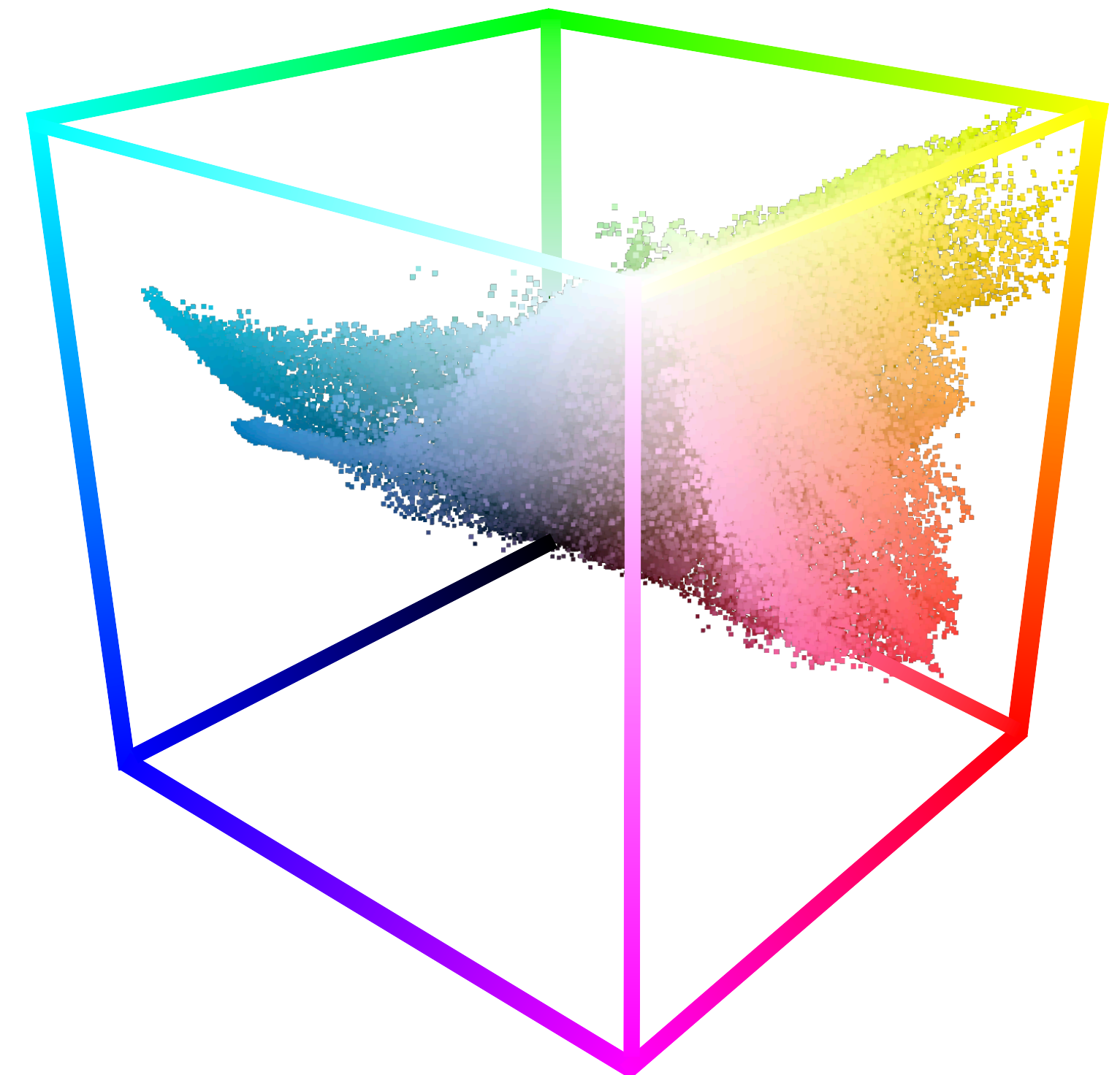
Histogram: [Morse et al. 2007]

Data-driven: [Lin & Hanrahan 2013; O'Donovan et al. 2011]



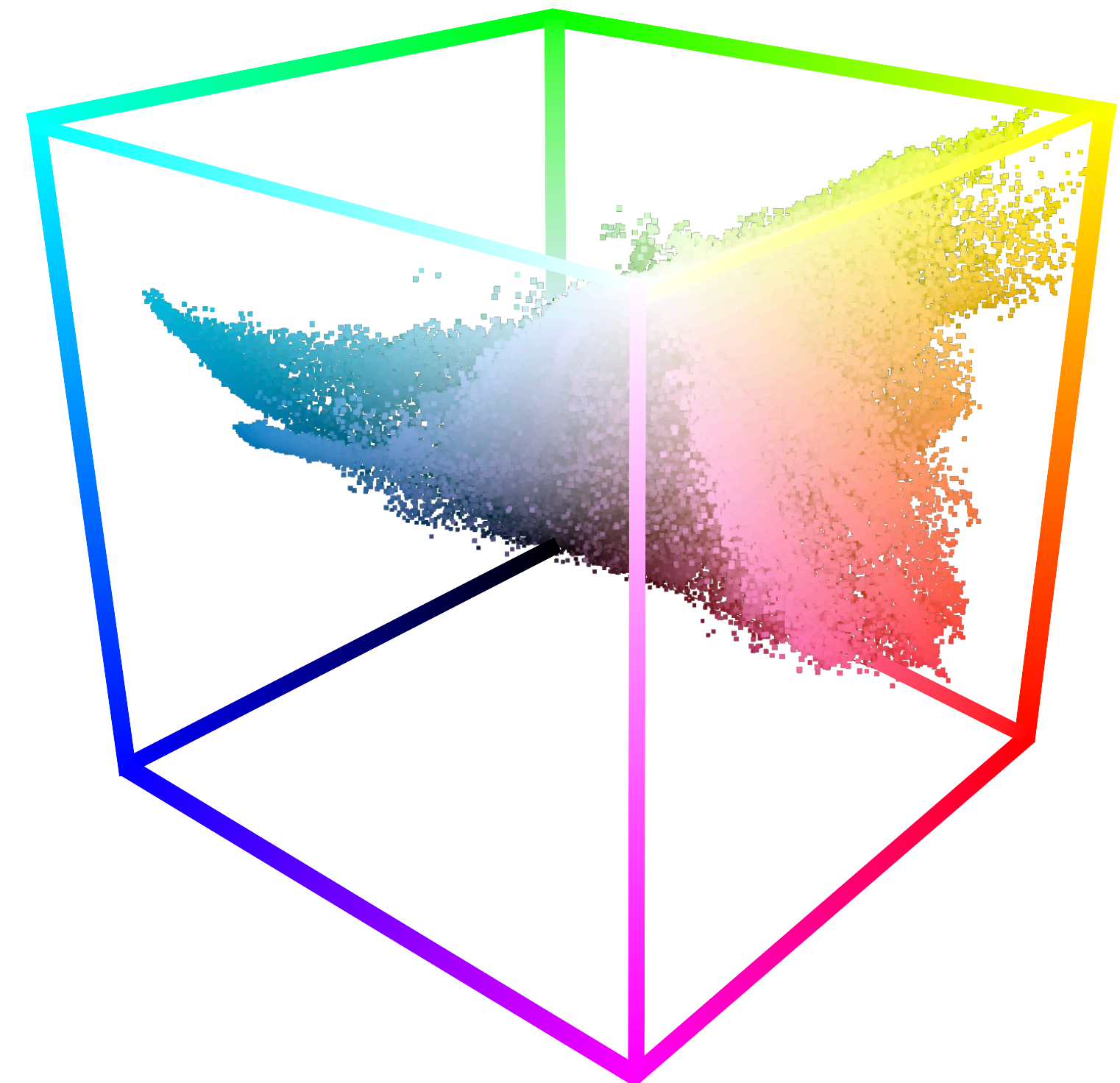
Geometric palette-based editing

Geometric approach: [Tan et al. 2016;
Tan et al. 2018; Wang et al. 2019]

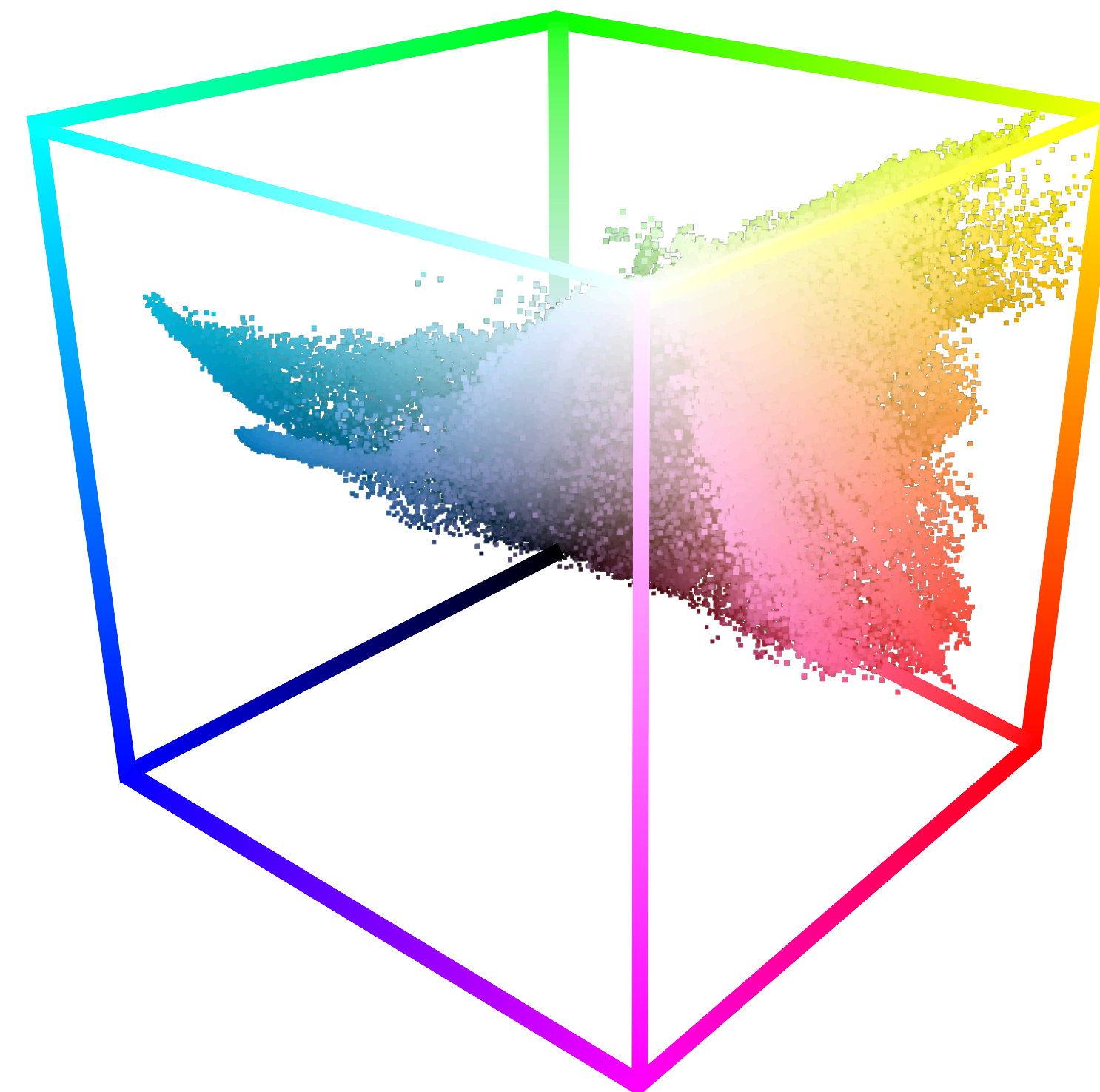


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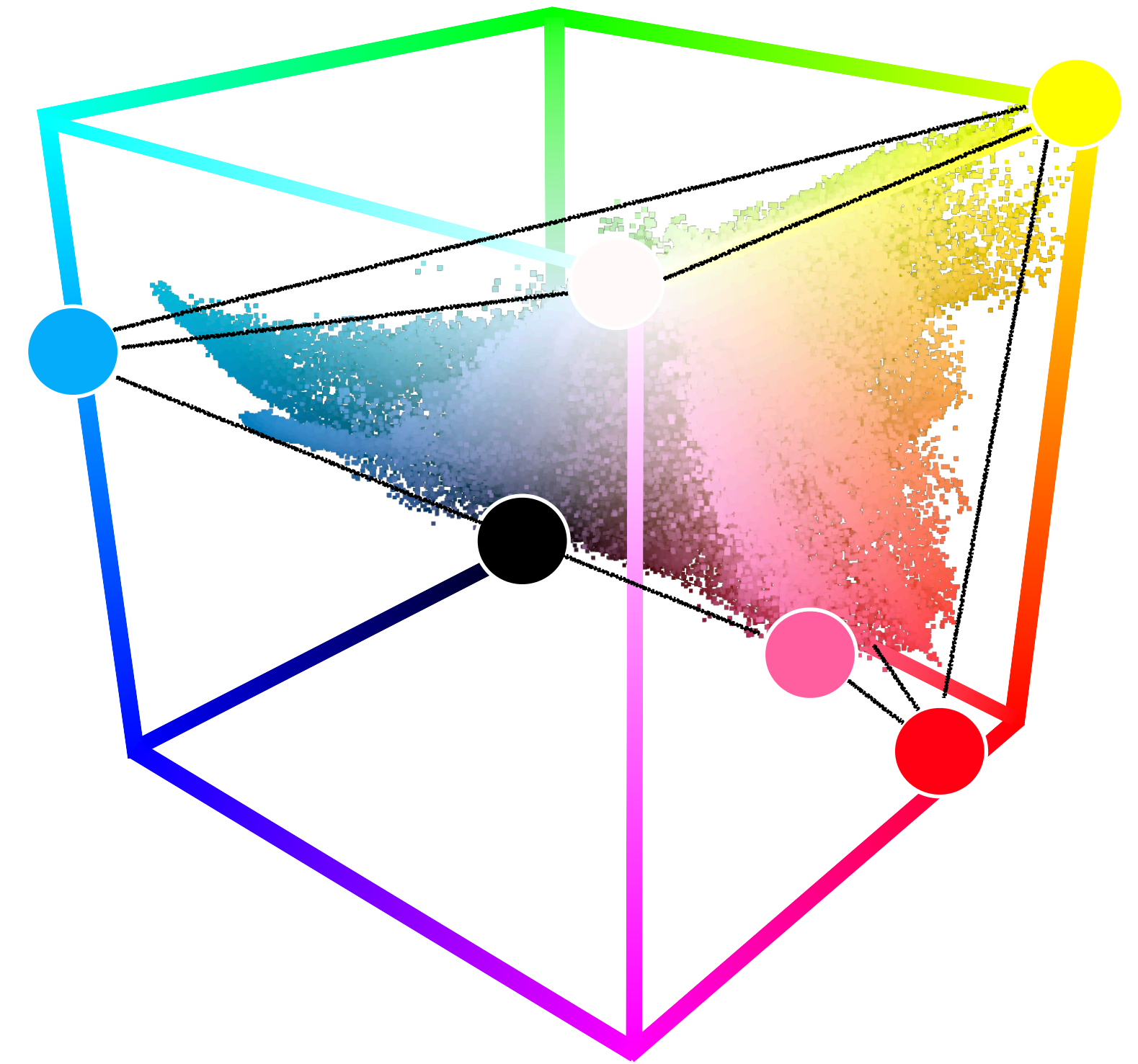
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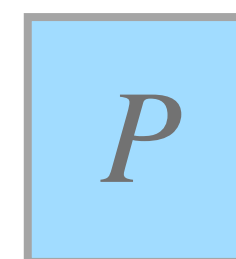
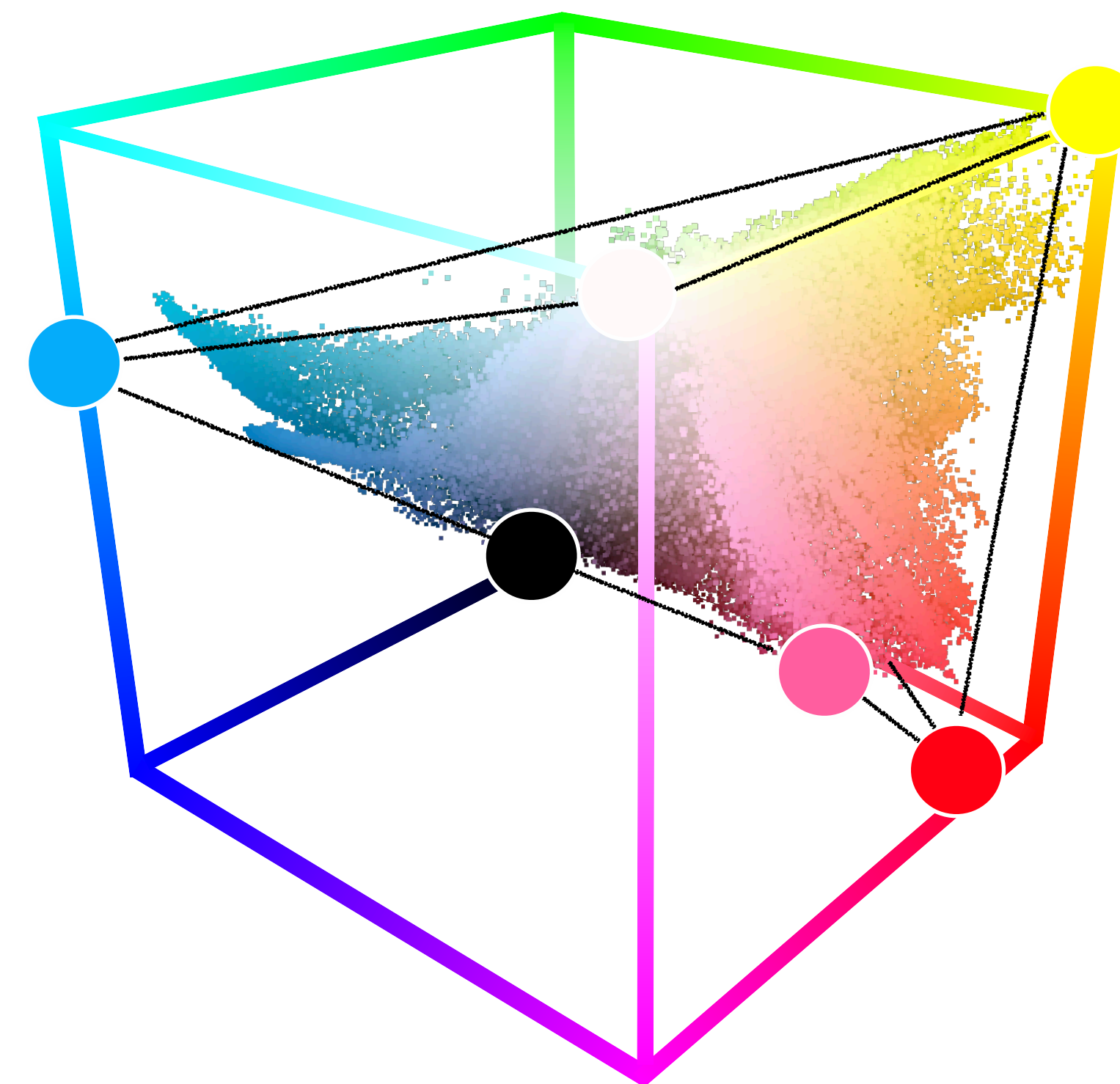
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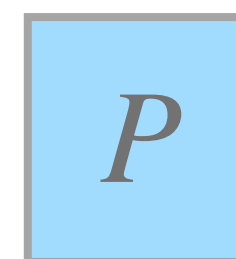
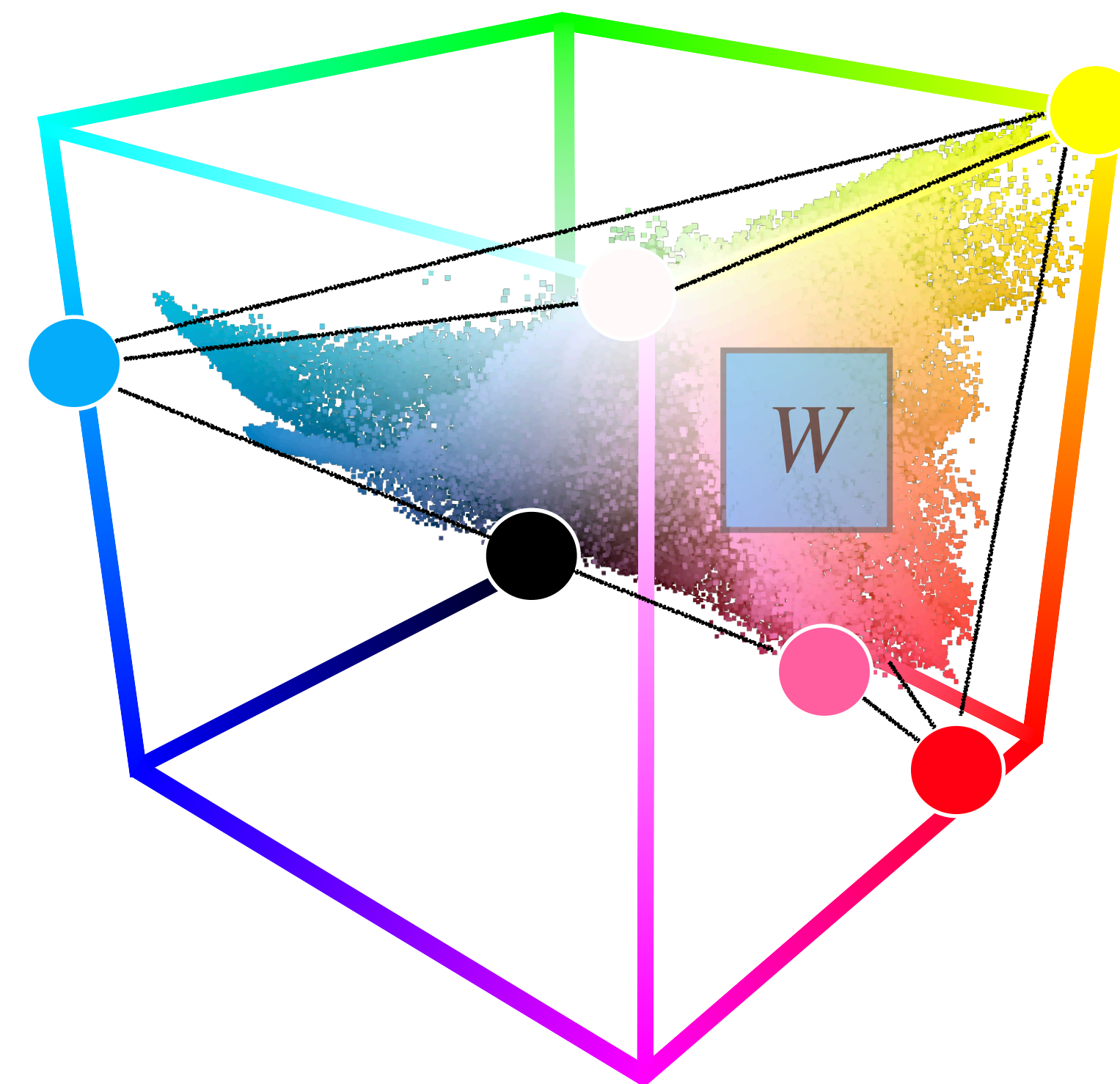
Geometric palette-based editing



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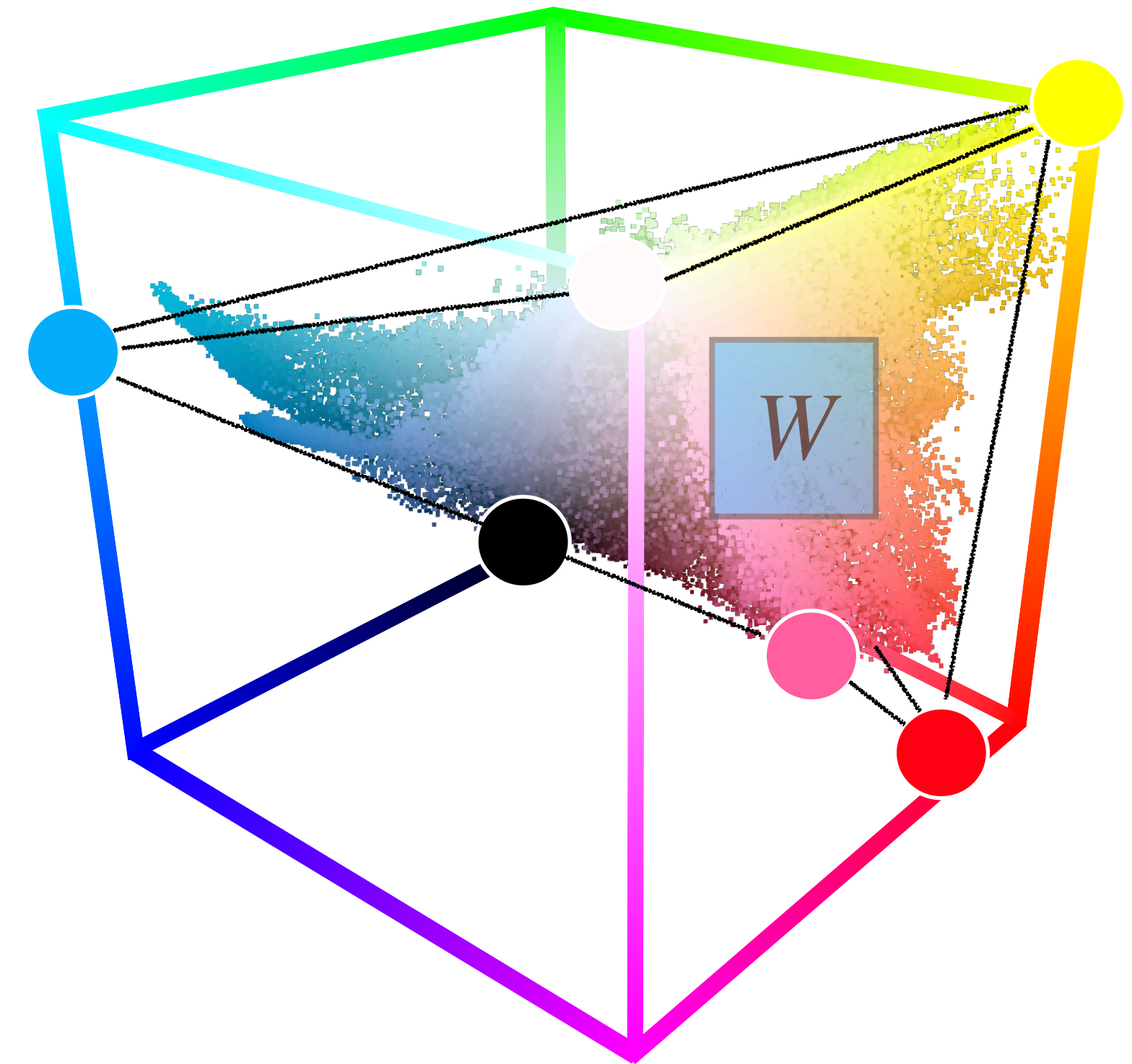


Geometric palette-based editing



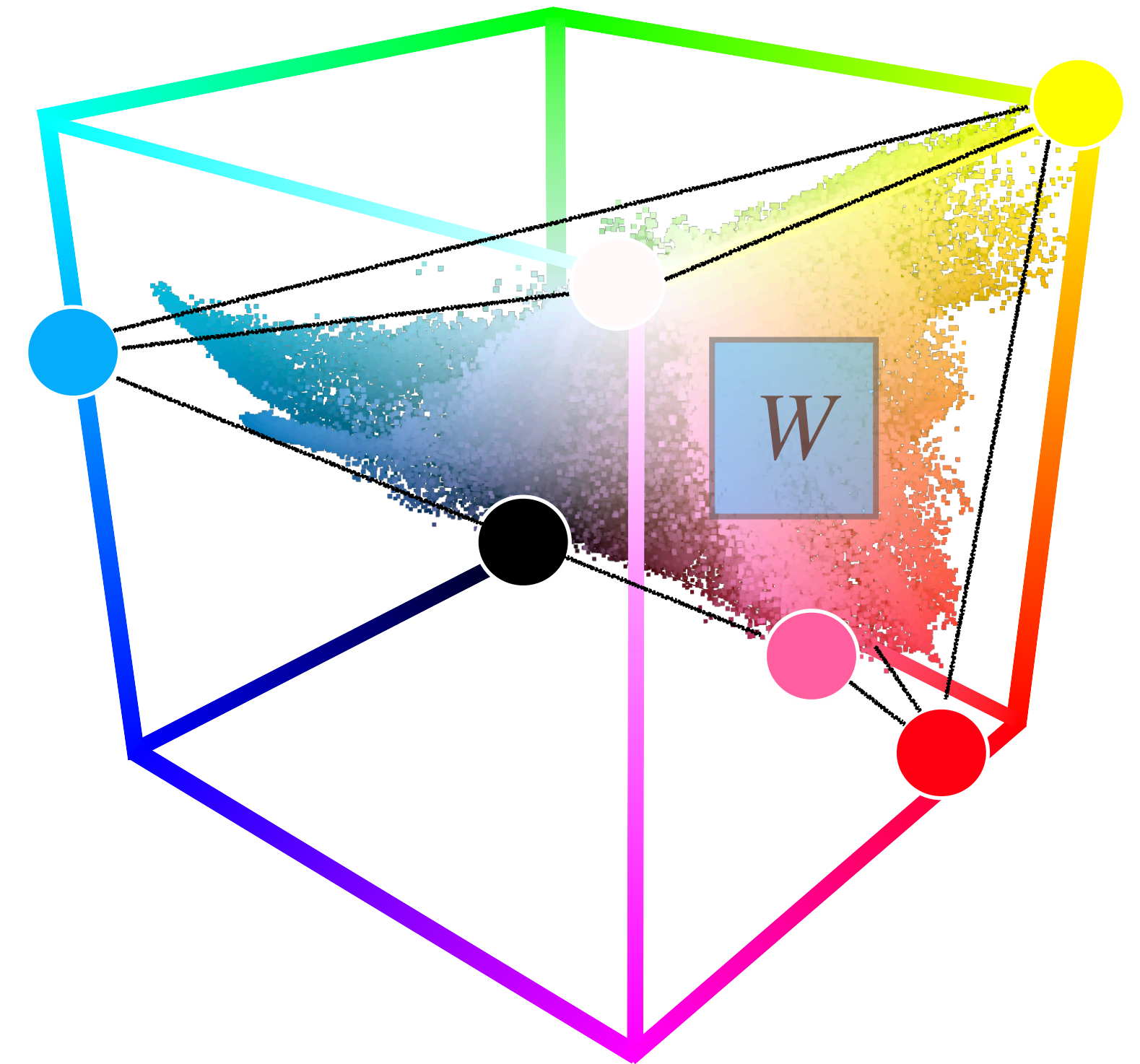
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$$I = W \cdot P$$



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P



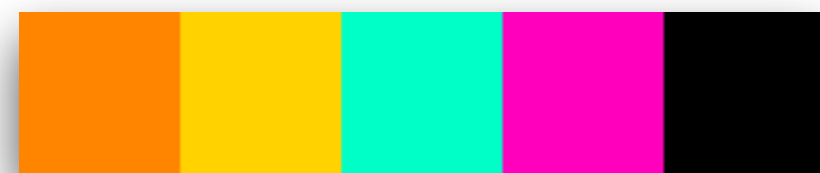
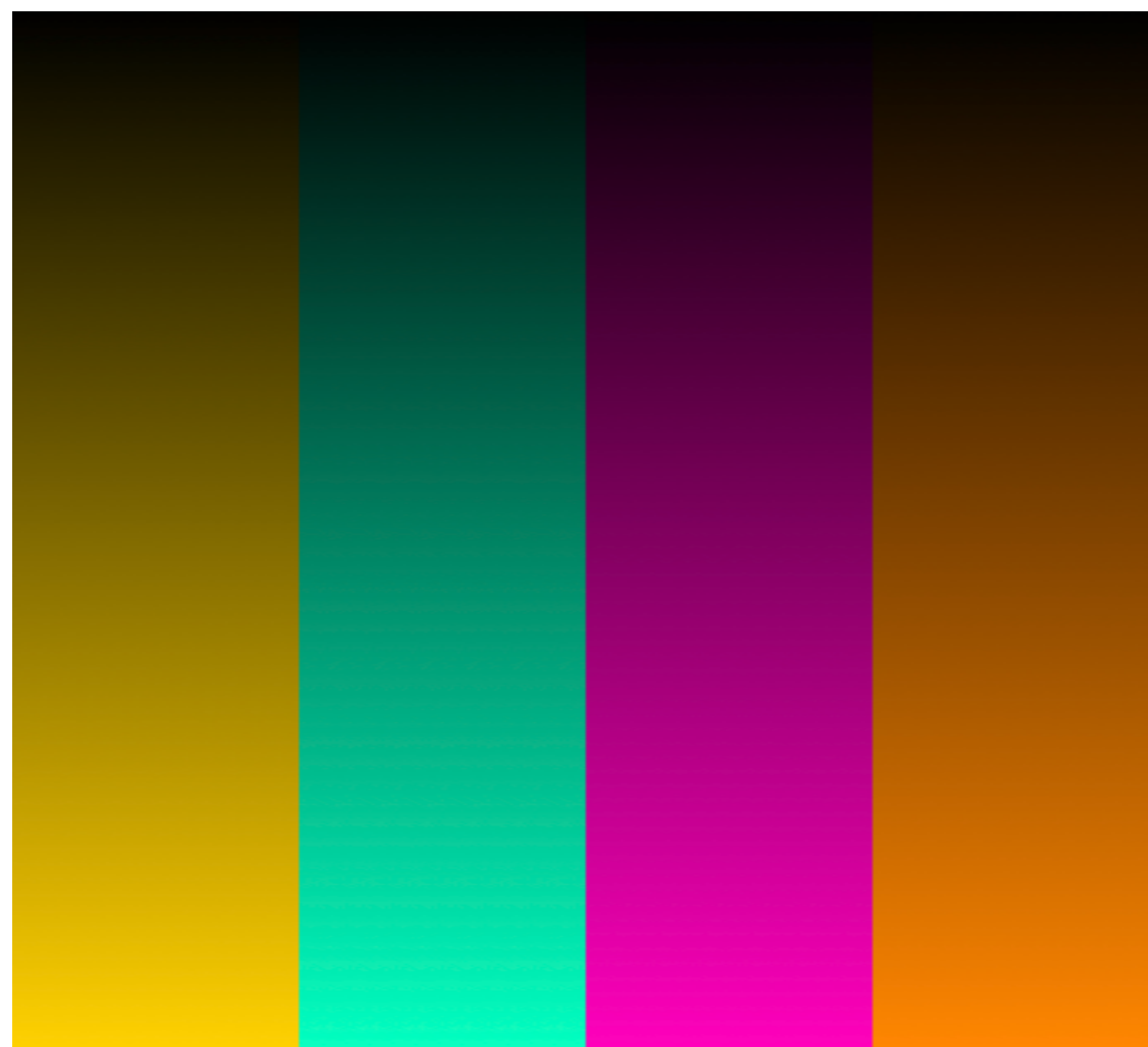
Lightness is hard to control

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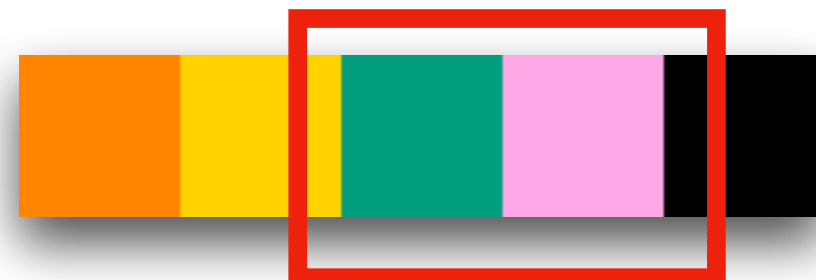
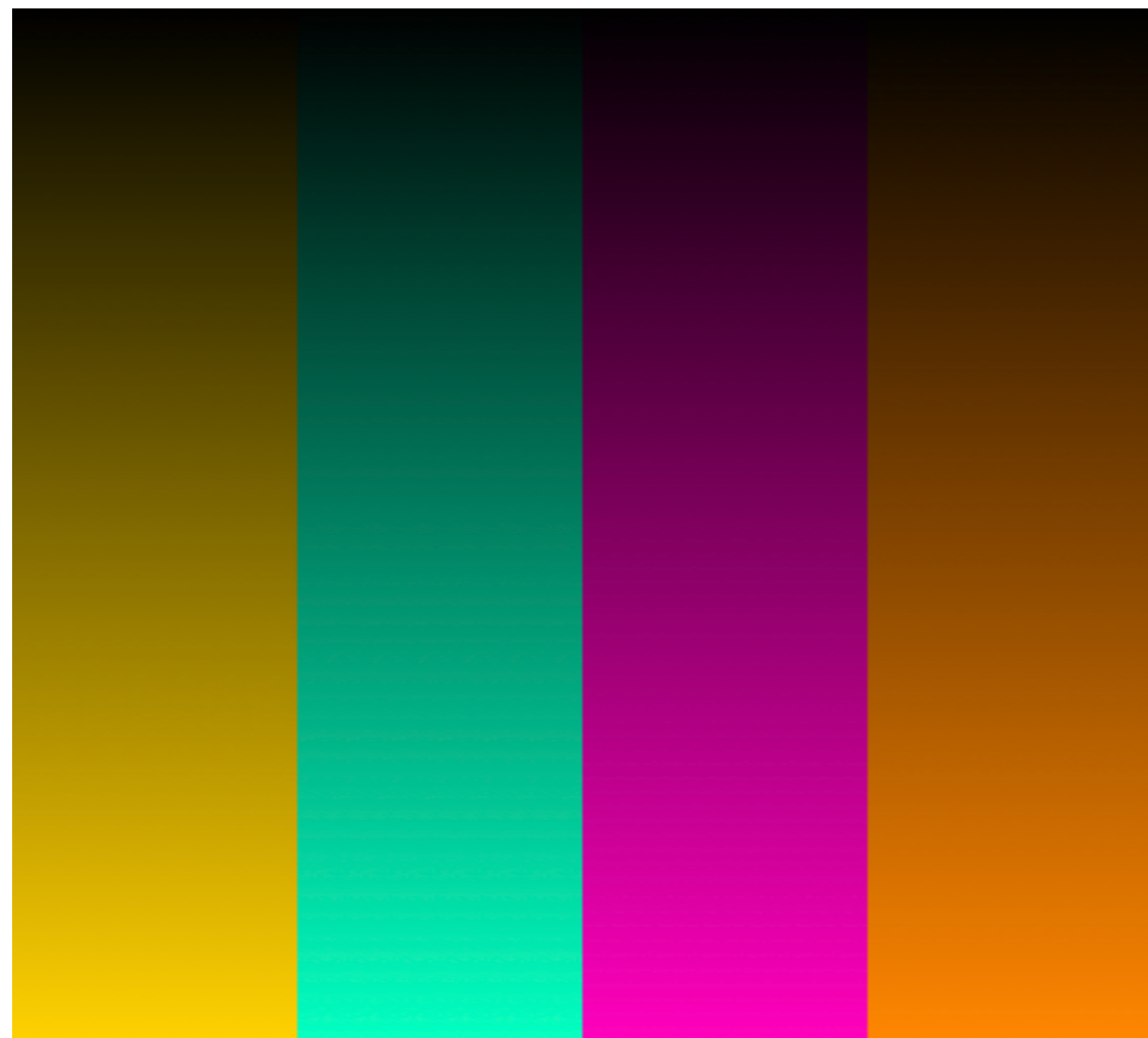
Input



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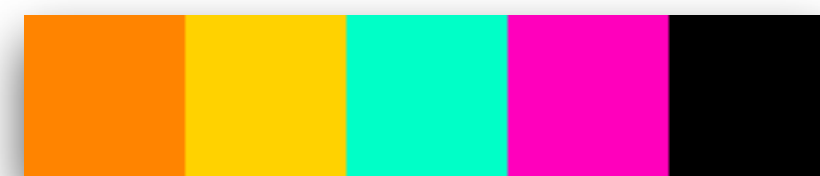
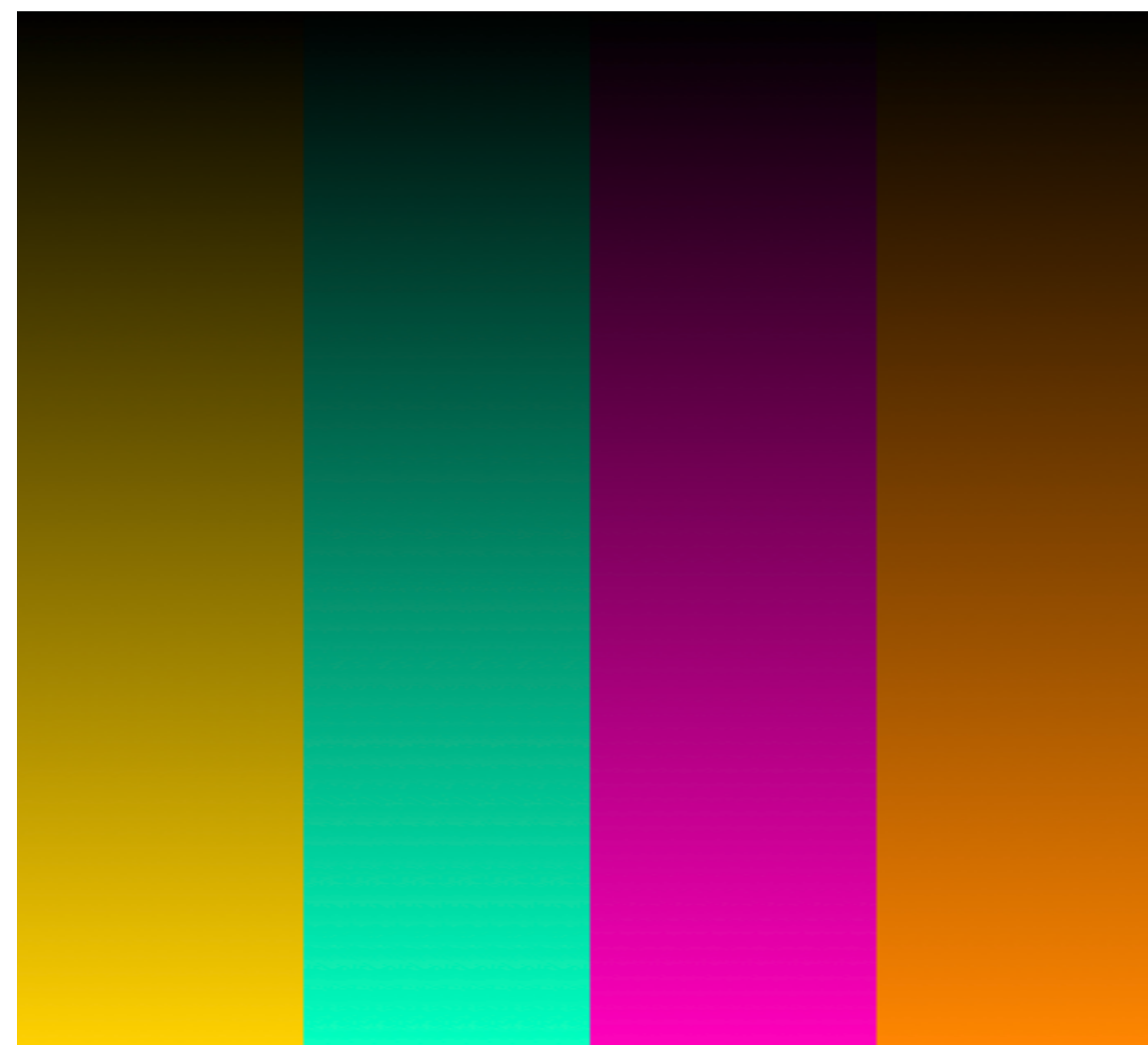
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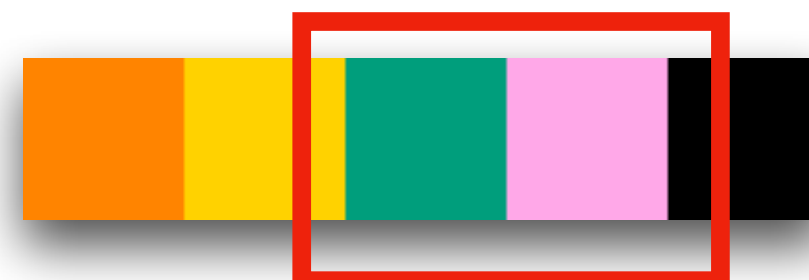
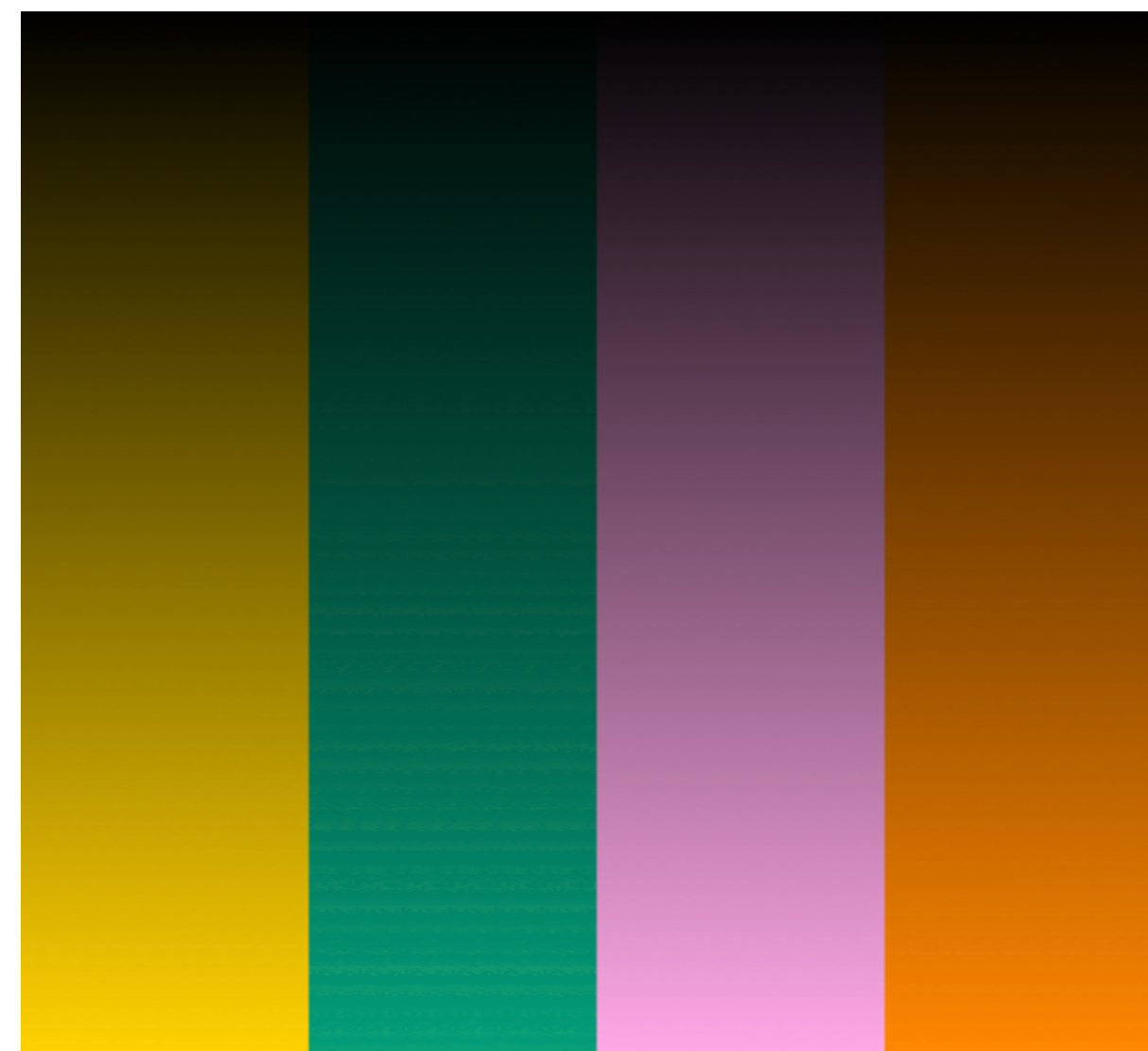
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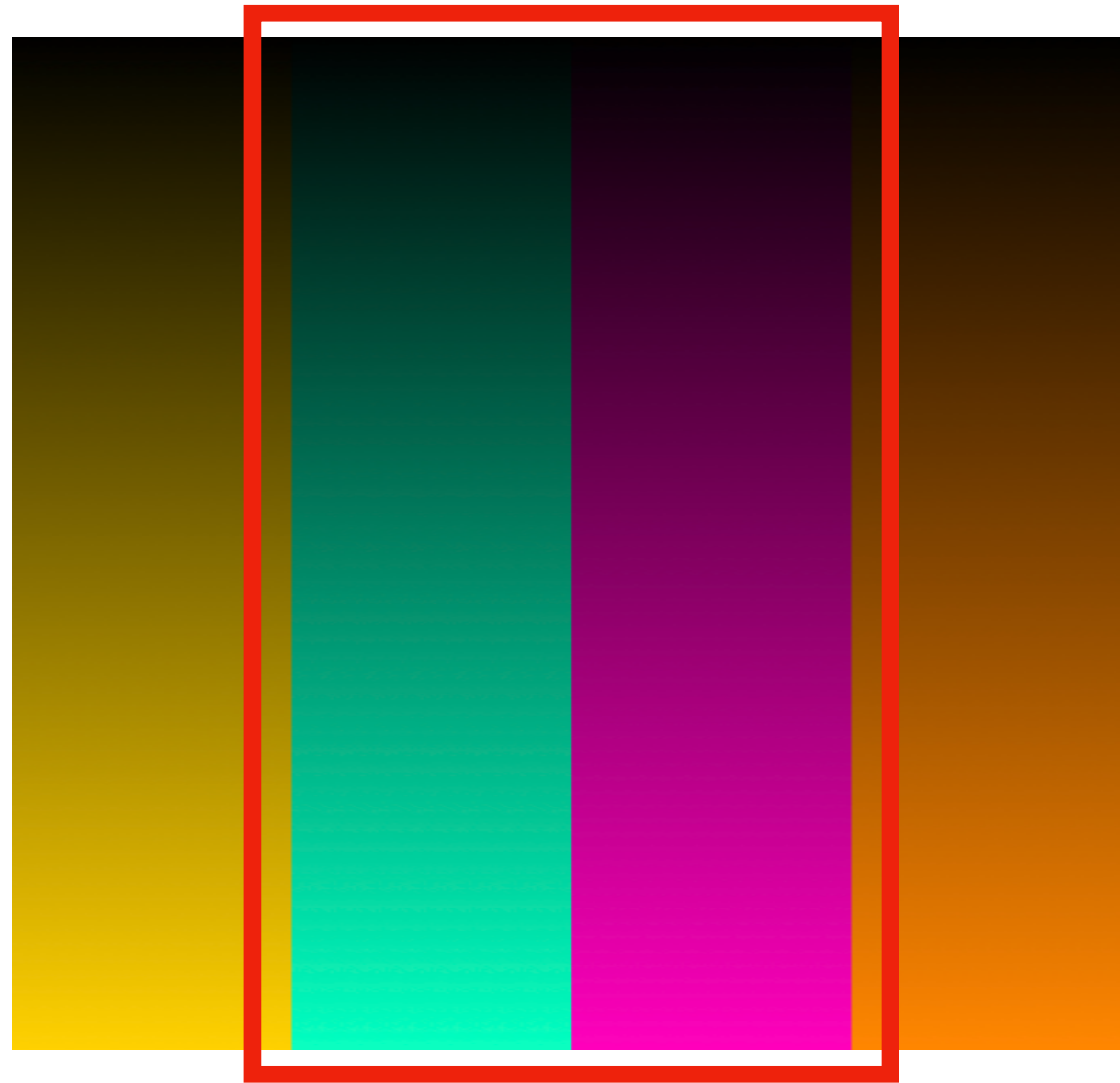
[Tan et al. 2018]



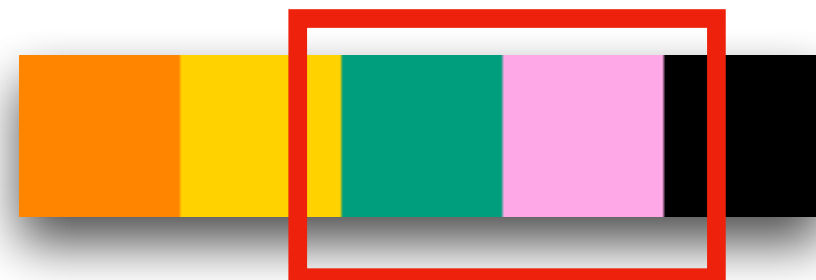
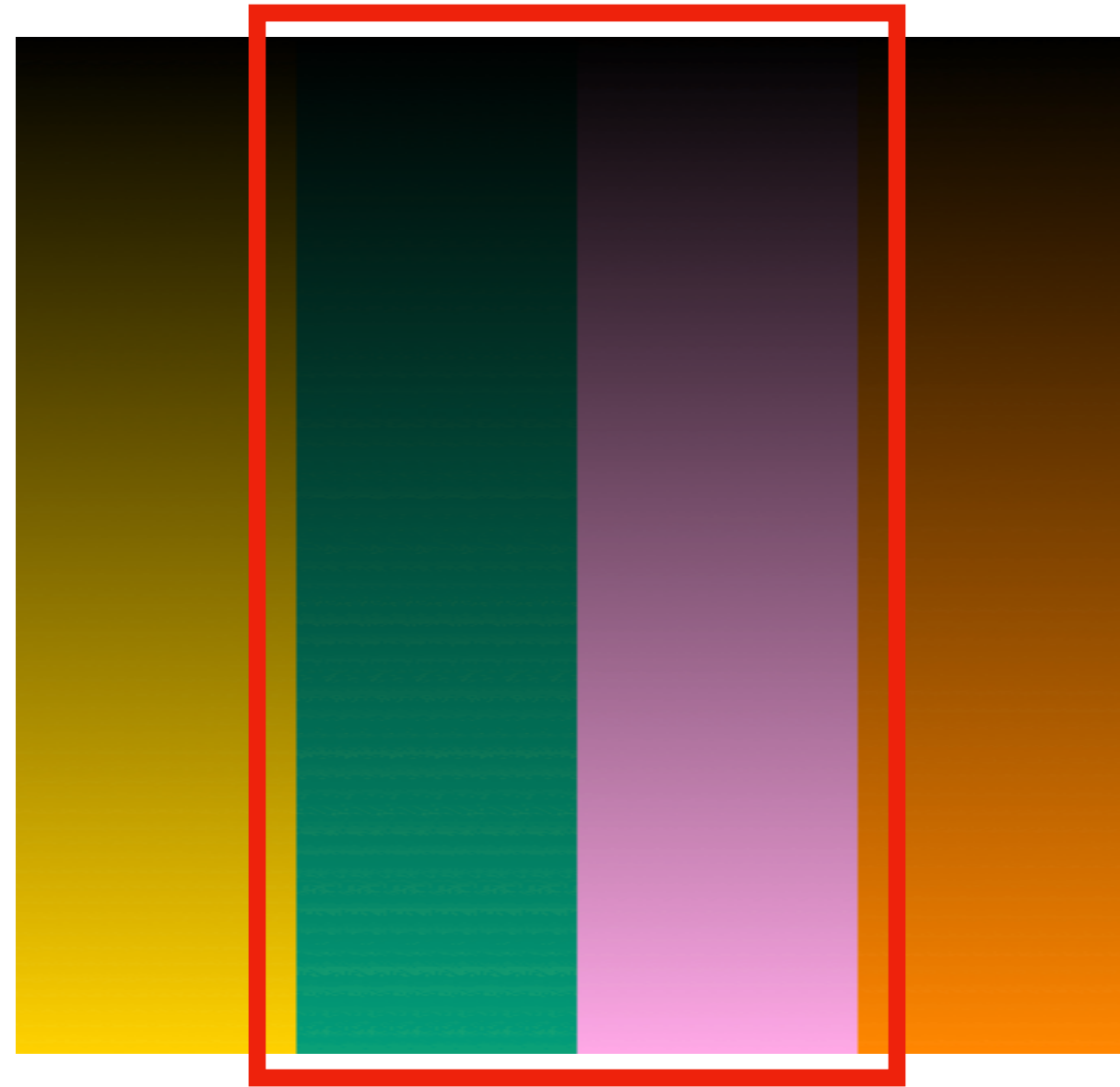
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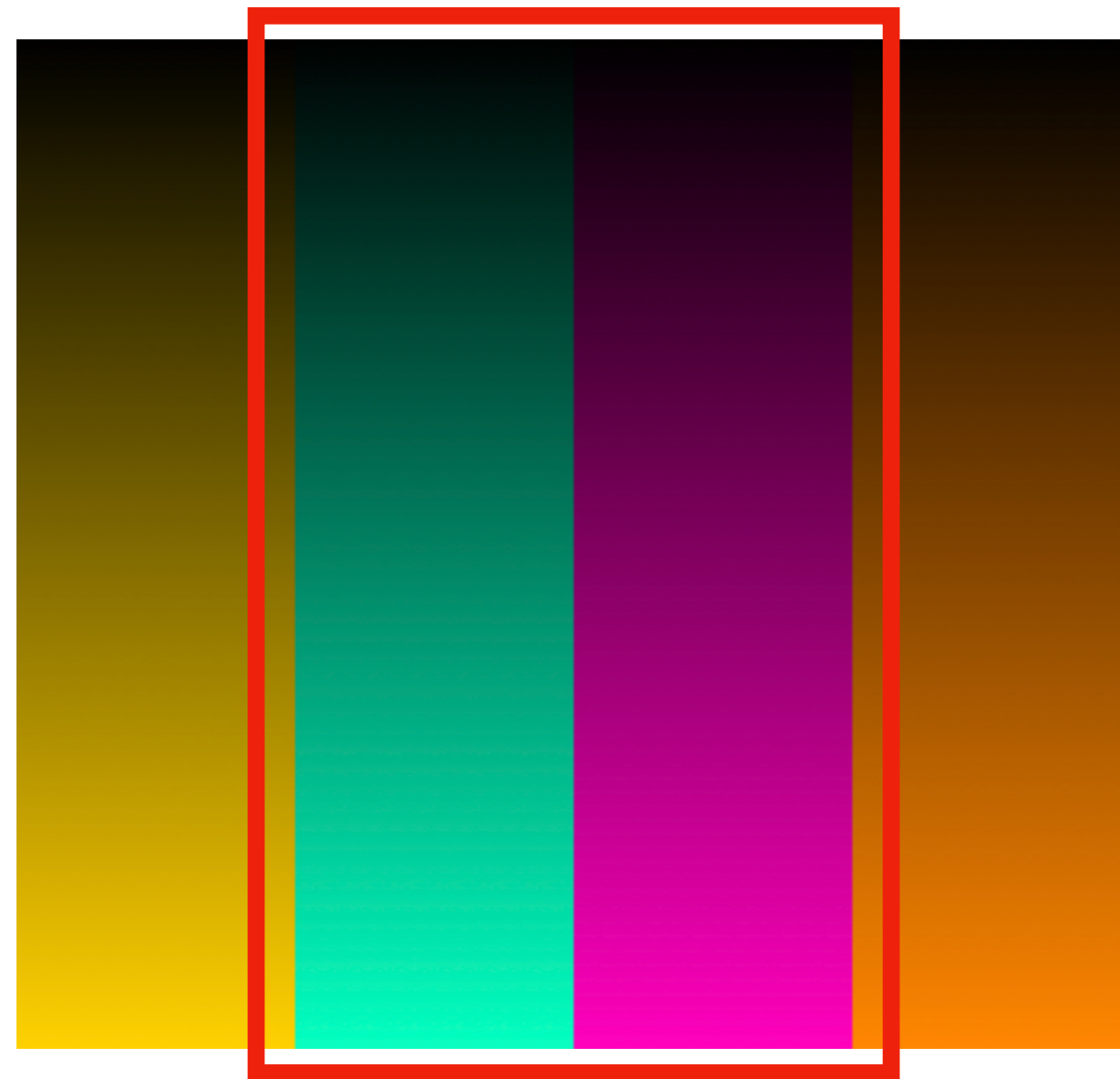
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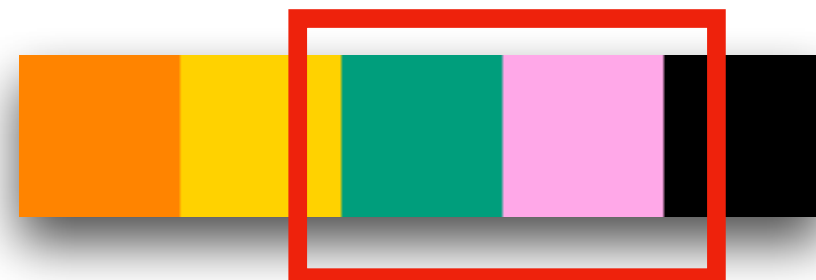
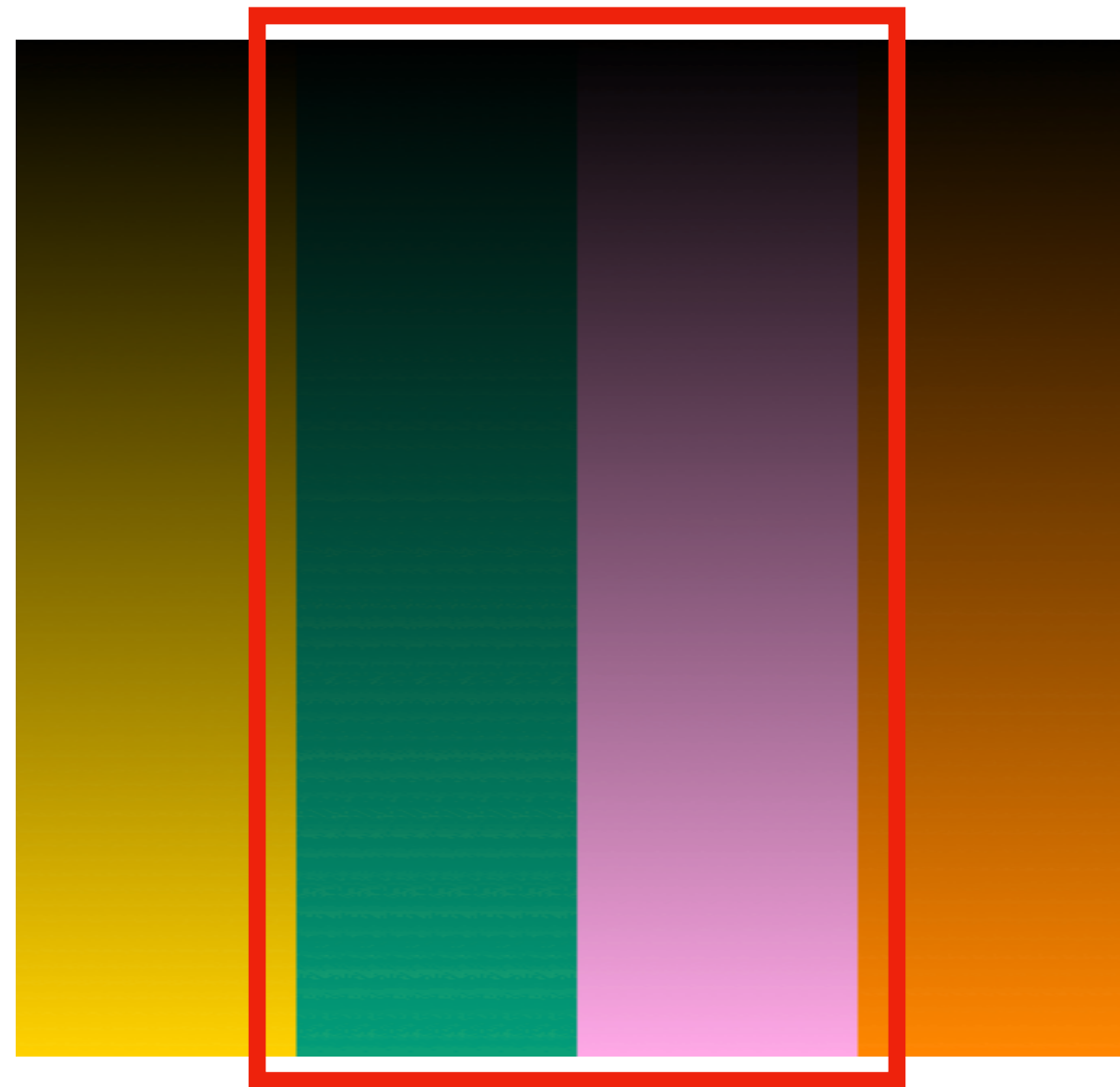
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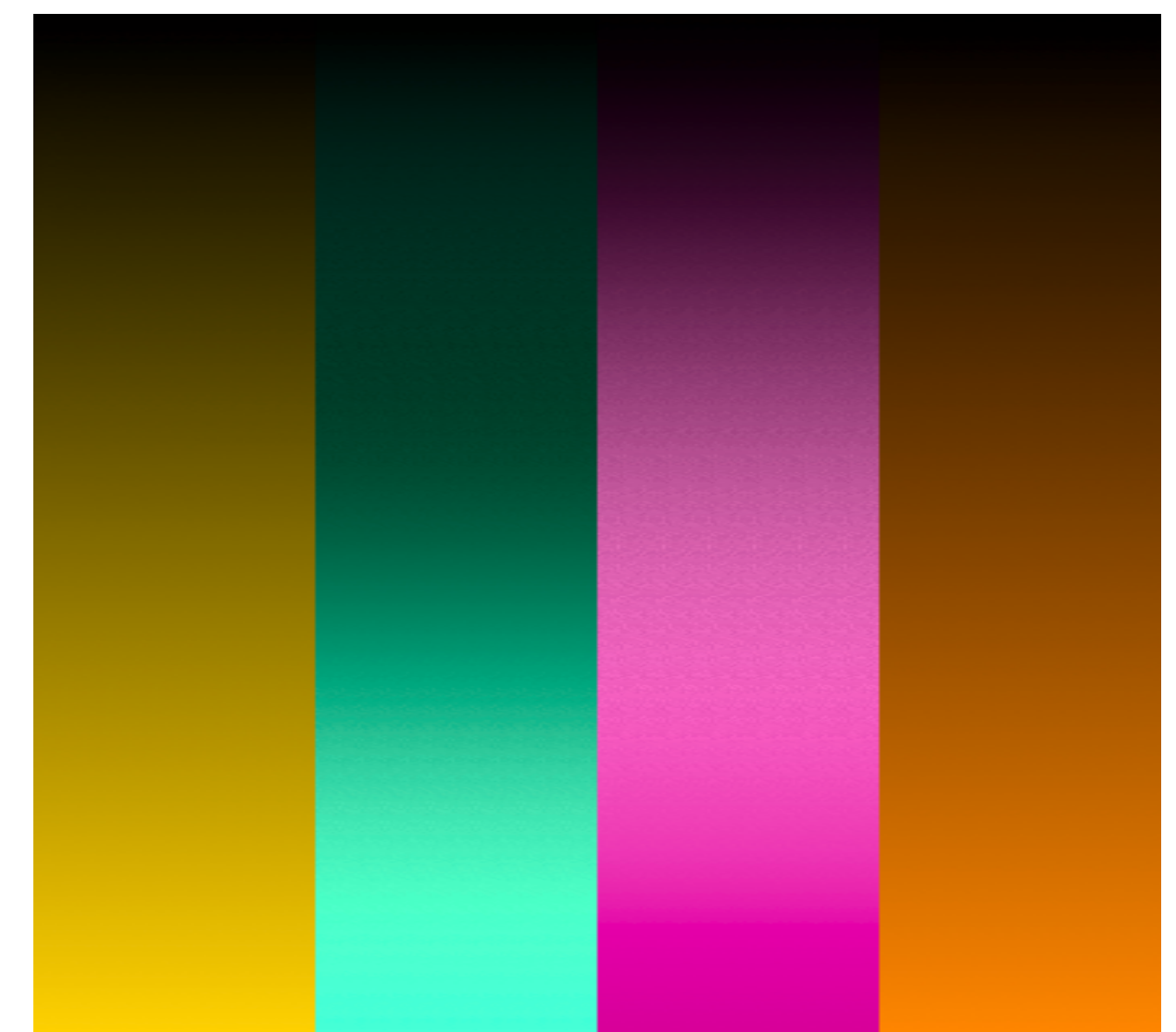
Input



[Tan et al. 2018]



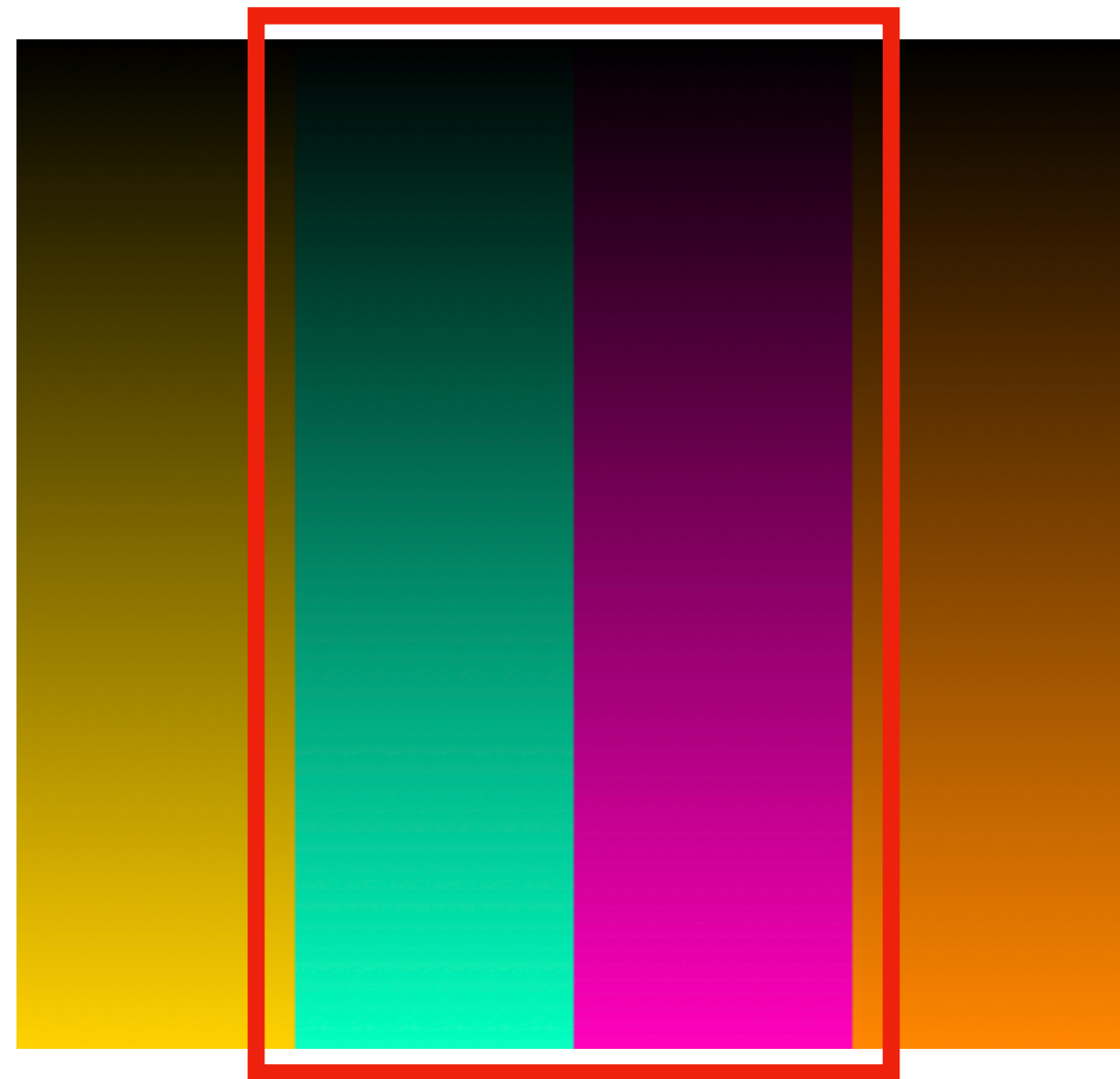
ColorfulCurves



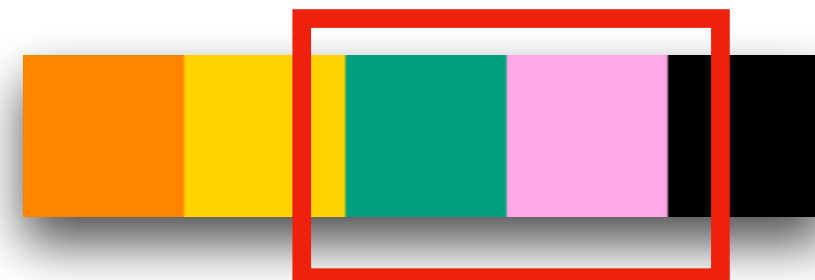
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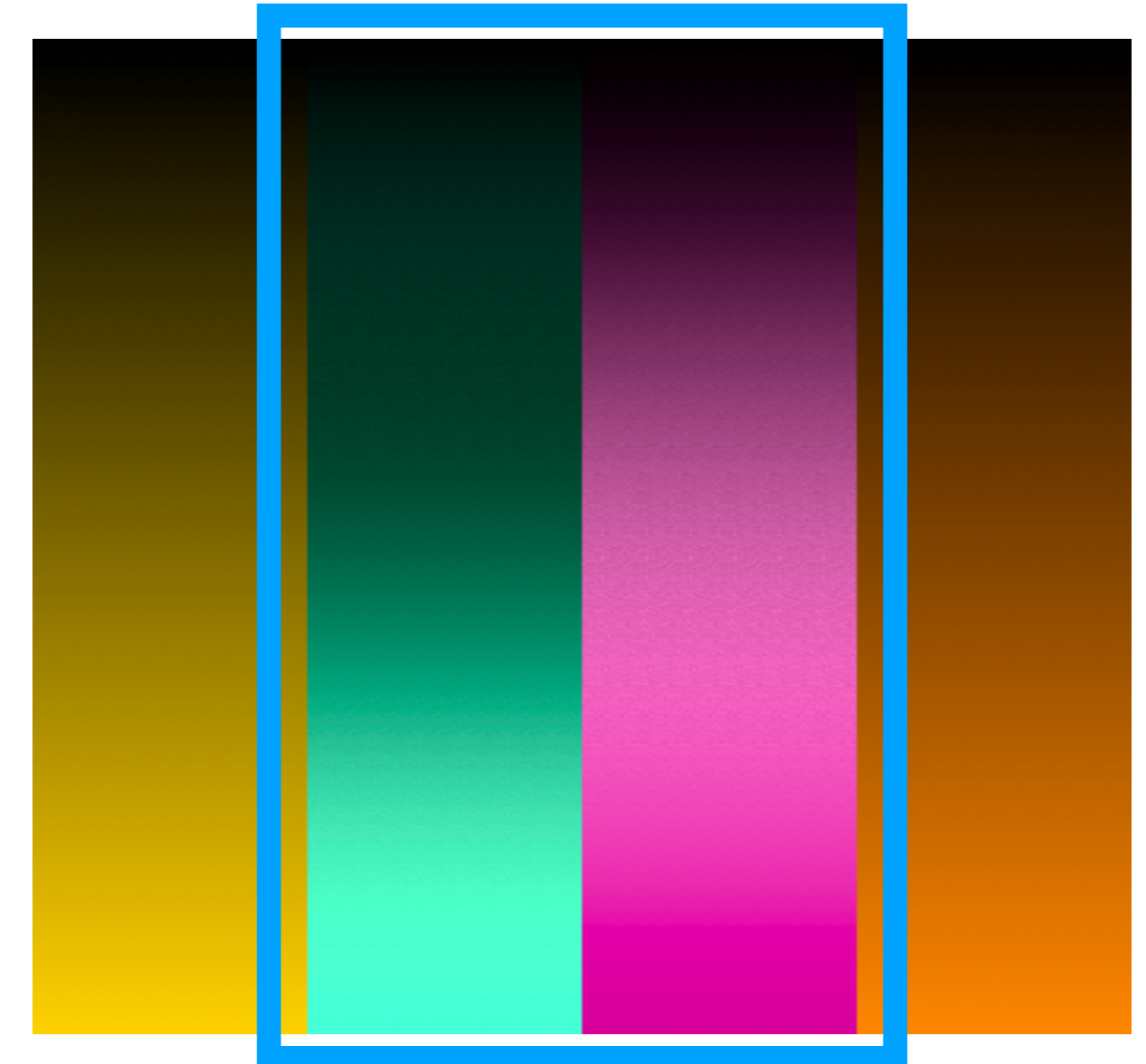
Input



[Tan et al. 2018]



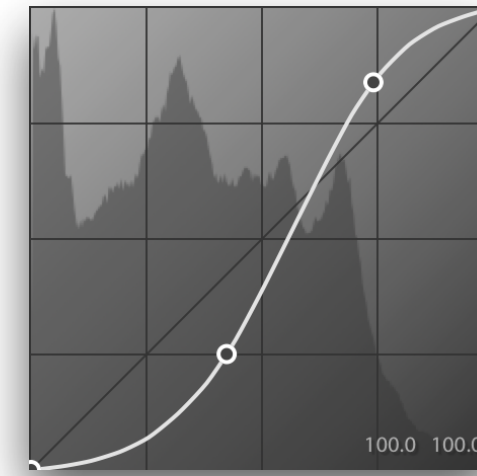
ColorfulCurves



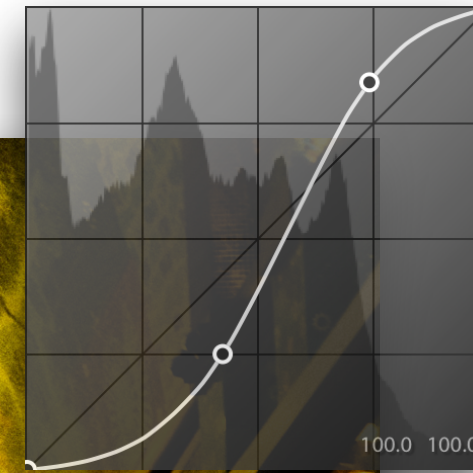
Tone curves aren't local or color-aware



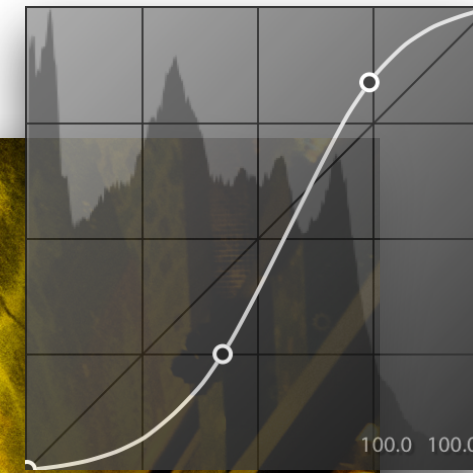
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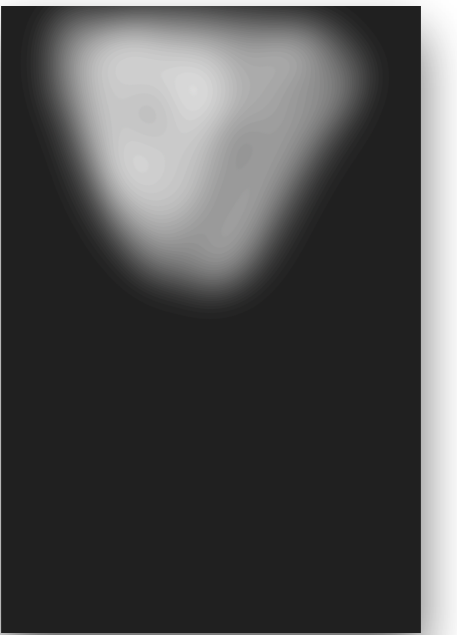
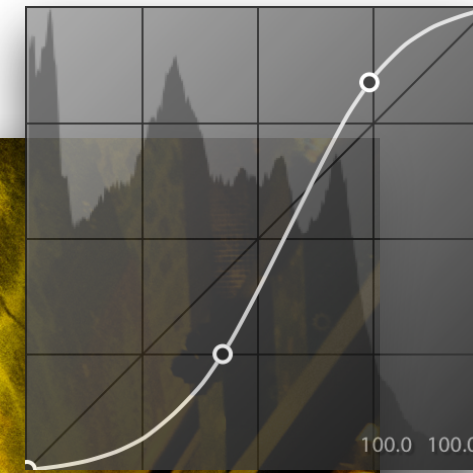
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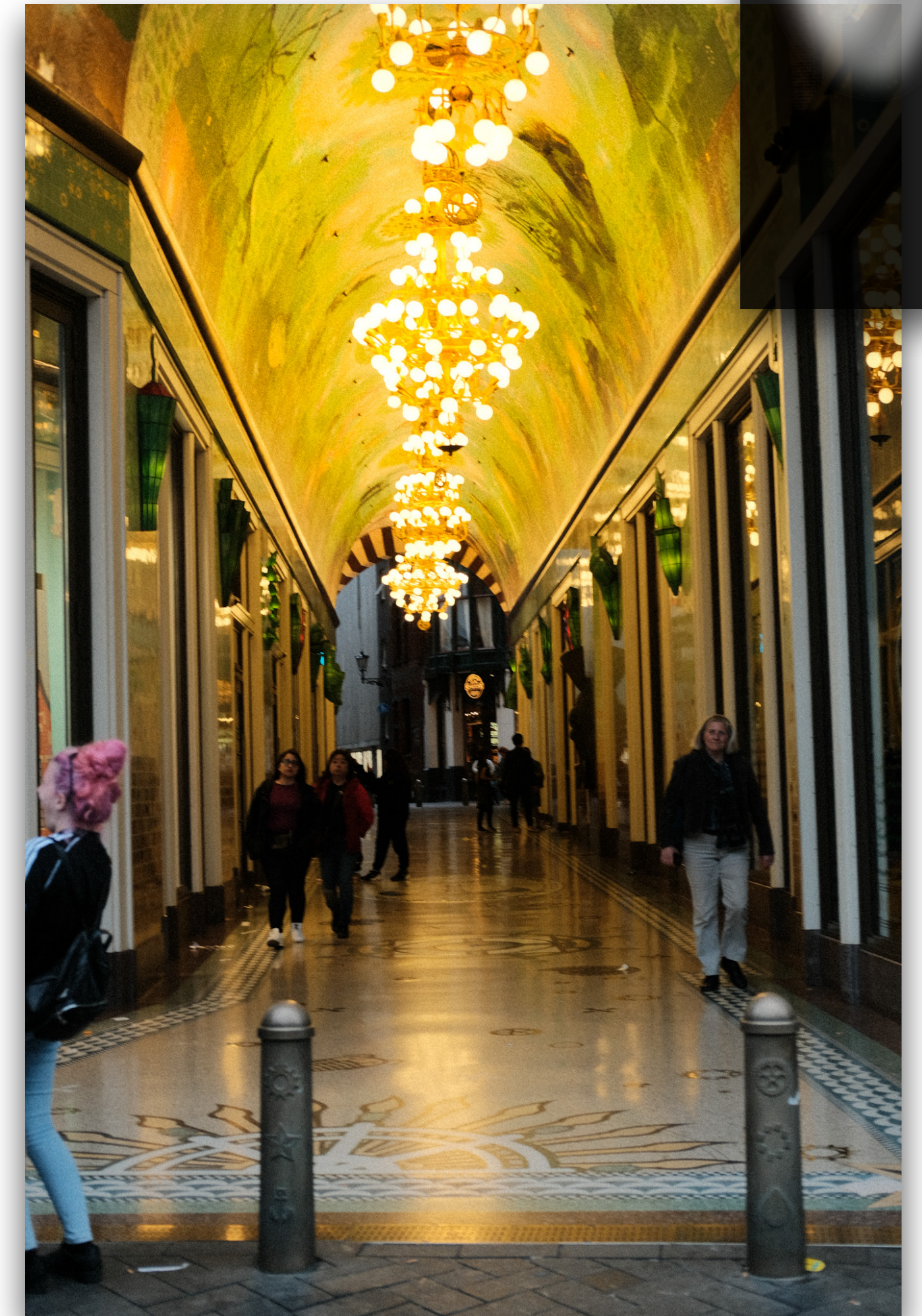
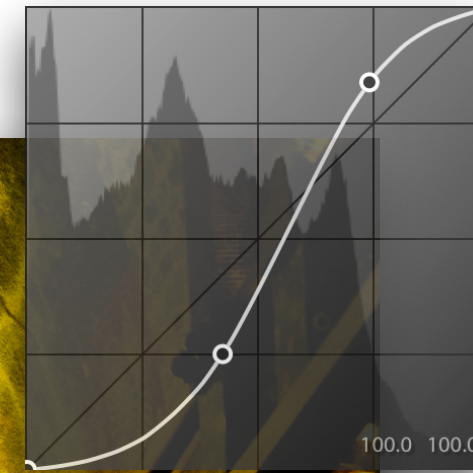
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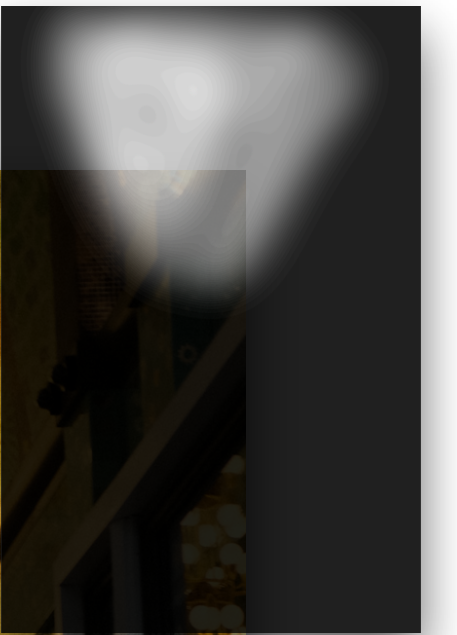
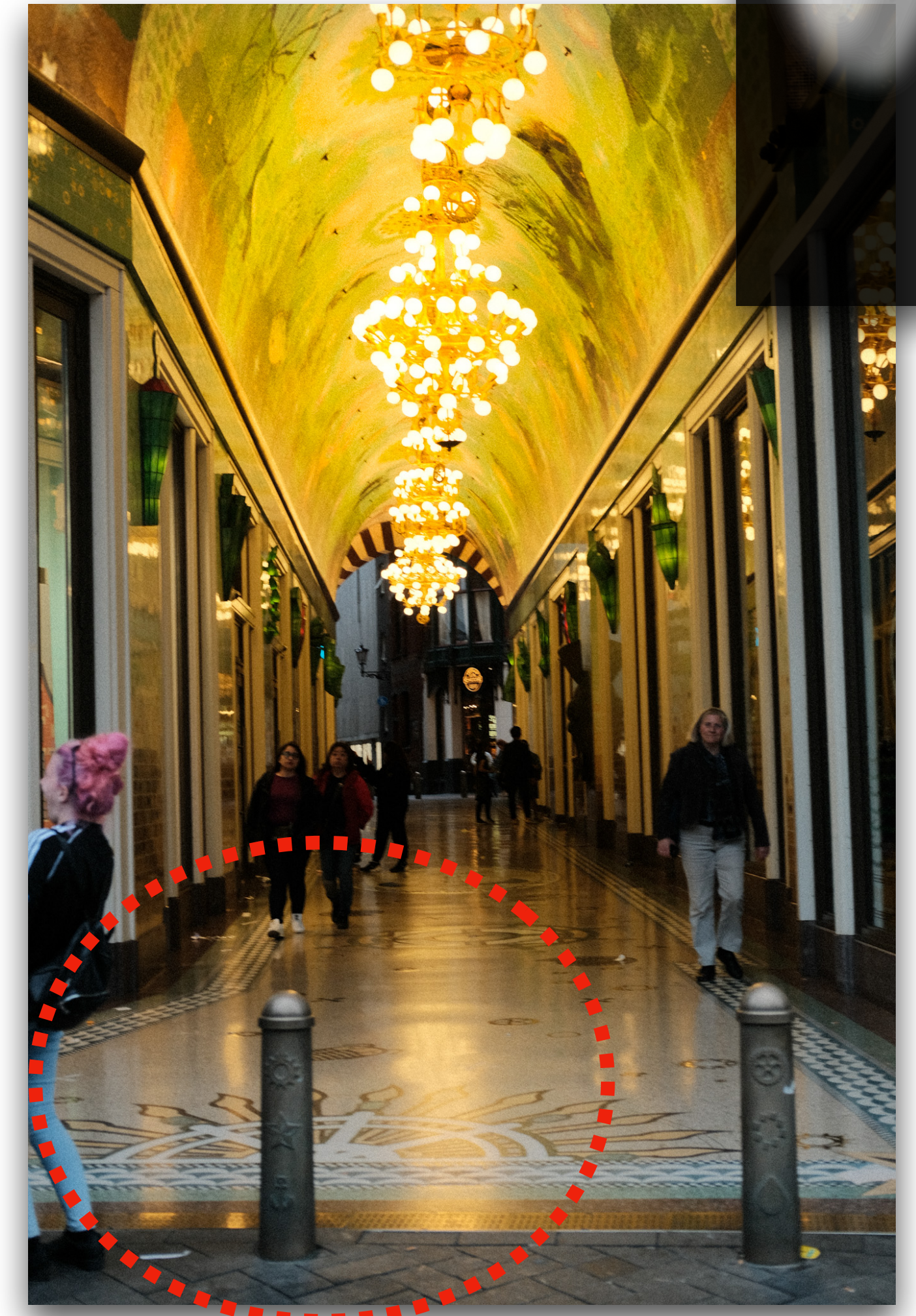
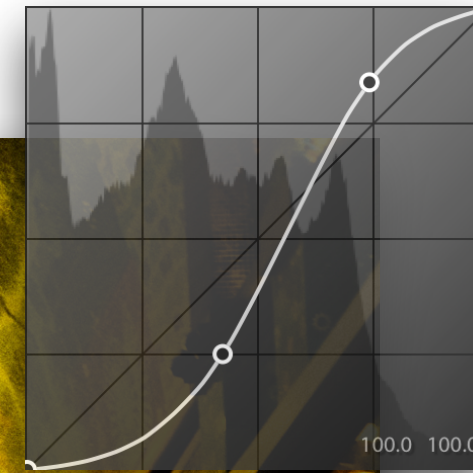
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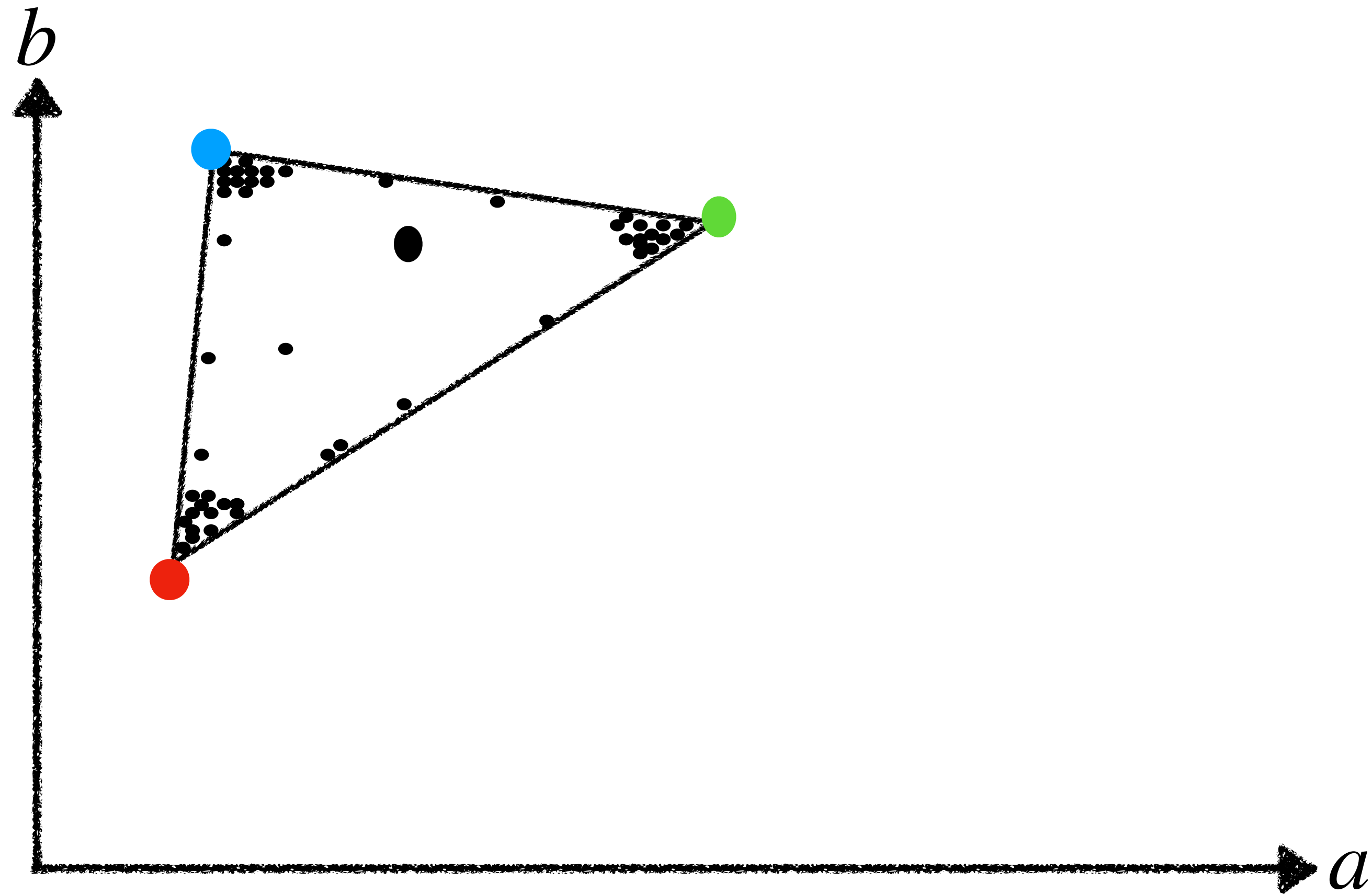


Editing a pixel needs tedious palette changes

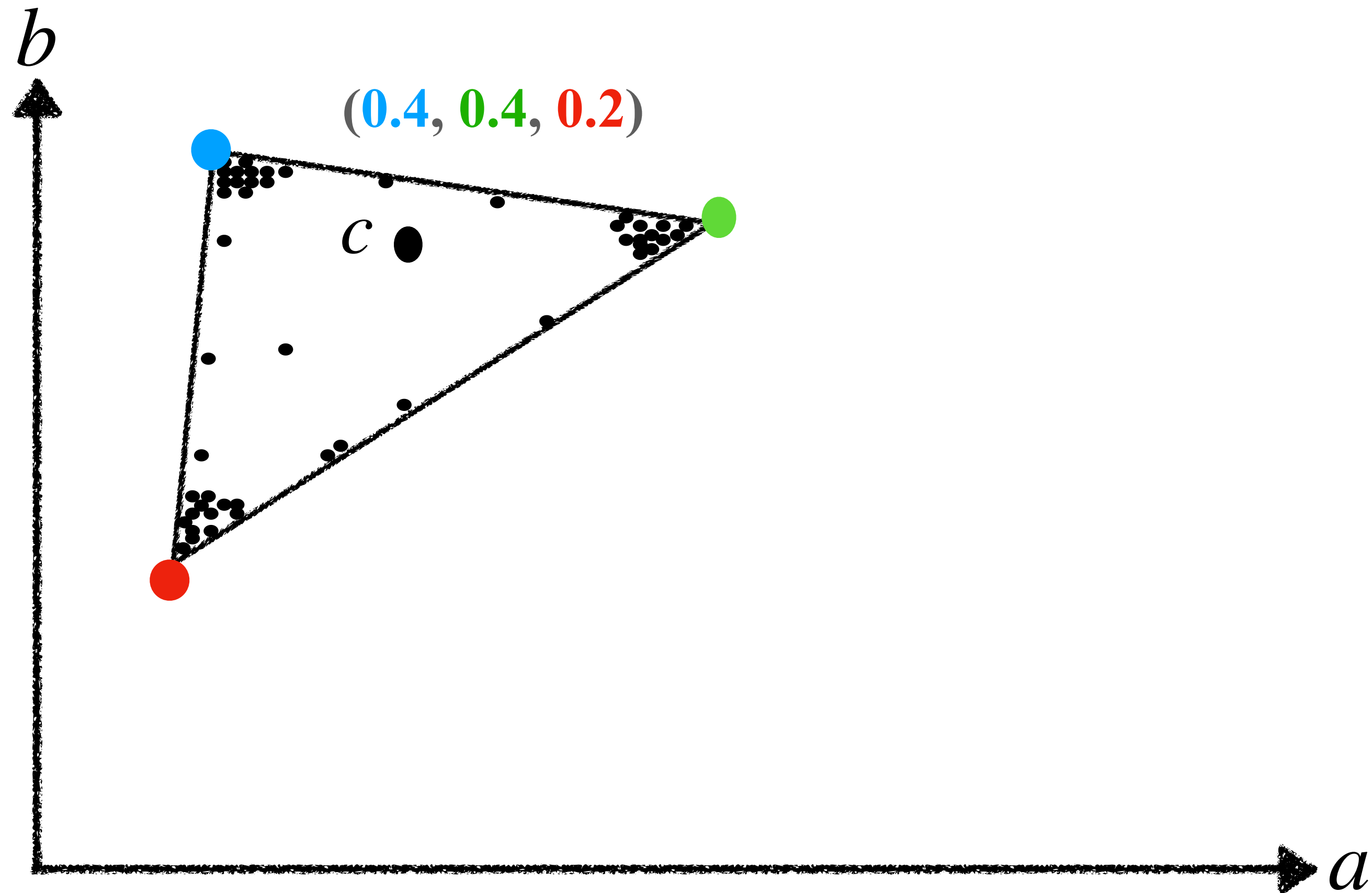
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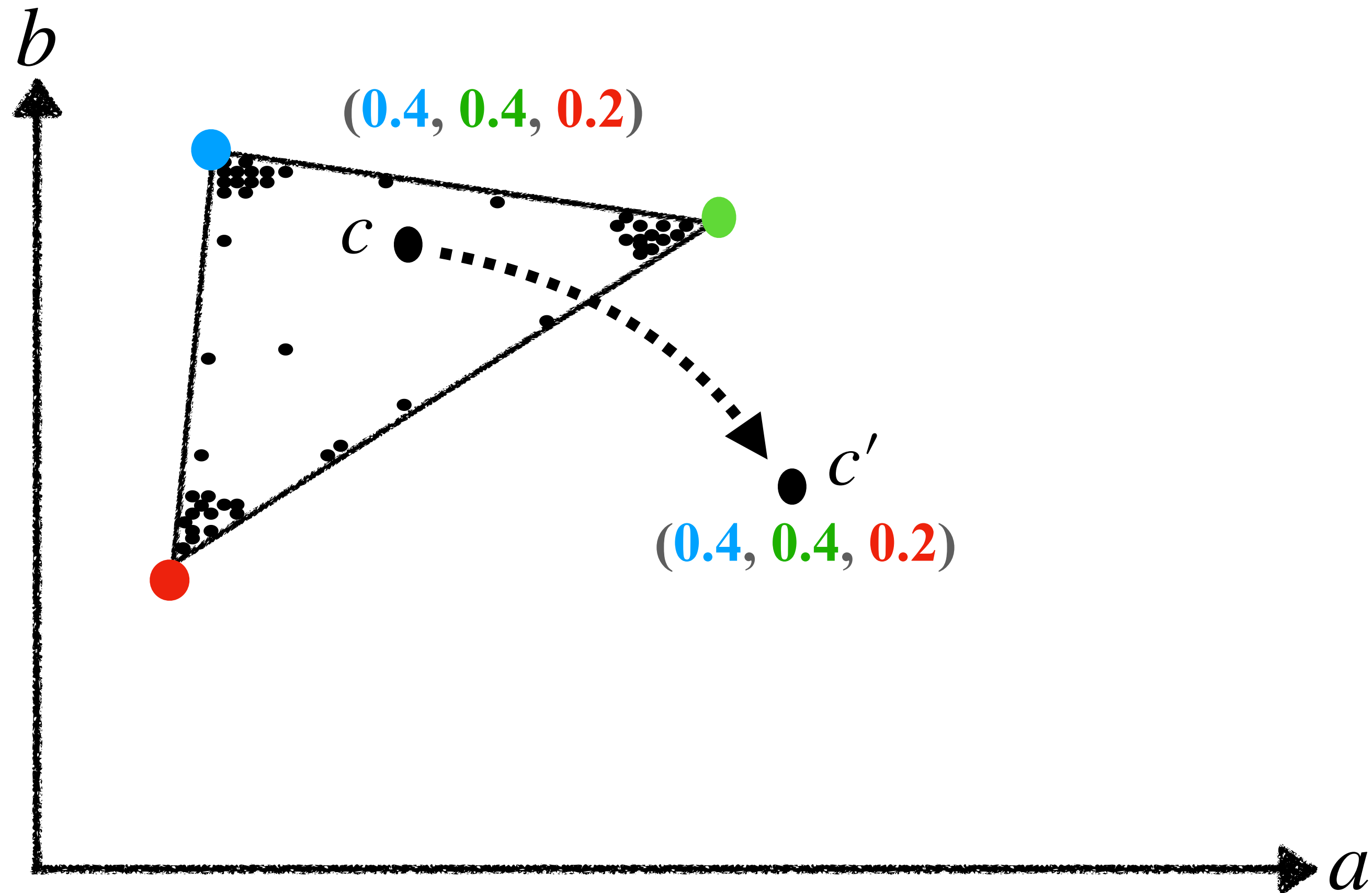
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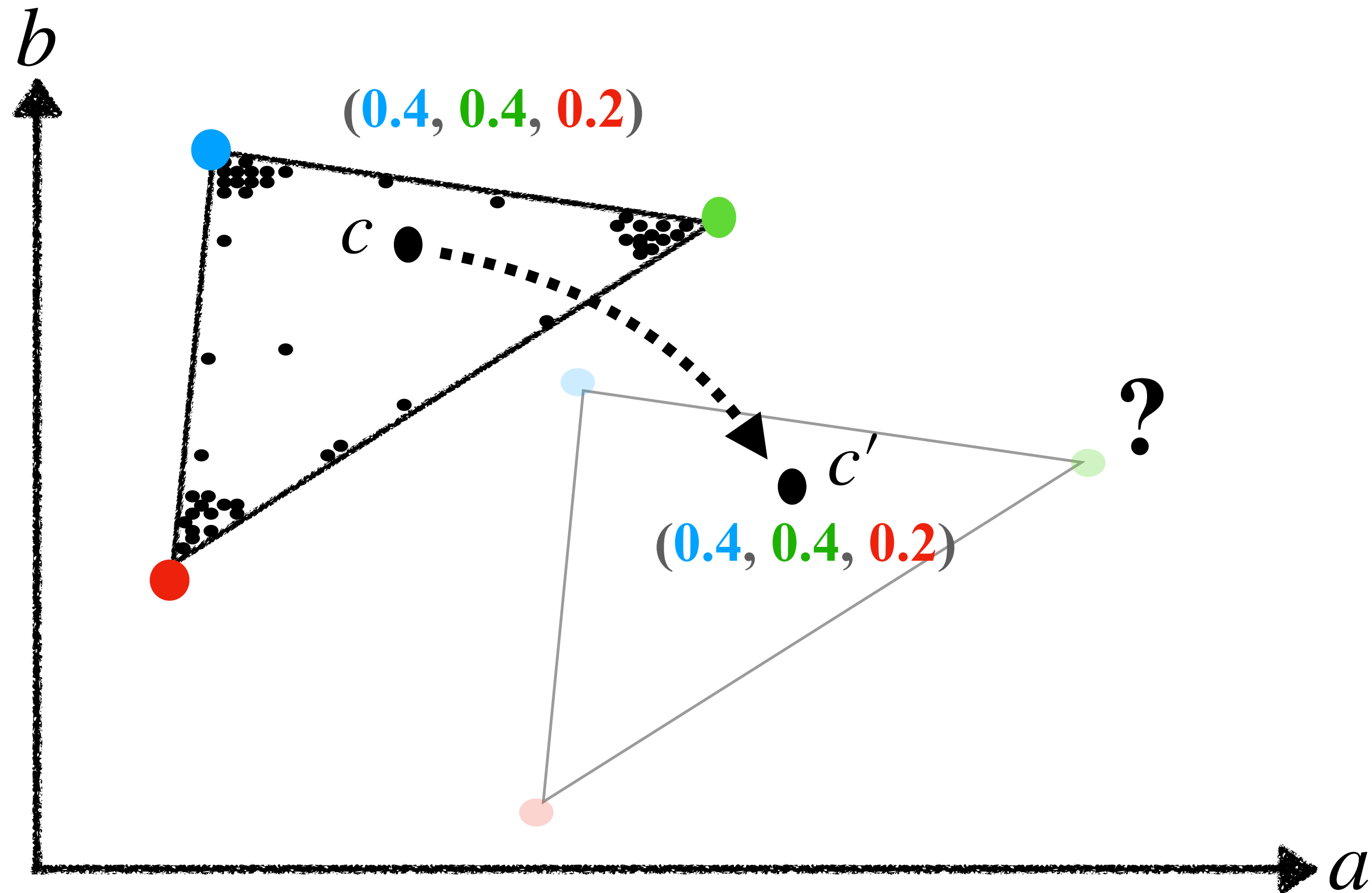
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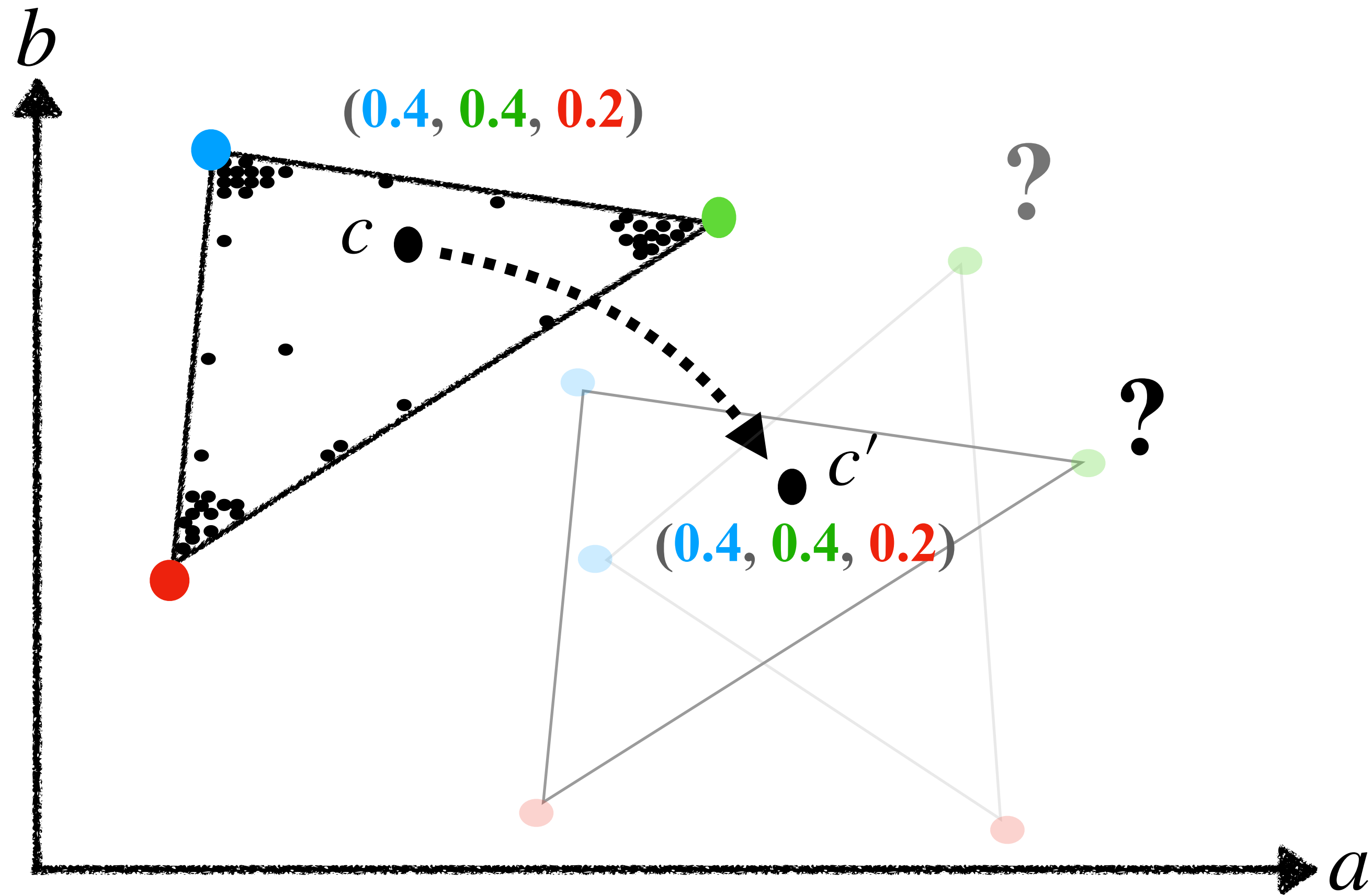
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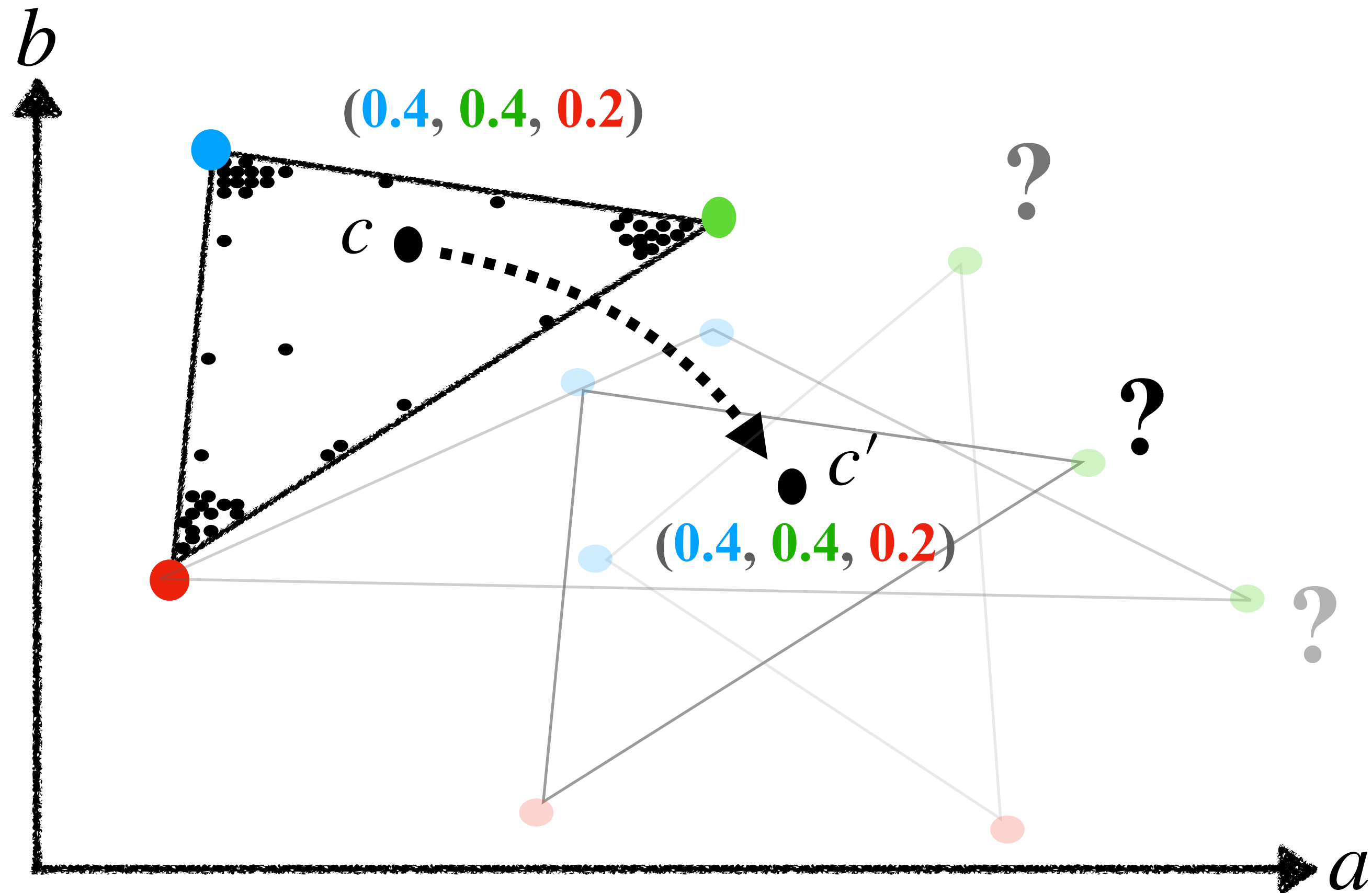
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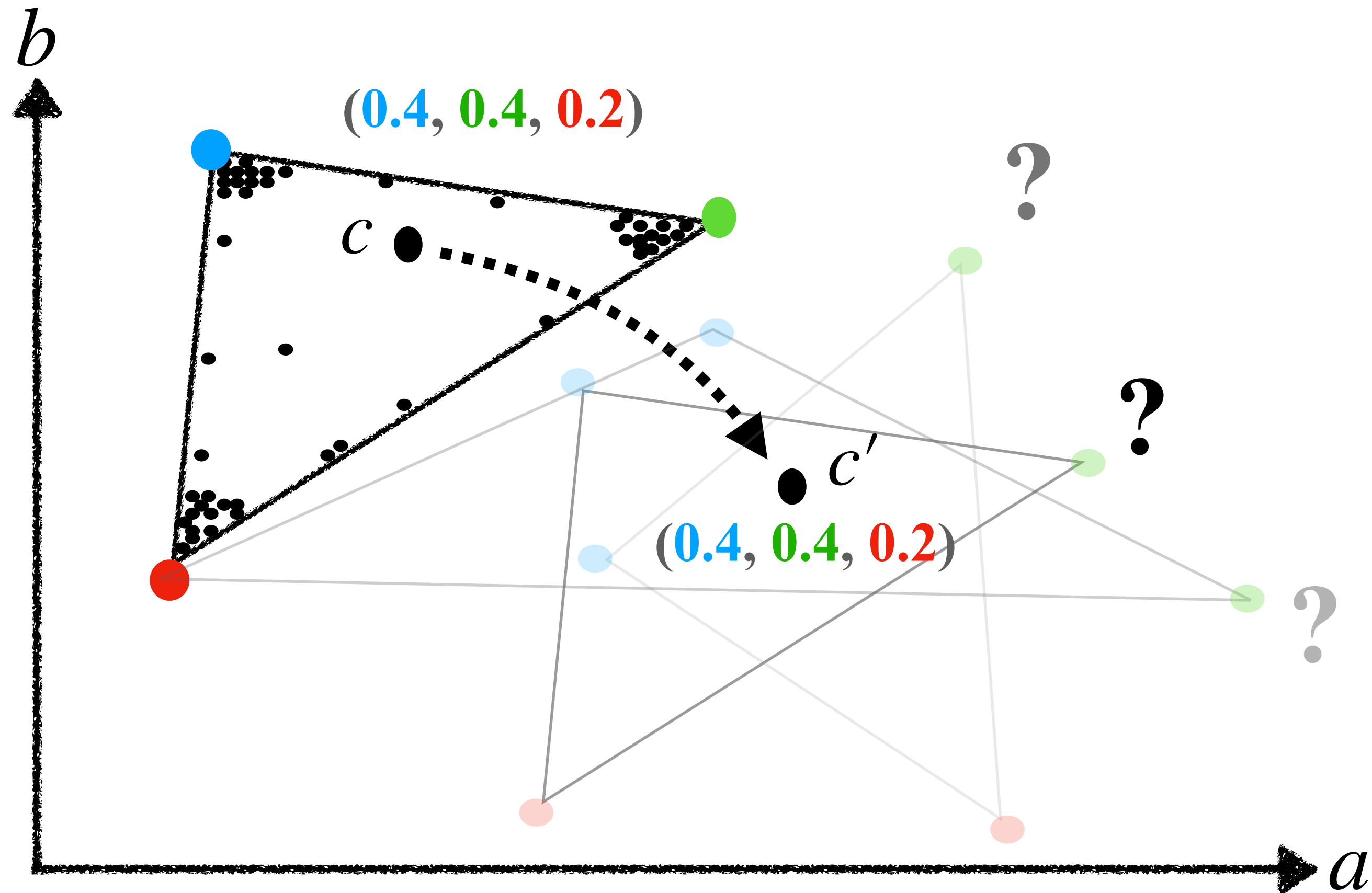
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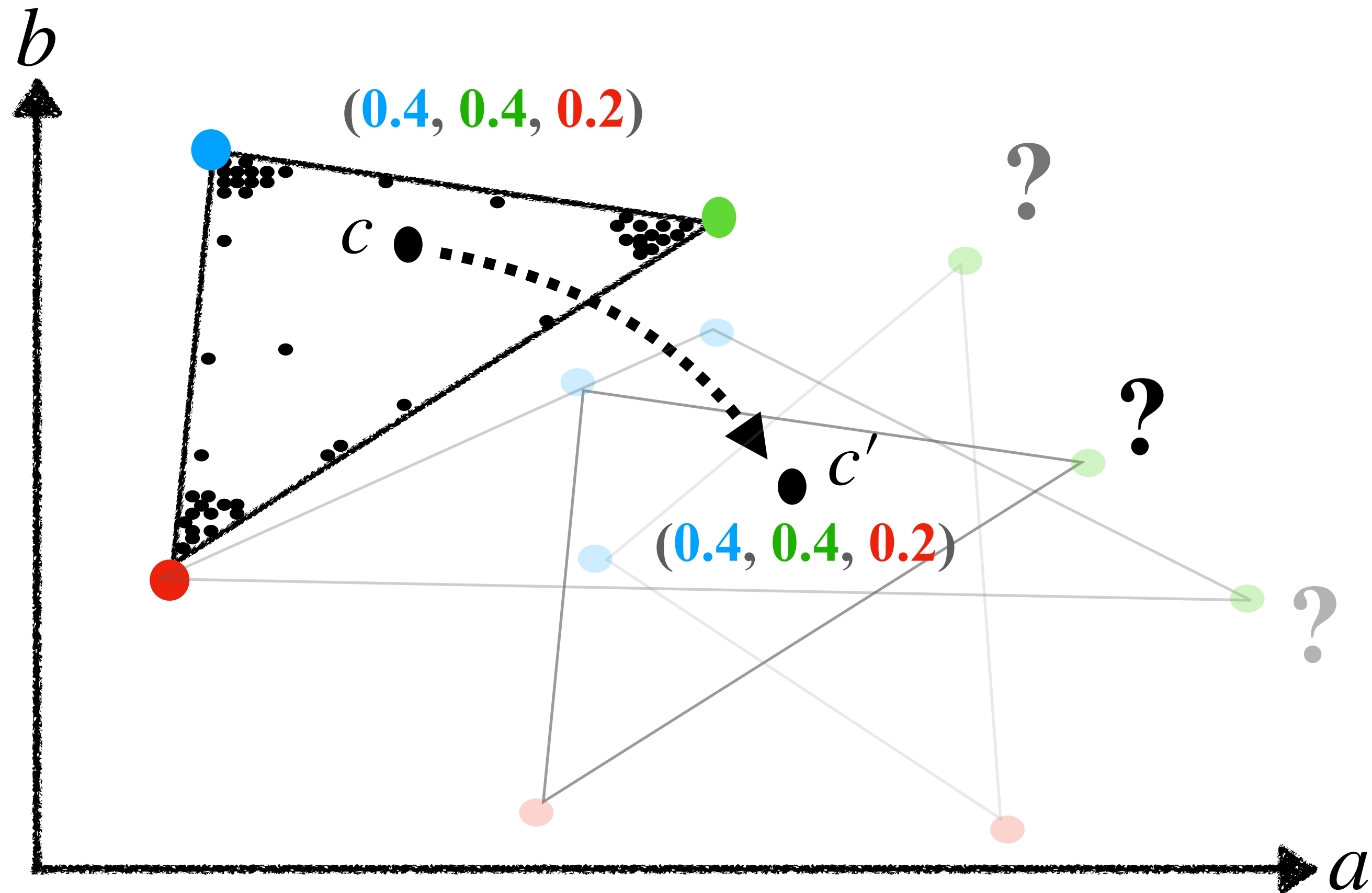
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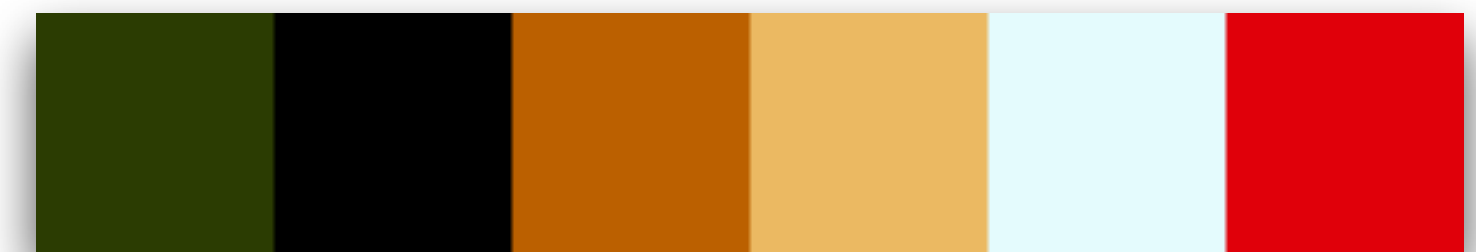
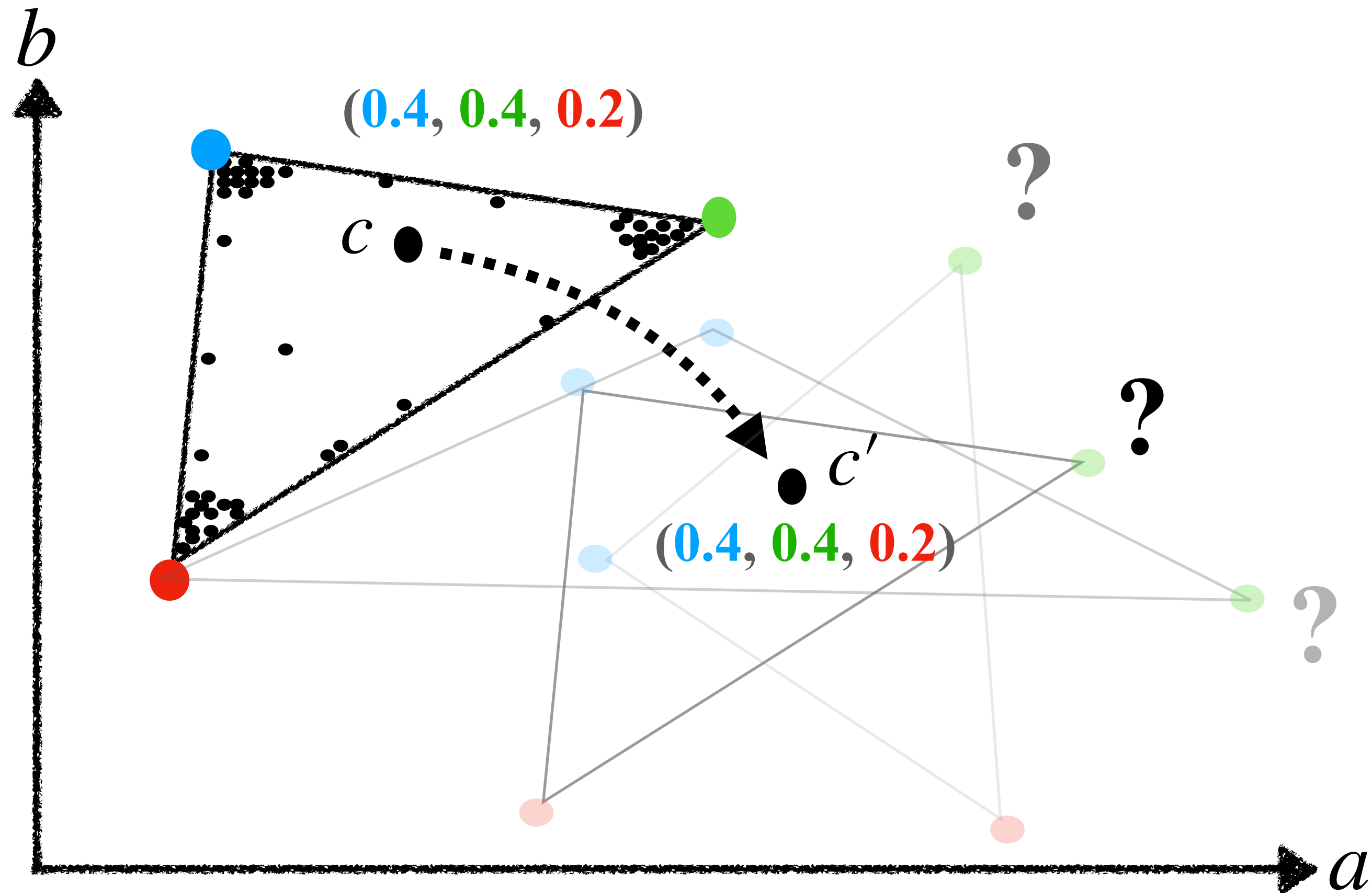
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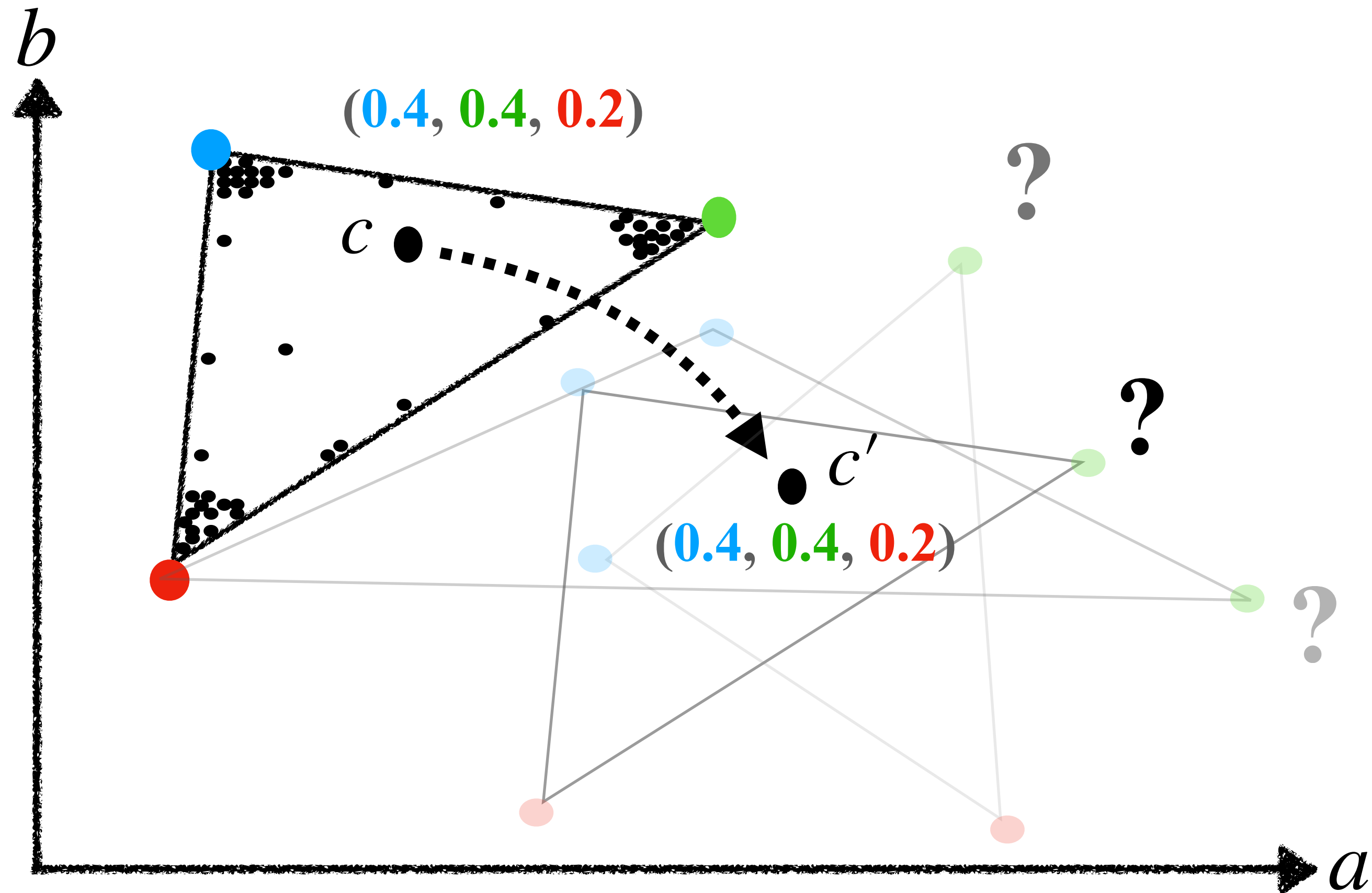
Editing a pixel needs tedious palette changes



Editing a pixel needs tedious palette changes



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High-level summary

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Palette-based editing

- ✓ Spatially coherent color edits

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 Hard to control lightness

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- ✗ Hard to control lightness
- ✗ Incompatible with directly changing pixel colors

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Tone curve editing

- ✓ Easy to control lightness

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- ✗ Hard to control lightness
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- ✗ Need manual masking

High-level summary

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Spatially coherent color edits

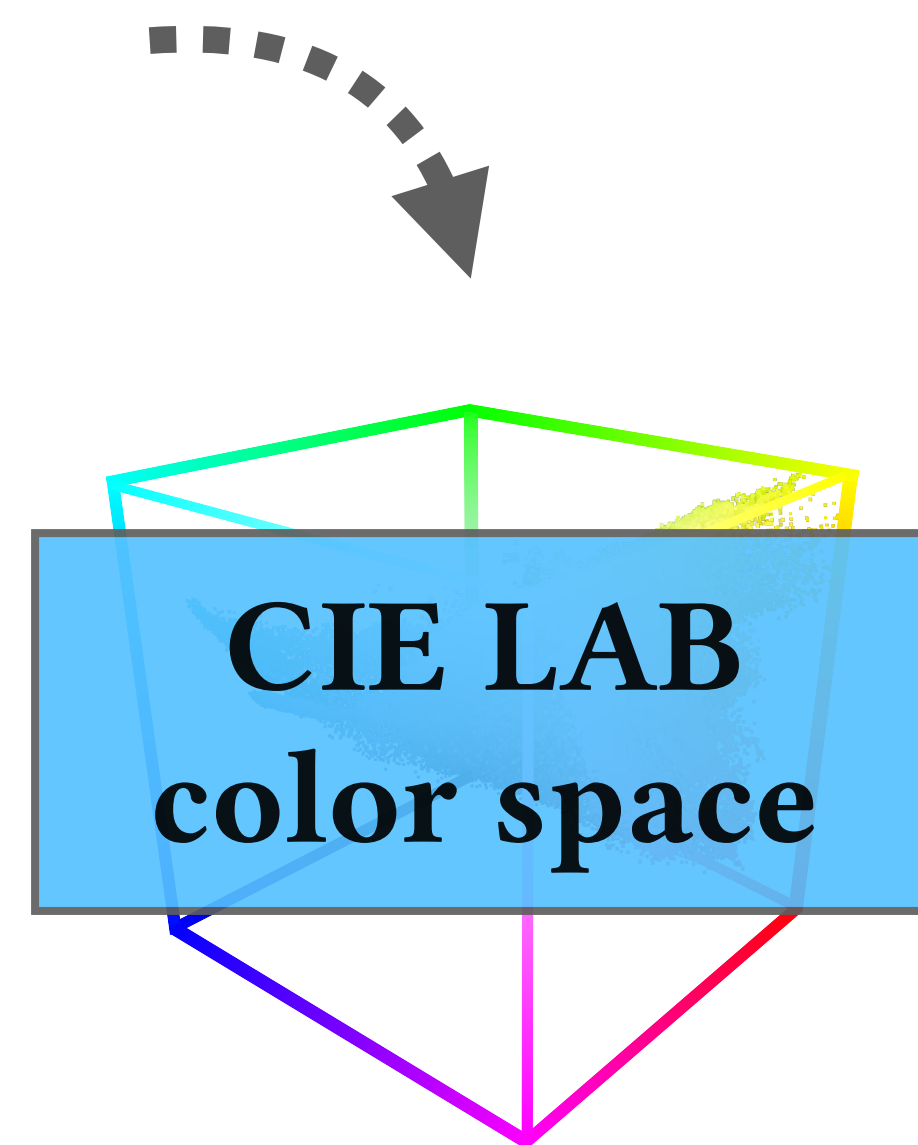


Compatible with directly changing pixel colors

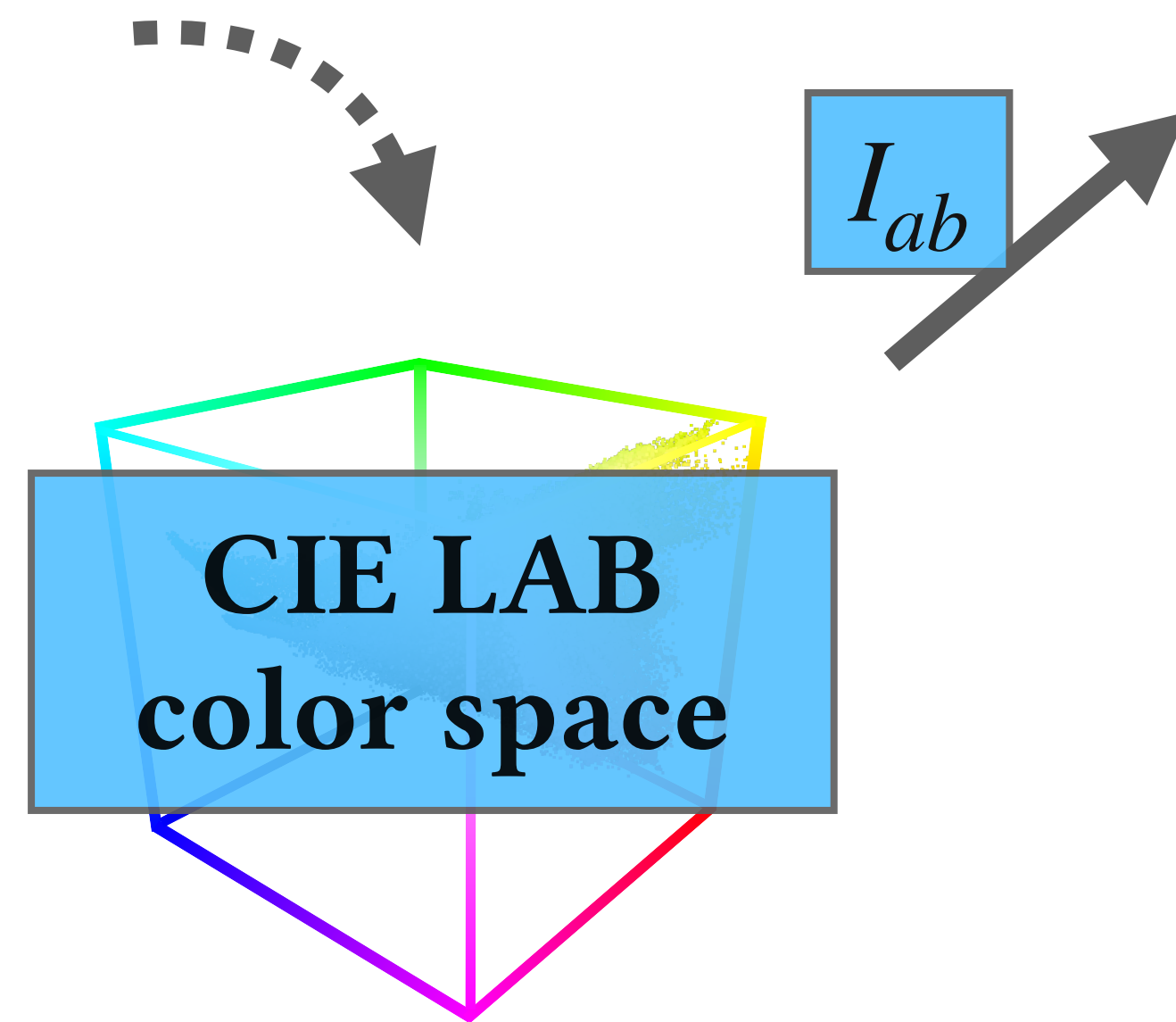
Re-formulating color decomposition



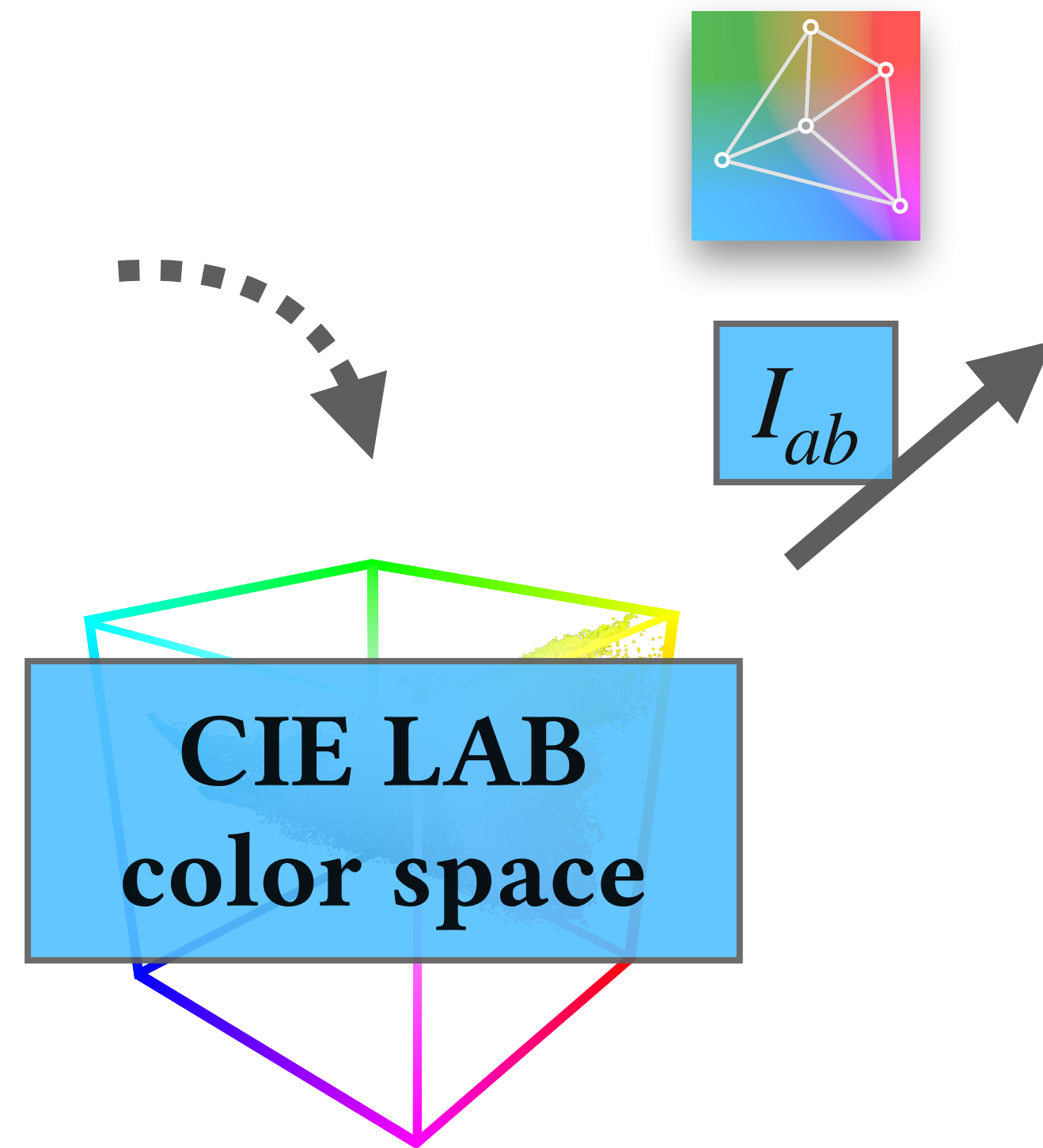
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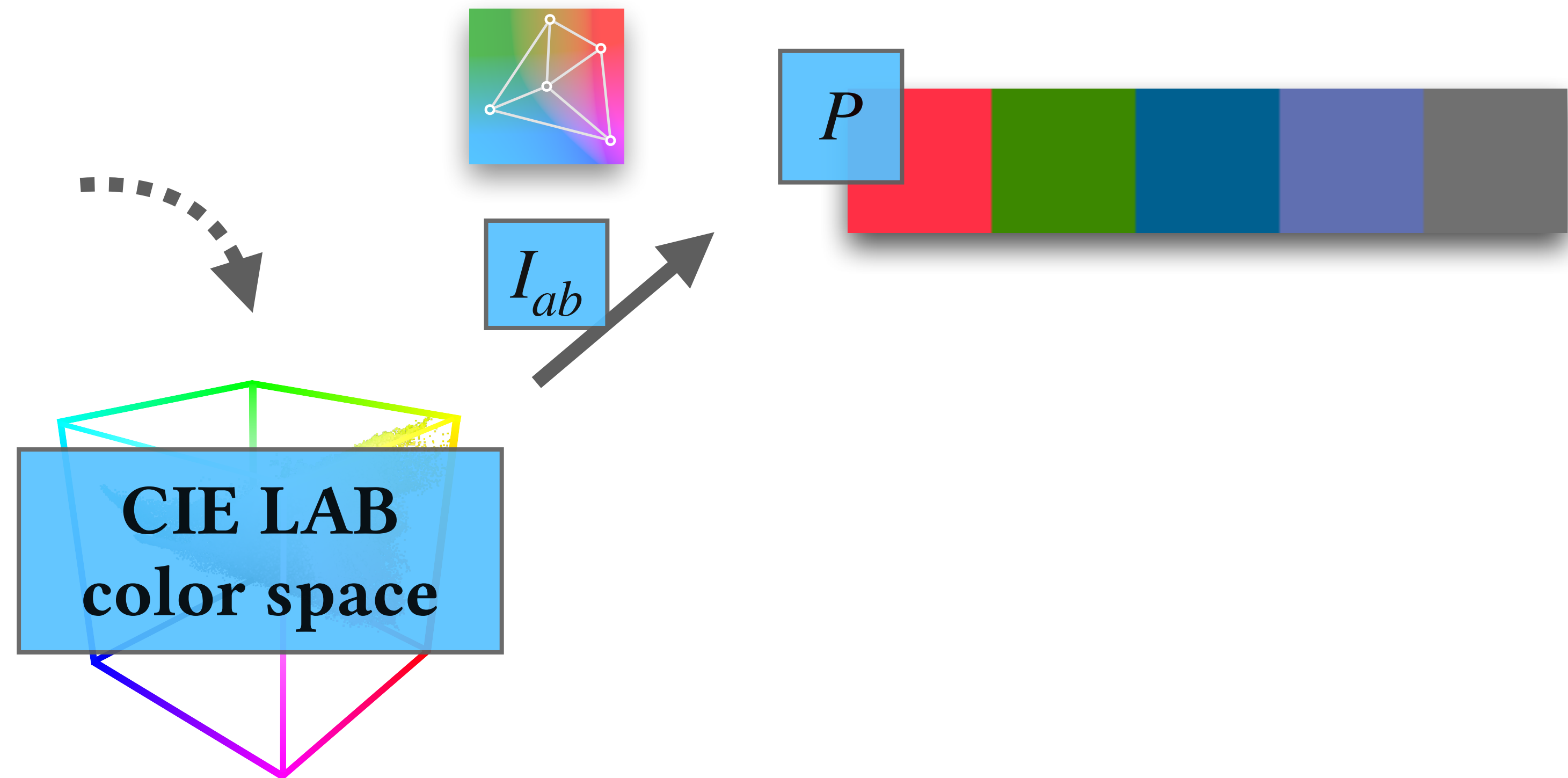
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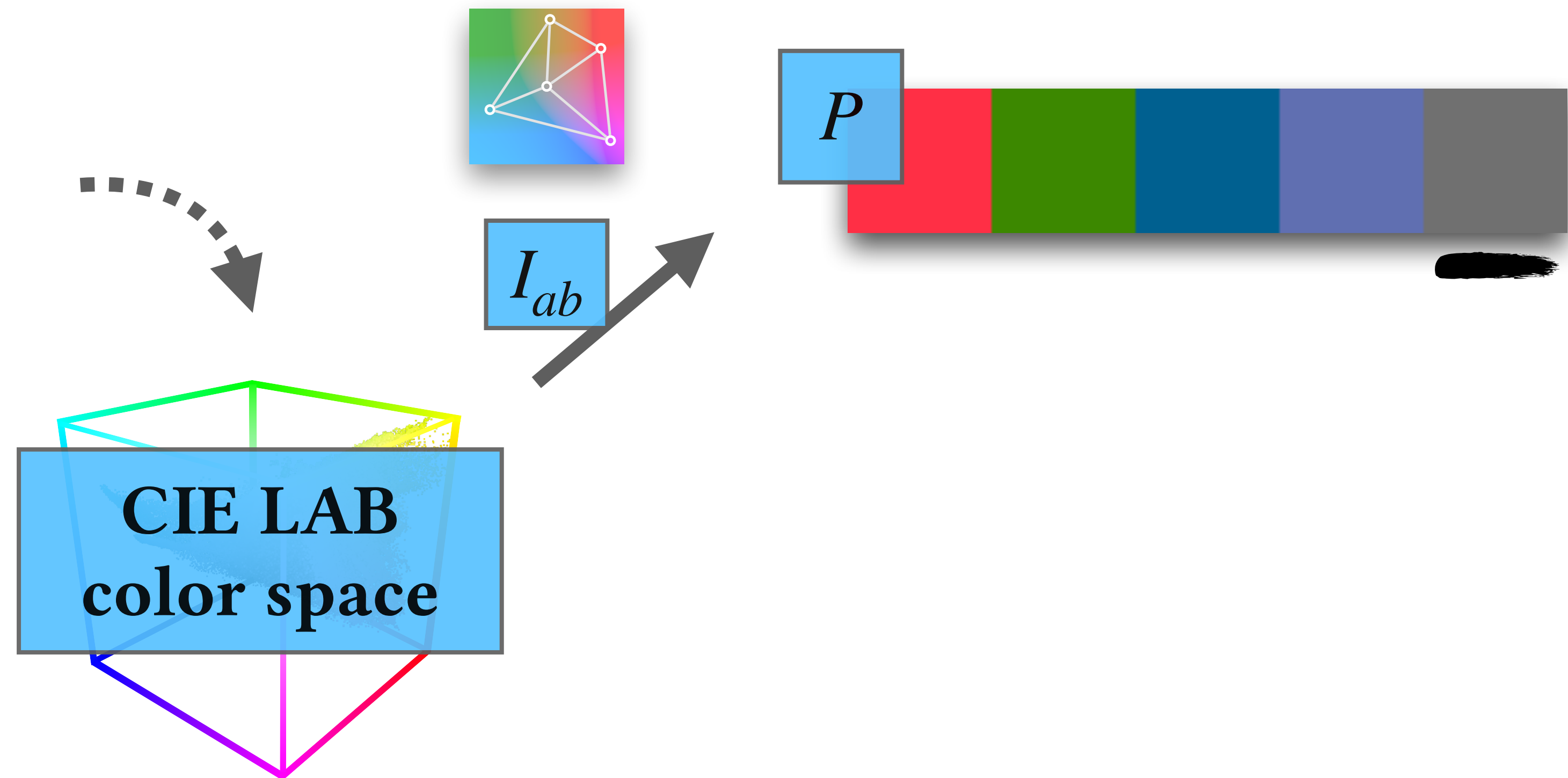
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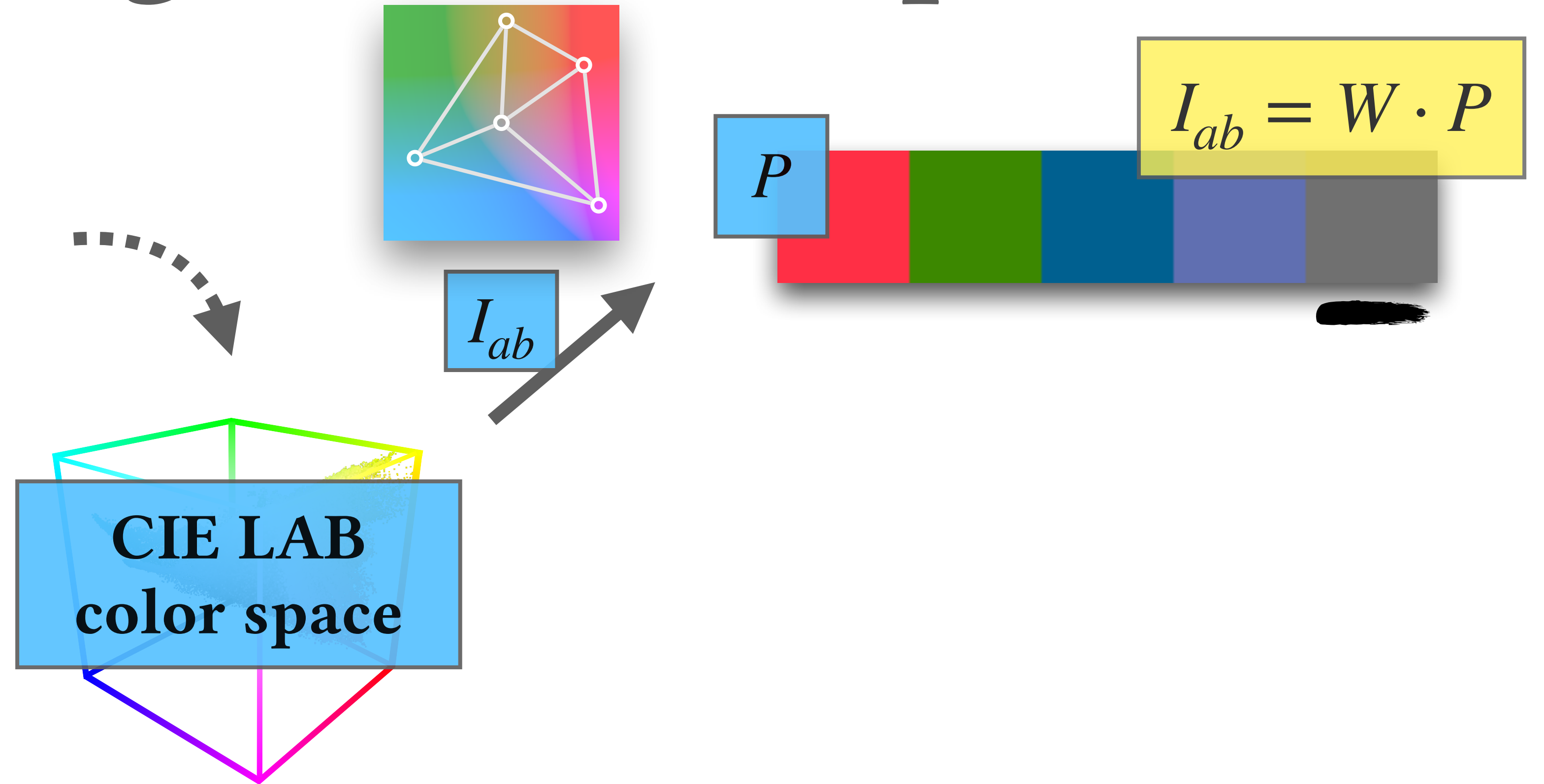
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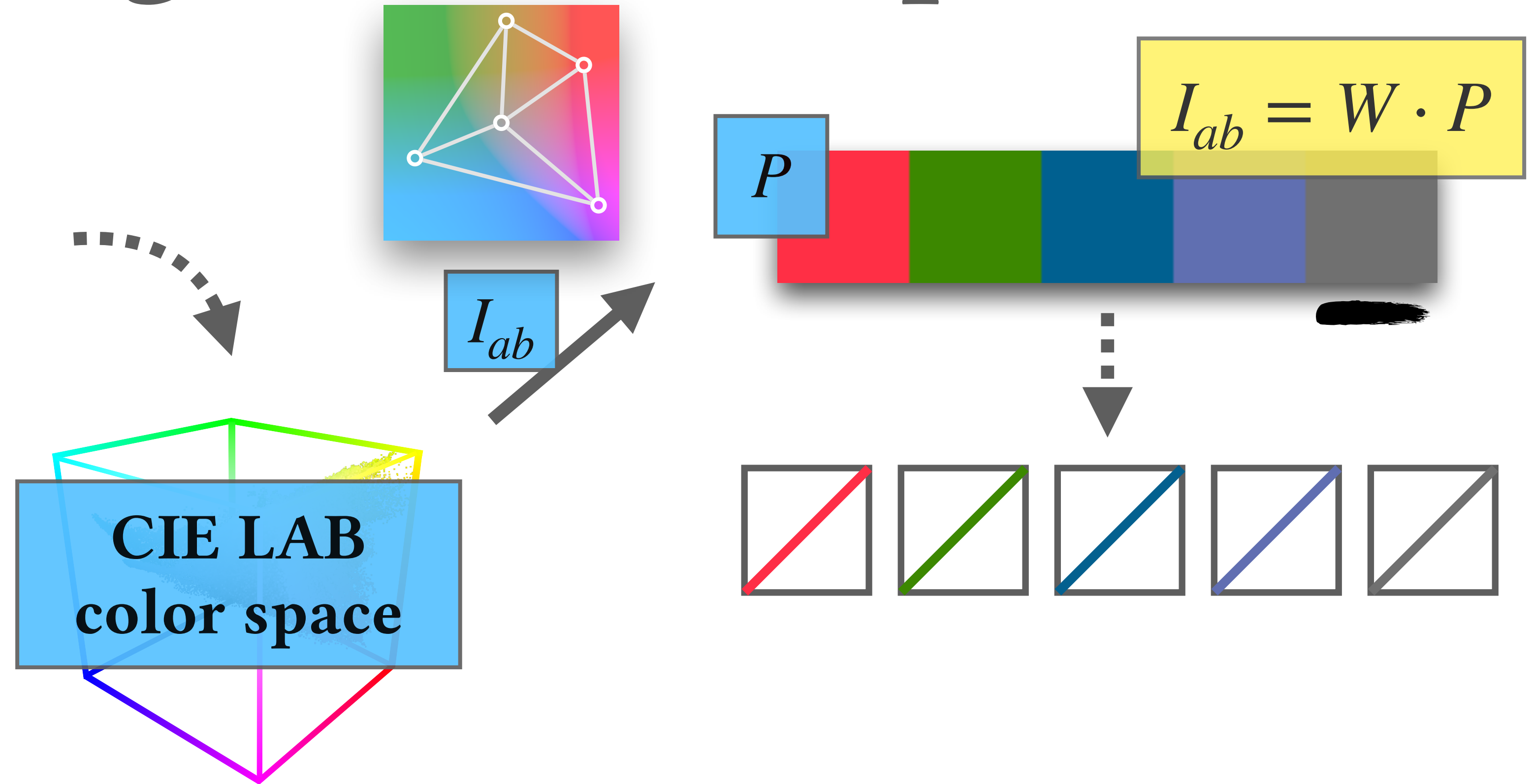
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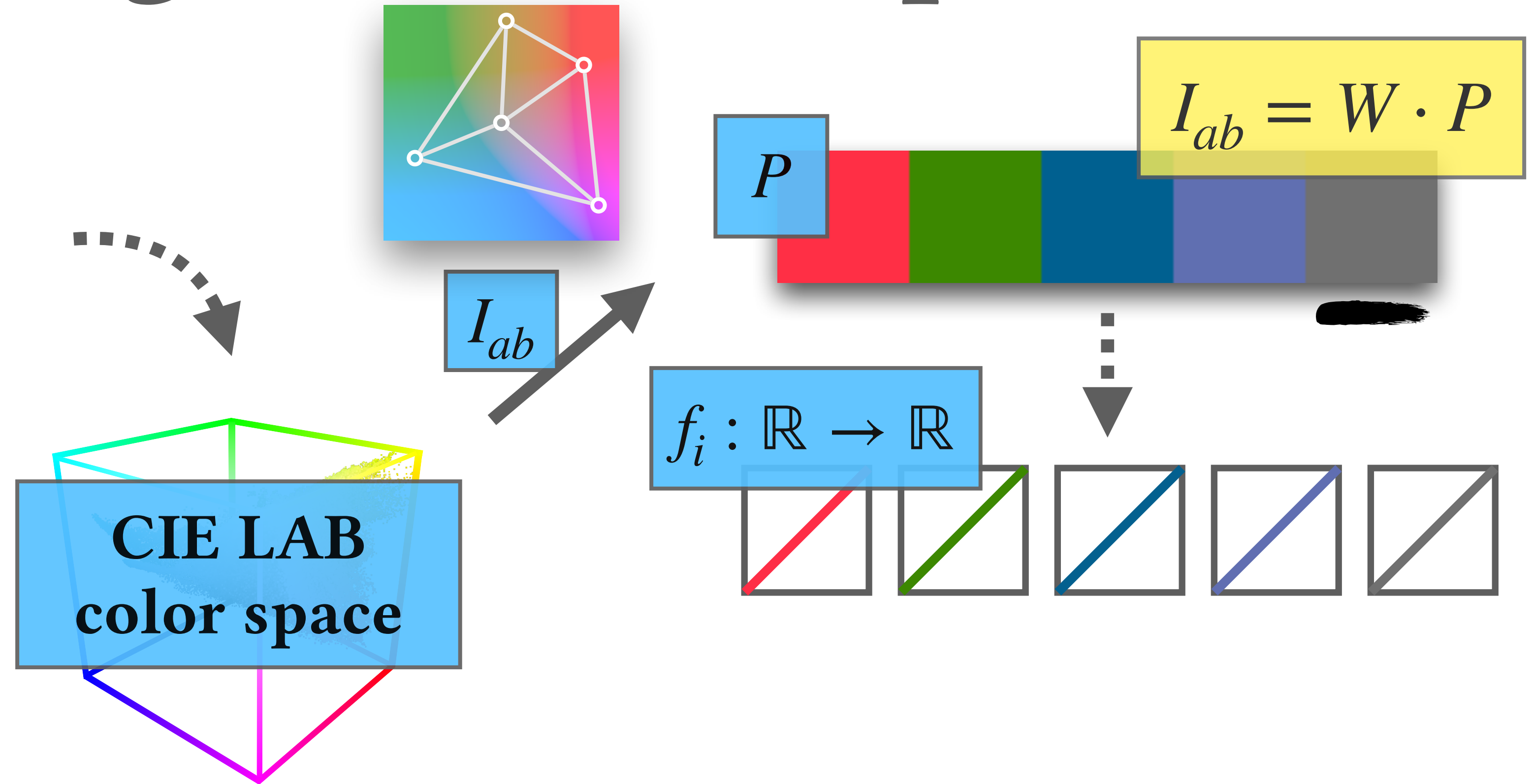
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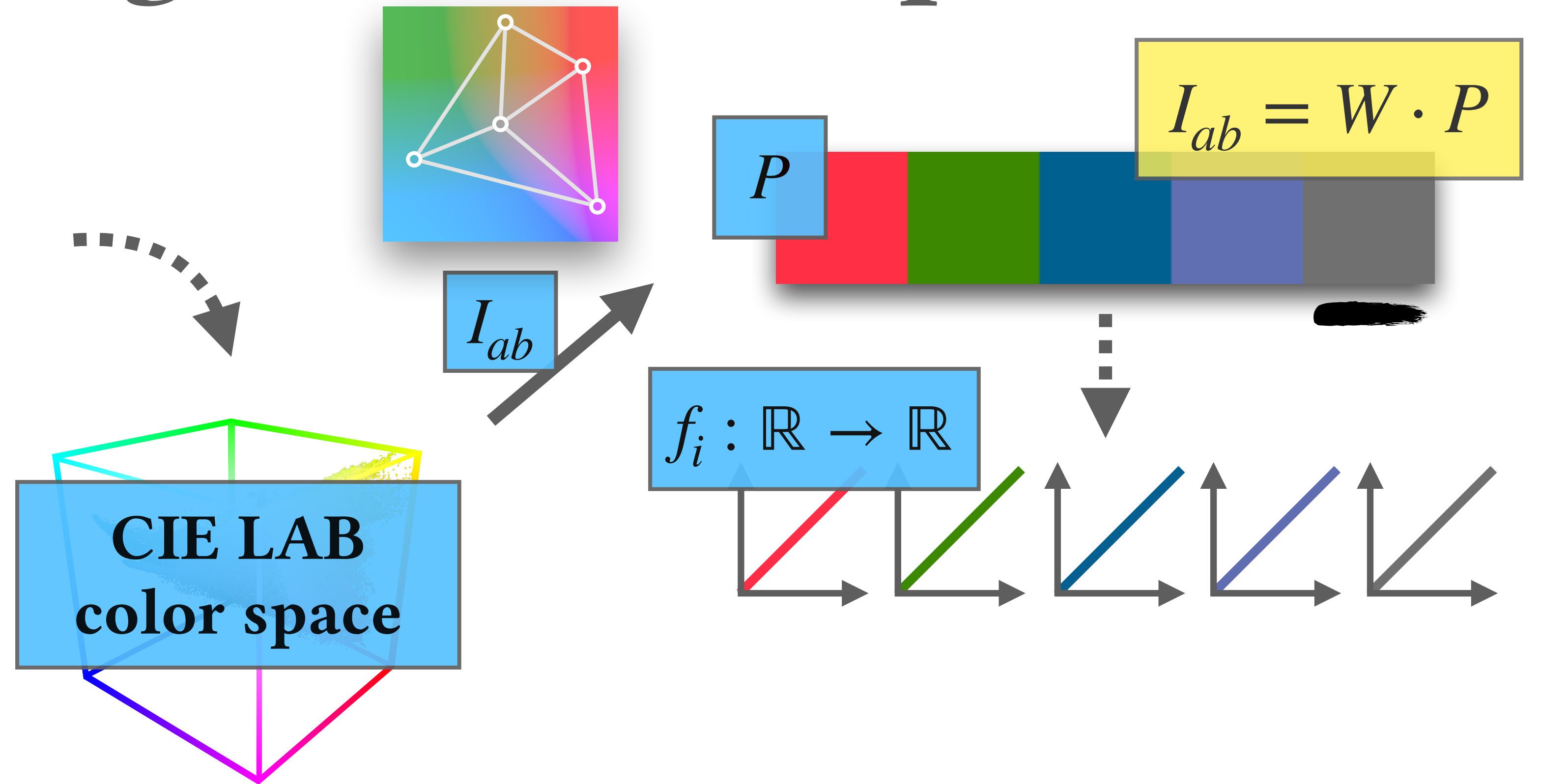
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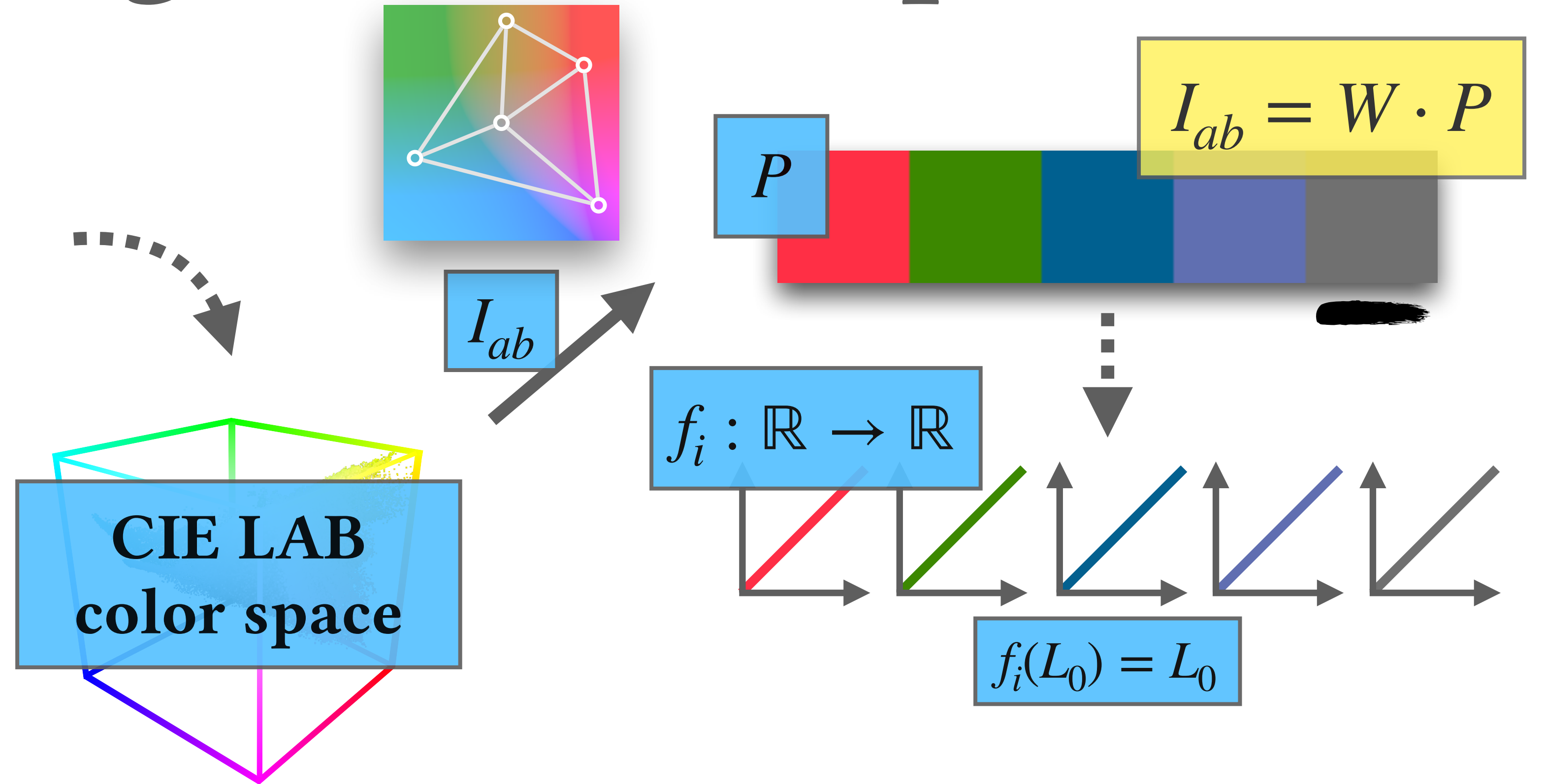
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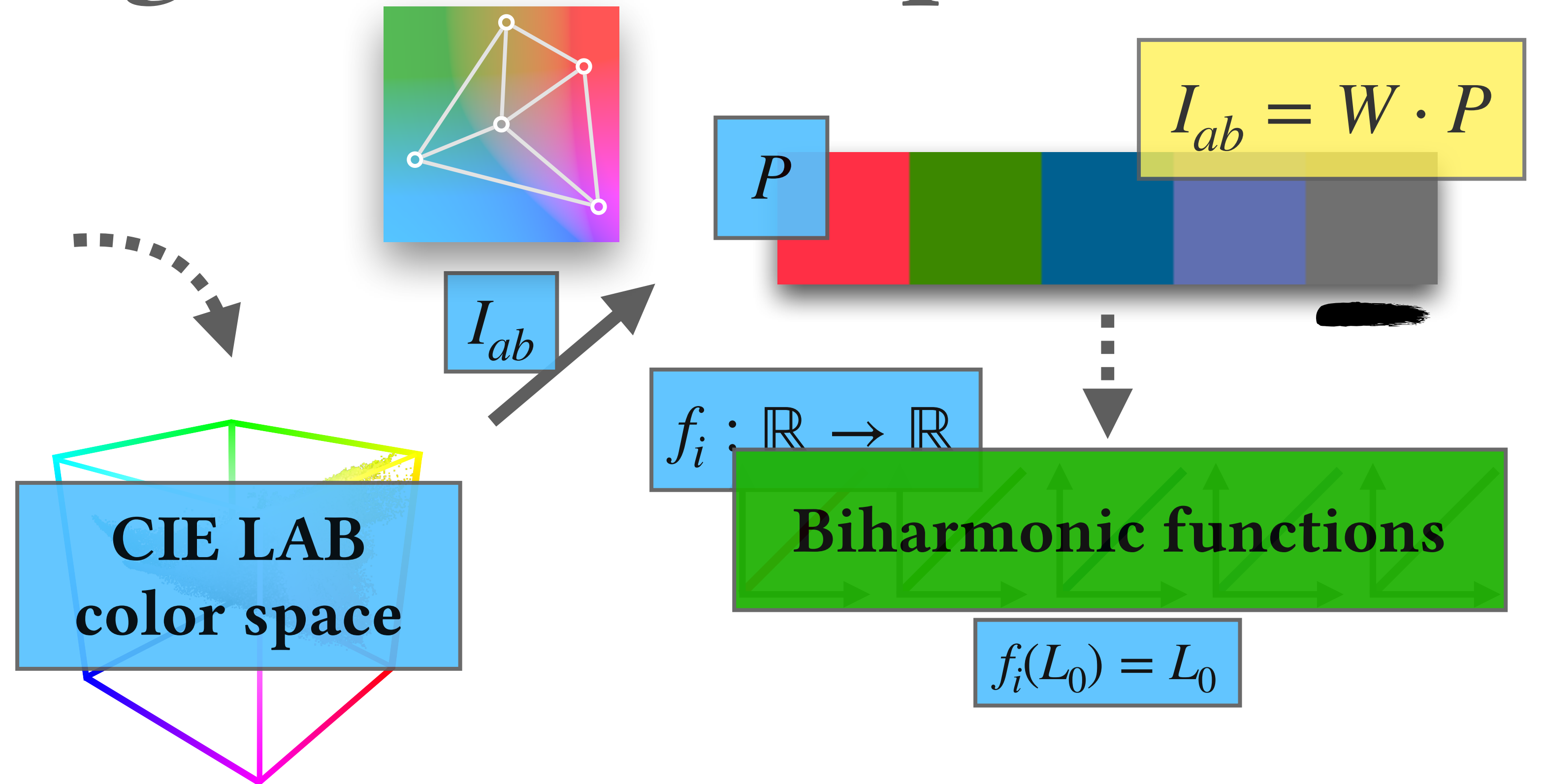
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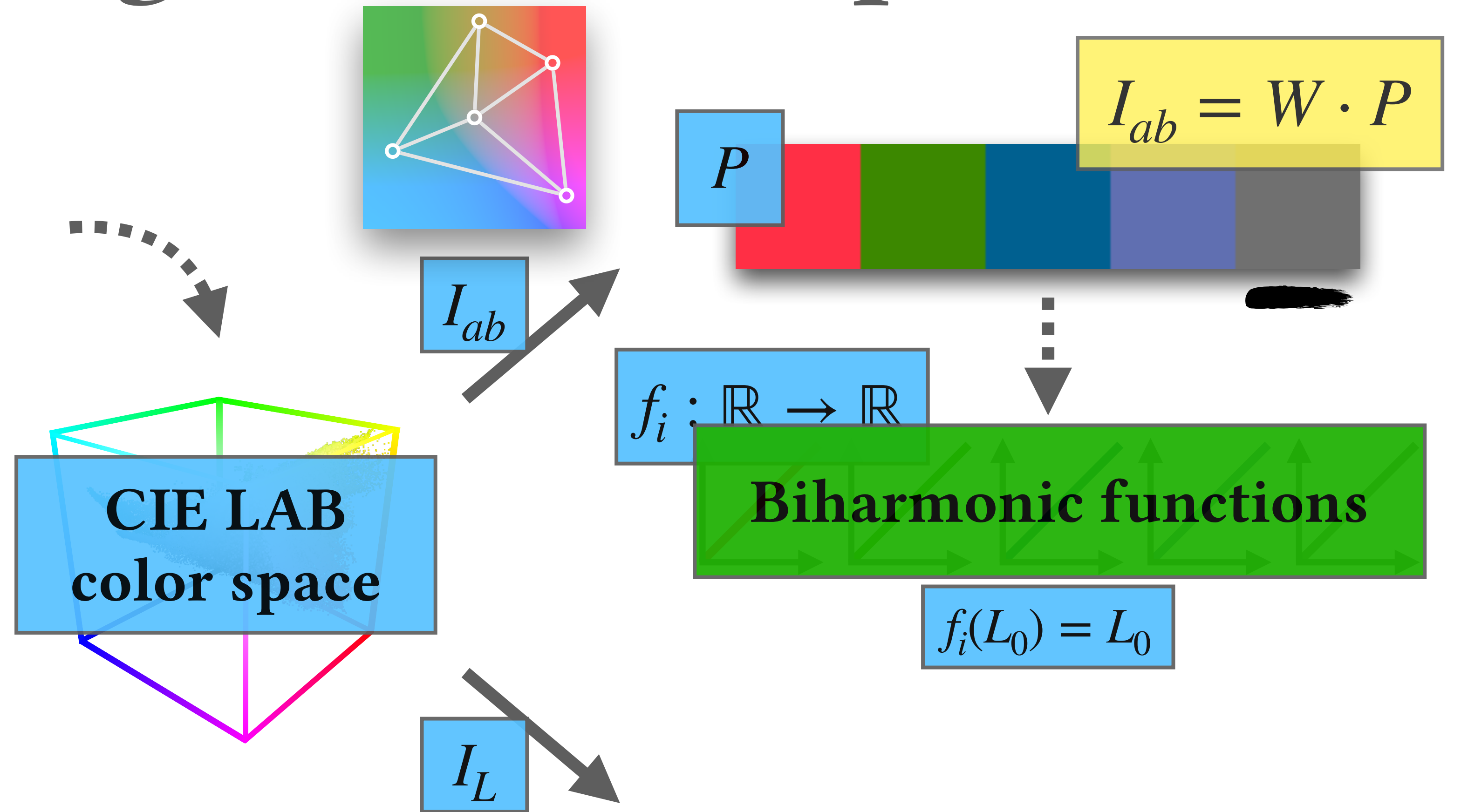
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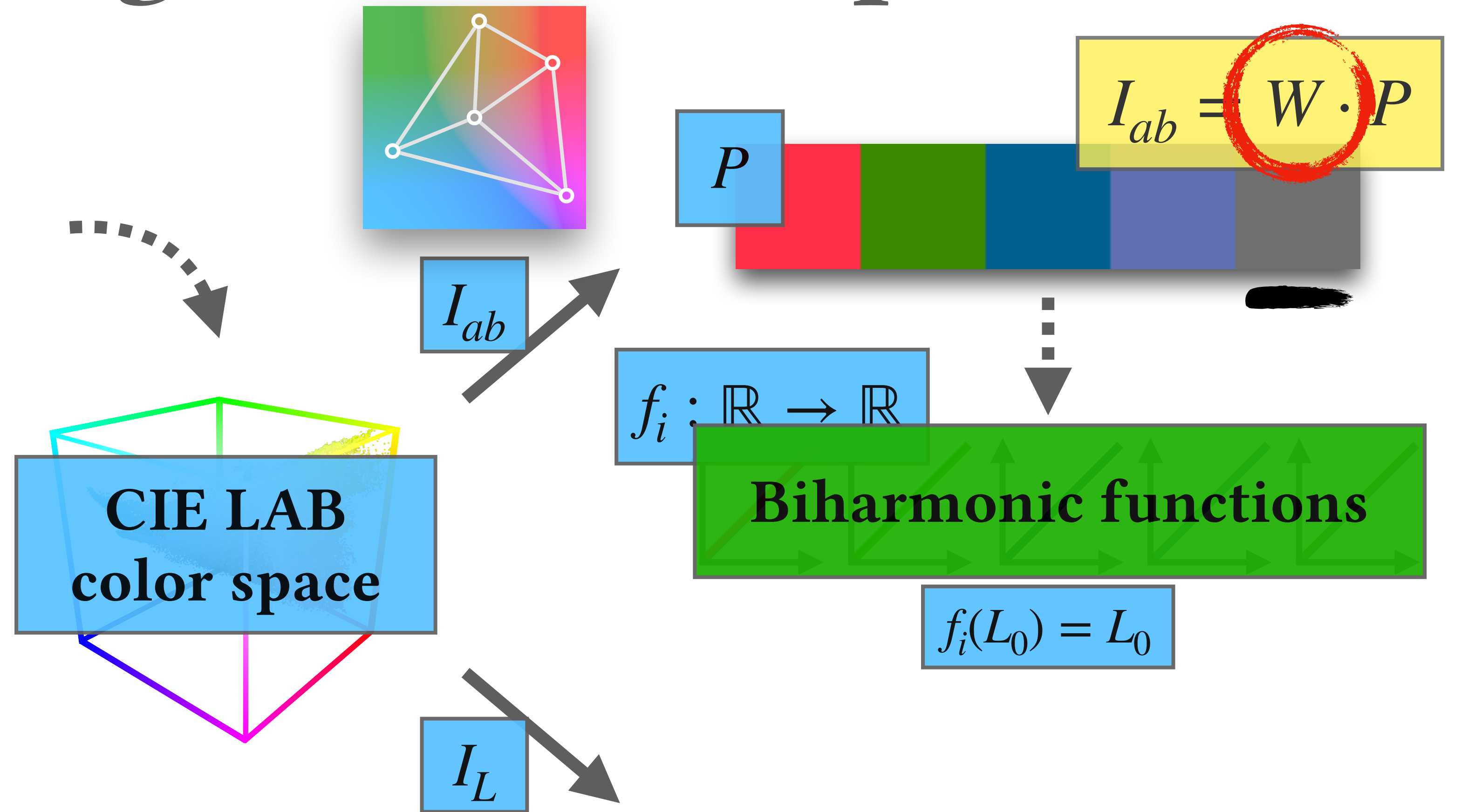
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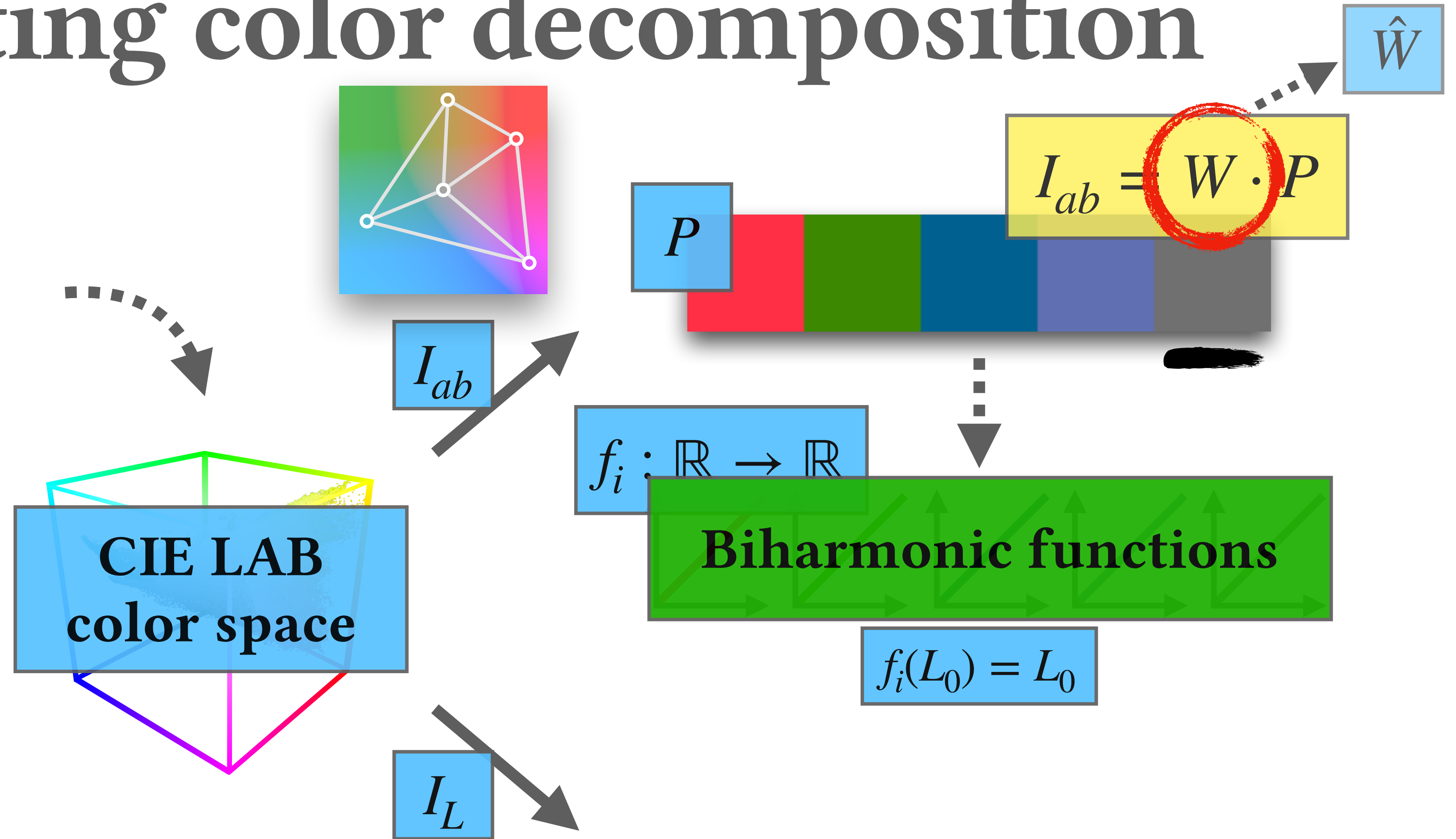
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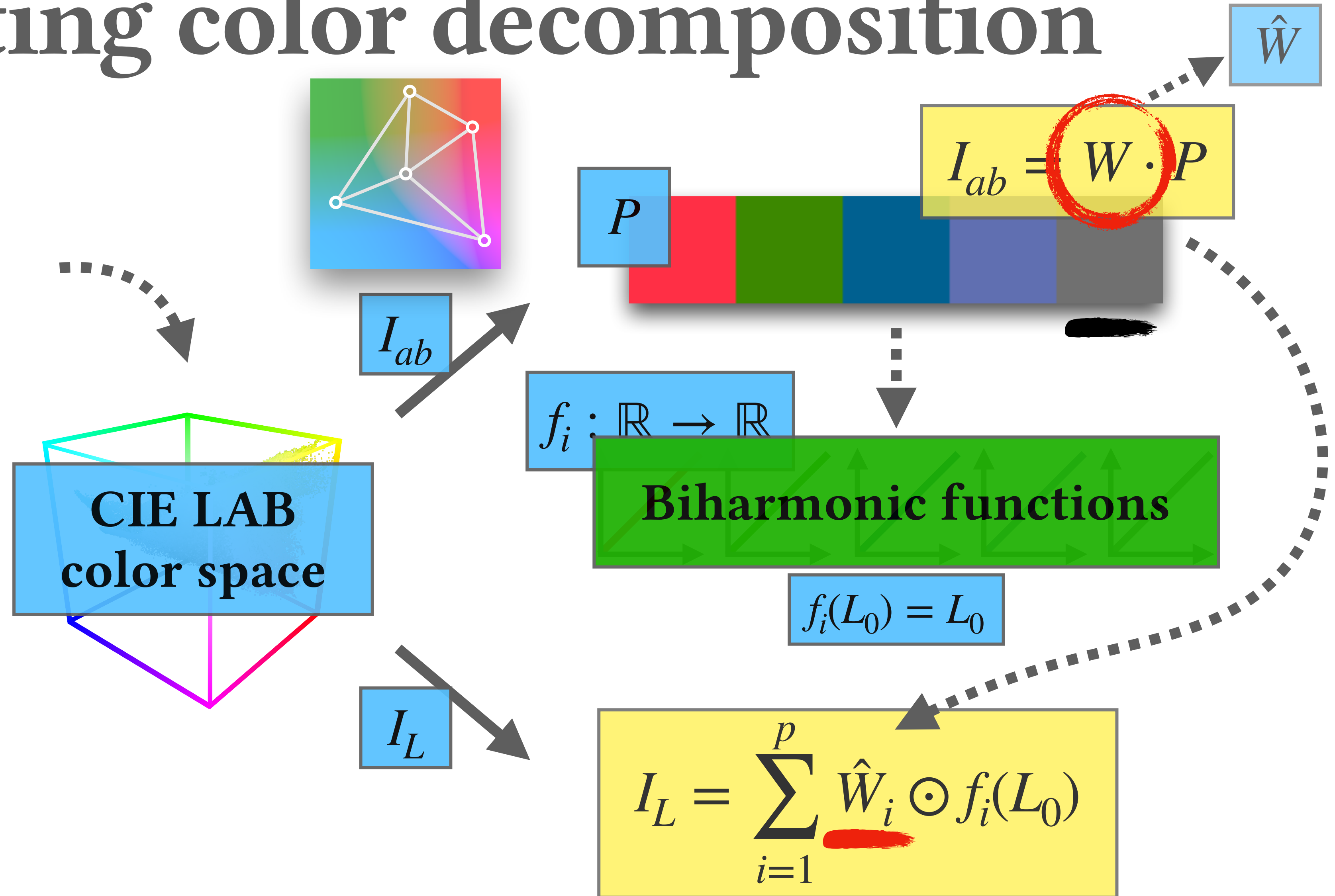
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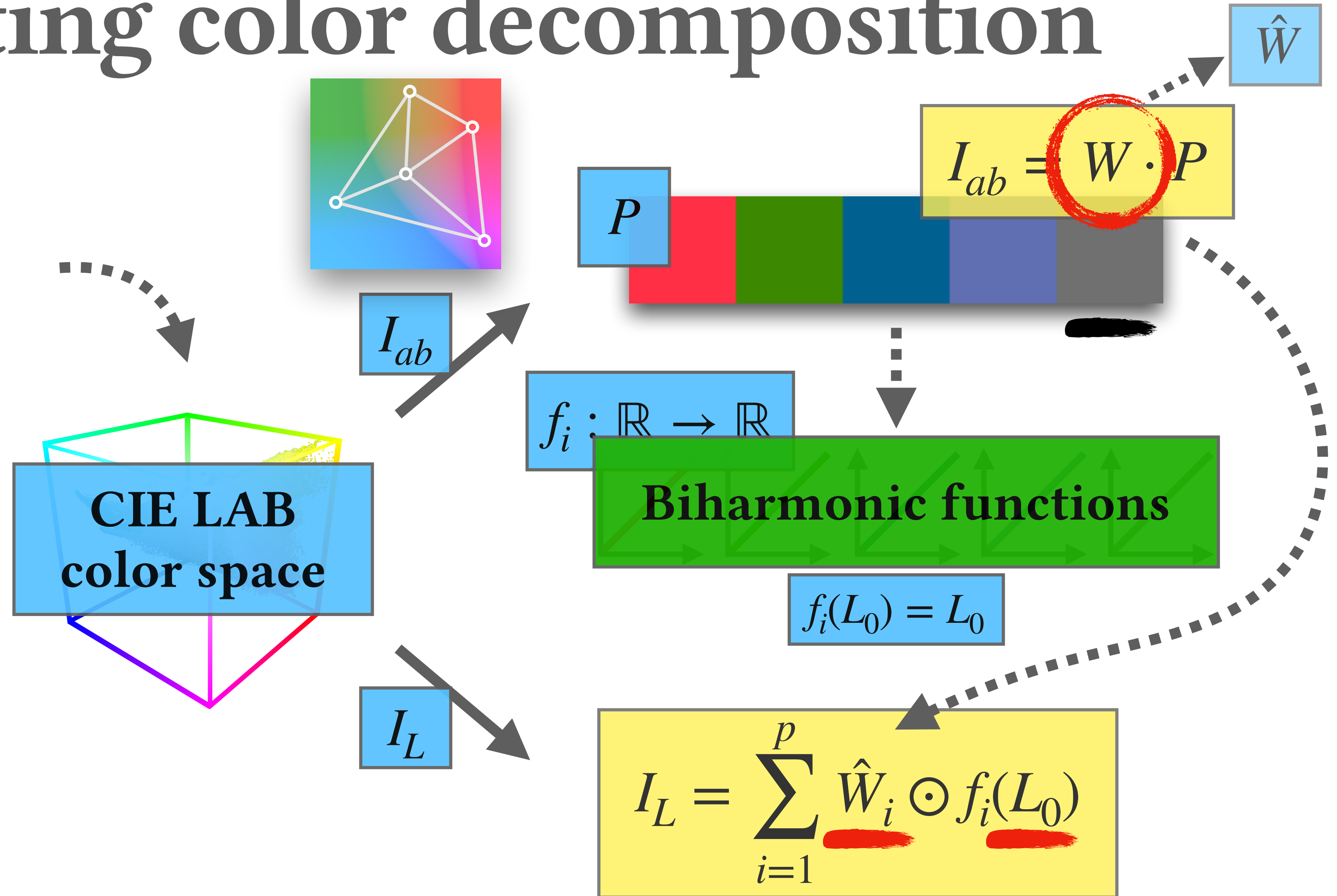
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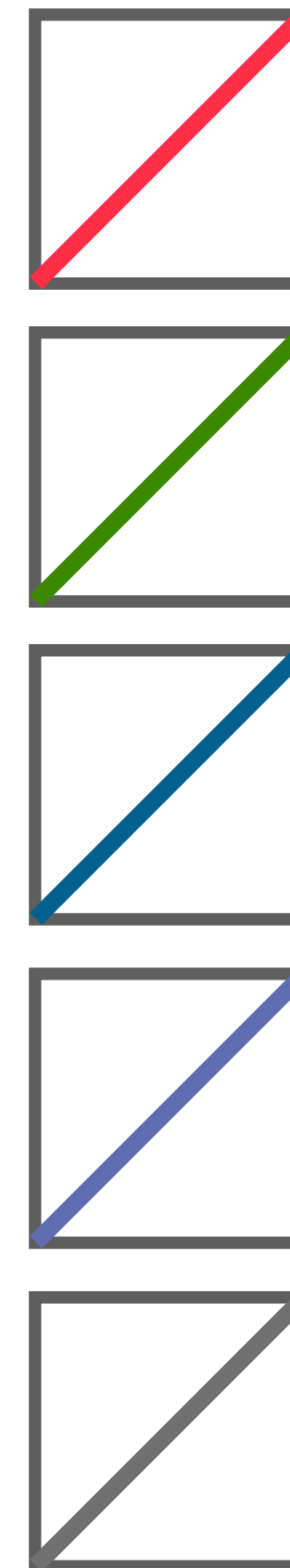
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Re-formulating color decomposition

$$I_{ab} = W \cdot P$$

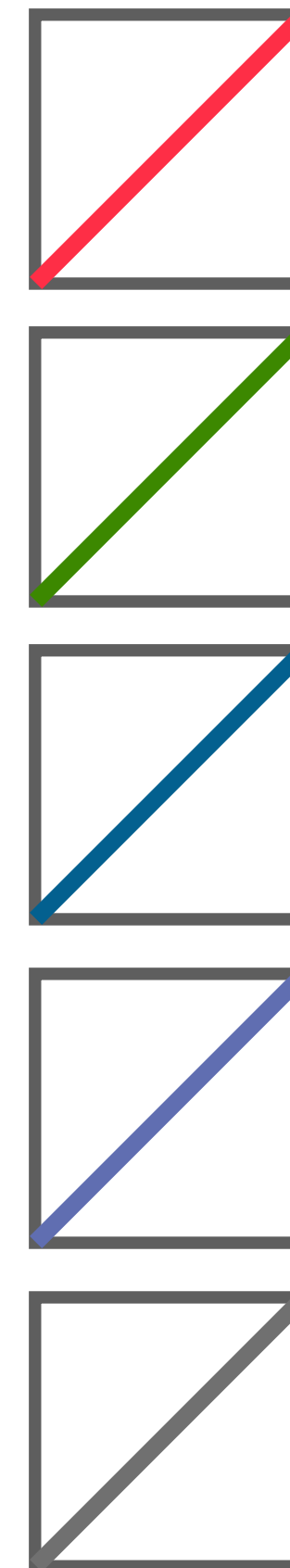
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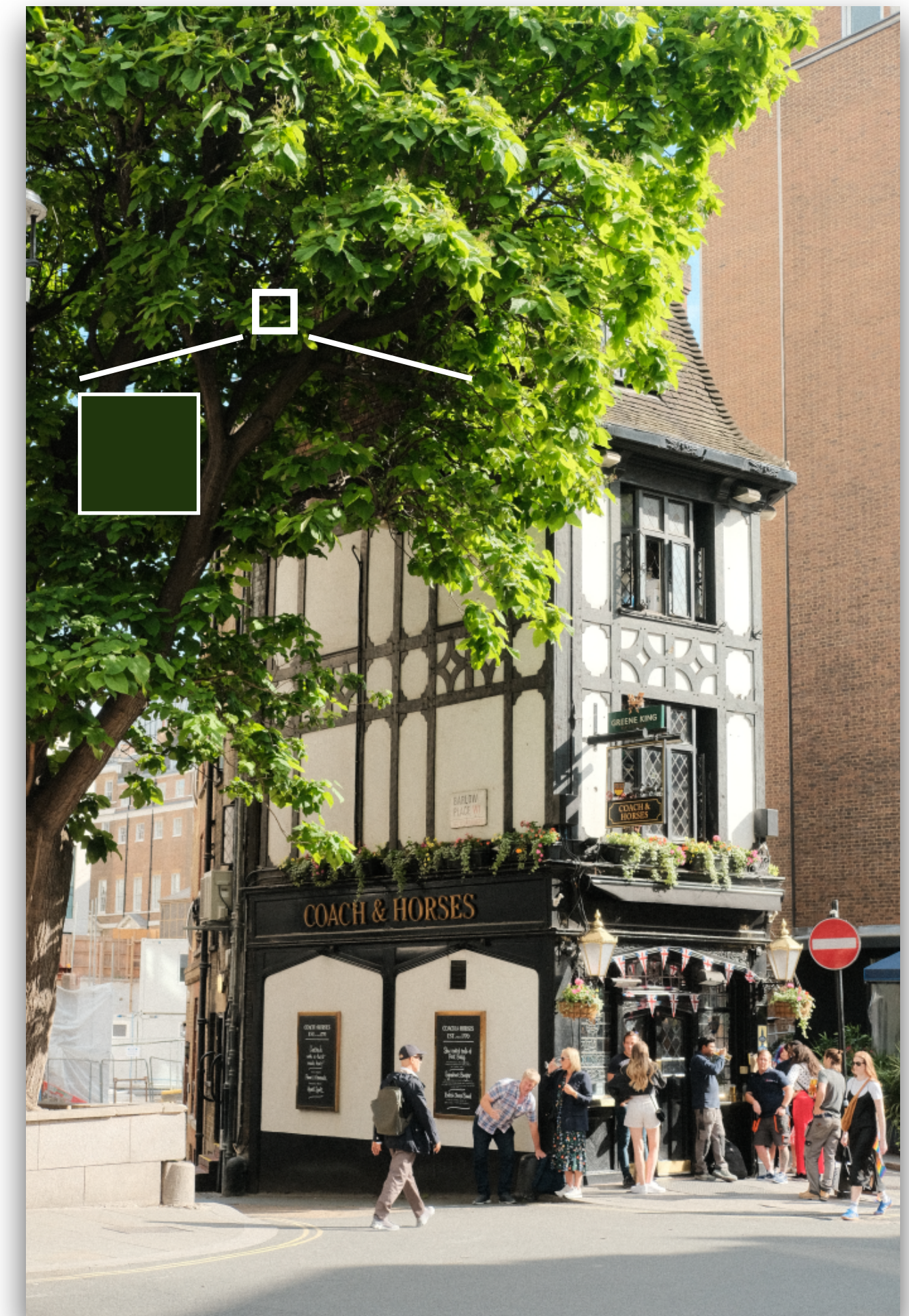
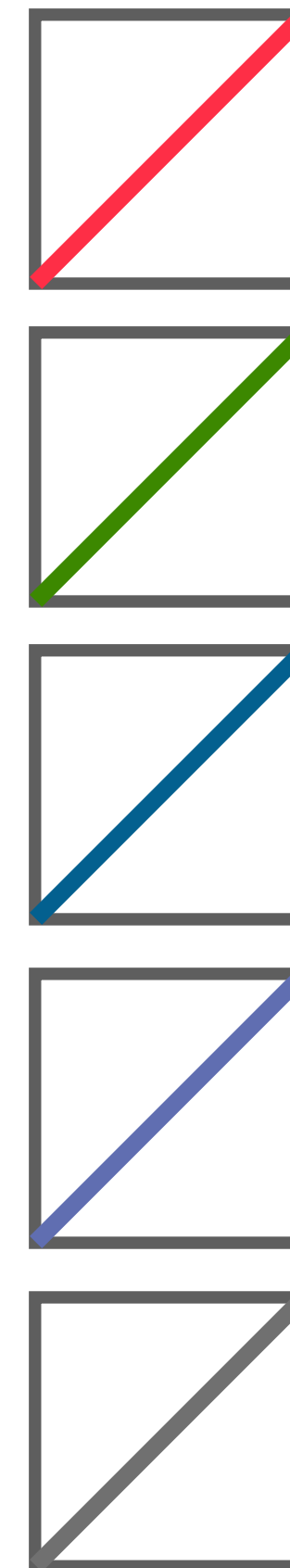
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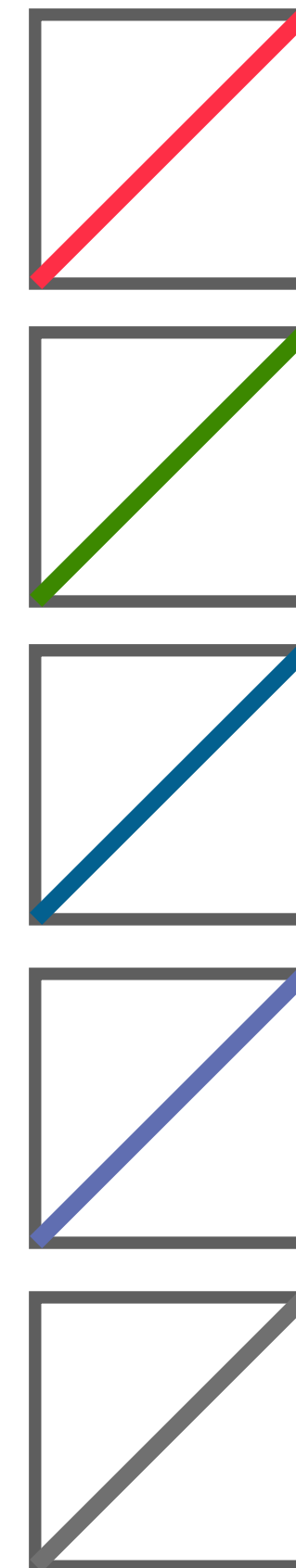
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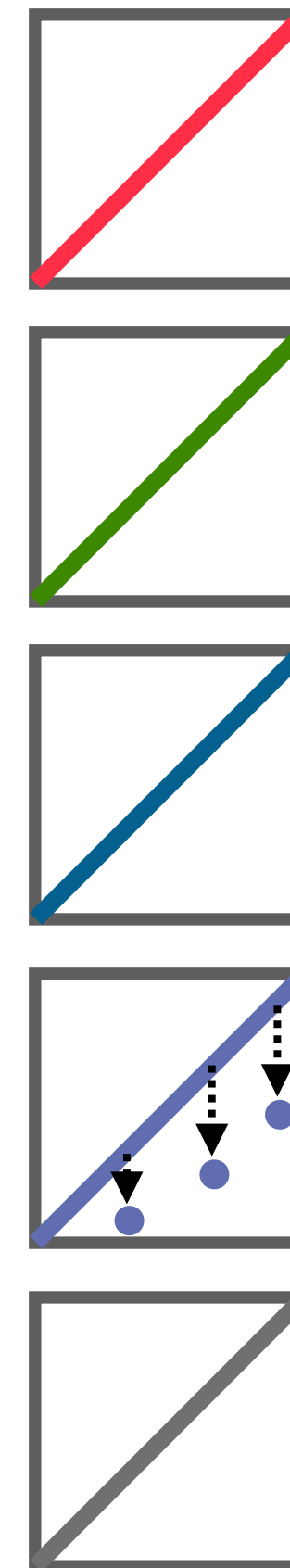
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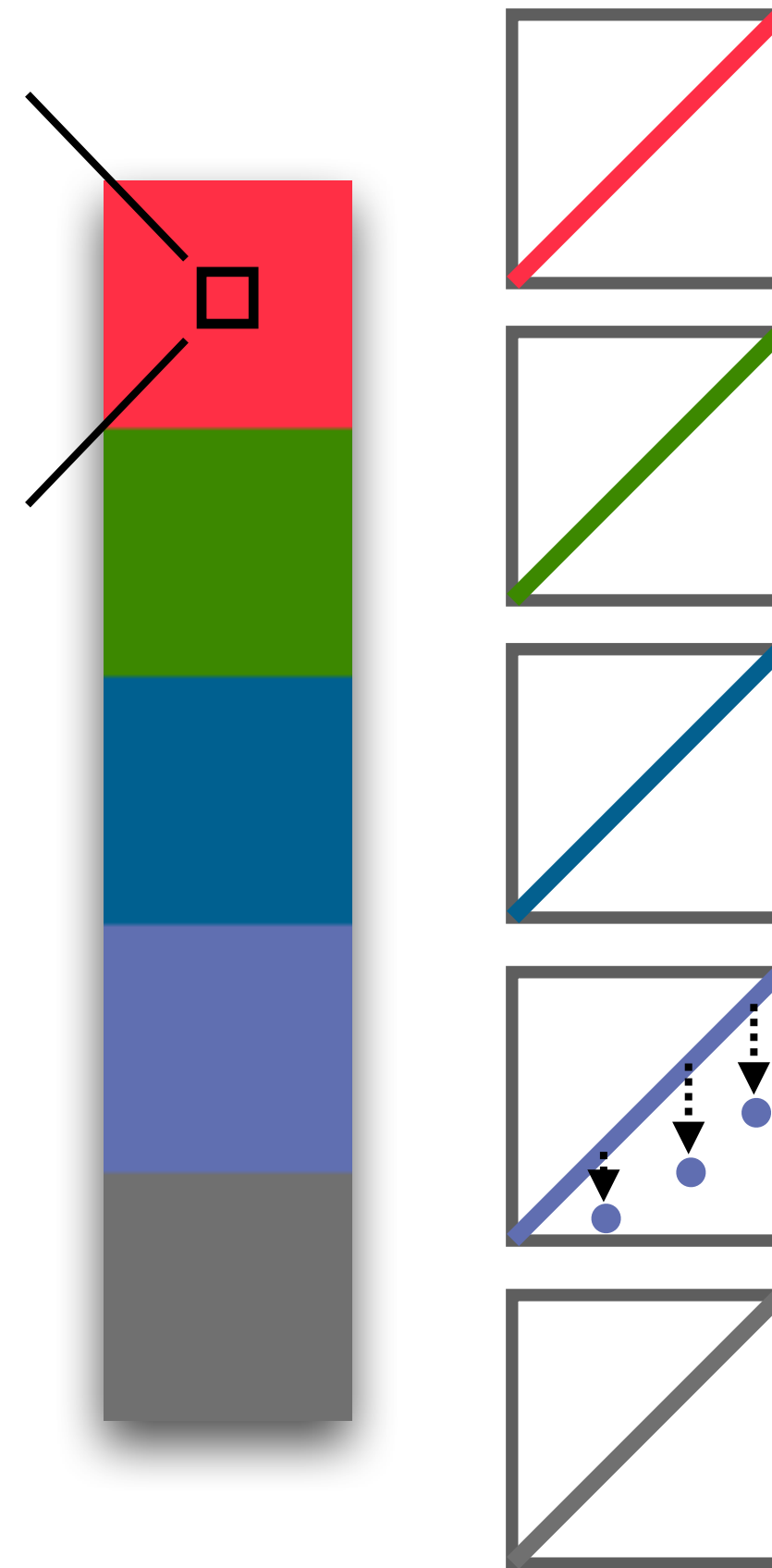
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$$I_{ab} = W \cdot P$$

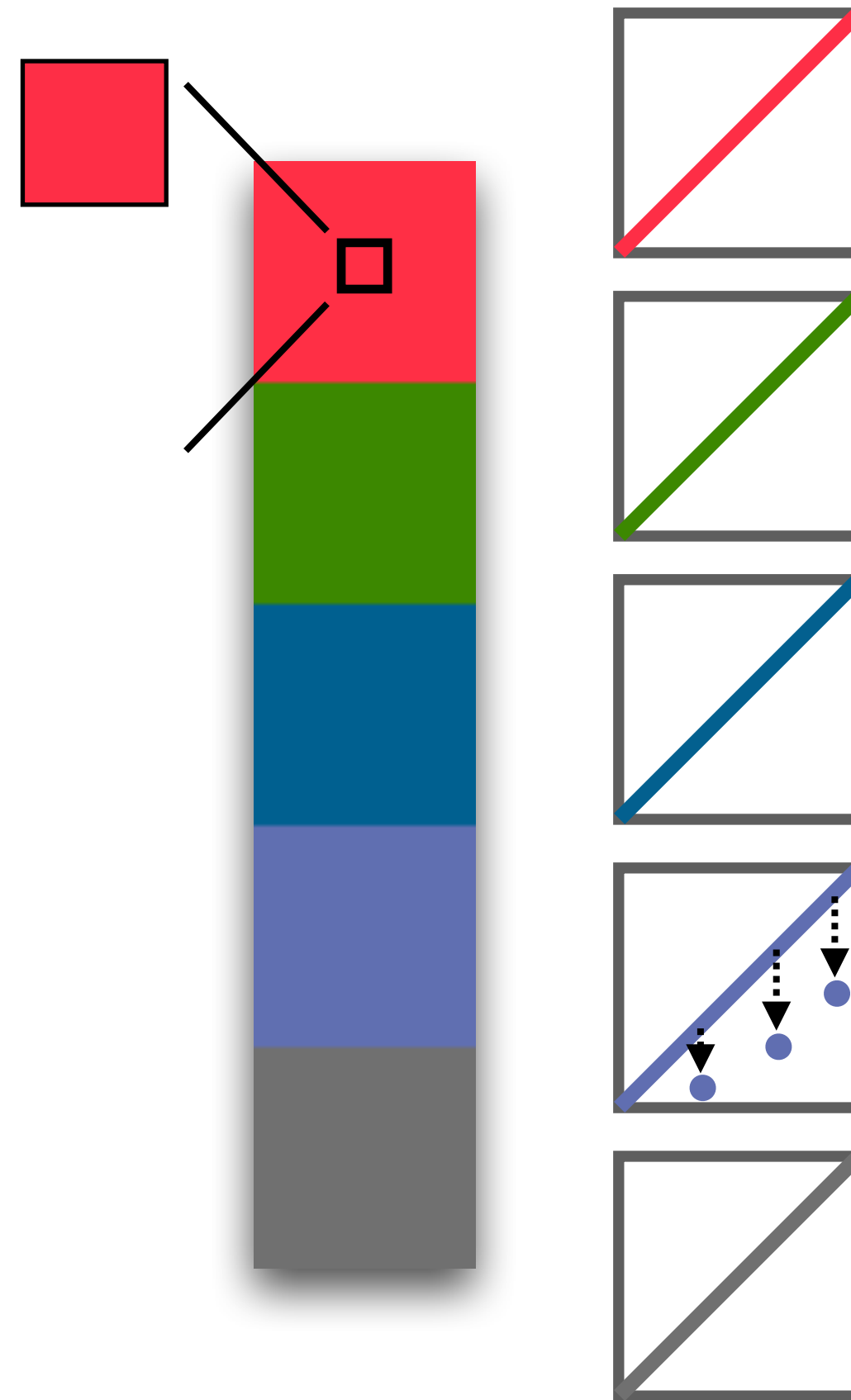
$$I_L = \sum_{i=1}^p \hat{W}_i \odot f_i(L_0)$$



Re-formulating color decomposition

$$I_{ab} = W \cdot P$$

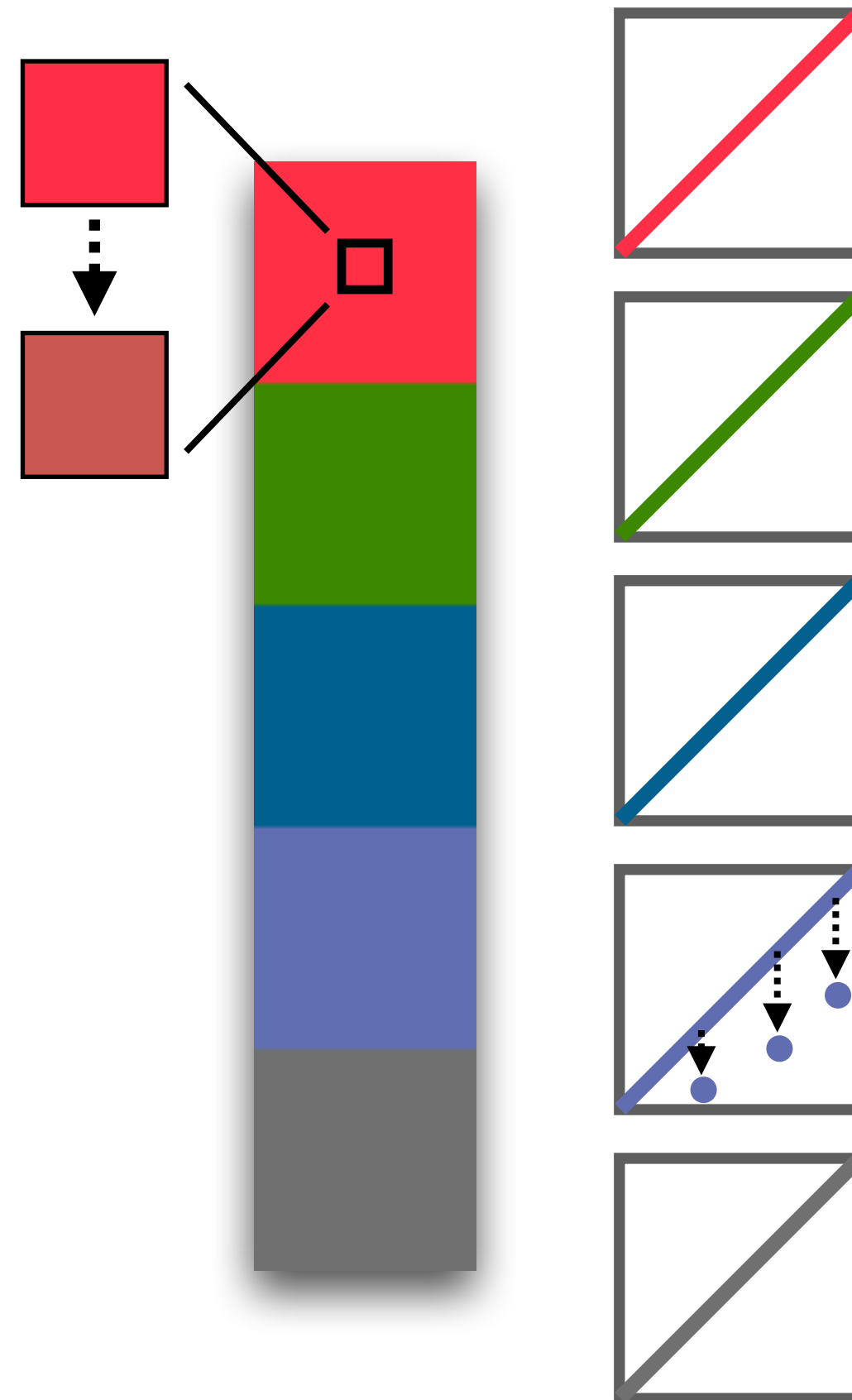
$$I_L = \sum_{i=1}^p \hat{W}_i \odot f_i(L_0)$$



Re-formulating color decomposition

$$I_{ab} = W \cdot P$$

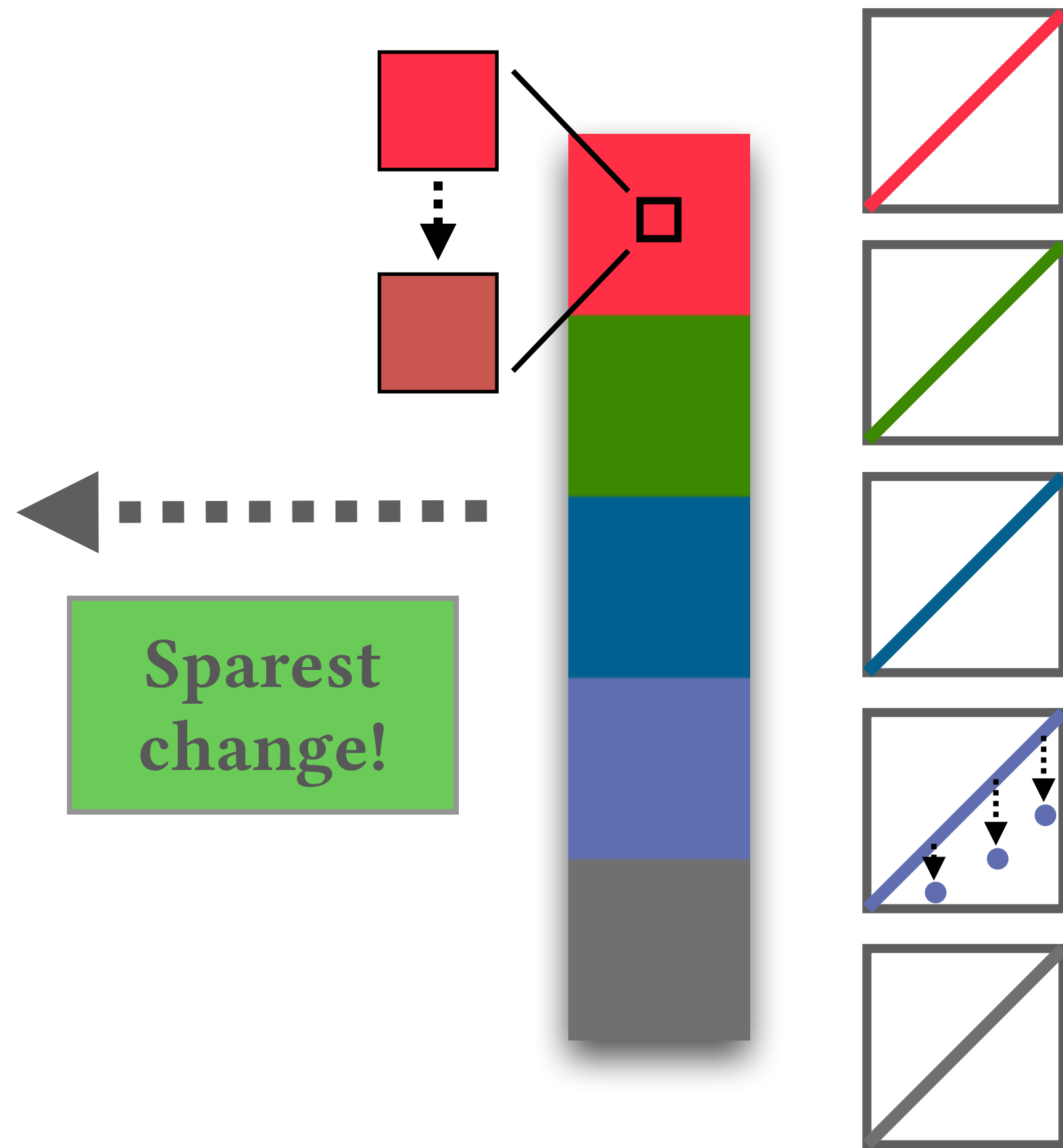
$$I_L = \sum_{i=1}^p \hat{W}_i \odot f_i(L_0)$$



Re-formulating color decomposition

$$I_{ab} = W \cdot P^*$$

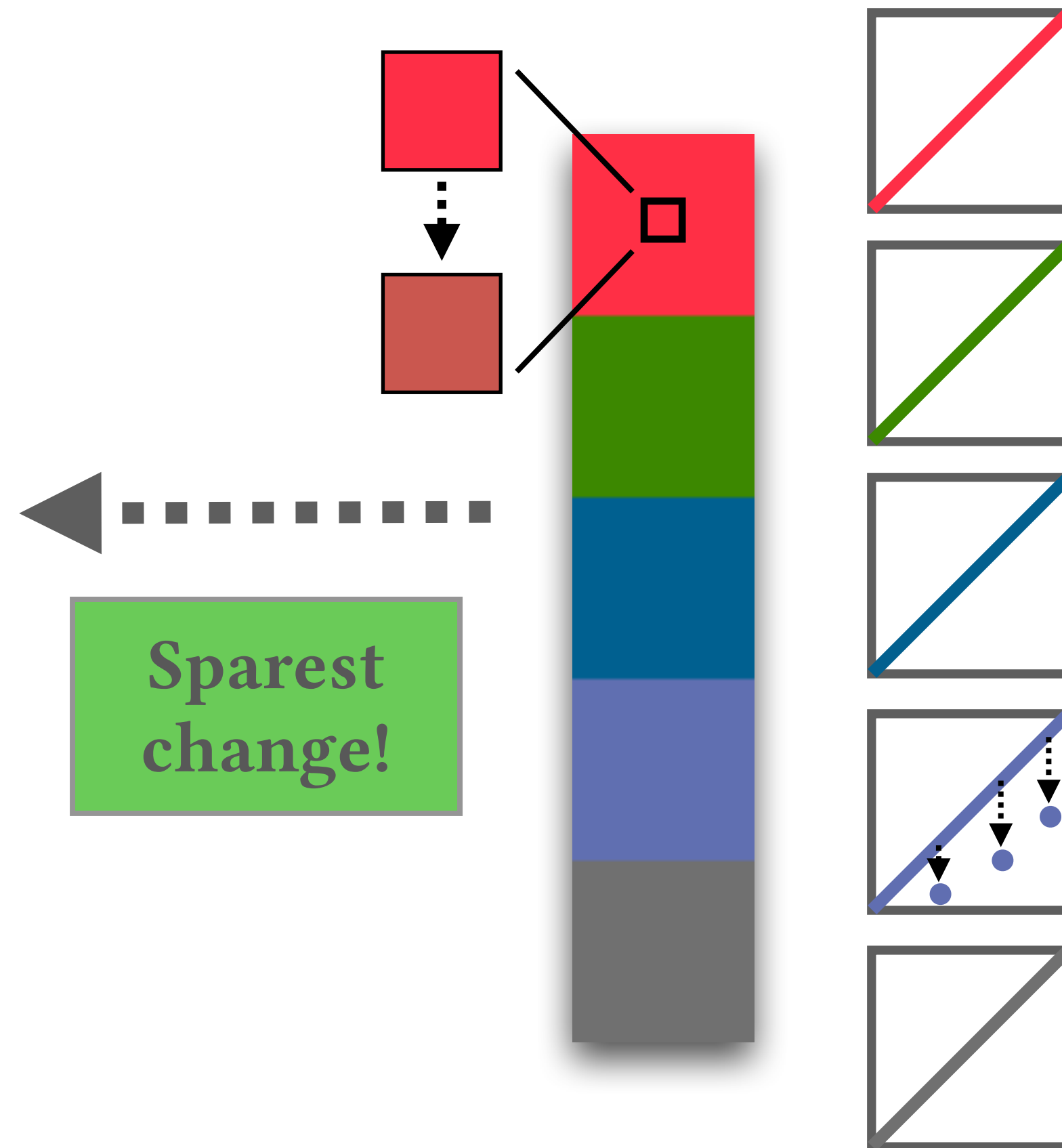
$$I_L = \sum_{i=1}^p \hat{W}_i \odot f_i^*(L_0)$$



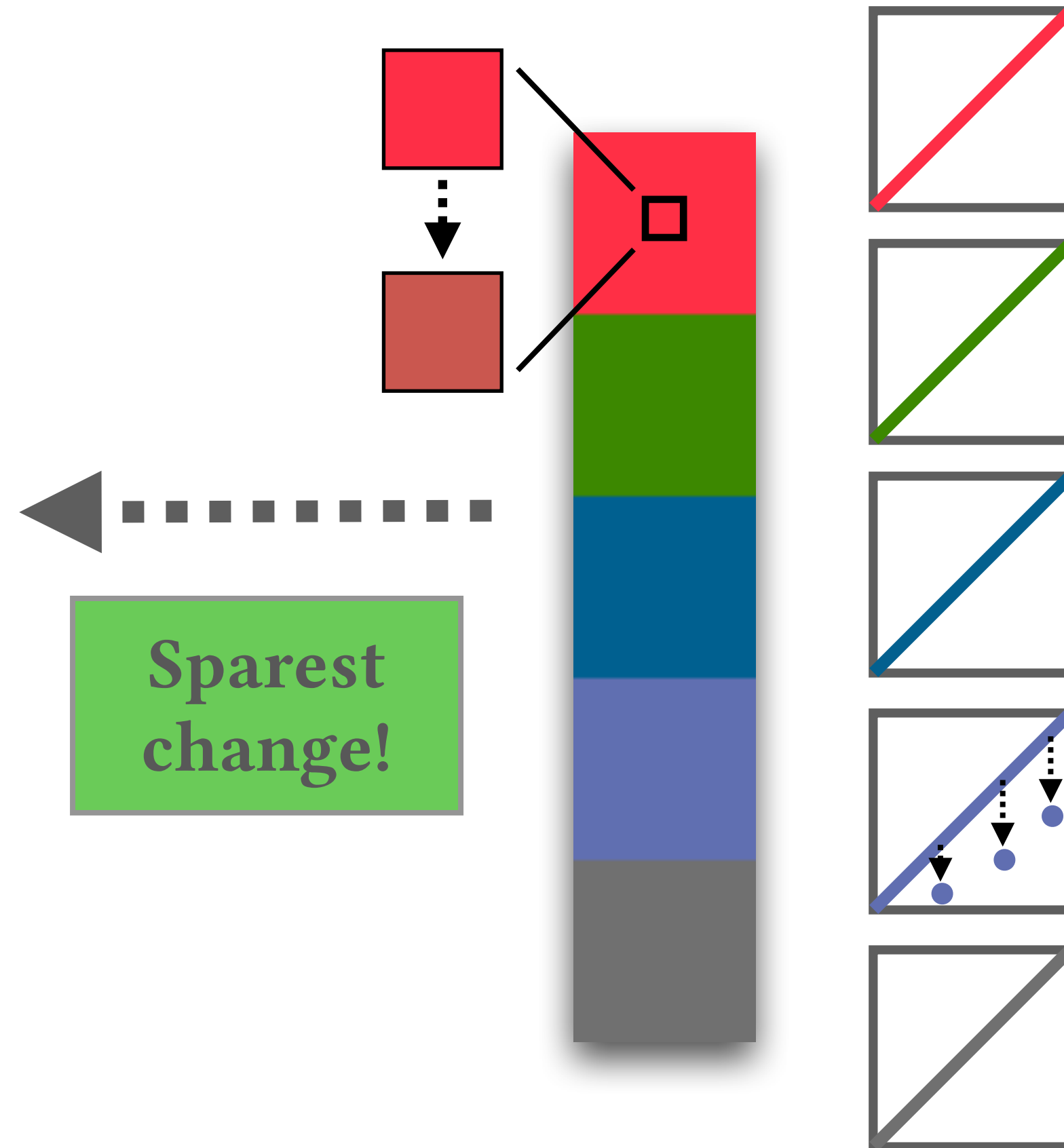
Re-formulating color decomposition

$$I_{ab}^* = W \cdot P^*$$

$$I_L^* = \sum_{i=1}^p \hat{W}_i \odot f_i^*(L_0)$$



Re-formulating color decomposition



Optimizing for sparse edits

 Find the **sparsest change** to palette and curves that **satisfy constraints**

Optimizing for sparse edits

 Find the **sparsest change** to palette and curves that **satisfy constraints**

Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**

$$E_{sp} = \sum_{i=1}^p \sqrt{L_i^T B^T B L_i + w_{sp} \cdot \|q_i \cdot \Delta P_{i,*}\|_2^2}$$

Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**

$L_{2,1}$ norm

$$E_{sp} = \sum_{i=1}^p \sqrt{L_i^T B^T B L_i + w_{sp} \cdot \|q_i \cdot \Delta P_{i,*}\|_2^2}$$

Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**

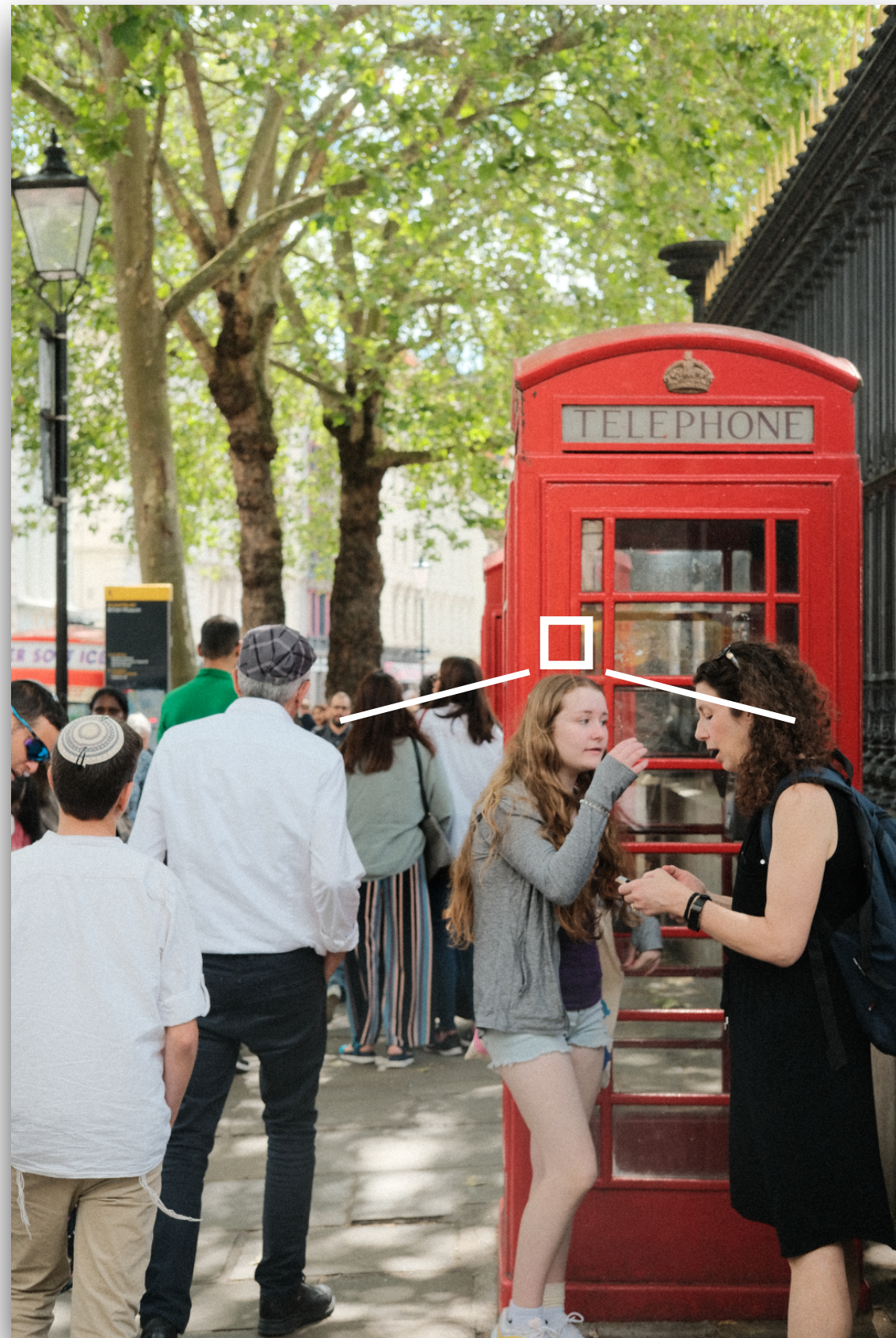


$L_{2,1}$ norm

$$E_{sp} = \sum_{i=1}^p \sqrt{L_i^T B^T B L_i + w_{sp} \cdot \|q_i \cdot \Delta P_{i,*}\|_2^2}$$

Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**

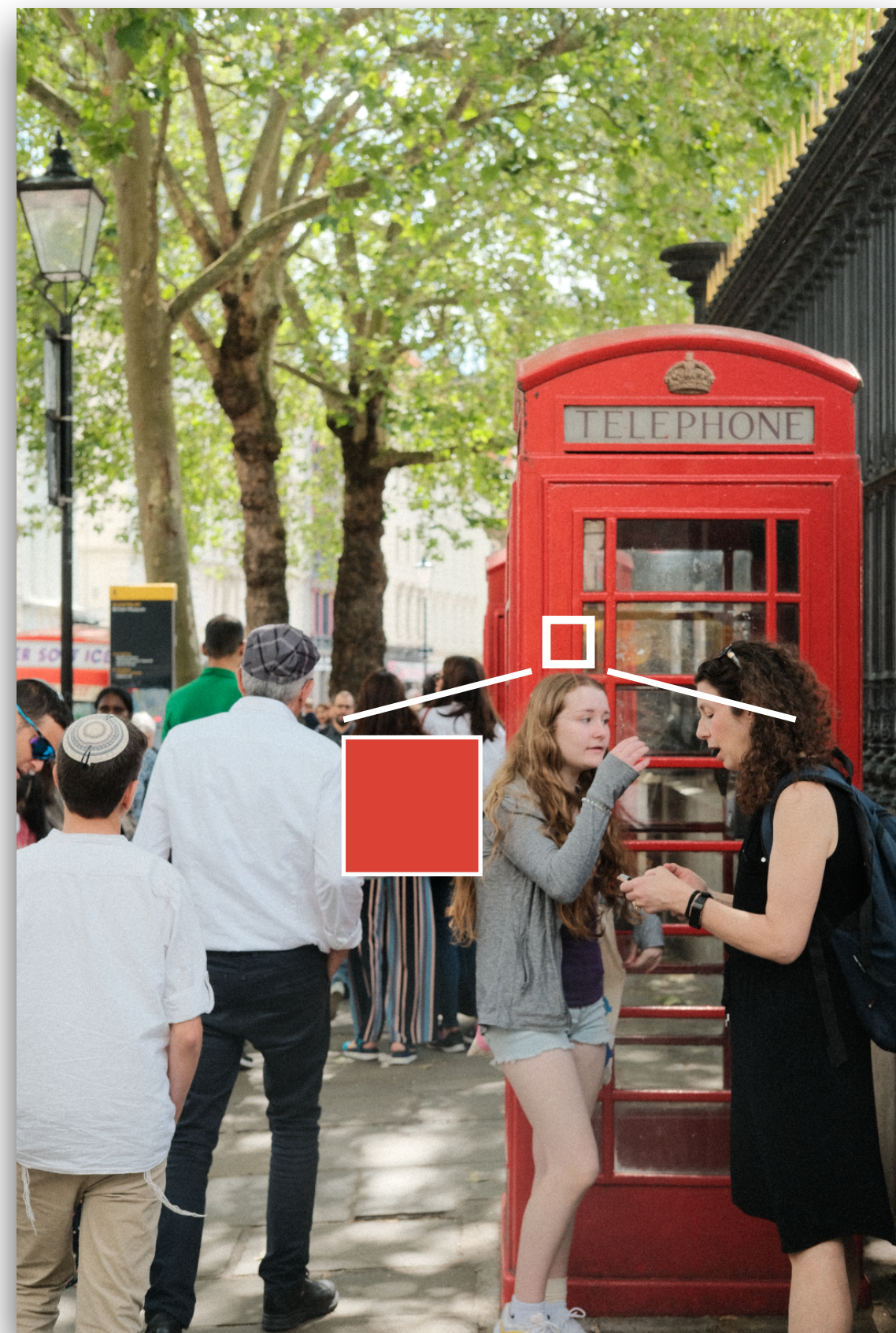


$L_{2,1}$ norm

$$E_{sp} = \sum_{i=1}^p \sqrt{L_i^T B^T B L_i + w_{sp} \cdot \|q_i \cdot \Delta P_{i,*}\|_2^2}$$

Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**

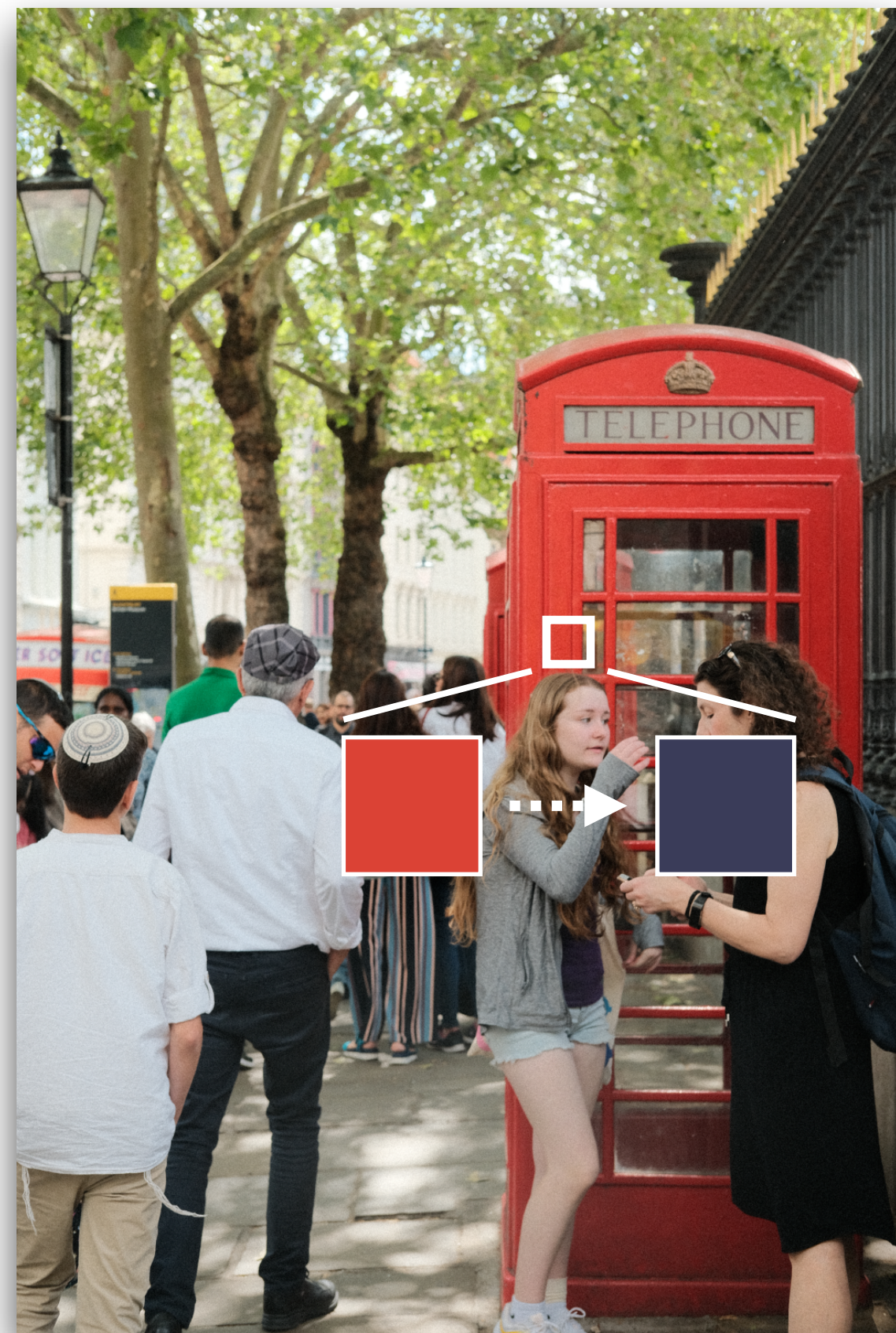


$L_{2,1}$ norm

$$E_{sp} = \sum_{i=1}^p \sqrt{L_i^T B^T B L_i + w_{sp} \cdot \|q_i \cdot \Delta P_{i,*}\|_2^2}$$

Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**

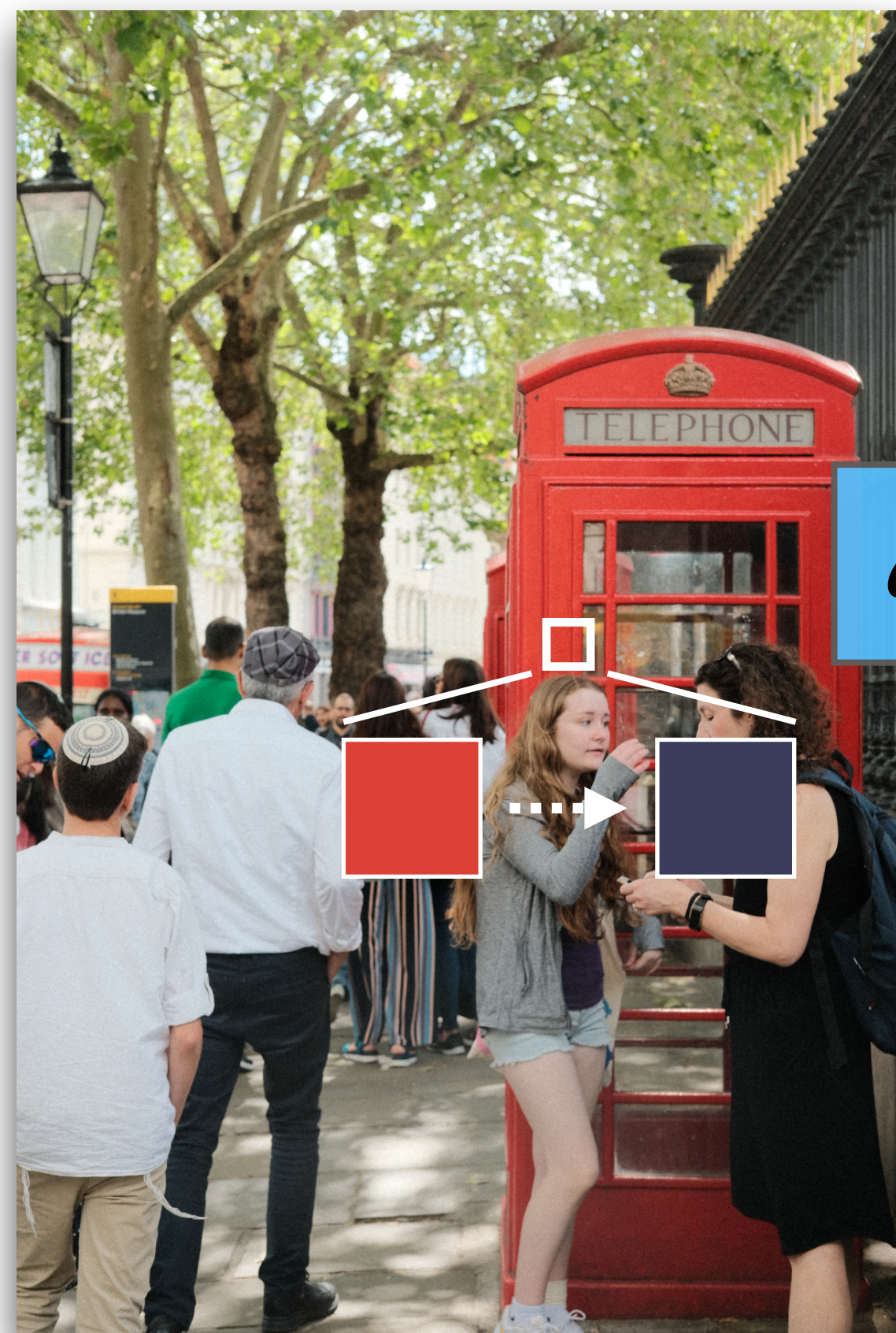


$L_{2,1}$ norm

$$E_{sp} = \sum_{i=1}^p \sqrt{L_i^T B^T B L_i + w_{sp} \cdot \|q_i \cdot \Delta P_{i,*}\|_2^2}$$

Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**

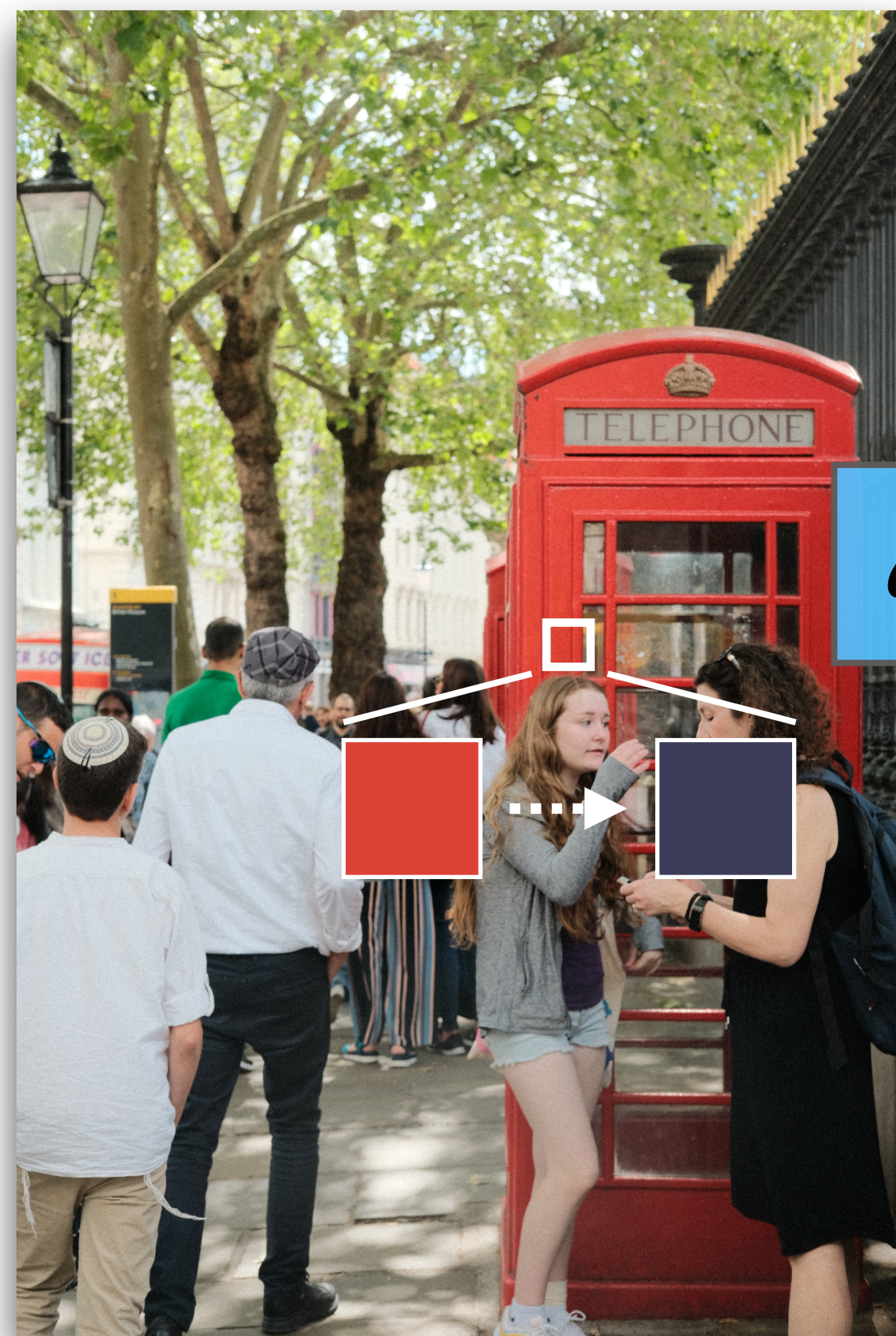


L_{2,1} norm

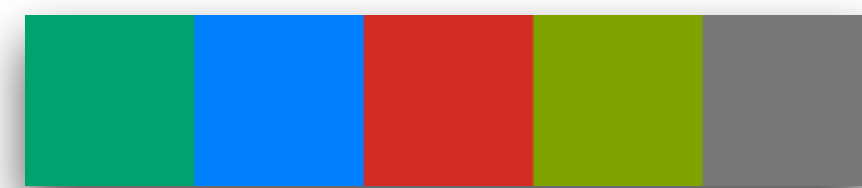
$$E_{sp} = \sum_{i=1}^p \sqrt{L_i^T B^T B L_i + w_{sp} \cdot \|q_i \cdot \Delta P_{i,*}\|_2^2}$$

Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**



ab

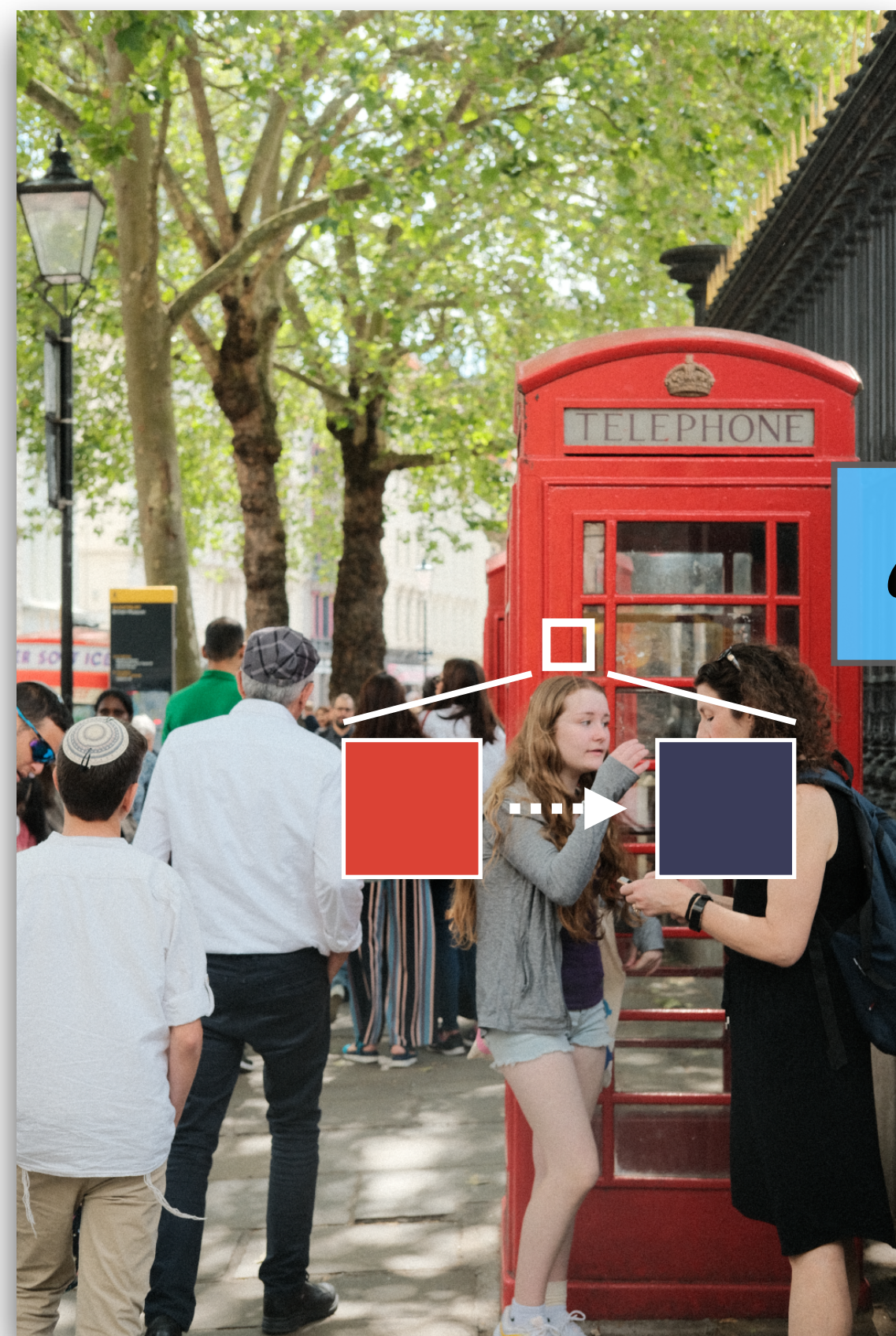


L_{2,1} norm

$$E_{sp} = \sum_{i=1}^p \sqrt{L_i^T B^T B L_i + w_{sp} \cdot \|q_i \cdot \Delta P_{i,*}\|_2^2}$$

Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**

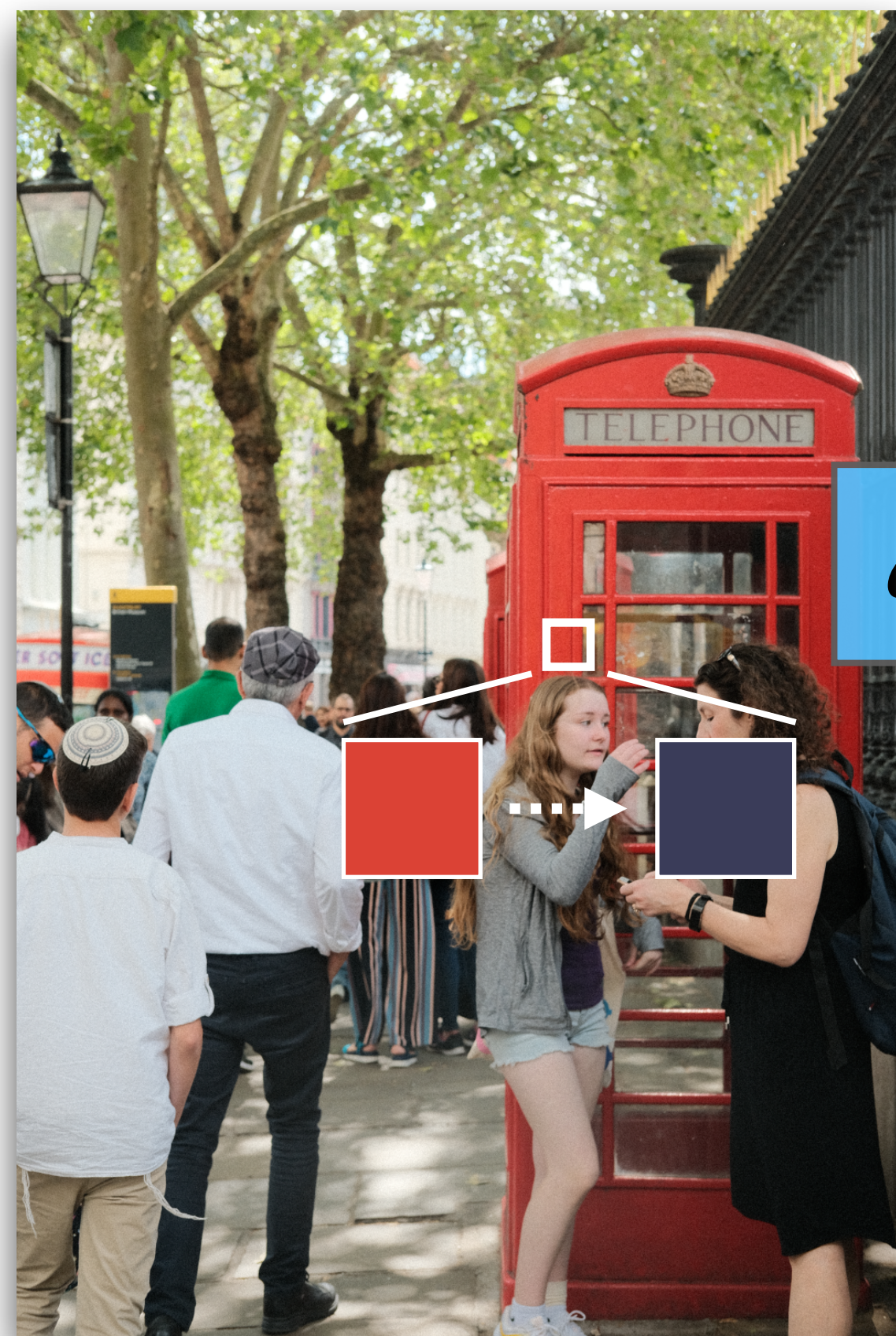


$L_{2,1}$ norm

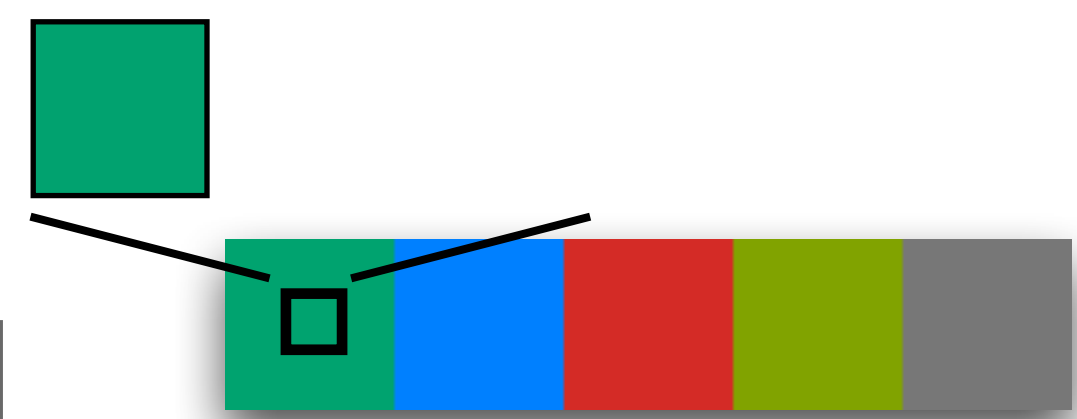
$$E_{sp} = \sum_{i=1}^p \sqrt{L_i^T B^T B L_i + w_{sp} \cdot \|q_i \cdot \Delta P_{i,*}\|_2^2}$$

Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**



ab

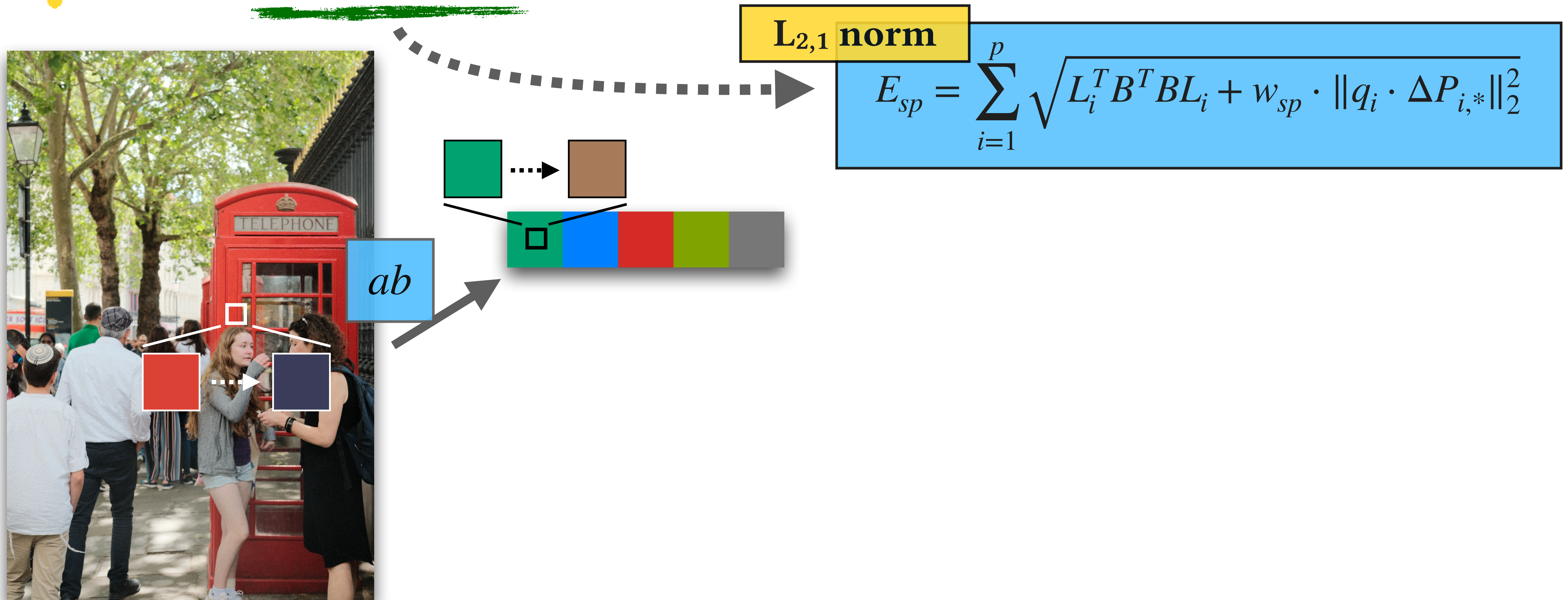


$L_{2,1}$ norm

$$E_{sp} = \sum_{i=1}^p \sqrt{L_i^T B^T B L_i + w_{sp} \cdot \|q_i \cdot \Delta P_{i,*}\|_2^2}$$

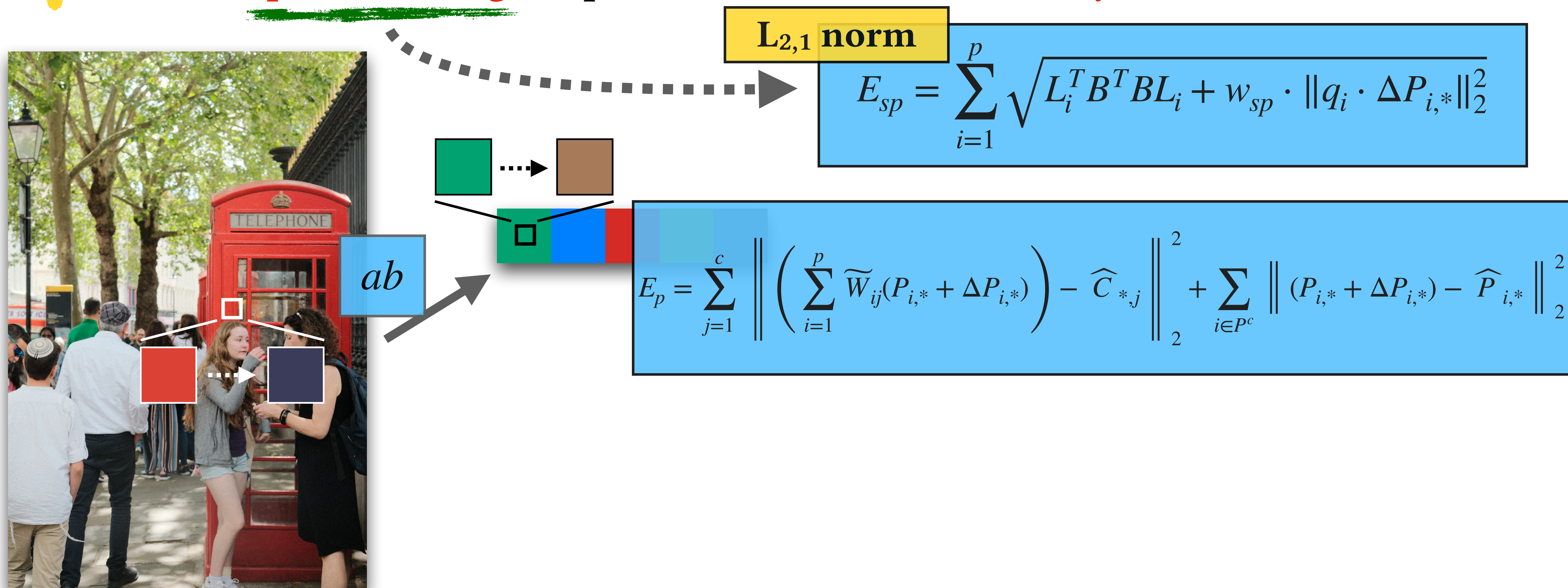
Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**



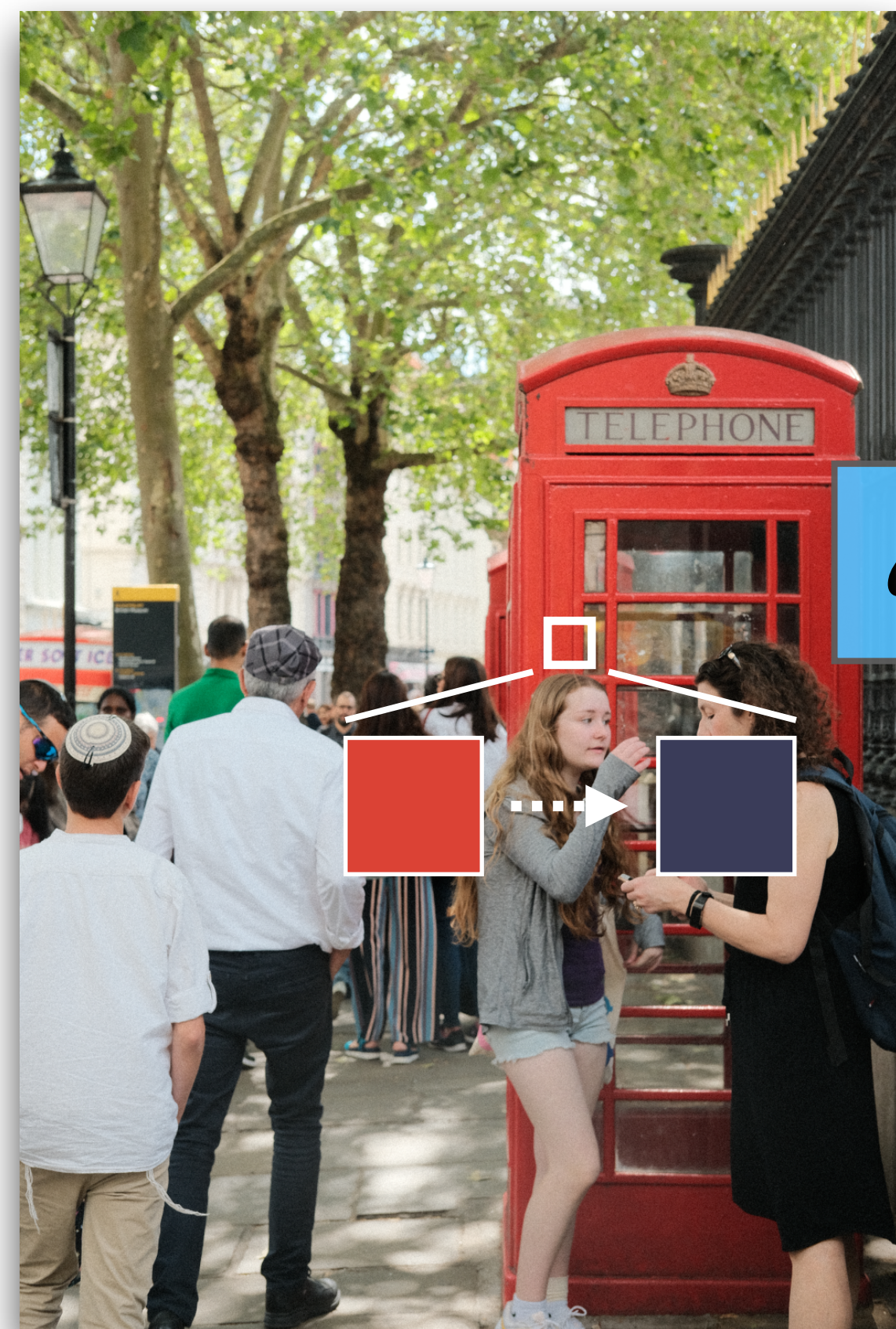
Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**



Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**



L_{2,1} norm

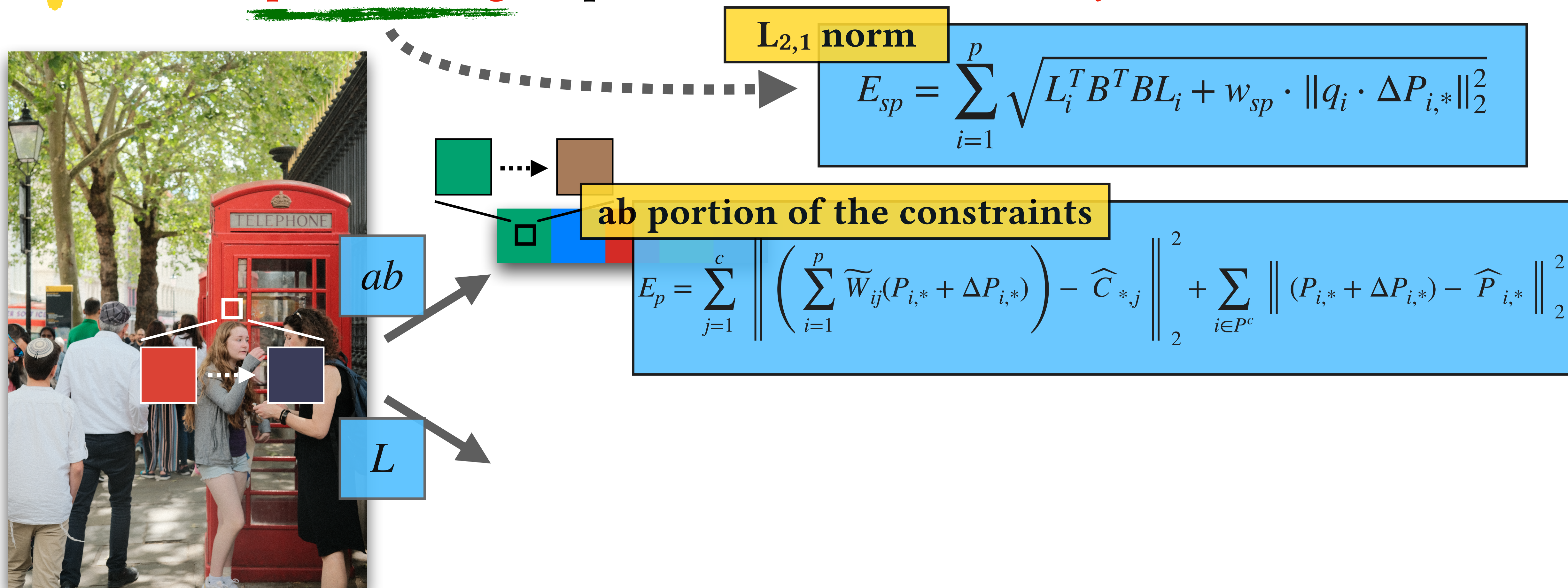
$$E_{sp} = \sum_{i=1}^p \sqrt{L_i^T B^T B L_i + w_{sp} \cdot \|q_i \cdot \Delta P_{i,*}\|_2^2}$$

ab portion of the constraints

$$E_p = \sum_{j=1}^c \left\| \left(\sum_{i=1}^p \widetilde{W}_{ij} (P_{i,*} + \Delta P_{i,*}) \right) - \widehat{C}_{*,j} \right\|_2^2 + \sum_{i \in P^c} \left\| (P_{i,*} + \Delta P_{i,*}) - \widehat{P}_{i,*} \right\|_2^2$$

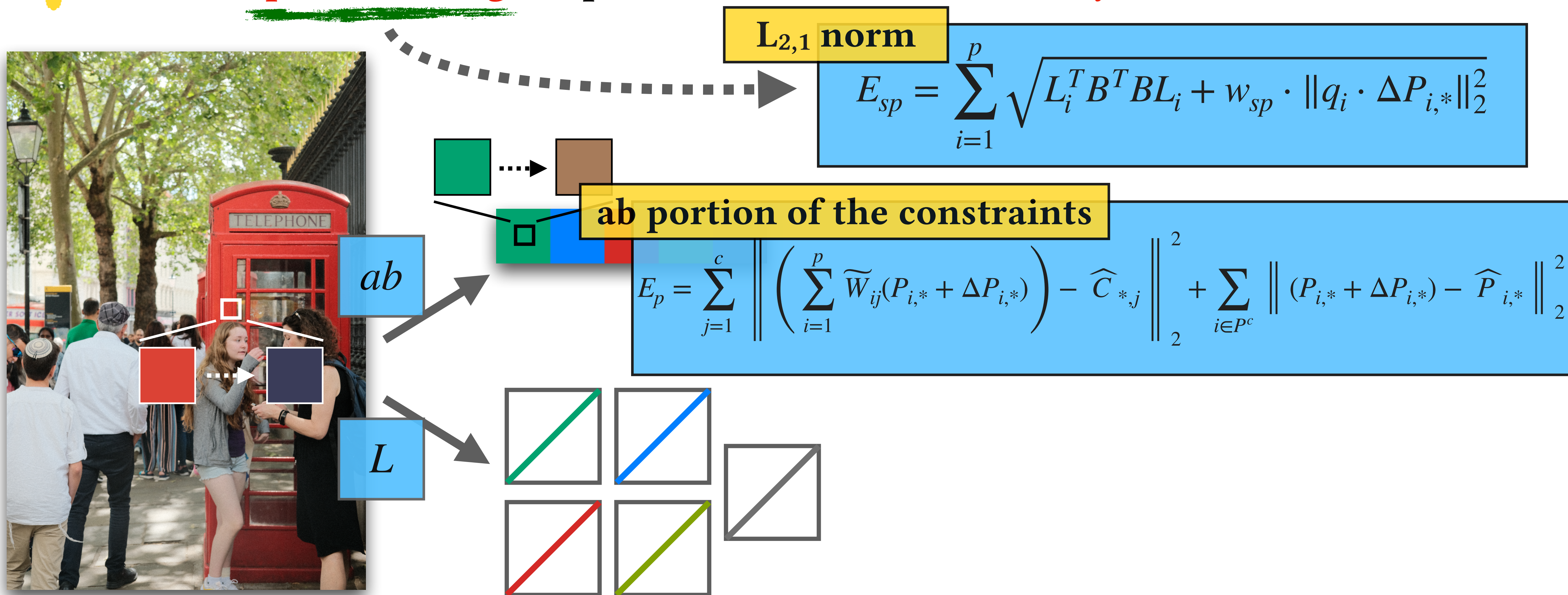
Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**



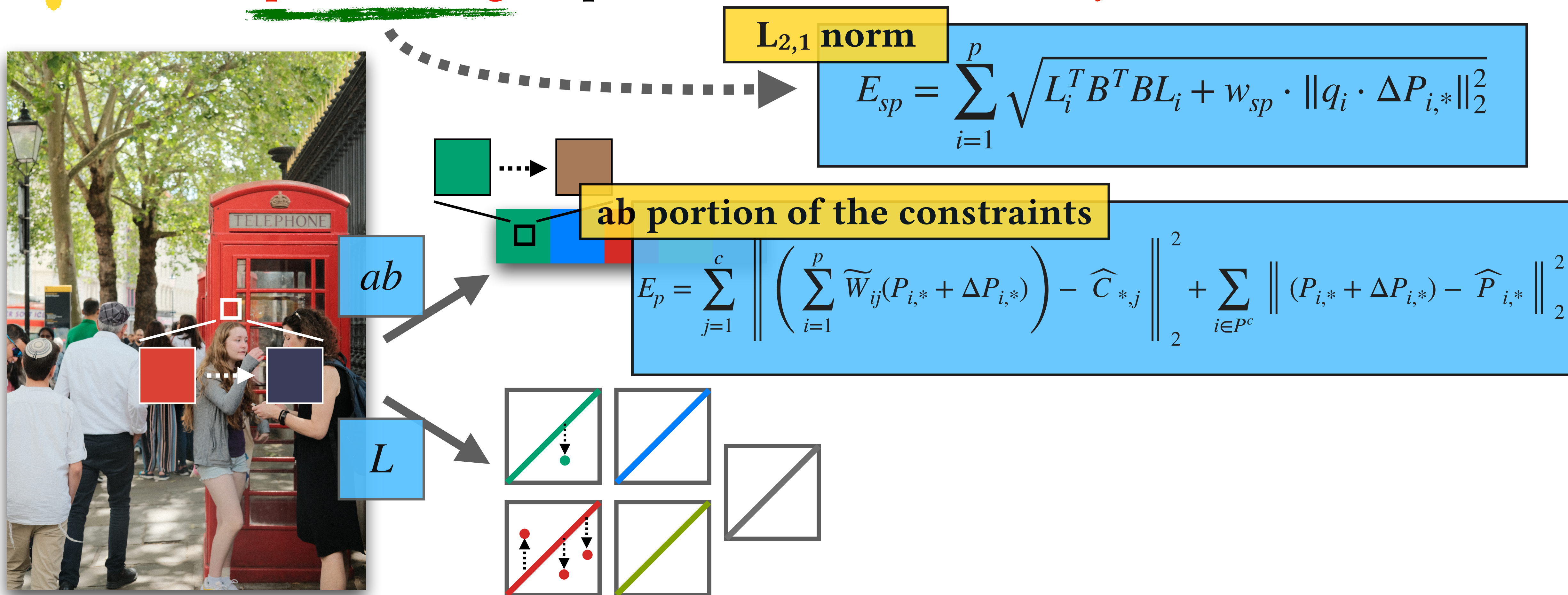
Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**



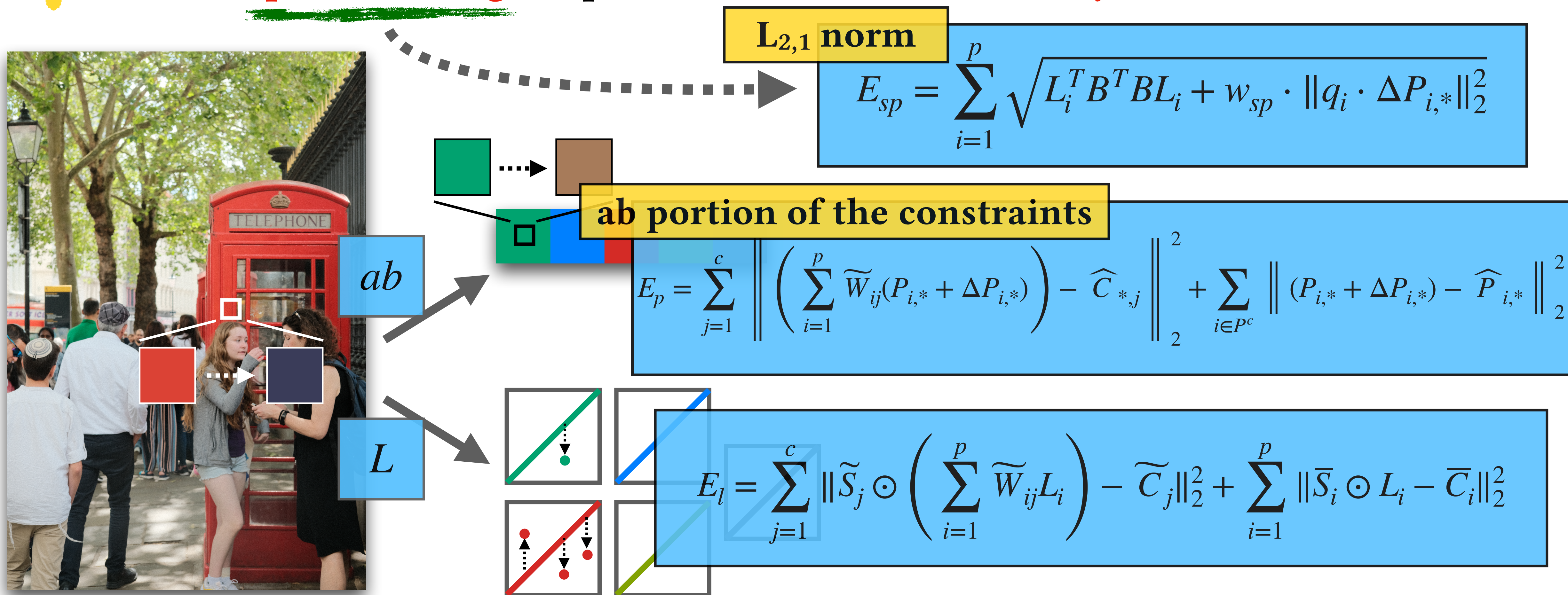
Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**



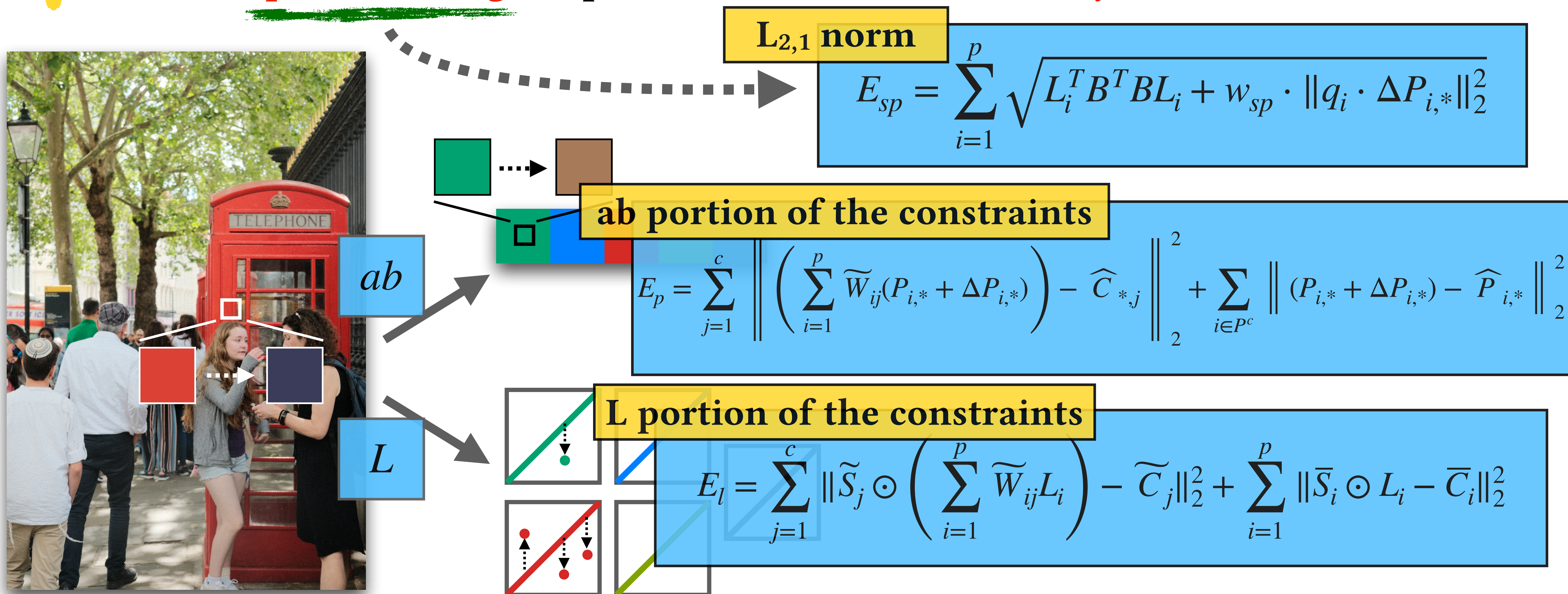
Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**



Optimizing for sparse edits

💡 Find the **sparsest change** to palette and curves that **satisfy constraints**



Optimizing for sparse edits

$$E_{sp} = \sum_{i=1}^p \sqrt{L_i^T B^T B L_i + w_{sp} \cdot \|q_i \cdot \Delta P_{i,*}\|_2^2}$$

$$E_p = \sum_{j=1}^c \left\| \left(\sum_{i=1}^p \widetilde{W}_{ij} (P_{i,*} + \Delta P_{i,*}) \right) - \widehat{C}_{*,j} \right\|_2^2 + \sum_{i \in P^c} \left\| (P_{i,*} + \Delta P_{i,*}) - \widehat{P}_{i,*} \right\|_2^2$$

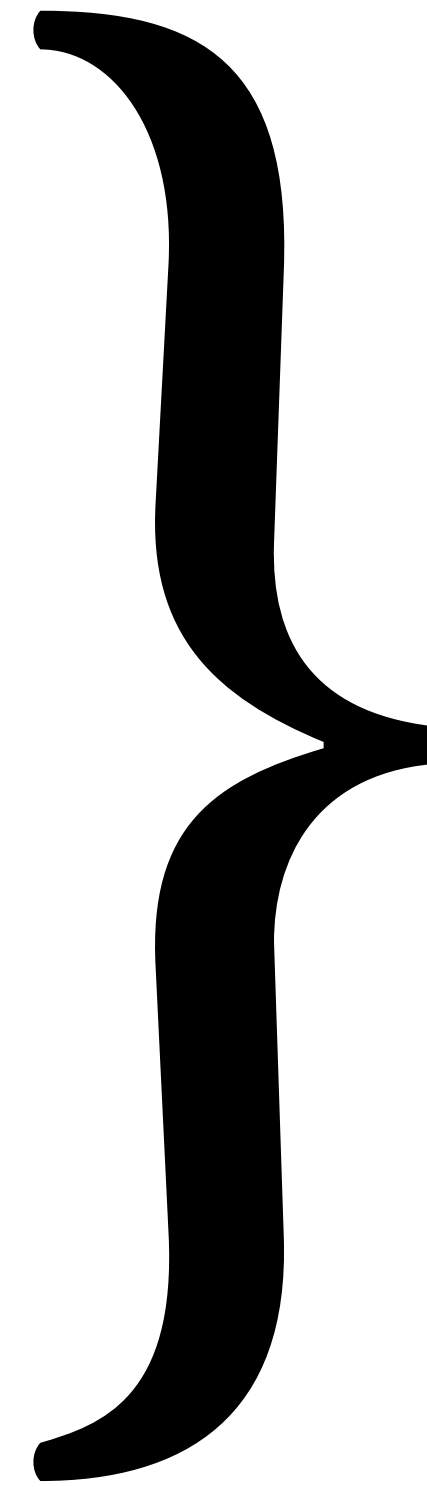
$$E_l = \sum_{j=1}^c \left\| \widetilde{S}_j \odot \left(\sum_{i=1}^p \widetilde{W}_{ij} L_i \right) - \widetilde{C}_j \right\|_2^2 + \sum_{i=1}^p \left\| \bar{S}_i \odot L_i - \bar{C}_i \right\|_2^2$$

Optimizing for sparse edits

$$E_{sp} = \sum_{i=1}^p \sqrt{L_i^T B^T B L_i + w_{sp} \cdot \|q_i \cdot \Delta P_{i,*}\|_2^2}$$

$$E_p = \sum_{j=1}^c \left\| \left(\sum_{i=1}^p \widetilde{W}_{ij} (P_{i,*} + \Delta P_{i,*}) \right) - \widehat{C}_{*,j} \right\|_2^2 + \sum_{i \in P^c} \left\| (P_{i,*} + \Delta P_{i,*}) - \widehat{P}_{i,*} \right\|_2^2$$

$$E_l = \sum_{j=1}^c \left\| \widetilde{S}_j \odot \left(\sum_{i=1}^p \widetilde{W}_{ij} L_i \right) - \widetilde{C}_j \right\|_2^2 + \sum_{i=1}^p \left\| \bar{S}_i \odot L_i - \bar{C}_i \right\|_2^2$$



Optimizing for sparse edits

$$E_{sp} = \sum_{i=1}^p \sqrt{L_i^T B^T B L_i + w_{sp} \cdot \|q_i \cdot \Delta P_{i,*}\|_2^2}$$

$$E_p = \sum_{j=1}^c \left\| \left(\sum_{i=1}^p \widetilde{W}_{ij} (P_{i,*} + \Delta P_{i,*}) \right) - \widehat{C}_{*,j} \right\|_2^2 + \sum_{i \in P^c} \left\| (P_{i,*} + \Delta P_{i,*}) - \widehat{P}_{i,*} \right\|_2^2$$

$$E_l = \sum_{j=1}^c \left\| \widetilde{S}_j \odot \left(\sum_{i=1}^p \widetilde{W}_{ij} L_i \right) - \widetilde{C}_j \right\|_2^2 + \sum_{i=1}^p \left\| \bar{S}_i \odot L_i - \bar{C}_i \right\|_2^2$$

$$\{L_i, \Delta P_i\} = \arg \min_{L_i, \Delta P_i} E_{sp} + w_{eq} (E_l + E_p)$$

Optimizing for sparse edits

$$E_{sp} = \sum_{i=1}^p \sqrt{L_i^T B^T B L_i + w_{sp} \cdot \|q_i \cdot \Delta P_{i,*}\|_2^2}$$

$$E_p = \sum_{j=1}^c \left\| \left(\sum_{i=1}^p \widetilde{W}_{ij} (P_{i,*} + \Delta P_{i,*}) \right) - \widehat{C}_{*,j} \right\|_2^2 + \sum_{i \in P^c} \left\| (P_{i,*} + \Delta P_{i,*}) - \widehat{P}_{i,*} \right\|_2^2$$

$$E_l = \sum_{j=1}^c \left\| \widetilde{S}_j \odot \left(\sum_{i=1}^p \widetilde{W}_{ij} L_i \right) - \widetilde{C}_j \right\|_2^2 + \sum_{i=1}^p \left\| \bar{S}_i \odot L_i - \bar{C}_i \right\|_2^2$$

$$\{L_i, \Delta P_i\} = \arg \min_{L_i, \Delta P_i} E_{sp} + w_{eq}(E_l + E_p)$$

subject to

$$-128 \leq P_i + \Delta P_i \leq 127$$

$$L_{i,1} = 0, \quad L_{i,s} = 1$$

Optimizing for sparse edits

$$E_{sp} = \sum_{i=1}^p \sqrt{L_i^T B^T B L_i + w_{sp} \cdot \|q_i \cdot \Delta P_{i,*}\|_2^2}$$

$$E_p = \sum_{j=1}^c \left\| \left(\sum_{i=1}^p \widetilde{W}_{ij} (P_{i,*} + \Delta P_{i,*}) \right) - \widehat{C}_{*,j} \right\|_2^2 + \sum_{i \in P^c} \left\| (P_{i,*} + \Delta P_{i,*}) - \widehat{P}_{i,*} \right\|_2^2$$

$$E_l = \sum_{j=1}^c \left\| \widetilde{S}_j \odot \left(\sum_{i=1}^p \widetilde{W}_{ij} L_i \right) - \widetilde{C}_j \right\|_2^2 + \sum_{i=1}^p \left\| \bar{S}_i \odot L_i - \bar{C}_i \right\|_2^2$$

$$\{L_i, \Delta P_i\} = \arg \min_{L_i, \Delta P_i} E_{sp} + w_{eq} (E_l + E_p)$$

subject to

$$-128 \leq P_i + \Delta P_i \leq 127$$

$$L_{i,1} = 0, \quad L_{i,s} = 1$$

**~30 secs
SLSQP solver**

Real-time optimization



Block coordinate descent

$$\{L_i, \Delta P_i\} = \arg \min_{L_i, \Delta P_i} E_{sp} + w_{eq}(E_l + E_p)$$

subject to

$$-128 \leq P_i + \Delta P_i \leq 127$$

$$L_{i,1} = 0, \quad L_{i,s} = 1$$

Real-time optimization



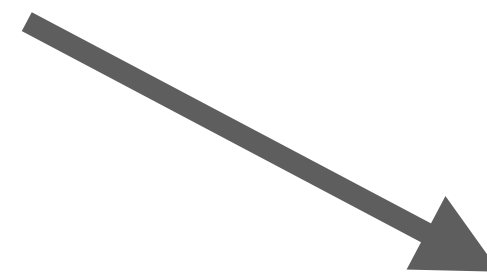
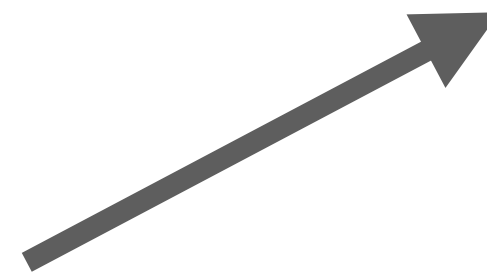
Block coordinate descent

$$\{L_i, \Delta P_i\} = \arg \min_{L_i, \Delta P_i} E_{sp} + w_{eq}(E_l + E_p)$$

subject to

$$-128 \leq P_i + \Delta P_i \leq 127$$

$$L_{i,1} = 0, \quad L_{i,s} = 1$$



Real-time optimization

 **Block coordinate descent**

$$\{L_i, \Delta P_i\} = \arg \min_{L_i, \Delta P_i} E_{sp} + w_{eq}(E_l + E_p)$$

subject to

$$-128 \leq P_i + \Delta P_i \leq 127$$

$$L_{i,1} = 0, \quad L_{i,s} = 1$$

fast linear solve

small QP problem

Real-time optimization

 **Block coordinate descent**

$$\{L_i, \Delta P_i\} = \arg \min_{L_i, \Delta P_i} E_{sp} + w_{eq}(E_l + E_p)$$

subject to

$$-128 \leq P_i + \Delta P_i \leq 127$$

$$L_{i,1} = 0, \quad L_{i,s} = 1$$

$$Ax_l = b$$

fast linear solve

small QP problem

Real-time optimization

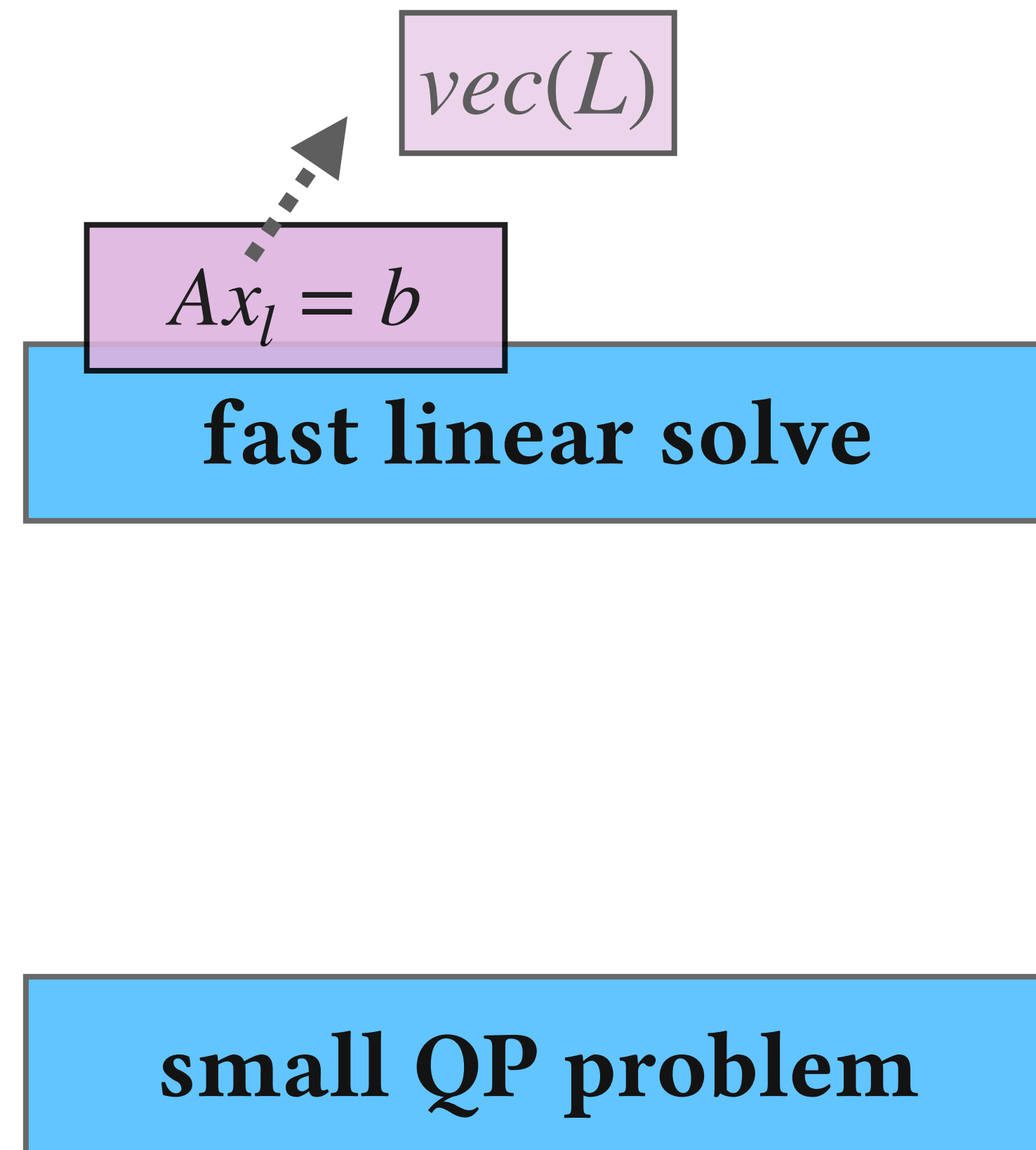
 **Block coordinate descent**

$$\{L_i, \Delta P_i\} = \arg \min_{L_i, \Delta P_i} E_{sp} + w_{eq}(E_l + E_p)$$

subject to

$$-128 \leq P_i + \Delta P_i \leq 127$$

$$L_{i,1} = 0, \quad L_{i,s} = 1$$



Real-time optimization

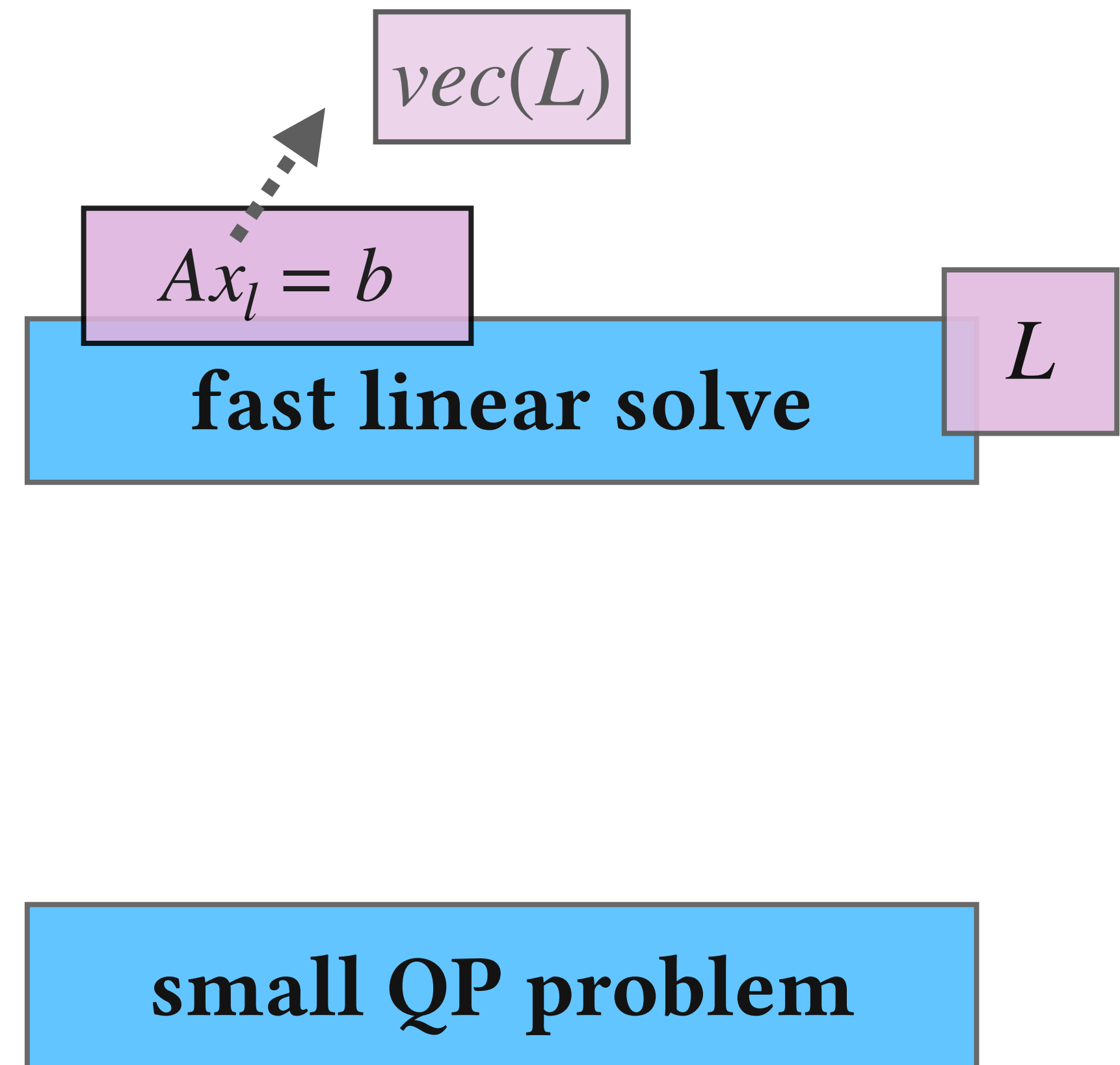
💡 **Block coordinate descent**

$$\{L_i, \Delta P_i\} = \arg \min_{L_i, \Delta P_i} E_{sp} + w_{eq}(E_l + E_p)$$

subject to

$$-128 \leq P_i + \Delta P_i \leq 127$$

$$L_{i,1} = 0, \quad L_{i,s} = 1$$



Real-time optimization

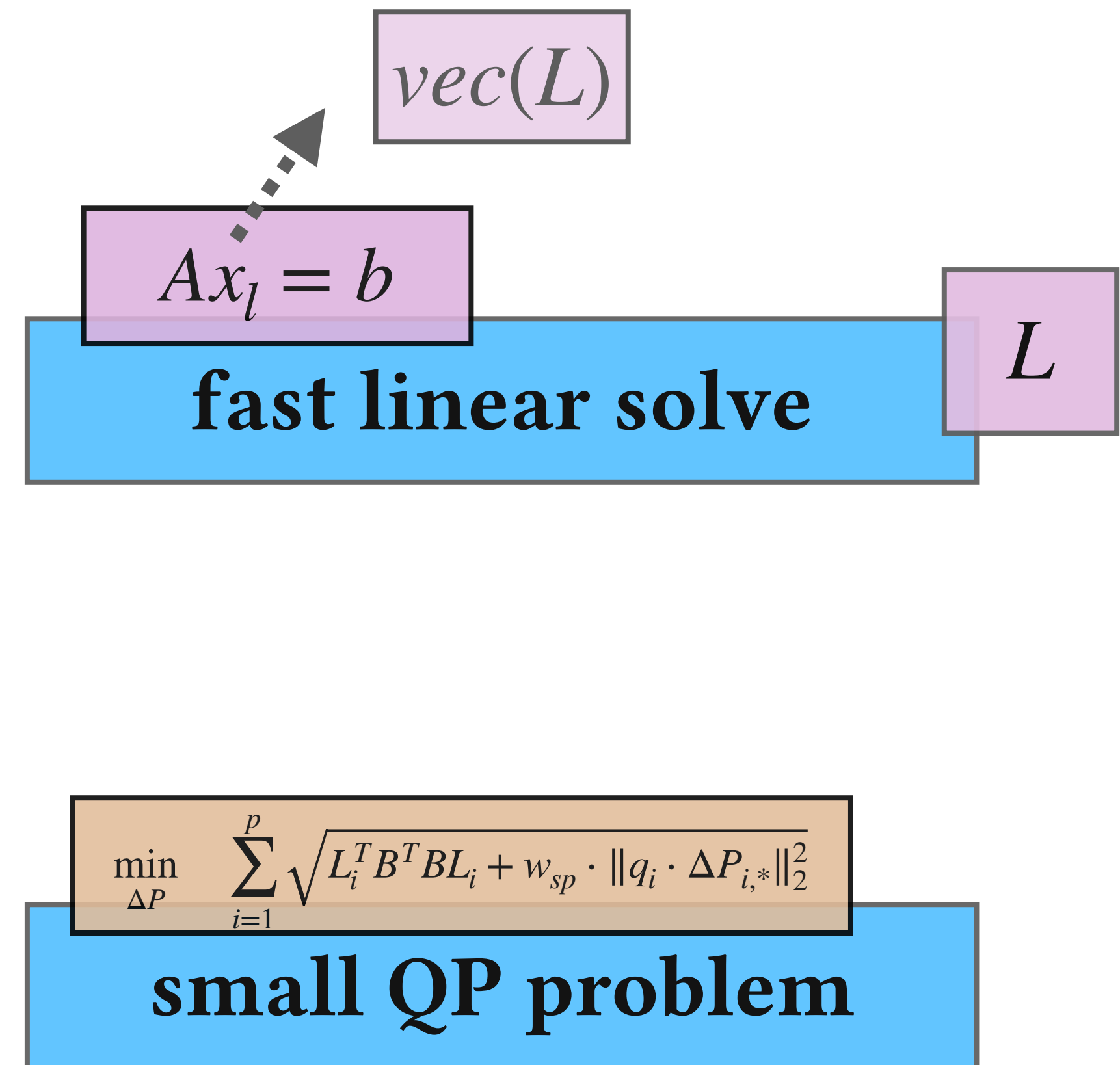
💡 **Block coordinate descent**

$$\{L_i, \Delta P_i\} = \arg \min_{L_i, \Delta P_i} E_{sp} + w_{eq}(E_l + E_p)$$

subject to

$$-128 \leq P_i + \Delta P_i \leq 127$$

$$L_{i,1} = 0, \quad L_{i,s} = 1$$



Real-time optimization

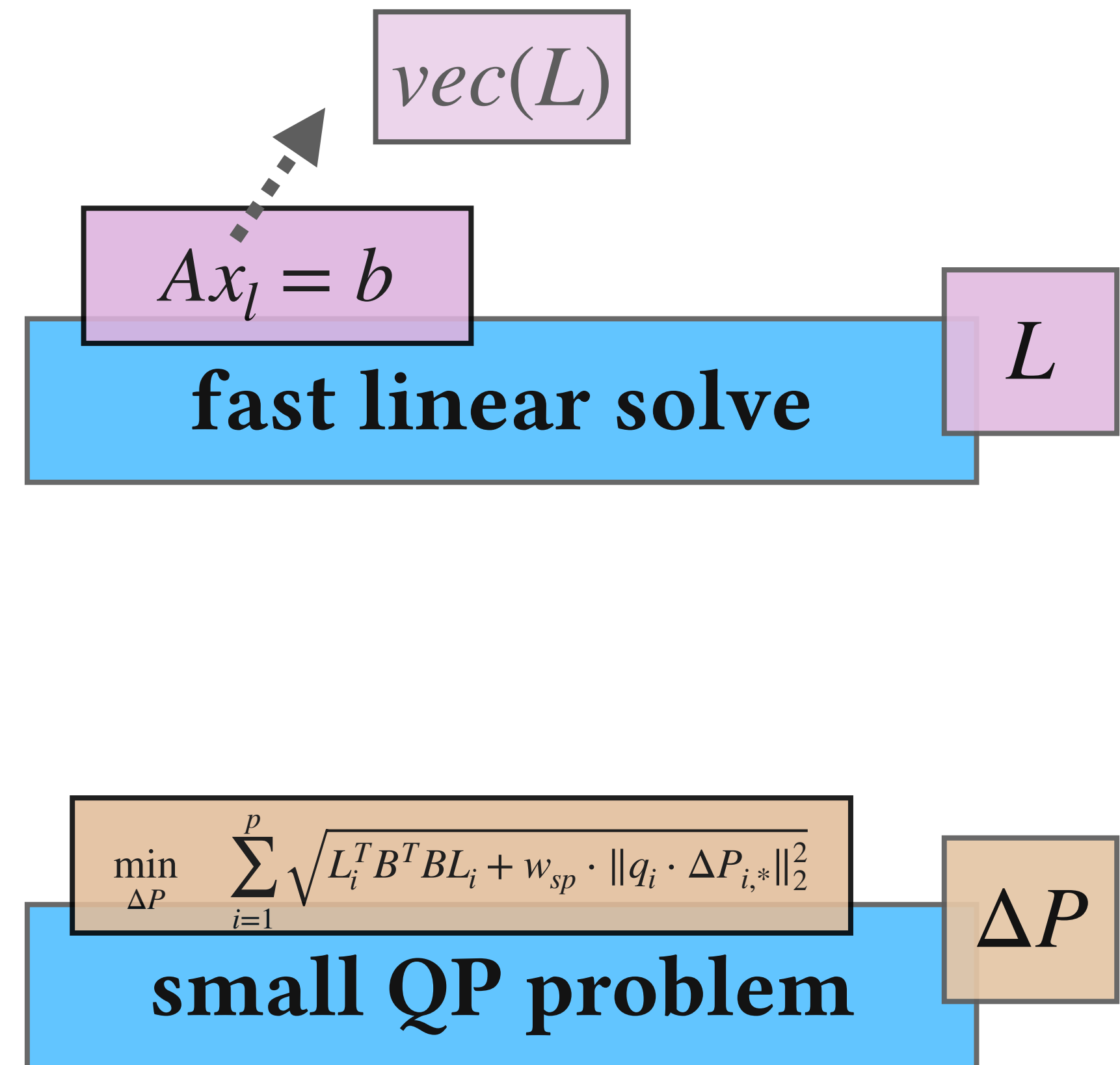
💡 **Block coordinate descent**

$$\{L_i, \Delta P_i\} = \arg \min_{L_i, \Delta P_i} E_{sp} + w_{eq}(E_l + E_p)$$

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Real-time optimization

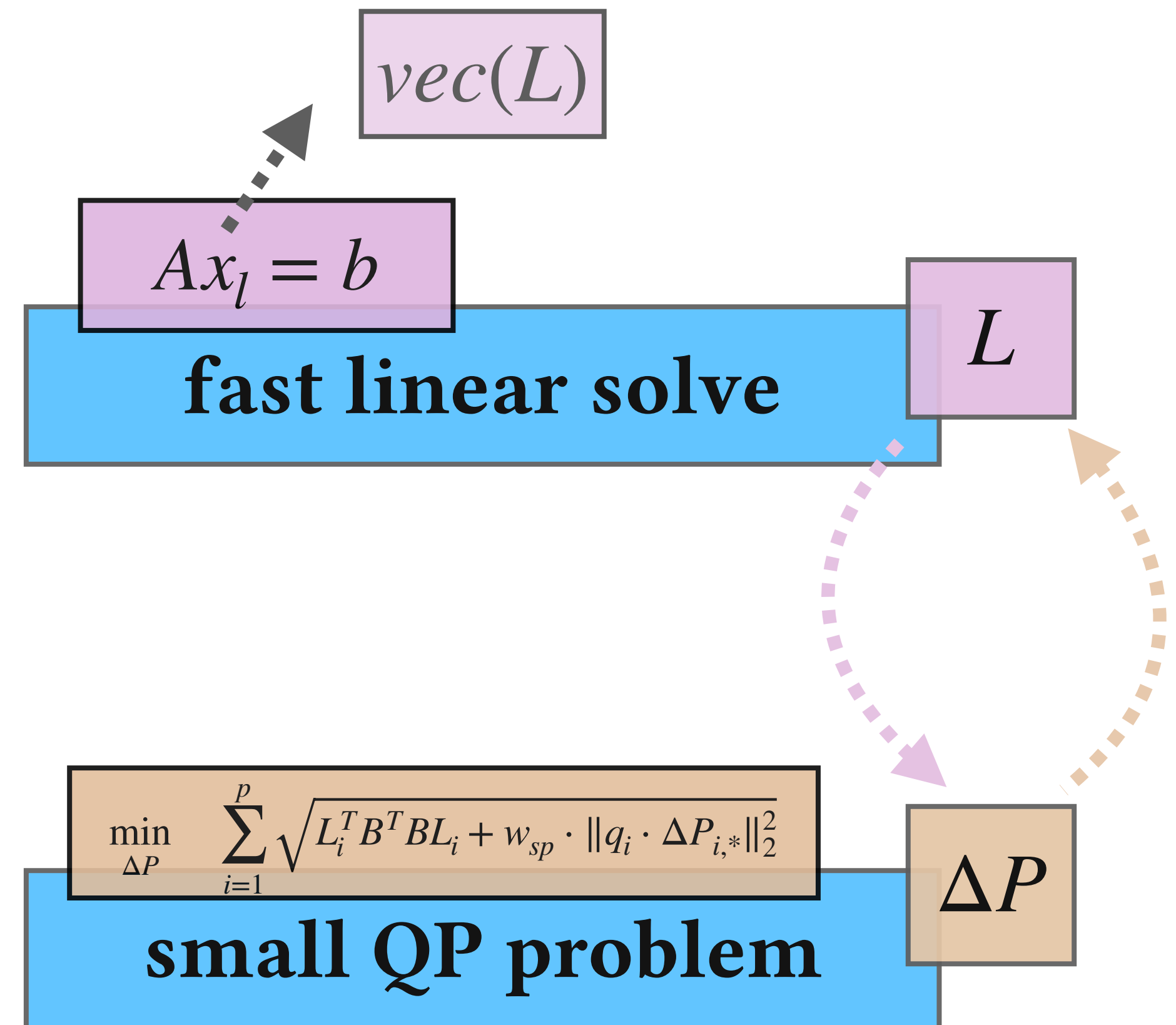
💡 **Block coordinate descent**

$$\{L_i, \Delta P_i\} = \arg \min_{L_i, \Delta P_i} E_{sp} + w_{eq}(E_l + E_p)$$

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Real-time optimization

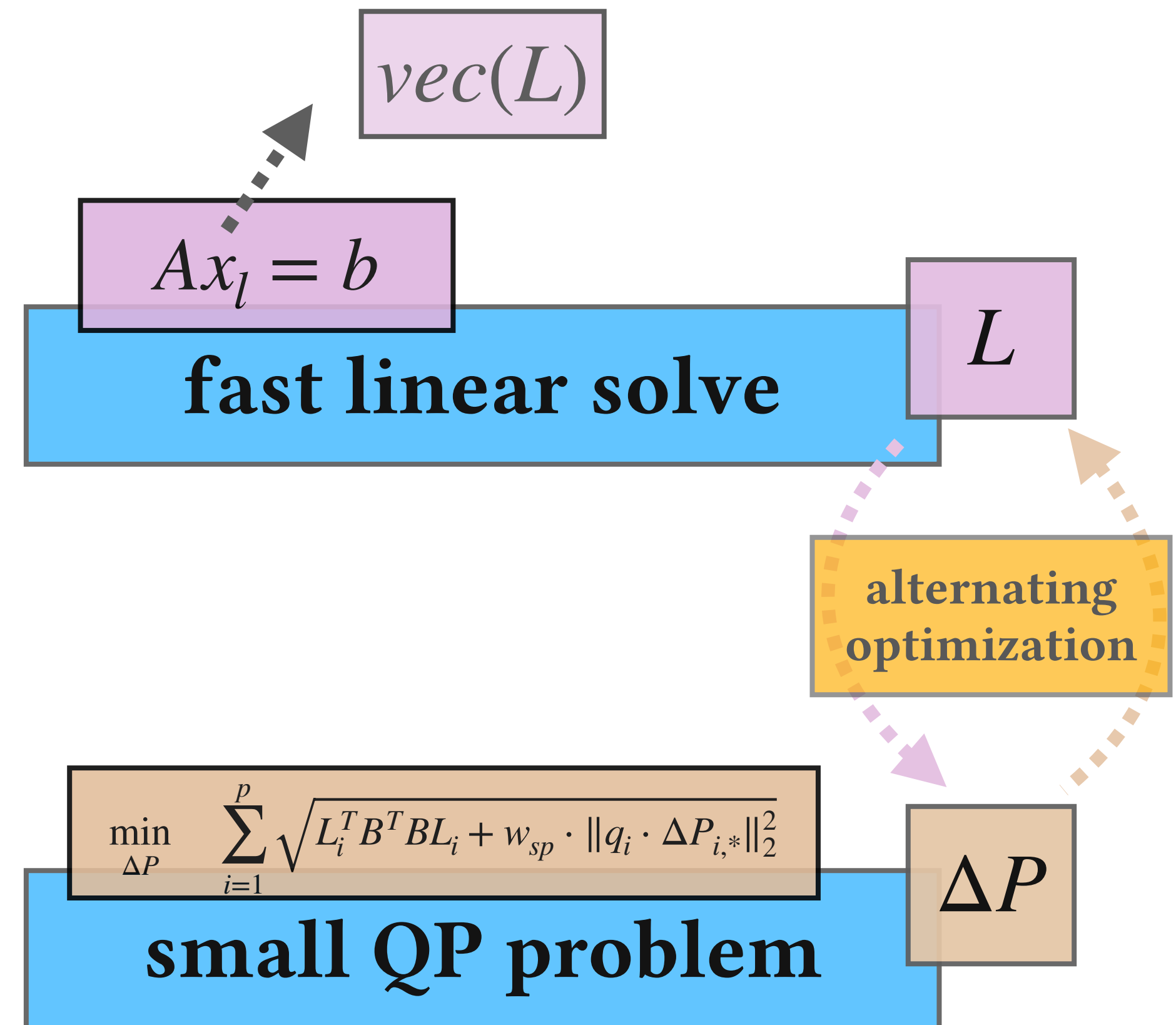
💡 **Block coordinate descent**

$$\{L_i, \Delta P_i\} = \arg \min_{L_i, \Delta P_i} E_{sp} + w_{eq}(E_l + E_p)$$

subject to

$$-128 \leq P_i + \Delta P_i \leq 127$$

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Real-time optimization

💡 **Block coordinate descent**

$$\{L_i, \Delta P_i\} = \arg \min_{L_i, \Delta P_i} E_{sp} + w_{eq}(E_l + E_p)$$

subject to

$$-128 \leq P_i + \Delta P_i \leq 127$$

$$L_{i,1} = 0, \quad L_{i,s} = 1$$

~400x speedup!
Real-time

$$Ax_l = b$$

$$vec(L)$$

fast linear solve

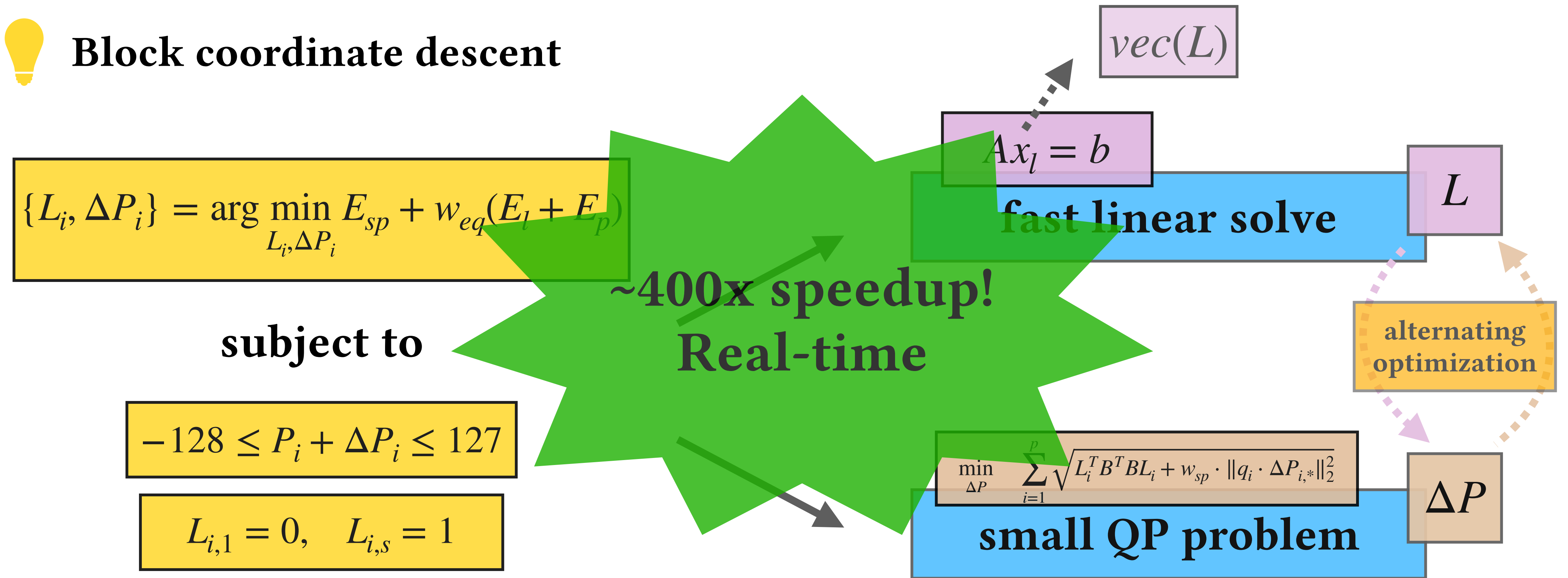
L

alternating optimization

$$\min_{\Delta P} \sum_{i=1}^p \sqrt{L_i^T B^T B L_i + w_{sp} \cdot \|q_i \cdot \Delta P_{i,*}\|_2^2}$$

small QP problem

ΔP



Palette-aware lightness control

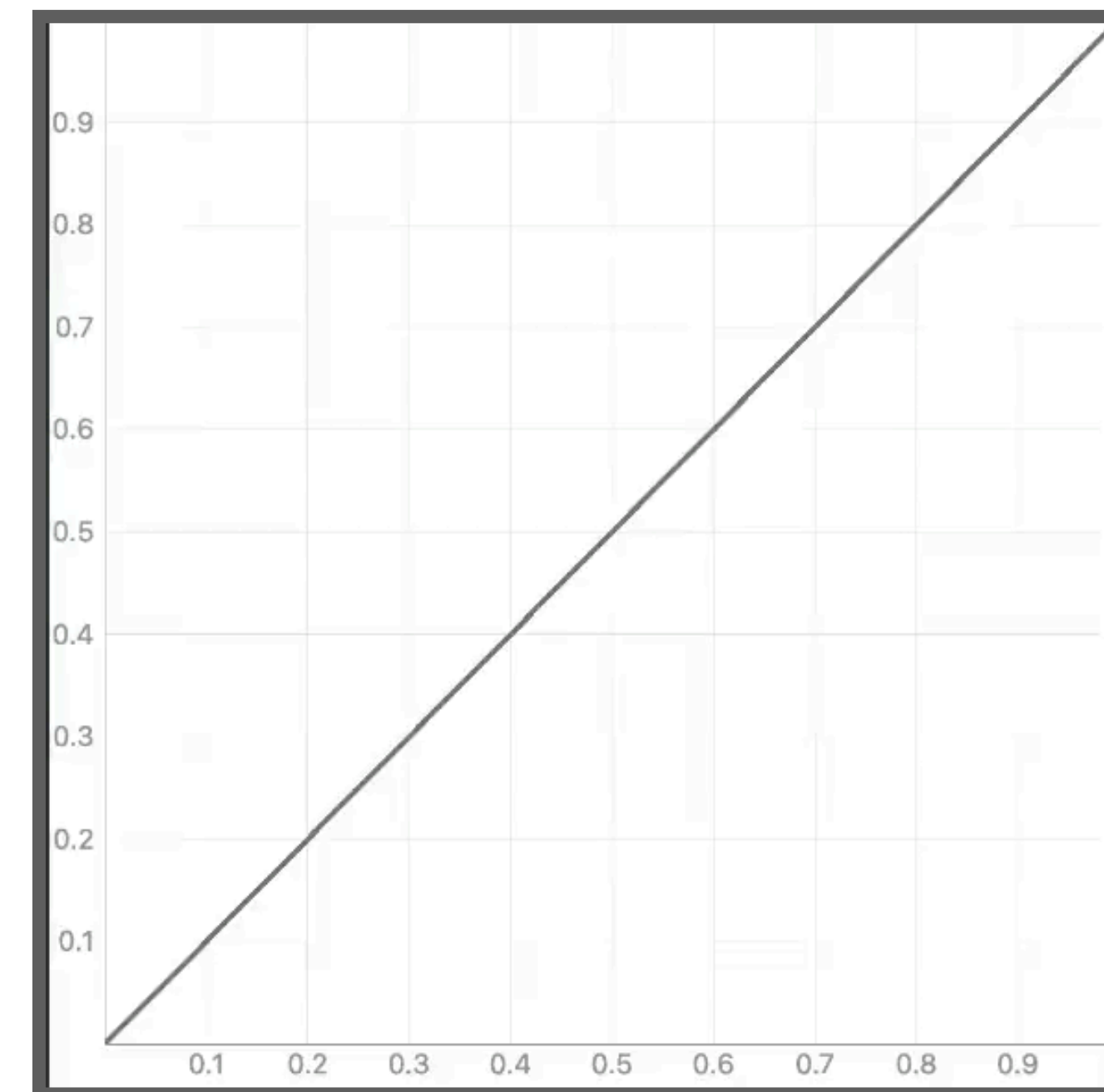
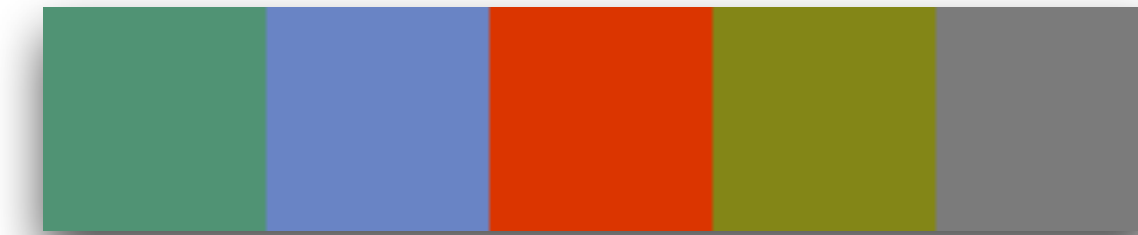


Photo credit: @Europeana

Palette-aware lightness control

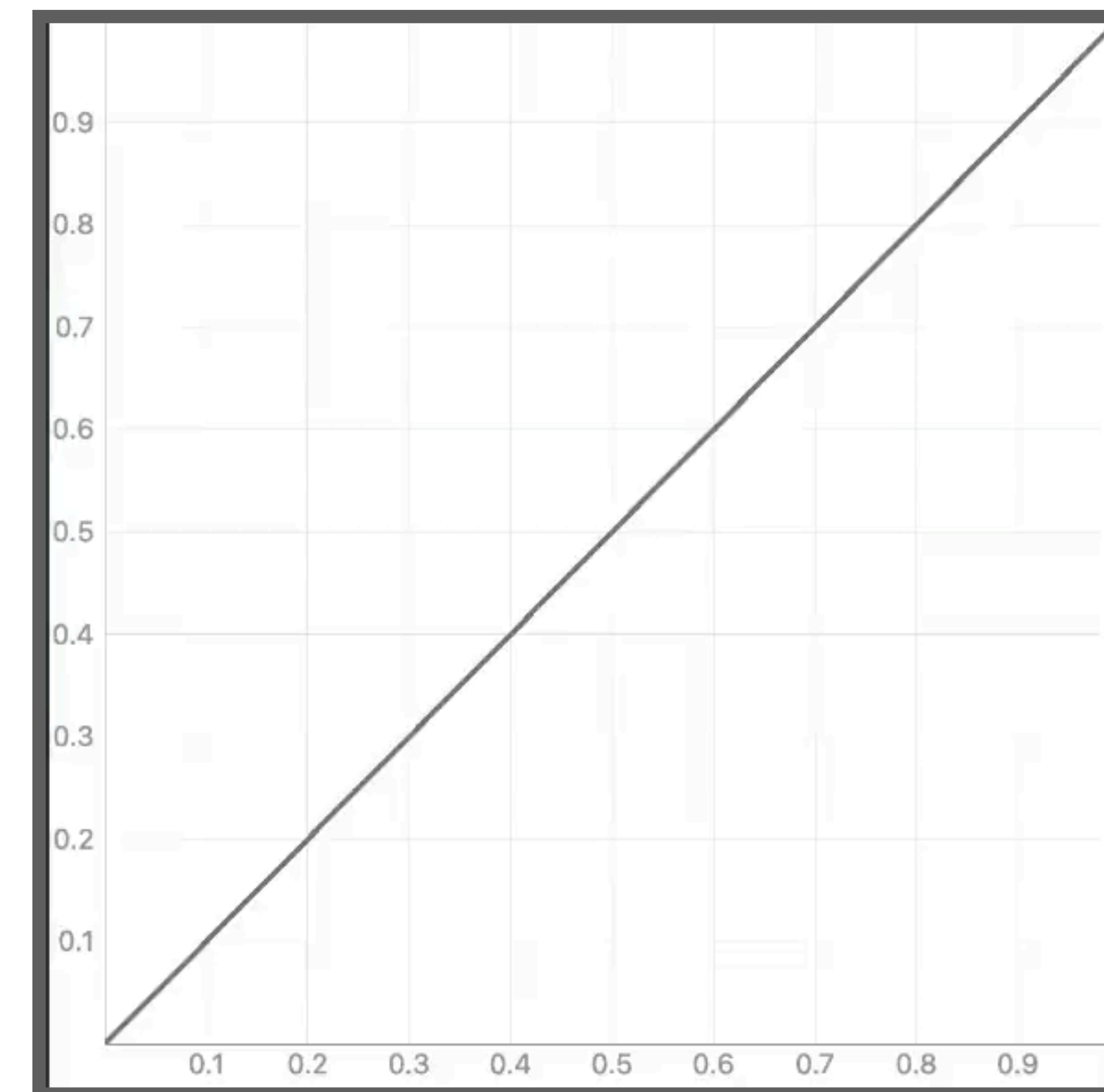
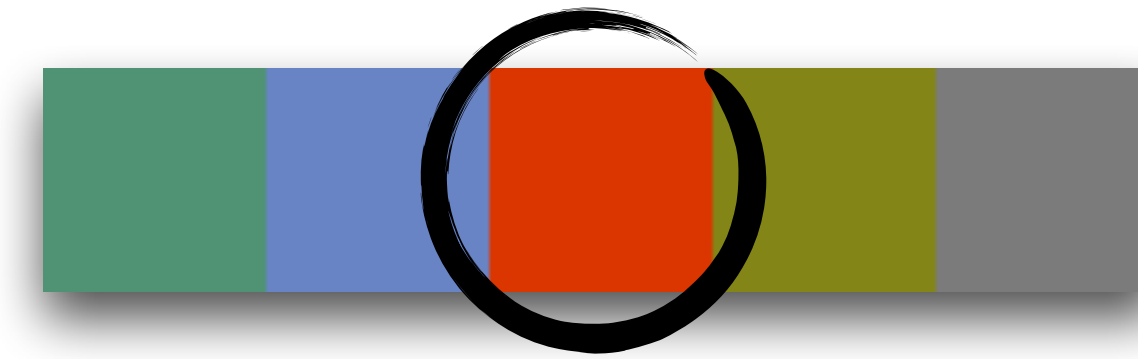


Photo credit: @Europeana

Constraint-driven color editing

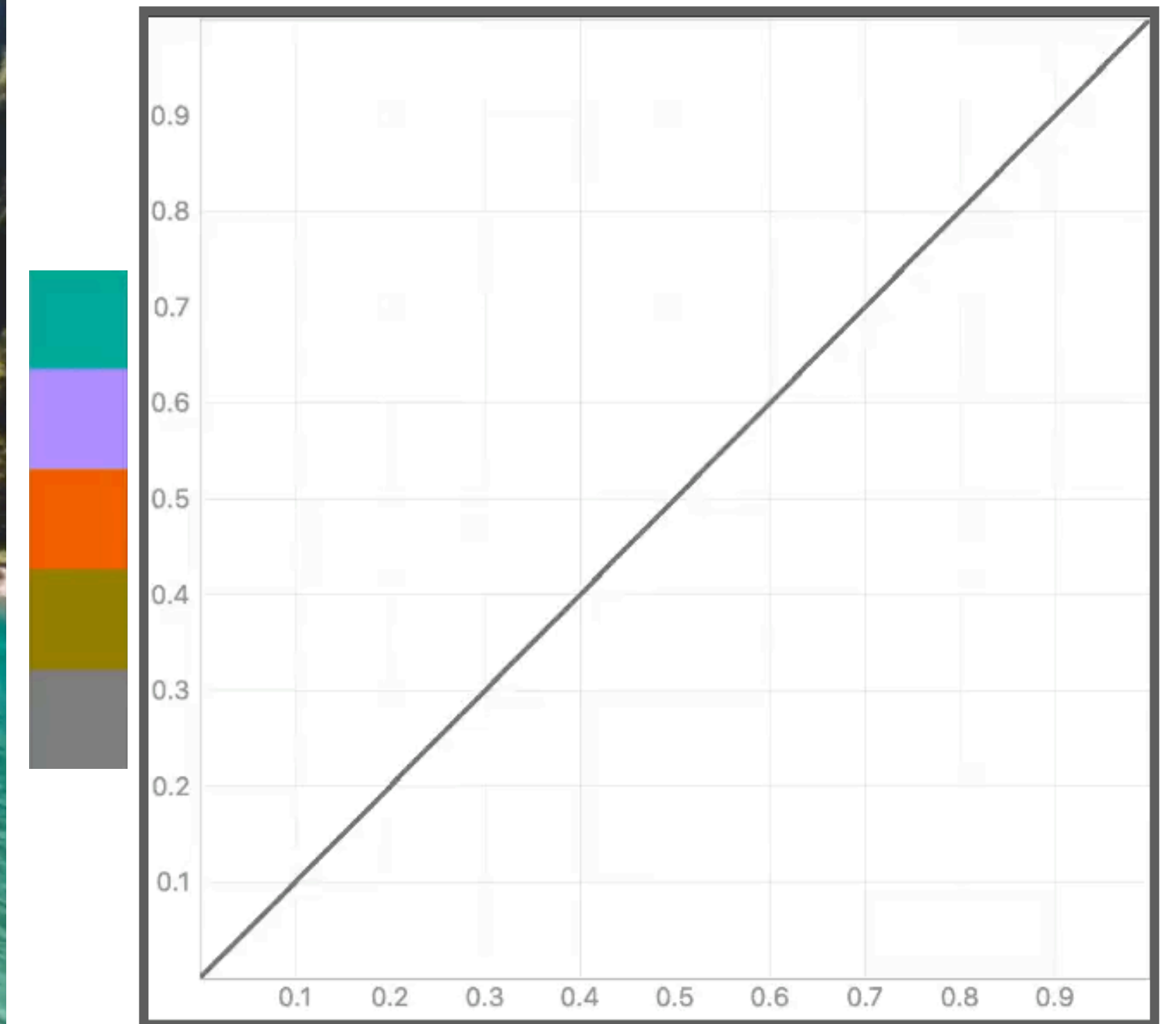


Photo credit: @ Pietro De Grandi

Constraint-driven color editing

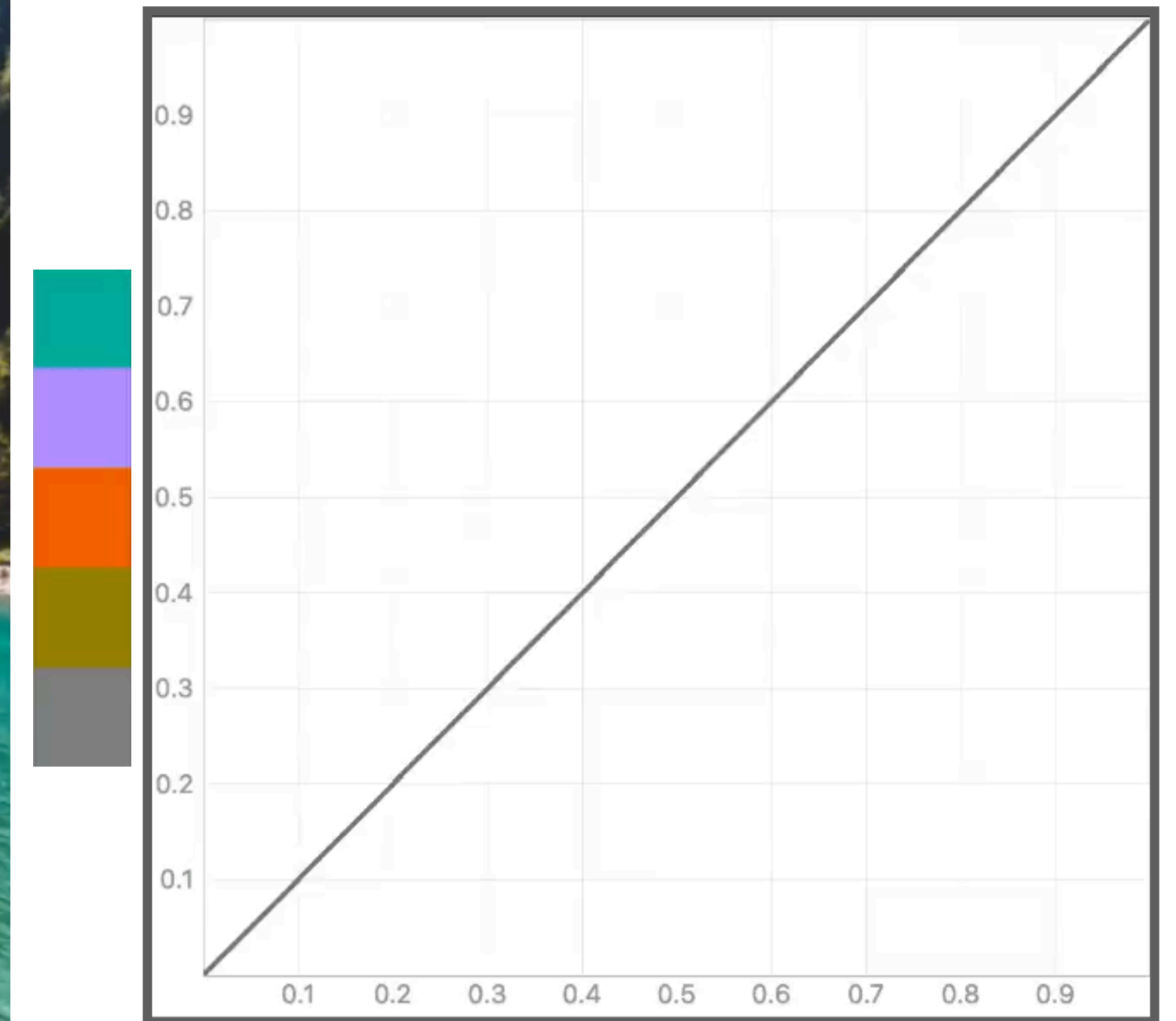



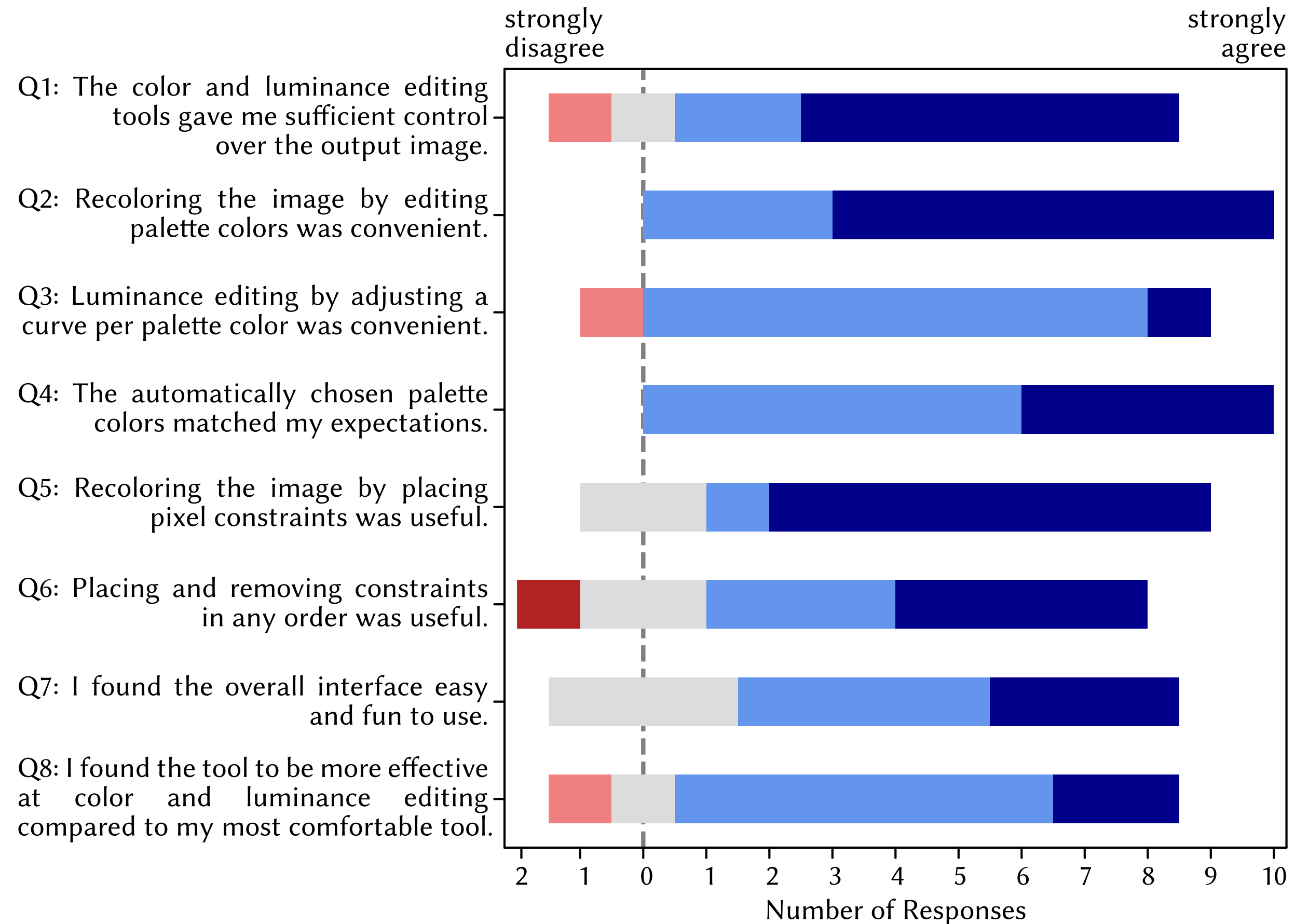
Photo credit: [@Pietro De Grandi](#)

Expert study

 **10 experts, average of 10 years (3-30 years) of photo editing experience**

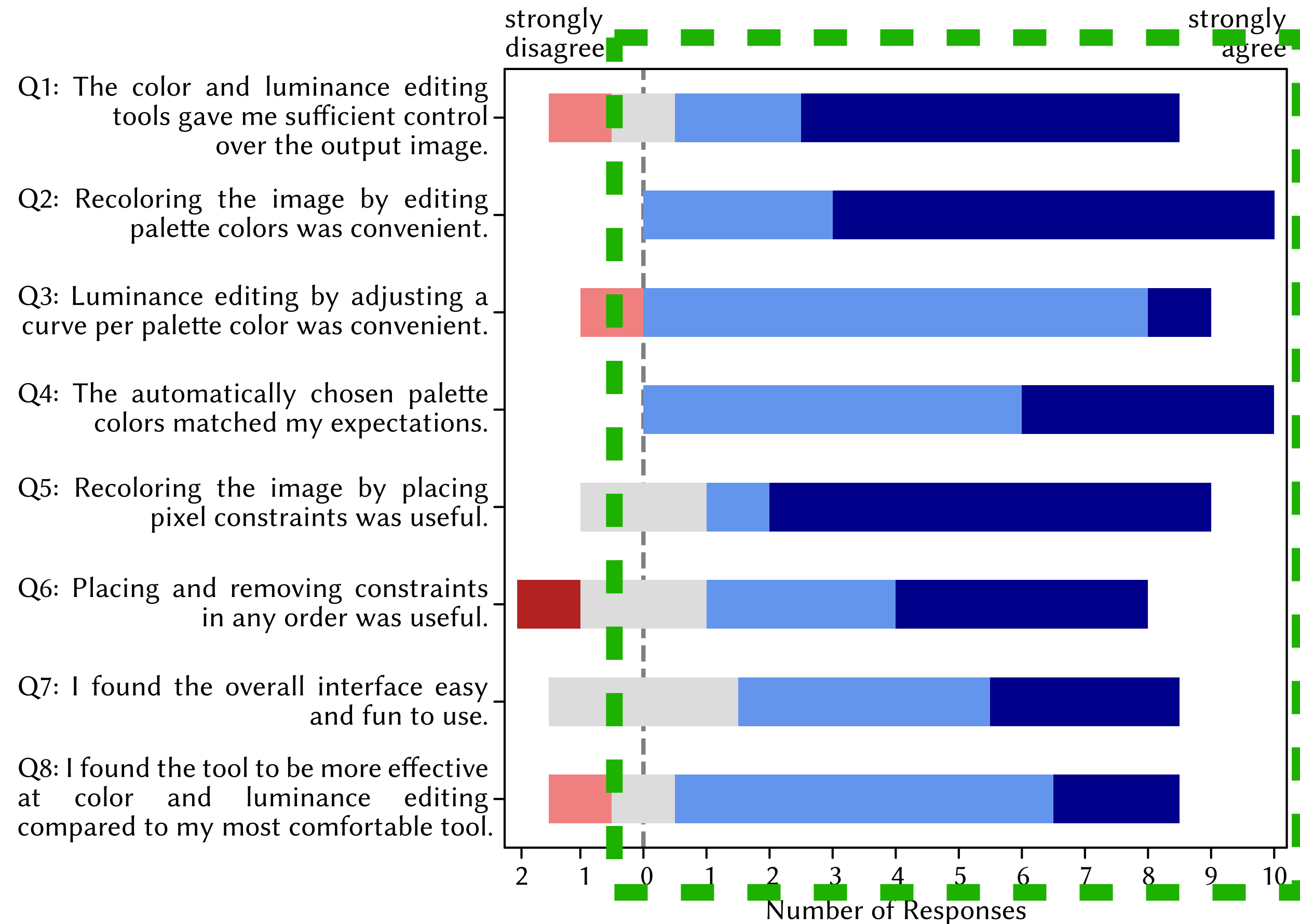
Expert study

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Expert study

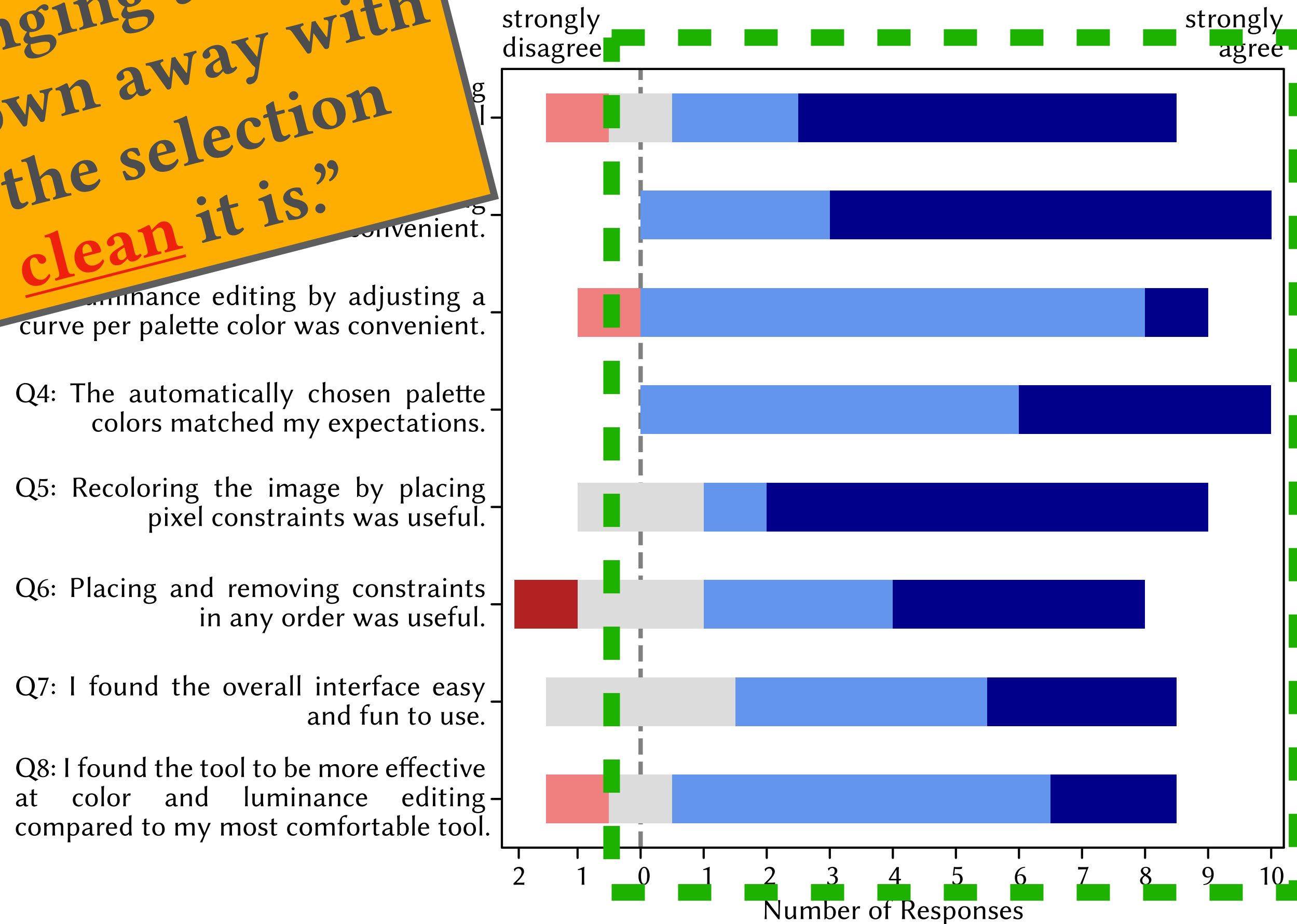
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Expert study

💡 10 experts, average of 17 years (3-30 years) of photo editing experience

“[T]he color changing tool is amazing. I was blown away with the accuracy of the selection tool and how clean it is.”



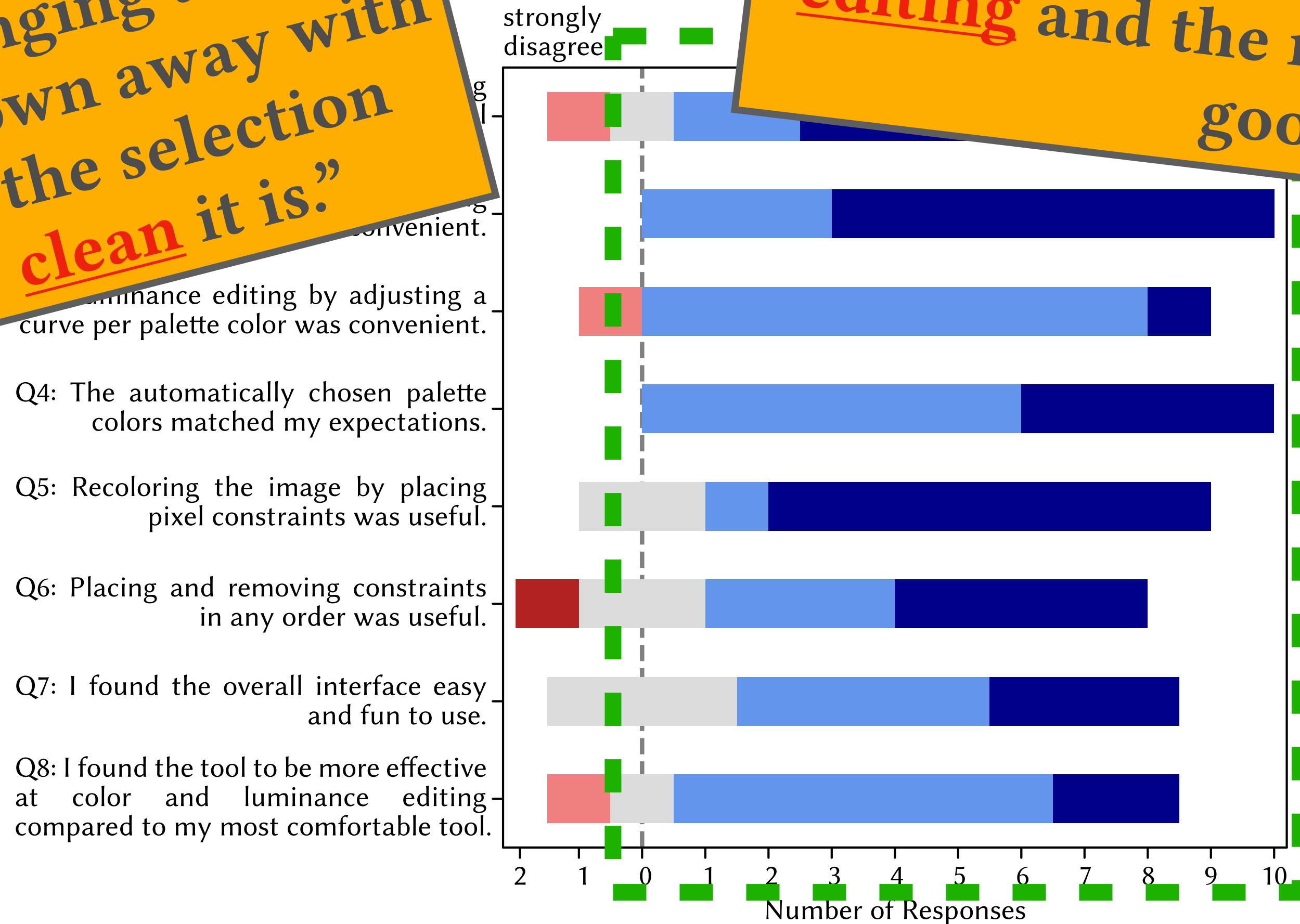
Expert study



10 experts, average of 7 years (3-30 years)

“[T]he color changing tool is amazing. I was blown away with the accuracy of the selection tool and how clean it is.”

“[T]o push the challenge further, I choose a portrait to do a skin tone editing and the results are really good.”



Expert study



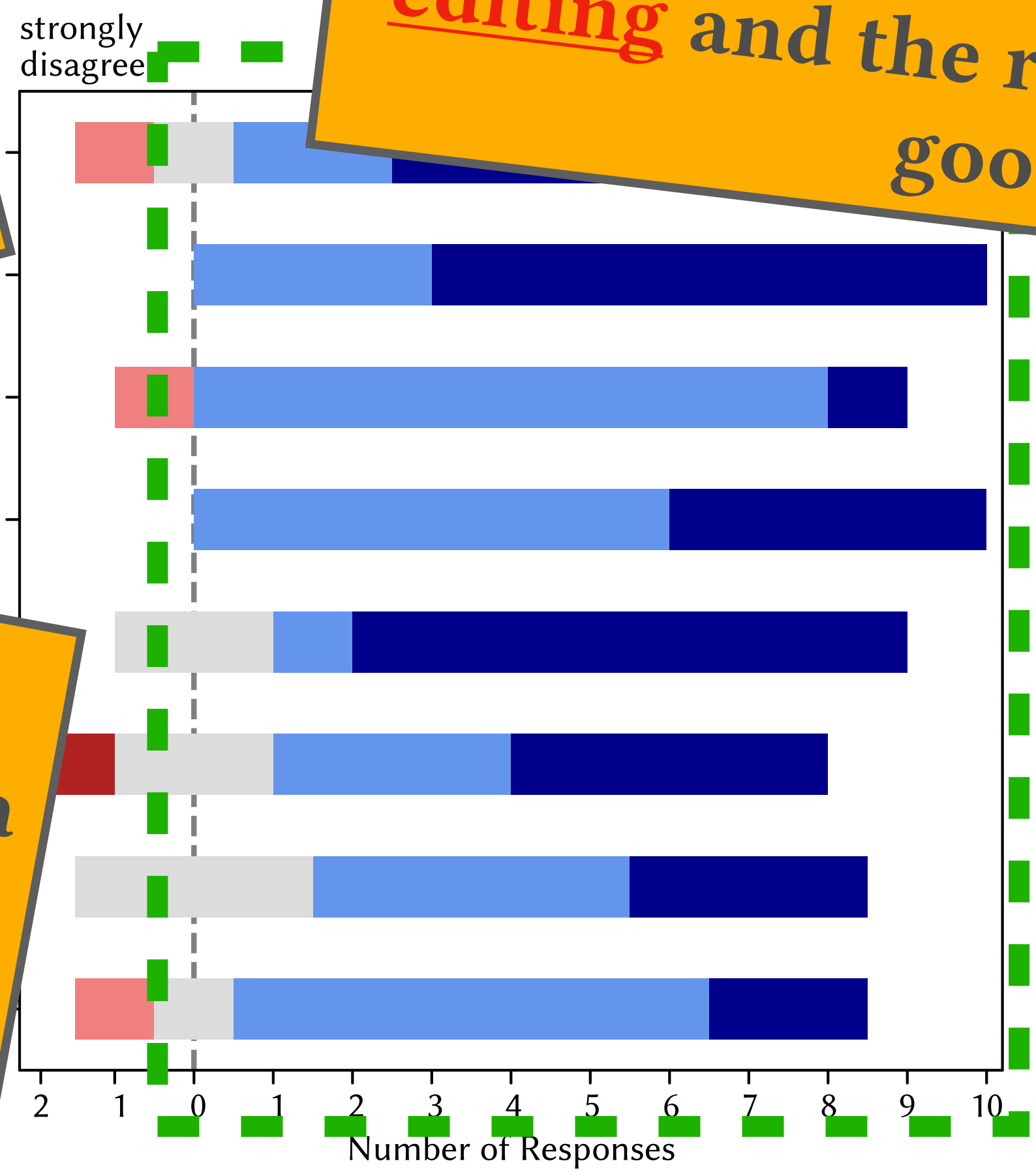
10 experts, average of 7 years (3-30 years)

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“[C]olorfulCurves is intuitive and easy to adjust the color of a specific area, which cannot be achieved with lightroom.”

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...convenient.
 ... dominance editing by adjusting a curve per palette color was convenient.
 Q4: The automatically chosen palette colors matched my expectations.
 ... at color... compared to my most...



Expert study



10 experts, average of 7 years (3-30 years)

“[T]he color changing tool is amazing. I was blown away with the accuracy of the selection and how clean it is”

“[V]ery easy to adjust for regional color, brightness.”

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Expert study



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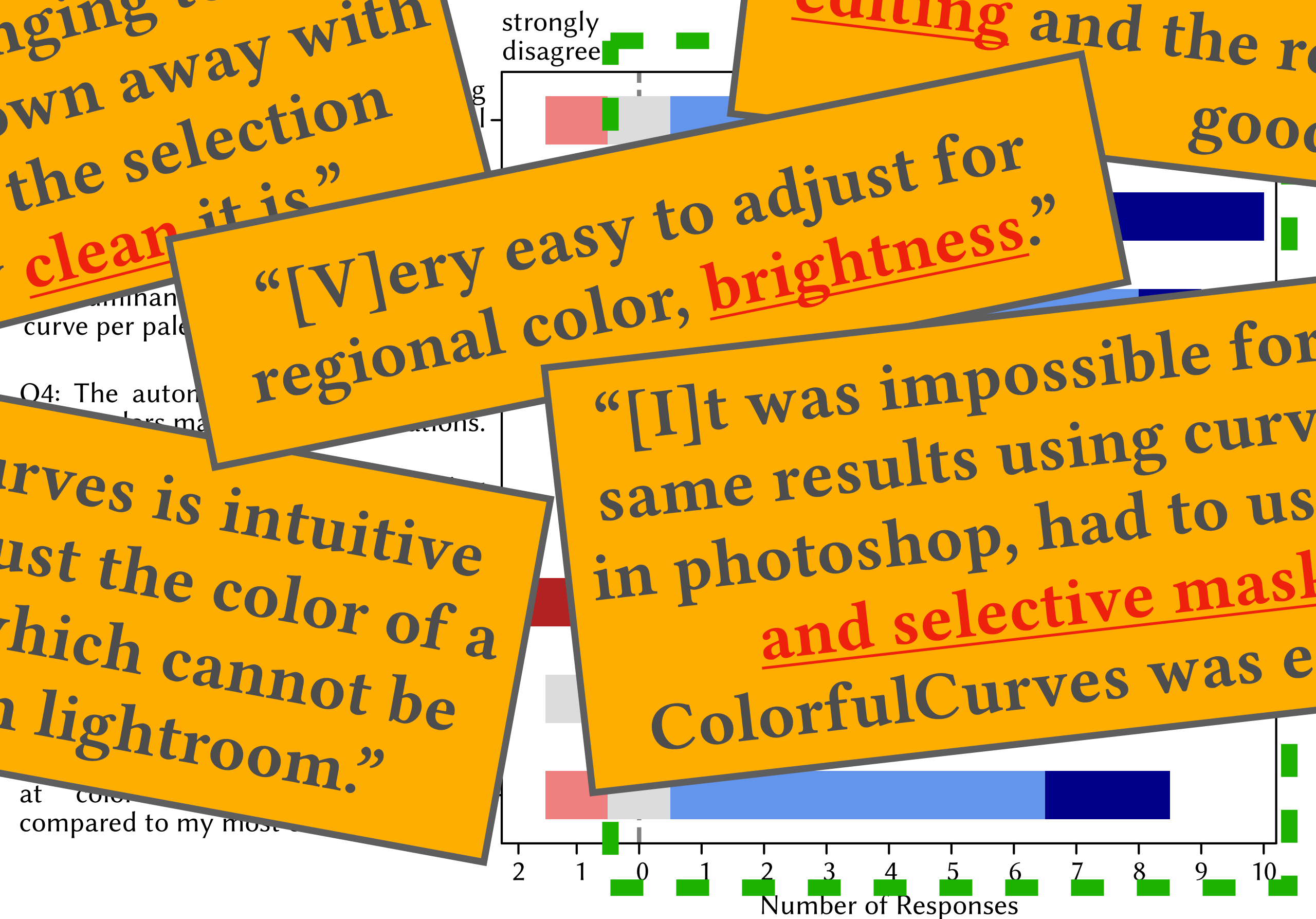
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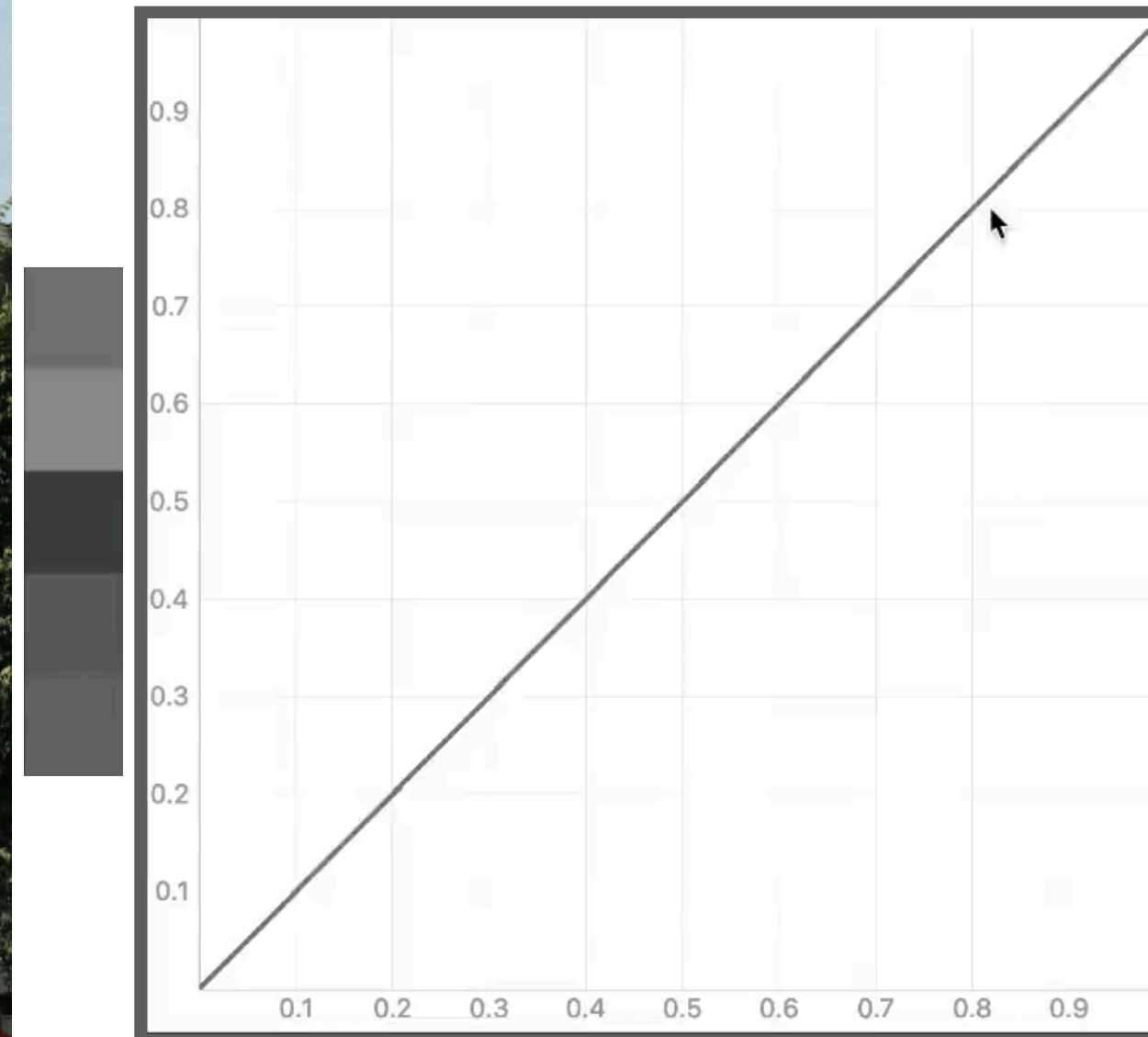
“[C]olorfulCurves is intuitive and easy to adjust the color of a specific area, which cannot be achieved with lightroom.”

“[I]t was impossible for me to achieve same results using curves adjustments in photoshop, had to use several curves and selective masking. Using ColorfulCurves was easy and quick.”

“[T]o push the challenge further, I choose a portrait to do a skin tone editing and the results are really good.”

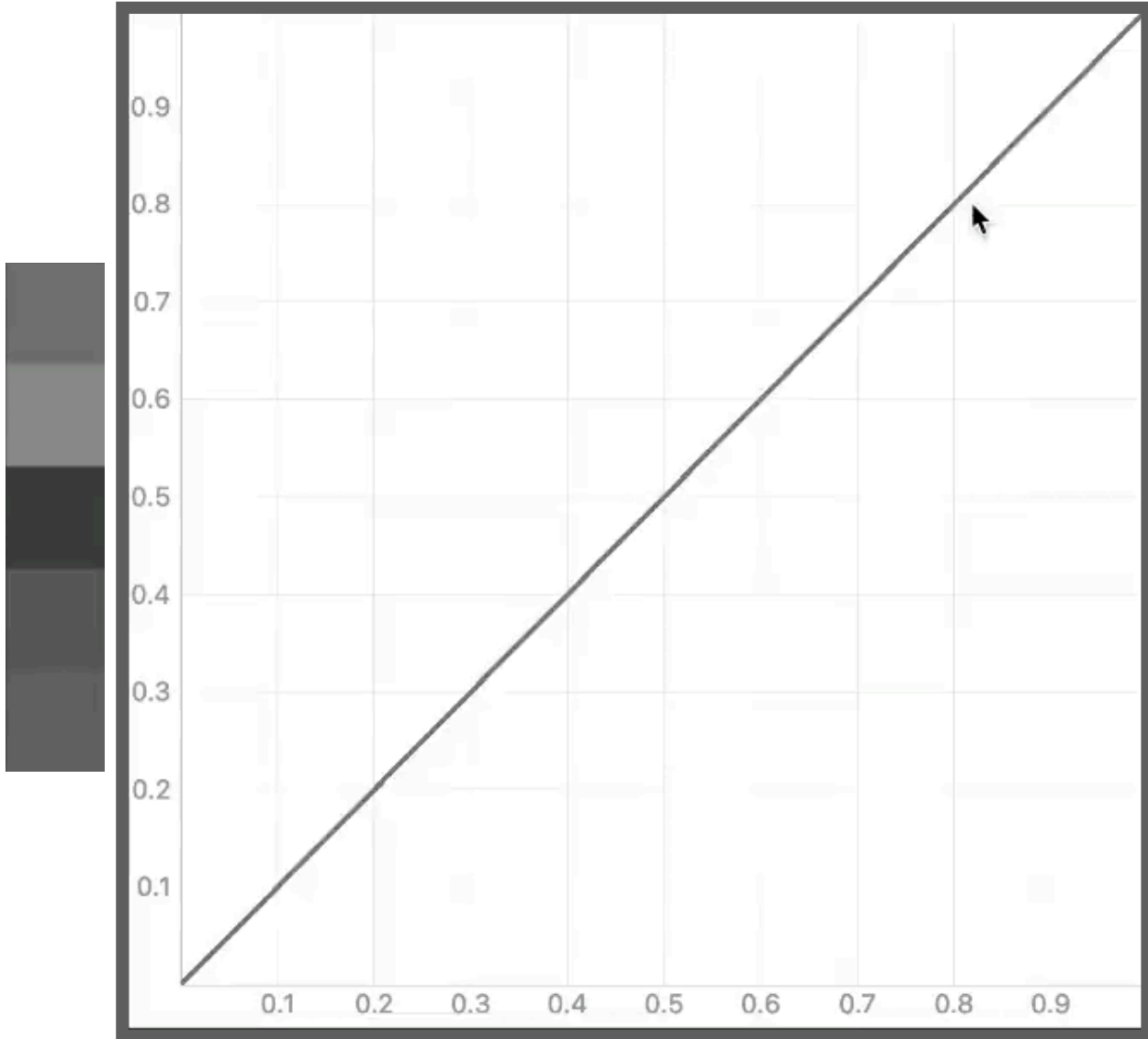


Applications



Applications

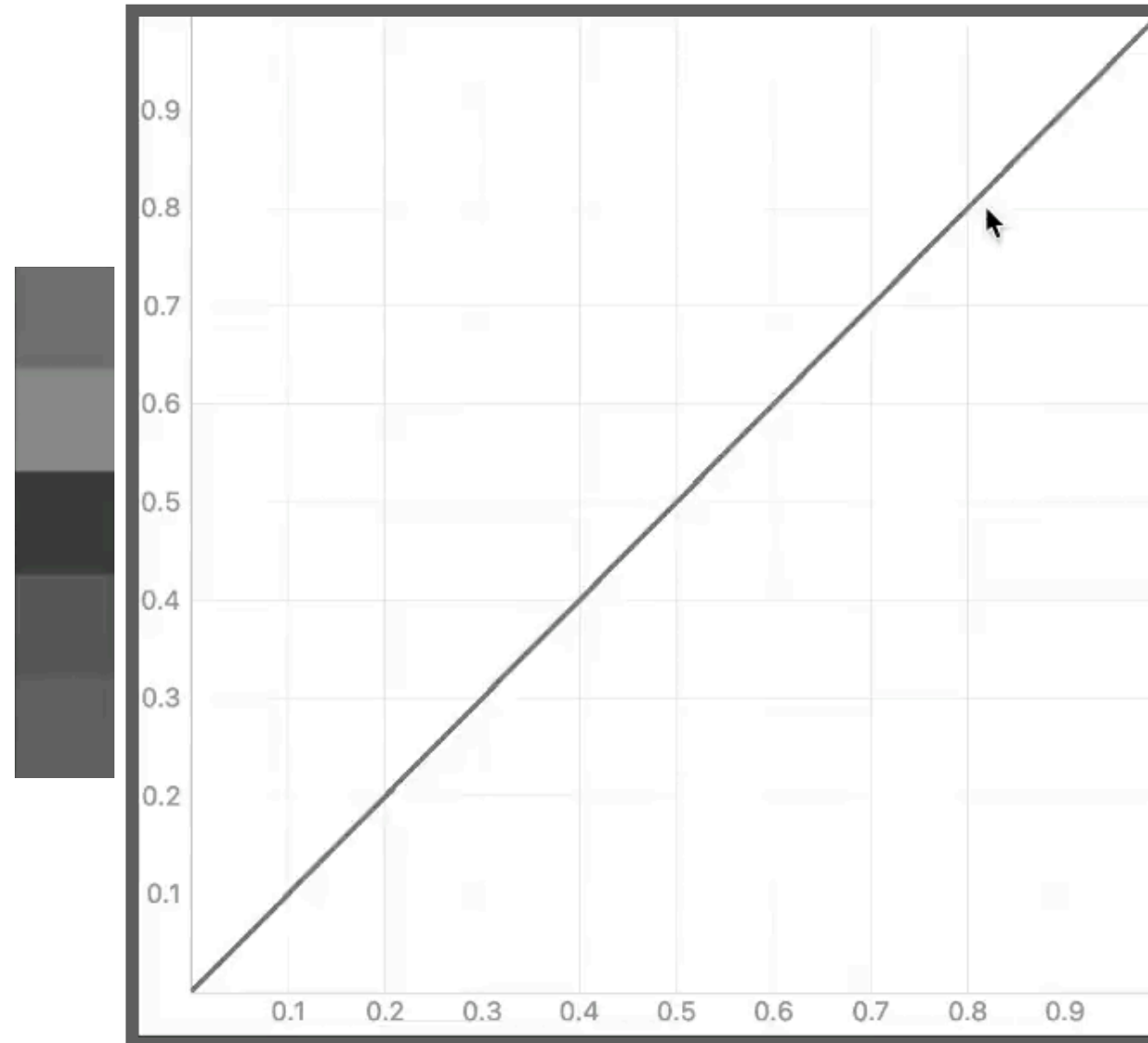
$$I_{ab} = W \cdot P$$



Applications

(0, 0)

$$I_{ab} = W \cdot P$$

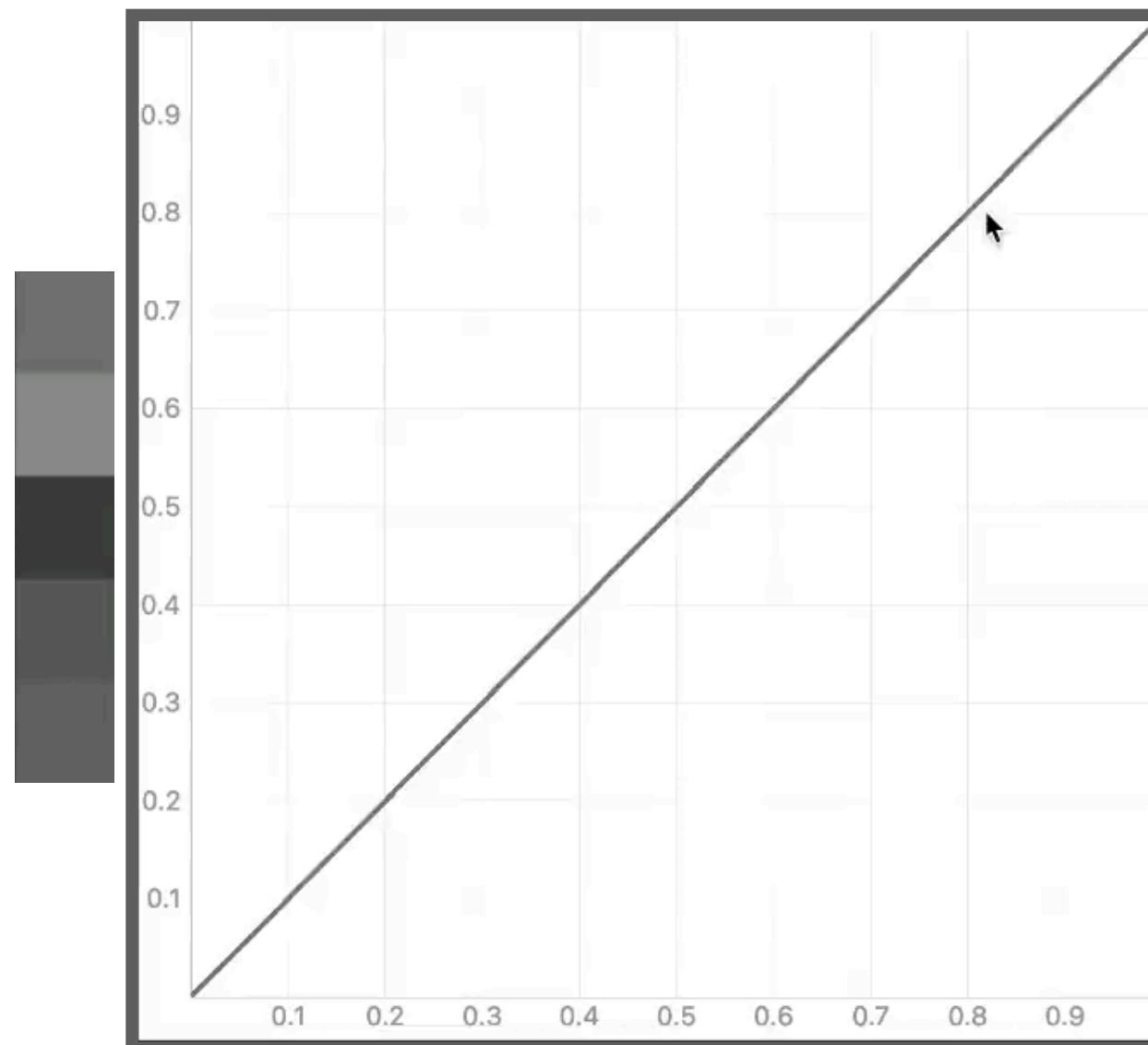


Applications

(0, 0)

$$I_{ab} = W \cdot P$$

$$I_L = \sum_{i=1}^p \hat{W}_i \odot f_i(L_0)$$

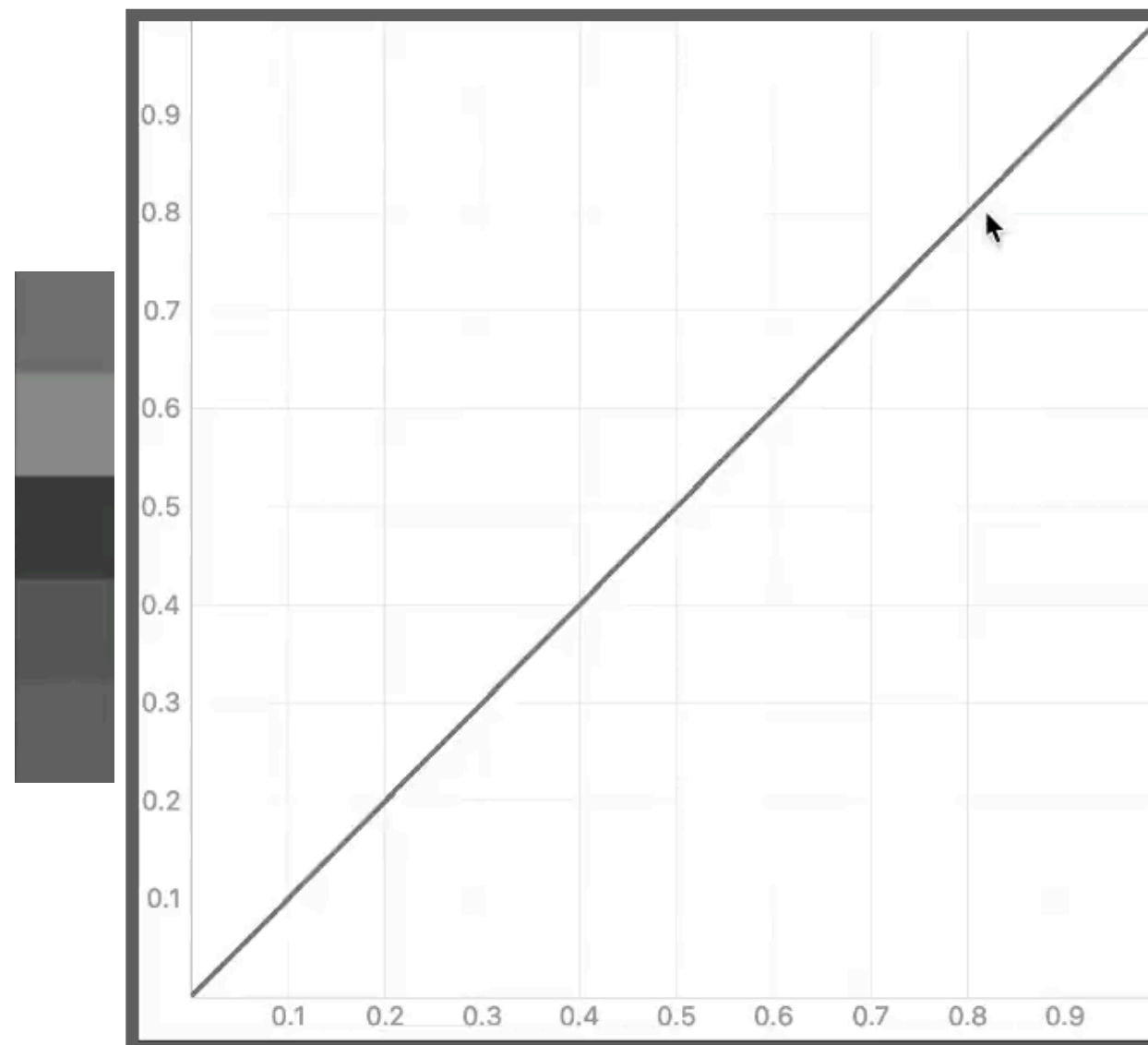


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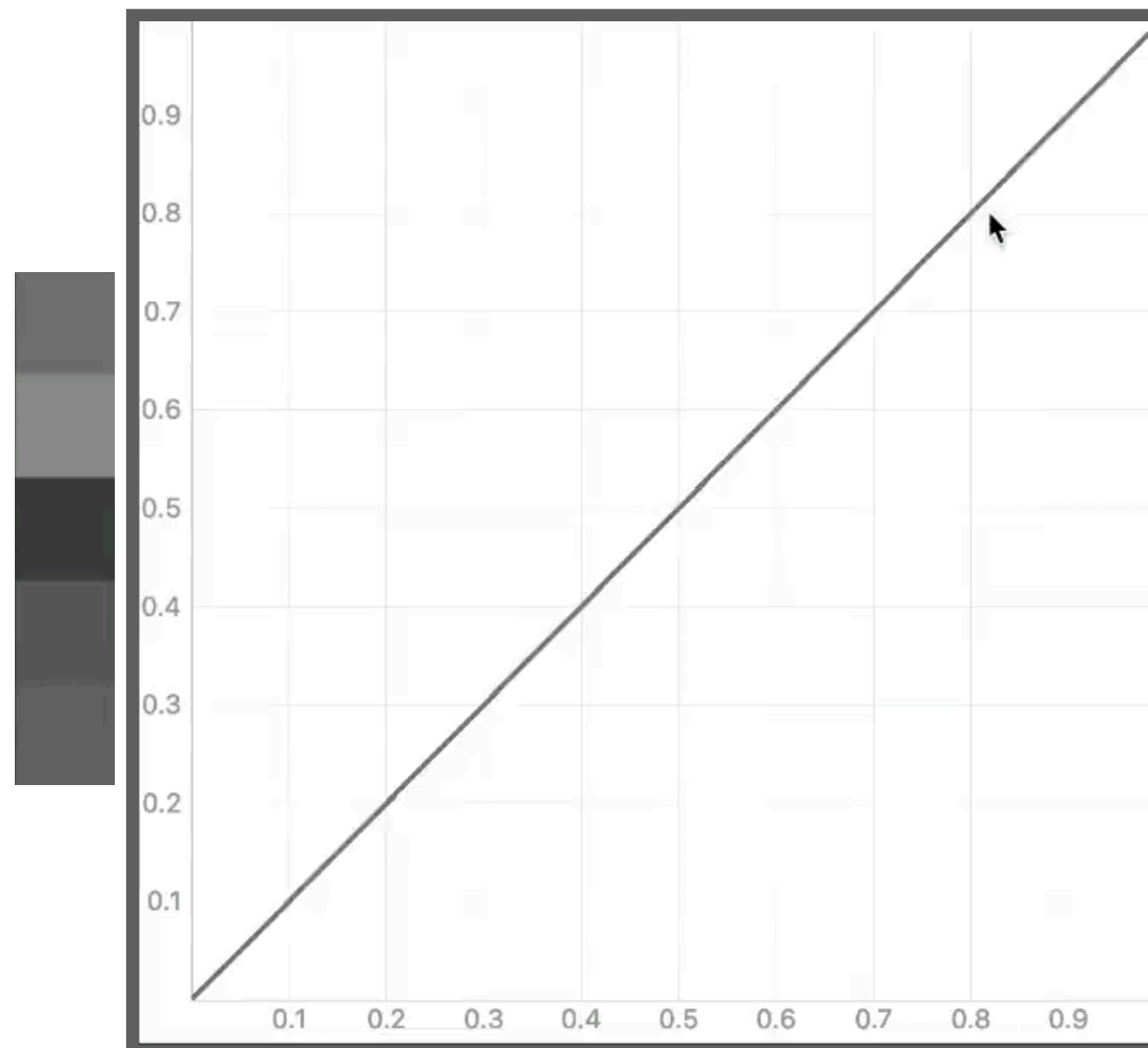


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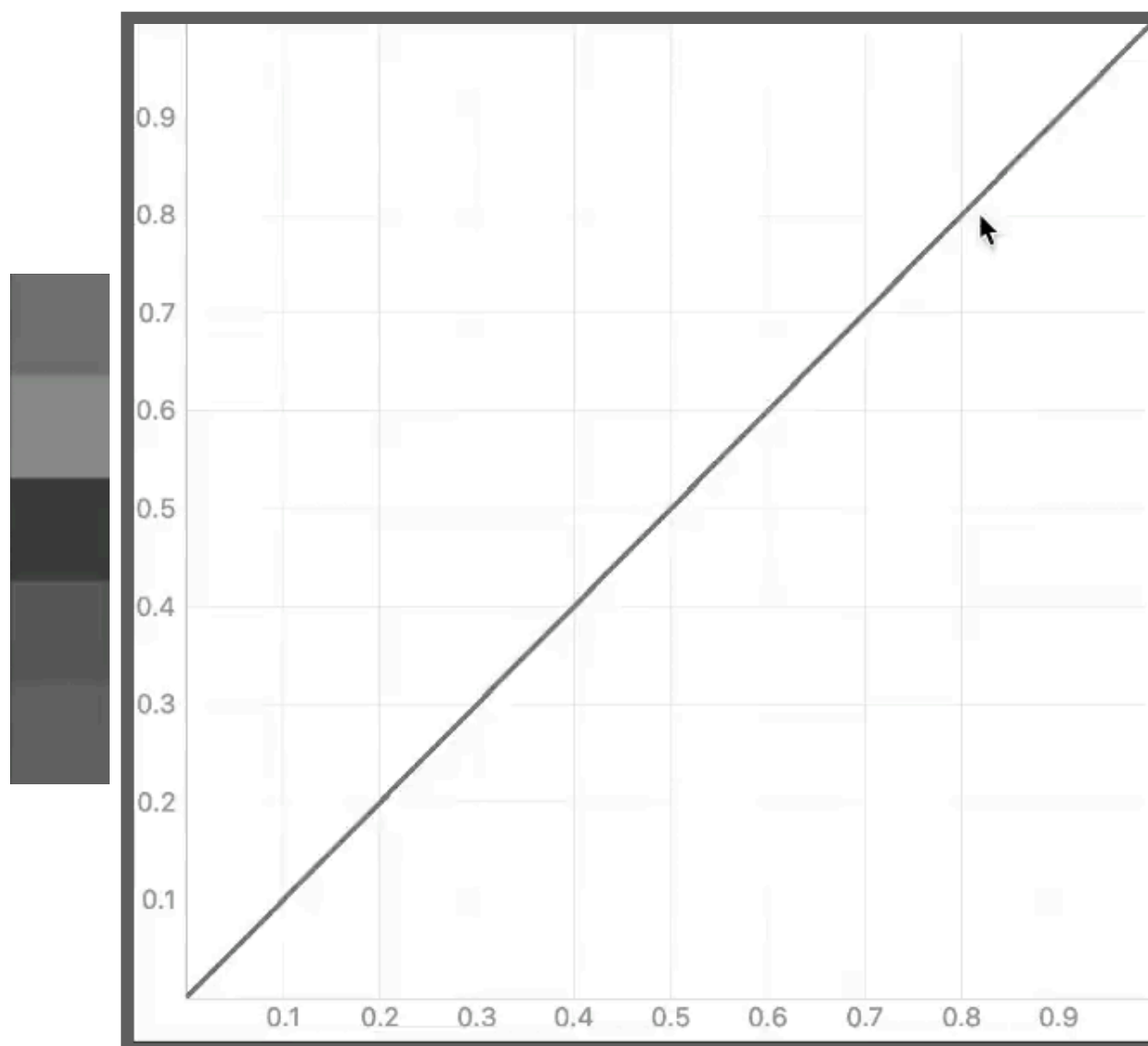
Applications



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[Miangoleh et al. 2021]



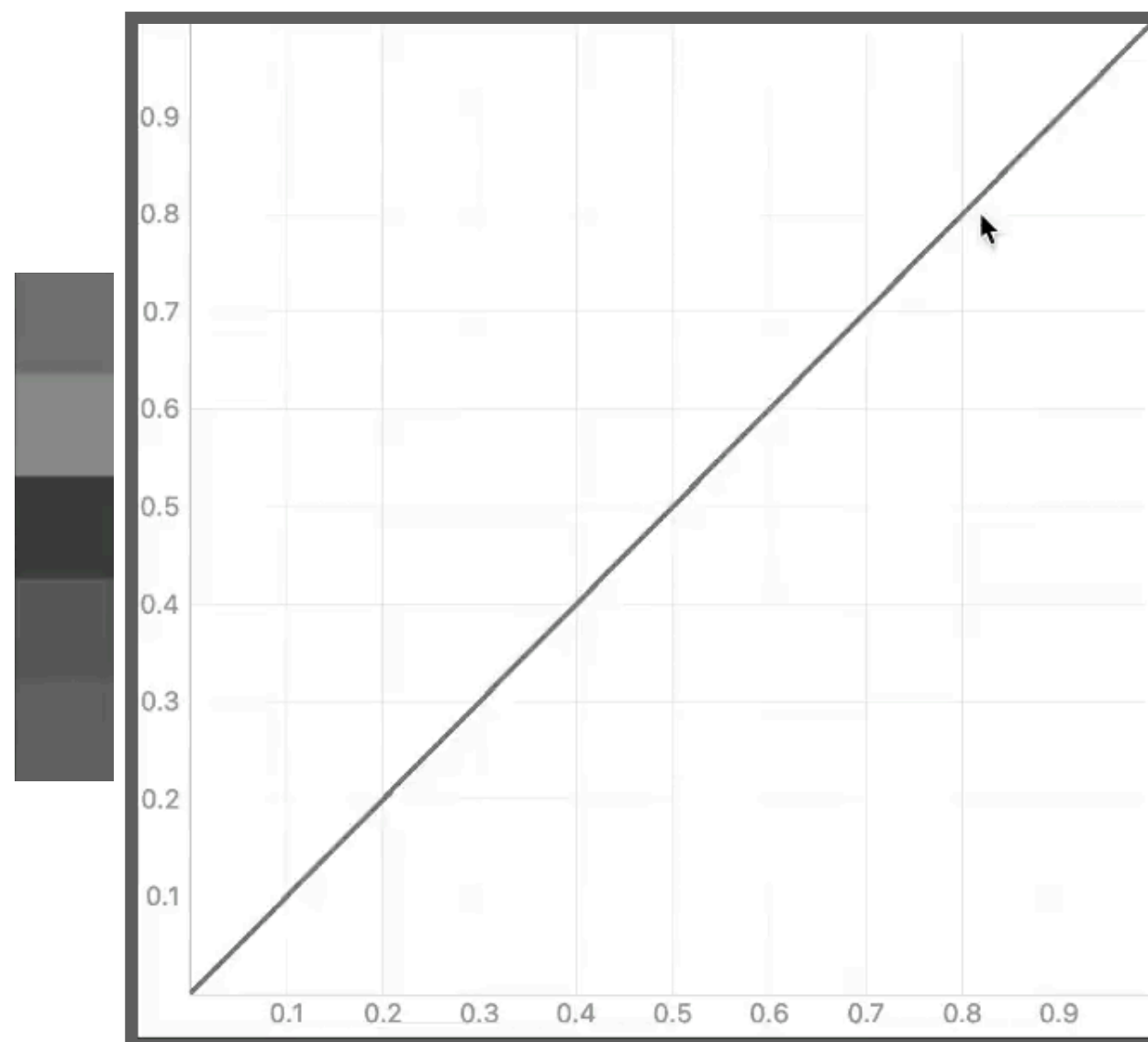
Applications



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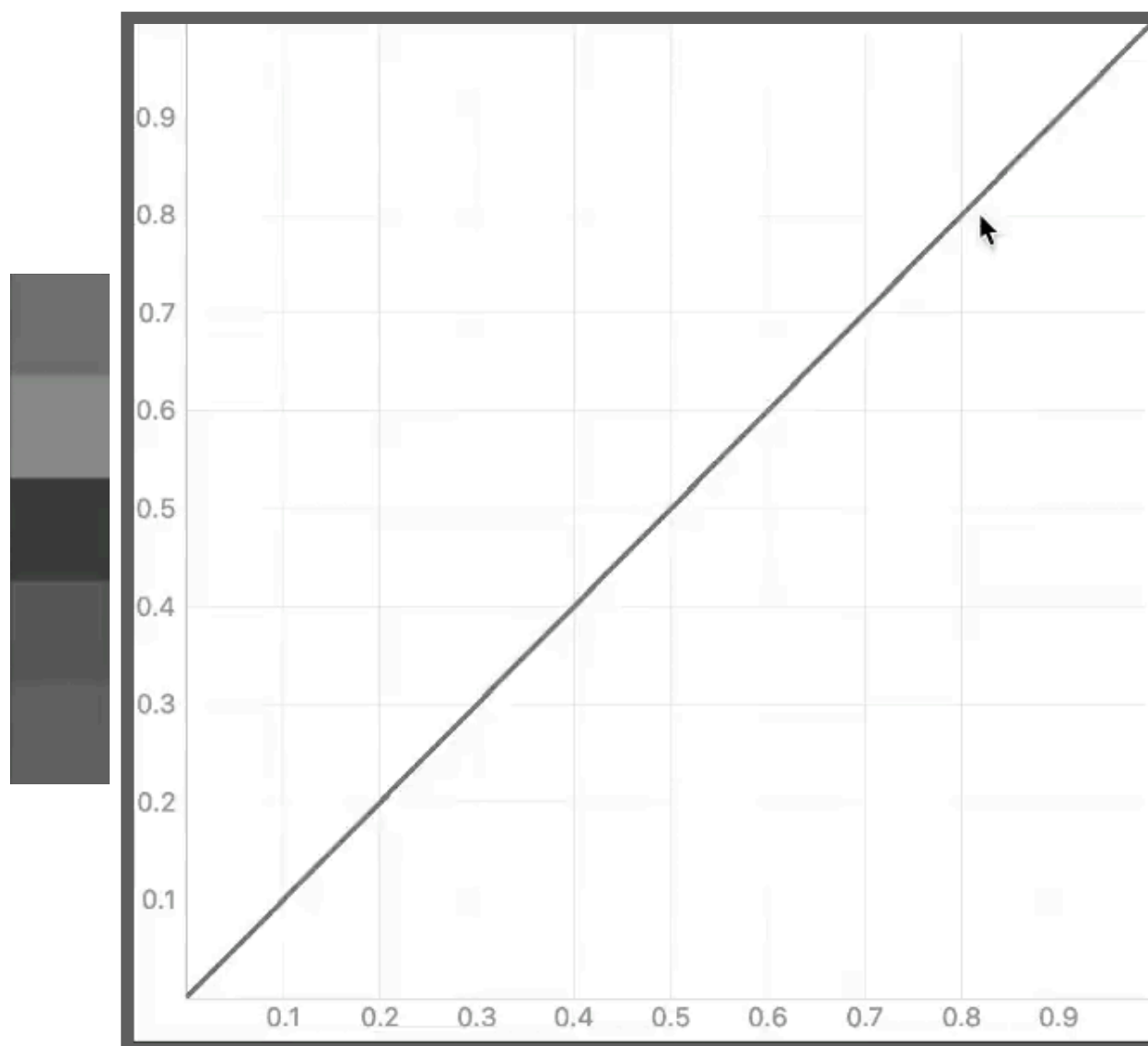
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Decrease the lightness



[Miangoleh et al. 2021]



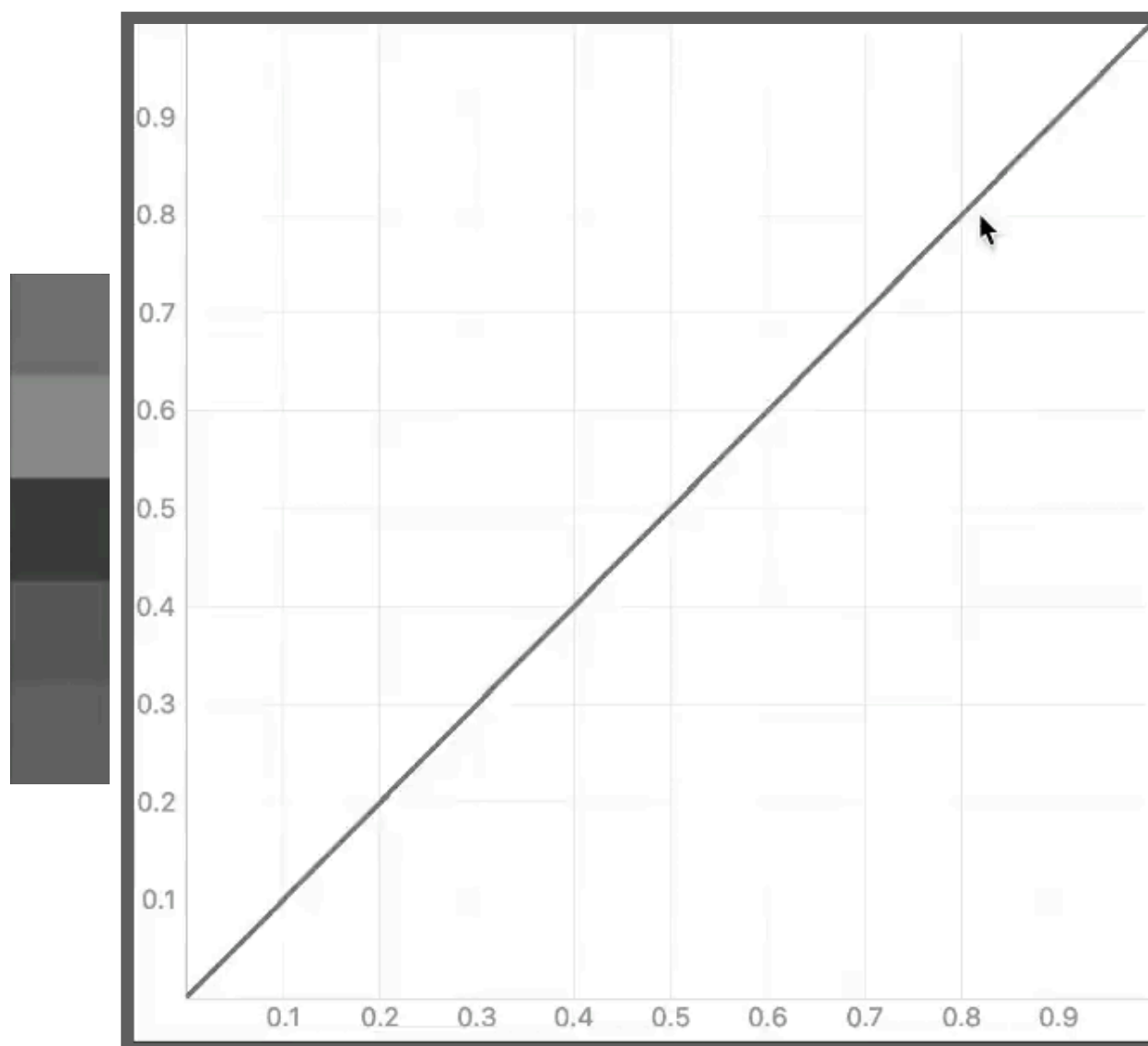
Applications



(0, 0)

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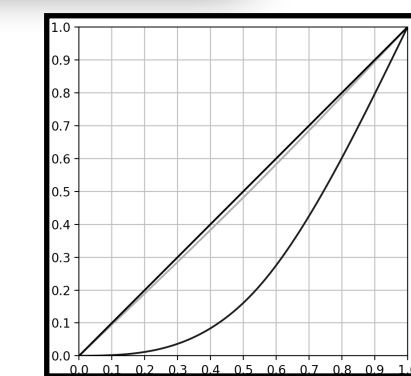
$$I_L = \sum_{i=1}^p \hat{W}_i \odot f_i(L_0)$$



Decrease the lightness



[Miangoleh et al. 2021]



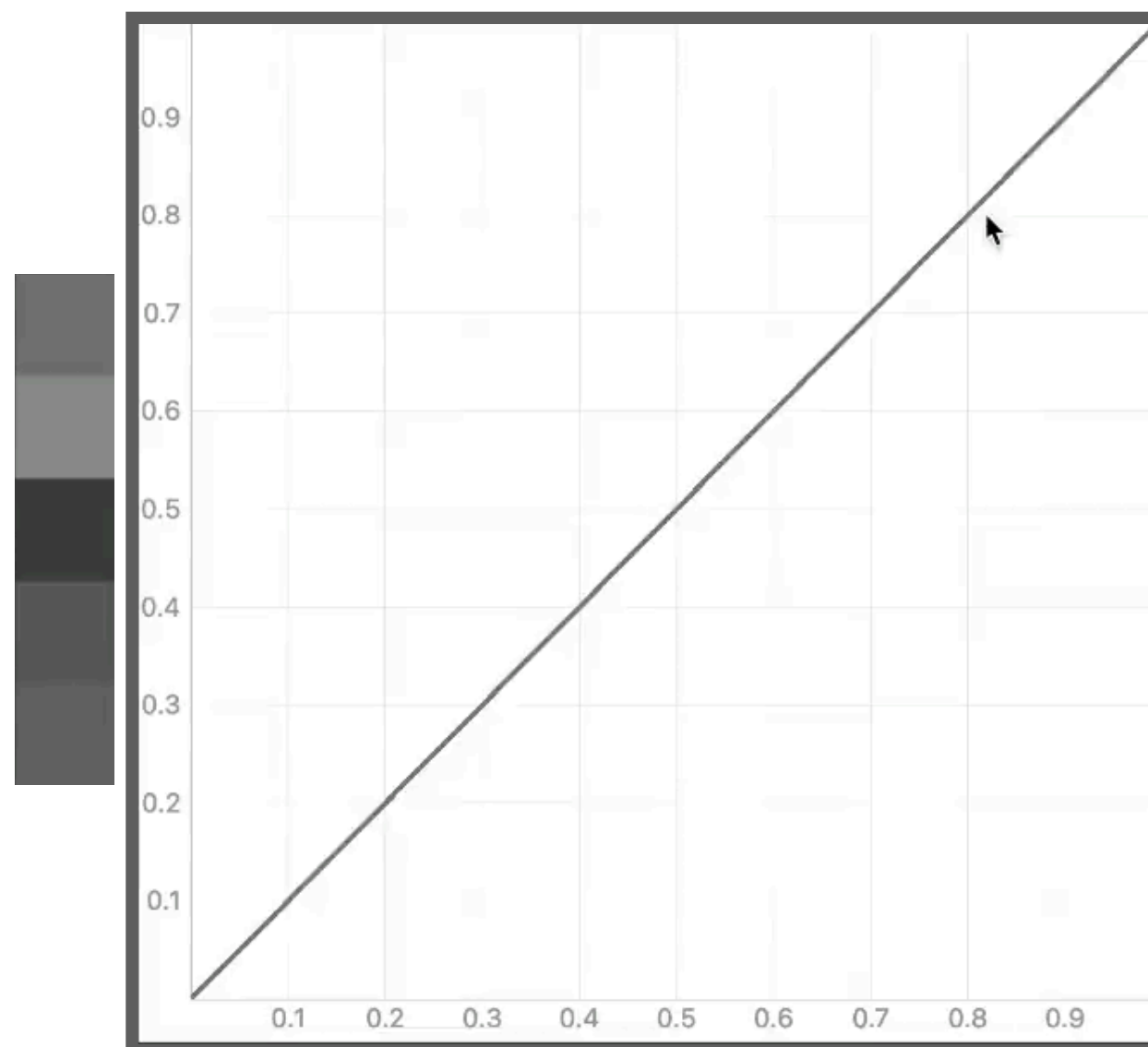
Applications



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Decrease the lightness

[Miangoleh et al. 2021]



Conclusions, Limitations, Future work

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💡 **Extend to video domain**

💡 **Text-guided professional photo editing**

💡 **Dynamic gamut deformation**

Acknowledgements



- **Project page:** <https://cragl.cs.gmu.edu/colorfulcurves/>
- **Code and data:** <https://github.com/tedchao/ColorfulCurves>
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