Histogrammes et Lookup-tables

UPEM - Master 1

Vincent Nozick

Histogramme

Histogramme d'une image en niveaux de gris :
Fonction qui associe à chaque valeur d'intensité le nombre de pixels de l'image ayant cette valeur.

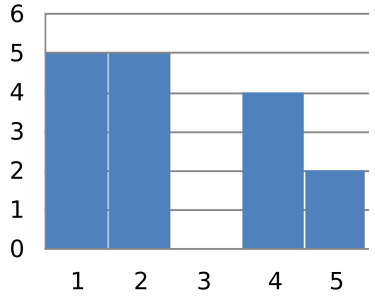
1	5	4	4
1	2	2	1
4	1	2	2
1	4	2	5

1	2	3	4	5
5	5	0	4	2

Histogramme

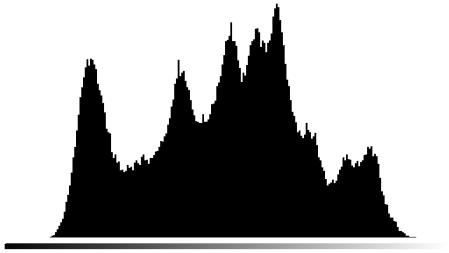
Histogramme d'une image en niveaux de gris :
s'exprime aussi sous forme de graphique.

1	2	3	4	5
5	5	0	4	2



Histogramme

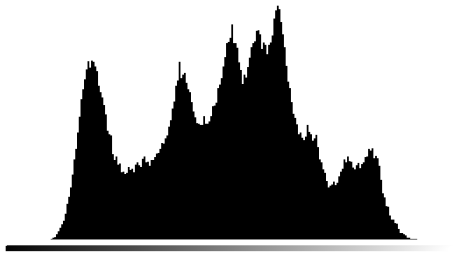
Histogramme d'une image :
Fonction qui associe à chaque valeur d'intensité le nombre de pixels de l'image ayant cette valeur.



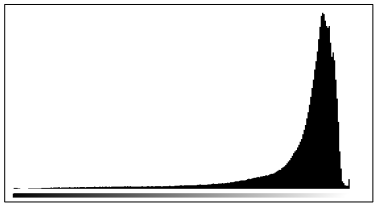
Histogramme

Histogramme d'une image :

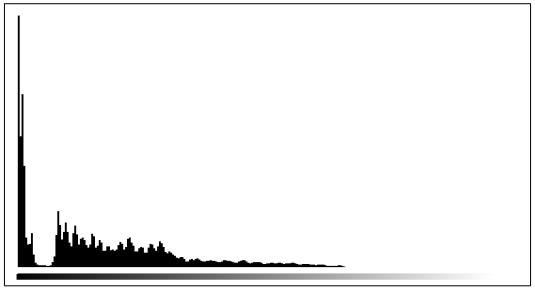
- fournit des informations :
  - la distribution statistique des niveaux de gris
  - les bornes de répartition des niveaux de gris
- mais aucune information spatiale !



Exemples



Exemples



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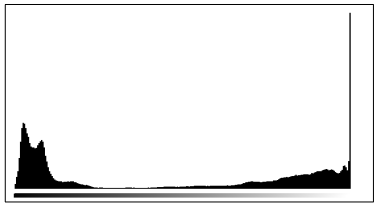
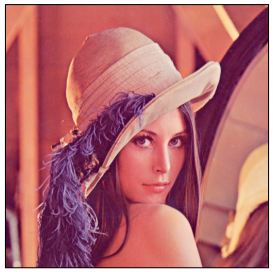
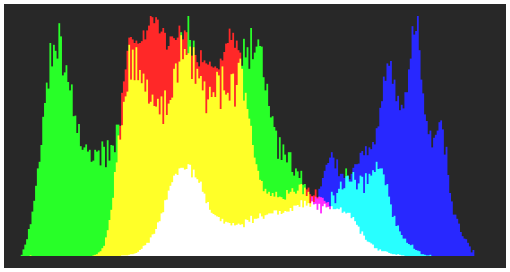


Histogramme

Histogramme couleur :
pour une image couleur, on traite chaque canal indépendamment.

Histogramme

Implémentation :

pour une image en niveaux de gris, codée sur 8 bits :

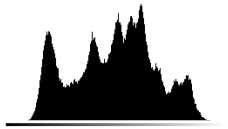
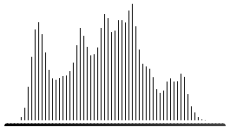
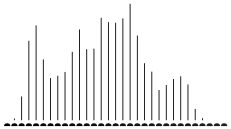
```
uint histogram[256]
histogram.fill(0)

for(x=0; x<width; ++x)
  for(y=0; y<height; ++y)
    histogram[I(x,y)]++
```

Remarque :

- pas simple à paralléliser sur GPU.

Nombre de bins

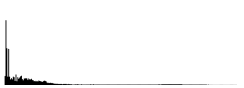
256 bins 64 bins 32 bins

→ extension aux images encodées sur des nombres flottants.

Autres espaces colorimétriques

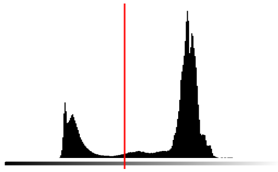


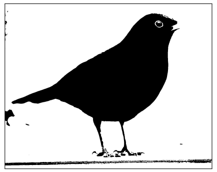



hue saturation value

Applications



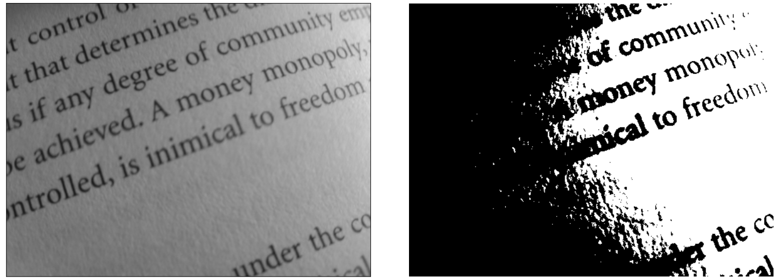


Seuillage automatique :

- choisir la coupe qui minimise la variance des 2 groupes (méthode d'Otsu)
- ...

Applications

Seuillage adaptatif :



Applications

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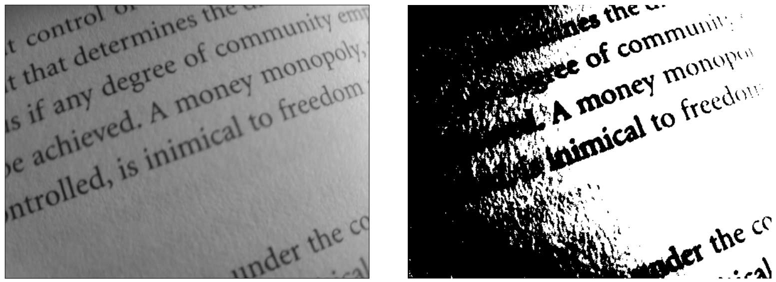

Applications

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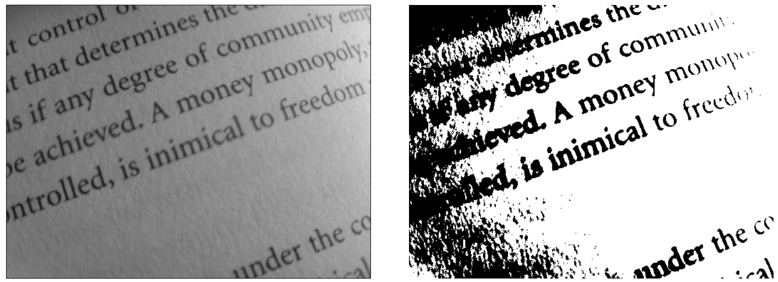

Applications

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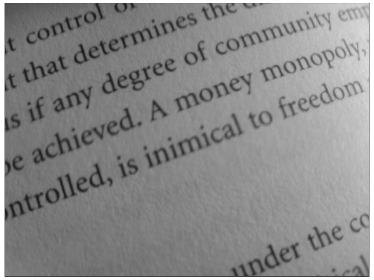

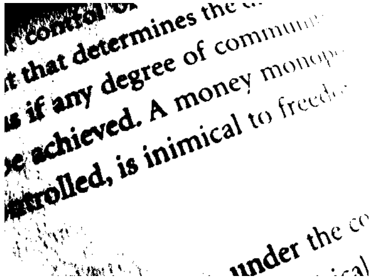

Histogrammes Transformations linéaires LUT Egalisation Couleur Applications

Applications

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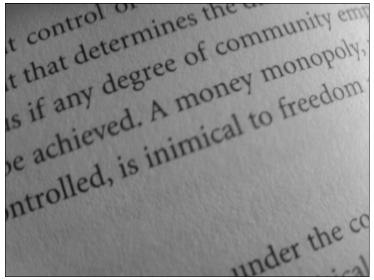

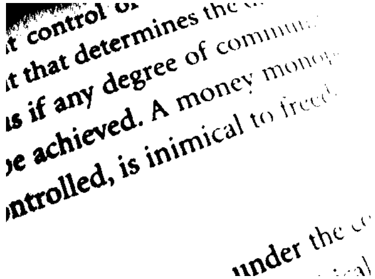

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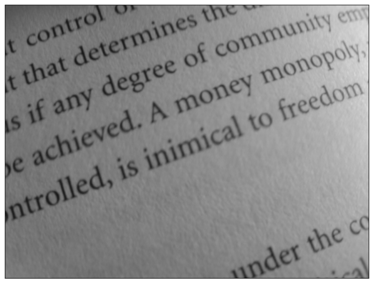

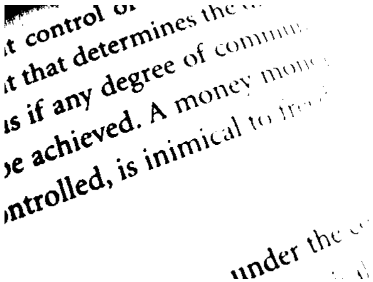

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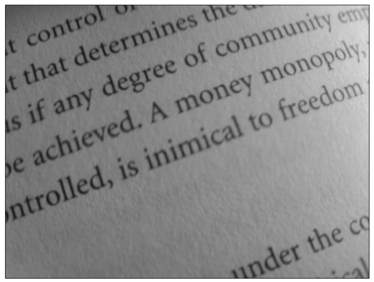

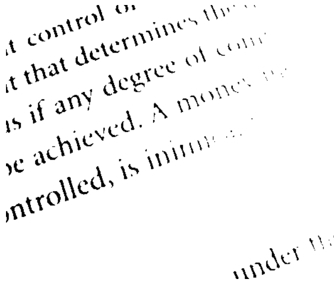

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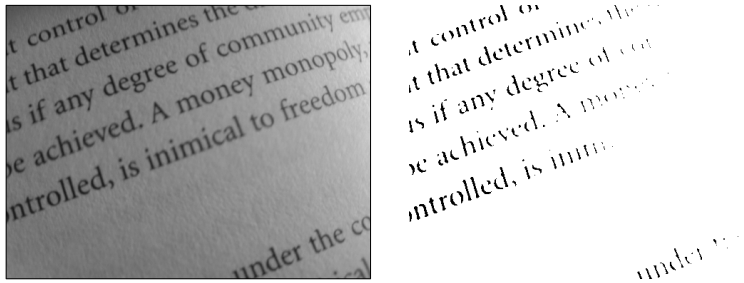
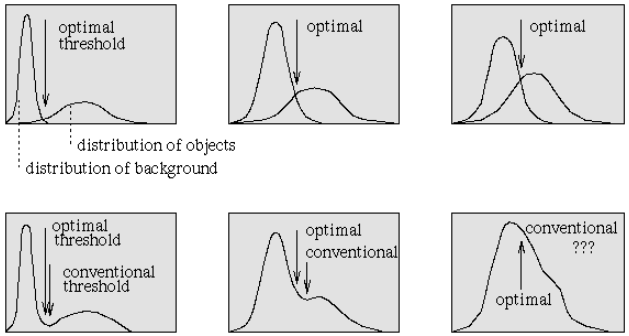
Applications

Seuillage adaptatif :



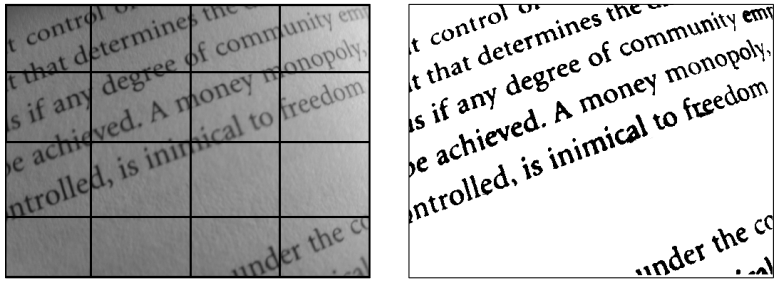
Applications

Seuillage adaptatif :



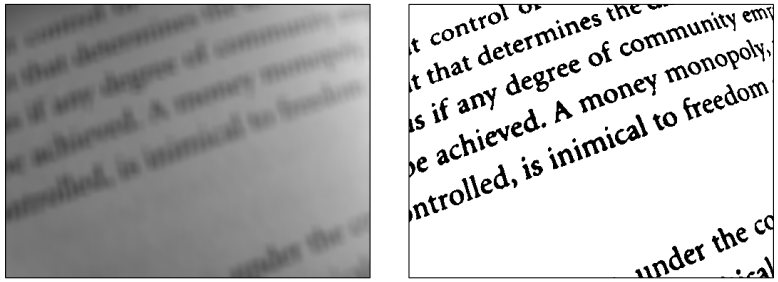
Applications

Seuillage adaptatif : méthode d'Otsu



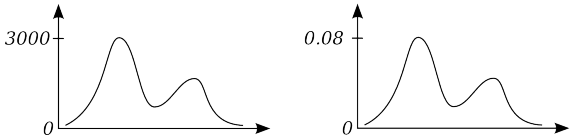
Applications

Seuillage adaptatif : méthode utilisant du flou



seuillage du pixel selon que $\mathtt{I}(x,y) > \text{blur}(\mathtt{I}(x,y)) - \alpha$

Histogramme normalisé



Définition :
on norme l'histogramme par le nombre de pixels dans l'image.

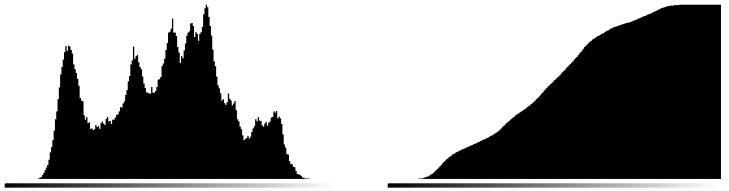
$$\mathtt{H}_n(k) = \frac{\mathtt{H}(k)}{w \times h}$$

L'histogramme $\mathtt{H}_n(k)$ donne une information statistique sur la probabilité qu'un pixel ait un niveau de gris k.

Histogramme cumulé

Principe :
indique le nombre de pixels dont le niveau de gris est inférieur à x :

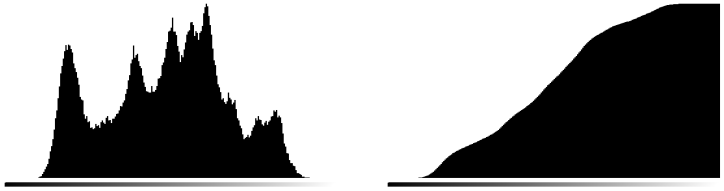
$$\mathtt{H}_c(x) = \sum_{i=0}^{x} \mathtt{H}(i)$$



Histogramme cumulé normalisé

Principe :
indique le **taux** de pixels dont le niveau de gris est inférieur à x :

$$\mathtt{H}_{cn}(x) = \frac{\sum_{i=0}^{x} \mathtt{H}(i)}{w \times h}$$



Histogramme cumulé normalisé

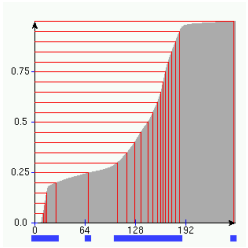
$$\mathtt{H}_{cn}(x) = \frac{\sum_{i=0}^{x} \mathtt{H}(i)}{w \times h}$$

Propriété :

le niveau de gris médian est x_m tel que $\mathtt{H}_{cn}(x_m) = 0.5$

Applications

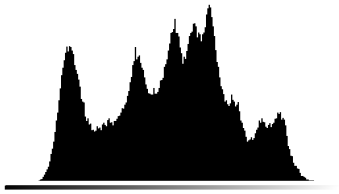
Segmentation :

images : Antoine Manzanera

Histogramme : invariances

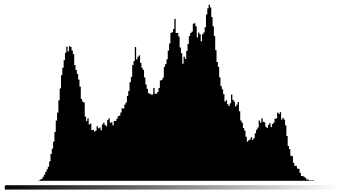
Invariance spatiale :

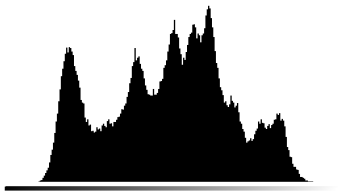




du moins en théorie, si on ne tient pas compte de l'interpolation.

Histogramme : invariances

Invariance spatiale :



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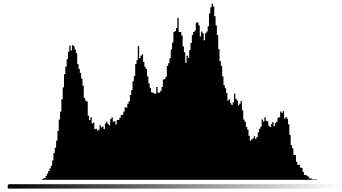
Histogramme : invariances

Résolution : 512×512 vs. 64×64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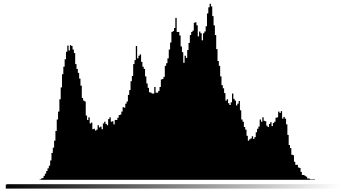

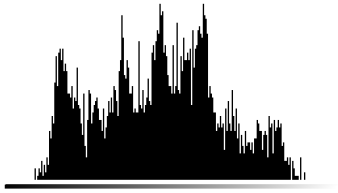

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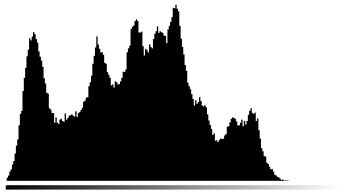
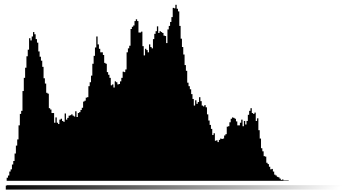
Histogramme : invariances

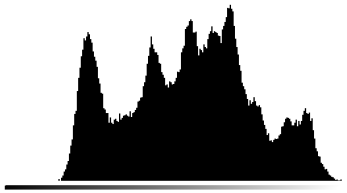
Luminance :


Histogramme : invariances

Luminance :



Vous avez dit “luminance” ?

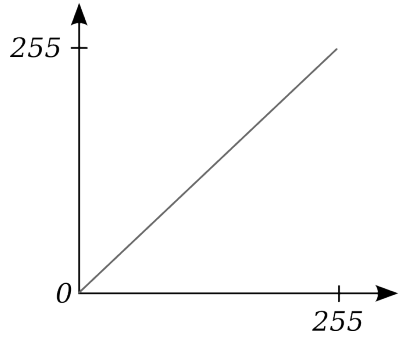

comment ça se formalise?

Vous avez dit “luminance” ?


comment ça se formalise?

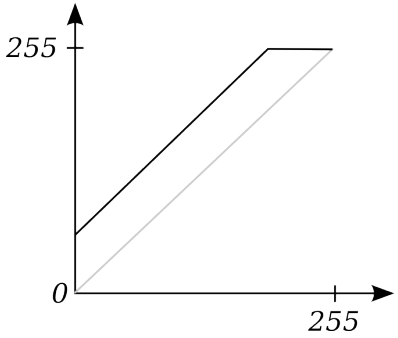
$$\mathtt{I}'(x,y) = \mathtt{I}(x,y) + \beta$$

Luminance

$$\mathtt{I}'(x,y) = \mathtt{I}(x,y)$$

Luminance

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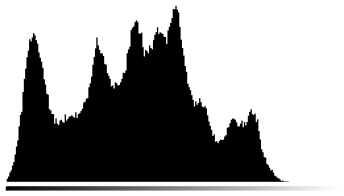
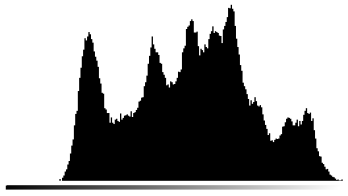
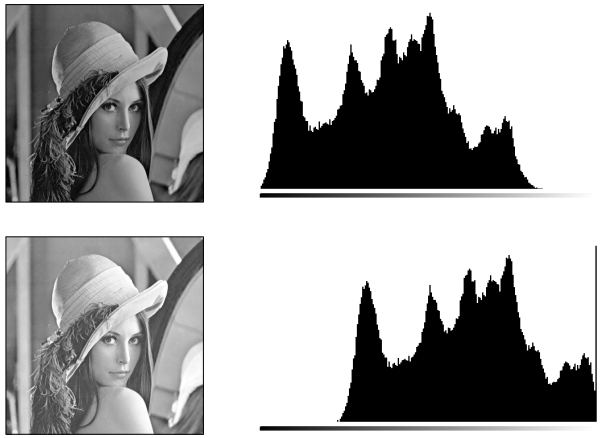
Luminance



Luminance : saturation et clamp



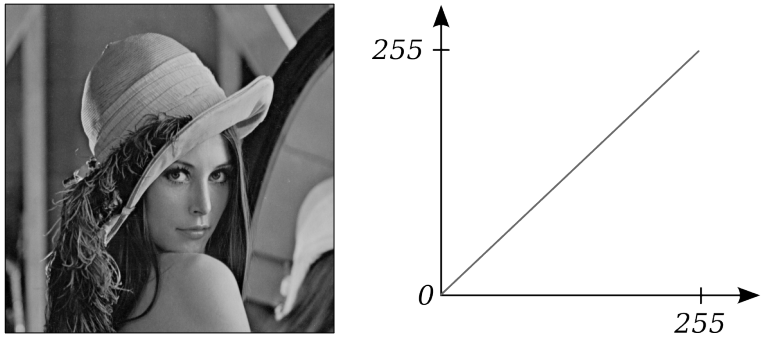
Luminance : saturation et clamp

Attention :
opération non réversible.

Contraste

$$\mathtt{I}'(x,y) = \alpha \cdot \mathtt{I}(x,y)$$

Contraste



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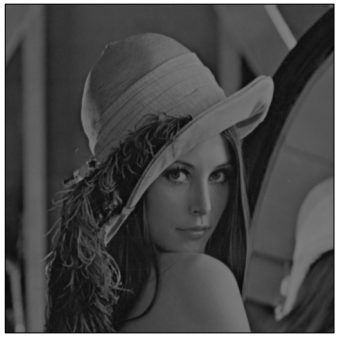

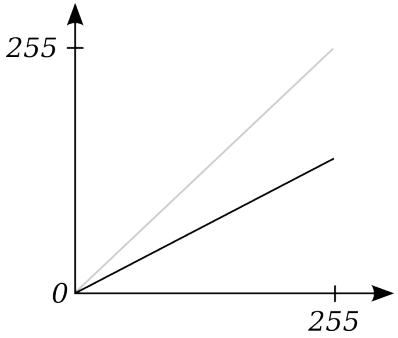

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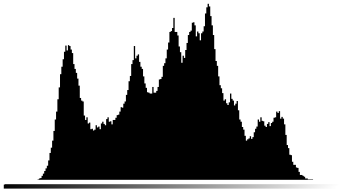
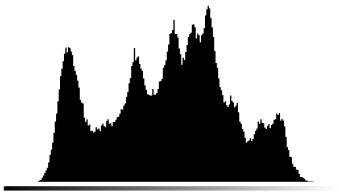
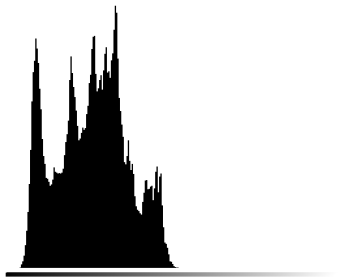


Contraste

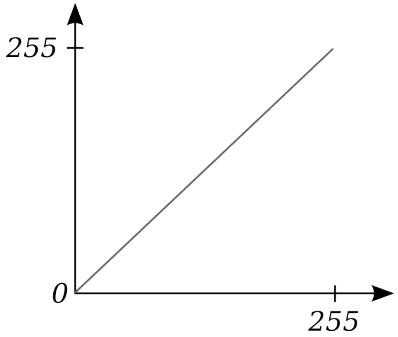




Luminance + Contraste

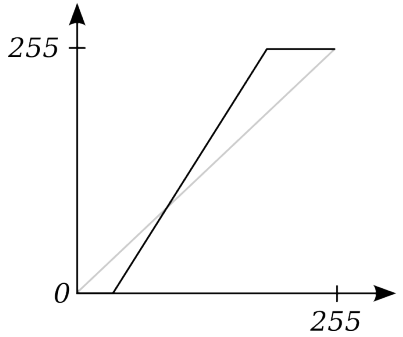
$$\mathtt{I}'(x,y) = \alpha \cdot \mathtt{I}(x,y) + \beta$$

Luminance + Contraste



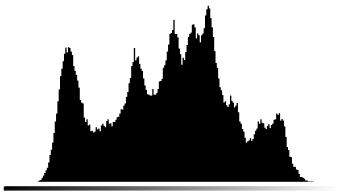
$$\mathtt{I}'(x,y) = \mathtt{I}(x,y)$$

Luminance + Contraste

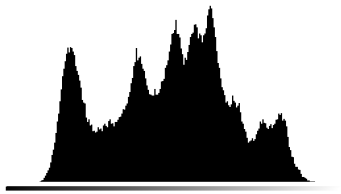


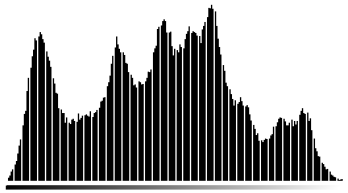
$$\mathtt{I}'(x,y) = \alpha \cdot \mathtt{I}(x,y) + \beta$$

Luminance + Contraste

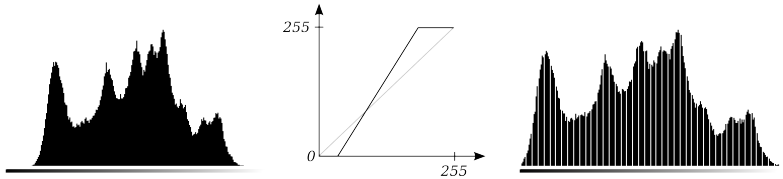


Luminance + Contraste

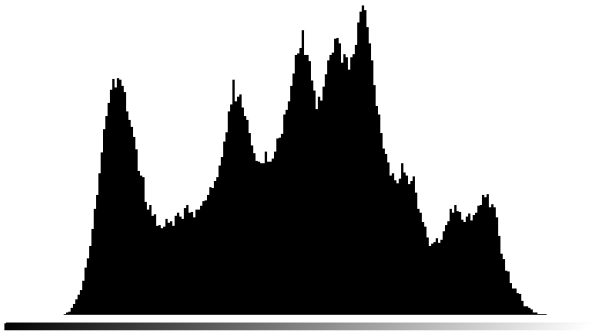




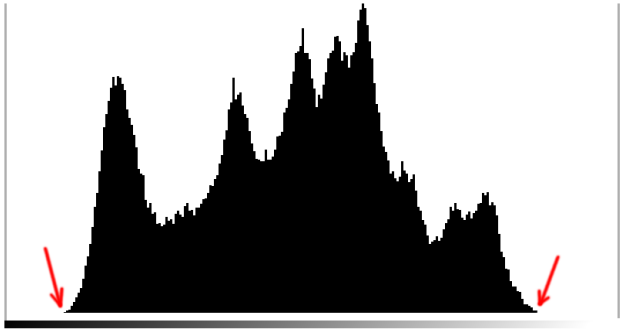
Luminance + Contraste



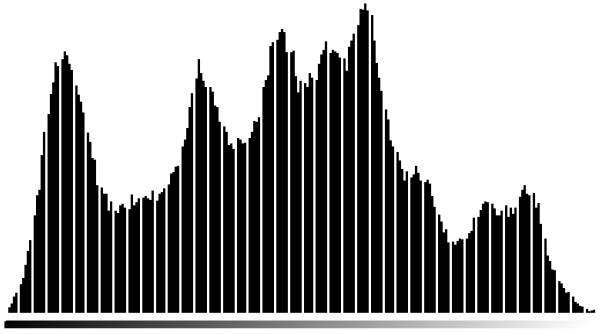
Luminance + Contraste



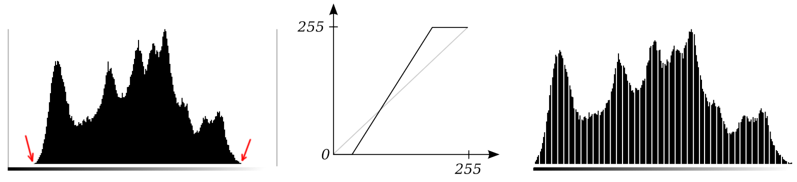
Luminance + Contraste



Luminance + Contraste



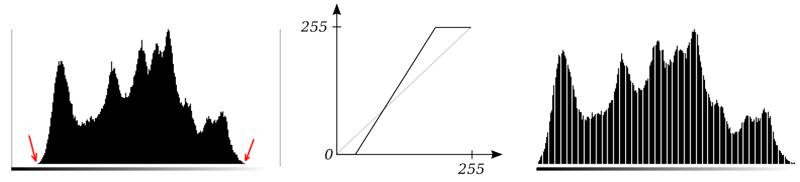
Luminance + Contraste



$$\mathtt{I}'(x,y) = \frac{\mathtt{I}(x,y) - \mathtt{I}_{\text{min}}}{\mathtt{I}_{\text{max}} - \mathtt{I}_{\text{min}}} \cdot 255$$

$$\mathtt{I}'(x,y) = \underbrace{\frac{255}{\mathtt{I}_{\text{max}} - \mathtt{I}_{\text{min}}}}_{\alpha} \cdot \mathtt{I}(x,y) - \underbrace{\frac{255.\mathtt{I}_{\text{min}}}{\mathtt{I}_{\text{max}} - \mathtt{I}_{\text{min}}}}_{\beta}$$

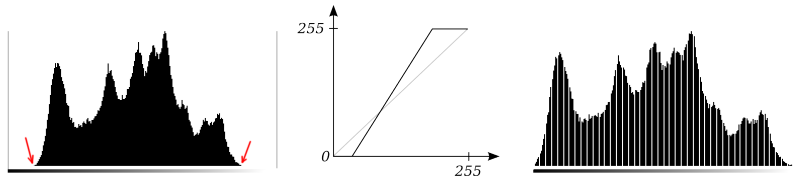
Luminance + Contraste



$$\mathtt{I}'(x,y) = \frac{\mathtt{I}(x,y) - \mathtt{I}_{\text{min}}}{\mathtt{I}_{\text{max}} - \mathtt{I}_{\text{min}}} \cdot 255$$

$$\mathtt{I}'(x,y) = \underbrace{\frac{255}{\mathtt{I}_{\text{max}} - \mathtt{I}_{\text{min}}}}_{\alpha} \cdot \mathtt{I}(x,y) - \underbrace{\frac{255.\mathtt{I}_{\text{min}}}{\mathtt{I}_{\text{max}} - \mathtt{I}_{\text{min}}}}_{\beta}$$

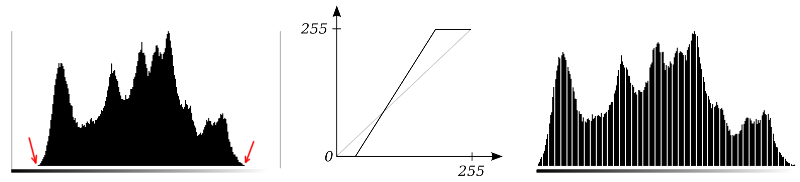
Luminance + Contraste



$$\mathtt{I}'(x,y) = \frac{\mathtt{I}(x,y) - \mathtt{I}_{\text{min}}}{\mathtt{I}_{\text{max}} - \mathtt{I}_{\text{min}}} \cdot 255$$

$$\mathtt{I}'(x,y) = \underbrace{\frac{255}{\mathtt{I}_{\text{max}} - \mathtt{I}_{\text{min}}}}_{\alpha} \cdot \mathtt{I}(x,y) - \underbrace{\frac{255.\mathtt{I}_{\text{min}}}{\mathtt{I}_{\text{max}} - \mathtt{I}_{\text{min}}}}_{\beta}$$

Normalisation d'histogramme



Normalisation d'histogramme :

- ou *expansion de dynamique*
- transformation affine du niveau de gris des pixels pour générer une image qui utilise toute la dynamique de représentation.

Normalisation d'histogramme

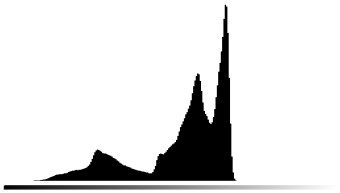
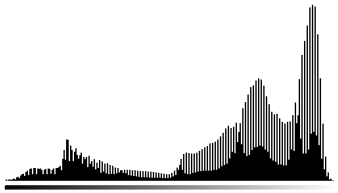



image initiale

après normalisation d'histogramme

Implémentation

$$\mathtt{I}'(x,y) = \frac{\mathtt{I}(x,y) - \mathtt{I}_{\mathsf{min}}}{\mathtt{I}_{\mathsf{max}} - \mathtt{I}_{\mathsf{min}}} \cdot 255$$

Version 1 :

```
for(x=0; x<width; ++x)
  for(y=0; y<height; ++y)
    I(x,y) = 255 * (I(x,y)-Imin)/(Imax-Imin)
```

↪ ça fait beaucoup d'opérations, à faire pour chaque pixel.

Implémentation

$$\mathtt{I}'(x,y) = \frac{\mathtt{I}(x,y) - \mathtt{I}_{\mathsf{min}}}{\mathtt{I}_{\mathsf{max}} - \mathtt{I}_{\mathsf{min}}} \cdot 255$$

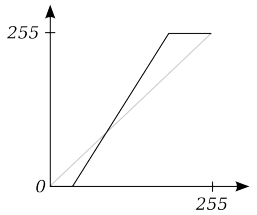
Version 2 : la LookUp Table (LUT)

```
for(i=0; i<255; ++i)
  LUT[i]=clamp( 255*(i-Imin)/(Imax-Imin), 0,255)

for(x=0; x<width; ++x)
  for(y=0; y<height; ++y)
    I(x,y) = LUT[I(x,y)]
```

↪ on perd du temps à l'initialisation
↪ qu'on regagne largement pendant le traitement

Lookup table



LUT :

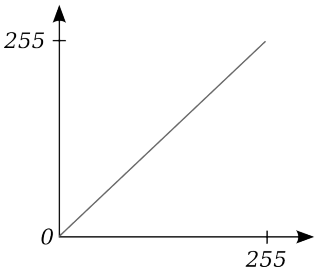
- une table de correspondance.
- une fonction injective.
  ↪ à chaque valeur de départ correspond une valeur d'arrivée

Lookup table

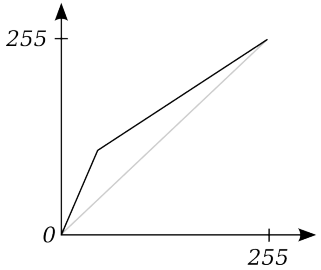
Avantages :

- plus rapide à appliquer à toute l'image
- on peut cumuler des LUT
  - en travaillant sur des flottant
    ↪ interpolation linéaire sur la lecture de la LUT
  - en autorisant les dépassement
    ↪ le clamp est fait tout à la fin
- générique, quelque soit la transformation

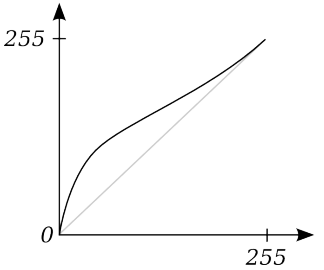
Transformations linéaires par morceaux



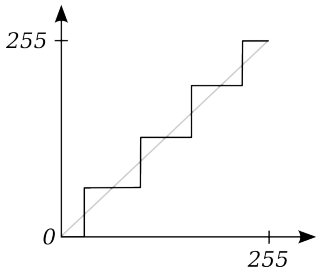
Transformations linéaires par morceaux



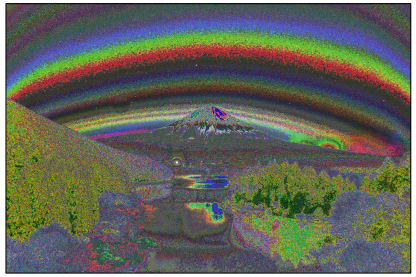
Transformations non-linéaires

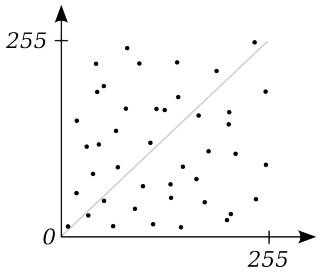


Transformations non-continues



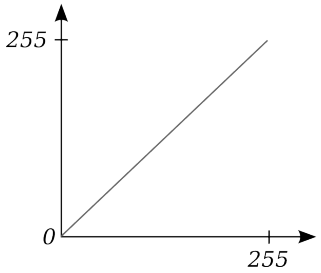
Transformations bizarres





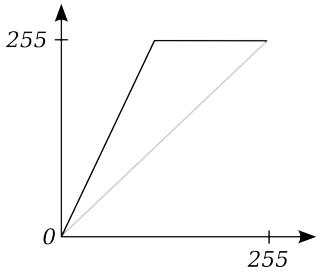
Combinaisons de LUT

Image initiale :



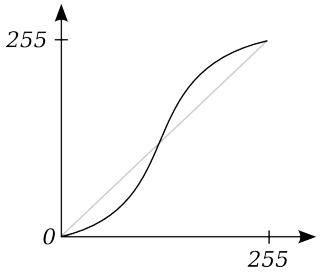
Combinaisons de LUT

Augmentation de la dynamique :



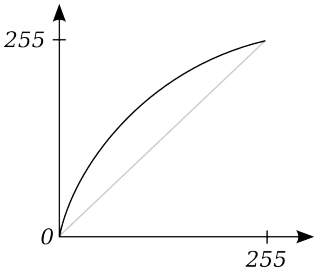
Combinaisons de LUT

Augmentation du contraste :

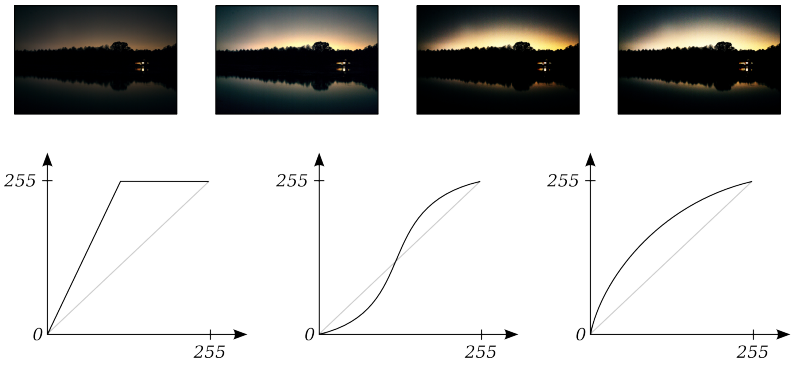


Combinaisons de LUT

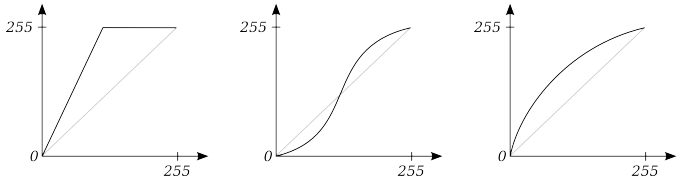
Correction gamma :



Combinaisons de LUT

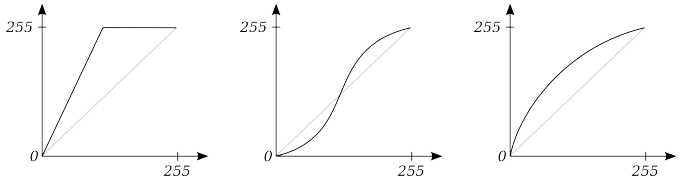


Combinaisons de LUT



$\texttt{LUT}_1$ $\texttt{LUT}_2$ $\texttt{LUT}_3$

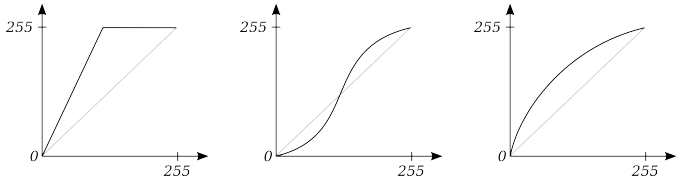
Combinaisons de LUT



$\mathtt{LUT}_1$ $\mathtt{LUT}_2$ $\mathtt{LUT}_3$

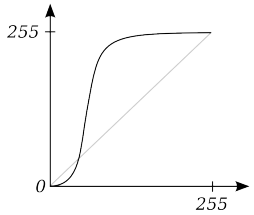
$$\mathtt{LUT}_4 = \mathtt{LUT}_3 \circ \mathtt{LUT}_2 \circ \mathtt{LUT}_1$$

Combinaisons de LUT



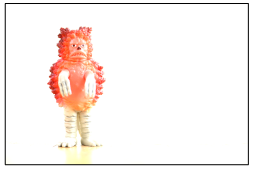
$\mathtt{LUT}_1$ $\mathtt{LUT}_2$ $\mathtt{LUT}_3$

$$\mathtt{LUT}_4 = \mathtt{LUT}_3 \circ \mathtt{LUT}_2 \circ \mathtt{LUT}_1$$



Quizz : image originale

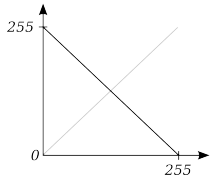
Quizz



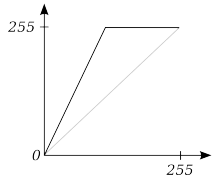
(a)

(b)

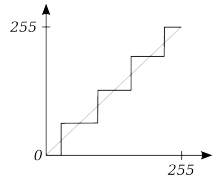
(c)



(1)

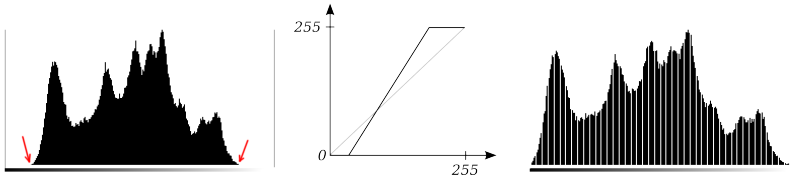


(2)



(3)

Normalisation d'histogramme



$$\mathtt{I}'(x,y) = \frac{\mathtt{I}(x,y) - \mathtt{I}_{\mathsf{min}}}{\mathtt{I}_{\mathsf{max}} - \mathtt{I}_{\mathsf{min}}} \cdot 255$$

$\downarrow$

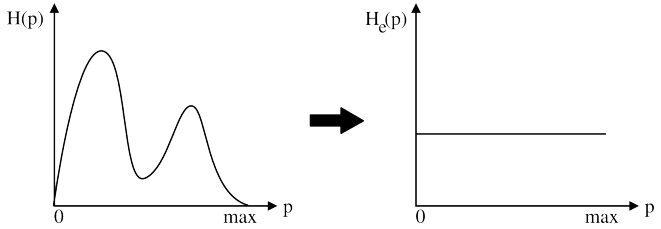
ne permet pas nécessairement d'équilibrer
les tons clairs et les tons foncés.

Egalisation d'histogramme

Egalisation d'histogramme :

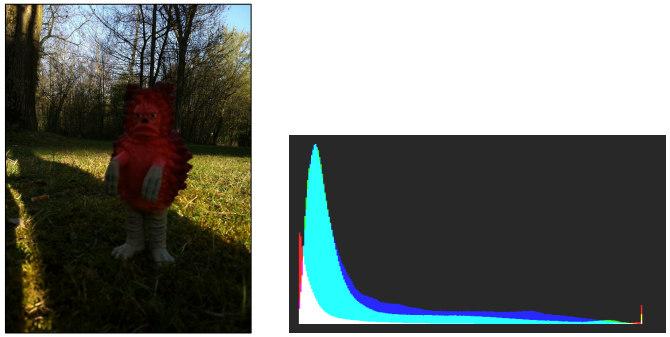
- transformation des niveaux de gris
- équilibrer la distribution des intensités des pixels

$\hookrightarrow$ idéalement, on cherche à obtenir un histogramme plat



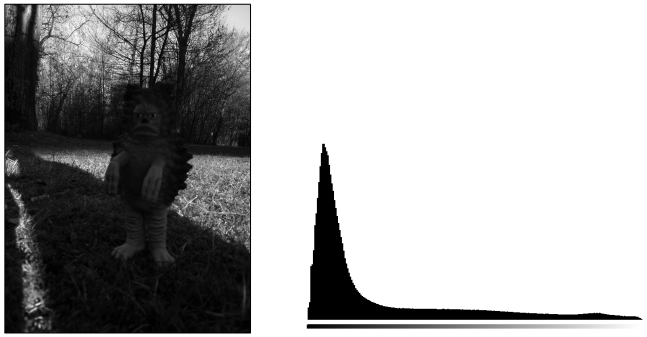
Histogramme : égalisation

Image initiale :



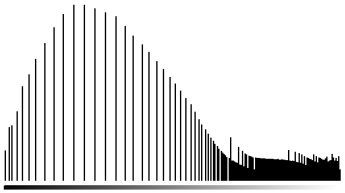
Histogramme : égalisation

Image initiale : niveaux de gris



Histogramme : égalisation

Image égalisée :



Histogramme : égalisation : méthode

Histogramme cumulé : $\mathtt{H}_c(x)$

Histogramme : égalisation : méthode

Histogramme cumulé normalisé : $\mathtt{H}_{cn}(x) = \frac{1}{w \times h}\mathtt{H}_c(x)$

$\mathtt{H}_{cn}(x) =$ pourcentage de pixels y tels que $\mathtt{I}(y) \leq \mathtt{I}(x)$

Histogramme : égalisation : méthode

Histogramme cumulé normalisé $\times 255$: $\mathtt{H}_{cn}(x) = \frac{255}{w \times h}\mathtt{H}_c(x)$

Fonction de transfert où chaque bin devient équiprobable.

Histogramme : égalisation

En pratique :

- calcul de l'histogramme $\mathtt{H}(x)$ de l'image
- calcul de l'histogramme cumulé $\mathtt{H}_c(x)$ correspondant :

$$\mathtt{H}_c(x) = \sum_{i=0}^{x} \mathtt{H}(i)$$

- construction d'une fonction de transfert :

$$\mathtt{LUT}(x) = \frac{255}{w \times h} \mathtt{H}_c(x)$$

Histogramme : égalisation

Image originale :

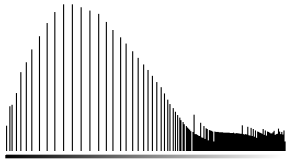
histogramme :

histogramme cumulé :

Histogramme : égalisation

Image égalisée :

histogramme :



histogramme cumulé :

Histogramme : égalisation

Image couleurs RGB :

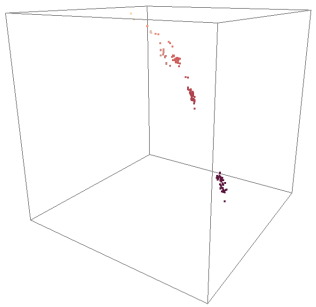
Histogramme : égalisation

Image couleurs RGB :


Attention :
l'égalisation d'histogrammes d'images couleurs peut "mal se passer" si chacun des canaux est traité indépendamment.

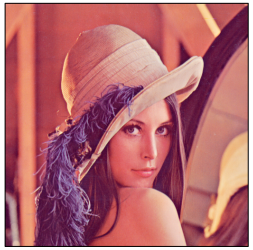
Et les images couleurs ?

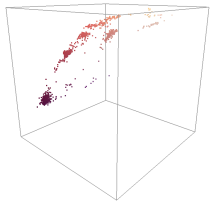
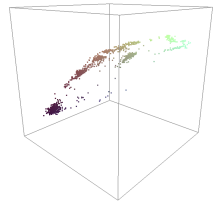
Histogramme 3D

Histogramme 3D : visualisation

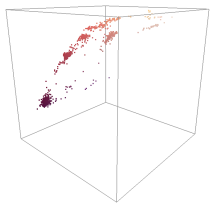
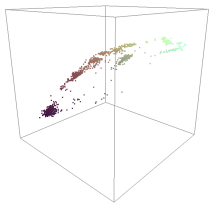
Application à la balance des blancs automatique



Histogramme 3D : visualisation

Application à la balance des blancs automatique

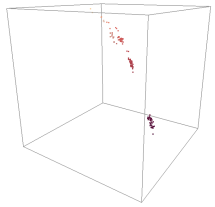
The grey world assumption :
on considère que la couleur moyenne d'une image est un gris neutre.

$$\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} = \begin{bmatrix} \frac{G_{moy}}{R_{moy}} & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & \frac{G_{moy}}{B_{moy}} \end{bmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

Histogramme 3D :

Application à la segmentation

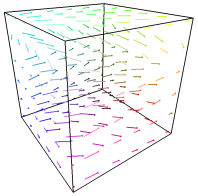




LUT 3D :

Application à la correction colorimétrique



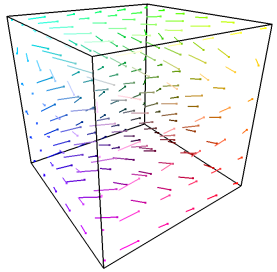


Les LUT 3D

3 LUT 1D :

- compact
- rapide
- limité

1 LUT 3D :



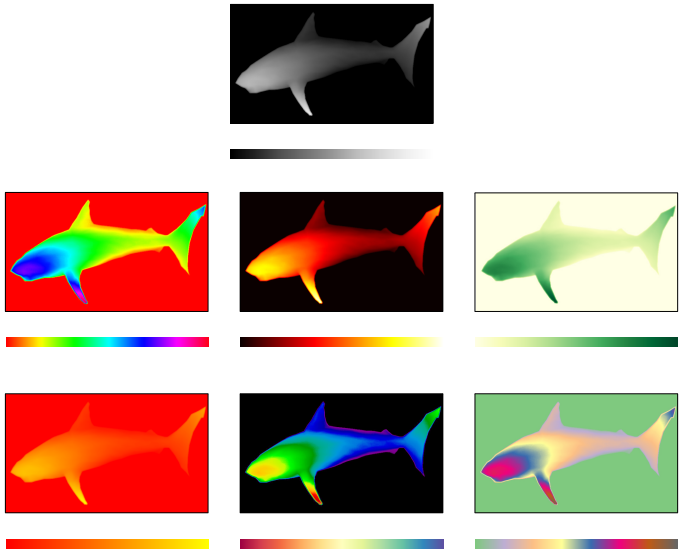
- volumineux (même en $32 \times 32 \times 32$)
- rapide
- puissant

LUT : applications

Calcul numérique :

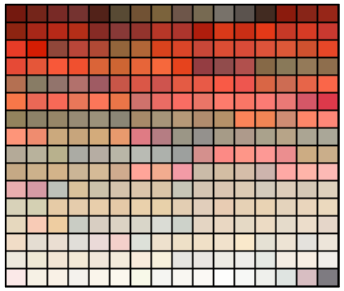
- calcul d'un $\cos$ et $\sin$ sur GPU
- calcul d'un $\exp$

Colormaps

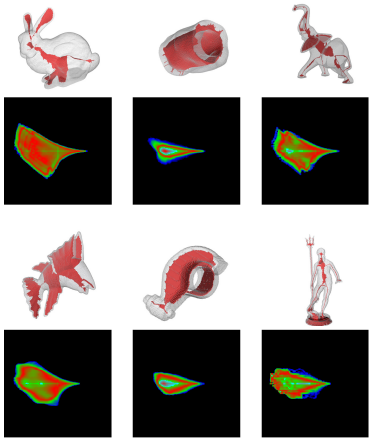


LUT : applications

Le format GIF :



Reconnaissance d'objets 3D



histogramme d'un bi-rapport leur squelette.

Question ouverte

Distance d'histogrammes :
peut-on estimer la ressemblance de 2 images en comparant leur histogramme?