Computer Graphics

Rendering Pipeline: Image Processing

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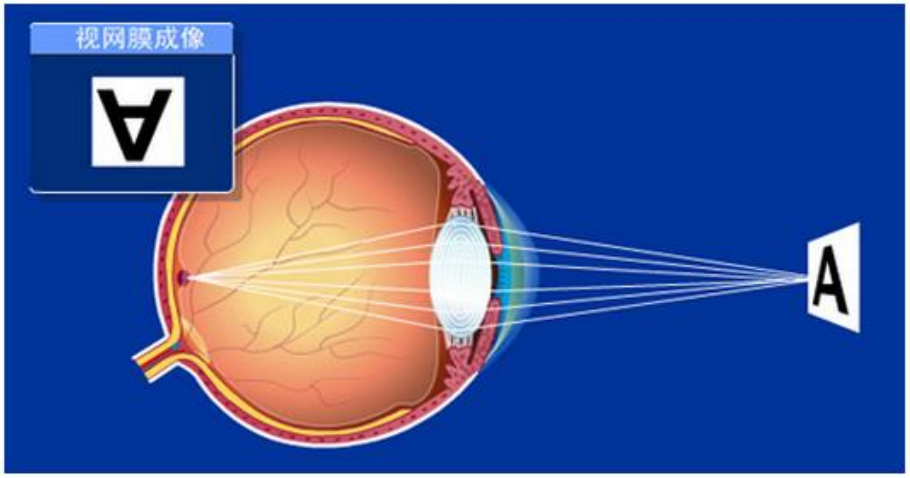
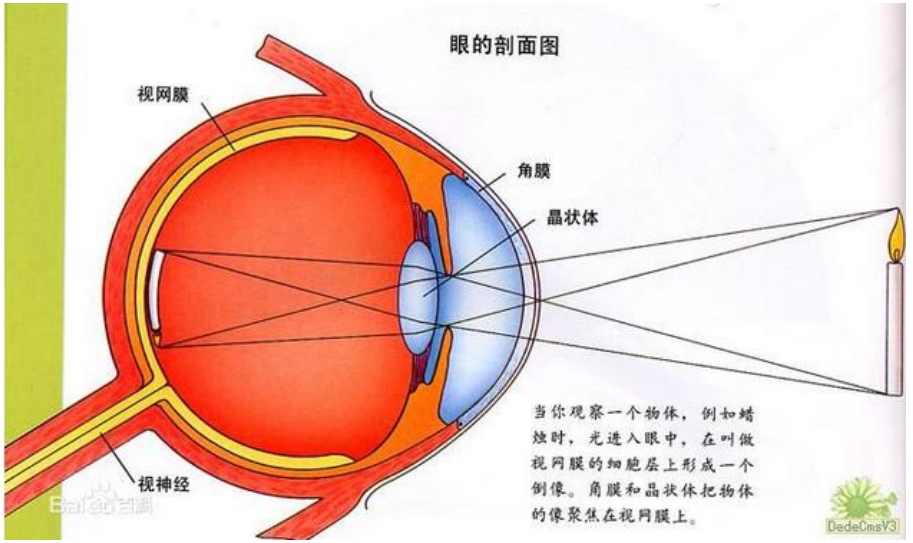
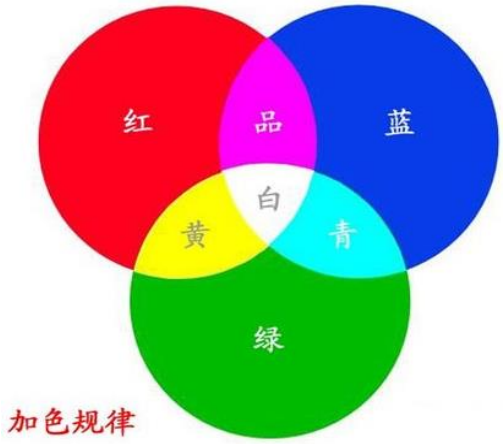
School of Data and Computer Science

视网膜成像：上亿个感光细胞

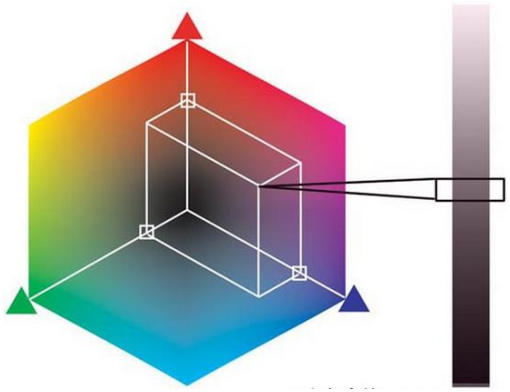




颜色三原色与RGB颜色空间



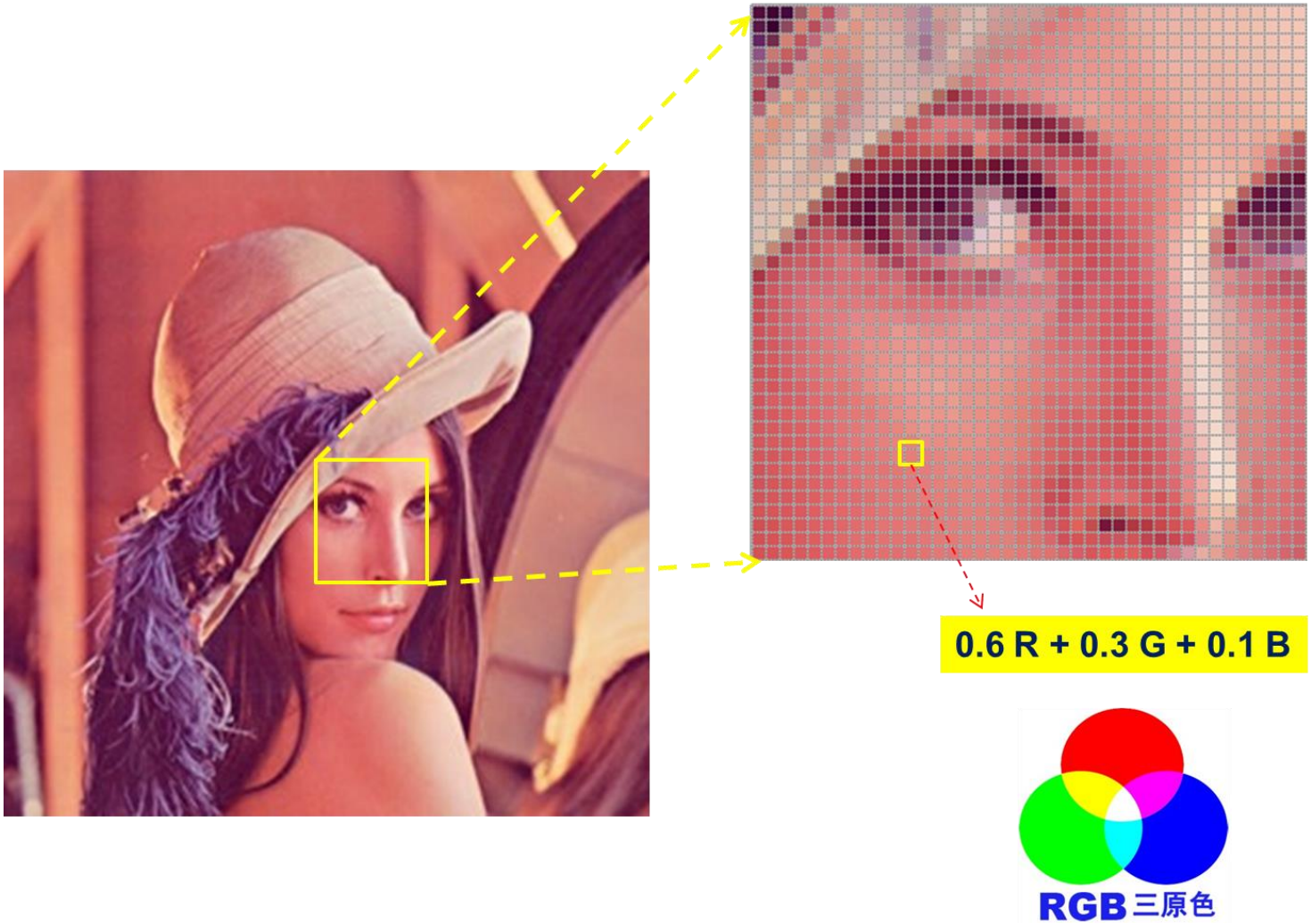
加色规律



Color = a R + b G + c B

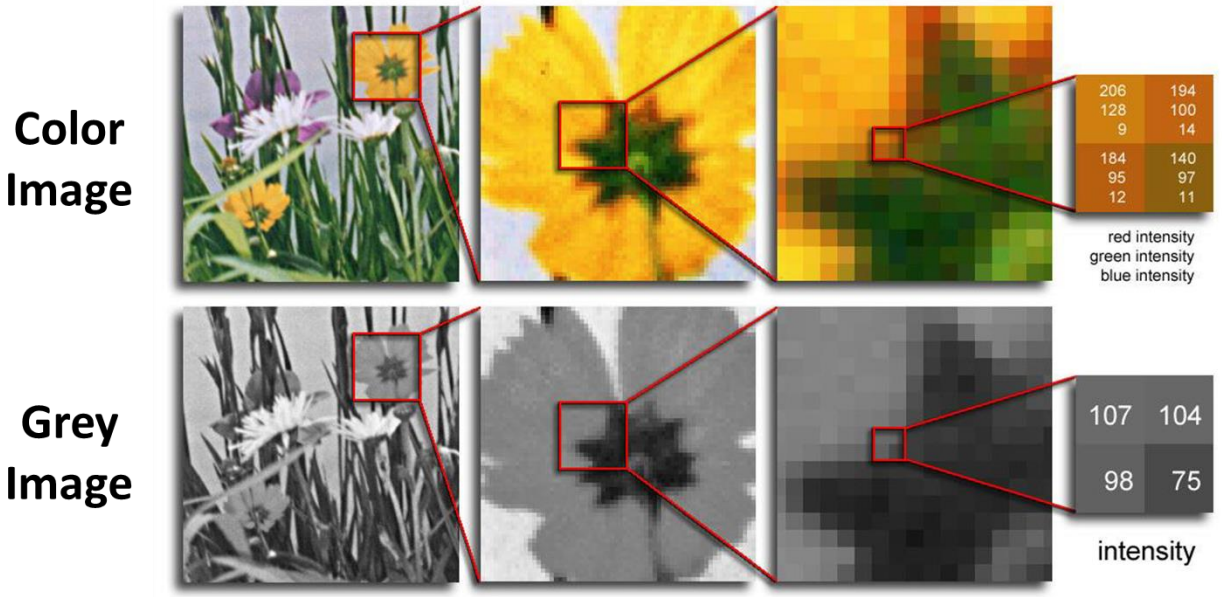
#FFFFCC	#CCFFFF	#FFCCCC	#99CCCC	#FFCC99	#FFCCCC	#FF9999	#996699	#FFCCCC
#CC9999	#FFFFCC	#CCCC99	#FFCCCC	#FFFF99	#CCCCFF	#0099CC	#CCCCCC	#FF6666
#FF9966	#FF6666	#FFCCCC	#CC9966	#666666	#CC9999	#FF6666	#FFFF66	#99CC66
#CC3333	#CCCCCC	#003366	#993333	#CCCC00	#663366	#CCCC99	#666666	#CC9999
#FF6666	#FFFF00	#0066CC	#CC0033	#333333	#CCCC00	#336633	#990033	#FFCC99
#993333	#CC9966	#003300	#FF0033	#333399	#CCCC00	#CC0033	#000000	#003399
#000000	#99CC00	#CC0033	#999933	#993333	#333300			

数字图像（Digital Image）



Digital Image

- Binary images (0 or 1)
- Gray images (0~255)
- Color images
  - indexed color images
  - full color images (24 bits per pixel, 8-red, 8-green, 8-blue))



Color Components

Image Format

- BMP: bitmap
  - Raw data，无压缩，文件大
- GIF
  - 文件小，能存储动画
- JPEG
  - 压缩率高
- JPEG 2000
  - 更高压缩率，支持渐近传输
- PSD, SWF…

Image Quality

- Image format and its compressive ratio.
- BMP，PNG，JPG

BMP
263 KB

PNG
112 KB

100% JPG 52 KB

10% JPG 6.38 KB

Video: Image Sequence

图像的连续数学模型：平面区域上的向量值函数

- 区域内每个点有个颜色值
  - 每种颜色值是红、绿、蓝三个成分的线性组合
  - 颜色空间是三维线性空间

0.6 R + 0.3 G + 0.1 B

图像的离散数学模型：矩阵

- 分辨率

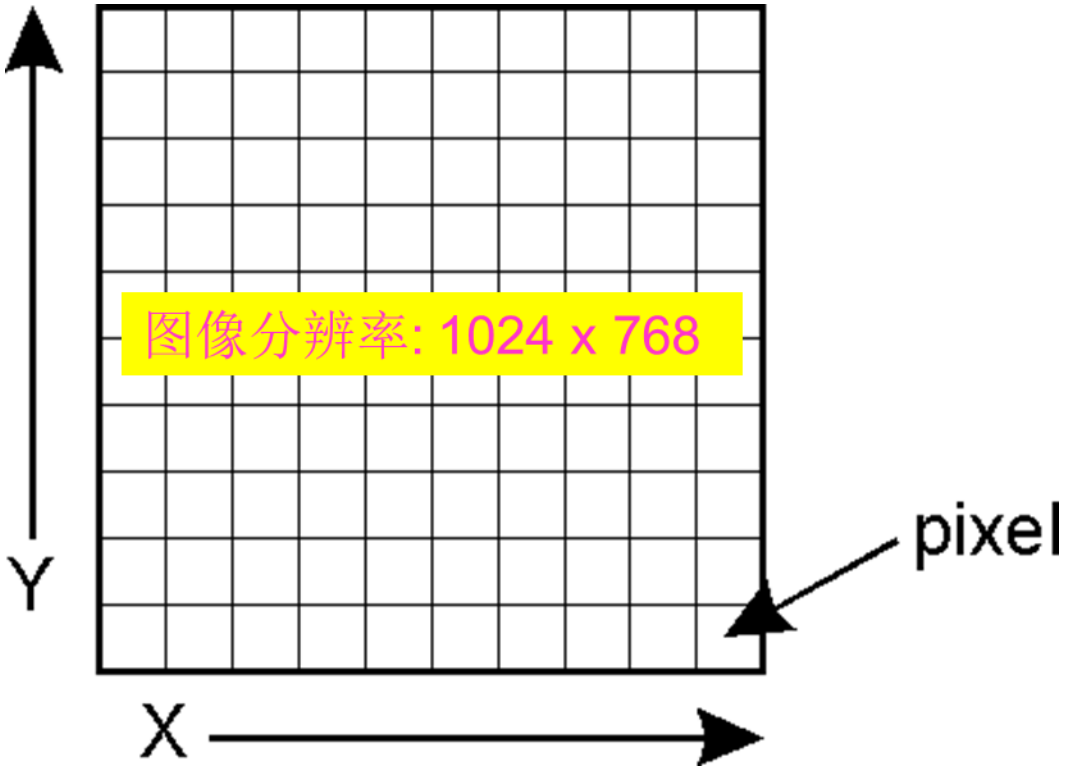


Image Programming

- 图像的抽象

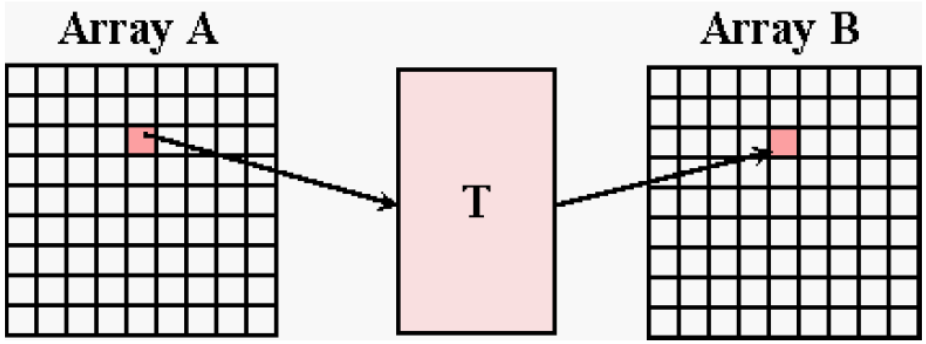
- 我们需要哪些信息可以决定一幅图像？
  - 宽、高
  - 每个元素的颜色

- 像素的矩阵！

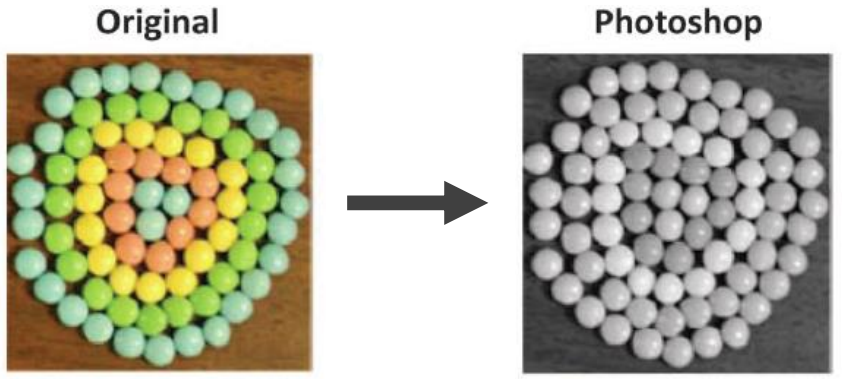
```
class CImage
{
    public:
        int GetWidth();
        int Get Height();
        CColor  GetPixelAt(int x, int y);
        void    SetPixelAt(int x, int y, CColor c);
};
```

Image Processing（ Image Transformation ）

$$\mathbf{B}[x, y] = T\big[\mathbf{A}[x, y]\big]$$

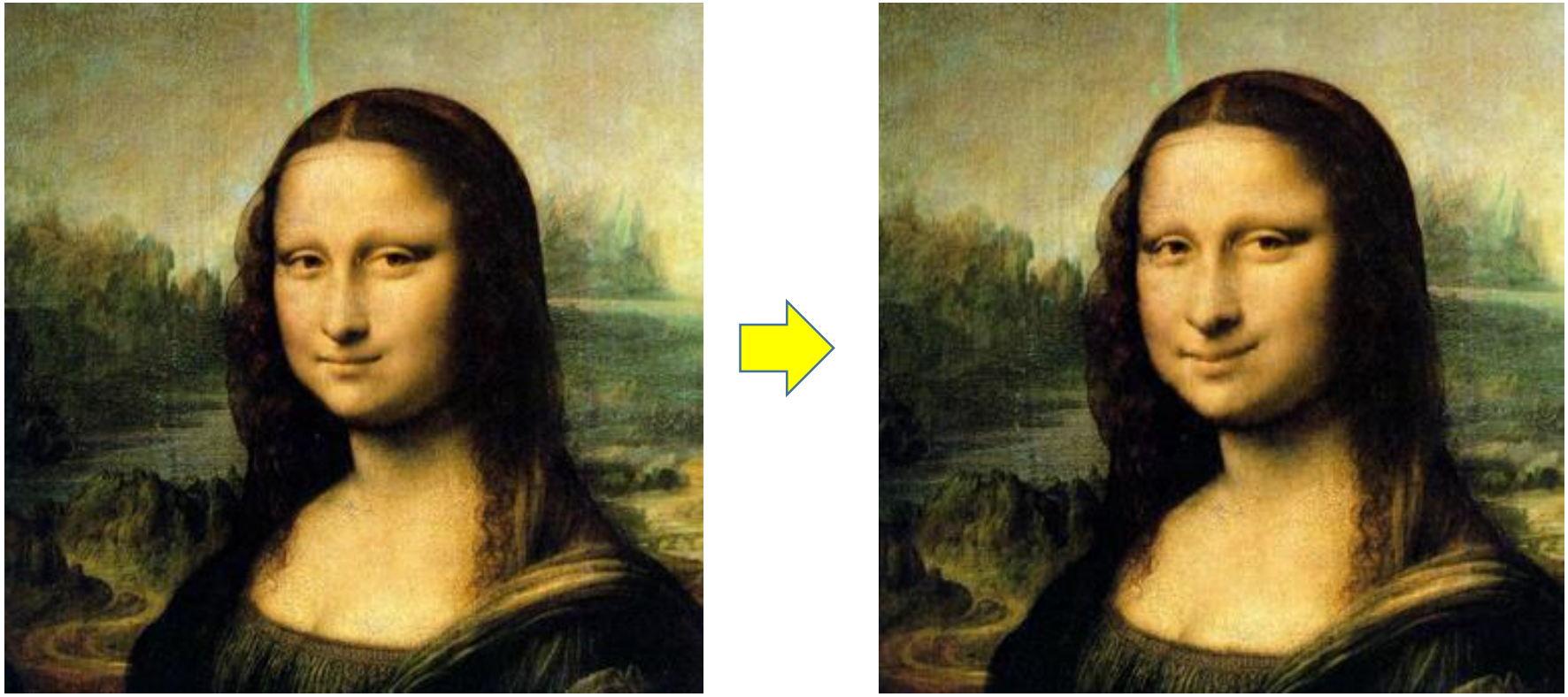


- Examples：Reverse color
- R, G, B channels
- Color2Gray
  - Gray = a R + b G + c B
  - Gray = R*0.299 + G*0.587 + B*0.114
- Add noise
- …



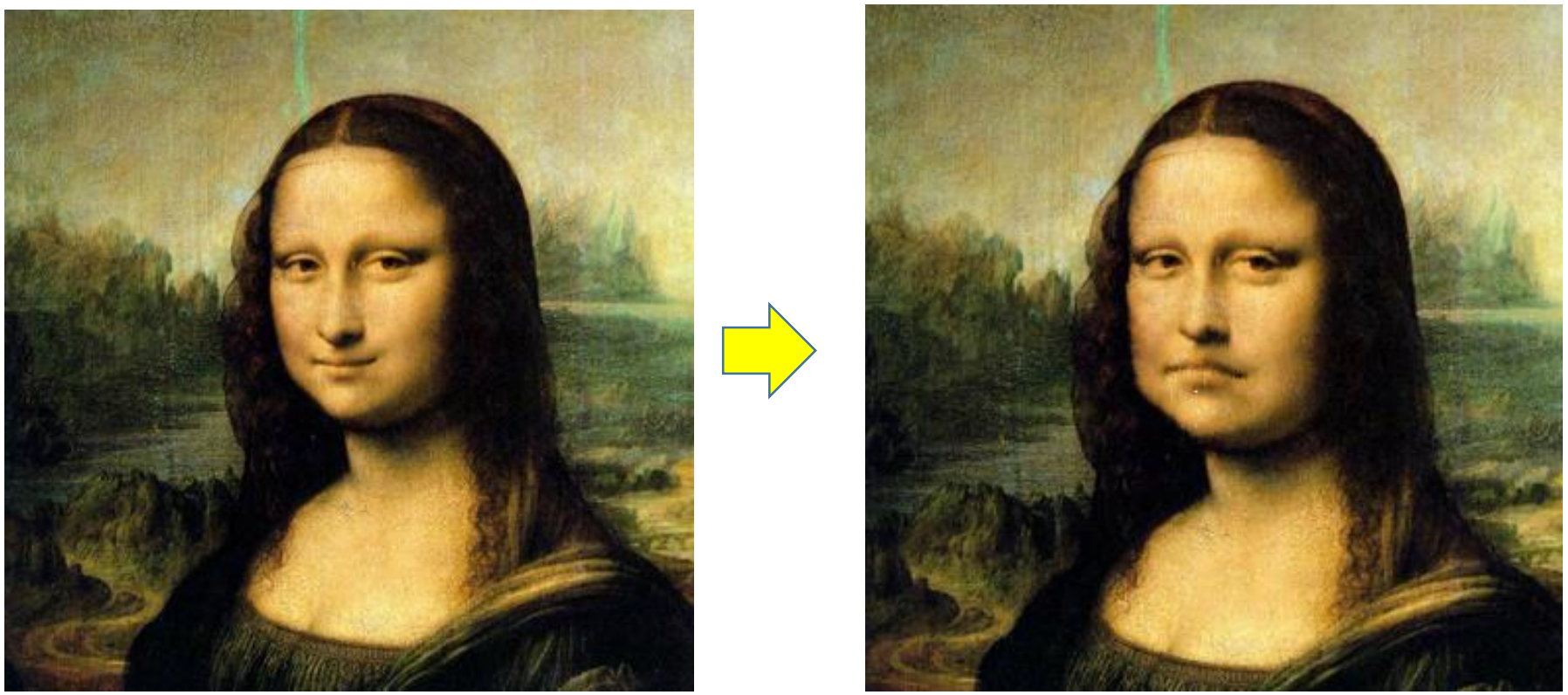
Case 1

- Image Deformation

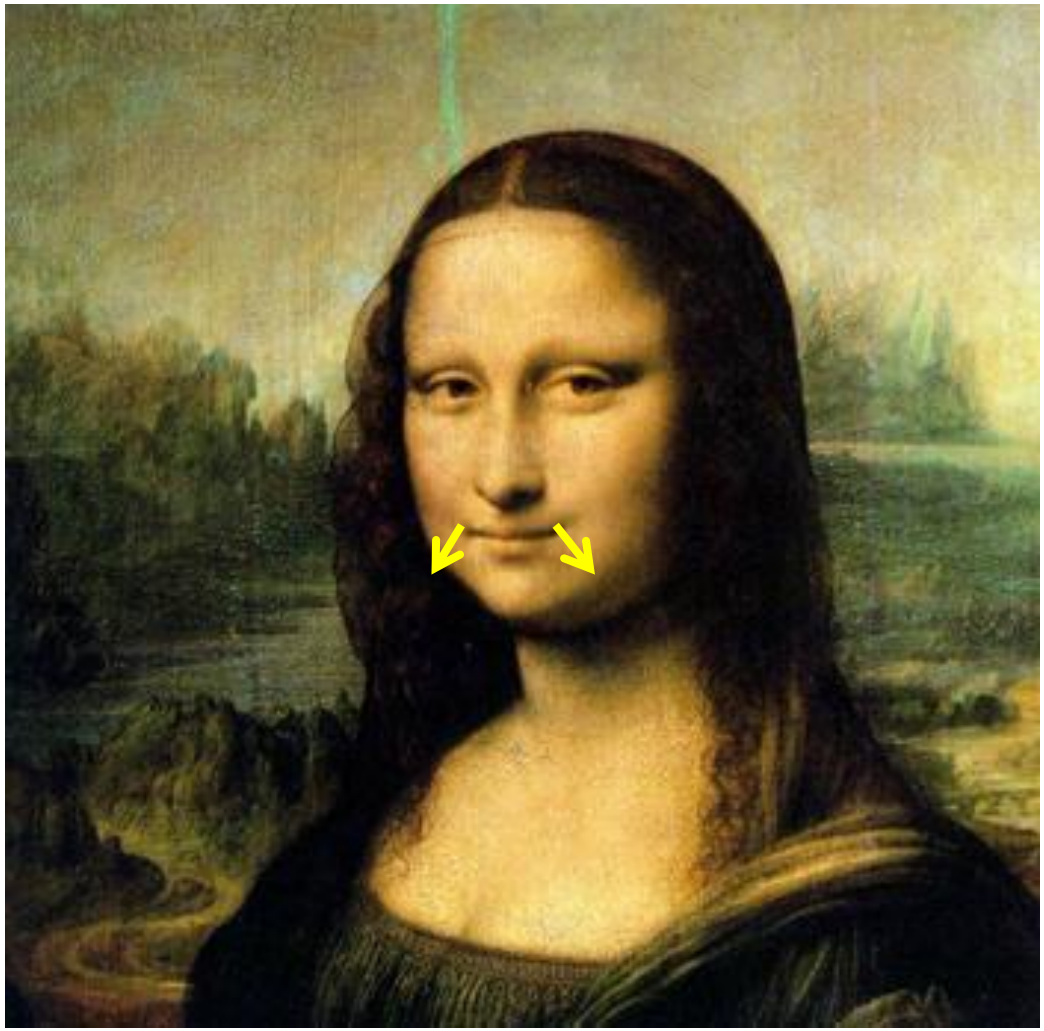


Case 1

- Image Deformation

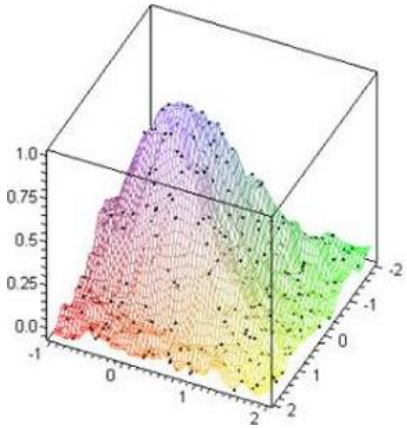


Case 1



Case 1

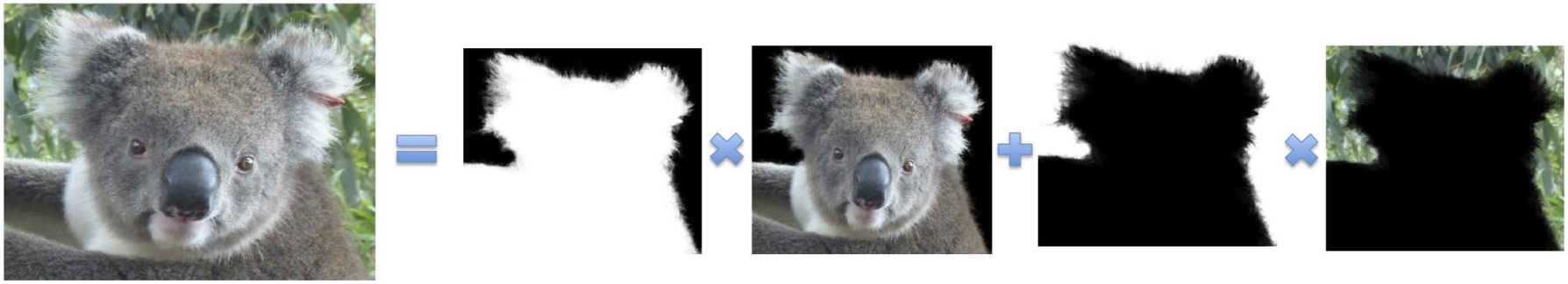
- How to do?



Scattered Point Interpolation

Case 2

- Image Matting
  - Cut out the object from a given image



Case 2

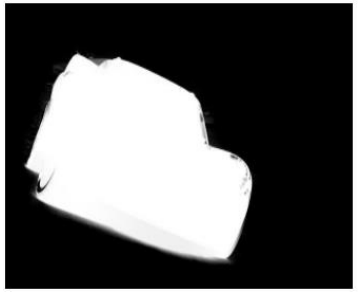
- How to do
  - Photoshop Magic Wand Tool

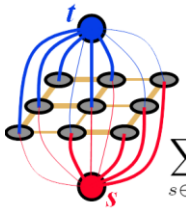
Original Image

Select an area with the Wand tool

Add additional areas

  - Interactive sketch



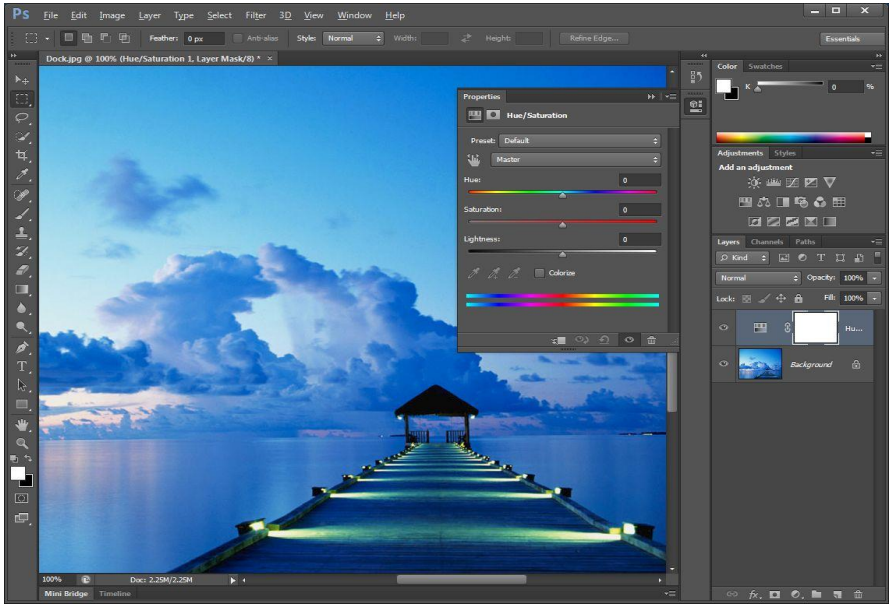


图论：最大流最小割算法

$$\sum_{s \in V} \bar{\theta}_s(x_s) + \sum_{(s,t) \in E} \bar{\theta}_{st}(x_s, x_t)$$

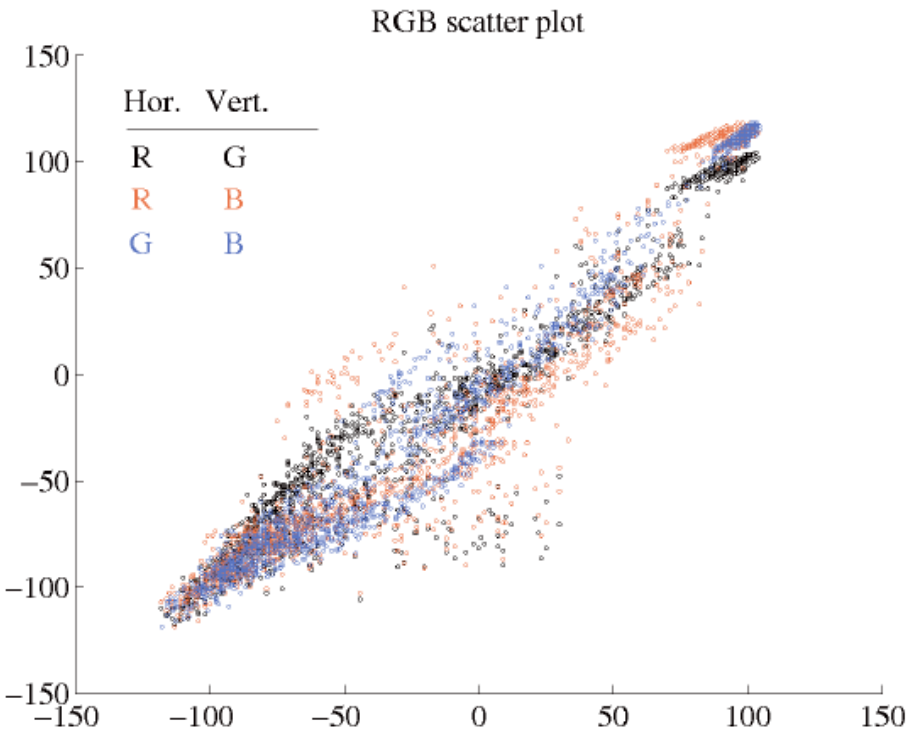
各种图像处理软件

- Photoshop (PS)
- CorelDraw
- Picasa
- 美图秀秀
- 光影魔术手
- …



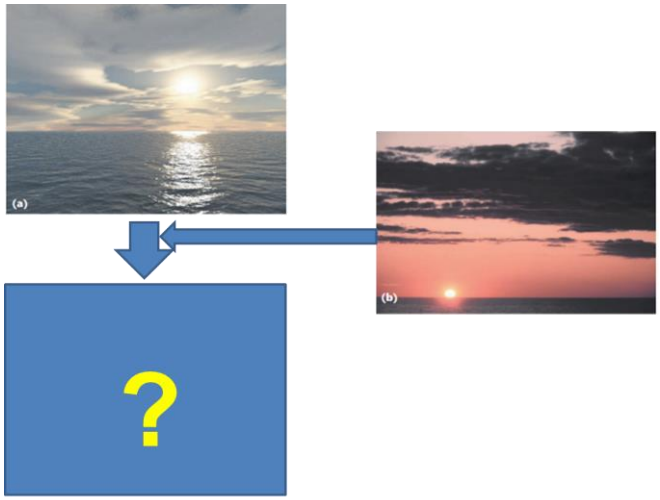
从数学的角度看图像处理

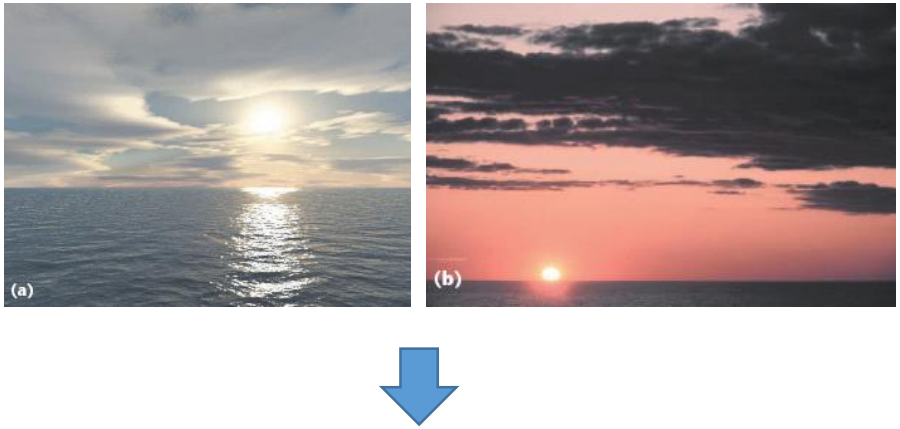
1、图像是线性空间的数据点集



从数学的角度看图像处理

- Example 1: Color Transfer





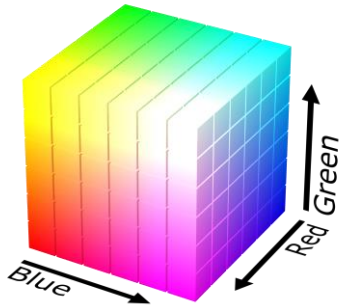
- 使点云位置、形状相似（均值和方差变换）

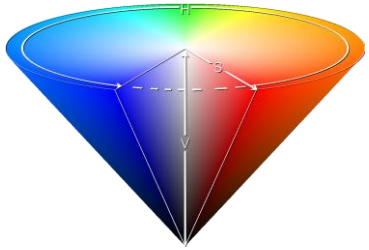
$$l^* = l - \langle l \rangle$$
$$\alpha^* = \alpha - \langle \alpha \rangle$$
$$\beta^* = \beta - \langle \beta \rangle$$

$$l' = \frac{\sigma_t^l}{\sigma_s^l} l^*$$
$$\alpha' = \frac{\sigma_t^\alpha}{\sigma_s^\alpha} \alpha^*$$
$$\beta' = \frac{\sigma_t^\beta}{\sigma_s^\beta} \beta^*$$

从数学的角度看图像处理

- Color Spaces: Different Basis
  - RGB
  - CMY
  - HSV
  - $l\alpha\beta$



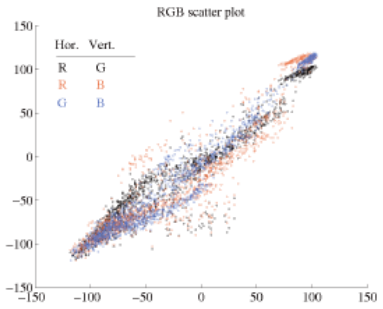


$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 0.3811 & 0.5783 & 0.0402 \\ 0.1967 & 0.7244 & 0.0782 \\ 0.0241 & 0.1288 & 0.8444 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

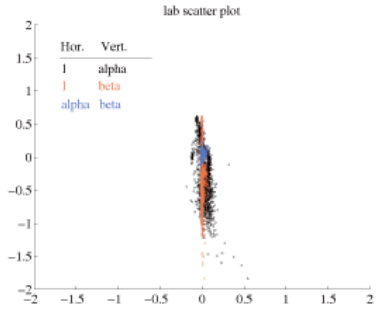
$$\begin{aligned} \boldsymbol{L} &= \log L \\ \boldsymbol{M} &= \log M \\ \boldsymbol{S} &= \log S \end{aligned}$$

$$\begin{bmatrix} l \\ \alpha \\ \beta \end{bmatrix} = \begin{bmatrix} \frac{1}{\sqrt{3}} & 0 & 0 \\ 0 & \frac{1}{\sqrt{6}} & 0 \\ 0 & 0 & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & -2 \\ 1 & -1 & 0 \end{bmatrix} \begin{bmatrix} \mathbf{L} \\ \mathbf{M} \\ \mathbf{S} \end{bmatrix}$$

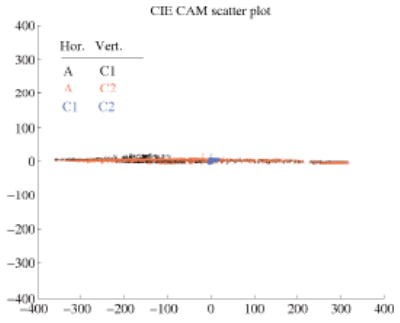
RGB



$l\alpha\beta$



CIE

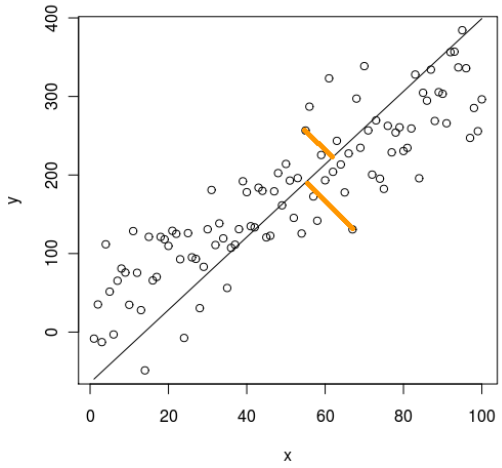


从数学的角度看图像处理

- Example 2: Color2Gray

Color　　Grayscale

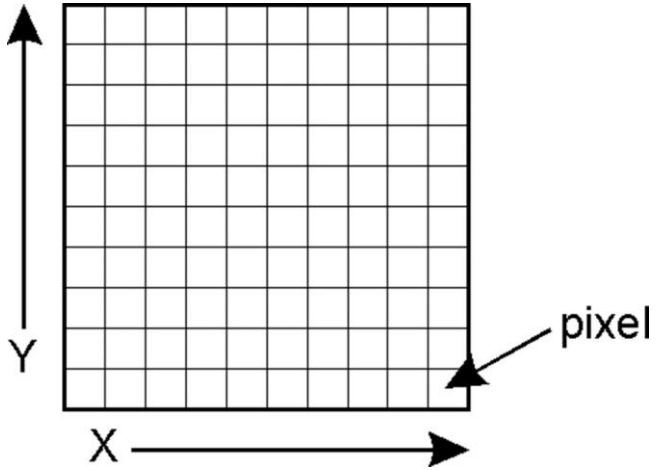
- Problem: Dimension reduction
  - 3D (Color) -> 1D (Gray)



从数学的角度看图像处理

- 2、图像是一个矩阵

This image is 600×465 pixels



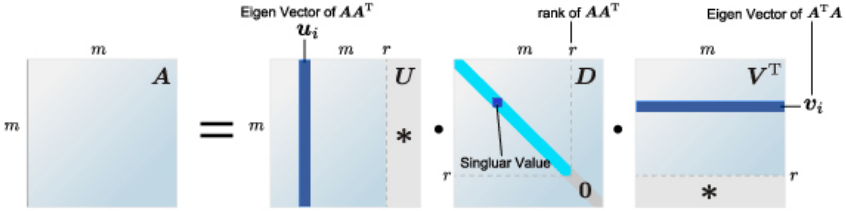
从数学的角度看图像处理

- Matrix Decomposition
  - LU Decomposition
  - QR Decomposition
  - Cholesky Decomposition
  - Jordan Decomposition
  - Spectral Decomposition
  - Singular Value Decomposition (SVD)
  - Low-Rank Decomposition

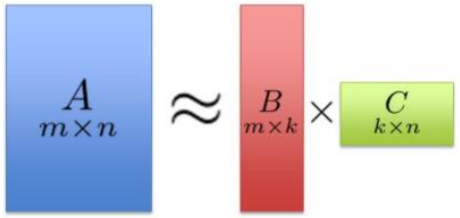
$$A = L\ U$$

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} = \begin{bmatrix} l_{11} & 0 & 0 \\ l_{21} & l_{22} & 0 \\ l_{31} & l_{32} & l_{33} \end{bmatrix} \begin{bmatrix} l_{11} & l_{12} & l_{13} \\ 0 & l_{12} & l_{23} \\ 0 & 0 & l_{33} \end{bmatrix}$$

$$\boldsymbol{A} = \boldsymbol{U}\boldsymbol{D}\boldsymbol{V}^{\mathrm{T}}$$

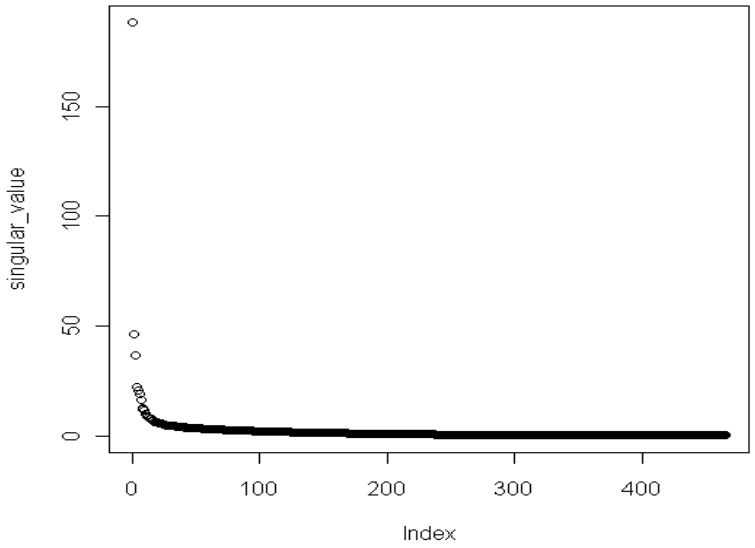


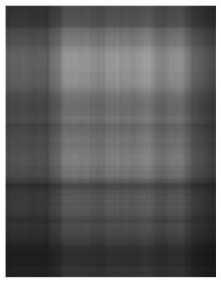
where $k \ll \min\{m, n\}$



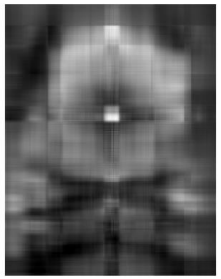
从数学的角度看图像处理

- Singular values of flowers image





Rank-1



Rank-5

Rank-20

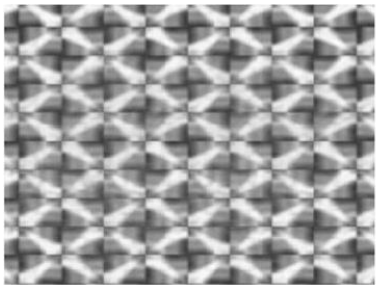
Rank-80

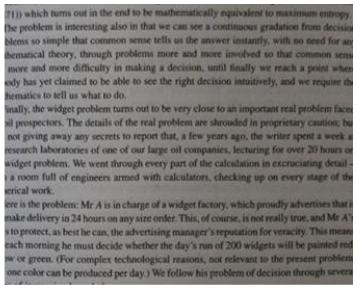
Rank-150

True Image

从数学的角度看图像处理

- Low Rank Matrix
  - 高维数据往往具有低维结构



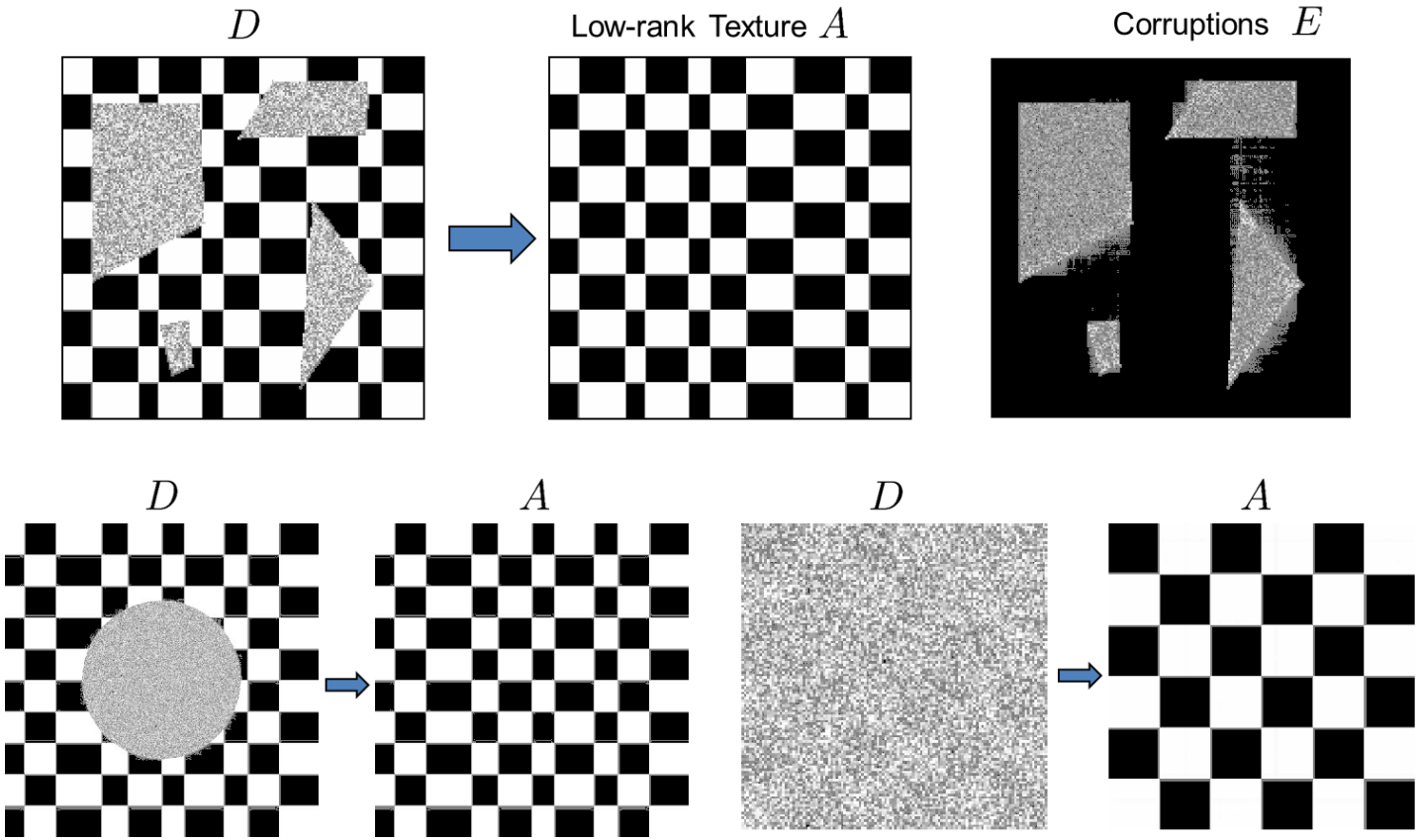




- Visual data exhibit low-dimensional structures due to rich local regularities, global symmetries, repetitive patterns, or redundant sampling.

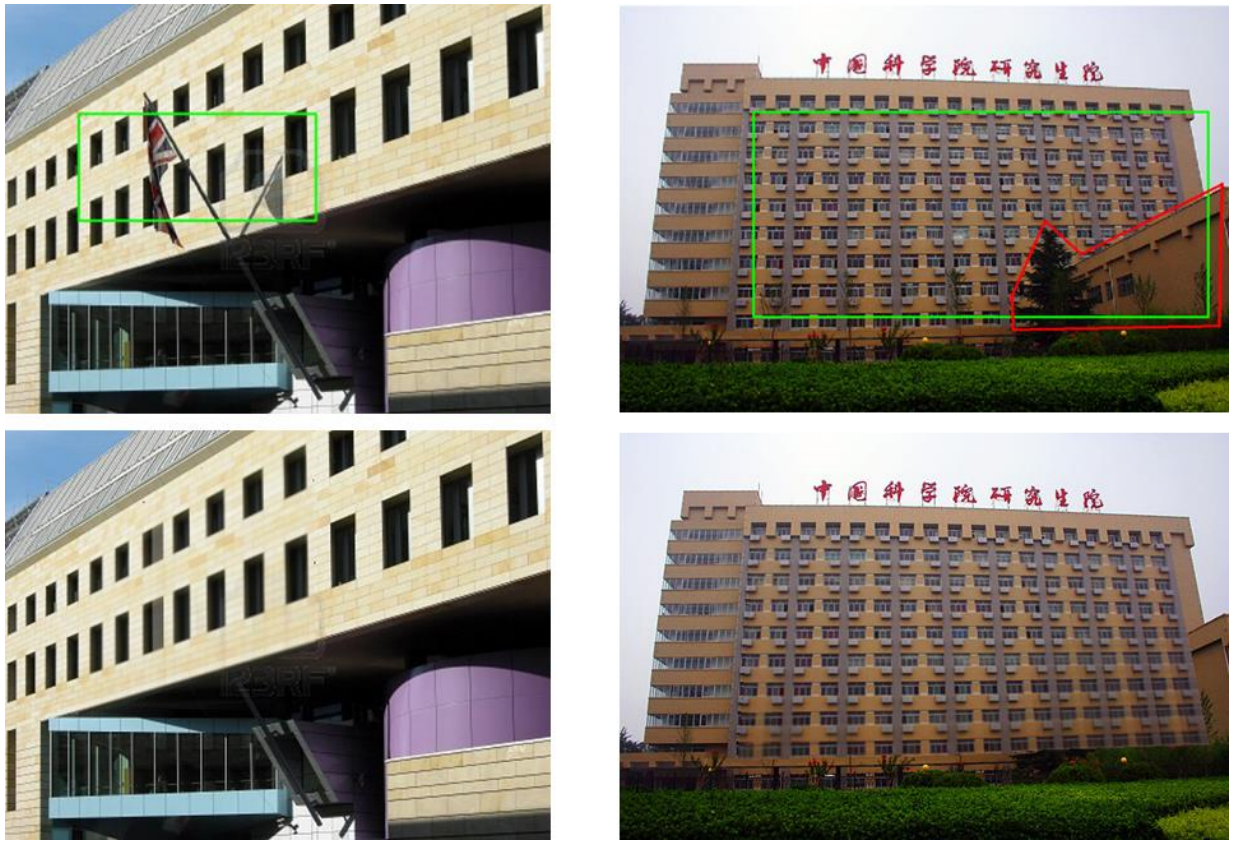
从数学的角度看图像处理

- Example 1: Image Completion



从数学的角度看图像处理

- Example 1: Image Completion



从数学的角度看图像处理

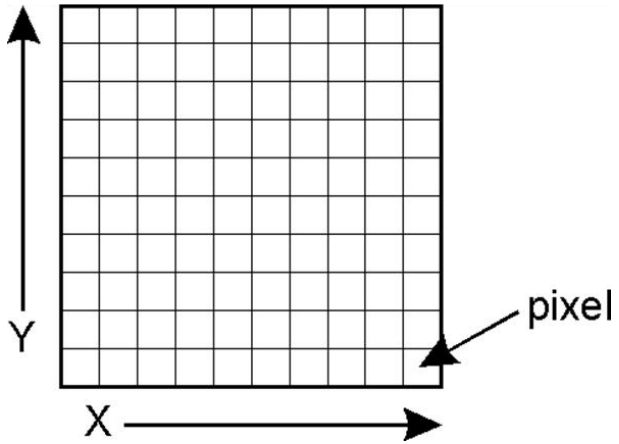
3、图像是一个函数

- 2D区域上的向量值函数

$$I = I(x, y)$$

Discrete sampling

$$I = f(i, j)$$

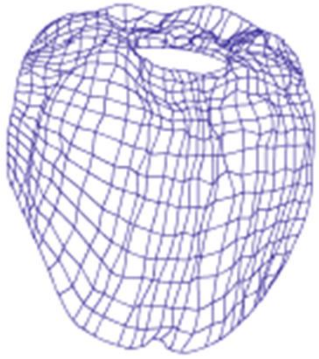


从数学的角度看图像处理

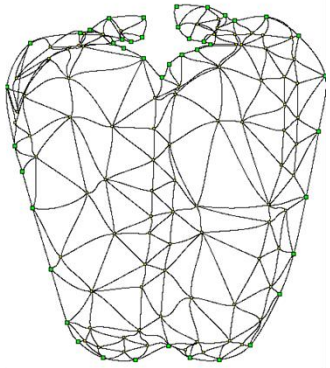
- Example 1: Vectorization

从数学的角度看图像处理

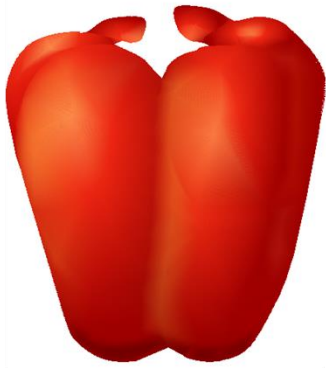
- Example 1: Vectorization



四边形域的函数

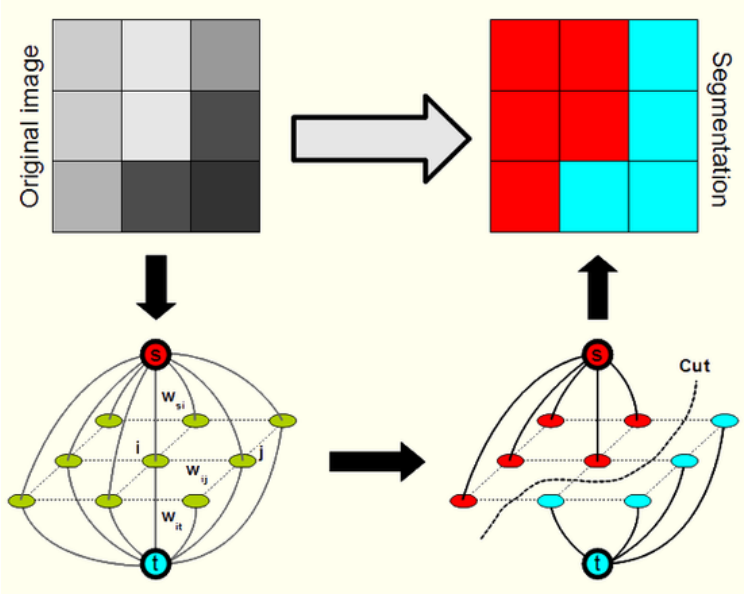


三角形域的函数

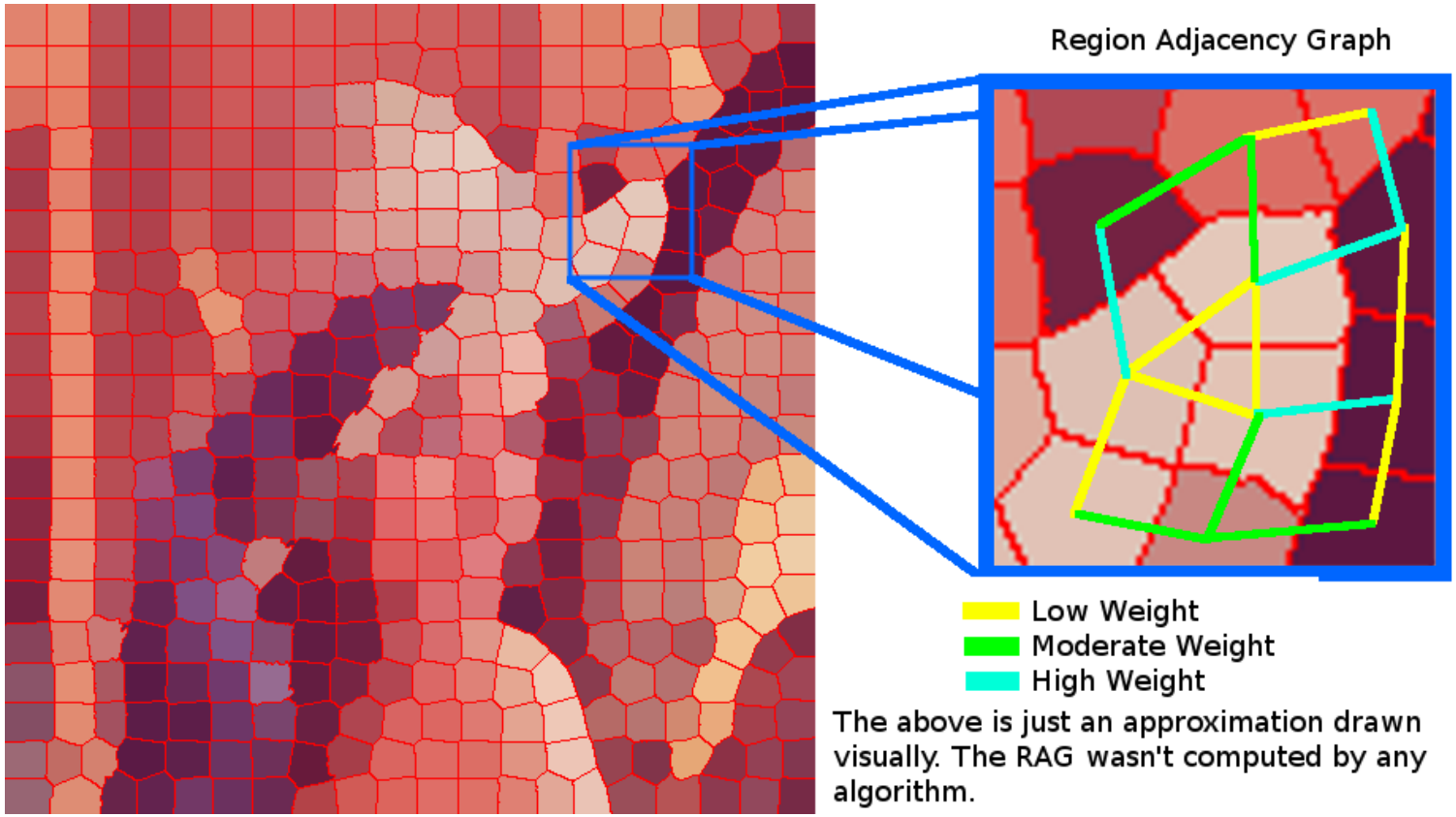


从数学的角度看图像处理

4、图像是一个图（Graph）



从数学的角度看图像处理



Acknowledgement

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  - http://staff.ustc.edu.cn/~lgliu/Courses/ComputerGraphics_2018_spring-summer/default.htm
- ZJU CAD Computer Graphics 2017, Dr. Hongxin Zhang
  - http://www.cad.zju.edu.cn/home/zhx/CG/2017/doku.php
- XMU Digital Geometry Processing, Dr. Zhonggui Chen
  - http://graphics.xmu.edu.cn/courses/dgp/index.html
- Tsinghua Computer Graphics, Prof. Shimin Hu
  - http://cg.cs.tsinghua.edu.cn/course/