

数字图像处理

Digital Image Processing

刘利刚

lgliu@ustc.edu.cn

<http://staff.ustc.edu.cn/~lgliu>

Graphics&Geometric Computing Lab
@USTC





欢迎来到数字图像处理的
神奇而美妙的世界！

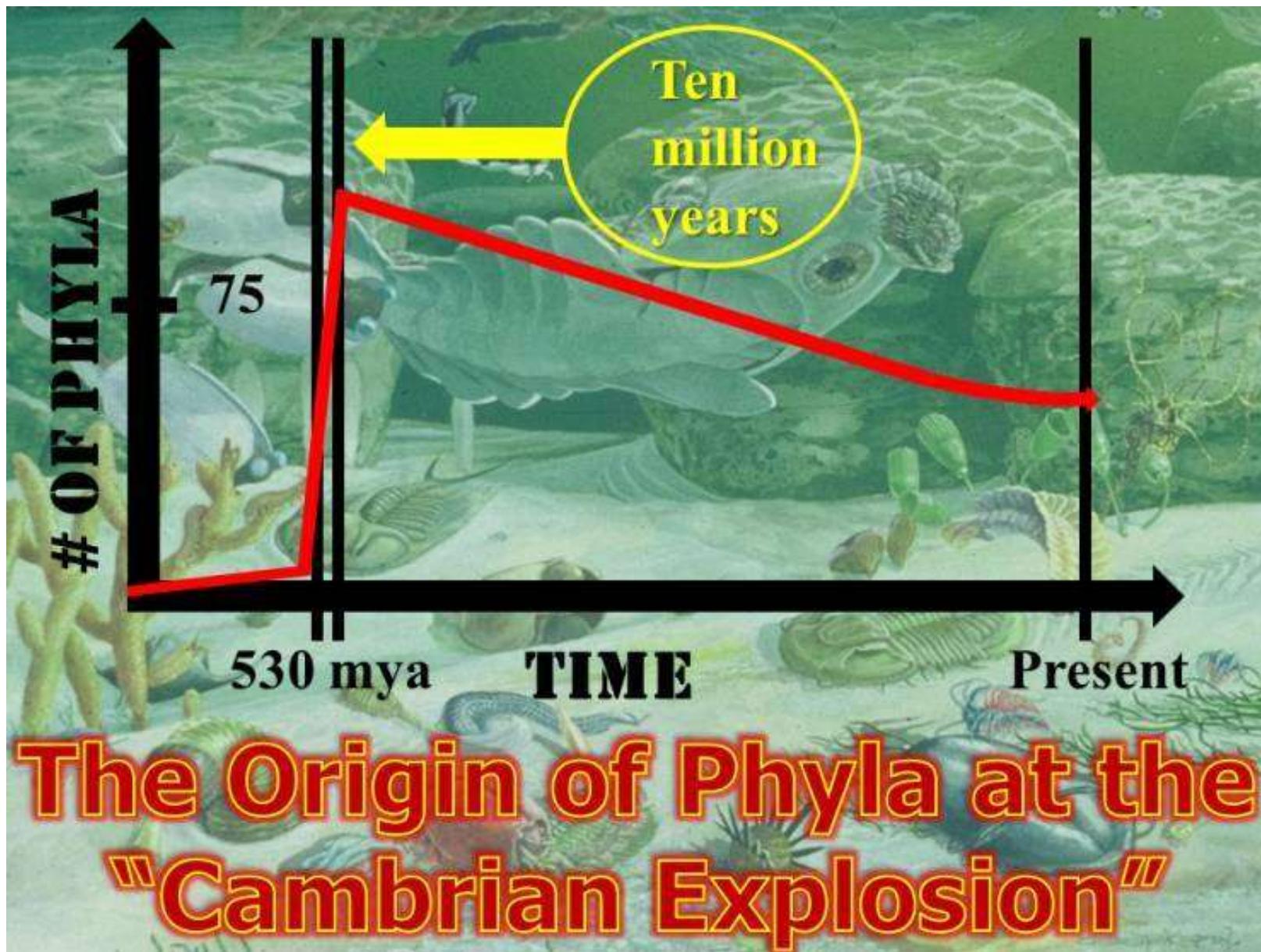
数字图像处理

数字**图像**处理

人类的感官系统



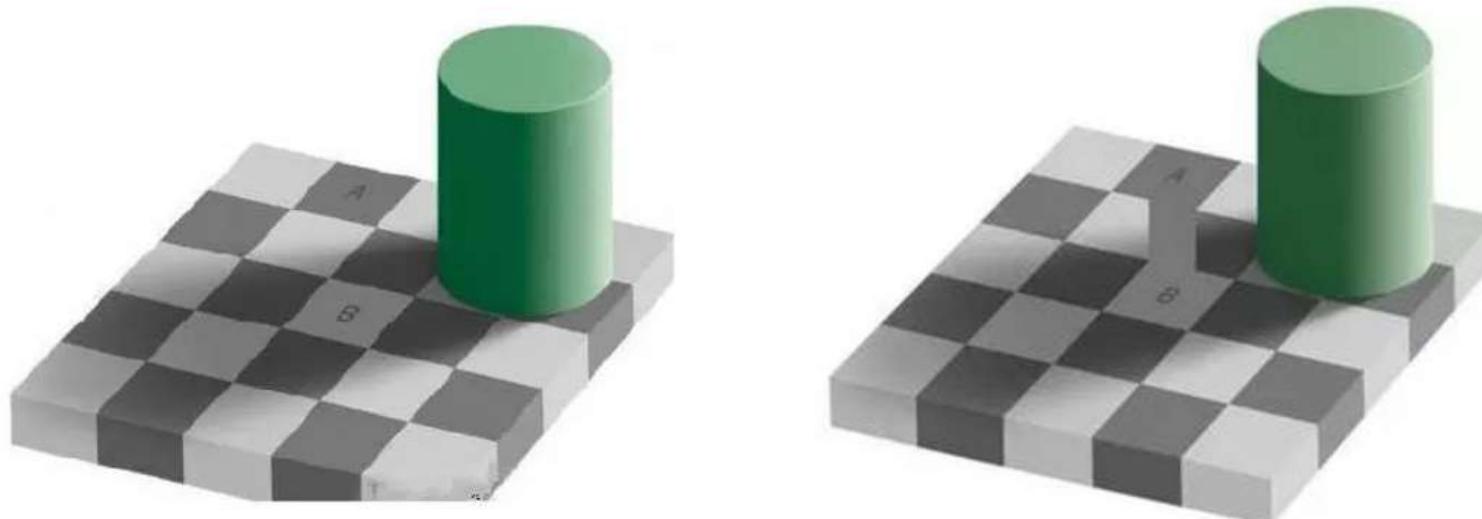
寒武纪大爆发：人类视觉的进化？



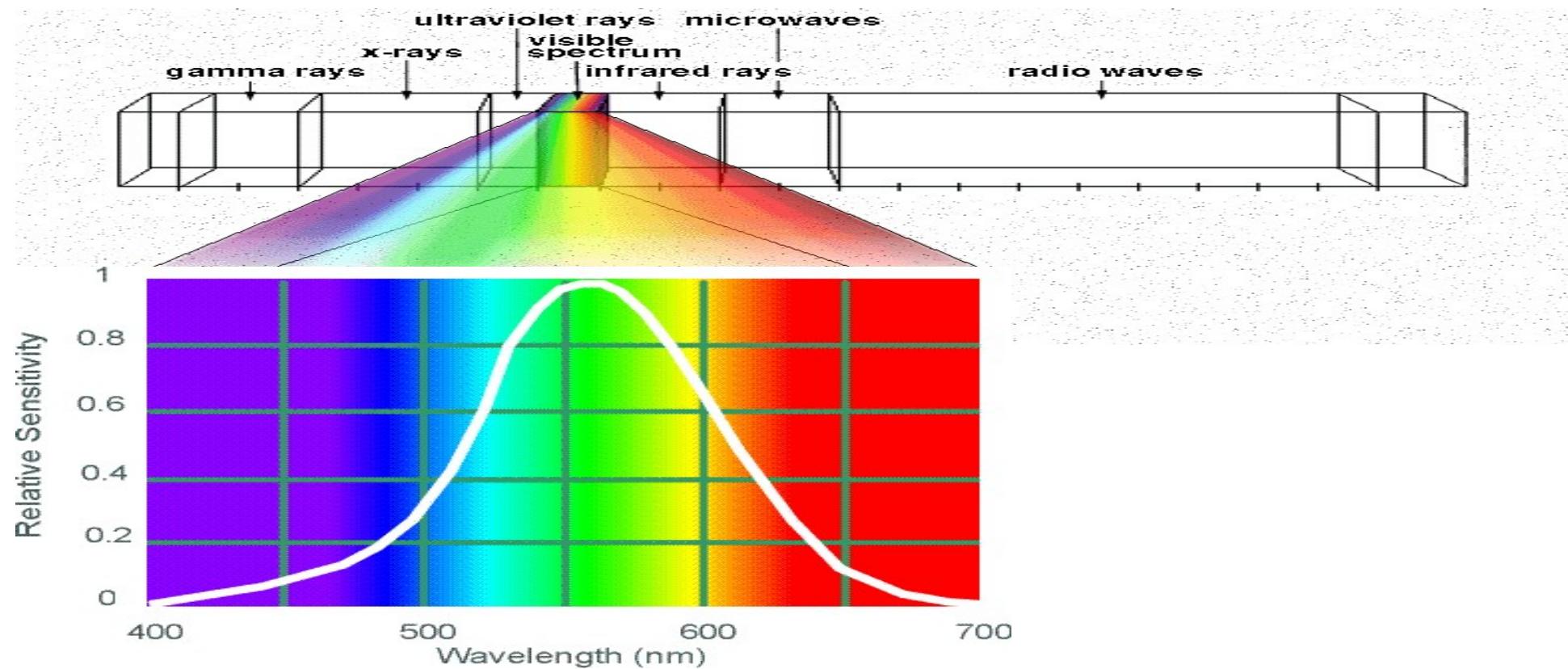
世界的色彩是如何产生的？

色彩产生的因素

- 客观物理因素
 - 光
 - 材质
- 视觉感知因素



Electromagnetic Spectrum

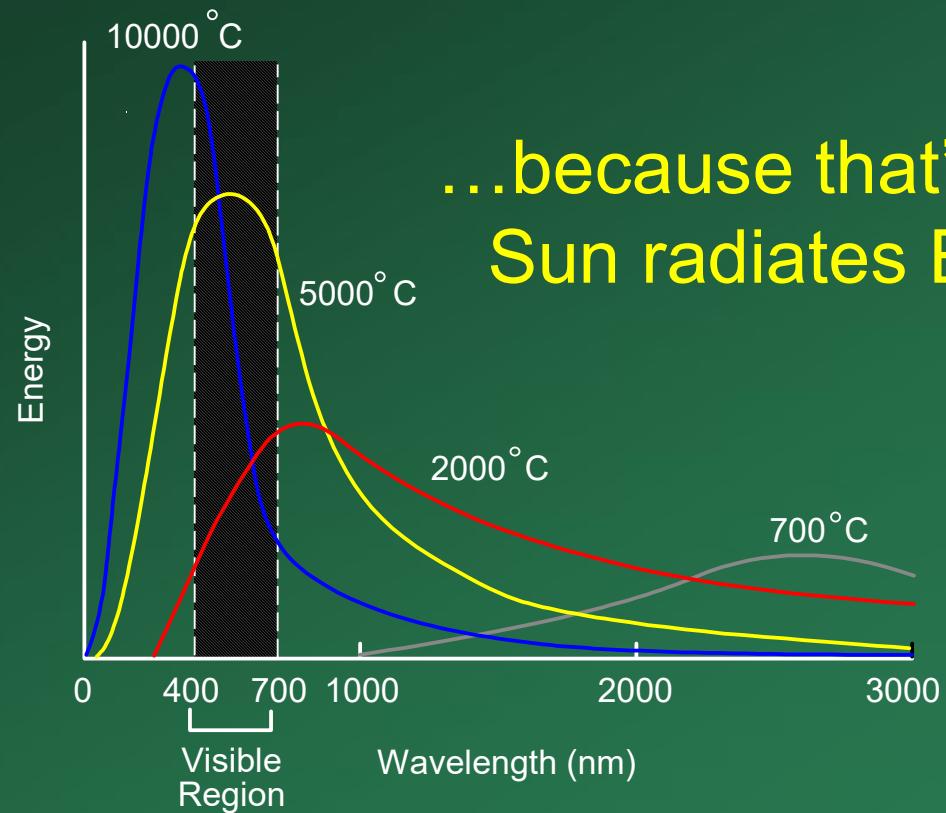


Human Luminance Sensitivity Function

<http://www.yorku.ca/eye/photopik.htm>

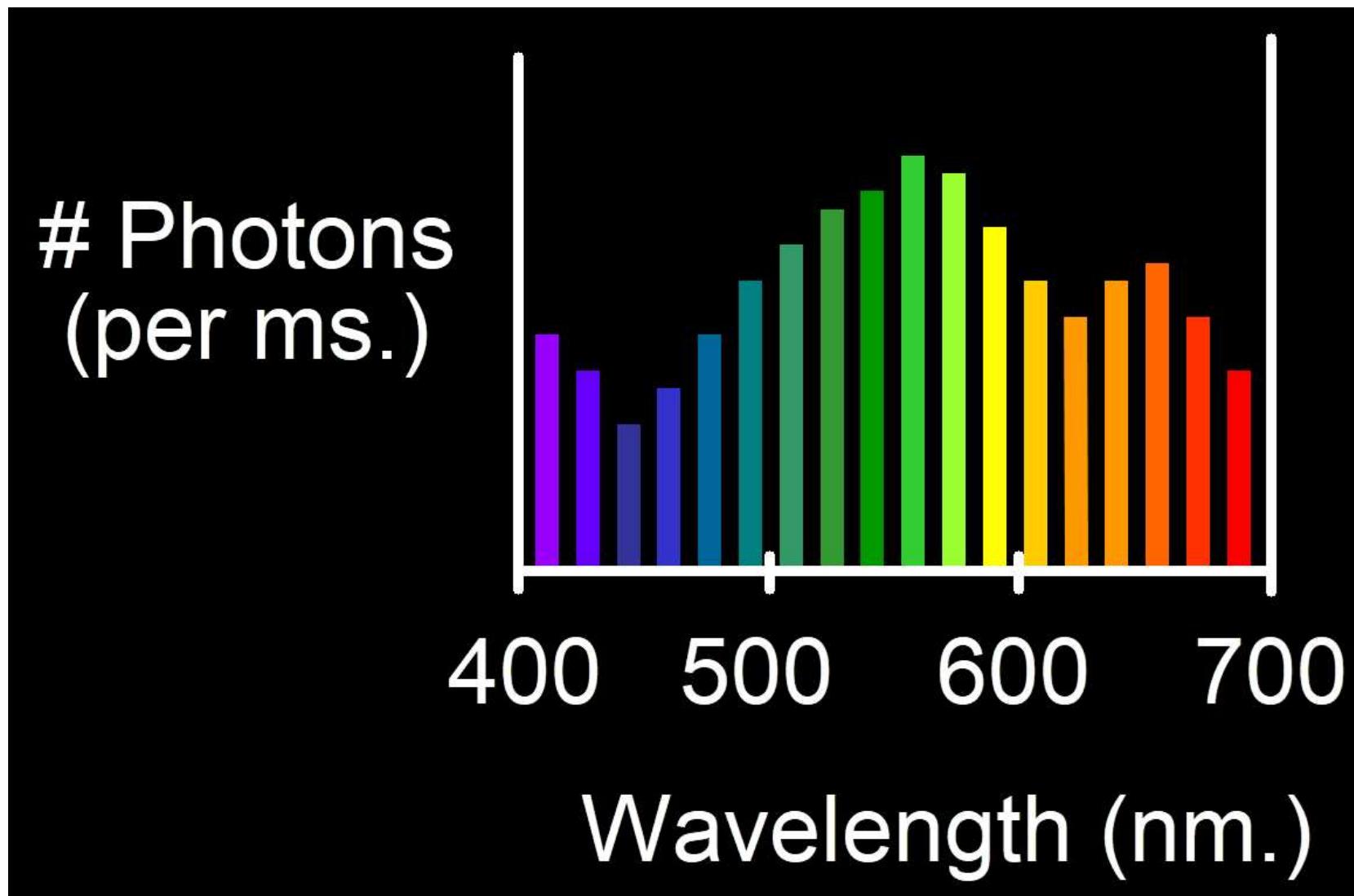
可见光

Why do we see light of these wavelengths?



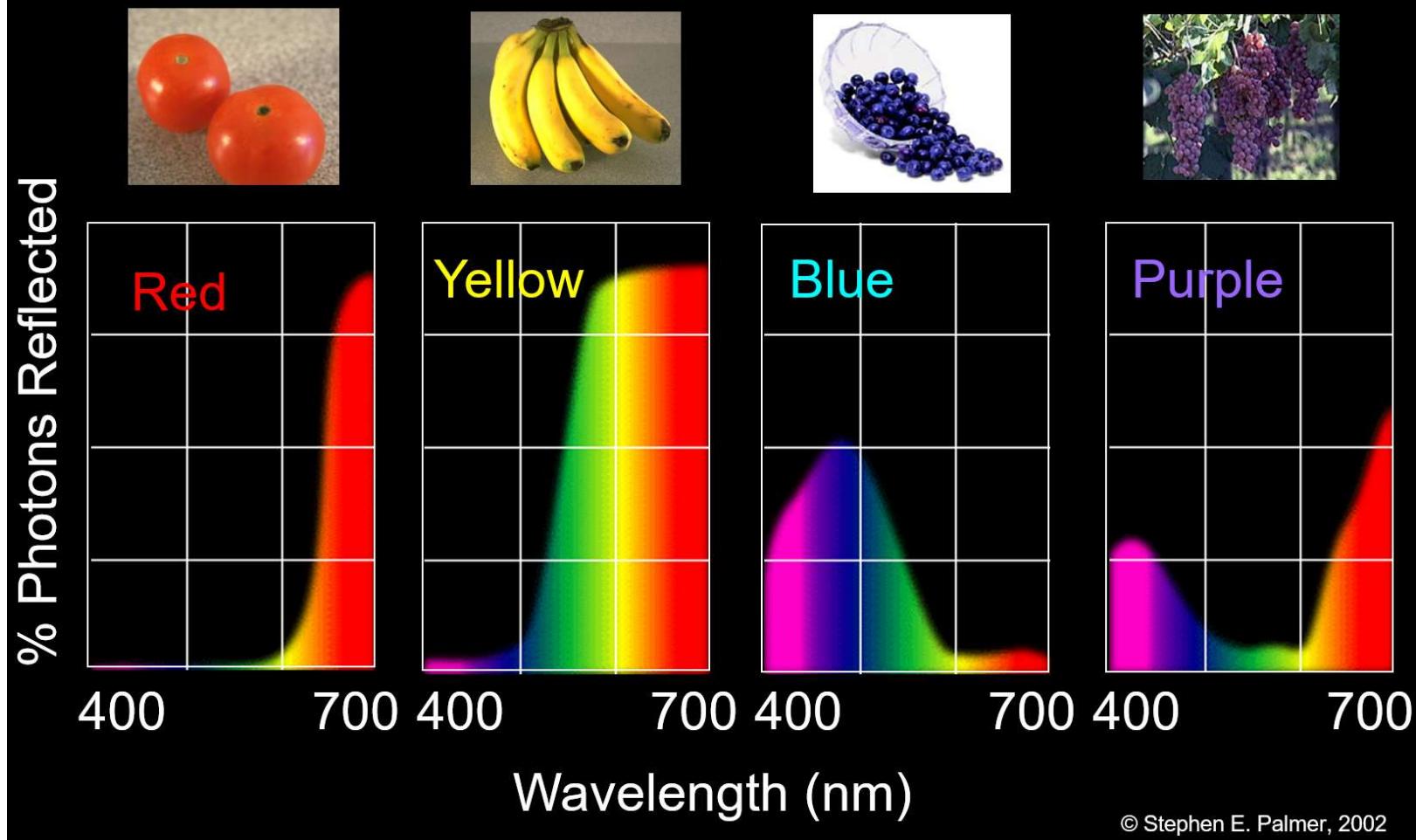
...because that's where the Sun radiates EM energy

可见光

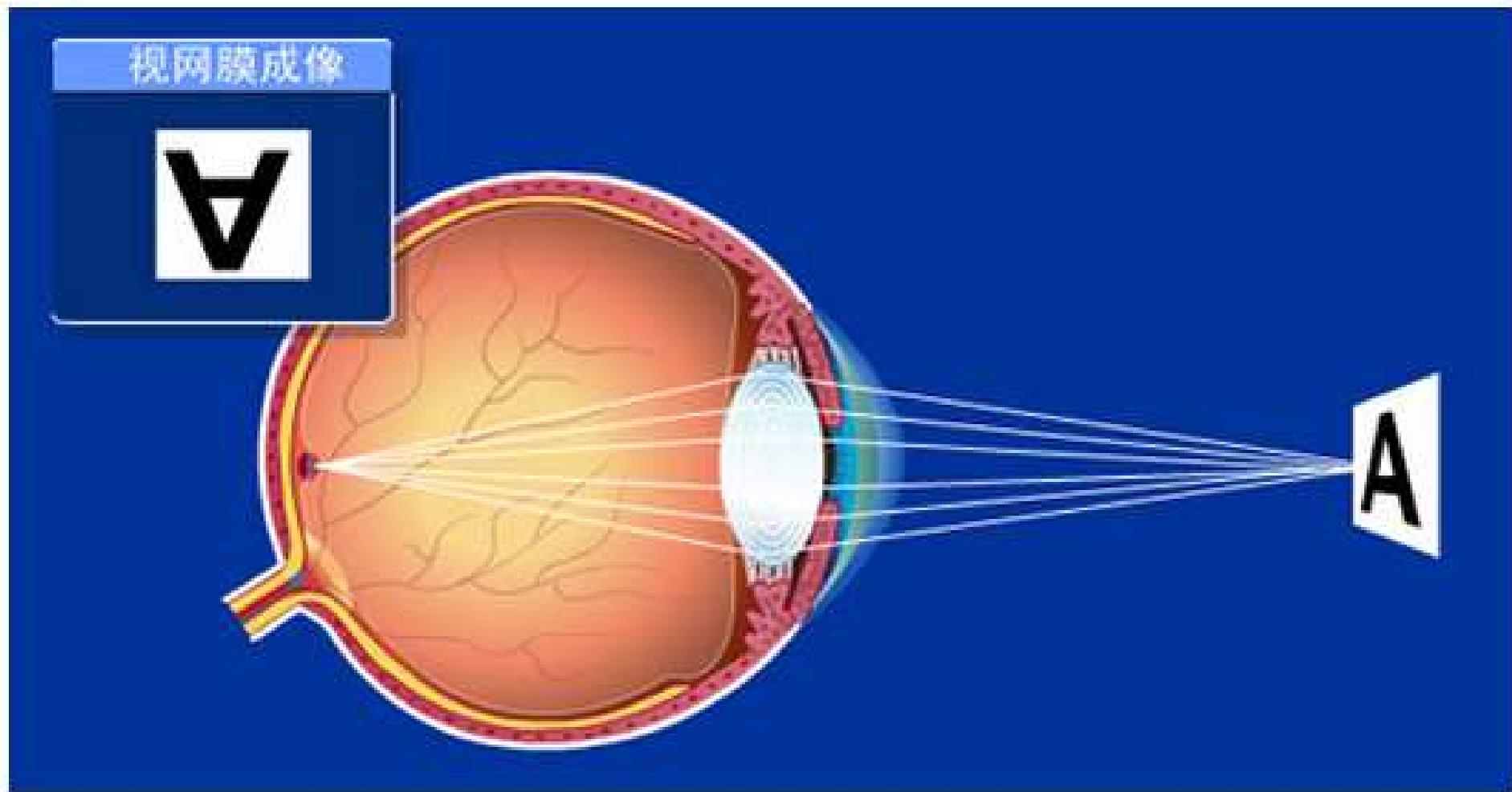


光与物质的作用产生色彩

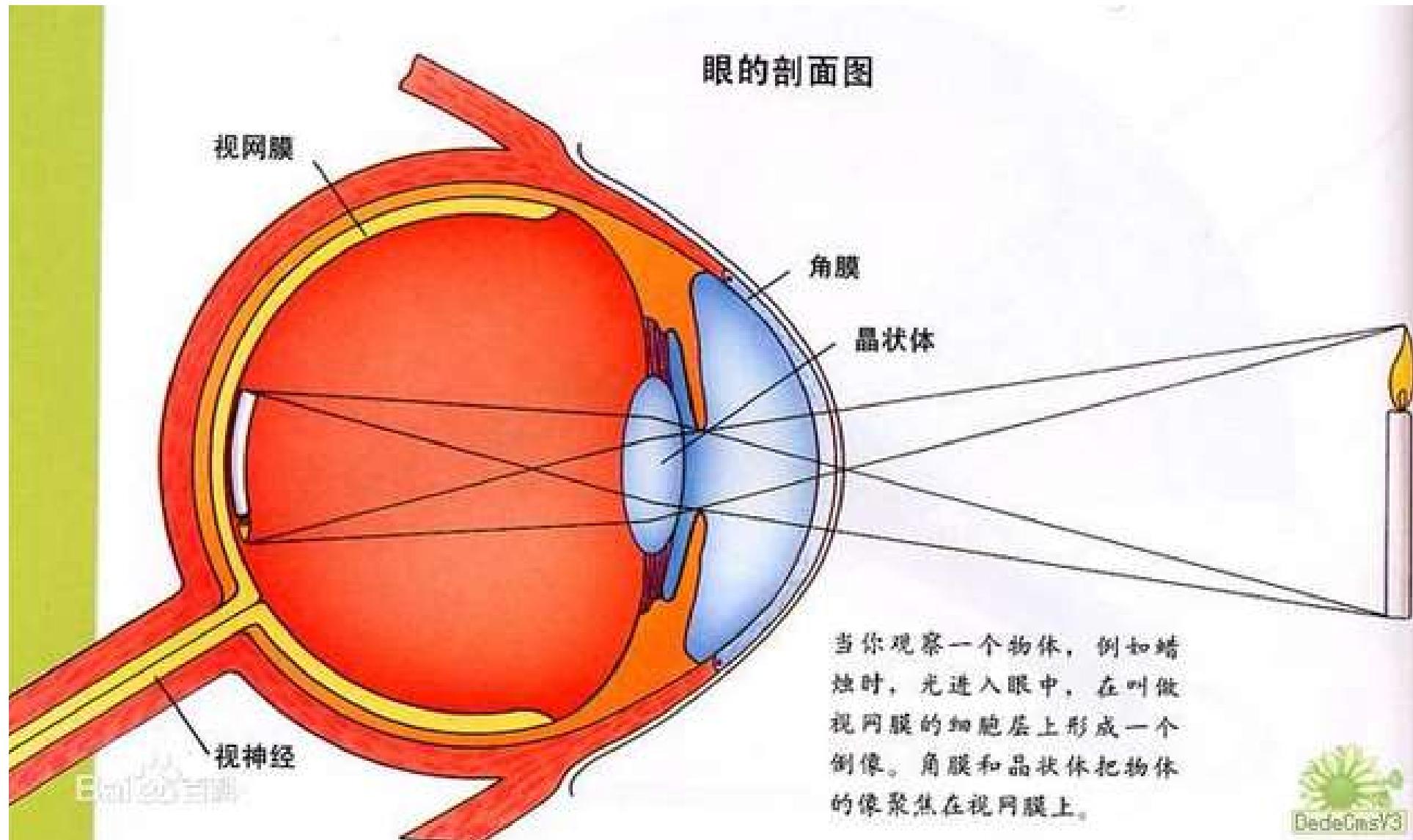
Some examples of the reflectance spectra of surfaces



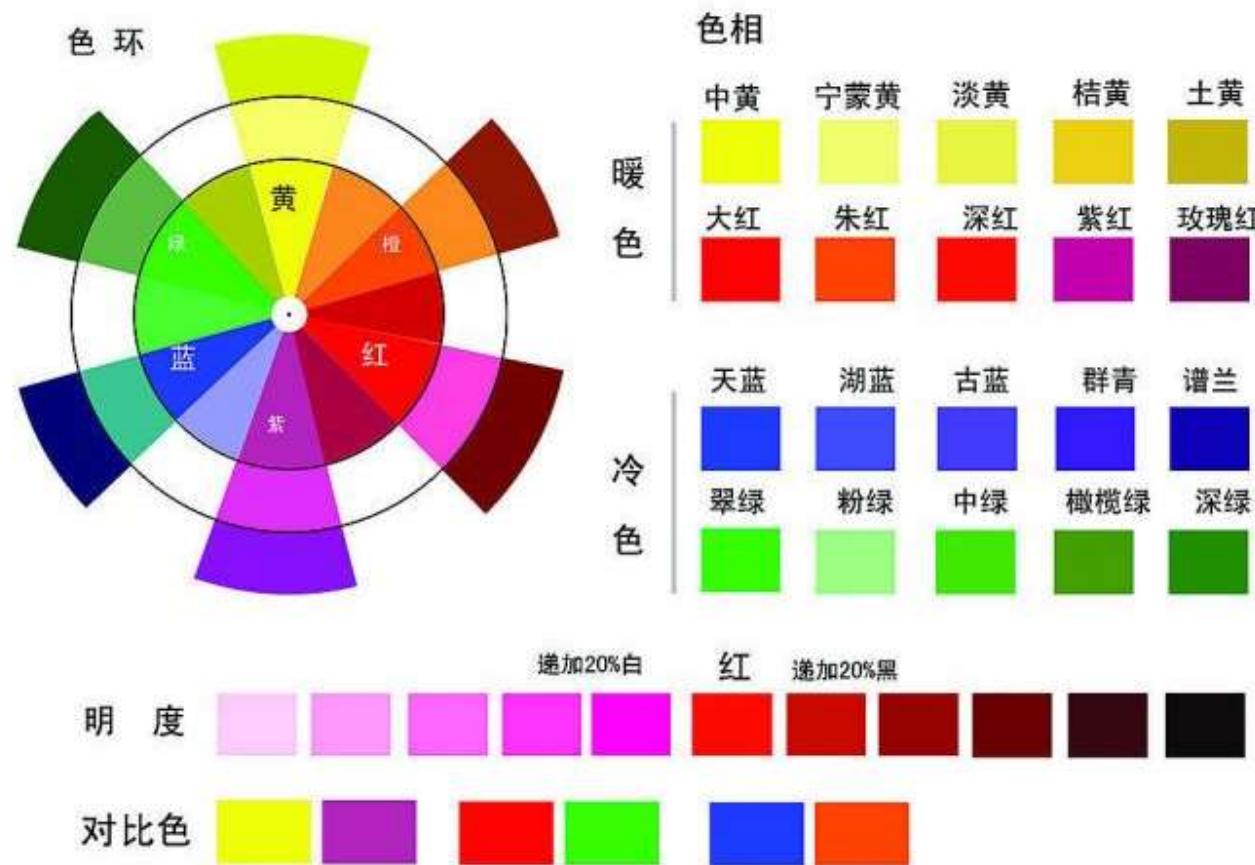
视网膜成像：上亿个感光细胞



视网膜成像：上亿个感光细胞



颜色的定义



每个人的“颜色”认知是一样的吗？

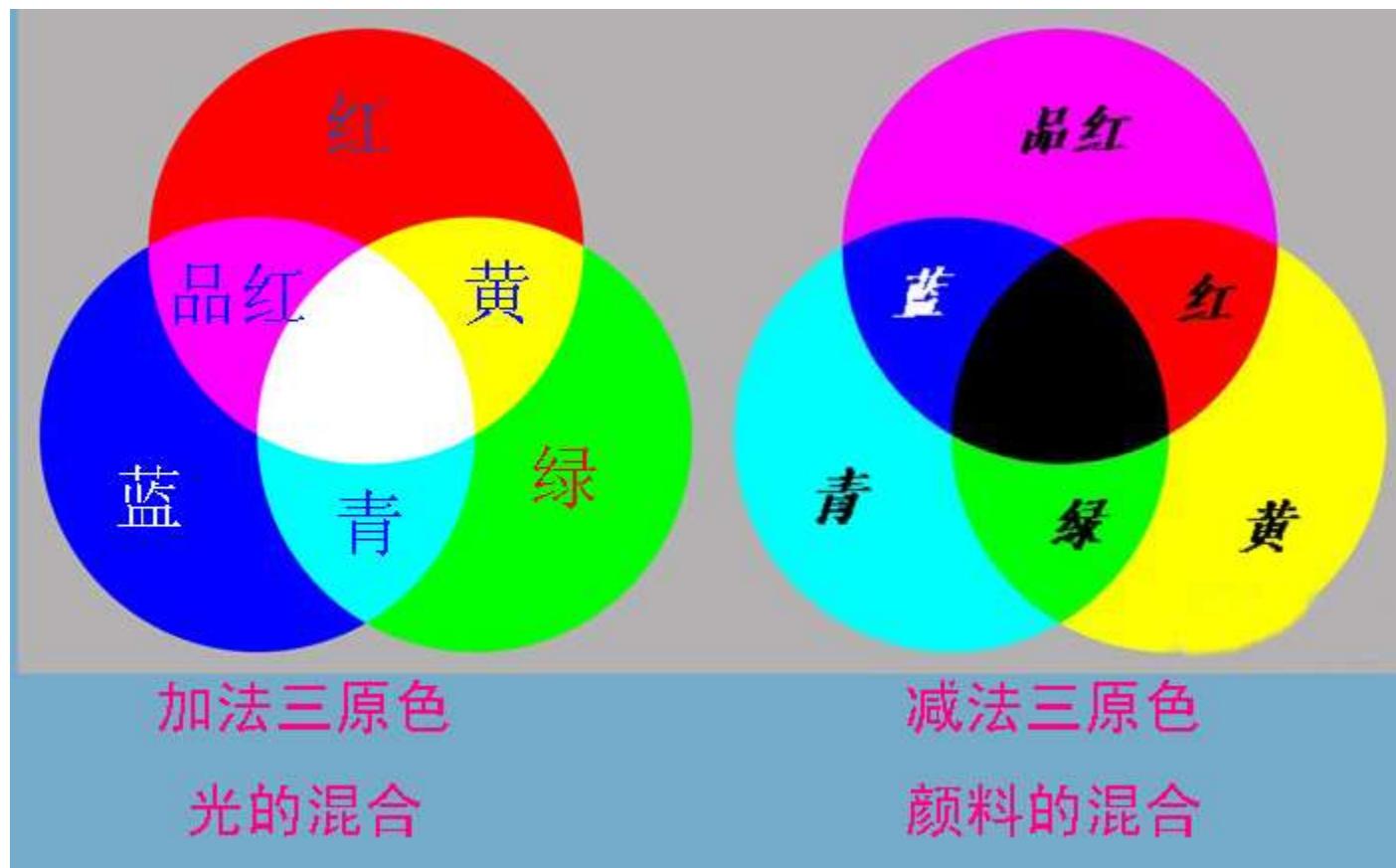
数字图像处理

颜色的数字化

- 颜色是如何量化的？
- 计算机：数字化
 - 表达
 - 存储
 - 计算

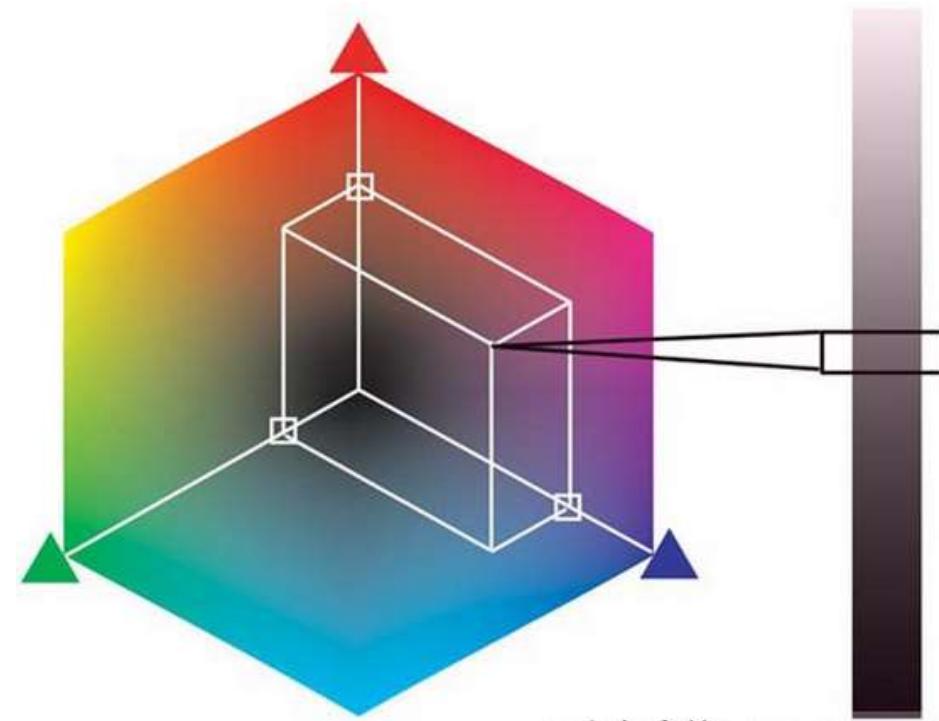
颜色三原色：红、绿、蓝

- 适合于显示设备的颜色的表达方式



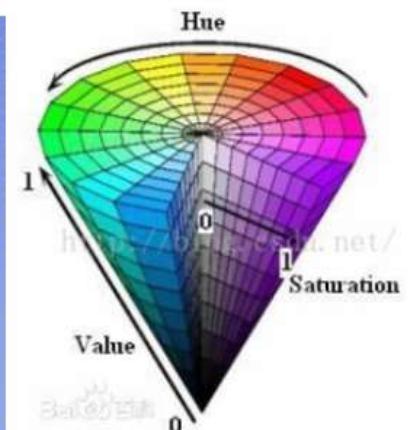
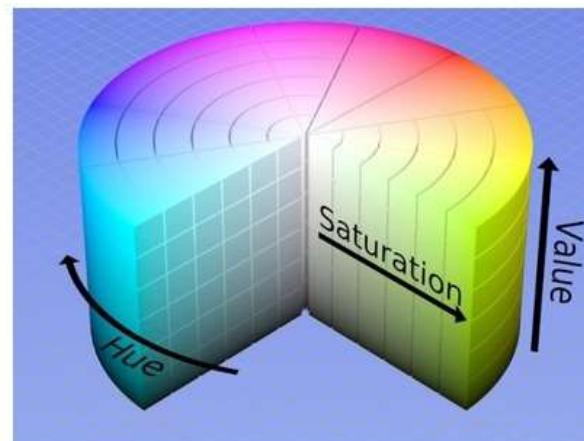
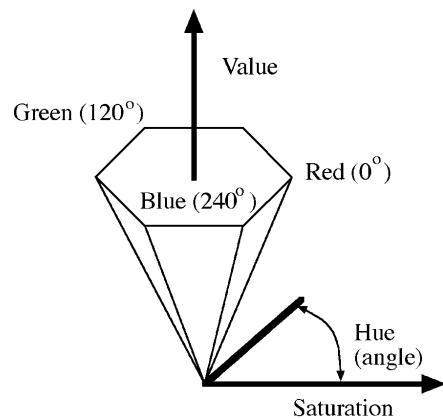
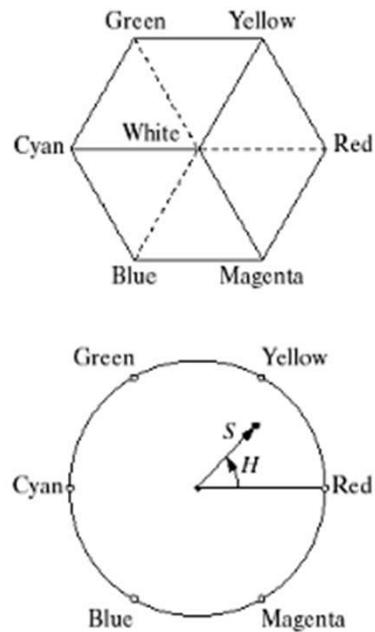
RGB颜色空间

- Color = a R + b G + c B
 - 适合于显示设备的颜色的表达方式



- RGB cube
 - Easy for devices
 - But not perceptual

HSV/HSL 颜色空间



- Hue (色度), Saturation (饱和度), Value /Lightness (亮度/值)
 - RGB cube on its vertex
- Decouples the three components (a bit)
- Use `rgb2HSV()` and `HSV2RGB()` in Matlab

Color Spaces: Different Basis

- RGB
- HSV/HSL
- CMY
- CIE XYZ
- $l\alpha\beta$

如何模拟人眼存储图像？

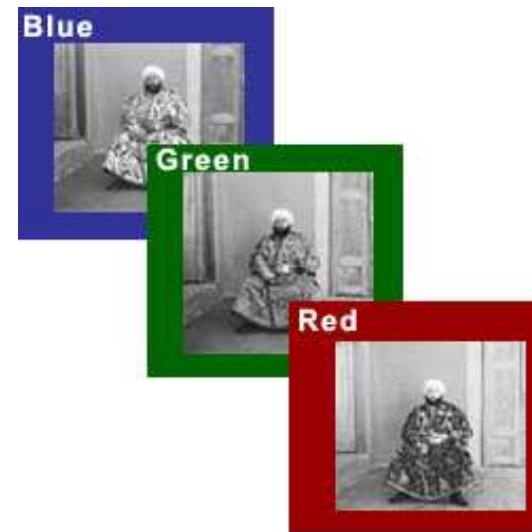
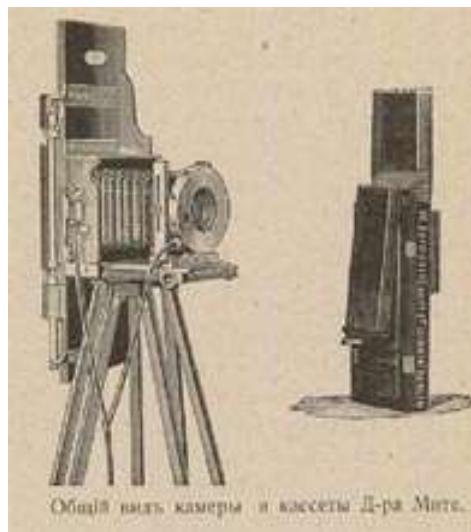
色彩传感器(sensor)



Daguerrotype, 1839

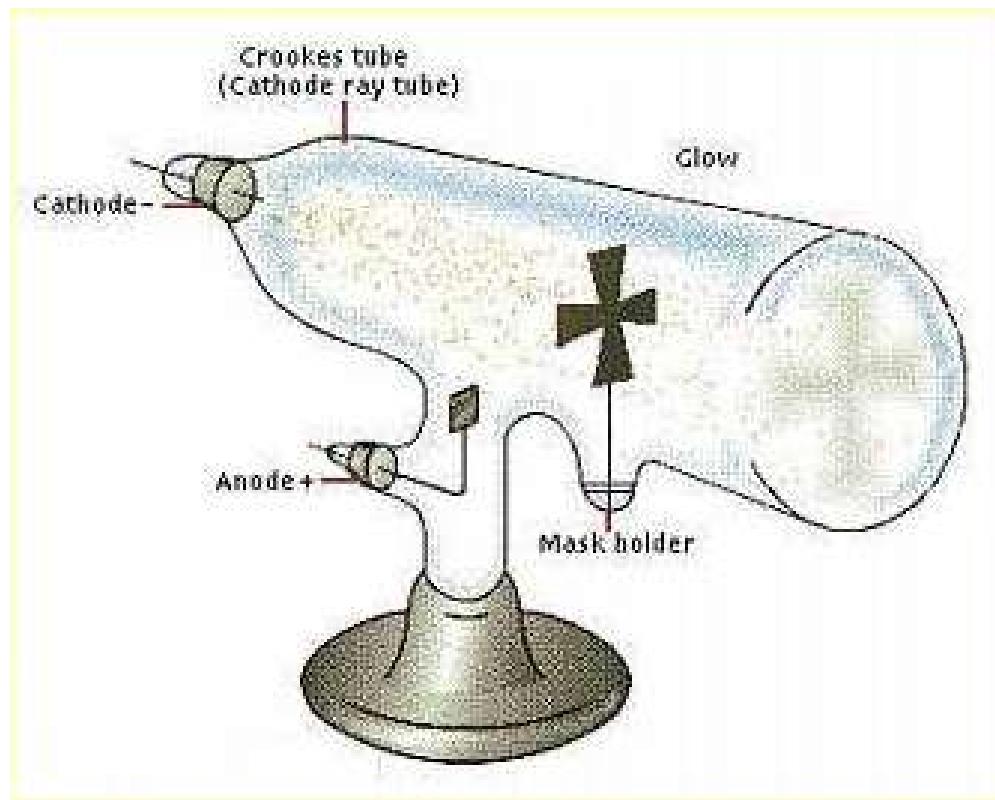
物理感光胶片 (film)

- 化学感光材料（卤化银）
- Oldest color photos still preserved (1861):
Prokudin-Gorskii
<http://www.loc.gov/exhibits/empire/>



数字化显示器

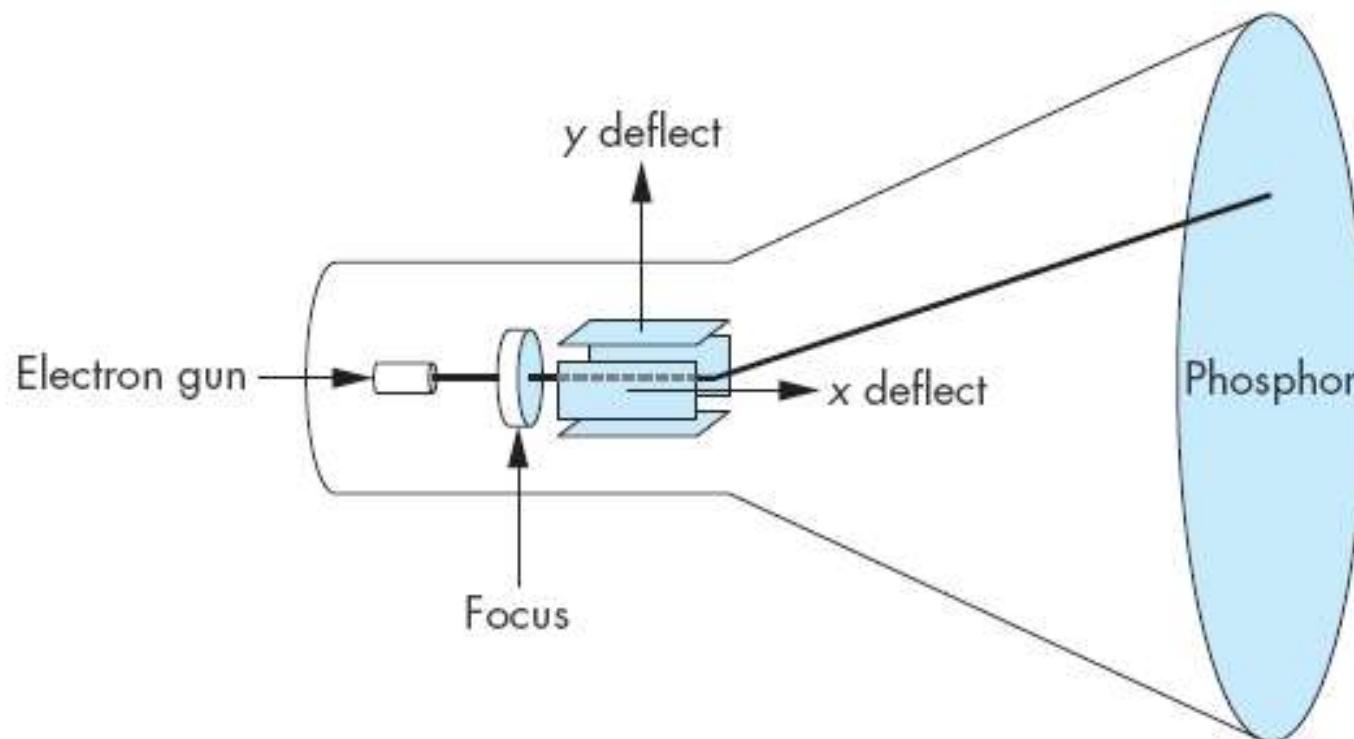
- CRT显示器



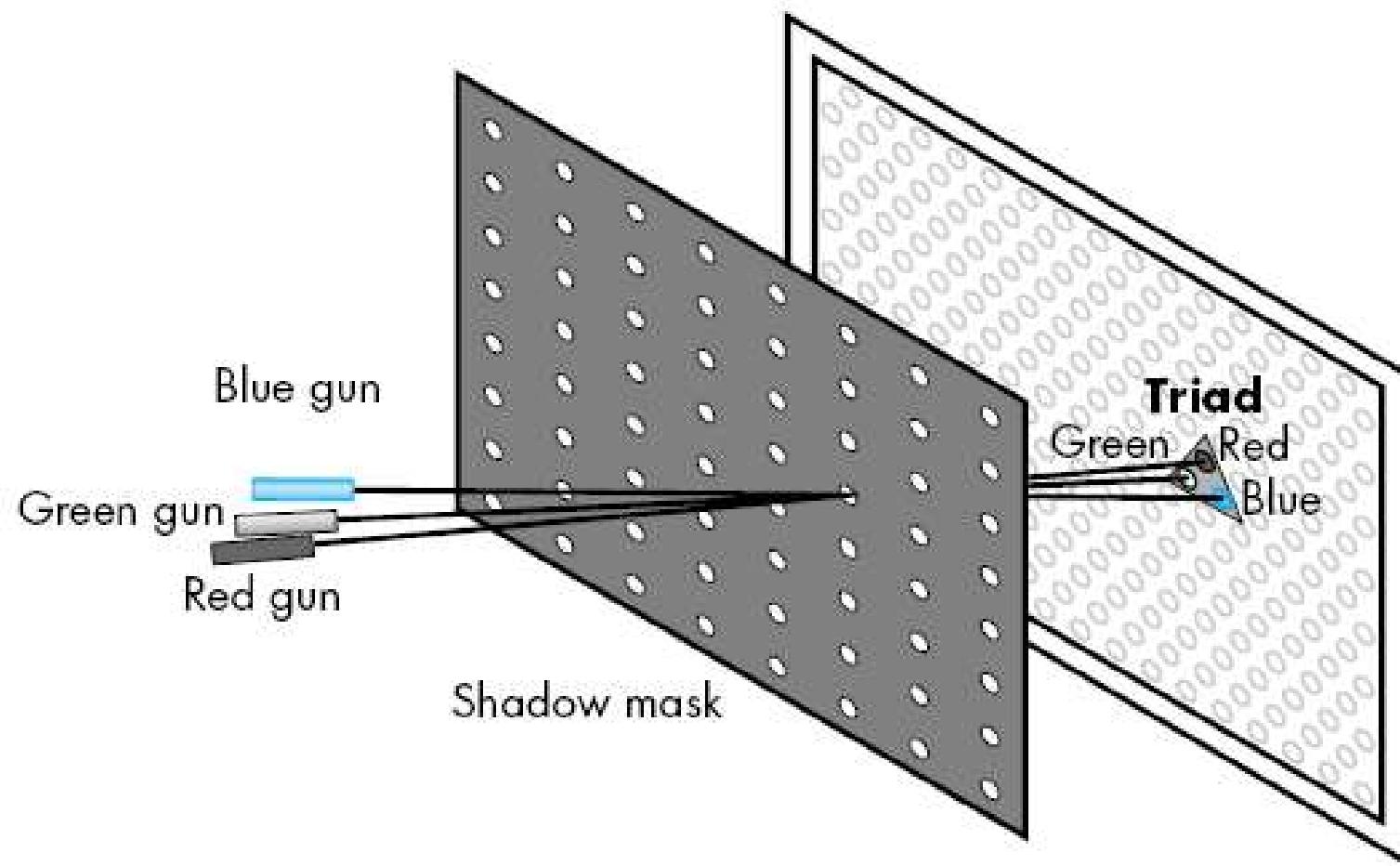
Karl Braun (1897)

阴极射线显像管显示器 (CRT)

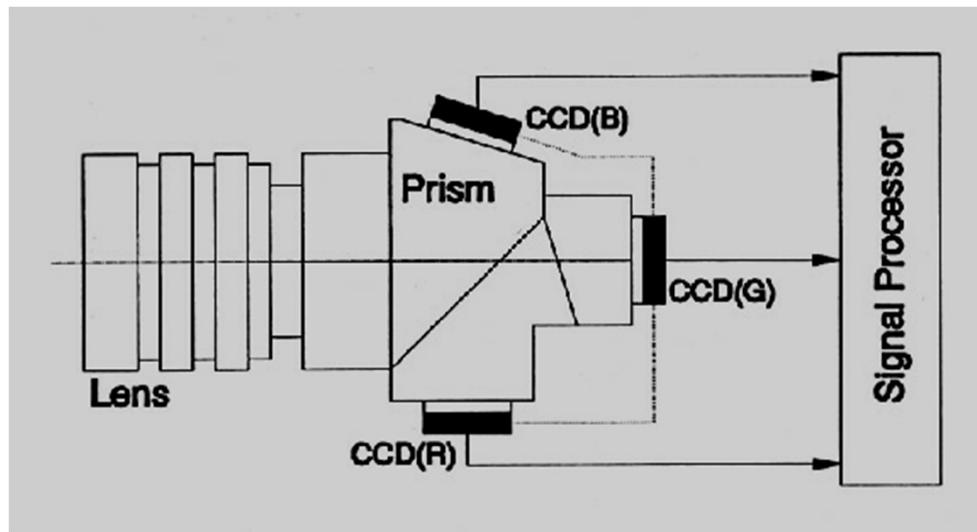
- 逐个将“点”打在屏幕上的相应位置
 - 逐行逐列扫描



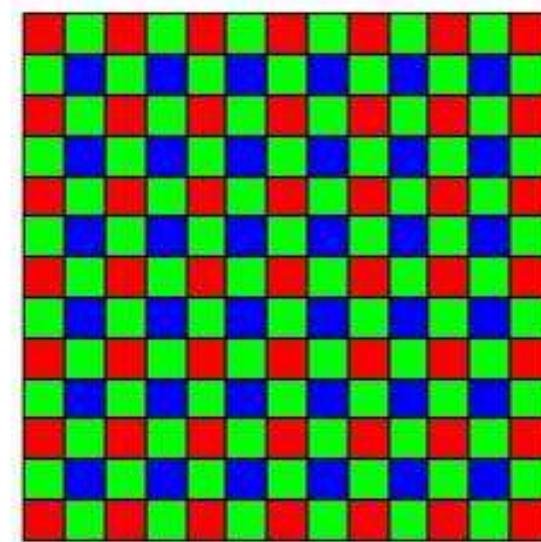
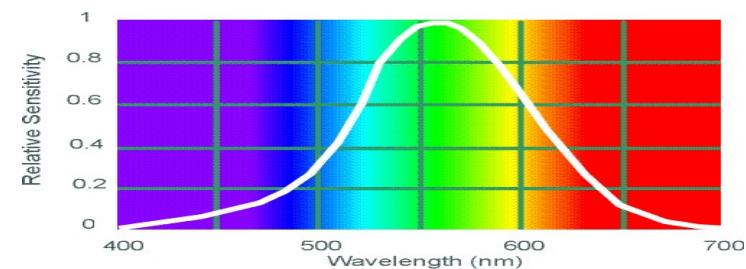
彩色CRT显示器（光栅显示器）



Color Sensing in Camera (RGB)



CMOS sensor

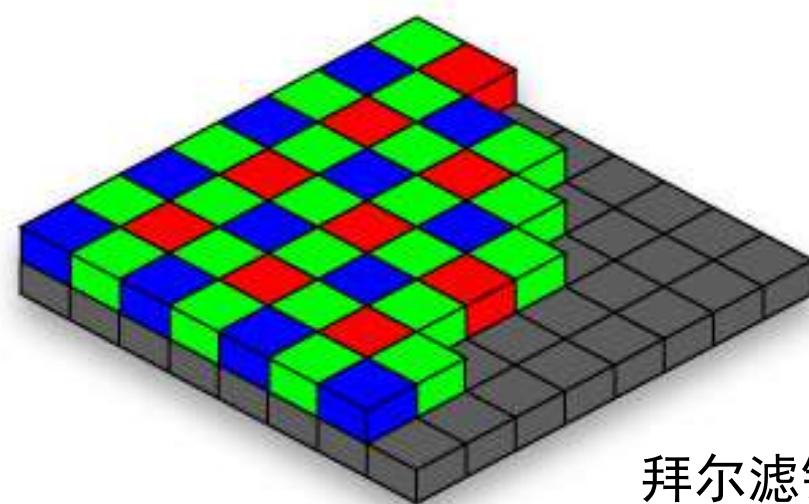
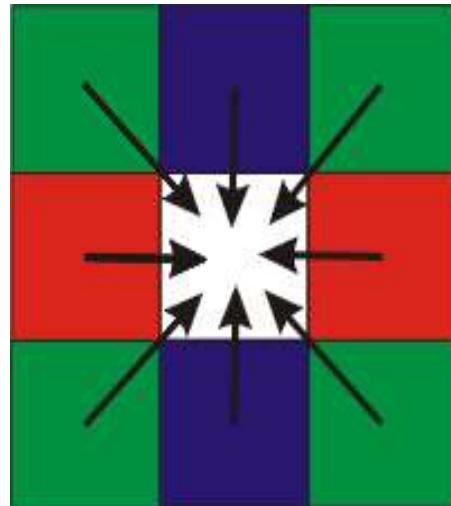


Bayer filter

Buff Works

<http://www.cooldictionary.com/words/Bayer-filter.wikipedia>

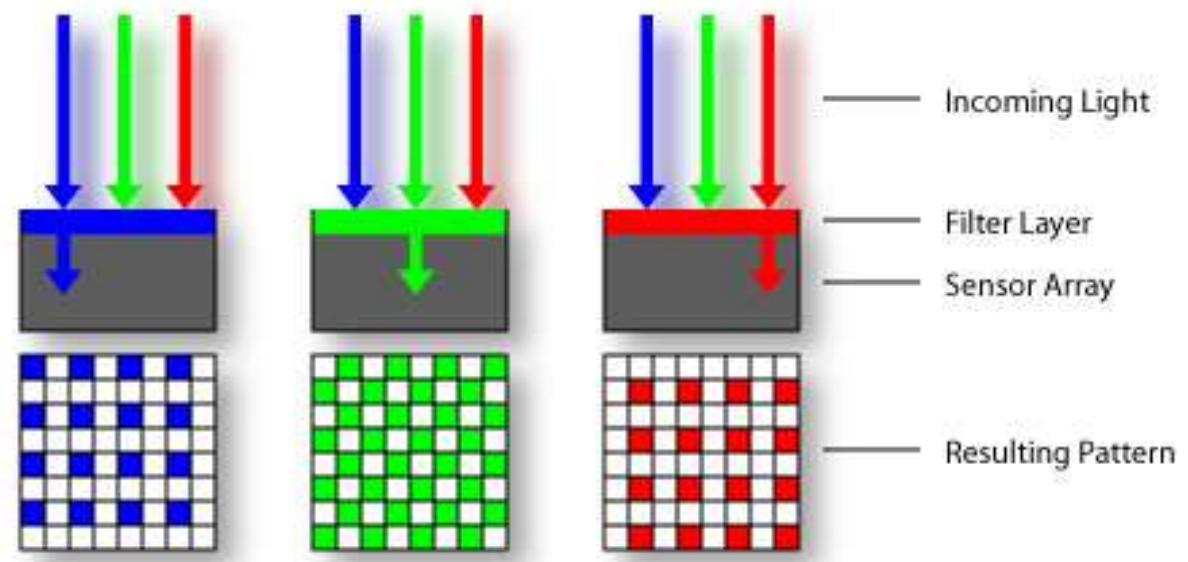
Practical Color Sensing: Bayer Grid



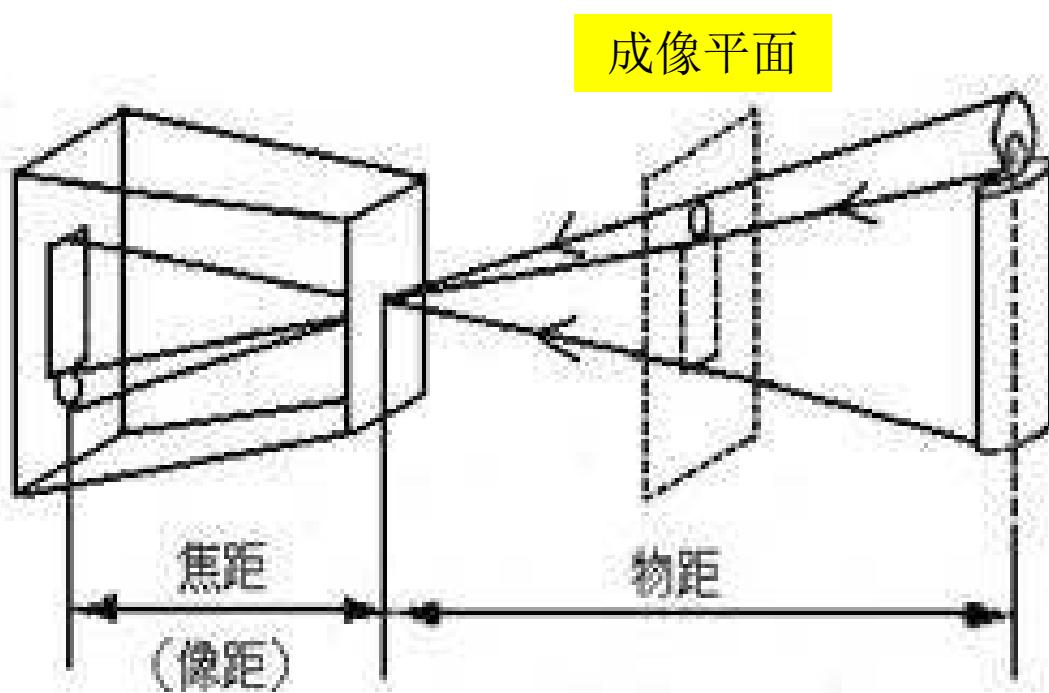
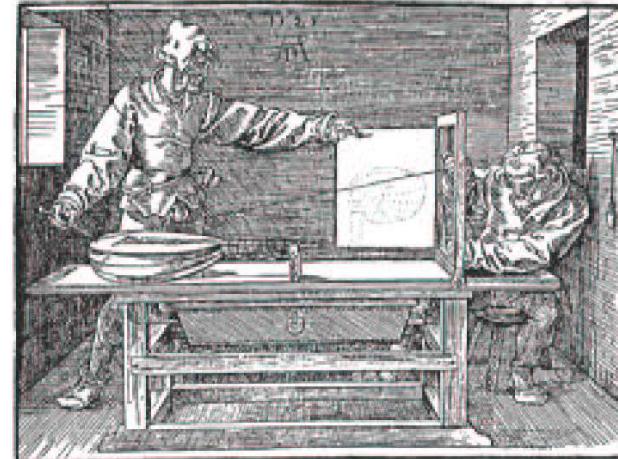
拜尔滤镜

- Estimate RGB at 'G' cells from neighboring values

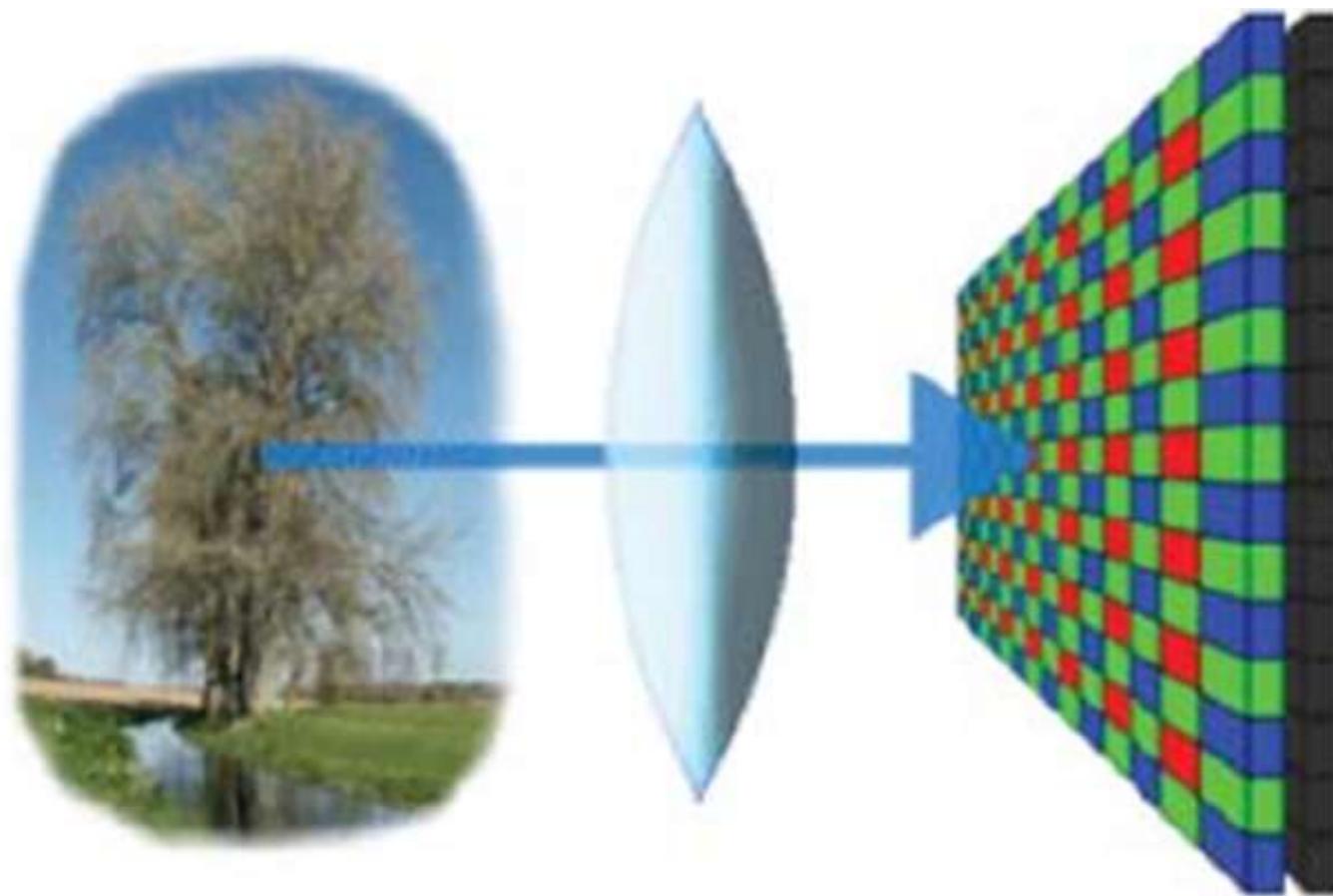
[http://www.cooldictionary.com/
words/Bayer-filter.wikipedia](http://www.cooldictionary.com/words/Bayer-filter.wikipedia)

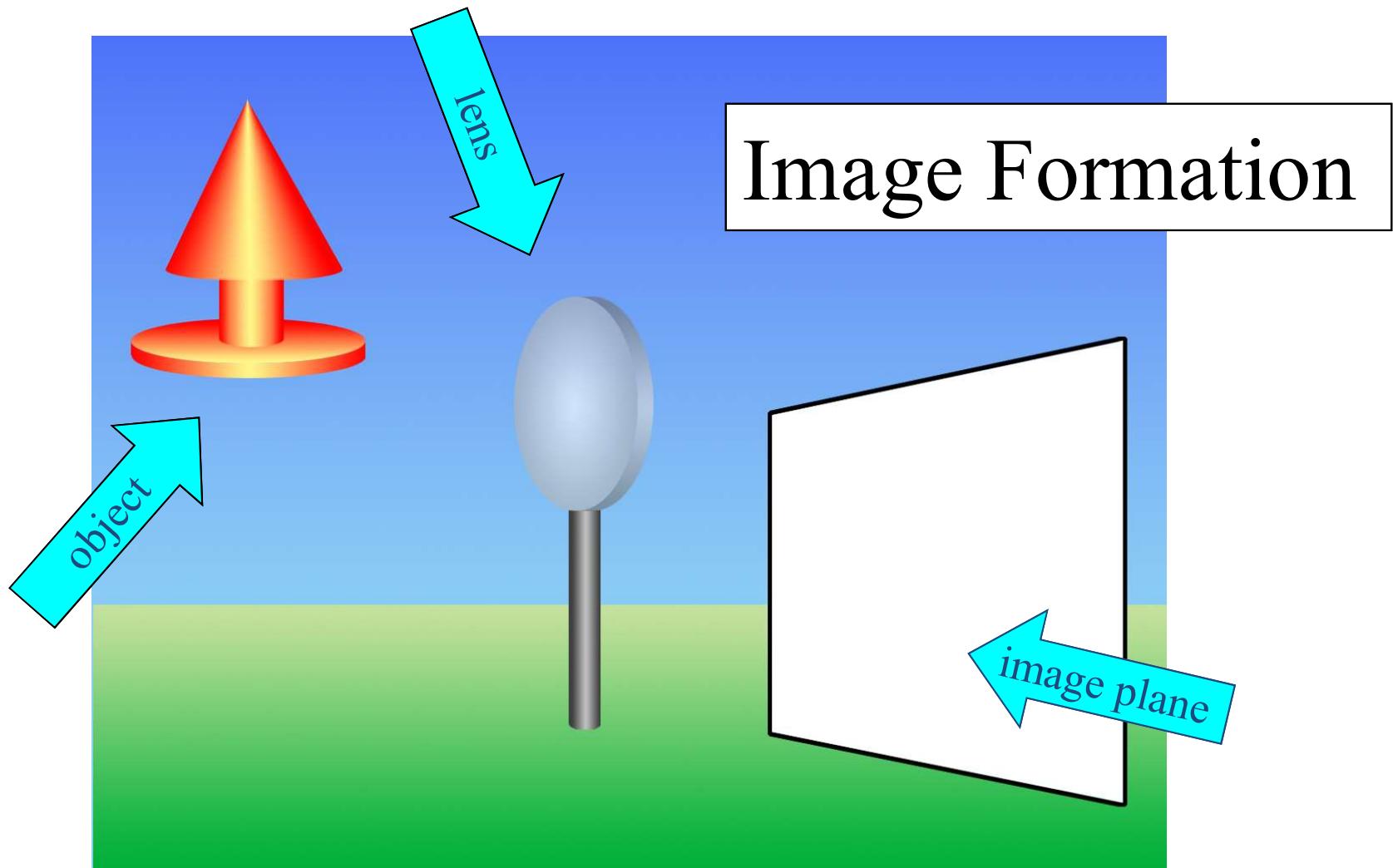


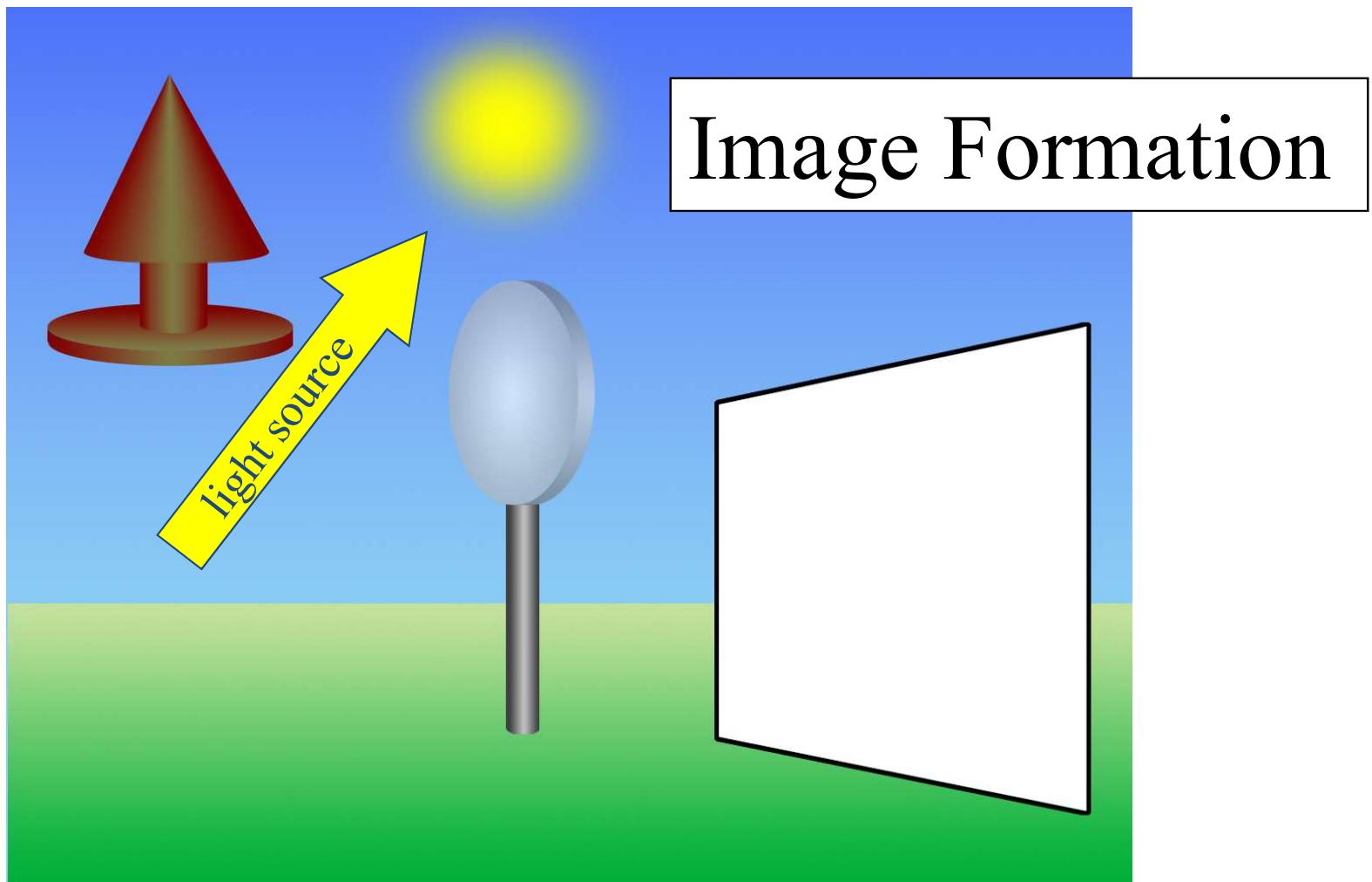
针孔成像 (Pin-hole)



数字图像







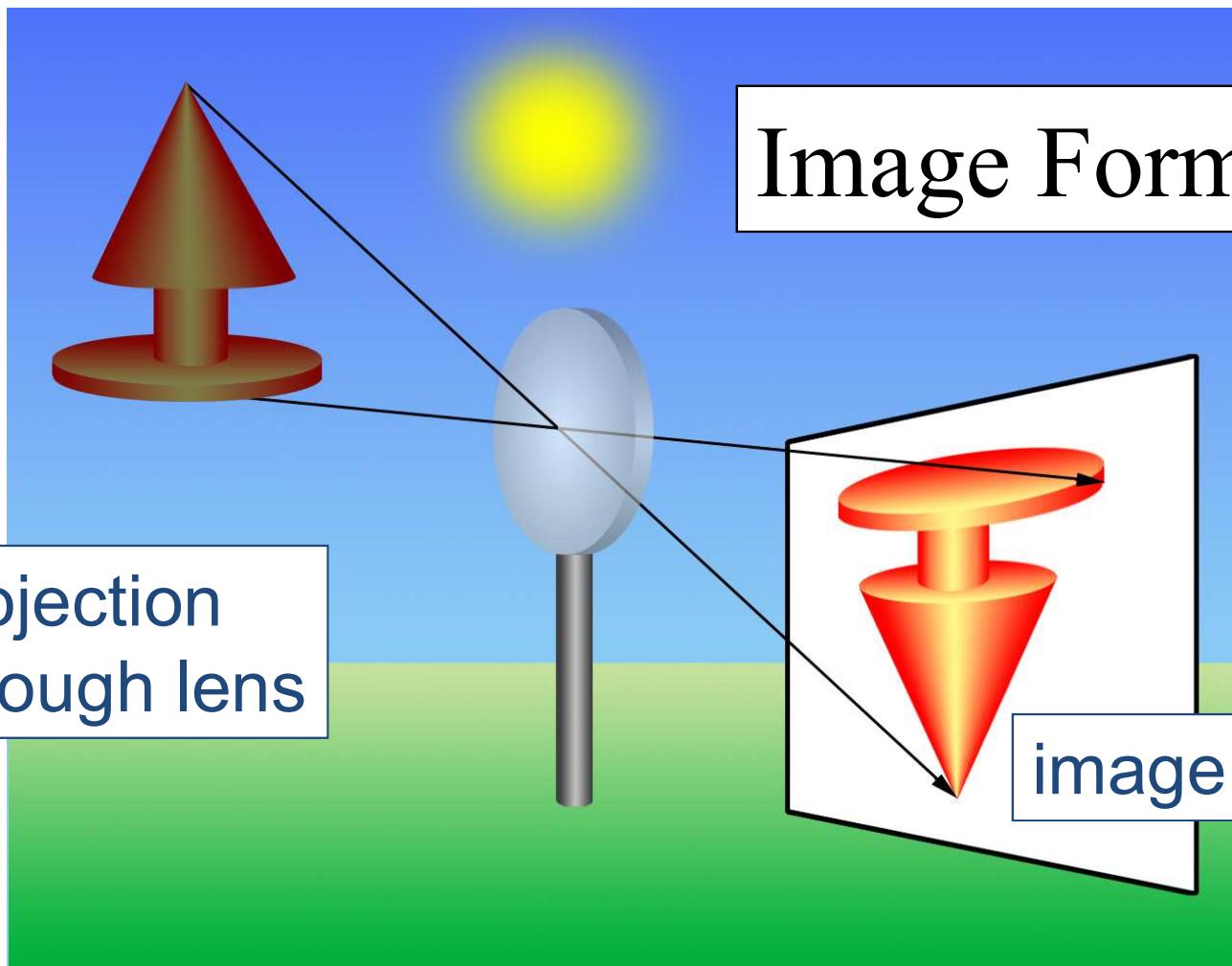
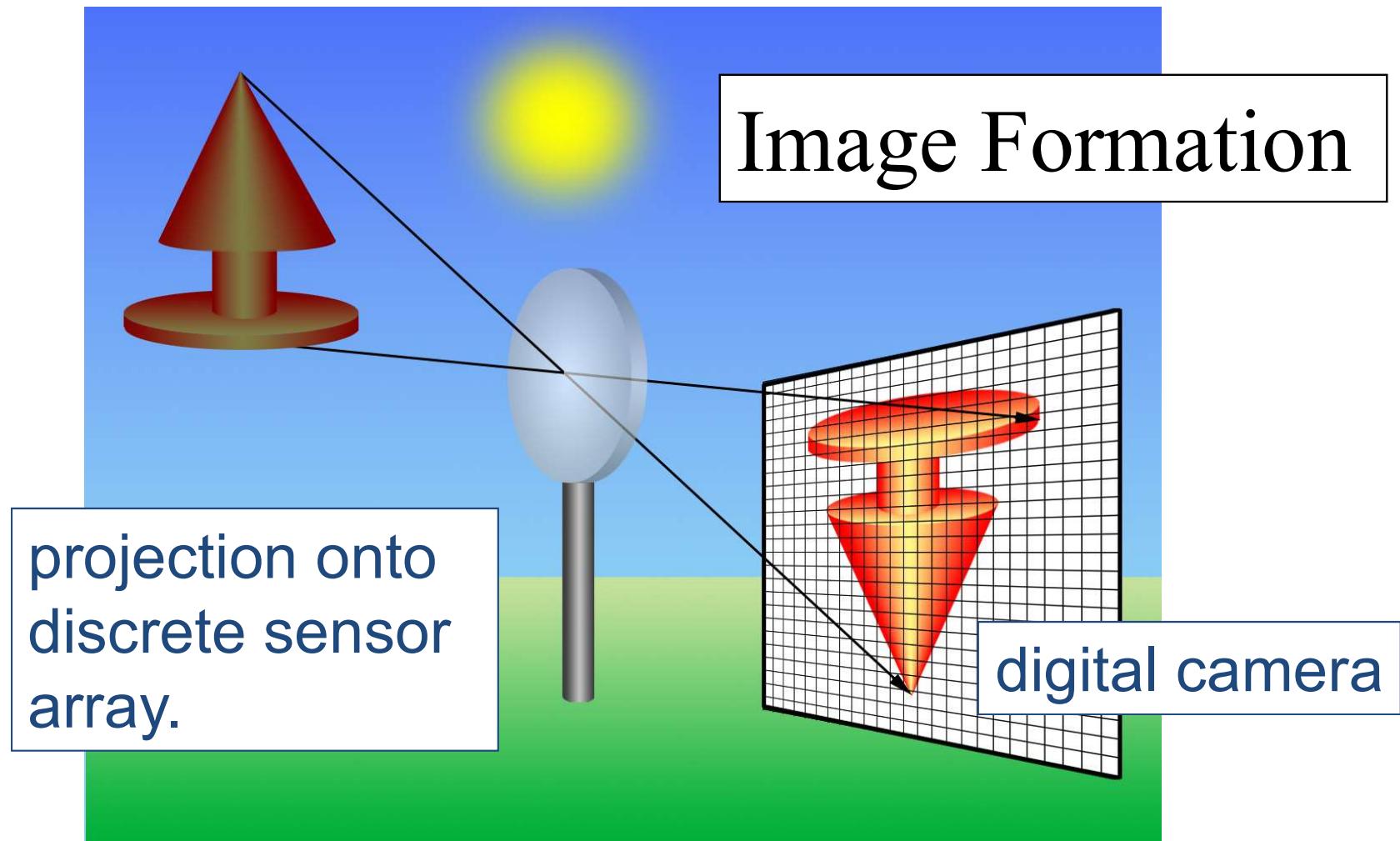
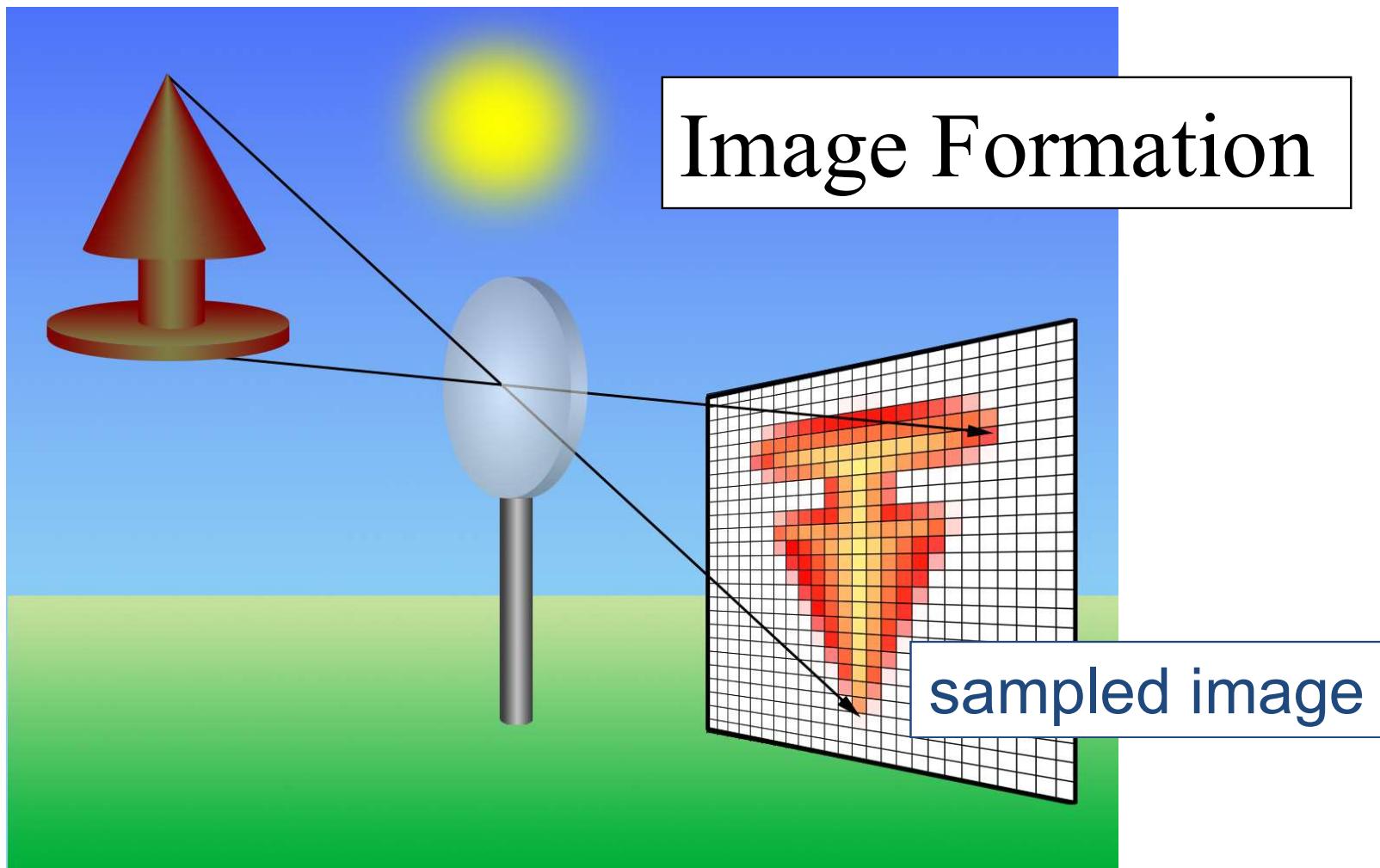


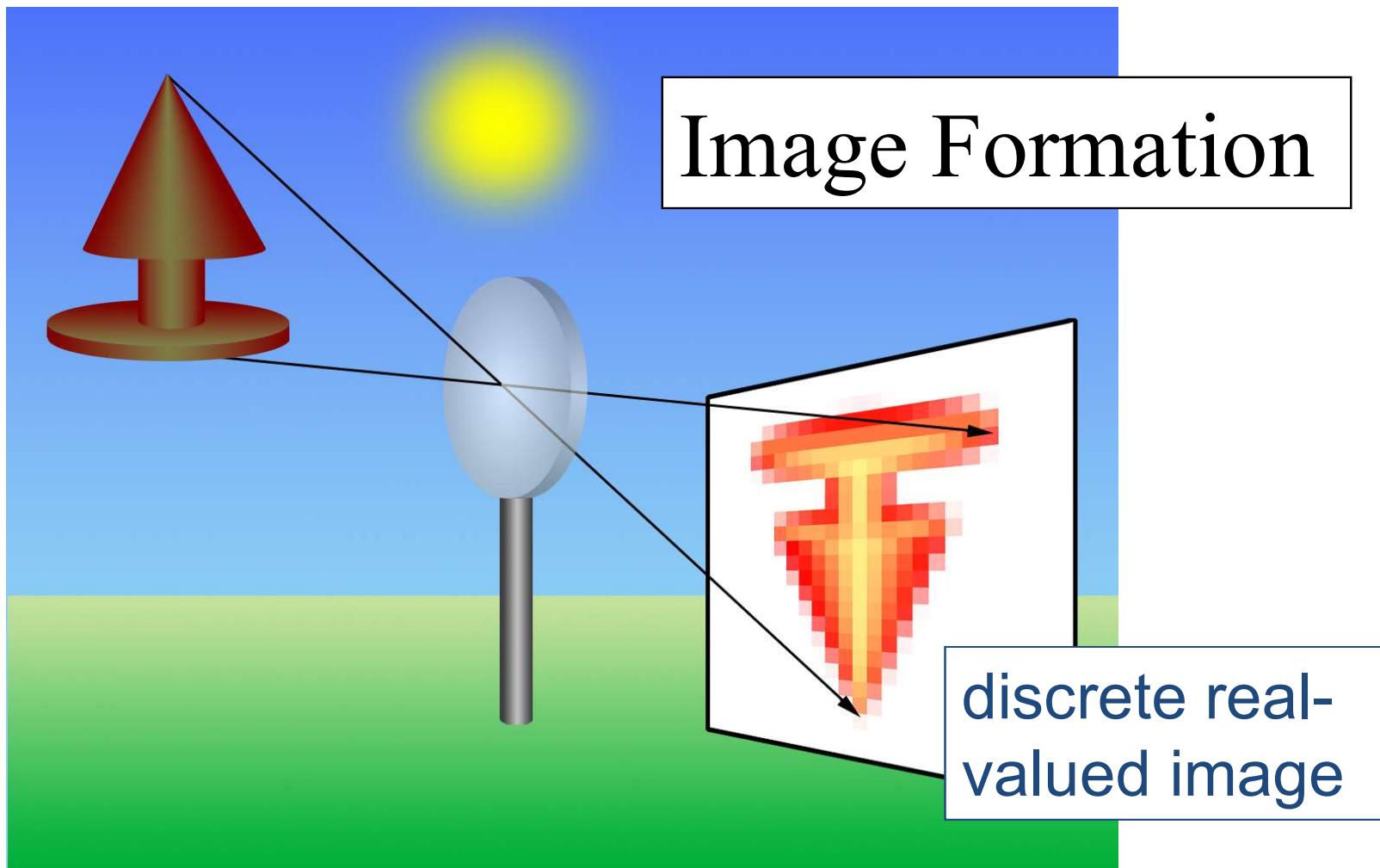
Image Formation

projection
through lens

image of object







Sensor array: 采样和量化

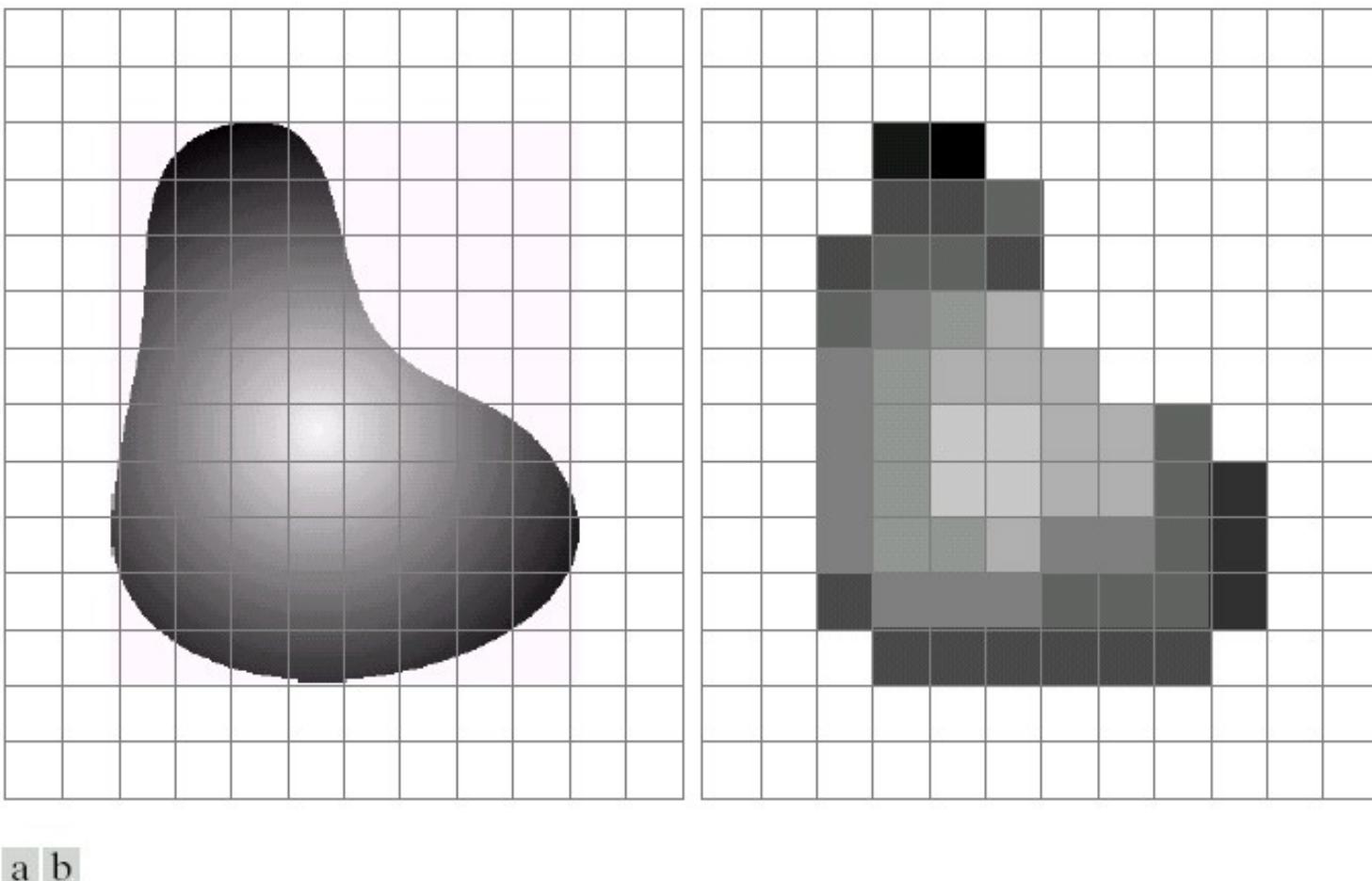


FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.

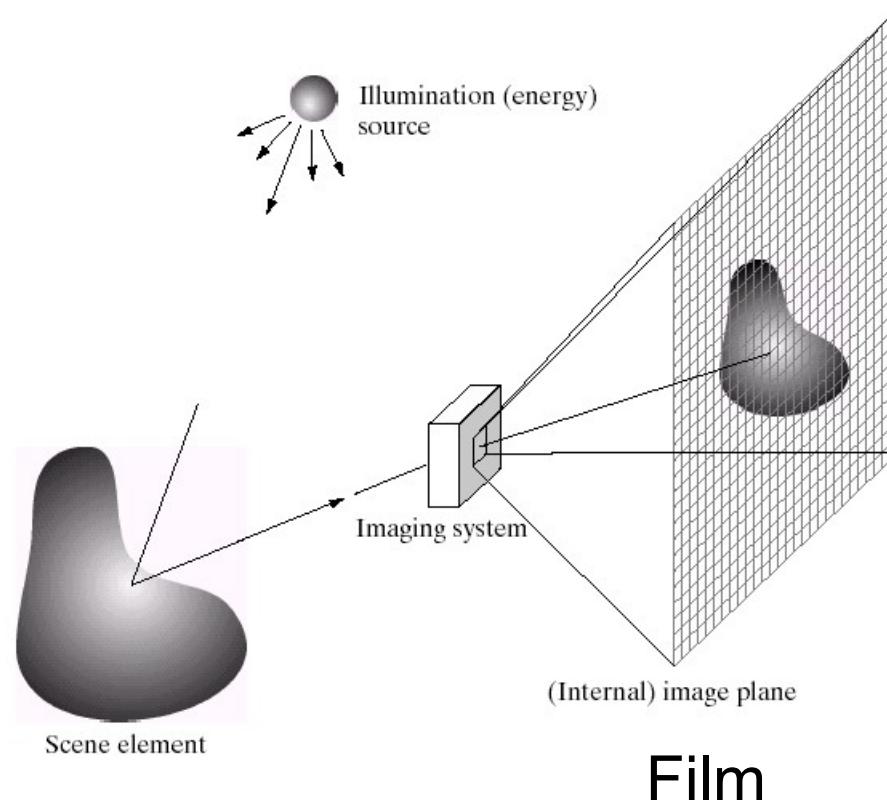
数码相机、手机



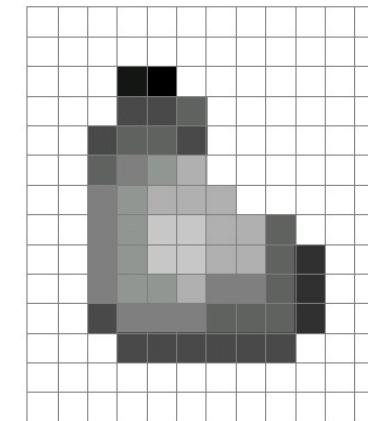
- A digital camera replaces film with a sensor array
 - Each cell in the array is light-sensitive diode that converts photons to electrons
 - Two common types
 - Charge Coupled Device (CCD)
 - CMOS
 - <http://electronics.howstuffworks.com/digital-camera.htm>

数字图像的表达与存储

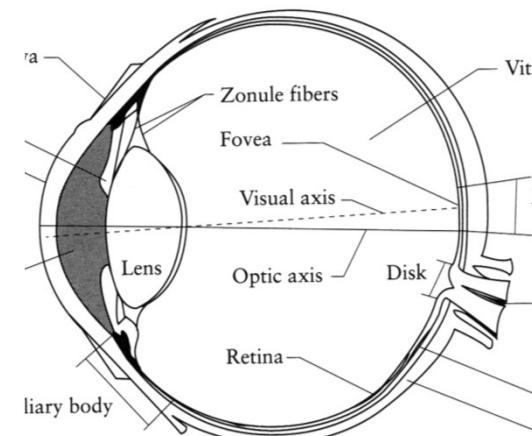
Recap: Image Formation



Film



Digital Camera



The Eye

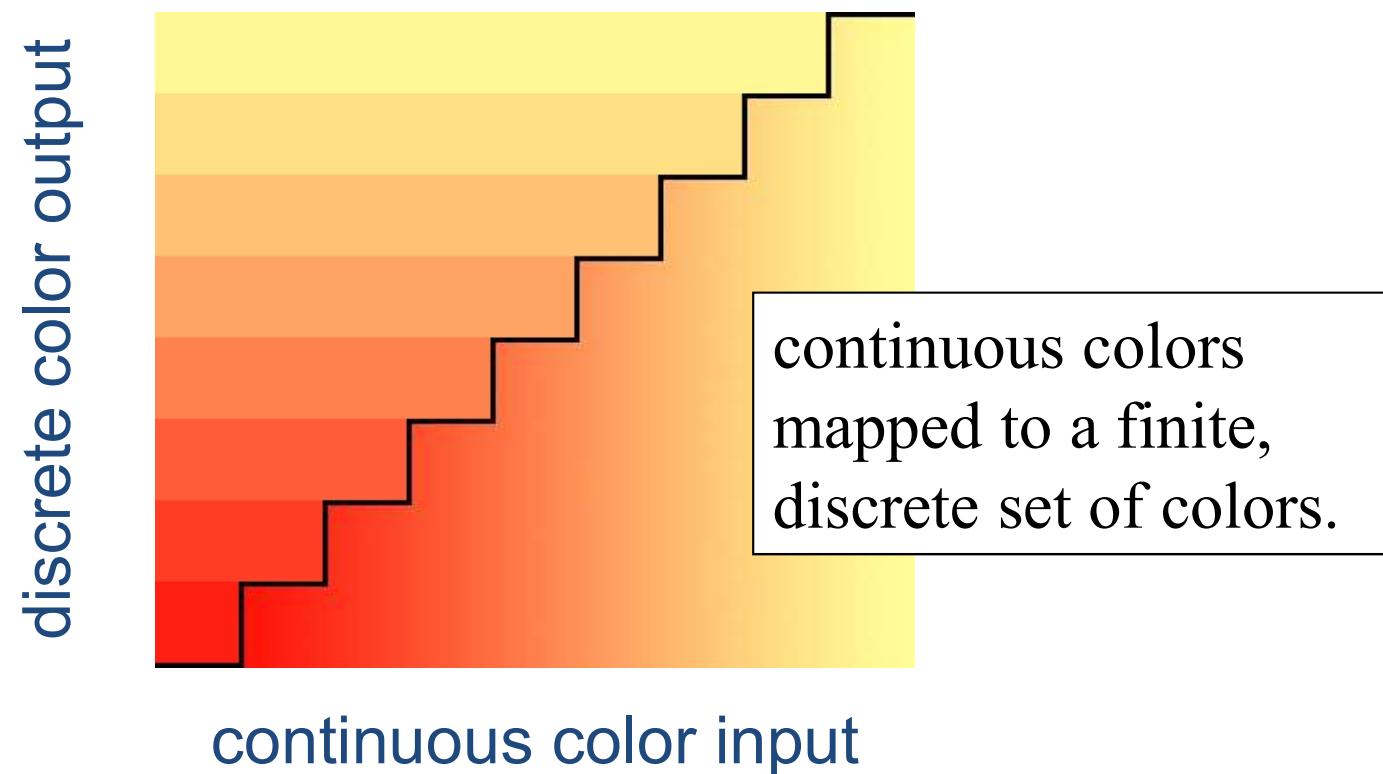
图像的连续数学模型： 平面区域上的向量值函数

- 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

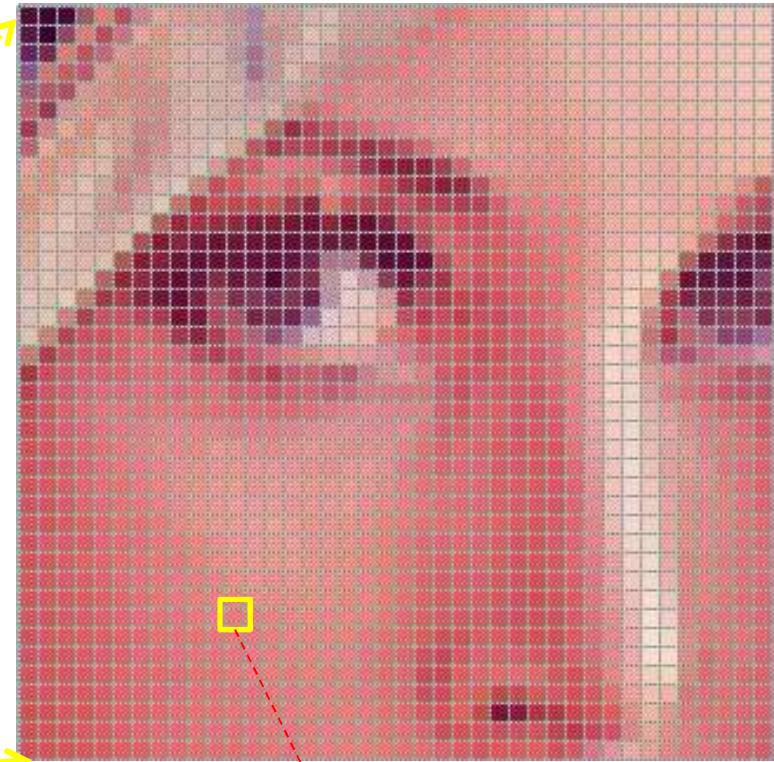
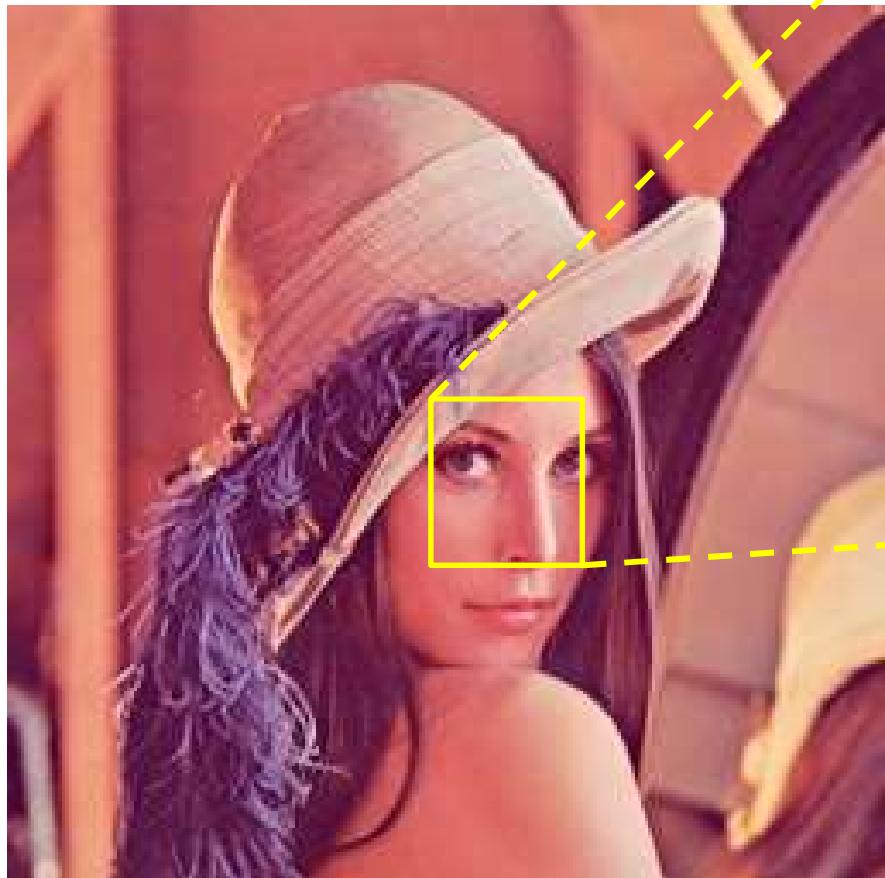


$$0.6 R + 0.3 G + 0.1 B$$

数字图像：连续空间的离散采样



Digital Image



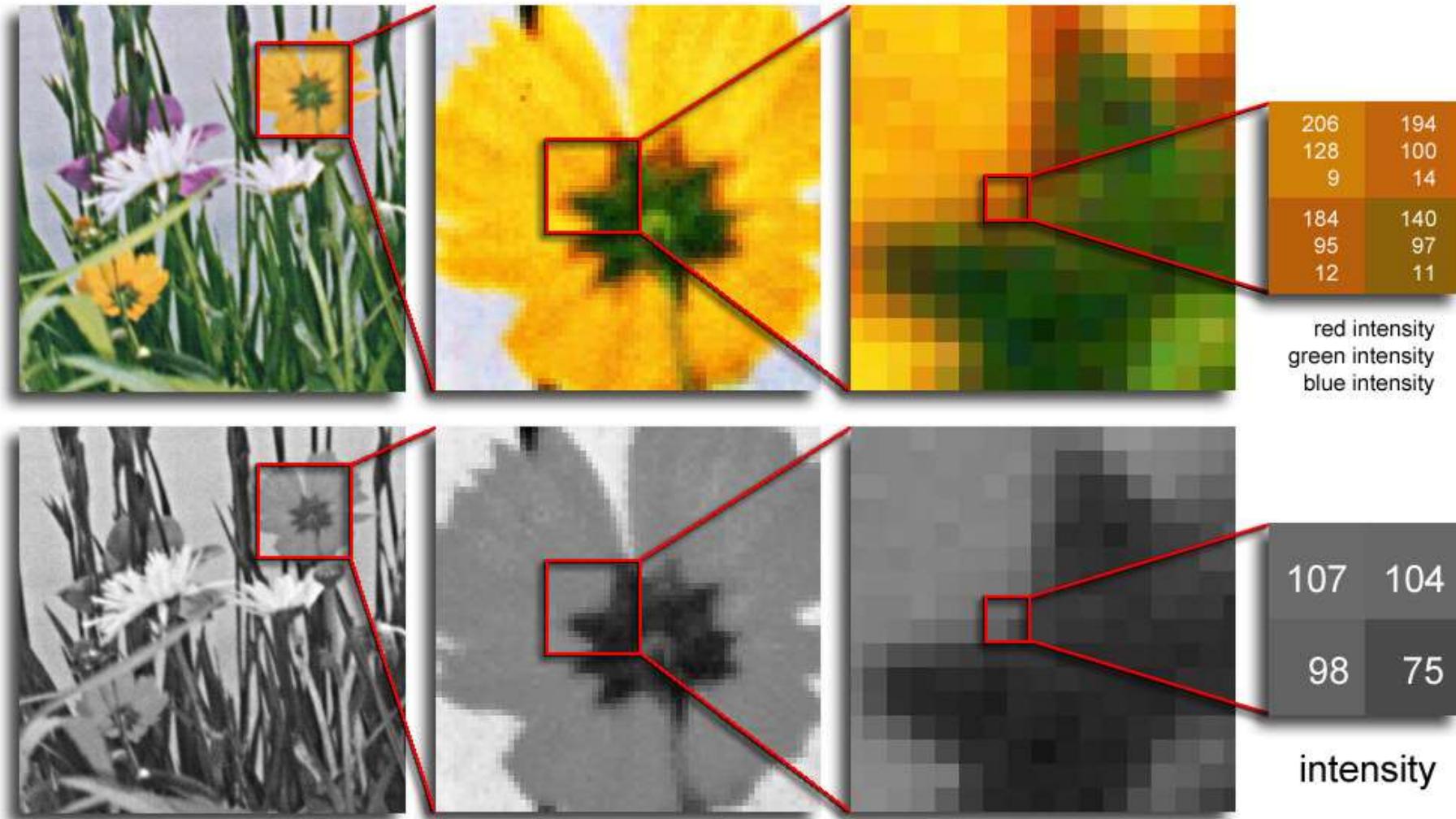
$0.6 R + 0.3 G + 0.1 B$



Color Components



数字图像的存储（通道）： 彩色图像与灰度图像



图像的不同存储方式与文件格式

- BMP (bitmap)
- JPEG
- PNG
- TIFF
- GIF
- ...

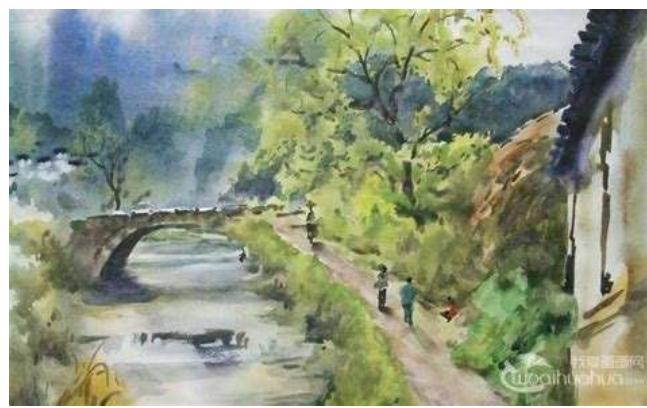
<https://zhidao.baidu.com/question/48785885.html>

产生图像的方式

1.拍照：直接获取现实世界的影像



2. 绘画：利用物理材料创造想象世界



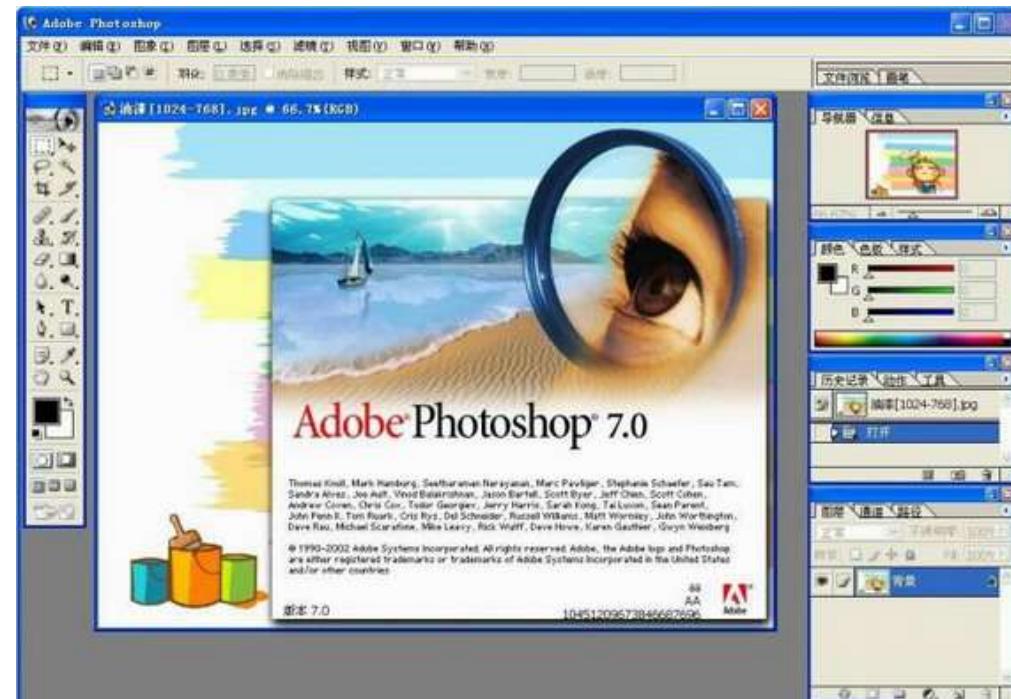
Non-professional paintings

Professional painting arts

Photorealistic paintings

3. 图像软件处理生成

- Adobe Photoshop (PS)
- Adobe AfterEffect (AE)
- CorelDraw
- Picasa
- 美图秀秀
- 光影魔术手
- ...



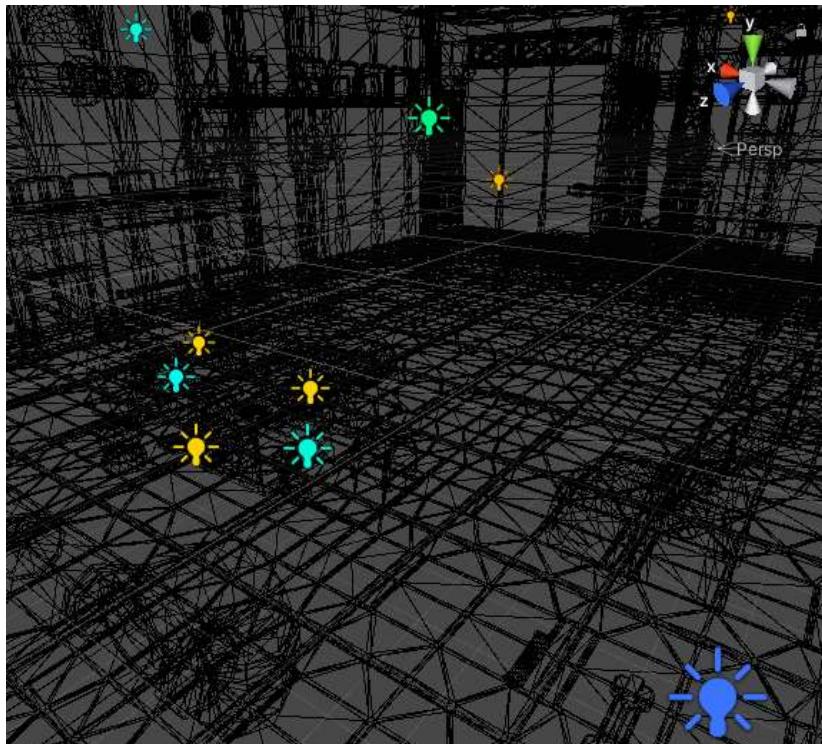
4. 图形学：算法生成虚拟世界的影像



Sketchpad, 1961, Ivan Sutherland

计算机图形学：真实感渲染

Photo-Realistic Rendering



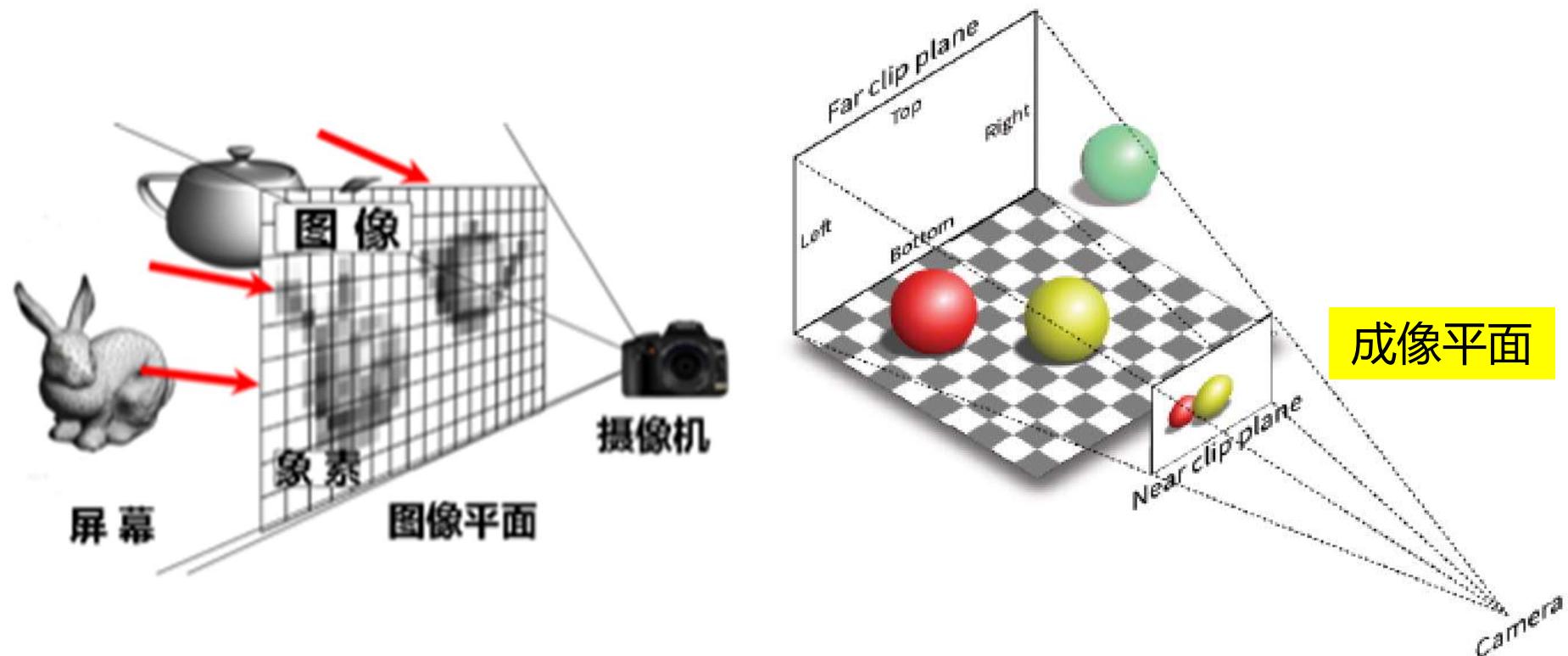
输入：几何、材质、纹理、光源、视点…



输出：照片级图片

计算机图形学：真实感渲染

Photo-Realistic Rendering



计算机图形学：真实感渲染

Photo-Realistic Rendering



(a)



(b)

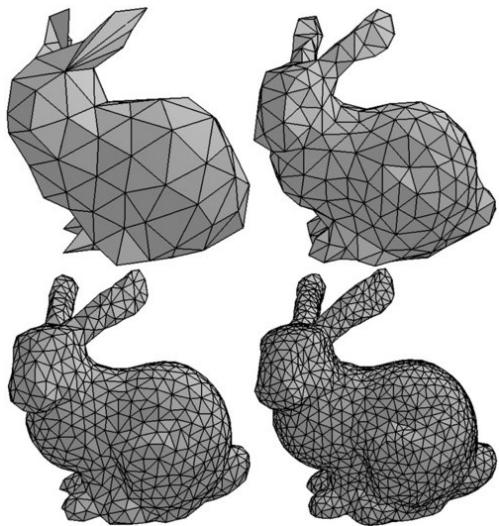


(c)



(d)

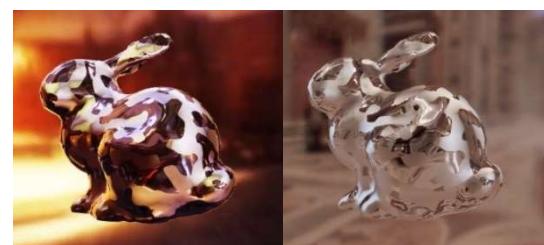
计算机图形学： 仿真计算创建虚拟数字化的平行世界



建模（设计）
Modeling



动画（仿真）
Animation



渲染（绘制）
Rendering

仿几何之真

仿运动之真

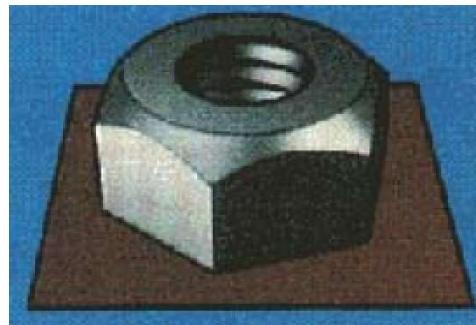
仿色彩之真

刘利刚：《计算机图形学》（2020）本科课程（含课件、录频、编程作业）

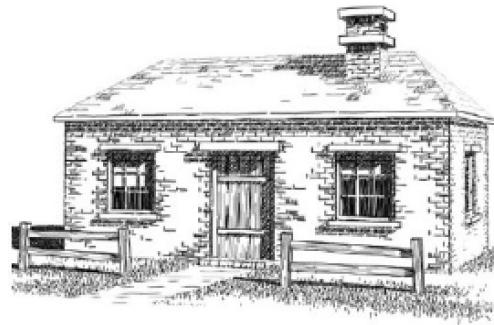
http://staff.ustc.edu.cn/~lglui/Courses/ComputerGraphics_2020_spring-summer/default.htm

5. 非真实感渲染

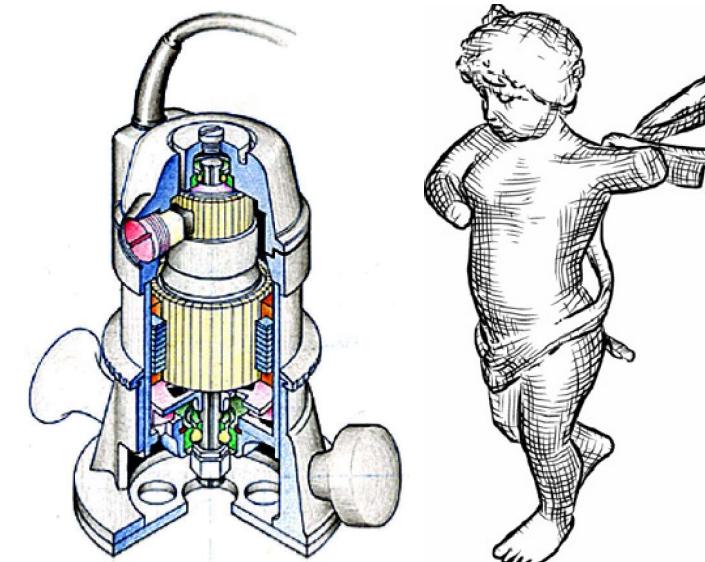
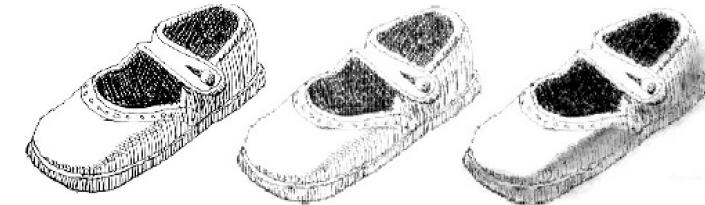
Non-Photorealistic Rendering (NPR)



Technical Illustration



Pen and Ink



Water Color



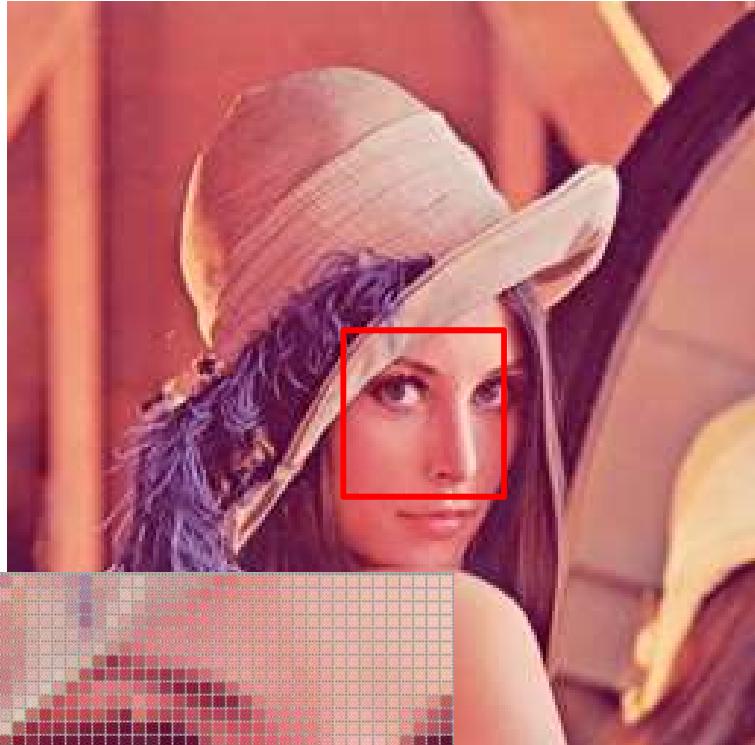
Oil Painting



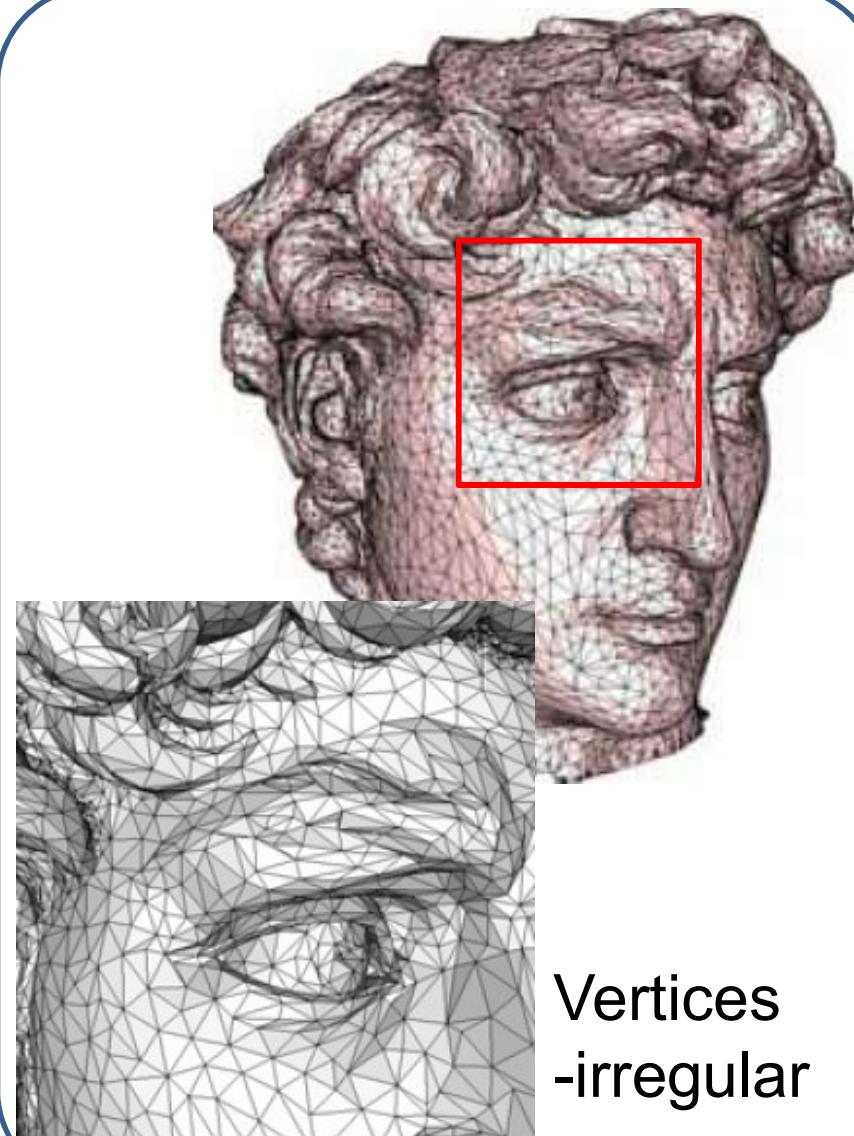
Video: Image Sequence



2D Image vs. 3D Geometry



Pixels
-regular

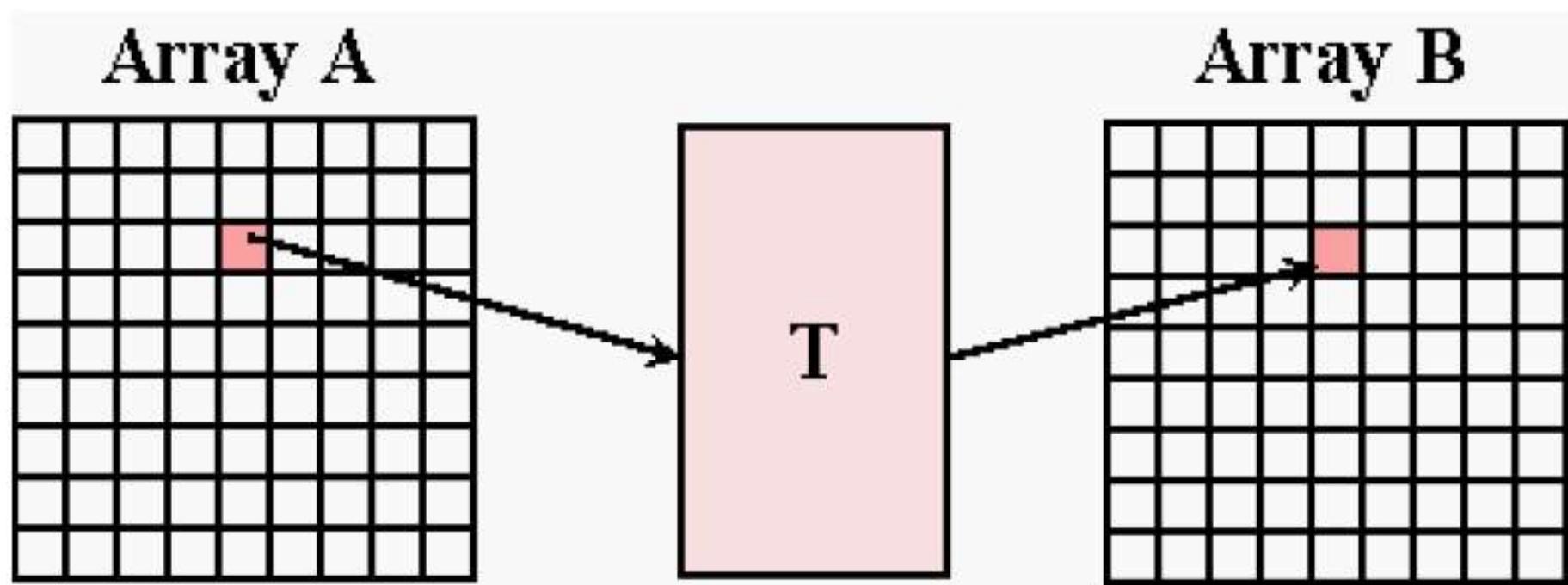


Vertices
-irregular

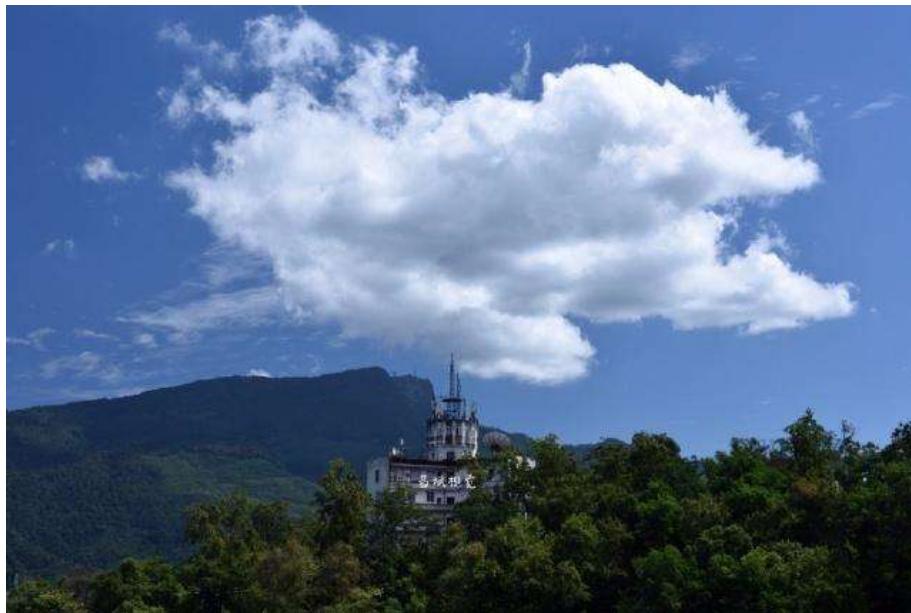
数字图像处理

图像处理：计算（变换）

$$B[x, y] = T[A[x, y]]$$



例子： 拍摄的照片



单反相机



手机

不同手机



手机的不同型号



nova 5i



荣耀 9X



荣耀 V9



坚果 3

百家号/智趣科技官方

手机的不同型号



nova 5i



荣耀 9X



荣耀 V9



坚果 3

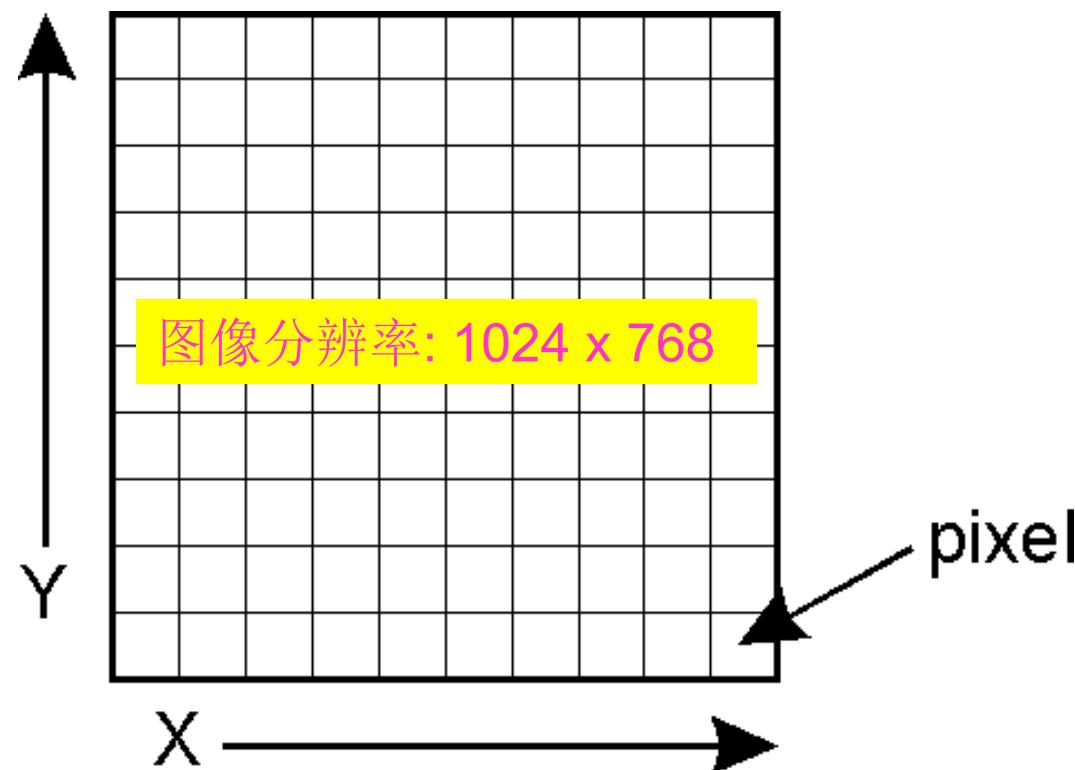
百家号/智趣科技官方

影响拍摄照片的因素

- 感光元件
- 制作工艺
- 算法处理
- ...
- “照骗” 永远是虚假的反应

图像处理的关键：数学模型

- 图像的直观离散数学模型



无处不在的图像应用



Everything

Images

Videos

News

Shopping

More

Sort by relevance

Sort by subject

Any size

Large

Medium

Icon

Larger than...

Exactly...

Any color

Full color

Black and white



风景

Search

SafeSearch

Advanced search

About 4,400,000 results (0.20 seconds)



Internet上的海量图像



数字图像处理无处不在

- 数码相机、手机
- 个人电子相册
- Photoshop处理



人们对图像的处理要求日益增多

例1：图像变形

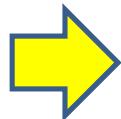
图像变形

- 特定效果的变形



图像变形

- 特定效果的变形

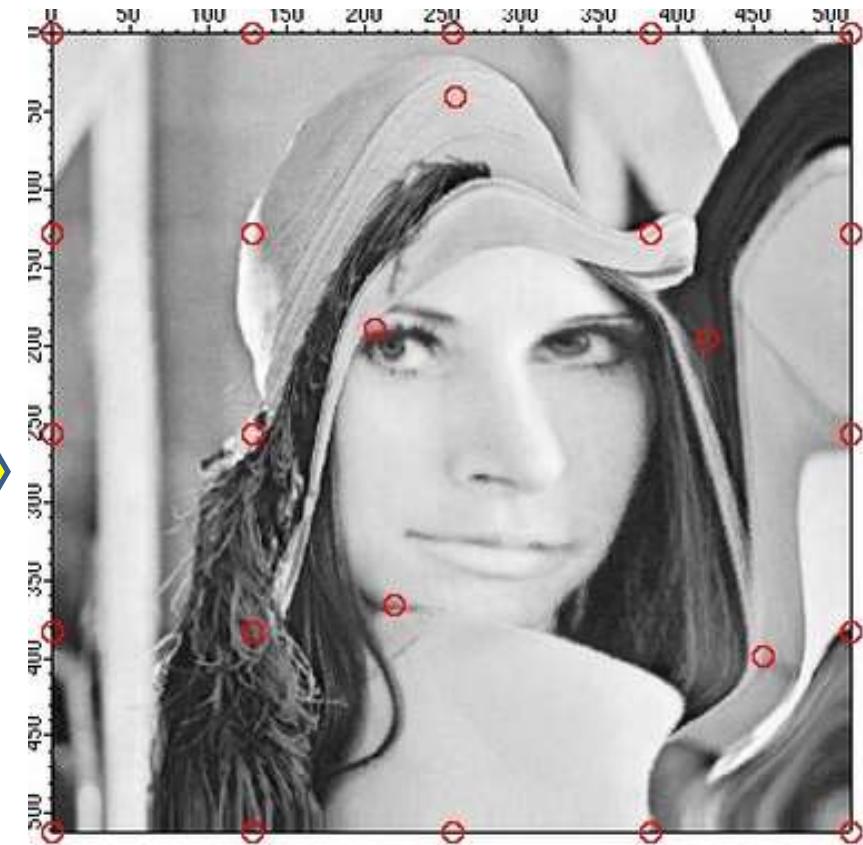
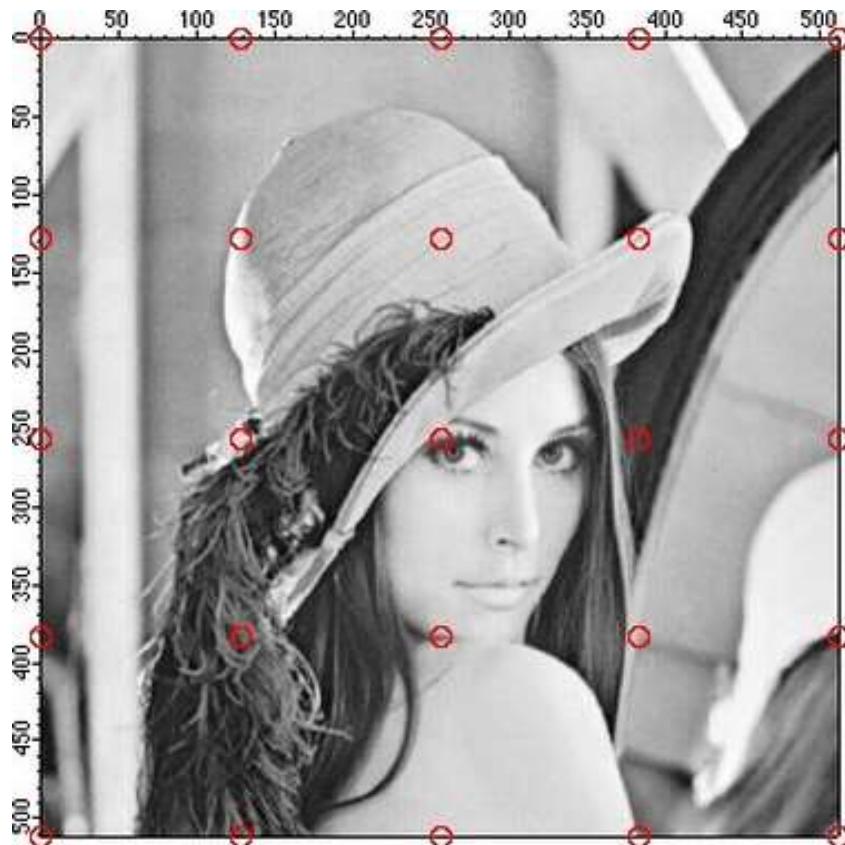


用户交互



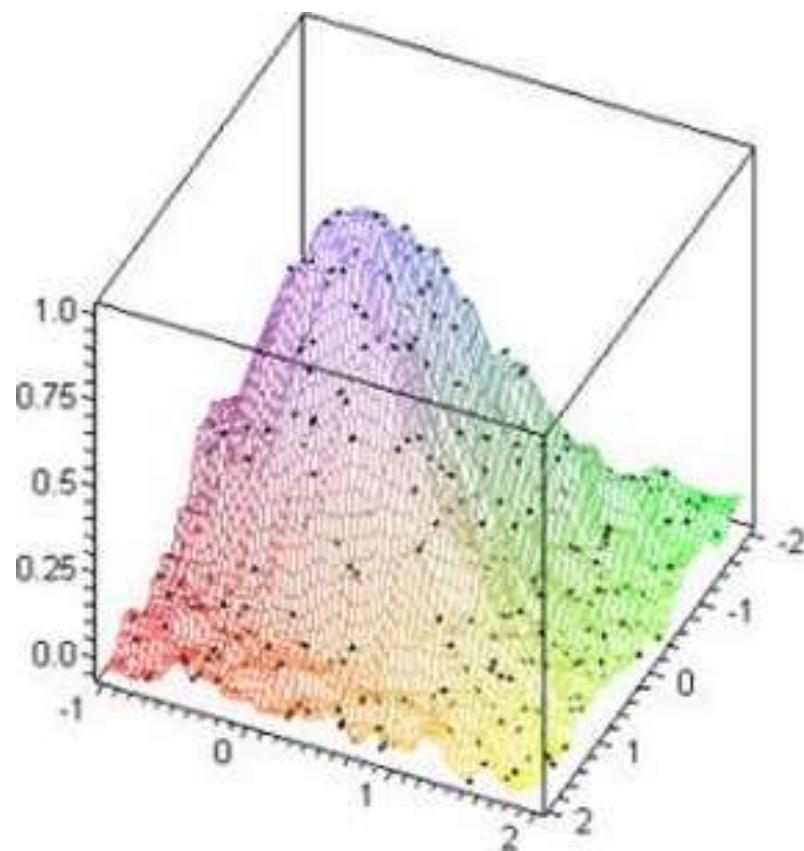
[Demo](#)

如何做到的？



数学原理

- 散乱点插值



例2：扣图

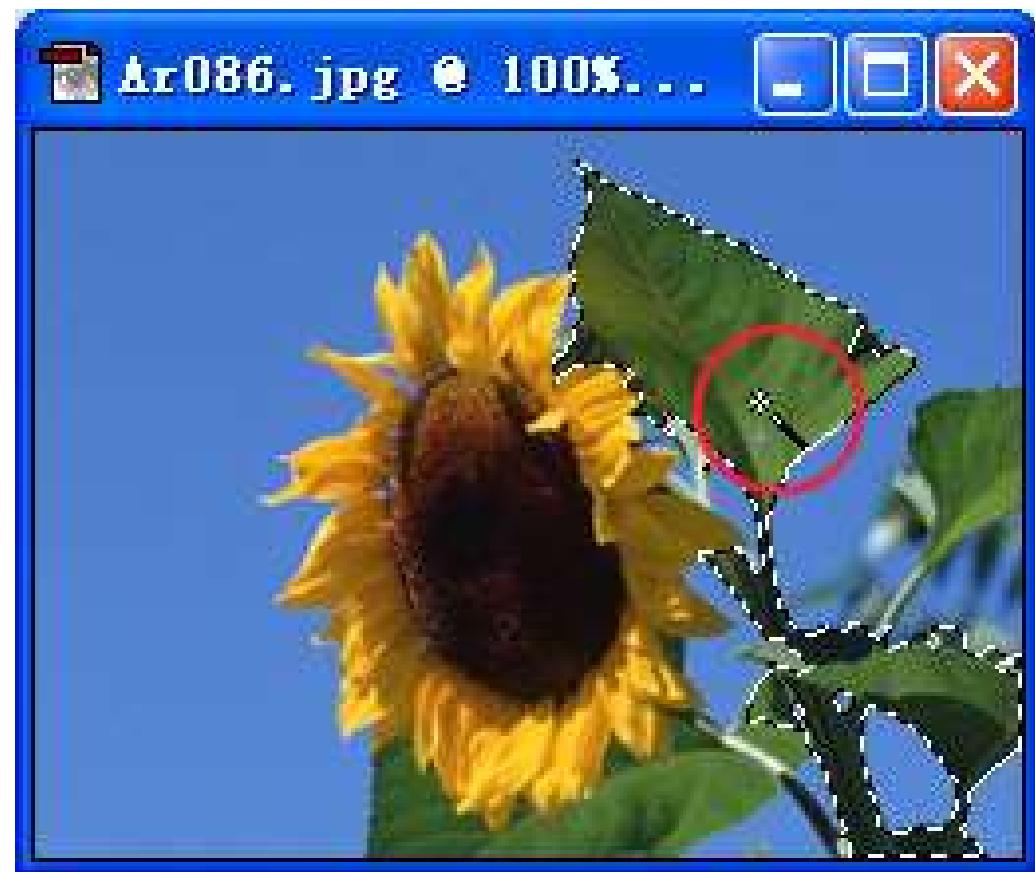
扣图

- 将物体从图像中分割出来



扣图

- Photoshop的工具：魔术棒
 - 用户交互指定边界
 - 繁琐，费时



扣图

- 智能做法：用户随意指定物体的大致内容



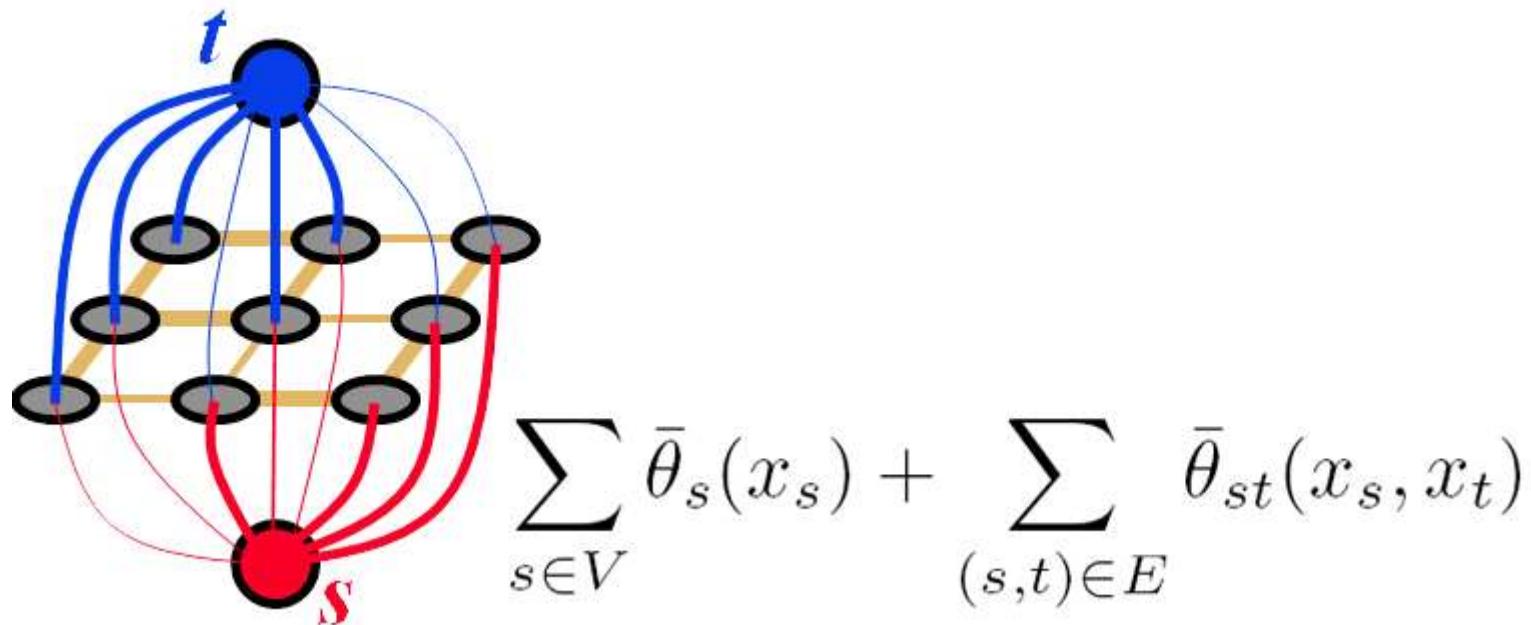
[Demo](#)

如何做到的？



数学原理

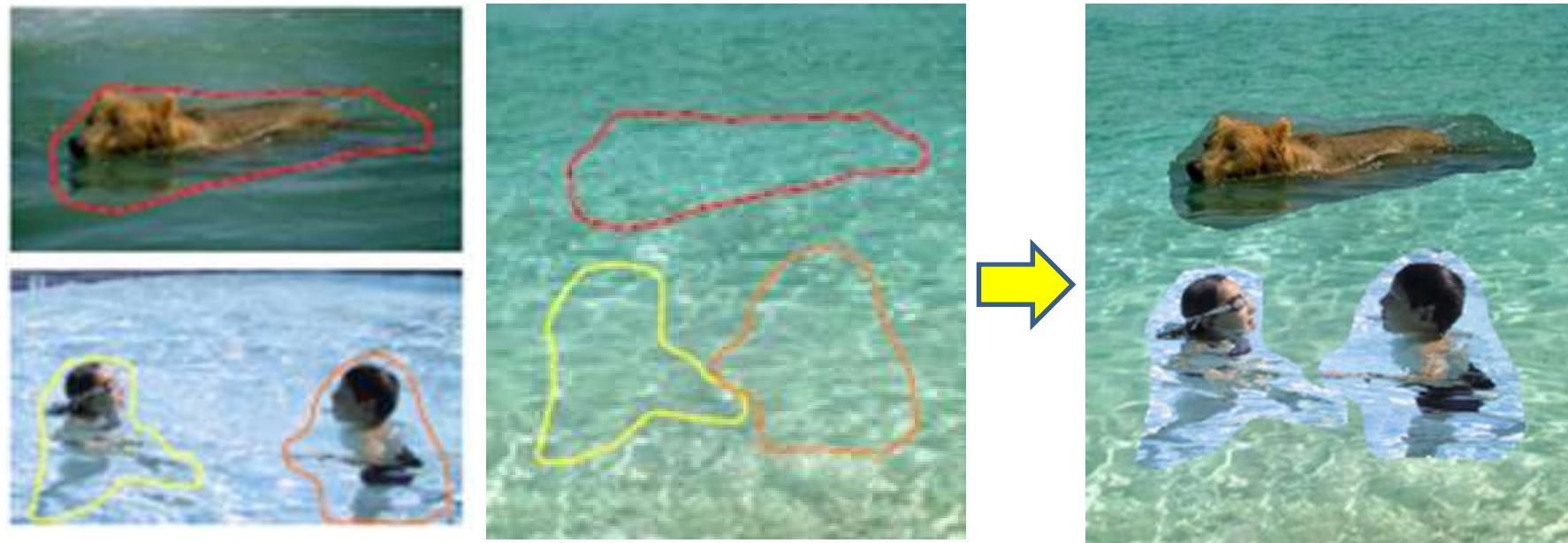
- 图论：图割方法
- 最大流最小割算法



例3：图像移植

图像移植

- 能否做到无缝移植？



[Demo](#)

如何做到的？



cloning



seamless cloning

sources/destinations

数学原理

泊松(Poisson)方程

$$\Delta\Phi = -\rho(x, y)$$

$$\Delta \equiv \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$$

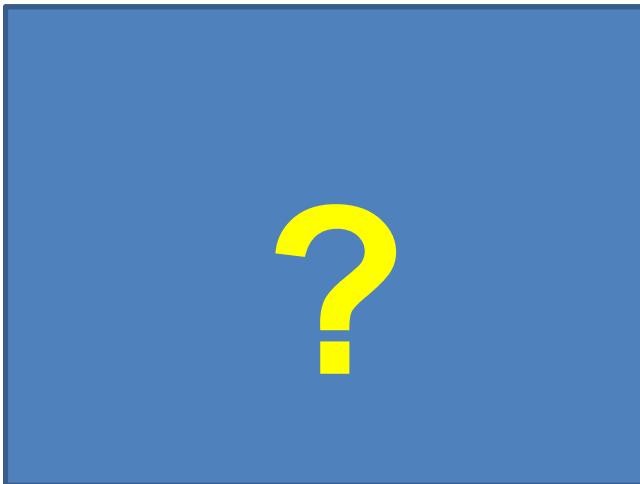


背后的原理是什么？

数学！ 数学！！ 数学！！！

其他各种应用

Color Transfer



Color2Grey



Color



Method 1



Method 2

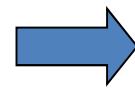
Colorization



Color Harmonization

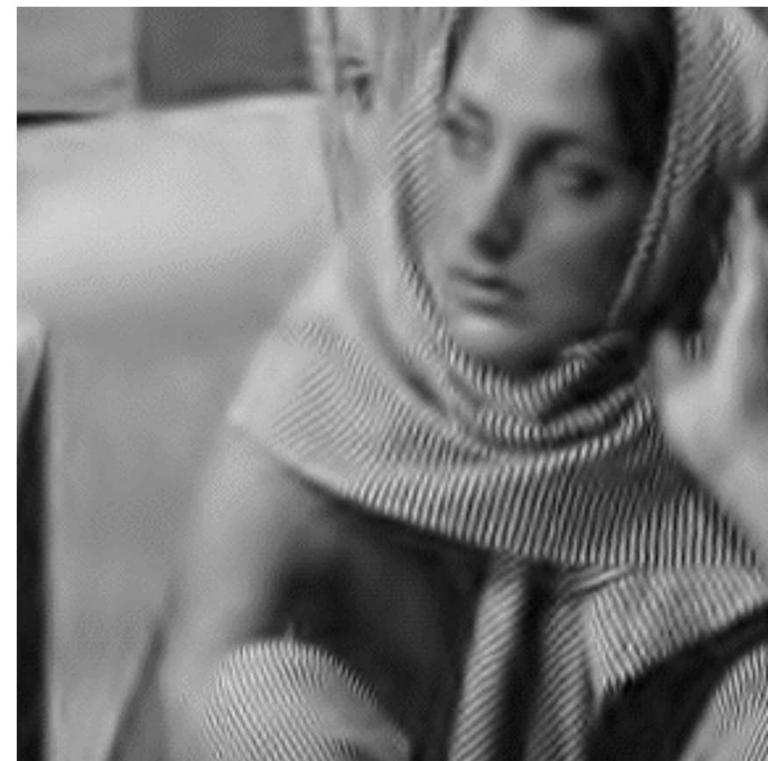


original image



harmonized image

Denoising



Deblurring

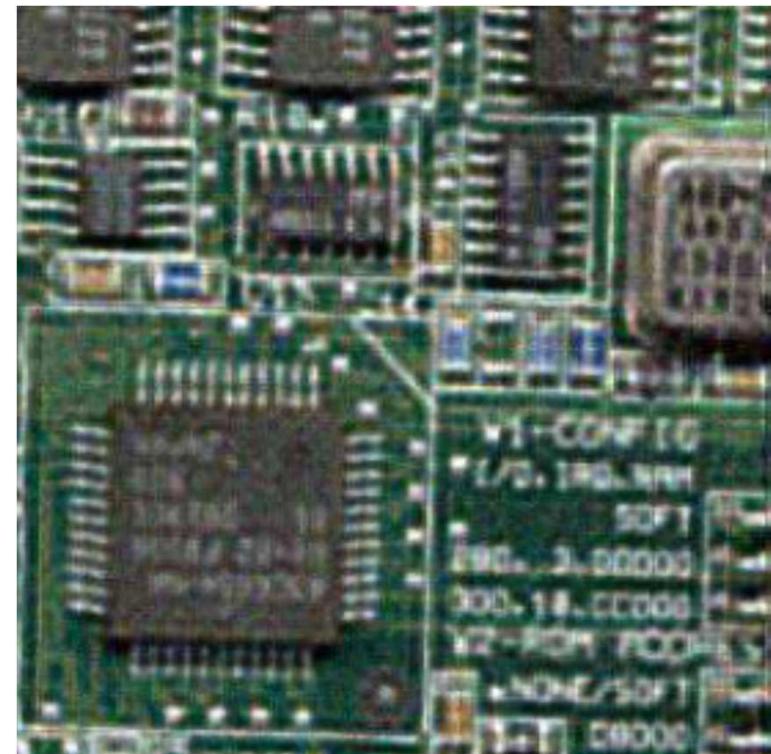
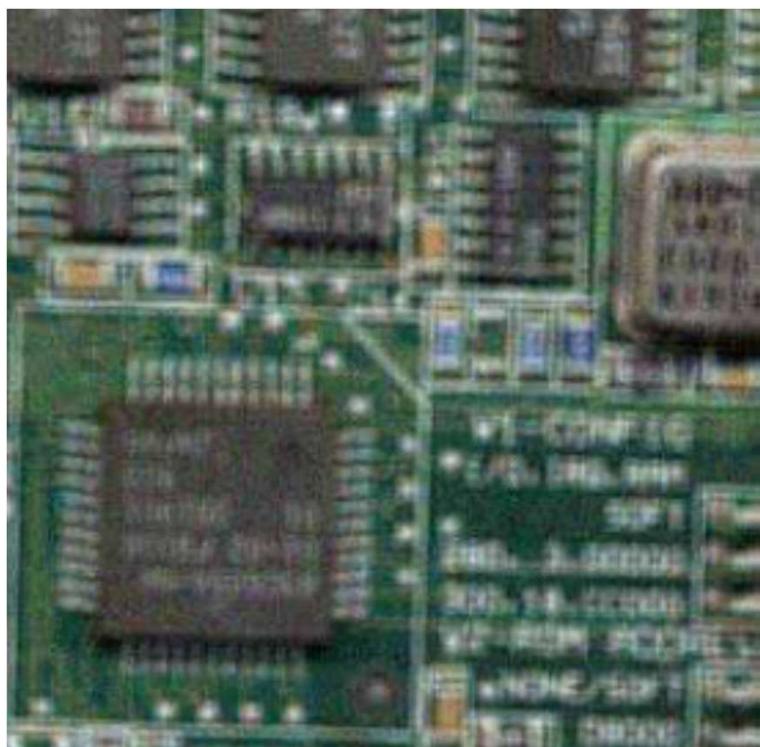
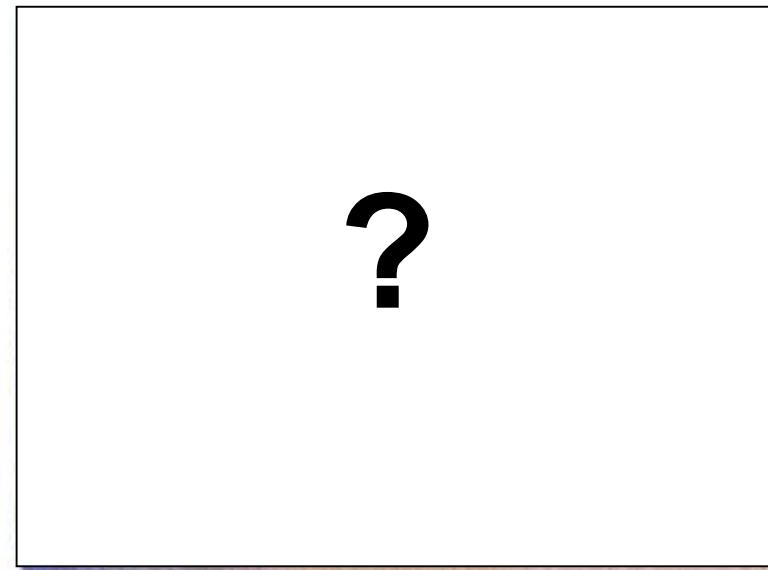
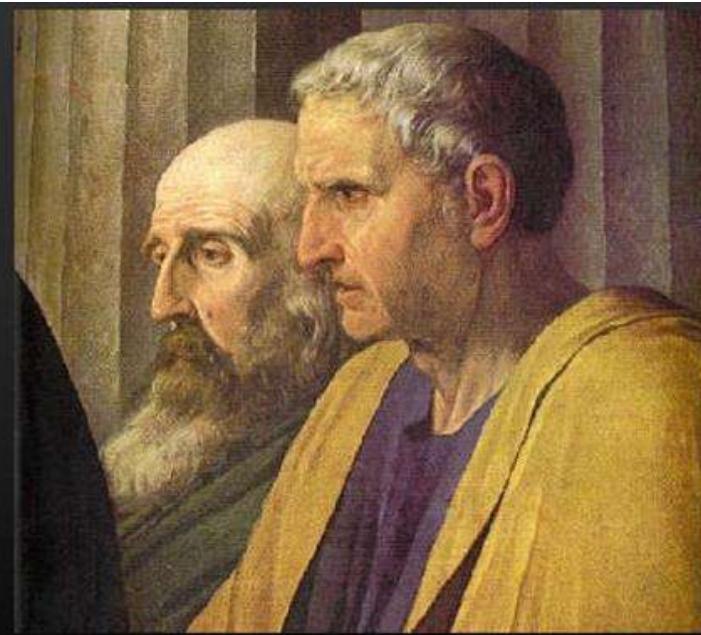
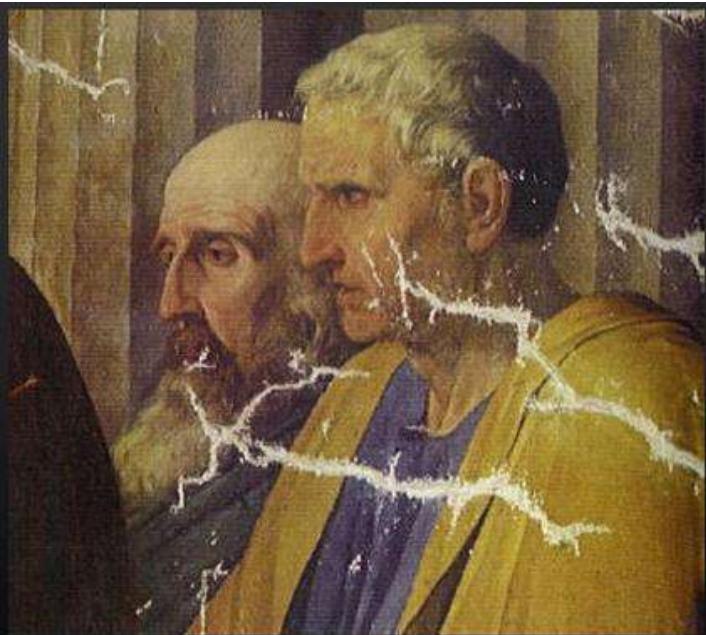
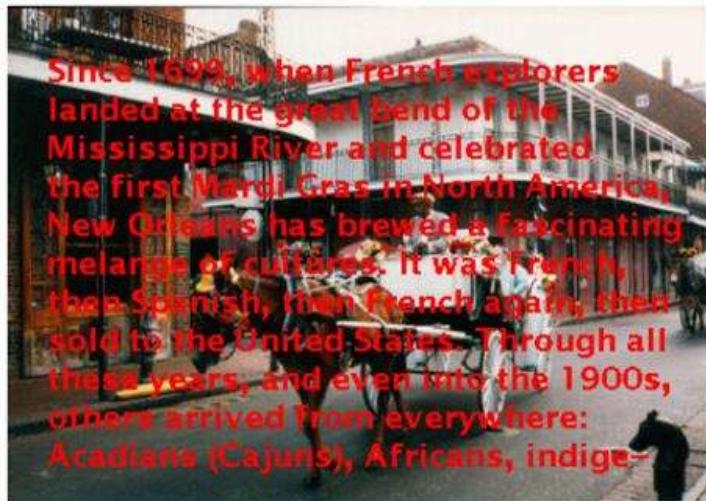


Image Analogies



Inpainting



Object Removal

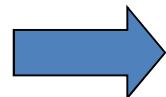


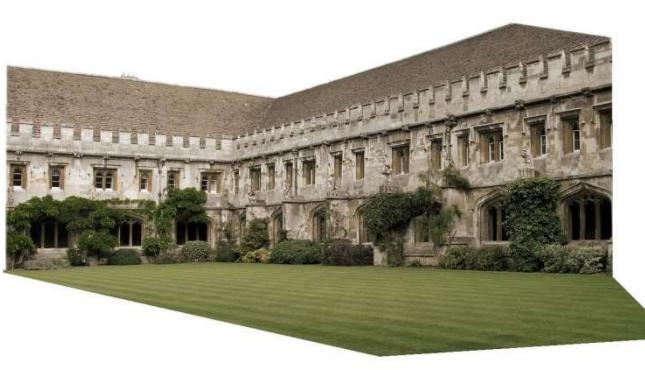
Image Morphing



Matting



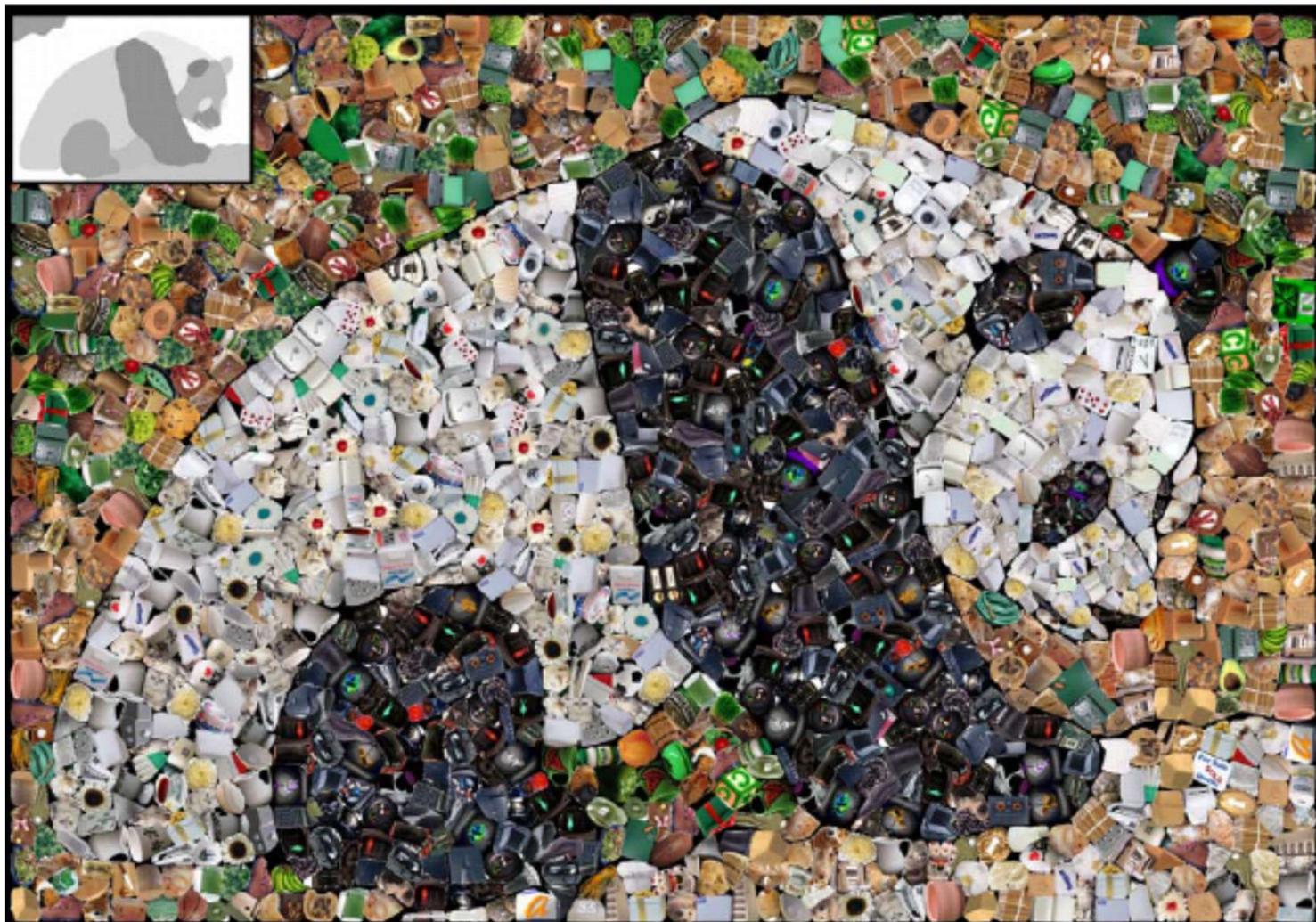
Tour Into Picture



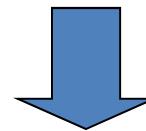
Input

Output

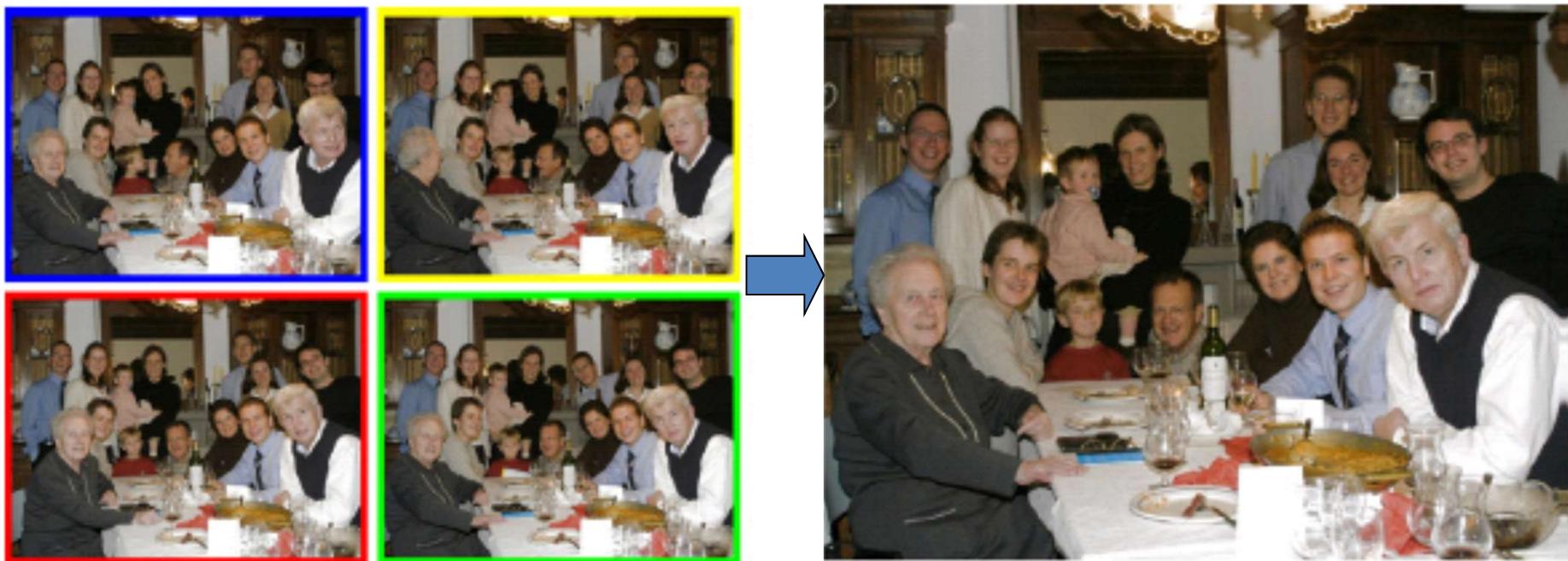
Mosaic



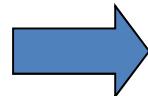
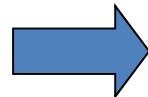
Panorama



Photomontage



Shake Removing



Exposure Synthesis



exposure time = 1/1000s



exposure time = 1/100s

input image



output image

Flash Synthesis

Ambient



Flash



Result





No-flash

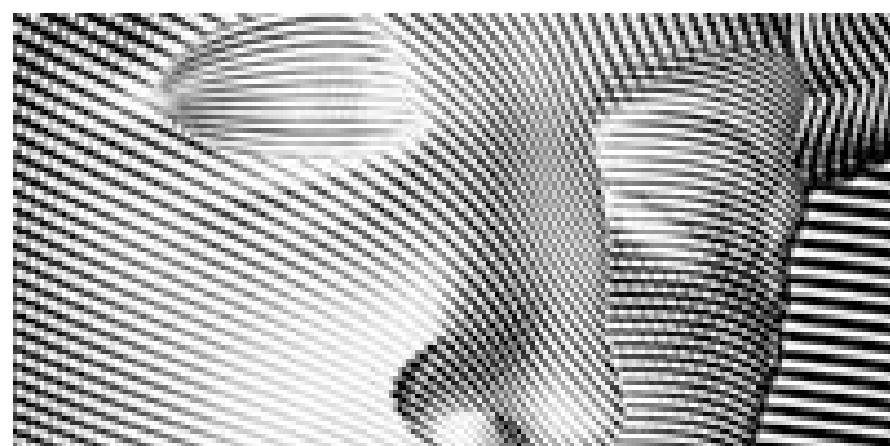
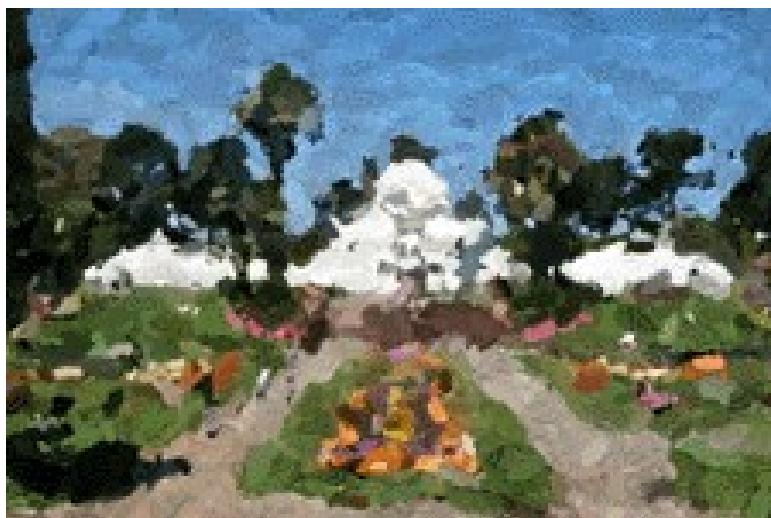
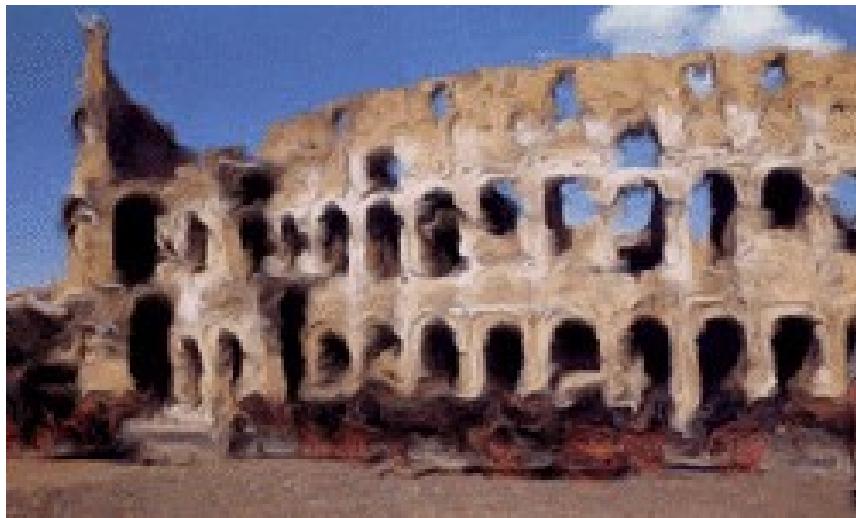


Flash

Photo Collage



Nonphotorealistic Rendering (NPR)

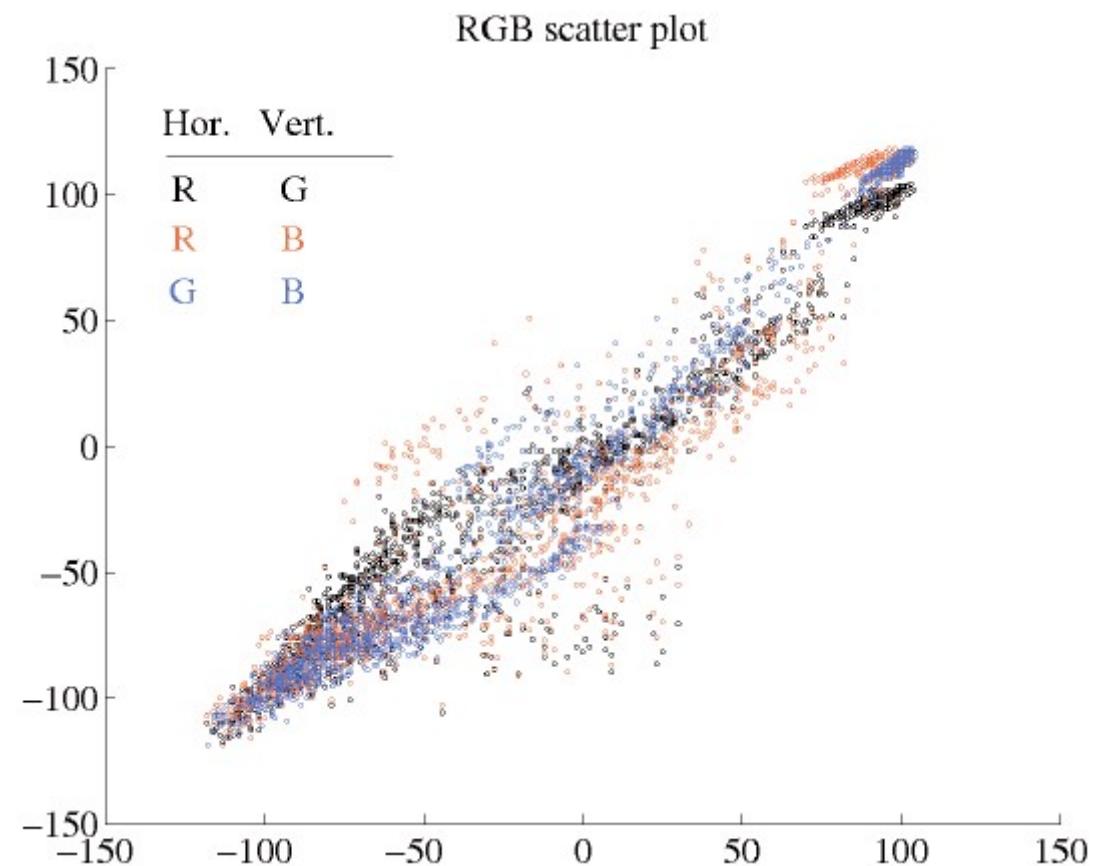


More...

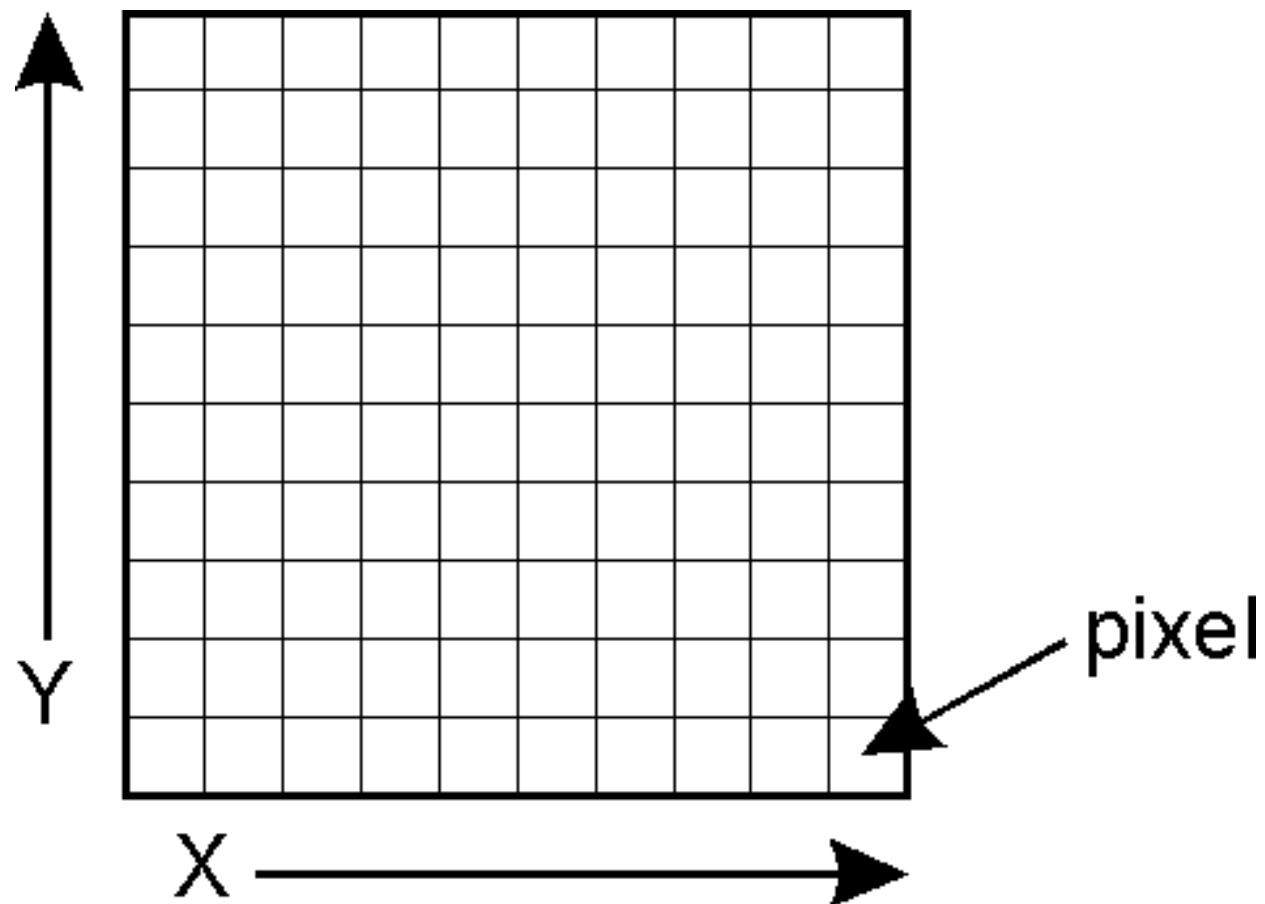
- Image compression
- Image retrieval
- Image registration
- Image based modeling
- Segmentation
- Object recognition
- Image understanding
- ...

图像的不同 数学模型及处理方法

1. 图像是一个点集(point cloud)



2. 图像是一个矩阵(matrix)



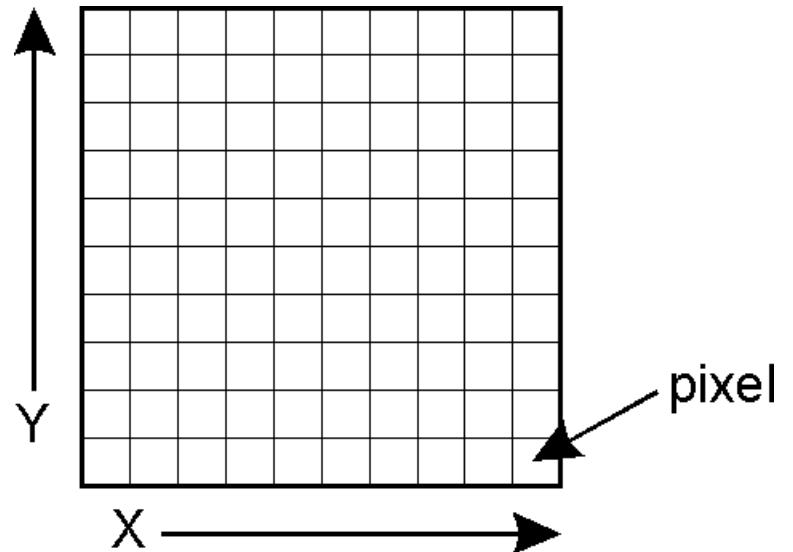
3. 图像是一个函数(function)

- 2D区域上的向量值函数

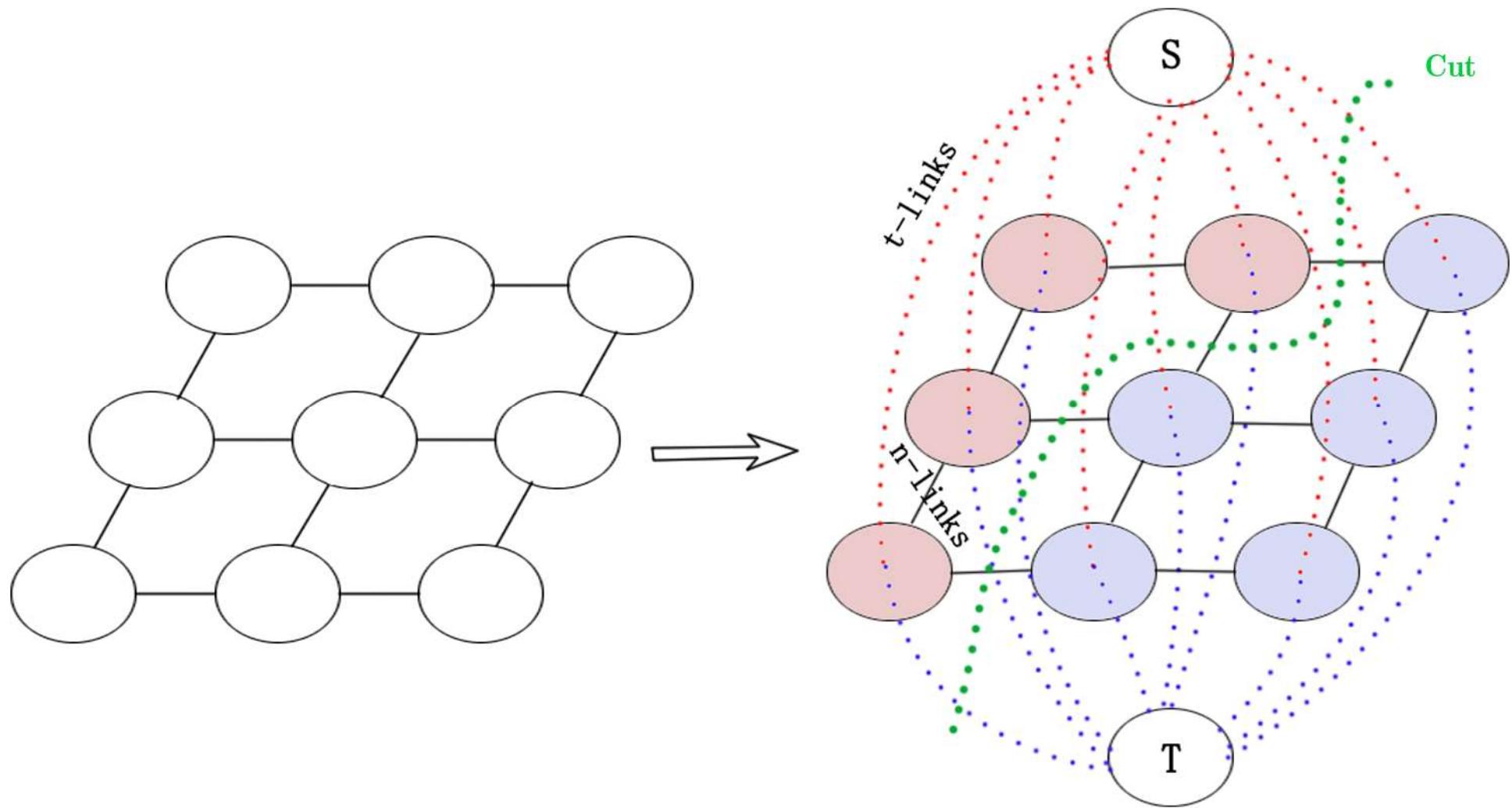
$$I = I(x, y)$$

Discrete sampling

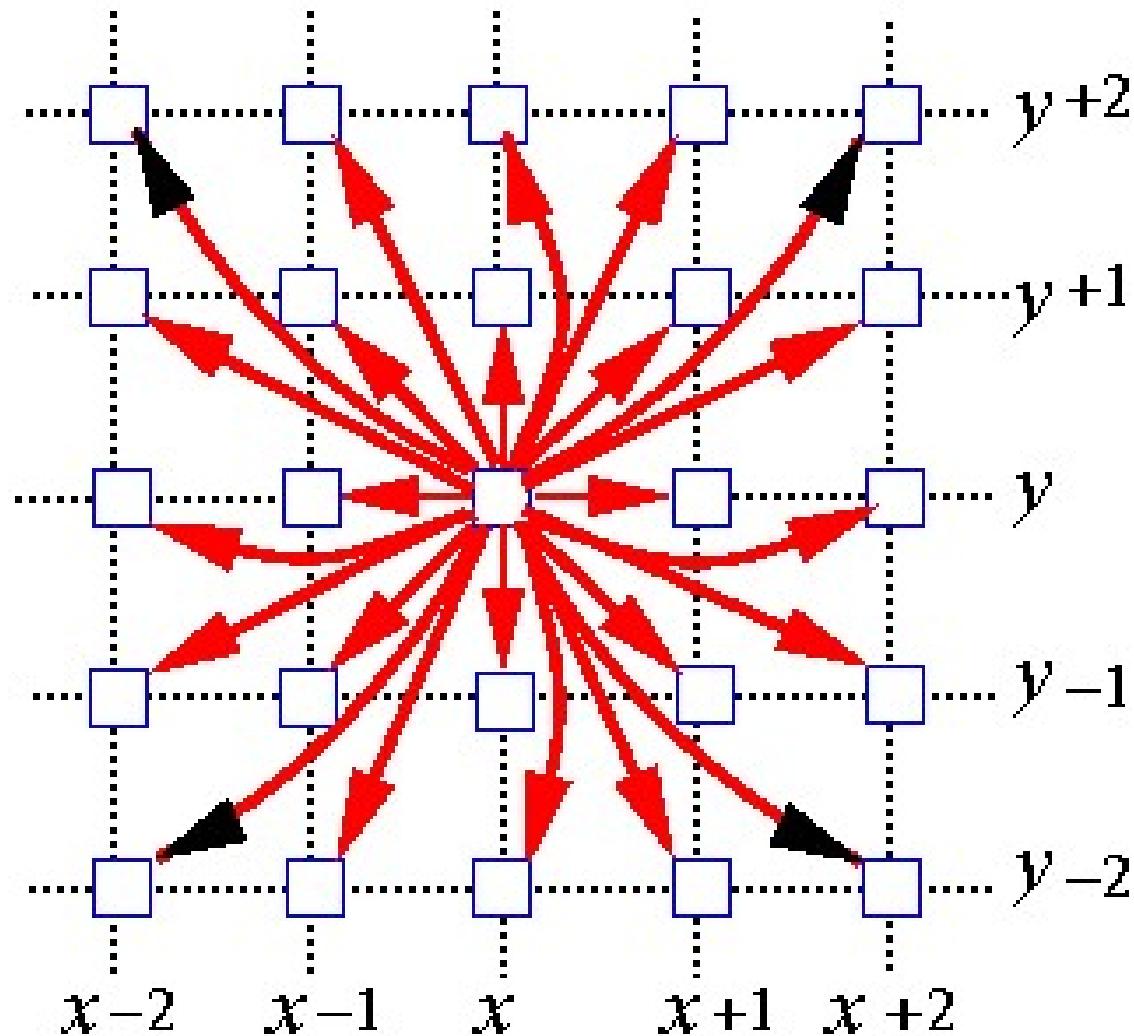
$$I = f(i, j)$$



4. 图像是一个图(Graph)

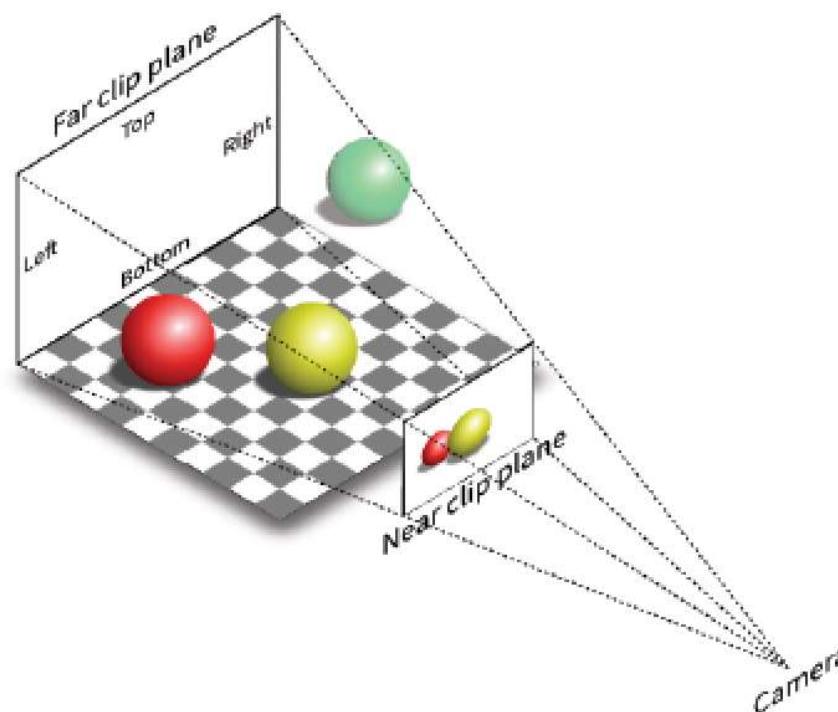


5. 图像是一个马尔可夫随机场 (Markov Random Field)

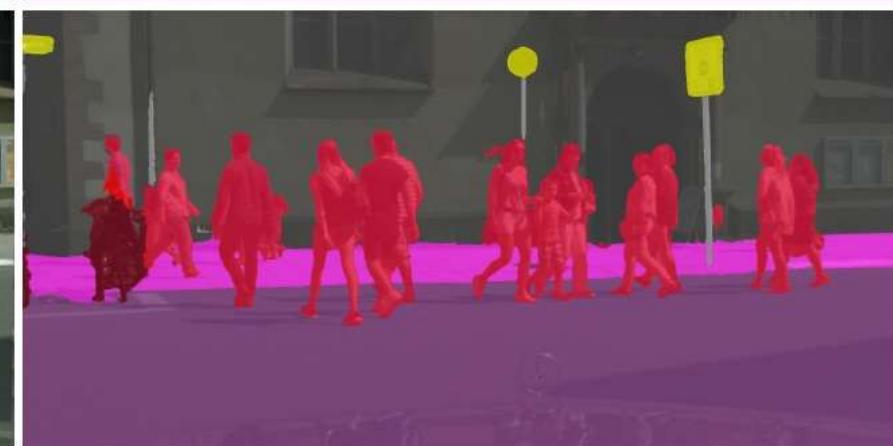


6. 图像是3D场景的投影

- 几何驱动的图像处理
- 可微渲染/逆向渲染



7. 图像是是一些语义物体的集合



从其他视角看图像？

Image Programming

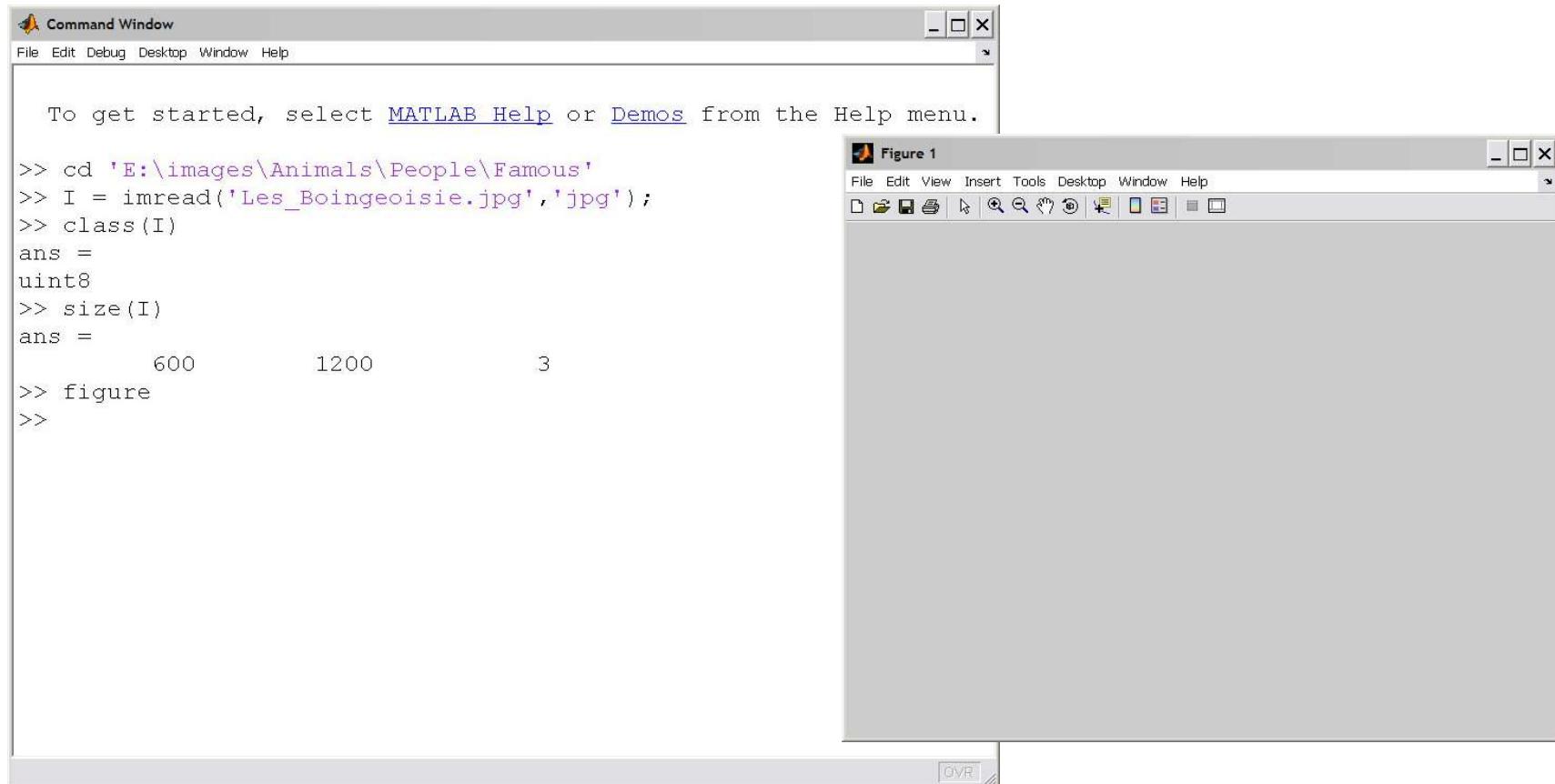
图像的数据结构

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

图像编程

- C/C++
- QT
- OpenCV (Open Computer Vision)
- Matlab
- Matlab与C++混合编程

Read a Truecolor Image into Matlab



Read a Truecolor Image into Matlab

To get started, select MATLAB Help or Demos from the Help menu.

```
>> cd 'E:\images\Animals\People\Famous'  
>> I = imread('Les_Boingeoisie.jpg','jpg');  
>> class(I)  
ans =  
uint8  
>> size(I)  
ans =  
      600       1200         3  
>> figure  
>> image(I)  
>> title('Les Boingeoisie: The Boing-Boing Bloggers')  
>> xlabel('Photo: Bart Nagel, 2006, www.bartnagel.com')  
>>
```

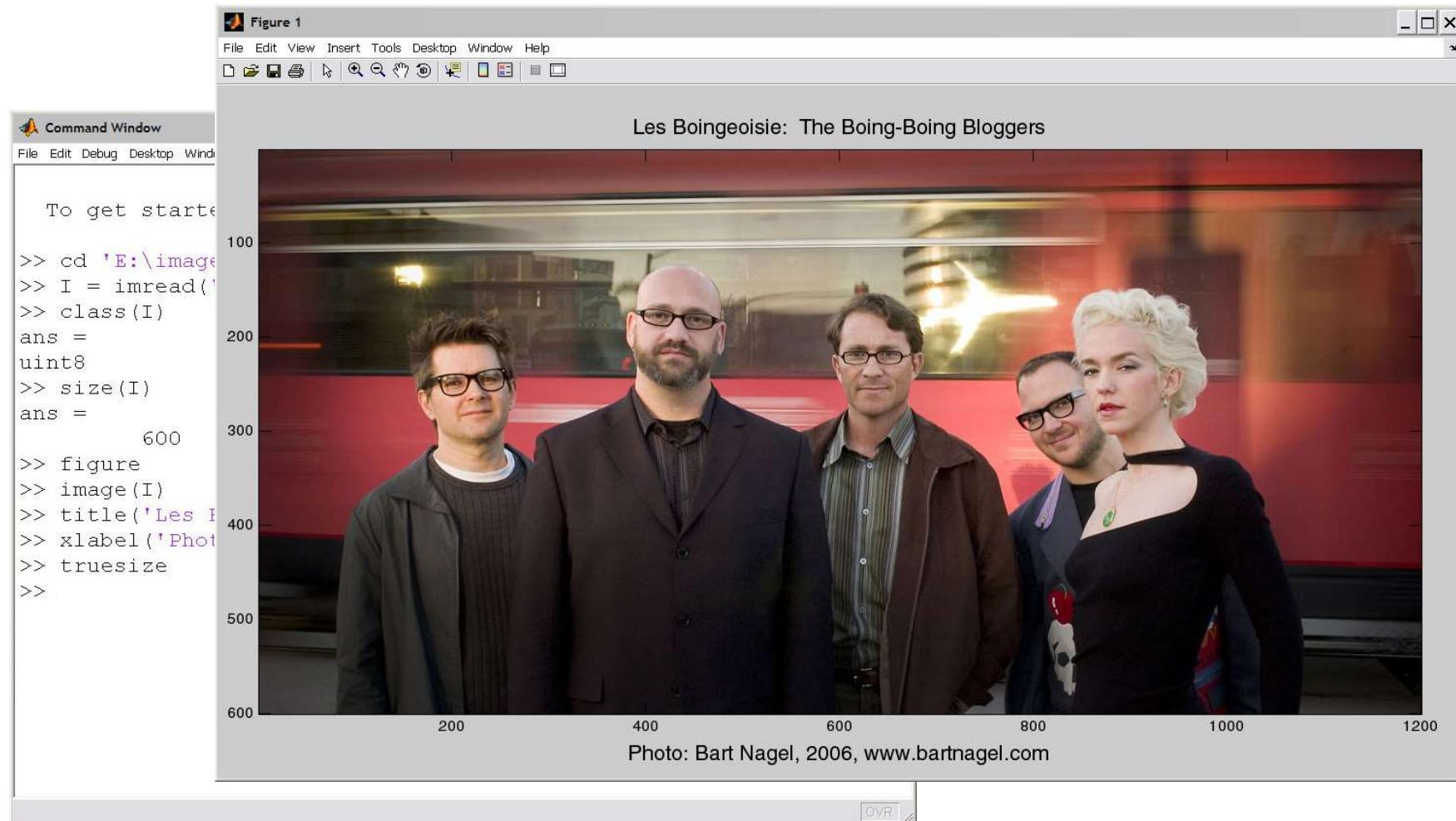
Figure 1

File Edit View Insert Tools Desktop Window Help

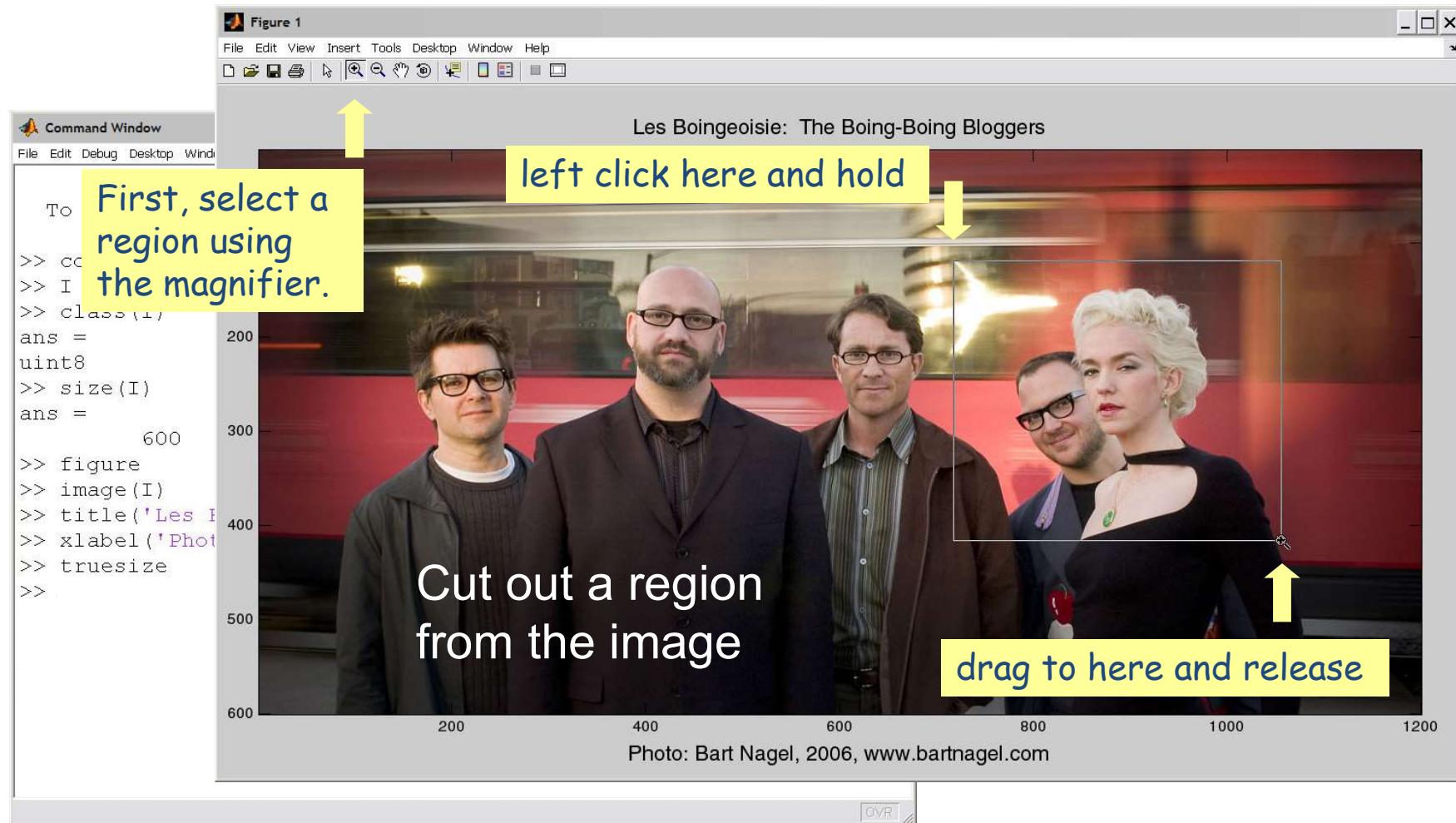
Les Boingeoisie: The Boing-Boing Bloggers

Photo: Bart Nagel, 2006, www.bartnagel.com

Read a Truecolor Image into Matlab



Crop the Image



课程信息与要求

课程主页

http://staff.ustc.edu.cn/~lqliu/Courses/DIP_2021_autumn-winter/default.htm

Prof. Dr. Ligang Liu (刘利刚)



Graphics&Geometric Computing Laboratory
School of Mathematical Sciences
University of Science and Technology of China
Hefei 230026, China

Phone/Fax: +86-551-63600985
Email: lqliu@ustc.edu.cn

通讯地址: 安徽省合肥市金寨路96号中国科技大学数学学院
邮政编码: 230026
办公室: 中科大东区管理科研楼1217室



[Short Bio](#) [Research](#) [Publications](#) [Professionals](#) [Teaching](#) [Resources](#)



- Digital Image Processing (数字图像处理), Graduates, MA0516701
 - Autumn-Winter, 2015
 - Autumn-Winter, 2021

在本课中，你能学到：

- 数字图像处理的基本内容与进展
- 图像处理的数学建模思维和方法
 - 数学建模
 - 实现算法
 - 阅读英文文献
 - 科研的初步方法：从数学建模到算法实现

预备知识：数学

- 线性代数
- 解析几何
- 微积分
- 数值方法与计算
- 最优化
- ...

还没有学没有关系：数学在使用的过程中中学得更快，能更深刻地深刻理解和掌握

数学不是没有用，而是不够用！

预备知识： 编程

- C/C++
- Python
- Matlab
- 各种专业应用软件
 - Photoshop...

工欲善其事必先利其器

教材： 没有教材！ 参考为主

- R. Gonzalez, R. Woods. Digital Image Processing. 2002.
- R. Gonzalez, R. Woods, S. Eddins. Digital Image Processing Using MATLAB. 2009.
- G. Sapiro. Geometric Partial Differential Equations and Image Analysis. 2006.
- T. Chan, J. Shen. Image Processing and Analysis: Variational, PDE, Wavelet, and Stochastic Methods. 2005.
-
- Various journal papers, conference papers, or WWW materials as appropriate.

课程作业和考试

- 平时程序作业: 70%
- 期末大程序作业: 30%

程序作业递交

- 作业递交是通过SmartChair投稿软件系统来完成，链接为：
 - <http://www.smartchair.cn/DIP2021>
 - 主页上有详细的使用说明
- 递交内容：
 - 作业报告（PDF格式），不需要提交代码
- 文件命名规则：**姓名_Homework1.pdf**
 - 比如：“张三_Homework1.pdf”
- 如文件大小超过**30M**无法上传，可以上传一个简单PDF，在其中给出文件的下载路径
 - 建议使用校内的睿客网rec.ustc.edu.cn，速度很快

作业要求 (1)

- 代码编写
 - 高质量代码
 - 符合一定的规范
 - 代码清晰
 - 尽量多的注释
 - 部分代码可以来源于网上
 - 站在巨人的肩膀上

作业要求 (2)

- 作业报告：类论文
 - 程序使用的简单说明，可截图说明
 - 明确的输入和输出
 - 测试结果和分析、小结等
 - 若是合作项目，需说明具体分工
 - 报告需规范
 - 在报告中说明所参考的来源
 - 网站、书籍
 - 致谢他人

作业要求 (3)

- 通过SmartChair系统来递交作业，不接受email递交作业
 - 严格按照规则命名
- 必须在规定的最后期限之前递交
- 超过最后期限系统将自动不再接受作业

作业要求 (4)

- 独立完成
- 相互帮助
- 团队合作
- 绝不允许抄袭！

上课及作业提交时间

- 每周二19:00-21:40
 - 周四无课
- 作业提交时间
 - 周日晚

Some Words for Graduates

Survive Graduate School

You do not have to be a "star" to survive graduate school, but you need to be well informed.

- Your motivation
- Who and what are available to help you?
- Your supervisor
- Some simple pointers about research

Your Motivation

- You goals
 - Diploma? ☹
 - Improve yourself? ☺
- Various abilities: **Do Things Right!**
 - Thinking
 - Writing
 - Communicating
 - Coding
 - ...

My Good Students

- Good attitudes
 - Enthusiasm and passion
- Good mathematics
 - Analyzing the problem professionally
- Good coding ability
 - Implementing what you have in mind

Who and what are available to help you?

You do not have to be a "star" to survive graduate school, but you need to be well informed.

- Supervisor
- Our vast research and teaching expertise
- Your fellow students
- Our lab, library, and on-line resources

How to become informed?

- Group seminar and other seminars
- Academic talks and reports
- Web pages of our faculty and research labs
- Library, on-line digital libraries, google, citeseers, etc.
- ...

Getting the most out of your supervisor?

- Meet regularly - at least once every other week
- Prepare for your meetings and email him/her a brief summary after every meeting
- Keep good records of major milestones
- Show your results as soon as possible
- Don't be afraid to disagree or ask the "silly" questions
- Take the initiative - don't always wait for orders
- Be active and productive

Simple pointers about research (1)

- Be organized
 - Make a journal of your research ideas
 - Set deadlines for yourself
 - Always know where you are
 - Keep your priorities straight and don't go off on a tangent
- Make realistic goals
 - Conquer one problem at a time
 - Publish your work and don't be afraid to say "future work"

Simple pointers about research (2)

- Confront your fears and weakness
 - Find every chance possible to strengthen your math
 - Talk about your research in public whenever you can
 - Practice writing up your work early
- Balance reading, thinking, writing, and coding
- Confidence in yourself, in your supervisor, and in your chosen topic - perseverance more likely to pay off than flip-flopping

Learn more...

- Learn from others
- Writing
- English
- Build up your network - make friends with your peers
- Have a lot of fun!

一个中心点

- 与你的导师、合作伙伴形成有效的沟通和
互动！
 - 积极思考，提出问题
 - 经常自我总结，写记录文档
 - 主动汇报进展
 - 得到导师的反馈后尽快处理并回复
 - “不要在沉默中死去...”

好的例子和不好的例子

两个基本点(Fortune Magazine)

- 激情
 - You don't run out of gas when you're enjoying what you're doing. The gas goes into the tank faster than it comes out.
 - Warren Buffet, July 8, 2002
- 专注
 - Only through focus can you do world-class things, no matter how capable you are.
 - Bill Gates, July 8, 2002

Enjoy Research and Your Life!

- *Make every day count*
- *Double-wins for everything as possible*



“每天早晨醒来，一想到所从事的工作和所开发的技术将会给人类生活带来的巨大影响和变化，我就会无比兴奋和激动！”

– Bill Gates

Thanks!