计算机视觉
Computer Vision

Lecture 1: Introduction

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主要内容

一、课程安排
二、关于计算机视觉
三、计算机视觉研究历史
四、计算机视觉研究主要内容
五、计算机视觉的应用

一、课程安排

- 课程目标
- 预修课程
- 课程主要内容
- 任课教师及助教
- 教材
- 参考书
- Web 链接
- 期刊
- 会议文集

课程目标

- **Provides introductory of principles, techniques, and algorithms to solve problems in computer vision.**
- **Topics cover fundamental vision issues as well as the latest results from the field.**
- **Offers opportunities to explore applications of computer vision techniques in solving real world problems.**

预修课程

- 线性代数
- 概率与数理统计
- 数字信号处理和数字图像处理
- 编程： **MATLAB 或 C++**

课程的主要内容

- 图像的形成
- 图像特征检测和匹配
- 立体视觉
- 三维重建
- 运动分析与跟踪
- 图像分割
- 物体识别

任课教师及助教

- **Instructor:**
  - 张　超
  - **Office: Room S2211, No. 2 Science Building**
  - **Phone: 62757000**
  - **Email: chzhang@cis.pku.edu.cn**
- **TA:**
  - 韩 凯　**hankai@pku.edu.cn**
  - 李 超　**454012948@qq.com**
  - **Lab: Room S2207, No.2 Science Building**

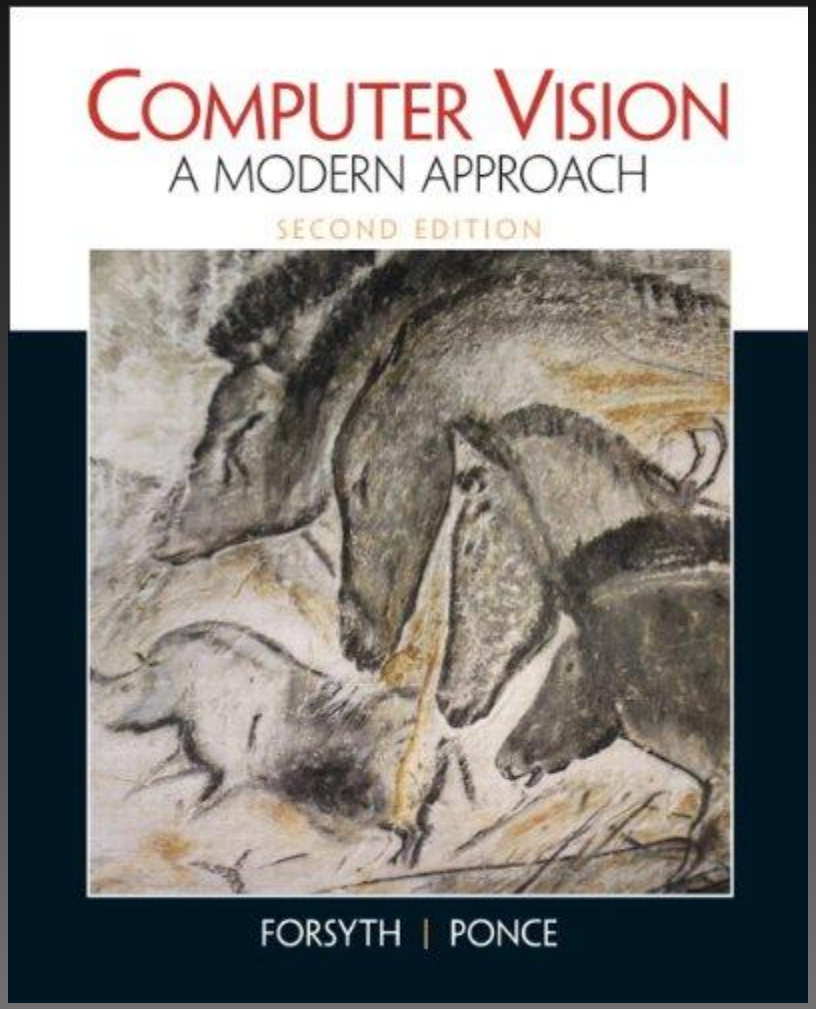
Course Information

- **Class Schedule:**
  - **Monday, 15:10-18:00 PM**
  - **421, No 2 Lecture Building**
- **Credits:**
  - **3**
- **Class website:**
  - 北大教学网

Course Information

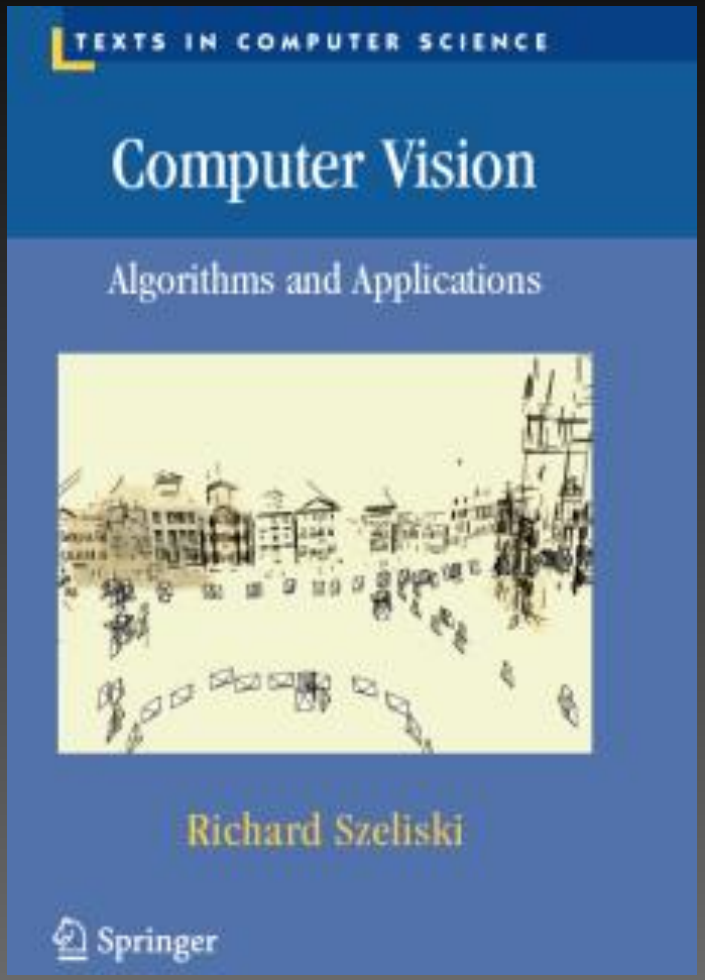
- **Grading:**
  - **48%: (6) written / programming assignments**
  - **12%: paper reading and demo**
  - **5%: Discussion and Attendance**
  - **35%: Final project**
- **Requirements**
  - **Individual work**
  - **Active participation in class discussions**
  - **Late policy: Zero tolerance without prior approval**

教材（必备）：



- ***“Computer Vision: A Modern Approach”*** (2nd Edition)
  By David Forsyth and Jean Ponce， Prentice Hall 2011
- 计算机视觉——一种现代方法(第二版)
  电子工业出版社 **2012**

教材:



- **Computer Vision: Algorithms and Applications**

  by Richard Szeliski， Springer; 2011

- 《计算机视觉：算法与应用》

艾海舟，兴军亮等译 清华大学出版社 **2012**

Online at: http://szeliski.org/Book/

教材:

- “*Multiple View Geometry in Computer Vision*”， **By Richard Hartley, Andrew Zisserman, Cambridge University Press, 2004.**

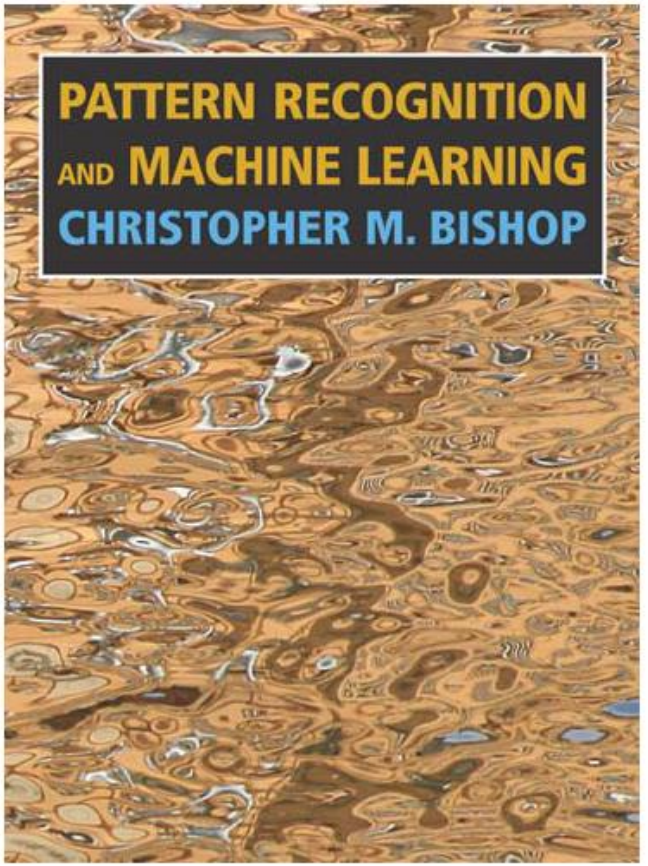
中译本:
《计算机视觉中的多视图几何》，
韦穗等译，安徽大学出版社，2002

教材

- **Pattern Recognition and Machine Learning**

Christopher Bishop, Springer, 2006.

- Excellent on classification and regression
- Quite advanced



参考书

- 《计算机视觉——计算理论与算法基础》
  马颂德，张正友著，科学出版社，1998
- 《计算机视觉—— 算法与系统原理》
  高文，陈熙霖著，清华大学出版社，广西科学技术出版社，1999
- 《机器视觉》
  贾云得 编著，科学出版社，2002

参考书

- " *Vision* ", by D. Marr, W. H. Freeman and Company, 1982.
  中译本：《视觉计算理论》，姚国正，刘磊，汪云九译，科学出版社，1988
- *"Computer Vision"*, by Dana H. Ballard and Christopher M. Brown, Prentice Hall, 1982.
  中译本：《计算机视觉》，王东泉等译，科学出版社，1987
- *"Robot Vision" by B. K. P. Horn, MIT Press, 1985.*
  中译本：《机器视觉》，王亮，蒋欣兰 译，中国青年出版社，2014
- " *Three Dimensional Computer Vision: A Geometric Viewpoint* ", By O. D. Faugeras, MIT Press, 1993
- " *Vision Science: Photons to Phenomenology* ", By Palmer, S.E. MIT Press. Cambridge, MA. 1999
- " *Computer Vision* ", By L. Shapiro and G. Stockman, Prentice Hall, 2001
- "*Image Processing, Analysis, and Machine Vision*" by Sonka, Hlavac, and Boyle, 2nd Edition, PWS publishing, 1998. 人民邮电出版社 2002影印版
  中文版：图像处理、分析与机器视觉》（第二版） 艾海舟、武勃等译，人民邮电出版社 2003

Web Links

- The Computer Vision homepage http://www.cs.cmu.edu/afs/cs/project/cil/ftp/html/vision.html (excellent index to vision resources on line)
- CV Online http://homepages.inf.ed.ac.uk/rbf/CVonline/ (closest thing to an online vision textbook, with topics contributed by many experts--terrific resource) .

期刊

- *IEEE Transactions on Pattern Analysis and Machine Intelligence.*
- *International Journal on Computer Vision*
- *Pattern Recognition*
- *Computer Vision and Image Understanding*
- *Machine Vision and its Application*
- *Image and Vision Computing Journal*
- *IEEE Transactions on Image Processing*
- *Pattern Recognition Letters*
- *IEEE Transactions on Systems, Man and Cybernetics*
- *Artificial Intelligence*

会议文集

- ***Proceedings of the International Conference on Computer Vision and Pattern Recognition.***
- ***Proceedings of the International Conference on Computer Vision.***
- ***Proceedings of the International Conference on Image Processing.***
- ***Proceedings of the European Conference on Computer Vision***
- ***Proceedings of the International Conference on Pattern Recognition.***

CVPapers : http://www.cvpapers.com/index.html

二、什么是计算机视觉？

What is Visual Perception all about ?

"The plain man's answer (and Aristotle's too) would be, to know what is where by looking. In other words, vision is the process of discovering from images what is present in the world, and where it is ".

[David Marr, 1982]

What is Visual Perception all about ?

The acquisition of knowledge

about

objects and events in the environment

through

information processing

of

light emitted or reflected from objects

What is Computer Vision all about ?

The ultimate goal - making computers "see"

But what does it mean?

Typical "definitions" include 4 components

***Automatic inference* (?) of *properties* (?) of the *world* (?) from *images* (?)**

What is Computer Vision all about ?

Automatic inference (?) of properties (?) of the world (?) from images (?)

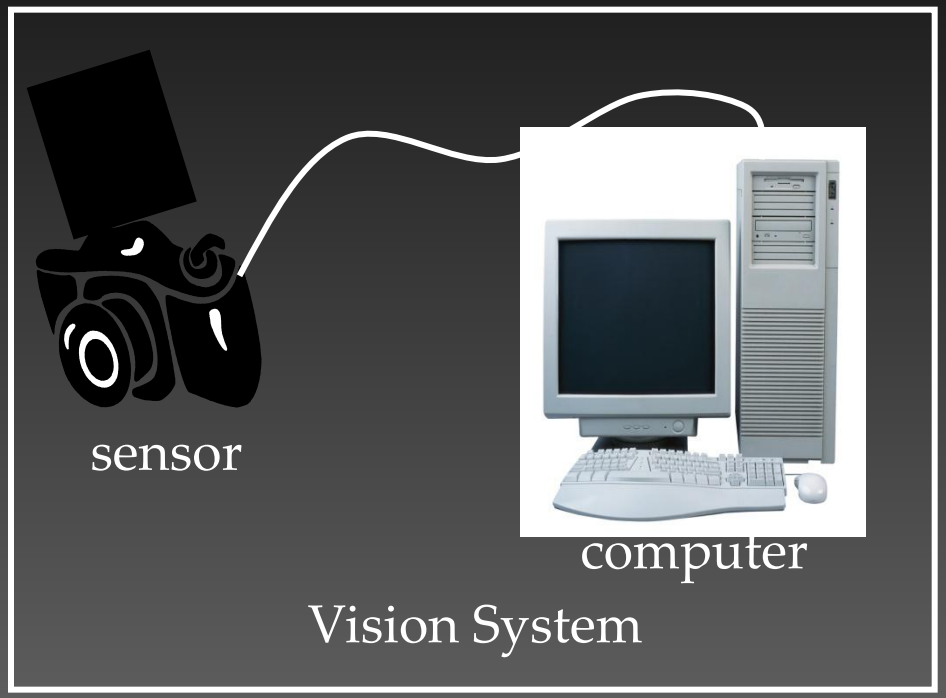
Automatic inference	• Inference without (or minimal) human intervention
The world	• The real unconstrained 3D physical world • Constrained/Engineered environments
Image	• 2D projection of the electromagnetic signal provided by the world
Properties	• Geometric: shape, size, location, distance, • Material : color, texture, reflectivity, transparency • Temporal: direction of motion (in 3D), speed, events • Illumination: light source specification, light source color • Symbolic: objects' class, object's ID

What is Computer Vision all about ?

Automatic inference (?) of properties (?) of the world (?) from images (?)

illumination

scene



Fruits
The red one is an apple
The pear is rotten

What is Computer Vision all about ?

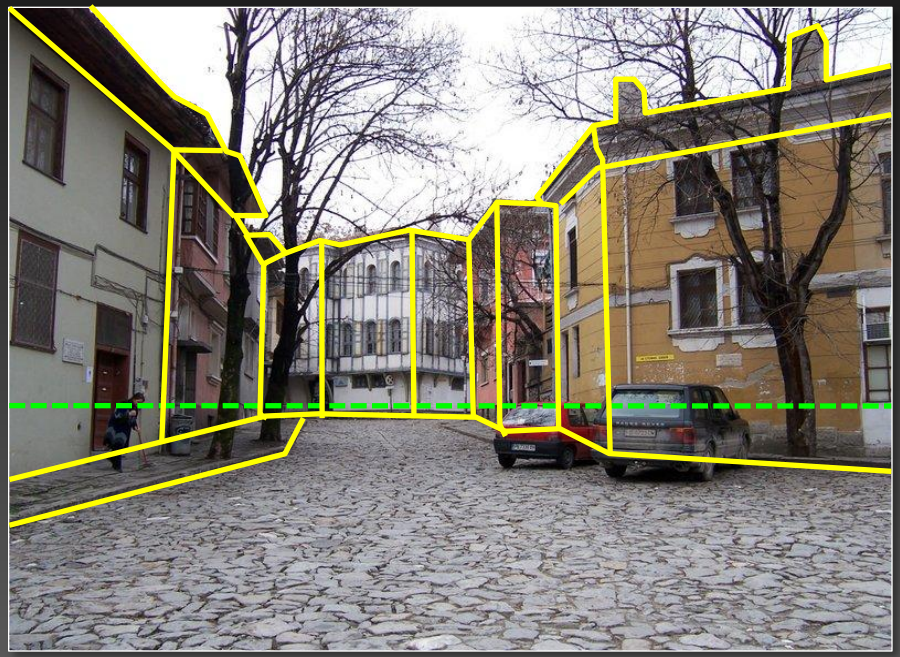
Automatic inference (?) of properties (?) of the world (?) from images (?)

What is Computer Vision all about ?

Automatic inference (?) of properties (?) of the world (?) from images (?)

What kind of information can be extracted from an image?

Semantic information



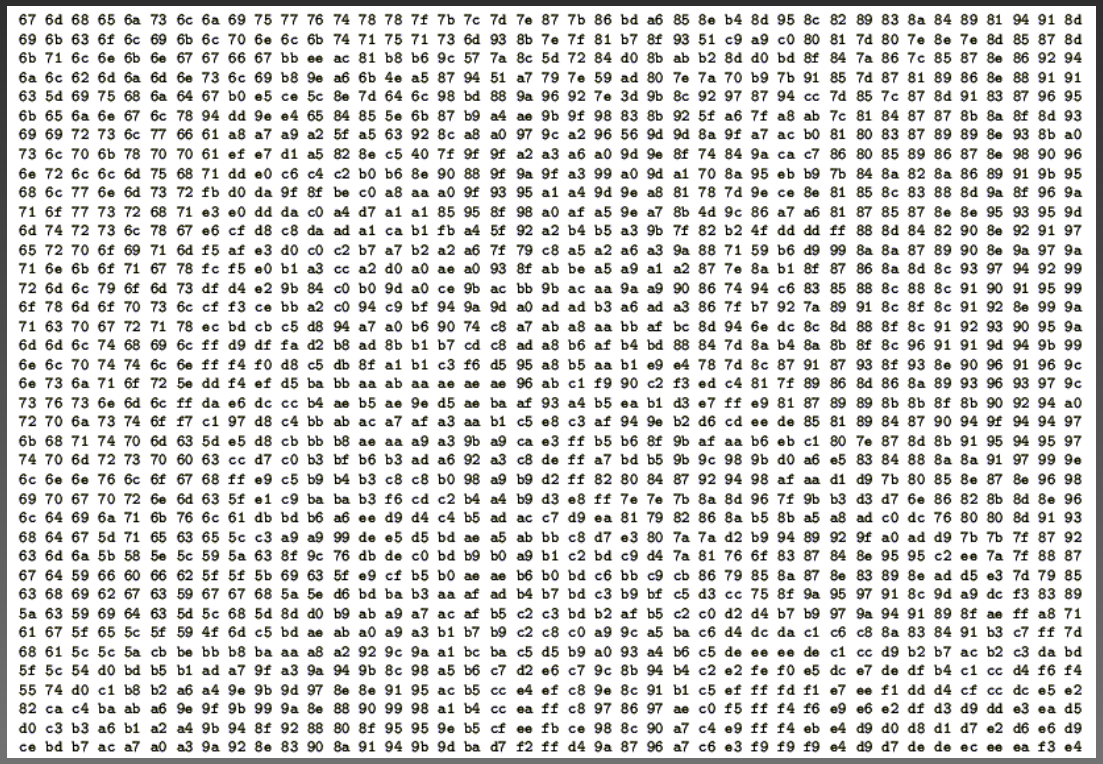
Geometric information

Computer vision must be very easy (?)

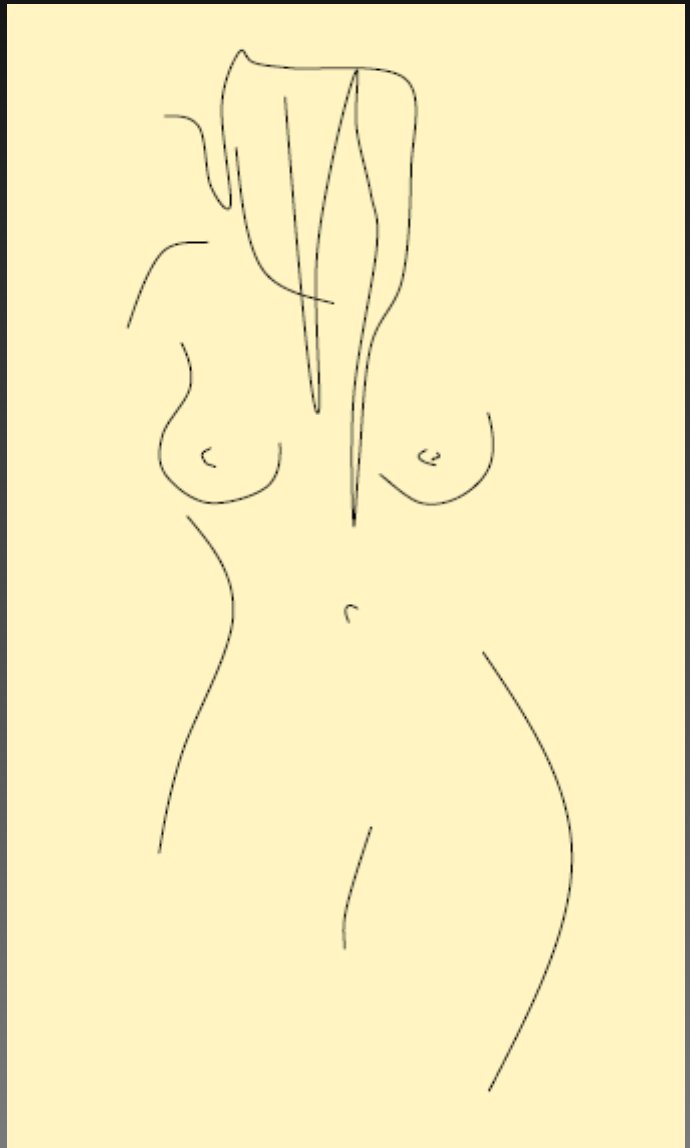
- **All people can “see” equally well (but only few can solve hard mathematical problems, play good soccer, or play good chess)**
- **Babies can “see”**
- **Really primitive animals can “see”**
- **We “see” effortlessly (at least it feels this way)**
- **Vision is immediate**
- **Vision appears to be flawless**

Computer vision must be very easy (?)

- 作业
- 给出如下图像，编制程序解释图像内容



Computer vision must be very easy (?)

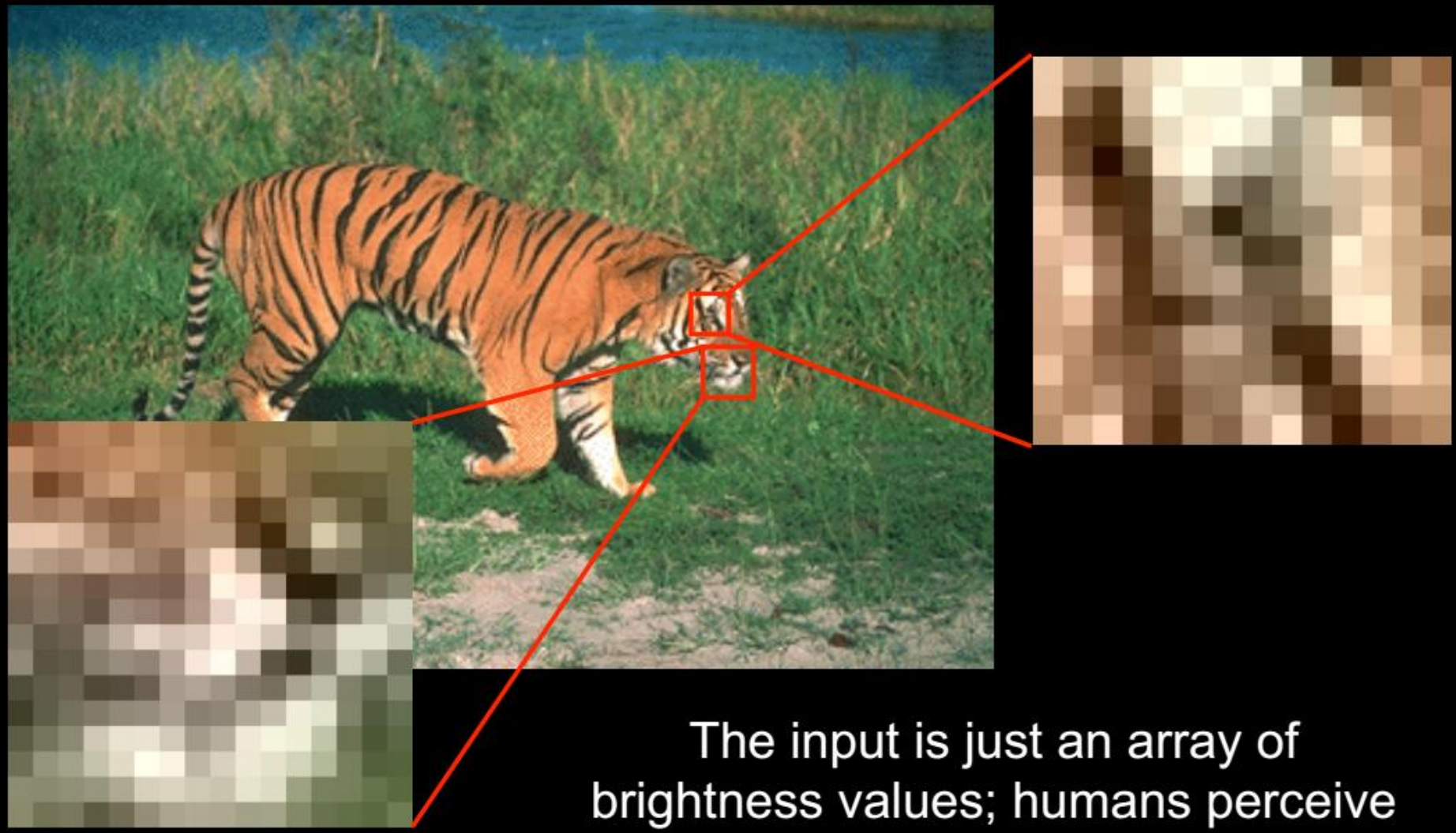


Computer vision must be very easy (??)

Computer vision must be very easy (? ?)

Computer vision must be very easy (???)

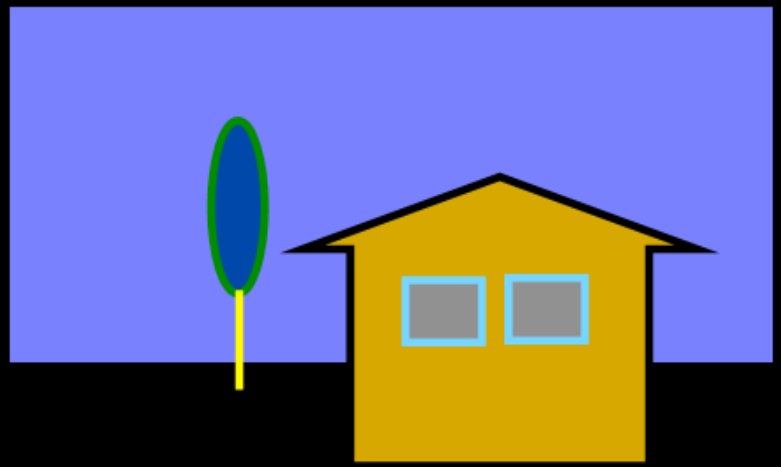
What is in an image?



The input is just an array of brightness values; humans perceive structure in it.

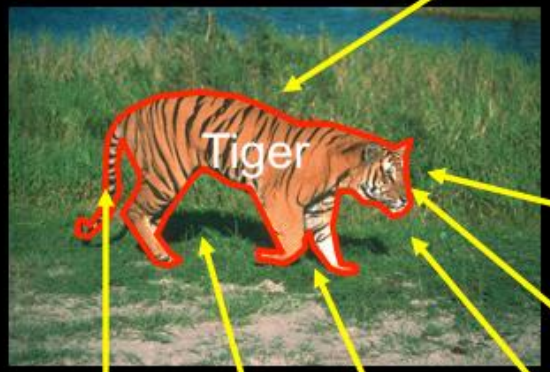
" I stand at the window and see a house, trees, sky. Theoretically I might say there were 327 brightnesses and nuances of color. Do I *have* 327? No. I have sky, house, and trees."

Laws of Organization in Perceptual Forms
Max Wertheimer (1923)



From Pixels to Perception

outdoor
wildlife



back
head
eye
tail
legs
mouse
shadow

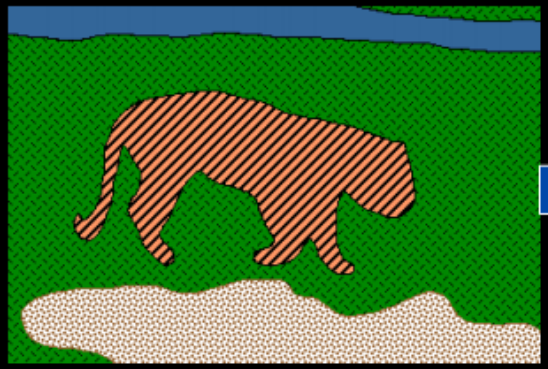
Slide from J. Malik, UC Berkeley

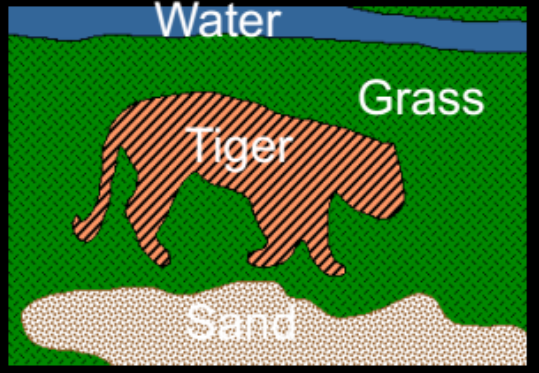
A (naïve) proposal: feed-forward processing

Pixels
Local Neighborhoods

Contours
Surfaces

Objects
Scenes





Low-level → Mid-level → High-level

Image Processing

Grouping
Figure/Ground
Surface Attributes

Recognition

A (naïve) proposal: feed-forward processing

“...Understanding vision is a key to understanding intelligence...”

T. Poggio

(Computer) vision is extremely hard (!!)

(Computer) vision is extremely hard (!!)

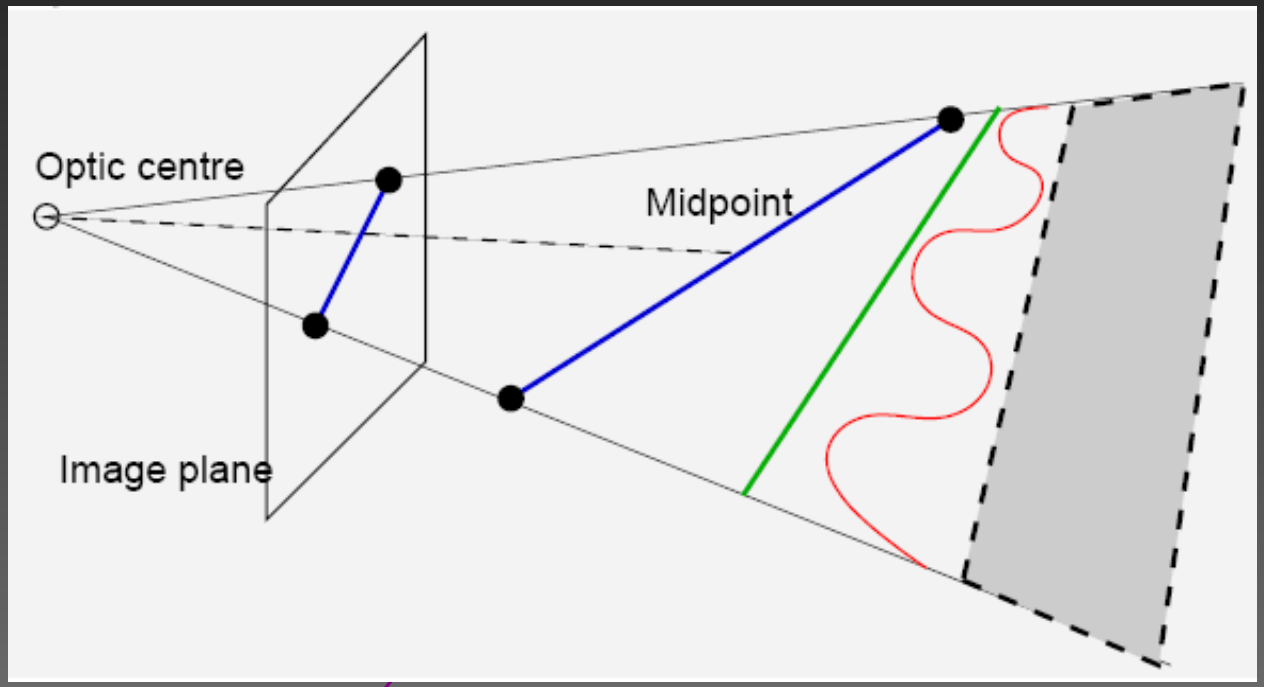
- **Vision is difficult**
  - **Half of primate cerebral cortex is devoted to visual processing**
  - **Achieving human-level visual perception is probably "AI-complete"**

(Computer) vision is extremely hard (!!)

- **Vision needs to reverse the imaging process which is a many-to-one mapping (…recover lost information).**

(Computer) vision is extremely hard (!!)

There are an infinite number of possible scenes that could produce the pixels in a single image



Vision is Fundamentally Ill-Posed

(Computer) vision is extremely hard (!!)

- **Real world is too complex**
  - **Difficult to formalize the notion of object, scene, event**
    - **Appearance: photometric and geometric properties**
    - **Functionality**
  - **Difficult to formalize all spatiotemporal relations between objects in the scene**

Challenges 1: view point variation

Michelangelo 1475-1564

Challenges 2: illumination

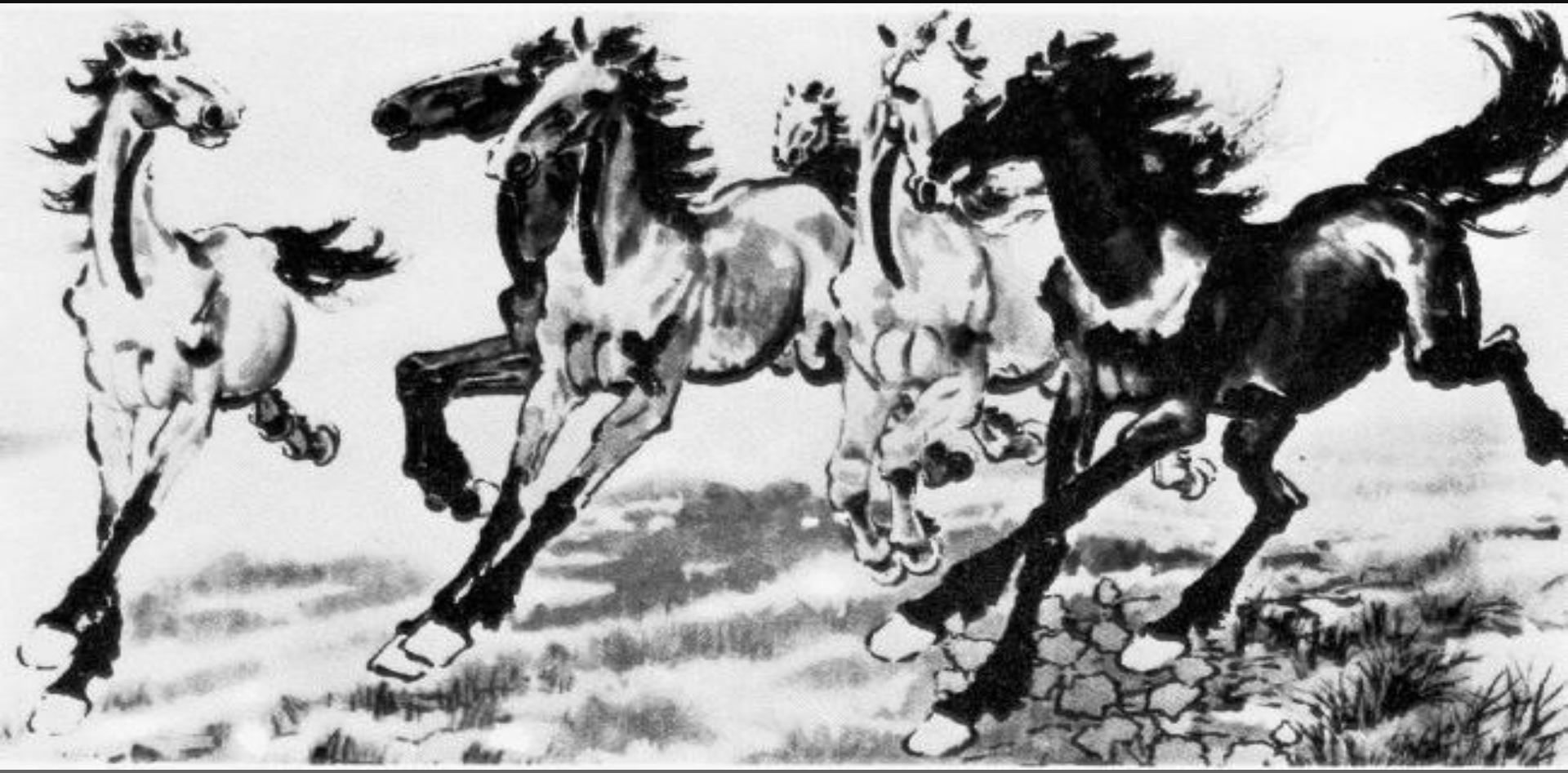
slide credit: S. Ullman

Challenges 3: occlusion

Magritte, 1957

Challenges 4: scale

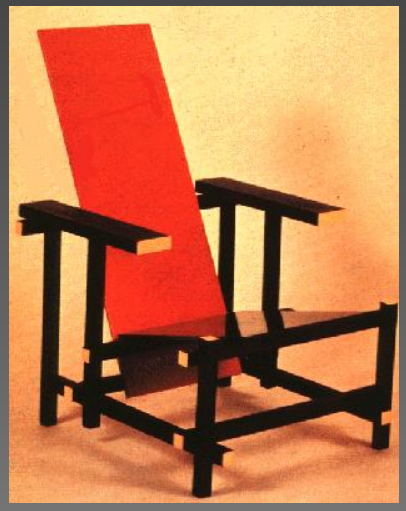
Challenges 5: deformation



Xu, Beihong 1943

Challenges 6: background clutter

Challenges 7: intra-class variation



ob


~10,000 to 30,000

Challenges 8: Motion

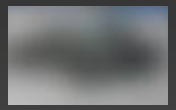
Challenges 9: ambiguity

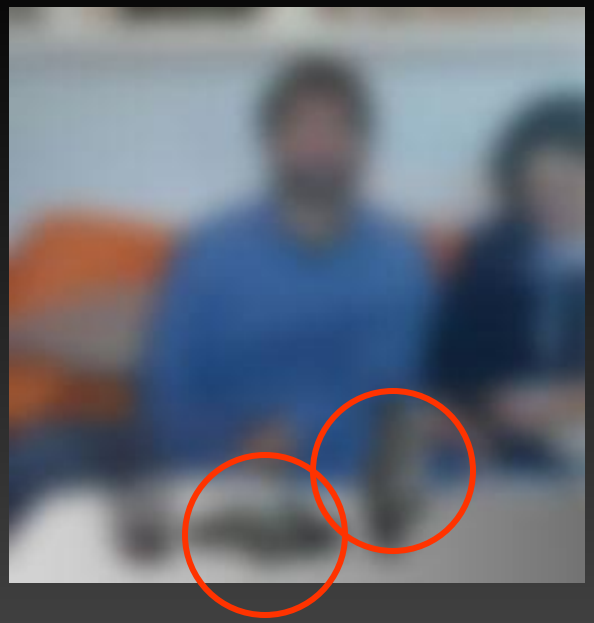
Source: Rob Fergus and Antonio Torralba

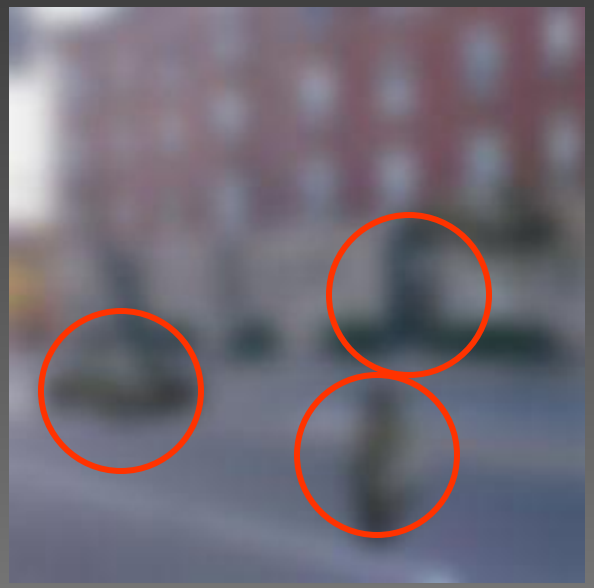
Challenges 9: ambiguity

Source: Rob Fergus and Antonio Torralba

Challenges 9: ambiguity





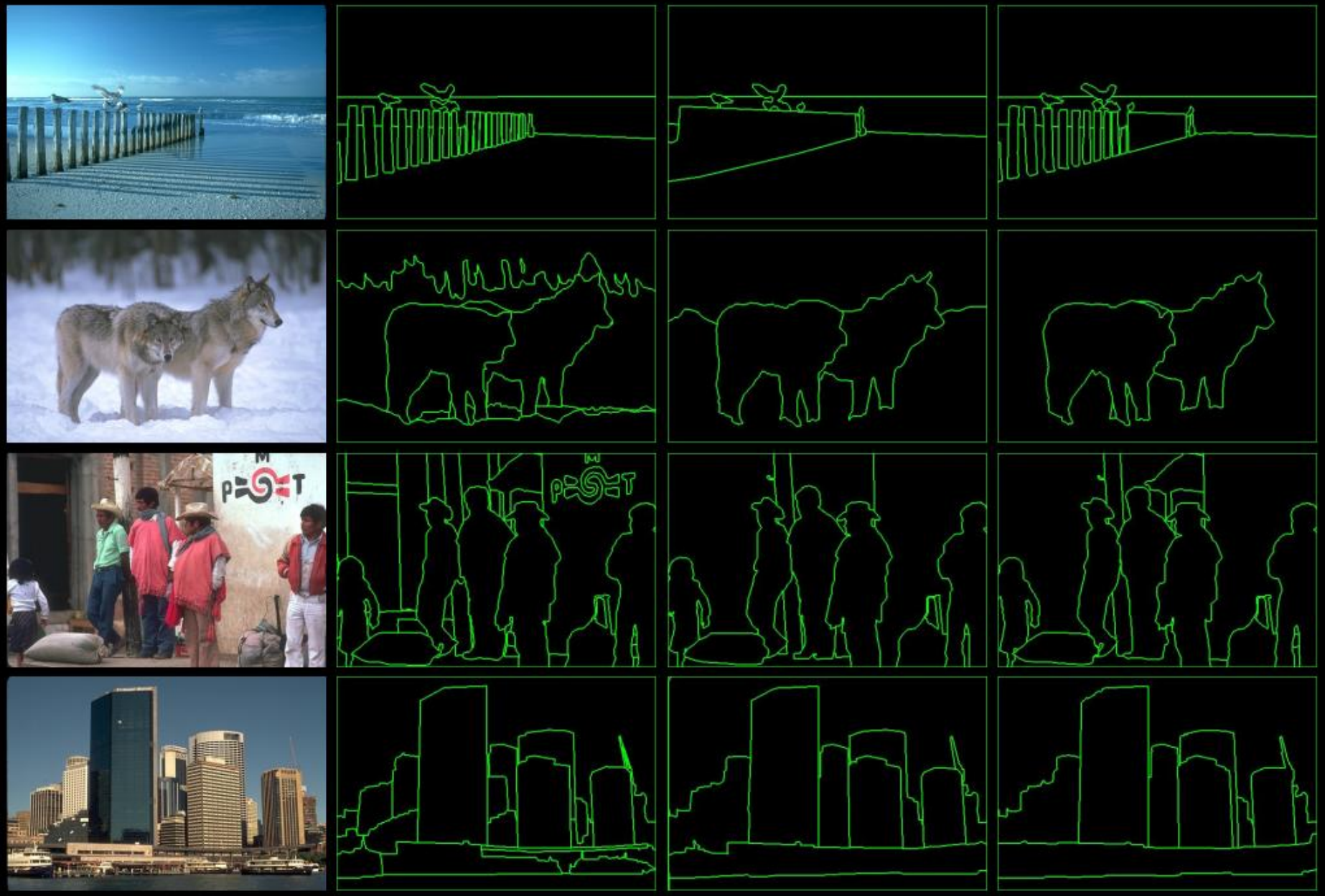


slide credit: Fei-Fei, Fergus & Torralba

Challenges or opportunities?

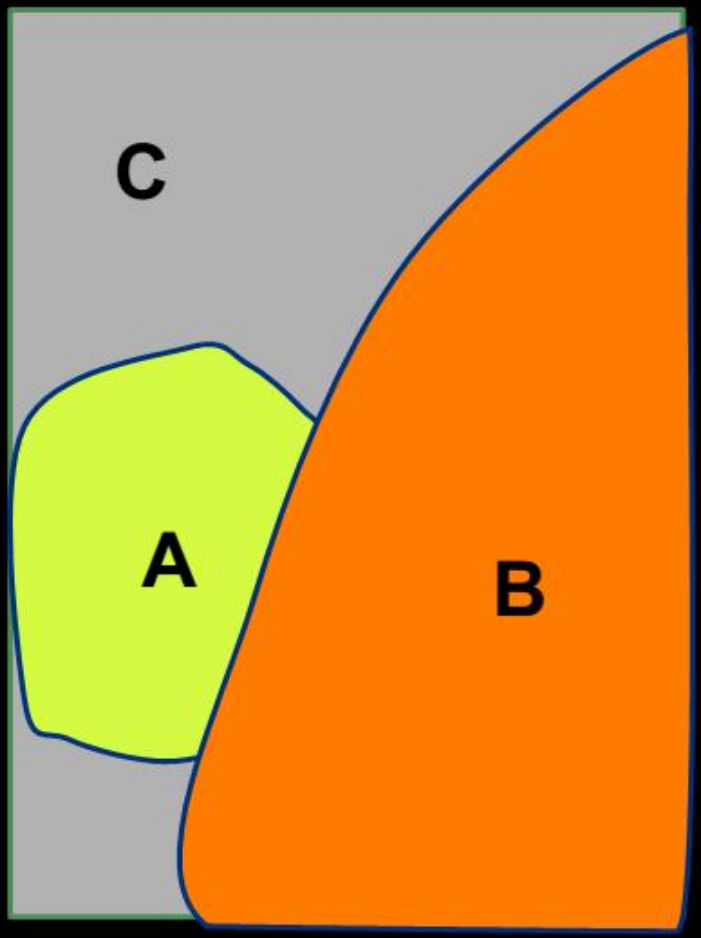
- **Images are confusing, but they also reveal the structure of the world through numerous cues**
- **Our job is to interpret the cues!**

Image source: J. Koenderink



Boundaries are often defined by discontinuities in image brightness, color and/or texture

Humans assign a depth ordering to surfaces across a contour



B is in front of A. A is in front of C. B is in front of C

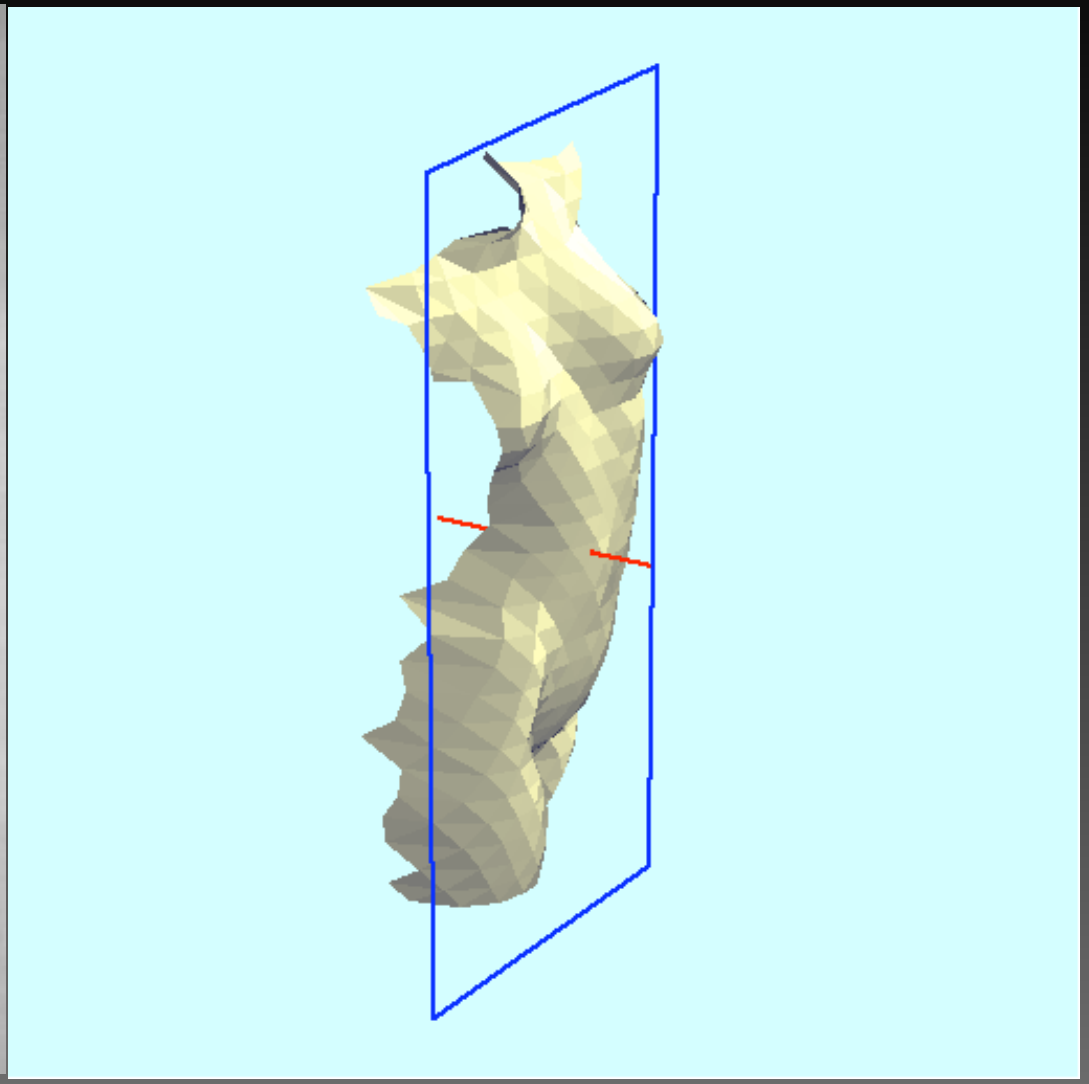
Depth cues: Linear perspective

Depth ordering cues: Occlusion

Source: J. Koenderink

Shape cues: Texture gradient

Shape and lighting cues: Shading

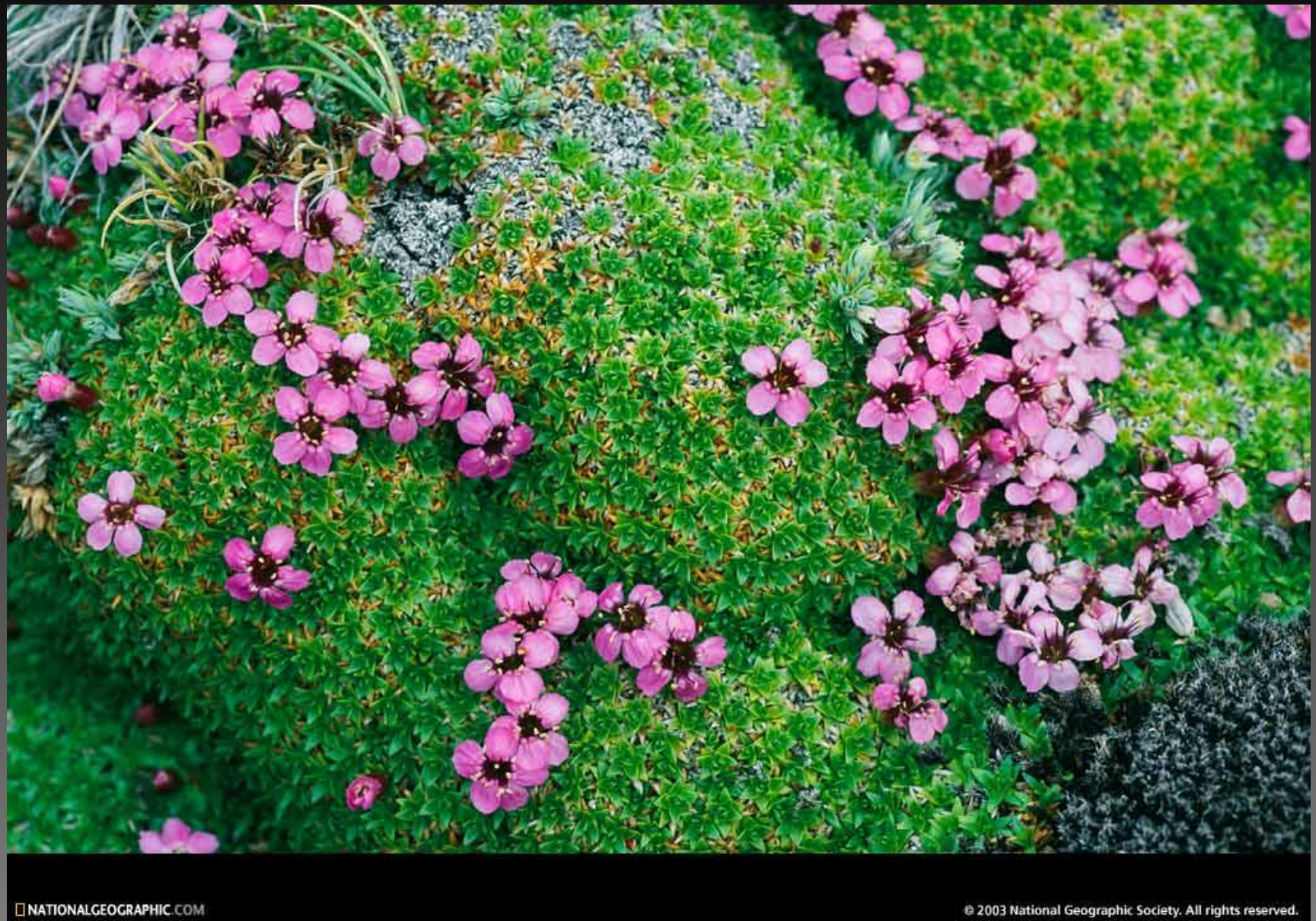


Source: J. Koenderink

Position and lighting cues: Cast shadows

Source: J. Koenderink

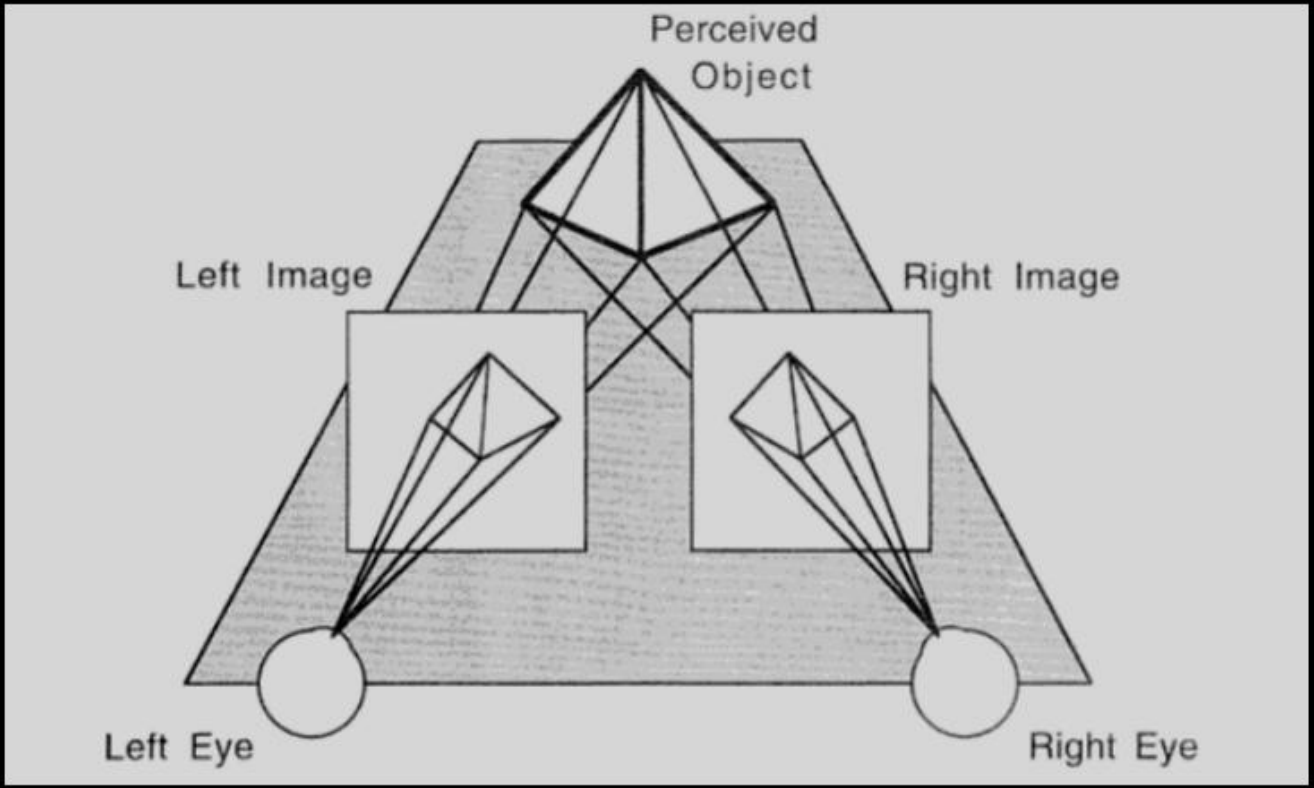
Grouping cues: Similarity (color, texture, proximity)



Grouping cues: “Common fate”

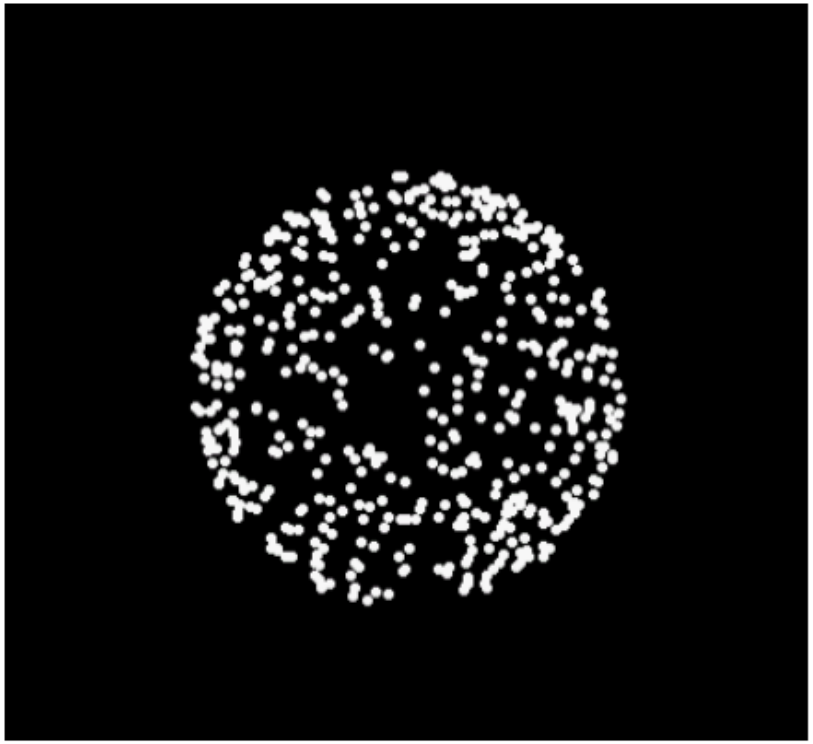
Image credit: Arthus-Bertrand (via F. Durand)

Binocular Stereopsis



Structure from Motion

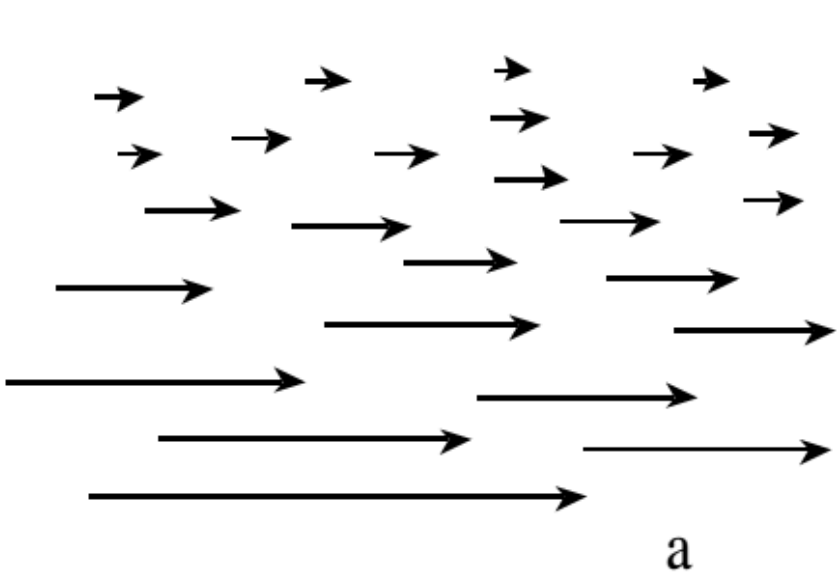
- Assumption of rigidity allows us to infer shape as objects move/rotate (Kinetic Depth Effect)

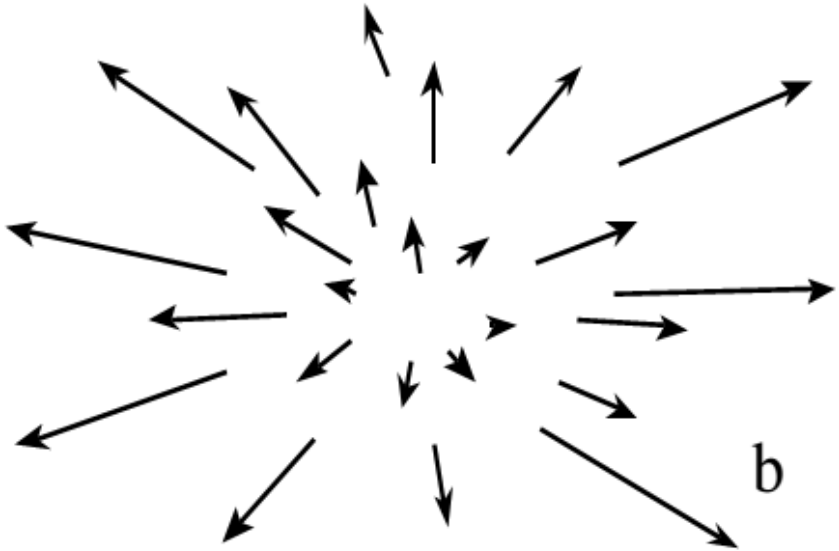


Video from:
http://www.lifesci.sussex.ac.uk/home/George_Mather/Motion/KDE.HTML

Structure from Motion

- Expanding center
- Motion Parallax





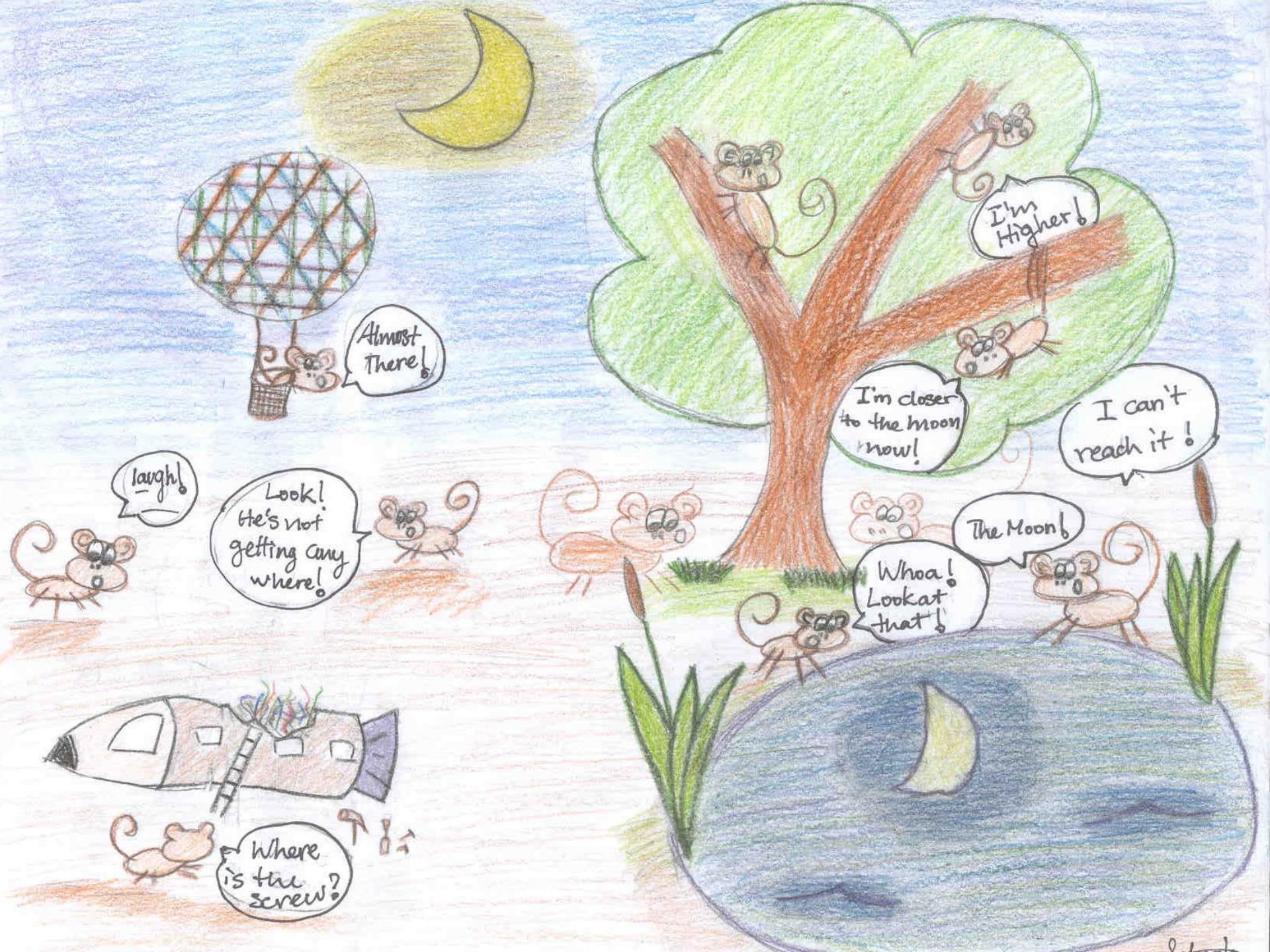
Bottom line

- **Perception is an inherently ambiguous problem**
  - **Many different 3D scenes could have given rise to a particular 2D picture**

- Possible solutions
  - Bring in more constraints (more images)
  - Use prior knowledge about the structure of the world
- Need a combination of different methods

三、计算机视觉的研究历史

- **Computer Vision started as an AI problem.**


Almost There!
laugh!
Look! He's not getting any where!
Where is the screw?
I'm Higher!
I'm closer to the moon now!
I can't reach it!
The Moon!
Whoa! Look at that!

三、计算机视觉的研究历史

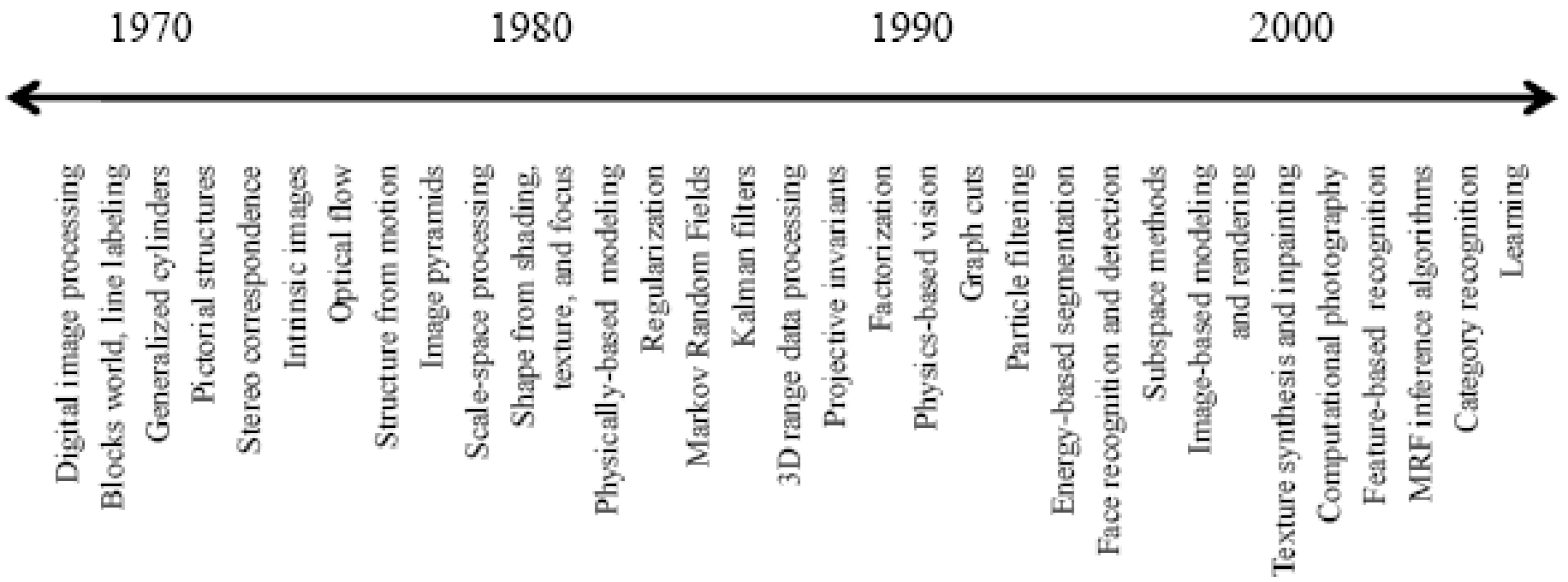


Figure 1.6 A rough timeline of some of the most active topics of research in computer vision.

A rough history of computer vision (1)

- 1955: A vision of Computer Vision
  - Selfridge: "… eyes and ears for the computer"
- Late 1950's-early 1960's: First image enhancement application
  - Space missions, aerial image processing
- Early 1960's : Character recognition
  - Pattern recognition paradigm
- Late 1960's: Interpretation of blocks world
  - Roberts 1965: 2D→3D
- 1979: Natural scenes with motion
  - Nagel: Digitization and analysis of traffic scenes
- 1988: Visual agents
  - Bajcsy: active vision

A rough history of computer vision (2)

- 1980's-mid 1990's: multi-view geometry & segmentation
  - Kass et al 1988: Snakes
- 1990's: face and gesture recognition, statistical methods
  - Turk & Pentland 1991: Eigen-faces
- 1990's – early 2000's: visual tracking and motion analysis
  - Isard & Blake 1998: particle filtering for visual tracking
- 2000's: more recognition, large scale image and video database
  - Viola & Jones 2001: the first real-time face detector
  - Lowe 2004: SIFT feature
- Mid 2000's: computational photography branched out
- 2011: advancement made by new sensors
  - Kinect

三、计算机视觉的研究历史

- 20世纪50年代从统计模式识别开始
  - 二维图像分析和识别：光学字符识别、工件表面、显微图片和航空图片的分析和解释等。

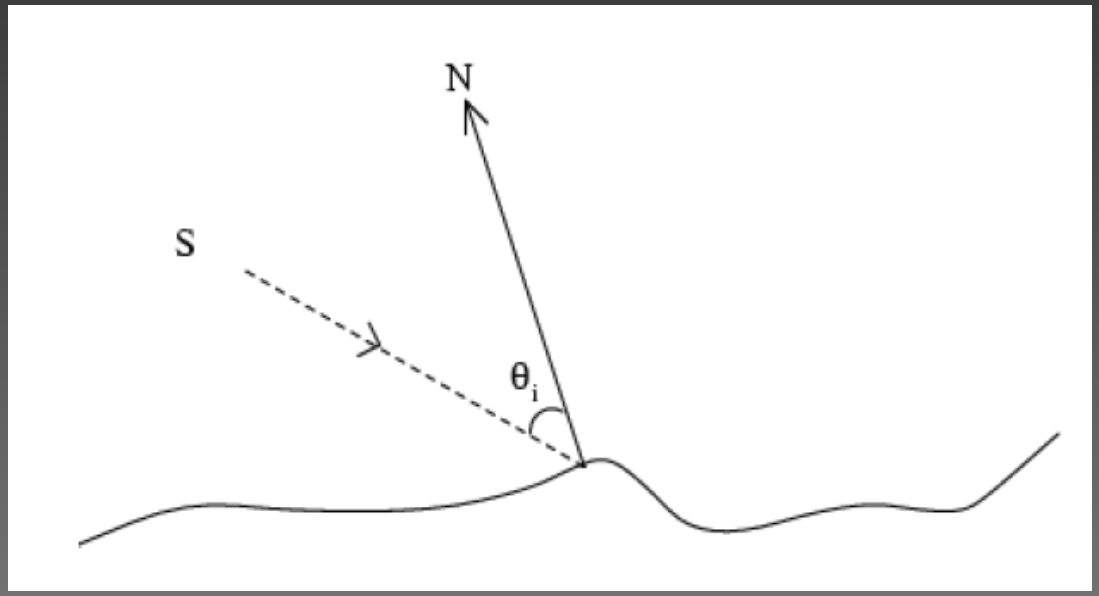
三、计算机视觉的研究历史

- 60年代，Roberts的“积木世界”
  - 通过计算机程序从数字图像中提取出诸如立方体、楔形体、棱柱体等多面体的三维结构，并对物体形状及物体的空间关系进行描述。

三、计算机视觉的研究历史

- 70年代中期，MIT AI实验室计算机视觉理论、算法、系统设计的研究

- **Horn: Physics Based Vision**
  - **Optics**
  - **Reflectance**
  - **Illumination**



三、计算机视觉的研究历史

- David Marr 1977年提出不同于“积木世界”分析方法的视觉计算理论 computational vision

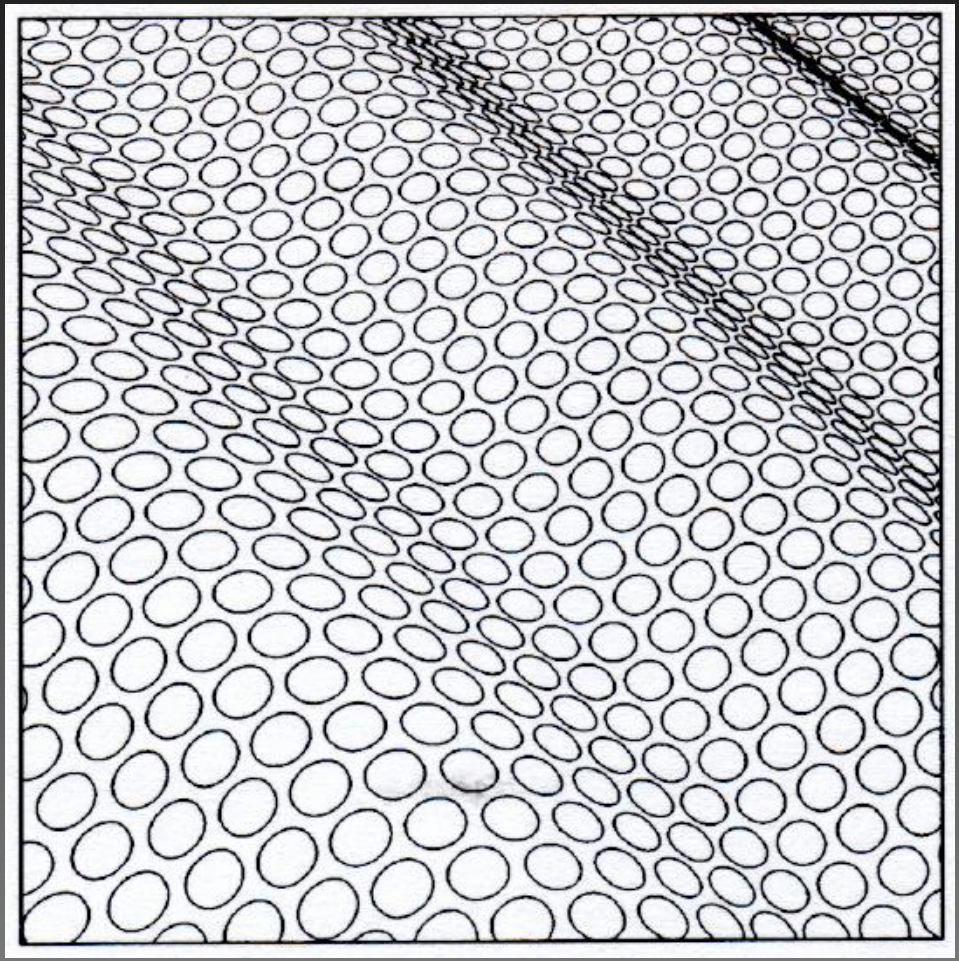
- **Human vision system**
- **Shape from X: Recover 3-D from 2-D**
- **Quantitative vs Qualitative**

三、计算机视觉的研究历史

- **Shape from X: Recover 3-D from 2-D**
  - **Shading**
  - **Stereo**
  - **Texture**
  - **Motion**
  - **Contours**

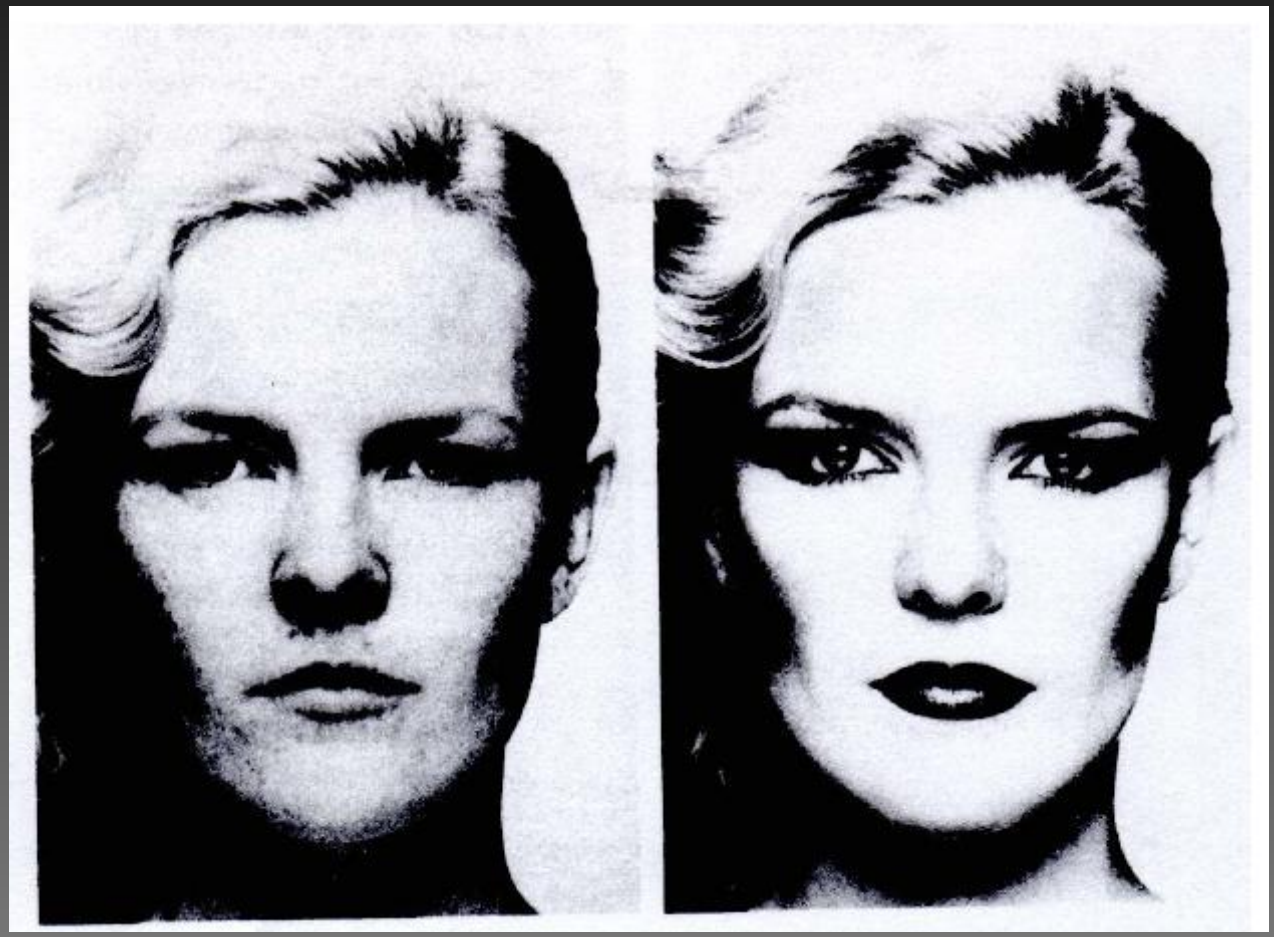
三、计算机视觉的研究历史

- **Shape from Texture**



三、计算机视觉的研究历史

- **Shape from Shading**



三、计算机视觉的研究历史

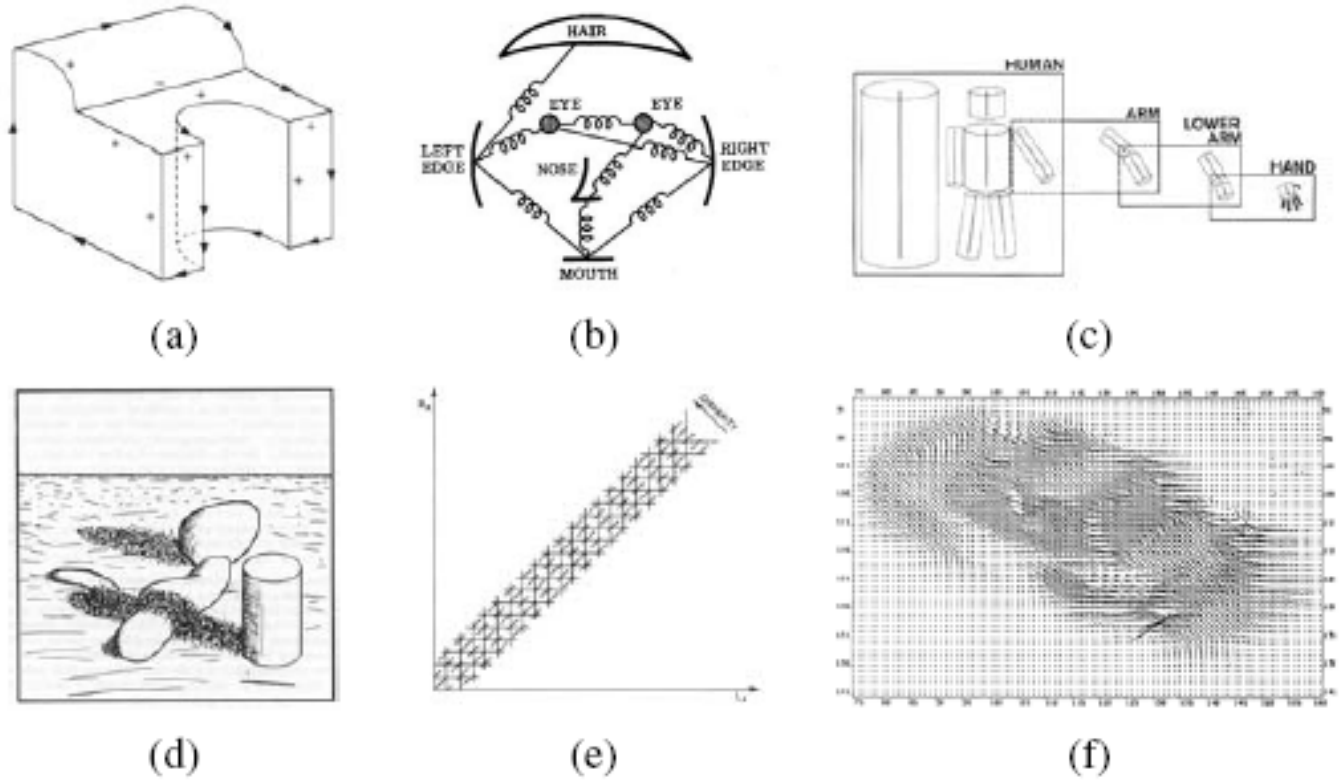


Figure 1.7 Some early (1970s) examples of computer vision algorithms: (a) line labeling (Nalwa 1993) © 1993 Addison-Wesley, (b) pictorial structures (Fischler and Elschlager 1973) © 1973 IEEE, (c) articulated body model (Marr 1982) © 1982 David Marr, (d) intrinsic images (Barrow and Tenenbaum 1981) © 1973 IEEE, (e) stereo correspondence (Marr 1982) © 1982 David Marr, (f) optical flow (Nagel and Enkelmann 1986) © 1986 IEEE.

三、计算机视觉的研究历史

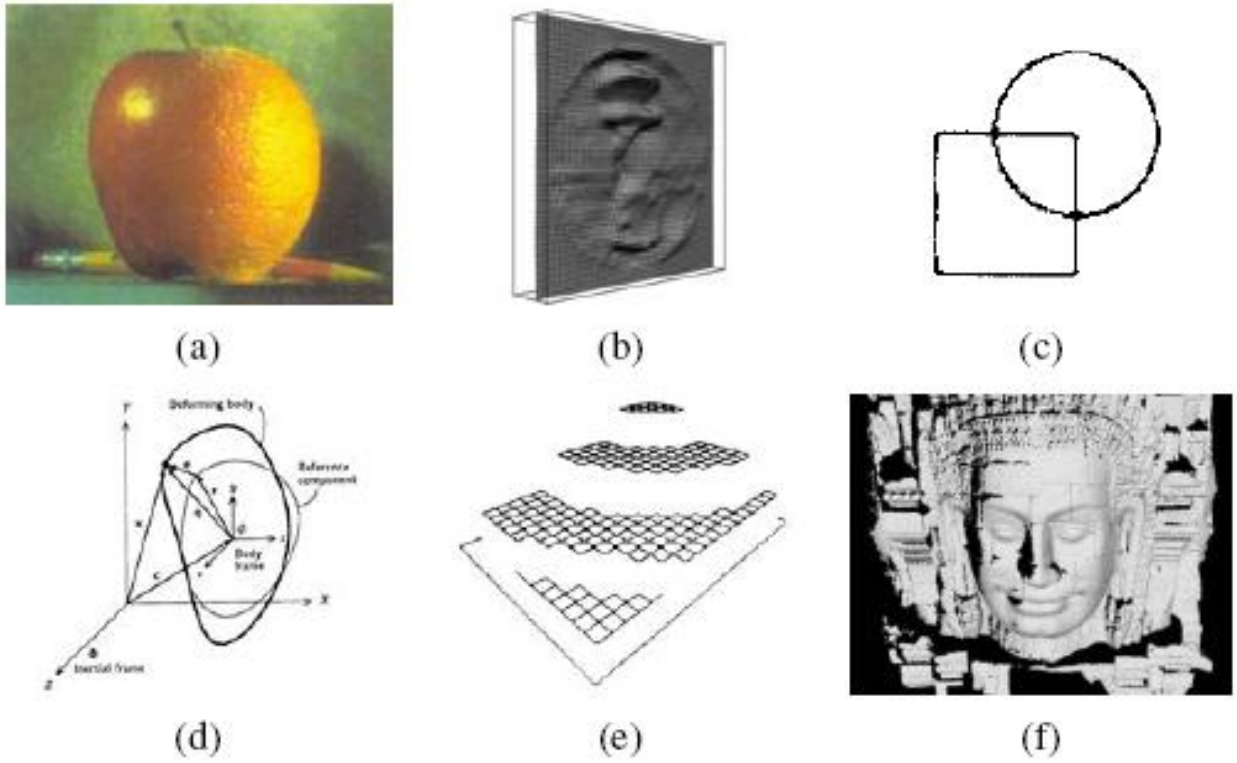


Figure 1.8 Examples of computer vision algorithms from the 1980s: (a) pyramid blending (Burt and Adelson 1983b) © 1983 ACM, (b) shape from shading (Freeman and Adelson 1991) © 1991 IEEE, (c) edge detection (Freeman and Adelson 1991) © 1991 IEEE, (d) physically based models (Terzopoulos and Witkin 1988) © 1988 IEEE, (e) regularization-based surface reconstruction (Terzopoulos 1988) © 1988 IEEE, (f) range data acquisition and merging (Banno, Masuda, Oishi *et al.* 2008) © 2008 Springer.

三、计算机视觉的研究历史

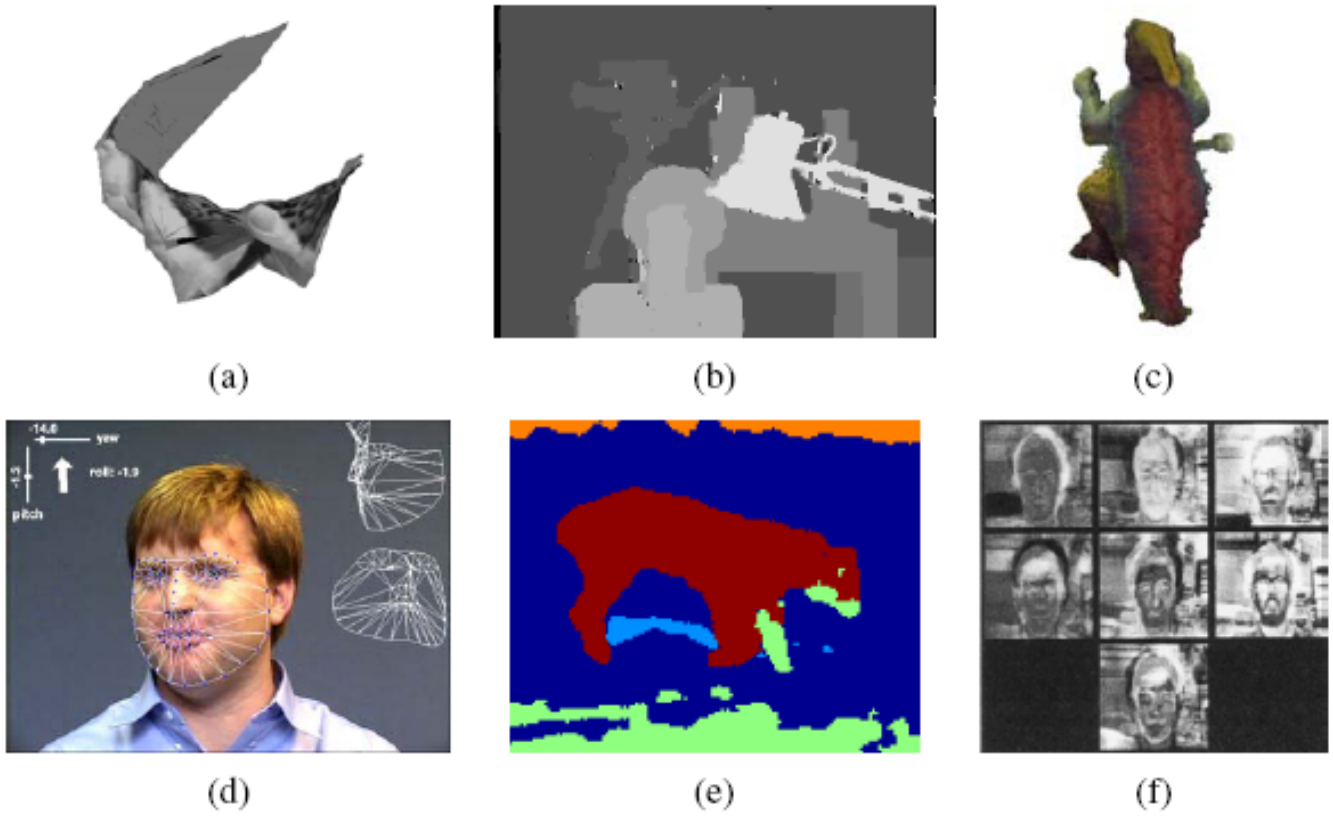
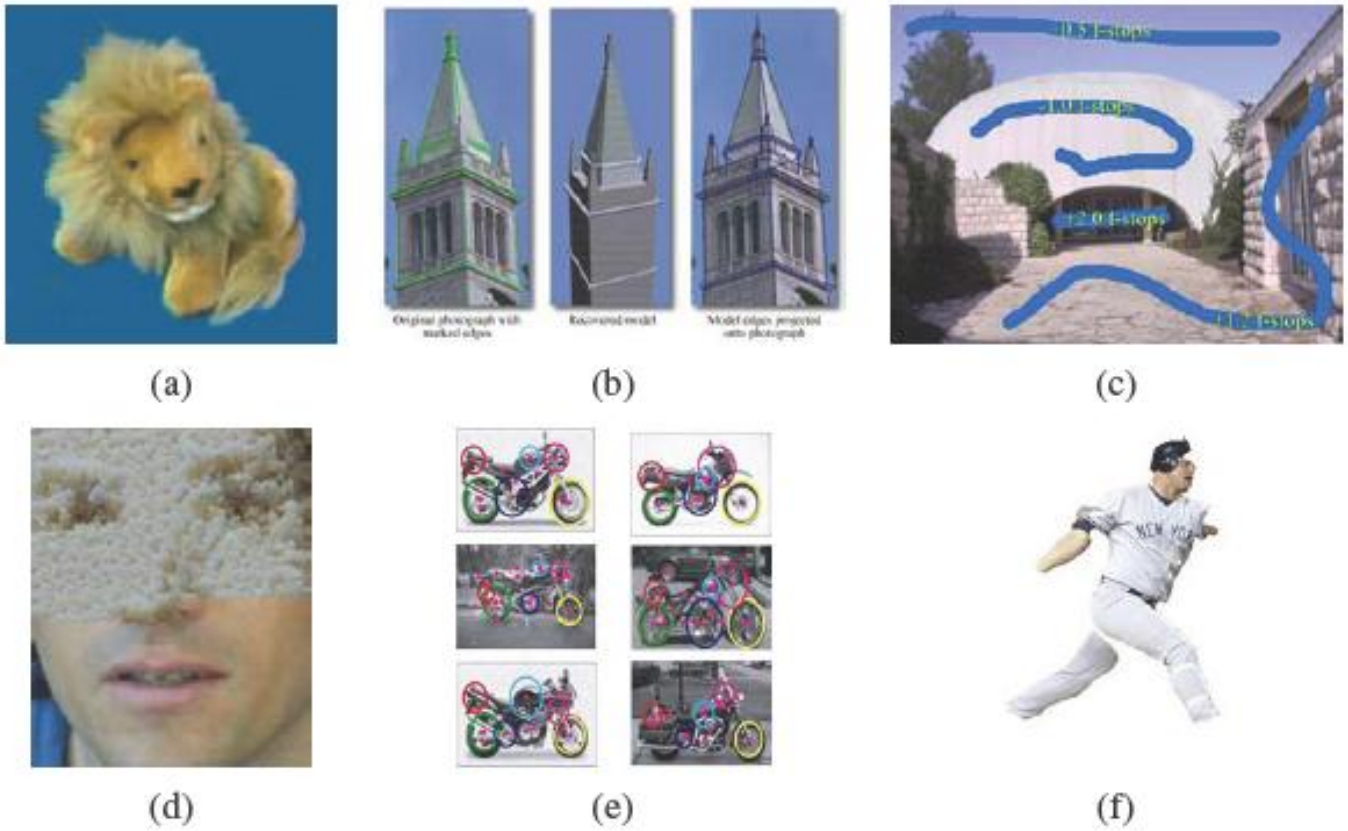


Figure 1.9 Examples of computer vision algorithms from the 1990s: (a) factorization-based structure from motion (Tomasi and Kanade 1992) © 1992 Springer, (b) dense stereo matching (Boykov, Veksler, and Zabih 2001), (c) multi-view reconstruction (Seitz and Dyer 1999) © 1999 Springer, (d) face tracking (Matthews, Xiao, and Baker 2007), (e) image segmentation (Belongie, Fowlkes, Chung *et al.* 2002) © 2002 Springer, (f) face recognition (Turk and Pentland 1991a).

三、计算机视觉的研究历史



(a) (b) (c)

(d) (e) (f)

Figure 1.10 Recent examples of computer vision algorithms: (a) image-based rendering (Gortler, Grzeszczuk, Szeliski *et al.* 1996), (b) image-based modeling (Debevec, Taylor, and Malik 1996) © 1996 ACM, (c) interactive tone mapping (Lischinski, Farbman, Uyttendaele *et al.* 2006a) (d) texture synthesis (Efros and Freeman 2001), (e) feature-based recognition (Fergus, Perona, and Zisserman 2007), (f) region-based recognition (Mori, Ren, Efros *et al.* 2004) © 2004 IEEE.

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Andrew Zisserman - Publication : 350
Oxford OX1 3PJ , UK
Department of Engineering Science; University of Oxford

R. Hartley, **A. Zisserman**, **Multiple view geometry in computer vision**, 2000, (Citation: 1679)

Takeo Kanade - Publication : 578
Carnegie Mellon University , 5000 Forbes Avenue,; Pittsburgh PA 15213-3891 , USA
Robotics Institute

Bruce D. Lucas, **Takeo Kanade**, **An Iterative Image Registration Technique with an Application to Stereo Vision**, 1981, (Citation: 1577)

Jitendra Malik - Publication : 225
Berkeley , CA 94720
University of California at Berkeley

Pietro Perona, **Jitendra Malik**, **Scale-Space and Edge Detection Using Anisotropic Diffusion**, 1990, (Citation: 1331)

Olivier D. Faugeras - Publication : 331
BP 109 - 06561 Valbonne Cedex - FRANCE
INRIA Sophia-Antipolis

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Andrew Blake - Publication : 238
2 Dean Trench Street; Smith Square; London SW1P 3HE
National Institute of Economic and Social Research

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Richard Szeliski - Publication : 231
One Kendall Square; Cambridge , Massachusetts 02139Real-Time Octree Generation
Microsoft Research, One Microsoft Way, Redmond, WA

Daniel Scharstein, **Richard Szeliski**, **A Taxonomy and Evaluation of Dense Two-Frame Stereo Correspondence Algorithms**, 2002, (Citation: 596)

Michael J. Black - Publication : 189
Kingston , Ontario K7L 3N6
Department of Computing and Information Science , Queen's University

Michael J. Black, P. Anandan, **The Robust Estimation of Multiple Motions: Parametric and Piecewise-Smooth Flow Fields**, 1996, (Citation: 423)

Shree K. Nayar - Publication : 277
Columbia University , New York , NY 10027
Columbia University; Jos'e da Silva; University of Blabla

Hiroshi Murase, **Shree K. Nayar**, **Visual learning and recognition of 3-d objects from appearance**, 1995, (Citation: 727)

Pietro Perona - Publication : 223
Pasadena , CA 91125; D.E.I. , Universit`a di Padova , Via Gradenigo 6/a , 35131 Padova (Italy)
perona@caltech.edu,Vision Group

Pietro Perona, Jitendra Malik, **Scale-Space and Edge Detection Using Anisotropic Diffusion**, 1990, (Citation: 1331)

Tomaso Poggio - Publication : 382
Cambridge , MA 02139
Center for Biological and Computational Learning, M.I.T., Cambridge, MA

T. Poggio, F. Girosi, **Networks for approximation and learning**, 1990, (Citation: 633)

Alex Pentland - Publication : 326
Room E15-387 , 20 Ames street; Cambridge , MA 02139
MIT Media Laboratory, 20 Ames Street, Cambridge, MA

Alex Pentland, Baback Moghaddam, Thad Starner, **View-Based and Modular Eigenspaces for Face Recognition**, 1994, (Citation: 646)

三、计算机视觉的研究历史

- 21世纪初最有影响力的20篇计算机视觉期刊论文

- [1] D. G. Lowe, “Distinctive image features from scale-invariant keypoints,” *International Journal of Computer Vision*, vol. 60, no. 2, pp. 91-110, Nov, 2004. (Cited=5663)
- [2] J. B. Shi, and J. Malik, “Normalized cuts and image segmentation,” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 22, no. 8, pp. 888-905, Aug, 2000. (Cited=2165)
- [3] T. F. Chan, and L. A. Vese, “Active contours without edges,” *IEEE Transactions on Image Processing*, vol. 10, no. 2, pp. 266-277, Feb, 2001. (Cited=2153)
- [4] D. Comaniciu, and P. Meer, “Mean shift: A robust approach toward feature space analysis,” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 24, no. 5, pp. 603-619, May, 2002. (Cited=1910)
- [5] Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli, “Image quality assessment: From error visibility to structural similarity,” *IEEE Transactions on Image Processing*, vol. 13, no. 4, pp. 600-612, Apr, 2004. (Cited=1879)
- ……

四、计算机视觉主要内容

Two major intertwining themes

- **Reconstruction**
  - **Build me a model of it**
- **Recognition**
  - **What is this like**

四、计算机视觉主要内容

Core technologies

- Describing local image patches
- Classification
  - stick in a patch, get yes/no
- Regression
  - stick in a patch, get out some value
- Clustering
  - group together data items that are similar

四、计算机视觉的主要内容

Reconstruction

- Projective geometry
- Photogrammetry
- Essential, fundamental, multiview, …
- Calibrated, uncalibrated, autocalibration, calibration-free,…
- Structure and Motion

四、计算机视觉的主要内容

Recognition

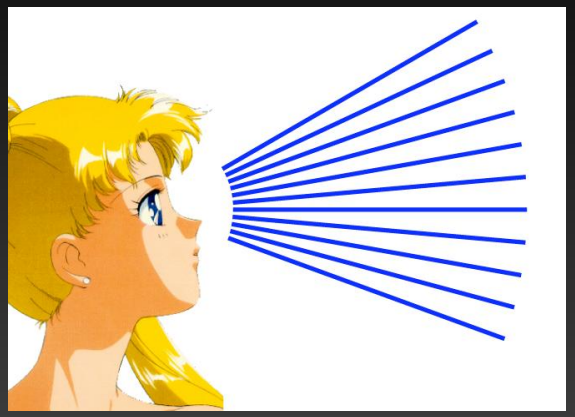
- Specific objects
  - PCA [Murase+Nayar 95], Eigenfaces [Pentland 93]
- Categories
  - Generative [Fergus 2003], discriminative [Opelt 2004]
- Recognition vs. localization
- Features (descriptors), grouping
  - Shape, texture, color, proximity, similarity,…
- Saliency (detectors)
- Active
  - Motion, space+time …

Course overview

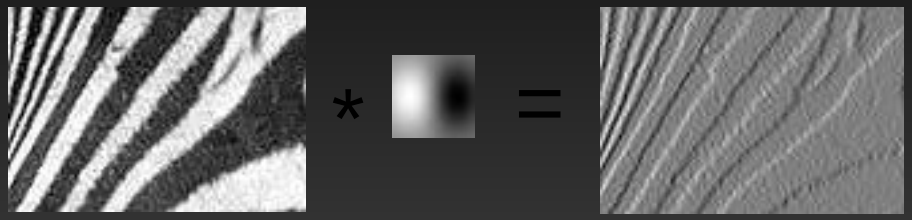
I. Early vision: Image formation and processing
II. Mid-level vision: Grouping and fitting
III. Multi-view geometry
IV. Recognition
V. Additional topics

I. Early vision

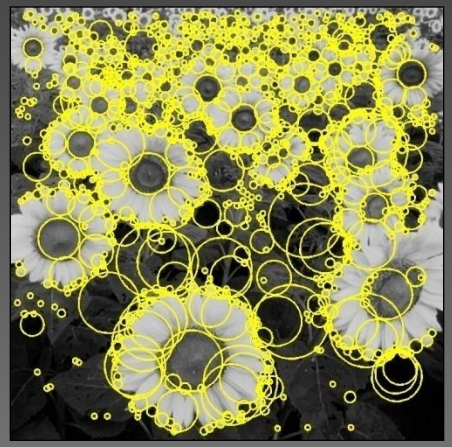
- **Basic image formation and processing**



Cameras and sensors
Light and color



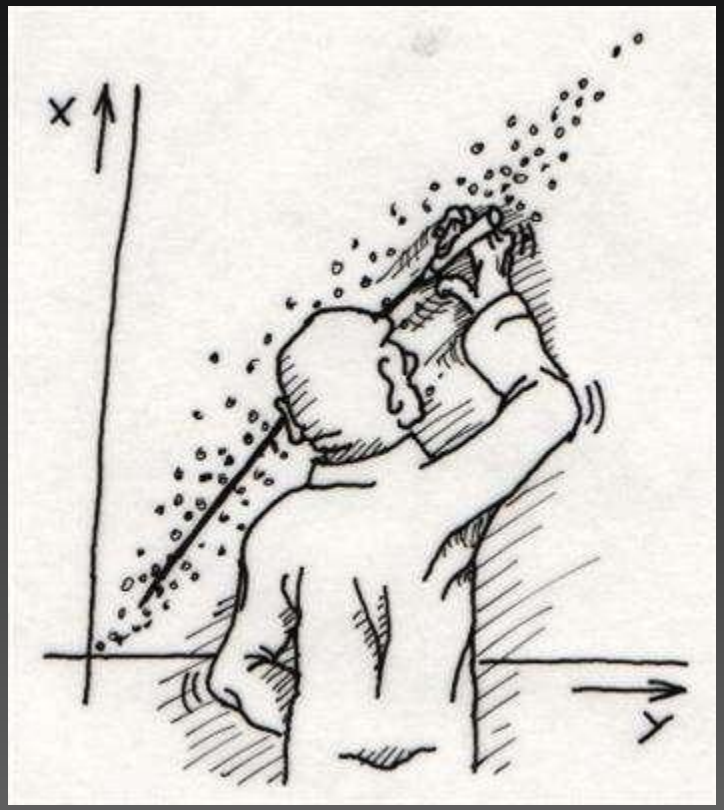
Linear filtering
Edge detection



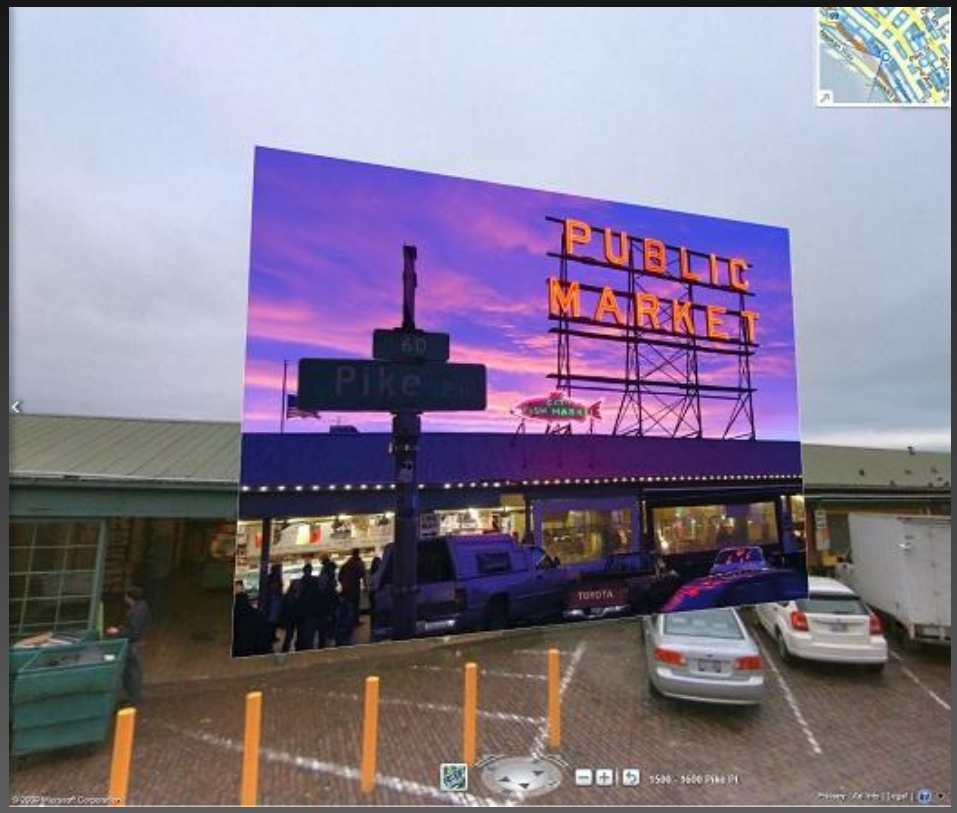
Feature extraction: corner and blob detection

II. “Mid-level vision”

- **Fitting and grouping**

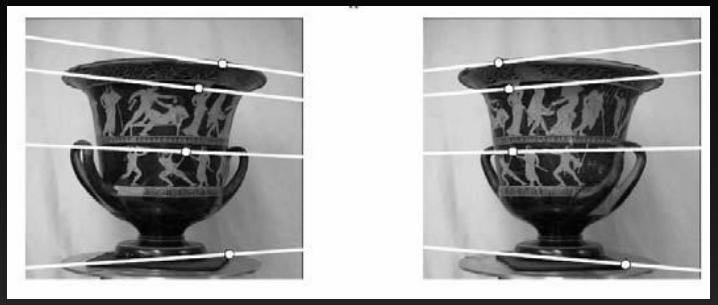


Fitting: Least squares
RANSAC



Alignment

III. Multi-view geometry



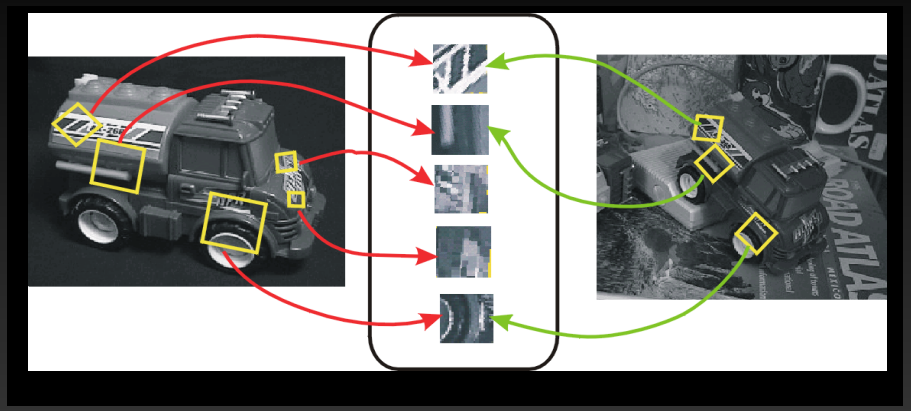
Epipolar geometry

Stereo

Драконъ, видимый подъ различными углами зрѣнія
По гравюрѣ на мѣди изъ „Oculus artificialis teledioptricus“ Цана. 1702 года.

Structure from motion

IV. Recognition



Instance recognition, large-scale alignment

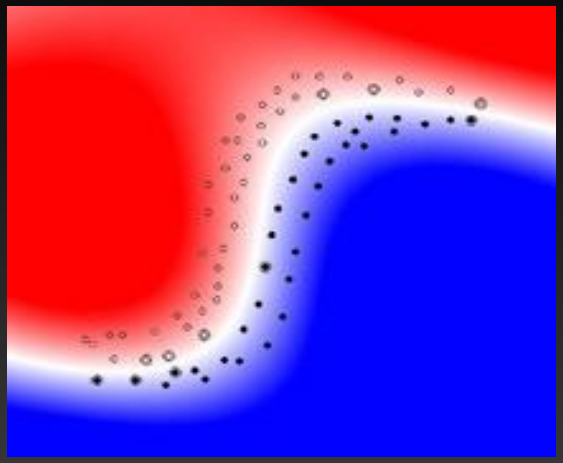
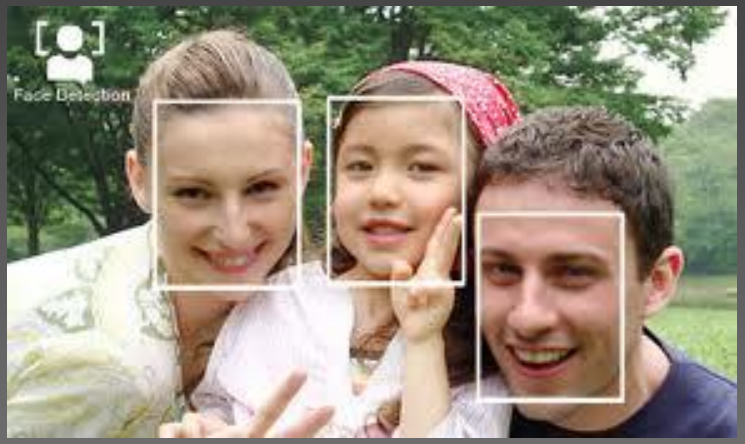
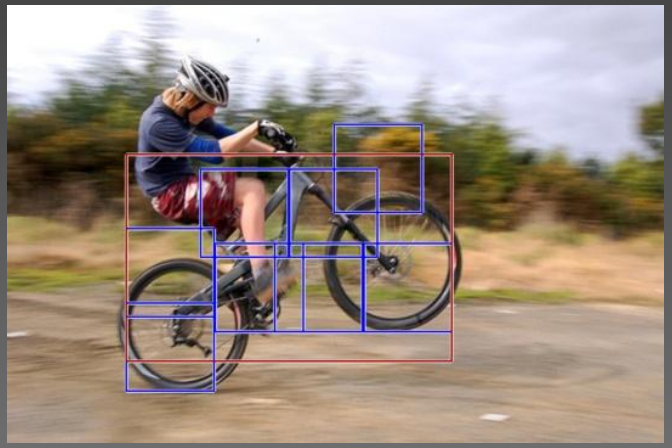


Image classification



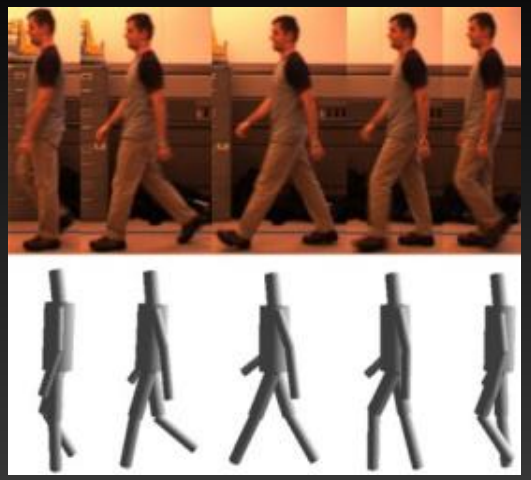
Object detection



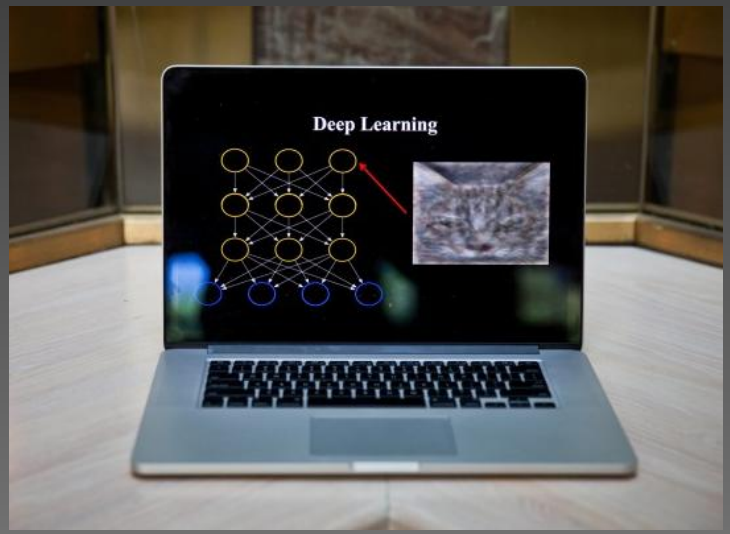
Part-based models

V. Additional Topics

Segmentation

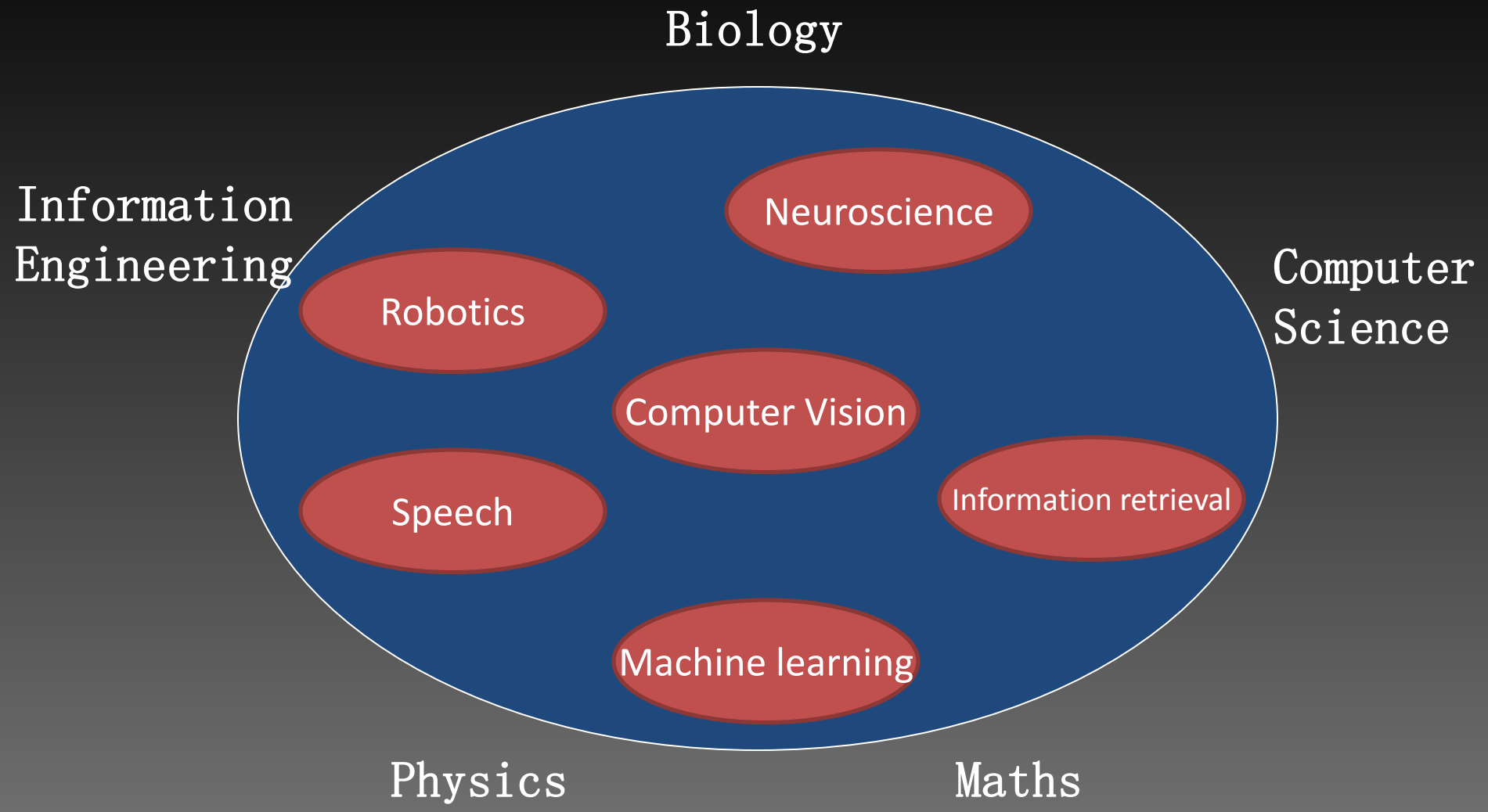


Motion and tracking



Deep learning

What is it related to?



五、计算机视觉的应用

Why study computer vision?

- Vision is difficult
- Vision is useful
- Vision is interesting

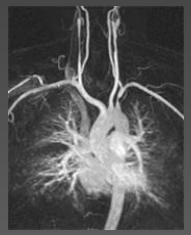
Why study computer vision?

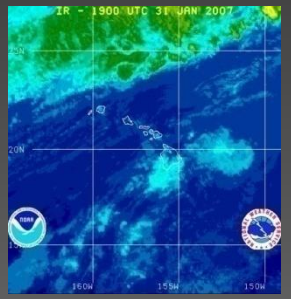
- Millions of images being captured all the time







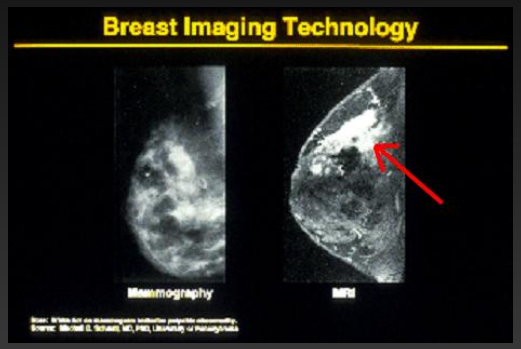




- Loads of useful applications

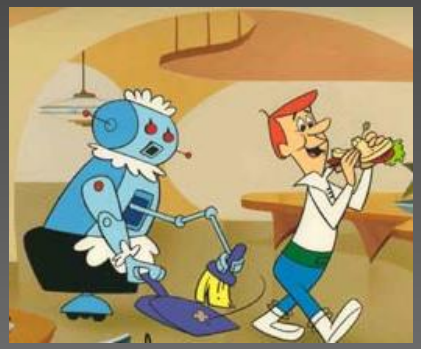
Why computer vision matters

Safety



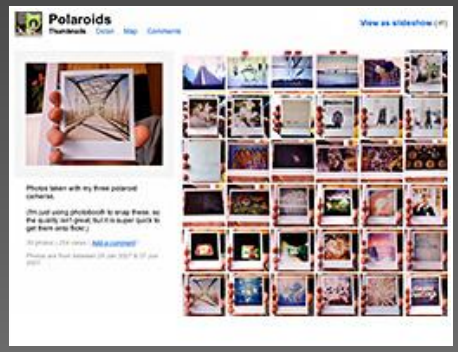
Health

Security



Comfort

Fun



Access

Current state of the art

- You just saw examples of current systems.
  - Many of these are less than 5 years old
- This is a very active research area, and rapidly changing
  - Many new apps in the next 5 years

Let's Start!

- Lots of interesting, unsolved problems
- Lots of opportunity for disruptive new technology
- Lots to fit into 16 weeks

After the class

- Prepare textbooks
- Familiar with Matlab
- OpenCV

- Links in class website