Lecture 1: Introduction

Introduction

easy to distinguish images of natural work from man-made pictures, those created randomly by computer: WHY?

natural images distinctive because contain particular types of structure: WHICH?

utility of studying natural images/scenes:

- understand typical behavior of image processing systems
- understand biological systems
- exploit natural image statistics to build inference algorithms

Statistical framework

images we encounter comprise small subset of all possible images (small volume of 65K-dim space of 256x256 images)

non-Gaussian, non-standard: "state-space describing probability density of natural scenes is highly predictable but does not have the shape that is widely presumed" (Field 87)

highly redundant – Kersten (87) demonstrated by asking human subjects to replace missing pixels in 4-bit digital image, estimated perceptual information content of pixel ≈ 1.4 bits

not random, so not best expressed on pixel-by-pixel basis

standard compression consider subimages such as horizontal scan lines (predictive coding) or 8x8 pixel blocks (JPEG)

work well, but ultimate limits unknown since statistics of real images not well characterized

Choosing dataset

what is good ensemble from which to estimate statistics?

- early work (Kretzmer, 52) looked at TV images
- more recently – images of nature, videos

Analyzing scene statistics

what statistical analysis to perform?

- like to estimate $P(I)$, but difficult – need huge number of images
- build model of $P(I)$, estimate parameters from data
- catalog moments, correlation functions of image distribution: evaluate expressions like

  $$< I(\mathbf{x}_1)I(\mathbf{x}_2), ..., I(\mathbf{x}_n) >$$

  second-order ($n = 2$) interpretable, but higher hard to interpret, visualize
- look for underlying structure, invariance property in distribution (e.g., translation invariance)

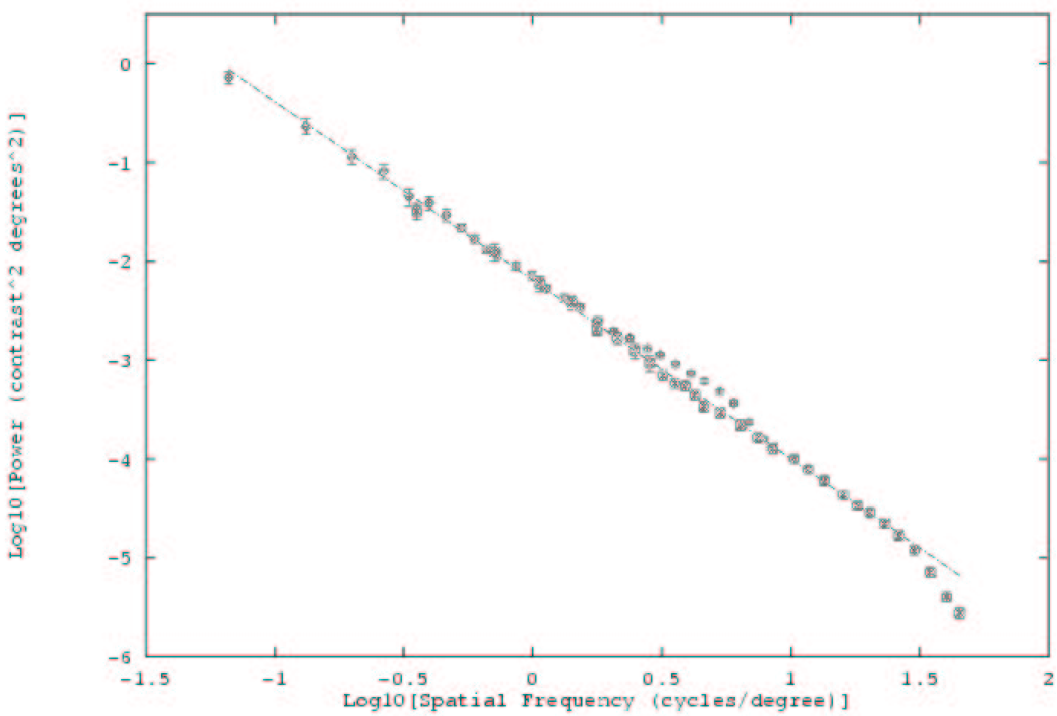
may be able to gain insight by studying sensory systems: development influenced by statistics of environment

Scale invariance

many studies found that ensemble power spectrum, averaged over orientations

$$S(k) = A/k^{-2+\nu}$$

- k: spatial frequency
- A: amplitude


Log10[Power (contrast^2 degrees^2)]
Log10[Spatial Frequency (cycles/degree)]
0
-1
-2
-3
-4
-5
-6
-1.5
-1
-0.5
0
0.5
1
1.5
2

Statistics of Natural Images and Models

Huang and Mumford analyzed 4000 1024x1538 images, from van Hateren database

work on log intensity

1. single pixel statistics
2. derivative statistics
3. joint distribution of adjacent pixels

Ecological constraints on sensory systems

neurons adapt at various timescales (evolution, development, behavioral) to sensory signals

assume that perceptual systems best process signals that occur most frequently ⇒ statistical properties of environment are relevant for sensory processing

need statistical prior model of environment (source coding, estimation, decision theory)

long-standing suggestion (Attneave, 1954): goal of visual perception is to produce efficient representation of incoming signal

- many variants of *efficient coding* hypothesis (Barlow, Laughlin, Field, Rieke)
- difficulto establish quantitative link between neural processing and environmental statistics

two approaches for testing, refining hypotheses

1. direct: examine statistical properties of neural responses under natural stimulation conditions

2. propose model for processing, compare to response properties of neurons