What Is the Goal of Sensory Coding?

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What is the goal of the paper

The underlying question:

What sort of an information processing strategy is used in the mammalian visual system?

How the paper covers the subject:

Two information processing strategies, compact coding and sparse coding are considered, first by analyzing how they work on natural scenes and then comparing the results with what is known from the mammalian visual system.

The concept of state space

The state space describes the space of all possible states, i.e. an n-pixel image has n dimensional state space.

Some notes:

- Every unique image has its own point in the state space.
- For white noise images every point in the state space has the same probability.
- As natural scenes have statistics that differ from the statistics of white noise the probability distribution of natural scenes in the state space is not uniform.
- More generally any redundancy in the data will result in an nonuniform distribution in the state space.
- An array of cells in the visual system can be considered as vectors pointing to unique locations in the state space.

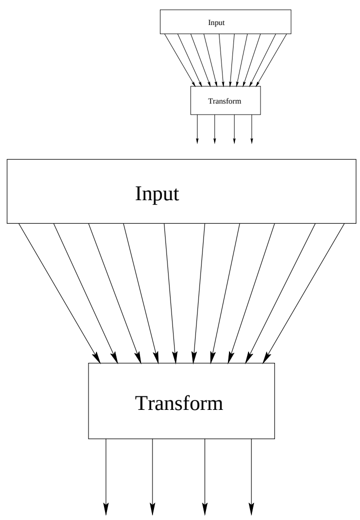
Some background information on natural scenes

- Statistics of natural scenes are stationary.
  This implies that:
  - The amplitudes of the Fourier coefficients are uncorrelated (Field 1989).
  - All of the correlations in the data are described by the amplitude spectra.
  - The amplitude spectrum describes the principal axes of the data in the state space(Pratt 1987).
- The amplitude spectra of natural scenes falls as roughly 1/f at all orientations.

Some background information on cells in the mammalian visual cortex

- The receptive fields are localized in space and are band pass in frequency but overlap in both space and frequency.
- The spatial frequency bandwidths are constant when measured on logarithmic axes (in octaves).
- They are orientation selective.

Compact coding



Compact coding;PCA

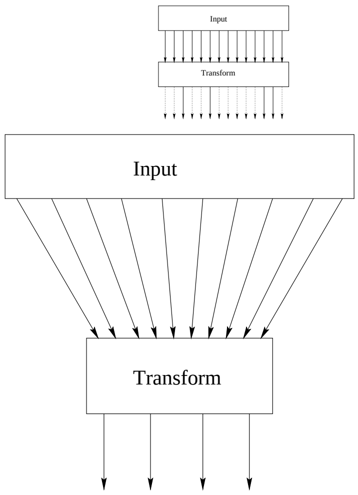
Good:

- PCA can be used to reduce the number of vectors when it is possible without losing important information.
  For example tirchromacity in human vision
- PCA can be used to determine which dimensions of the state space are needed to represent the data.

Bad:

- The principal components depend only on the amplitude spectra, phase spectra is ignored.
- Because the symmetry in the amplitude spectra the principal components don't always have an unique solution.
- A function is localized only when the phases of the Fourier coefficients are aligned. Because PCA ignores the phase spectra it wont reflect the presence of local structure in the data.

Sparse coding



Sparse coding

- The change in the response histograms can be represented in terms of kurtosis:

$$K = \frac{1}{n} \sum \left[\frac{(x - \bar{x})^4}{\sigma^4} \right] - 3 \tag{1}$$

- For a sparse code to be possible, a large set of vectors is needed to describe all possible images but only a small set is needed to describe any single image.
- An effective sparse code is determined by the relation between the data and the vectors.
- When searching for a sparse code, the goal is to find a set of units that are as independent from each other as possible.
- By maximizing the kurtosis of the response histograms, the statistical dependencies between units is minimized (Field 1987).

Tests on natural scenes

The following types of filters were used as models for cells in the visual cortex:

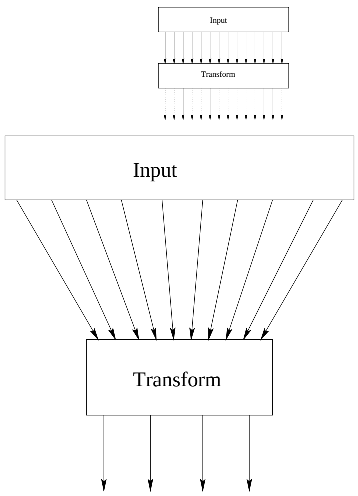
Difference of gaussians:

$$g(x, y) = 9e^{-(x^2+y^2)/2(\sigma)^2} - e^{-(x^2+y^2)/2(3\sigma)^2} \tag{2}$$

log-Gabor (Field 1987):

$$G(k) = e^{\ln(k/k_0)^2/[\ln(\sigma/k_0)]^2} \tag{3}$$

results



Possible benefits of sparse coding

- Sparse coding can increase the signal-to-noise ration.
- Recognition of corresponding structures.
- Storage and retrieval from associative memory.

Conclusions

- The measured response histograms form cells in the visual system is similar to results from filters that produce a sparse code in response to natural scenes.
- Filters that produce a sparse code find independent features from the data.
- By maximizing the kurtosis of the response histograms effectively minimizes the statistical dependencies between units.