Detecting Salient Contours Using Orientation Energy Distribution

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Based on Sarma and Choe (2006) and Lee and Choe (2003)

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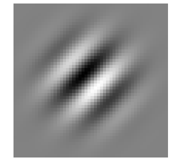
The Problem: How Does the Visual System Detect Salient Contours?



- Neurons in the visual cortex have Gabor-like receptive fields.
- Looking at the **response properties** of these neurons can help us answer the question.
- The simplest statistical property can be measured by looking at the **response histogram**.

Questioning from a slightly different perspective, "**how can the particular response property of visual cortical neurons be utilized by later processing?**"

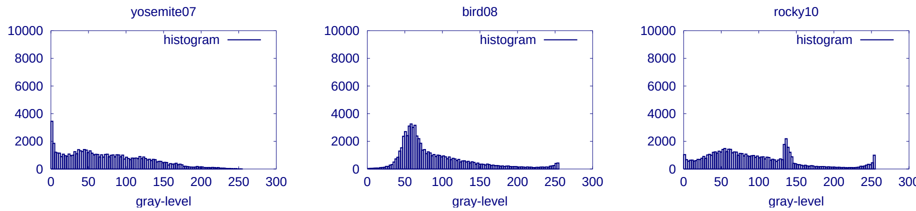
Observation

- Grayscale intensity distributions are quite **different** across different images.
- However, Gabor response distributions are quite **similar** across different images.

A Typical Grayscale Image

- Although not evident from the above, the intensity histogram can be widely different across different images.

Grayscale Intensity Distribution

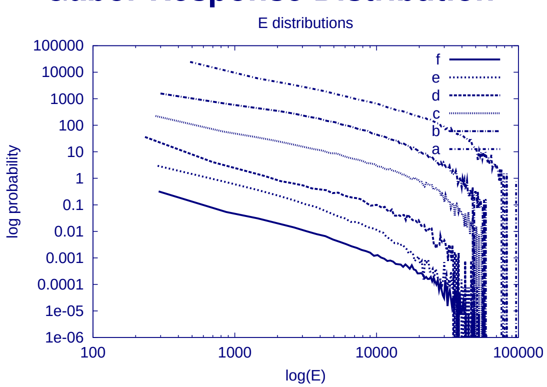


- Grayscale intensity histograms are drastically different across different images.
- Thus, a general algorithm for utilizing the intensity distribution cannot be easily derived.

A Typical Gabor Response (Orientation Energy)

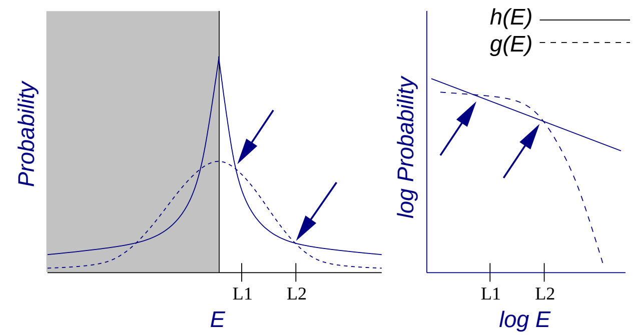
- High values near contours or edges.
- The energy distribution is strikingly uniform across images.

Gabor Response Distribution



- The Gabor response (or **orientation energy**; E) distributions on the other hand are quite similar across differen images (shown in Log-Log plot).
- The distribution shows a power law property ($f(x) = 1/x^a$): sharp peak and heavy tail.

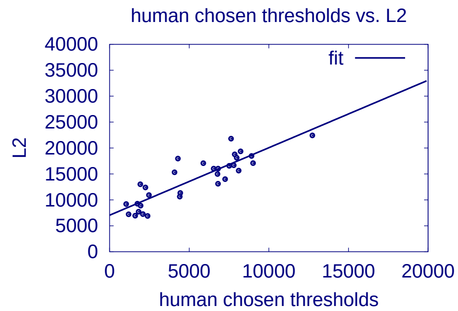
What to Make of the Power Law?



(a) linear scale (b) log−log scale

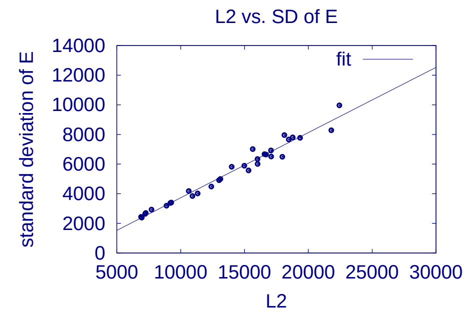
- Comparing the power law distribution with a normal distribution with the **same variance** can provide us with some information.
- **Assumption**: normal distribution can be a suitable standard.
- The point $L2$ where $h(E)$ becomes greater than $g(E)$ may be important, i.e., orientation energy is **suspiciously high**.

Exploiting the Power Law in E



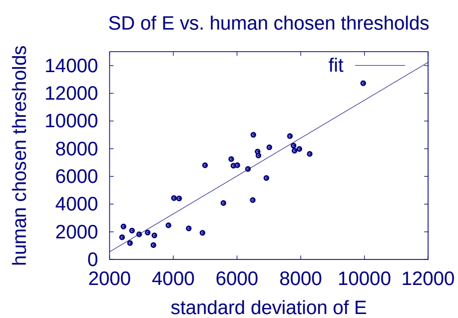
- High orientation energy E indicate a strong edge component in images.
- Can there be a relationship between the threshold of E above which humans see it as **salient** and the point $L2$?
- Clearly, there is a **linear relationship** between the two!

Further Discoveries: $L2$ and σ



- Further, the raw standard deviation σ of the orientation energy distribution is **linearly related** to $L2$.
- Question: Is there an analytical solution to $1/x^a = b \times exp(-x^2/c)$, where the constants a, b, and c depend on σ?

Using σ to Estimate Optimal E Threshold

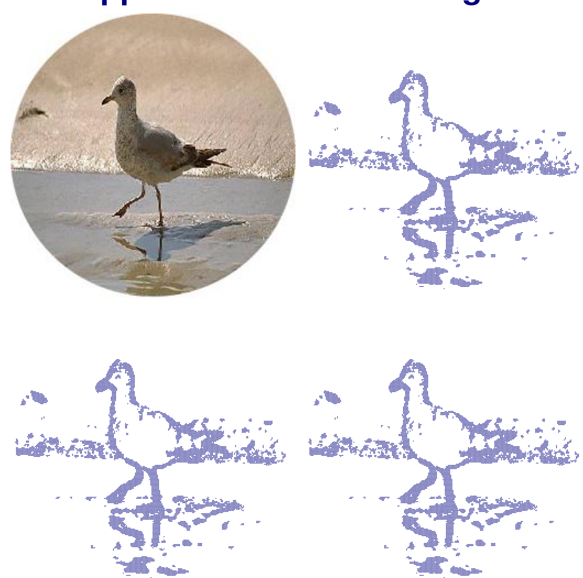


- Relating σ back to the human-chosen E threshold gives again a **linear relation**:

$$T_\sigma = 1.37\sigma - 2176.59.$$

- Thus, instead of calculating the histogram, etc., we can simply calculate the raw standard deviation σ to estimate the appropriate E threshold.

Application: Thresholding E



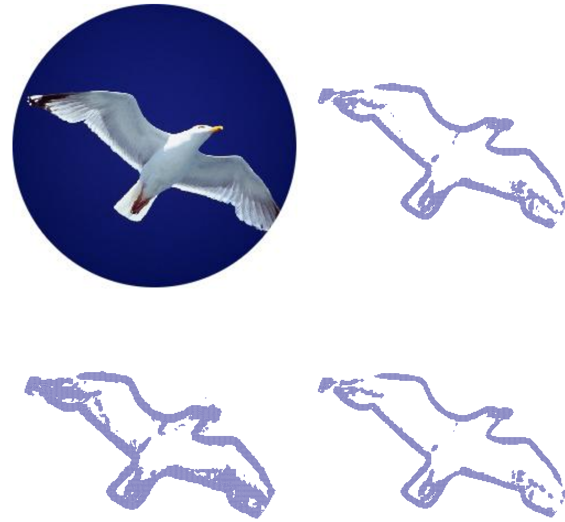
- Original, human-selected, 85-percentile, and T_σ.

Extraction of Salient Edges

(a) Original Image (b) Thresholded Edges (c) Magnified (b)

- Using T_σ as a threshold gives good results, comparable to humans' preference.

Thresholding E: Limitations of Fixed Percentile



- Original, human-selected, 85-percentile, and T_σ.

Thresholding E: Limitations of Global Thresholding

- Original, human-selected, 85-percentile, T_σ, and T_σ local.

Summary of Thresholding Results

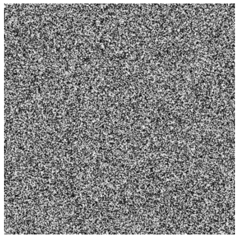
- Fixed percentile thresholding does not give consistent results.
- The σ-based T_σ threshold works well.
- However, globally applying the same threshold has limitations.
- This problem can be overcome by applying the **same principle** derived here to calculate the **local thresholds**.
- The proposed method is an **efficient** way of detecting salient contours.

Relationship Between T_σ Thresholding and Suspicious Coincidence

- What is the relationship between **salience** defined as **super-Gaussian** and the conventional definition of **suspiciousness** (Barlow 1994, 1989)?

$$P(A, B) > P(A)P(B).$$

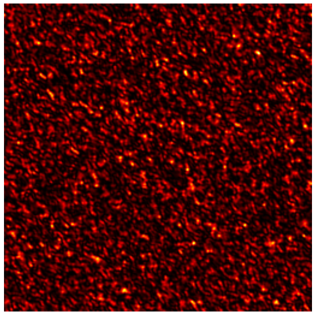
White-Noise Analysis

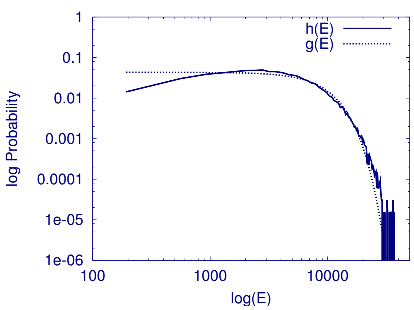


- If the Gaussian baseline assumption was correct, the E response distribution to white noise images should not be perceived as salient compared to a Gaussian with the same variance.
- In white-noise images, each pixel is independent, so, given pixel A and pixel B:

$$P(A, B) = P(A)P(B).$$

Gabor Response to White Noise Images



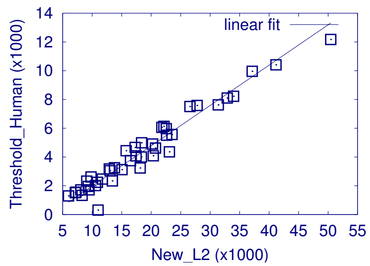


- The orientation energy distribution is very close to a Gaussian, especially near the high E values.
- Thus, the T_σ thresholding will result in no salient contours in white noise images.

Use of White Noise Response as a Baseline

- Can we use the white-noise response as a baseline for thresholding E?: Yes!
- Generate white noise response, and scale it by σ_h/σ_r where σ_h and σ_r are the STD in the natural image response and the white noise response.
- Recalculate the response distribution (if necessary).

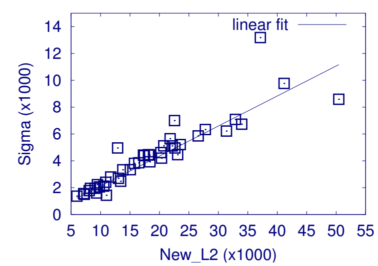
New Baseline for Salience vs. Humans



New L_2 vs. Human Chosen Threshold ($r = 0.98$)*

- Strong linearity is found between the new L_2 and the human selected threshold.
- * This is much tighter than the Gaussian baseline ($r = 0.91$)!

New Baseline for Salience vs. σ



New L_2 vs. σ ($r = 0.91$)

- The same linearity between L_2 and the σ is maintained.

Related Work

- Malik et al. (Malik et al. 1999) used peak values of orientation energy to define boundaries of regions of coherent brightness and texture.
- The non-Gaussian nature of orientation energy (or wavelet response) histograms has also been recognized and utilized for some time now, especially in denoising and compression (Simoncelli and Adelson 1996).
- Other kinds of histograms, e.g., spectral histogram by Liu and Wang (2002), or spatial frequency distributions (Field 1987), may be amenable to a similar analysis.

Discussion

- The local (or even global) threshold calculation can be easily implemented in a neural network.

$$\sigma^2 = \sum_{i,j} w_{ij} g(V_{ij}),$$

  where w_{ij} are connection weights serving as normalization constants, $g(x) = x^2$, and V_{ij} is the V1 response at location i, j.
- The resulting value can be passed through another activation function $f(x) = \sqrt{x}$.
- These are all plausible functions that can be implemented in a biological neural network.

Summary

- Gaussian baseline was found to have a close relationship to the idea of suspicious coincidence by Barlow (1994)

Lesson Learned

- Studying statistical properties of raw natural signal distributions can be useful in determining why the visual system is structured in the current form (e.g., PCA, ICA, etc. predicts the **receptive field** shape).
- However, **what's more interesting** is that the response properties of cortical neurons can have certain **invariant properties** and this can be **exploited**.
- So, we need to **go beyond** finding out what receptive fields look like and why, and start to explore how cortical neuron response can be utilized by the rest of the brain.

References

Barlow, H. (1994). What is the computational goal of the neocortex? In Koch, C., and Davis, J. L., editors, Large Scale Neuronal Theories of the Brain, 1–22. Cambridge, MA: MIT Press.

Barlow, H. B. (1989). Unsupervised learning. Neural Computation, 1:295–311.

Field, D. J. (1987). Relations between the statistics of natural images and the response properties of cortical cells. Journal of the Optical Society of America A, 4:2379–2394.

Lee, H.-C., and Choe, Y. (2003). Detecting salient contours using orientation energy distribution. In Proceedings of the International Joint Conference on Neural Networks, 206–211. IEEE.

Liu, X., and Wang, D. (2002). A spectral histogram model for texton modeling and texture discrimination. Vision Research, 42:2617–2634.

Malik, J., Belongie, S., Shi, J., and Leung, T. K. (1999). Textons, contours and regions: Cue integration in image segmentation. In ICCV(2), 918–925.

Sarma, S., and Choe, Y. (2006). Salience in orientation-filter response measured as suspicious coincidence in natural images. In Gil, Y., and Mooney, R., editors, Proceedings of the 21st National Conference on Artificial Intelligence. 193–198.

Simoncelli, E. P., and Adelson, E. H. (1996). Noise removal via bayesian wavelet coring. In Proceedings of IEEE International Conference on Image Processing, vol. I, 379–382.