Efficient Implementation of Foveation Filtering

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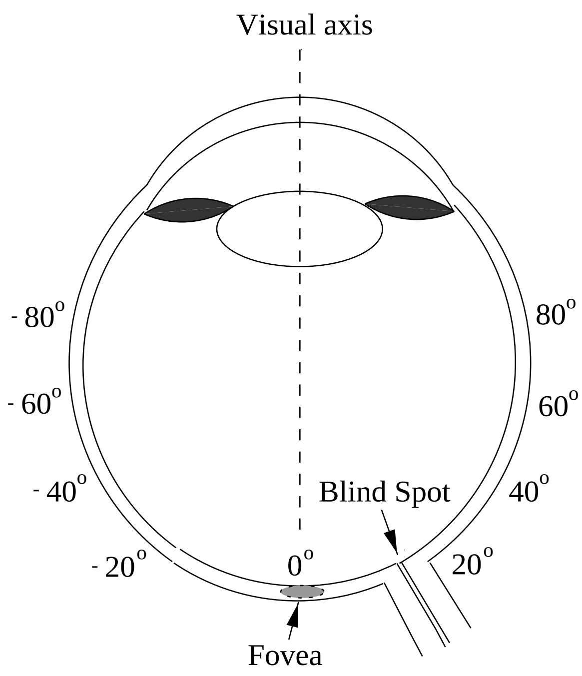
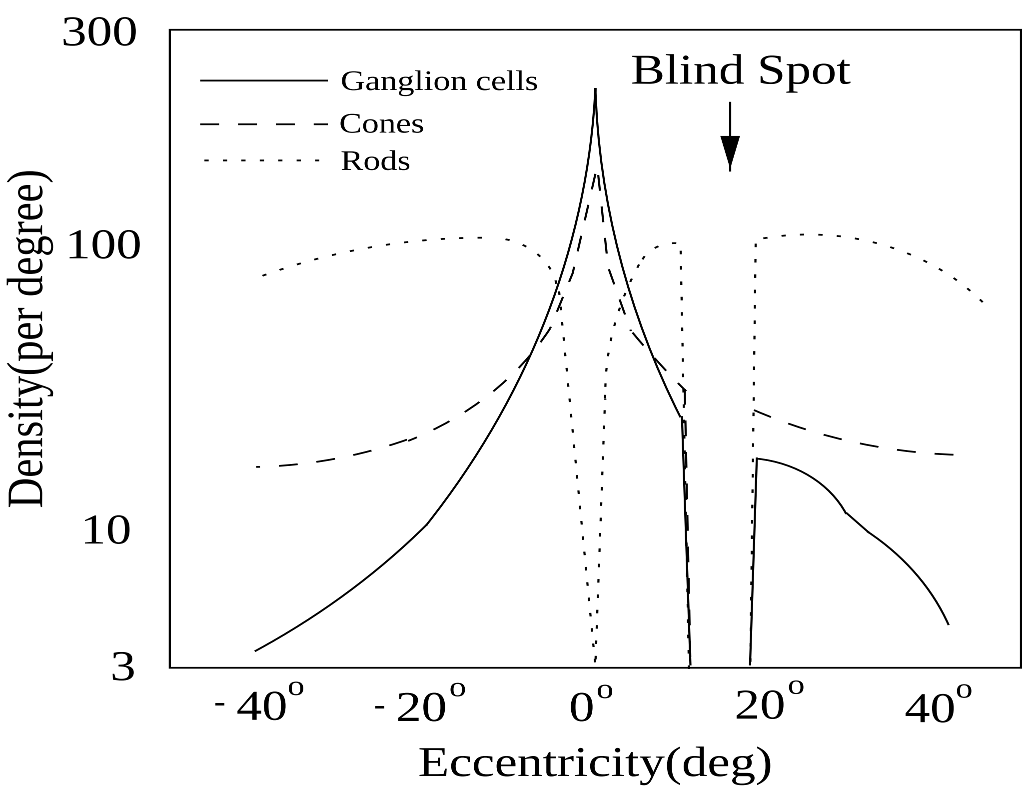
Motivation

- Fast foveation filter design
  - Reduce the number of operations (additions and mulitiplications)
  - Obtain the high visual quality of foveated images

Human eye and photoreceptor density





Foveated image: *news* (352 x 28)

Foveated video vs. regular video

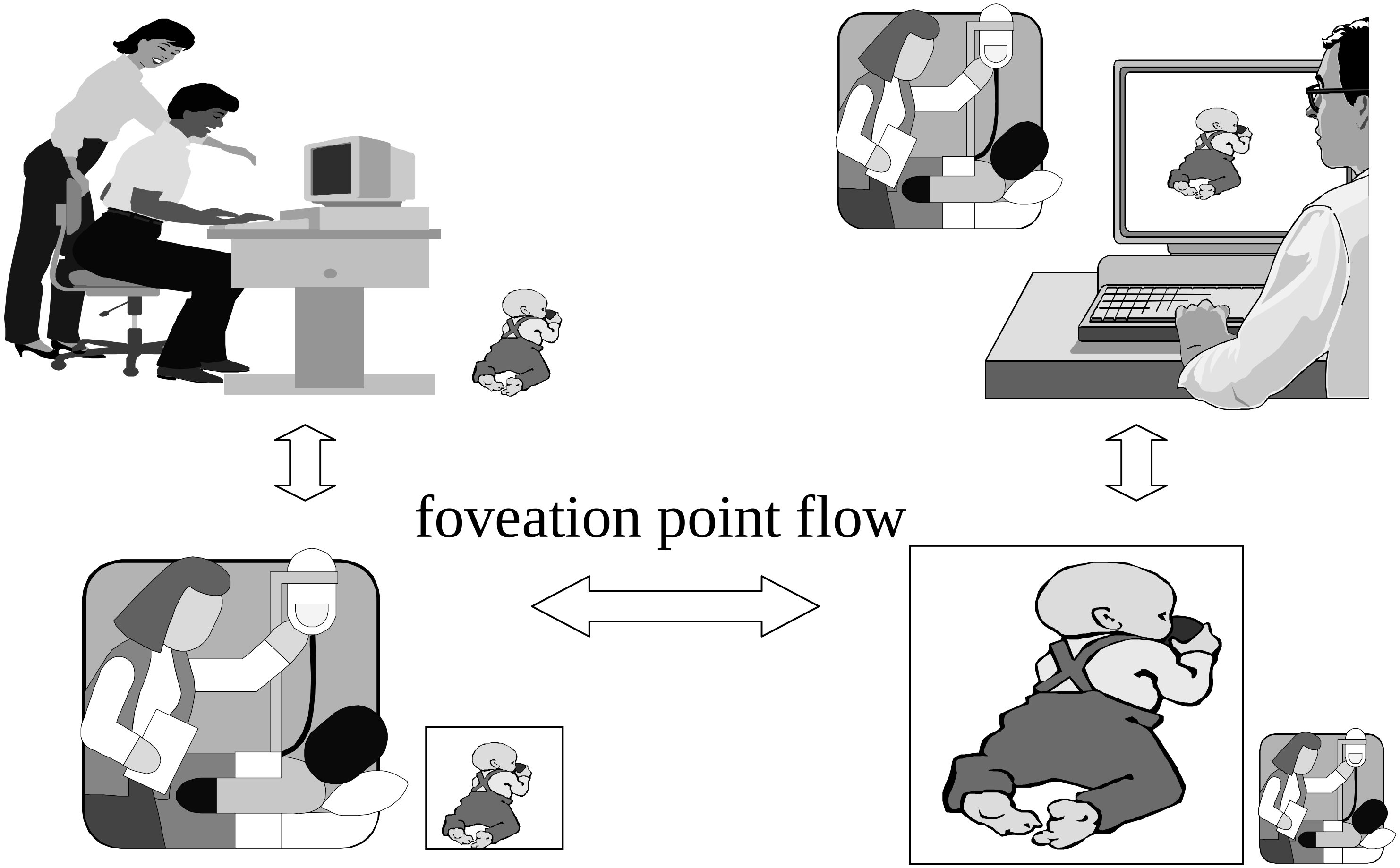
- PSNR = 30.10
- FPSNR = 29.54

- PSNR = 33.92
- FPSNR = 35.01

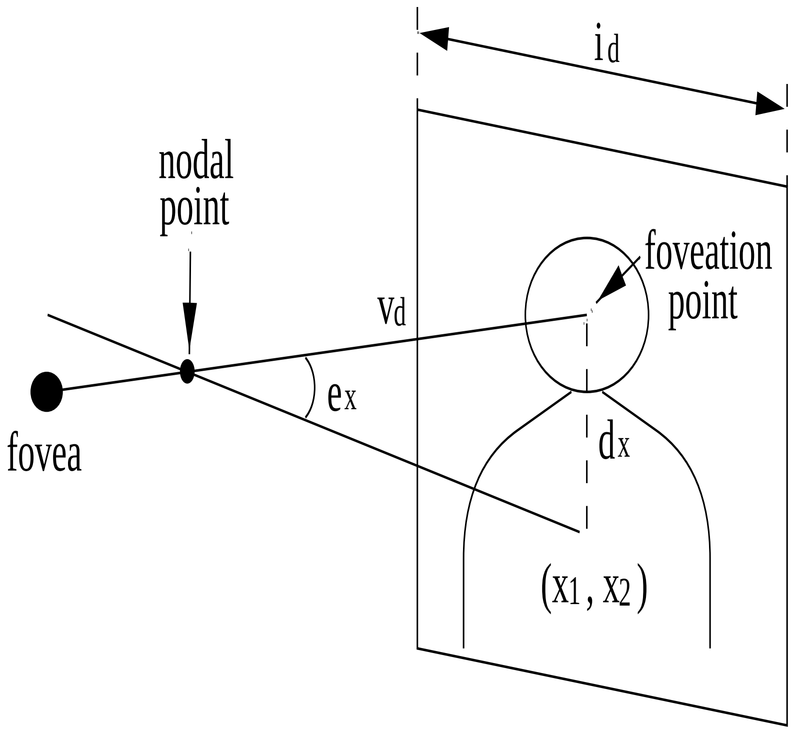
Foveation point selection

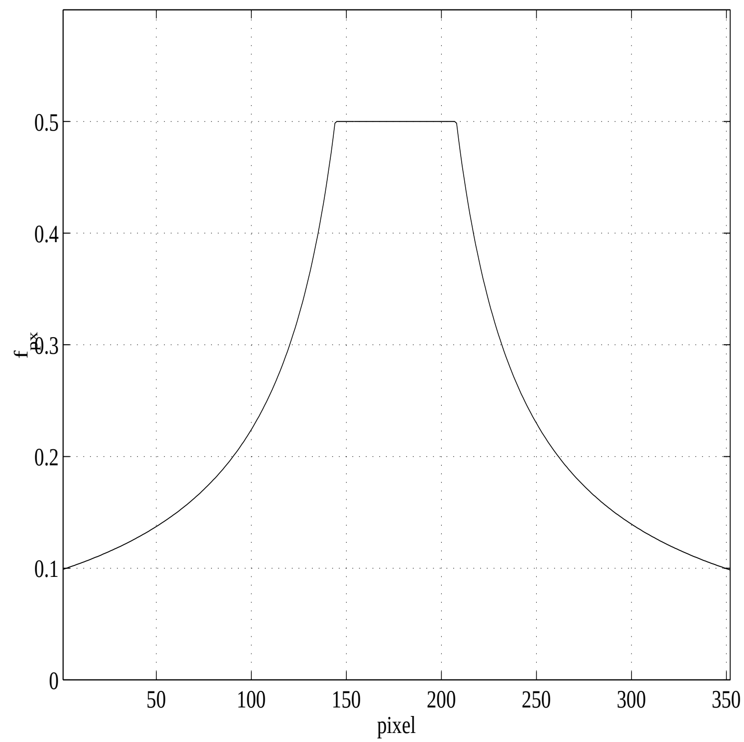
- Stored video application
  - Web news: prior to video compression
- Real-time visual communications
  - Selected by both sender and receiver
  - Automatic detection for face-to-face communications
- Remote navigation or emergency vehicles: eye tracker

Human interactive multimedia



Human visual system modeling





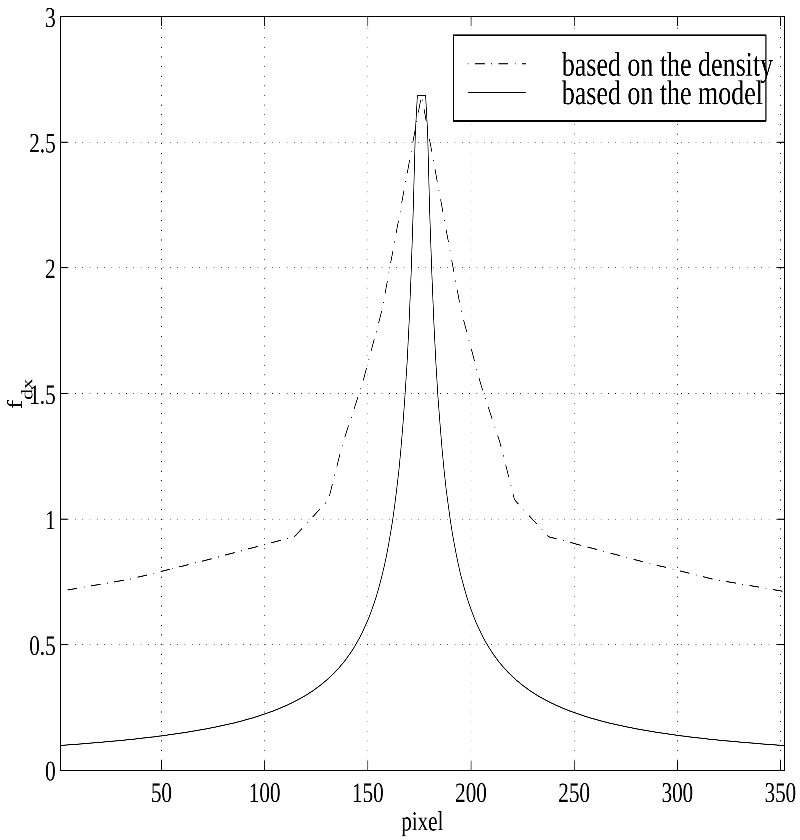
Viewing parameter

Spatial frequency (cyc/deg)

v_d visual distance, e_x eccentricity, i_d image size

$$e_x = \tan^{-1} (i_d \, d_x / (i_p \, v_d))$$

Local bandwidth acquisition



- Calculate eccentricity at each pixel by
  $e_x = \tan^{-1} (i_d d_x / (i_p v_d))$
- Derive detectable frequency from the spatial mosaic of cones based on the sampling theorem
  $f_d = \gamma / (e_x + \eta) - \zeta$
- Obtain the local bandwidth from the detectable frequency
- Use the local bandwidth as the cutoff frequency in the filter design

Ideal foveation filter design

- Parseval's theorem

$$\sum_{i=-\infty}^{\infty} h^{*2}(i) = \frac{1}{2\pi}\int_{-\pi}^{\pi} |H^{*}(e^{i\omega})|^{2}\, d\omega = \frac{\omega_c}{\pi}$$

$$where H^{*}(e^{i\omega}) = 1,\ |\omega| < \omega_c \text{ and } 0,\ \omega_c \triangleleft |\omega| < \pi$$

  - If ω_c is changed according to each pixel such as $\omega_c = 2\pi f_{pn}$, then the ideal low pass filter $H^{*}(., f_{pn})$ is used to create foveated images

Practical foveation filter design

- Let $h(i)$ and $H(e^{i\omega})$ be the Fourier transform pair of low pass filter with the filter length N
- Then, the total energy of the error signal becomes
$$e = \sum_{i=-\infty}^{\infty} [h^*(i) - h(i)]^2$$
- The error ratio $\tau = e\pi / \omega_c$ is inversely proportional to the cutoff frequency
- We can decide the filter length *N* while τ is less than a constant associated with the cutoff frequency at each pixel

Separable even symmetric filter

- To reduce the number of multiplications, we use a separable even symmetric low pass filter $l_n(i_1,i_2)=l_n(i_1)l_n(i_2), \text{ if } -N_n/2 \le i_1,i_2 \le N_n/2$

$$=0, \qquad \text{otherwise}$$

  – where N_n is the filter length at the n^{th} pixel
- For the separable even symmetric filter, the number of operations is reduced to

$$2(N_n/2+1)$$

for additions and multiplications for each pixel

Circularly symmetric filter

- Using circularly symmetric filters, we can obtain more symmetric frequency response associated with the local bandwidth
- The octal symmetry of circularly symmetric filters $l_n(i_1,i_2)=l_n(\pm i_1)l_n(\pm i_2)=l_n(\pm i_2)l_n(\pm i_1)$
- The number of operations for each pixel
  - For additions $7(N_n/2+1)(N_n/2+2)/2-6$
  - For multiplications

$$(N_n/2+1)(N_n/2+2)/2-1$$

Simulation results

- The distribution of foveation points is assumed to be a Gaussian function

$$p(n_1, n_2) = \alpha\, e^{-2\pi^2\sigma^2 r^2 / i_p^2}$$

where *r* is the distance from foveation point to pixel *n*, i_p is the number of pixels in horizontal line, σ is selected by the half-peak radius

Average number of multiplications at each pixel

	separable			circularly		
	τ			τ		
	0.15	0.1	0.05	0.15	0.1	0.05
$\sigma=0.38$	7.4	10.1	20.9	8.4	16.1	69.0
$\sigma=0.57$	7.2	9.8	20.8	7.9	15.2	63.9

Original image

Foveated image

sep., adaptive N_n, $\tau = 0.1$

Conclusions

- Implement very efficient real-time foveation filtering having low pass filters with continuously varying cutoff frequencies
- Obtain the cutoff frequency based on human visual modeling
- Reduce the computation complexity by changing the filter length according to the magnitude of cutoff frequencies

Foveated image

circular., N=31

Foveated image

circular, adaptive N, $\tau = 0.1$