
FAST-MOST INFORMATION EXTRACTION BY RETINAL Y-X CELLS

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ABSTRACT

In mammalian retina, the Y (or M) ganglion cells respond more transiently, have larger receptive fields, and are less spectral selective than the X (or P) cells. A “fast-most” model is introduced to show that the differences between the cells can be explained by assigning different functional goals to them. The goal of the Y cells is to extract as *fast* as possible the *minimum* amount of information necessary for quick responses. In contrast, the X cells are to extract as *much* information as possible.

1 MOTIVATIONS FOR DIFFERENT VISUAL GOALS

Earlier works ([8], [1]) proposed that the retinal ganglion cells in cats or monkeys are designed to transmit the maximum information possible. They explained the properties of the retinal X (or P) cells, but do not explain another type of ganglion cells — the Y cells in cats or M cells in monkeys ([3], [9]). (The distinctions between cats and monkeys are left outside the paper). Compared to X cells, Y cells have lower spatial resolution, more transient responses, less spectral sensitivity, and a larger conduction velocity. Unlike X (P) cells, Y (M) cells send axons to Superior Culliculus involved in eye movements.

It is generally believed that while the X channel analyzes the *fine* structures in the visual image, the Y channel does the *initial* analysis of the *gross* structure

[6]. In the present study, such different goals are formulated explicitly — while the X cells extract as *much* visual information as possible; the Y cells are modeled to extract as *fast* as possible, only the *minimum* amount of information needed for quick responses. It will be shown that the X and Y receptive fields are optimal to achieve their respective goals. Briefly, the sustained response by X cells integrates inputs, and thus enhances the signal-to-noise but sacrifices the speed. Therefore, the survival need to quickly locate relevant visual objects for visual feedback to, e.g., motor tasks, can only be served by the Y cells, whose transient response leads to fast reaction but “inaccurate” information. Denoting the X path as the “most” path (referring to extracting as much information as possible), then the Y path is the “fast” path. Roughly, the Y path detects “where”, and then the X path recognizes “what”, the objects are.

This “fast-most” model suggests that information preservation is not necessarily the goal for every pathway in the sensory systems — even at the early processing stages. *Fast* extraction of *minimum necessary* information is an important goal as well. It is consistent with the shorter latency of the Y cell signals to arrive in the cortex ([5], [2]). At higher visual levels, X-Y paths remain segregated ([10]), feeding the fast information back to the “most” path at lower visual levels can enhance the extraction of “more” information by attention. More details of the work can be found in [7].

2 INFORMATION EXTRACTION VS. IMPULSE RESPONSE

Let the visual input and noise at time t be $S(t)$ and $N(t)$ respectively. The ganglion cell with impulse response $A(t)$ and intrinsic noise $N_\delta(t)$ has outputs $O(t) = \sum_{t'} A(t-t')(S(t') + N(t')) + N_\delta(t)$. (Only linear response properties of the cell are considered for simplicity). Let $I(a; b)$ be the amount of information carried by a about b , we ask how much of the new information brought in by $S(0)$ at time 0 is extracted by outputs $O^t \equiv \{O(t), O(t-1), O(t-2), \dots, O(-\infty)\}$ over all time up to $t \geq 0$. The answer is $I_{out}(t) \equiv I(O^t; S^{t'=0}) - I(O^t; S^{t'=-1})$, where S^t is defined analogously to O^t .

By causality, $I_{out}(t < 0) = 0$. It increases with t and saturates as $t \rightarrow \infty$. A large $I_{out}(t)$ for small t or a short saturation time for I_{out} are signatures for a fast extraction; while a larger $I_{out}(\infty)$ means more total information extraction. $I_{out}(t)$ depends on $A(t)$. For (a trivial) example, if the output receives inputs with a delay δt , i.e., $A(t \leq \delta t) = 0$, then $I_{out}(t \leq \delta t) = 0$ by causality.

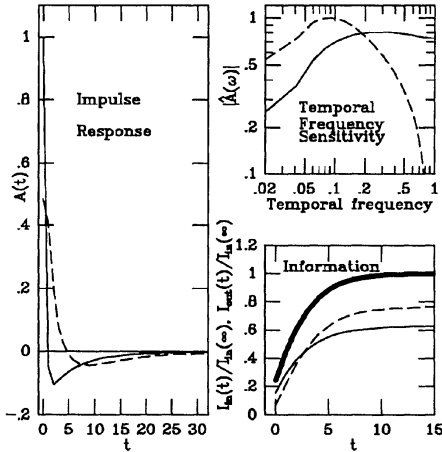


Figure 1 Results of “fast” and “most” cells in thin solid and dashed curves, respectively. Both impulse responses $A(t)$ have short time excitation and long time inhibition, but of different durations. The temporal frequency sensitivity $\hat{A}(\omega)$ is the Fourier transform of the impulse responses $A(t)$. The information plot shows $I_{out}(t)$ for “fast” and “most” cells (thin solid and dashed curves), and in thick solid curve is the input information $I_{in}(t)$, analogous to $I_{out}(t)$.

For their goals, X and Y cells should have impulse responses $A(t)$ to enlarge, respectively, $I_{out}(\infty)$ and $I_{out}(small\ t)$, or, with some output cost constraint C , to minimize, respectively, E^{most} and E^{fast} :

$$E^{most} \equiv C - \lambda^{most} I_{out}(\infty)$$

$$E^{fast} \equiv C - \lambda^{fast} F \equiv C - \lambda^{fast} \sum_t f(t)(I_{out}(t) - I_{out}(t-1))$$

where F is a rough measure of the fast information characterized by $f(t) = e^{-t/T}$ or other monotonously decreasing functions, T approximates the animal reaction time. Constants λ^{fast} and λ^{most} weight the information extraction goals against the output costs.

3 FROM “FAST-MOST” TO Y-X

The impulse responses are obtained by performing a gradient descent of E^{fast} (or E^{most}) on the space of $A^{fast}(t)$ (or $A^{most}(t)$) modelled with finite duration d with $0 \leq t \leq d-1$. (The input signals are approximated as gaussian with correlations $\langle S(t')S(t'-t) \rangle \equiv R(t) = S^2 e^{-t/\tau}$ and noises are assumed white.) Figure 1 shows that the fast cell has shorter durations in both the excitory and the inhibitory parts of its impulse response, i.e., more transient, and is thus more sensitive to higher temporal frequencies. At about the same output cost, the fast cell is faster ($I_{out}^{fast}(0) > I_{out}^{most}(0)$) while the “most” cell eventually extracts more information ($I_{out}^{fast}(\infty) < I_{out}^{most}(\infty)$). Thus, the transient and sustained responses are required by the “fast” and “most” goals, respectively. This is even more so if one considers X-Y cooperation, when the most path concentrates only on the information missed by the fast one ([7]).

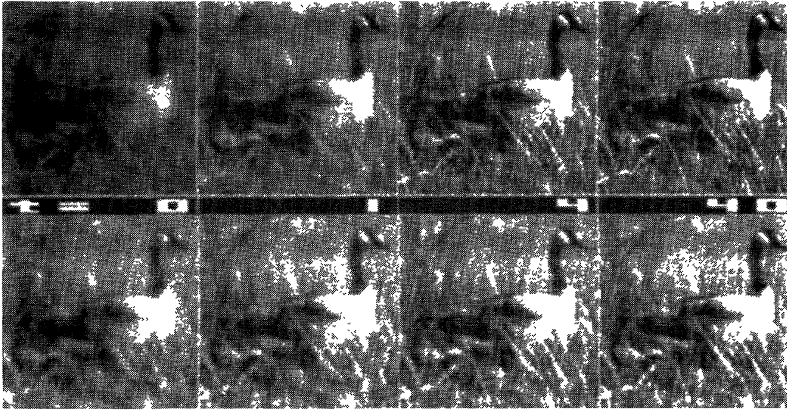


Figure 2 The top and bottom rows are the reconstructions of a retinal input image by the X and Y paths, respectively, in a model retina at time 0 ms, 10 ms, 40 ms, and 400 ms (from left to right, 10 ms per time step) after the image's onset, assuming no synaptic delays. The input layer is presented with spatial-temporal white noises until at time 0 when a natural image is added and stays on, retinal outputs from the X and Y paths are obtained using sustained-small and transient-large receptive fields, respectively, plus output white noises. The signal-to-noise at each input pixel at each time is around 1.5. At t , a homunculus (the brain) at the output reconstructs the inputs of time 0 using only the outputs before and up to time t from the X or Y path. It knew beforehand nothing of the inputs (including the image presentation time and the fact that the image is static) except the receptive field structures and the statistical properties in inputs and noises. A better reconstruction means more information extracted from the inputs. Note the goseling at its mother's lower right.

The impulse responses can be obtained for stimuli (or gratings) of all spatial frequencies, taking into account that signals of higher f have smaller signal powers (decreases as $1/f^2$ [4]) and shorter correlation times. In addition, λ^{fast} decreases with f to reflect the “minimum information” requirement for the “fast” cells. From the results, the center-surround receptive fields can be derived, demonstrating the lower spatial resolution of the “fast” cells. Color-blindness of the “fast” cells can be understood similarly [7].

4 CONCLUSIONS AND DISCUSSIONS

The agreements between the model consequences and the physiological observations supports the “fast-most” goals for Y-X cells — the Y cells extract the *minimum* information needed for responses as *fast* as possible, while the X cells extract as *much* information as possible. Figure 2 demonstrates such goal differences — while the Y path immediately detects objects, it never sees clearly; the X path sees well eventually, although slowly.

The “fast-most” model implies that the Y path is more likely to be concerned with visual attention task, and is likely the source of feedbacks to the X path in the lower visual levels. It stresses that retinal X and Y paths have different goals, and it is an alternative view to that of Van Essen and Anderson [10] who proposed that the retinal X and Y paths are complementary specializations to the same goal of transmitting the most information to the brain.

REFERENCES

- [1] Atick J.J., Redlich A. N., Neural Comp. 1990 v. 2 p. 308-320. and v. 4 p. 196-210 (1992). also Atick J.J., Li Z, Redlich A.N. v. 4 p. 559-572 (1992)
- [2] Cleland B.G. , Levick W.R, and Sanderson K.J. (1973) J. Physiol. 1973 v. 228, p. 649-680.
- [3] Derrington A.M, Lennie P. J. Physiol. 1982 v. 333 p. 343-366, and v. 357 p. 219-240 (1984).
- [4] Field D.J. J. Opt. Soc. Am. 1987 v. 4 p. 2379-2394
- [5] Ikeda H., Wright M.J. J. Physiol. 1972 v. 227 p. 769-800.
- [6] Kandel E.R., Schwartz J. H. “Principles of Neural Science” 1985 Second Ed. Elsevier
- [7] Li Z. International Journal of Neural. Systems. 1992 v. 3(3)
- [8] Linsker R, Computer 1988 21 v. 3 p. 105-117. and “Advances in Neural Information processing Systems I”, ed D. Touretzky p. 186-194.
- [9] Shapley R, and Perry V. H. Trends in Neurosci. 1986 v. 9 p. 229-235.
- [10] Van Essen D. C, Anderson C. H. In “Introduction to Neural and Electronic Networks” 1990 eds S.F. Zornetzer, J.L. Davis, C. Lau. Academic Press, Orlando, Florida.