Supplemental material 1

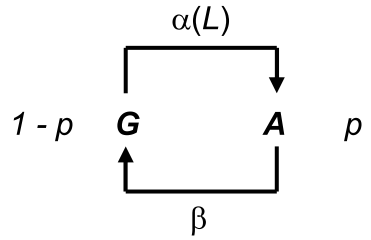

Fig. S1 The simple photocycle model consists of two states, the ground state (*G*) where the channel gate is closing and the activated state (*A*) where the gate is open (Fig. S1). The macroscopic rate constant from *G* to *A*, $\alpha(L)$, is a function of light power density (L), the photon density. The macroscopic rate constant from *A* to *G*, β, is not dependent on light. If the molecule is in the state *A* with a probability p, the current amplitude I is related to p by the following relationship,

$$I = i\,N p, \tag{1}$$

where, N is the number of molecules in a cell and i is the current produced by a single molecule. When $L = 0$, all the molecules are in *G* ($p = 0$). Upon turning on the light with a given intensity L, the probability increases by Δp in a period of Δt in a relation as follows.

$$\Delta p = \alpha(L)\,(1 - p)\,\Delta t - \beta\,p\,\Delta t\,. \tag{2}$$

That is,

$$\Delta p = \alpha(L)\,\Delta t - [\alpha(L) + \beta]\,p\,\Delta t\,, \tag{3}$$
$$dp/dt = \alpha(L) - [\alpha(L) + \beta]\,p. \tag{4}$$

Therefore, during the turning-on transition, p increases with a time constant of $[\alpha(L) + \beta]^{-1}$. This gives the ON rate constant of photocurrent activation as a function of L,

$$\text{ON rate constant} = \alpha(L) + \beta. \tag{5}$$

When light is turned off, $\alpha(L) = 0$ in equation (4). That is,

$$dp/dt = -\beta\, p. \tag{6}$$

Since p decreases with a time constant of β^{-1} during the turning-off transition, the OFF rate constant of photocurrent is equal to β.

$$\text{OFF rate constant} = \beta. \tag{7}$$

On the other hand at the steady-state ($dp/dt = 0$), the steady state current, I_{ss} is equal to,

$$I_{ss} = i\,N\,p_{ss} = i\,N\,\alpha(L) / [\alpha(L) + \beta]. \tag{8}$$

If G to A is a single photon reaction,

$$\alpha(L) = \varepsilon\,\phi\,L, \tag{9}$$

where the constant ε is a molar absorption coefficient and the constant ϕ is a quantum yield. Therefore, the ON rate constant is predicted to be a first order relation of L,

$$\text{ON rate constant} = \varepsilon\,\phi\,L + \beta. \tag{10}$$

If the relationship (9) is also applied to (9), we can predict that

$$I_{ss} = i\,N\;\varepsilon\,\phi\,L / (\varepsilon\,\phi\,L + \beta). \tag{11}$$

Using Lineweaver-Burk plot, the following relationship is predicted between $(I_{ss})^{-1}$ and L^{-1} as,

$$(I_{ss})^{-1} = (i\,N)^{-1}\,\{1 + (\beta\varepsilon^{-1}\phi^{-1})\,L^{-1}\}, \tag{12}$$

which gives the linear line with a x-intersection at $(-\beta^{-1}\varepsilon\phi)$ and a y-intersection at $(i\,N)^{-1}$. Therefore, both relationships (10) and (12) enables one to estimate $(\varepsilon\phi)$, the value representing the intrinsic light sensitivity of the molecule.

Supplementary material 2

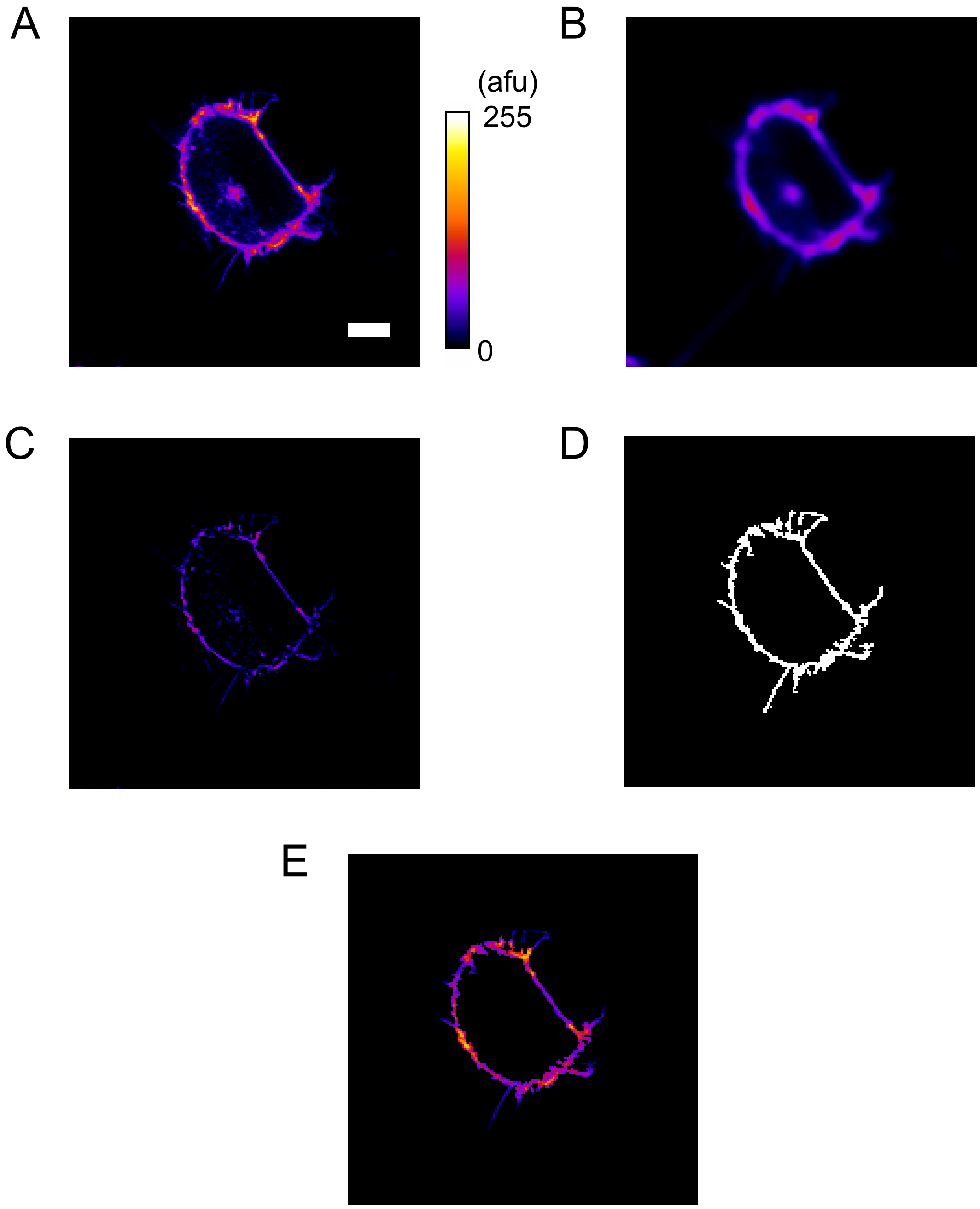

Fig. S2 Algorism to identify a cell's contour.
(**A**) A confocal images of the representative HEK293 cell expressing Venus-conjugated ChR2(1-315). Scale bar, 5 μ m. The fluorescence intensity is scaled by the arbitrary fluorescent unit (afu) and expressed in pseudocolor ratings. (**B**) The 2-pixel Gaussian-filtered image. (**C**) The difference image between A and B. This difference is expected to be large in a region where the spacial change of fluorescence is large. (**D**) The cell's contour is thus dichotomously extracted using ImageJ's wand (tracing) tool. This image gives the number of pixels in the plasma membrane region. (**E)** Multiplied image of A and D. The sum fluorescence is calculated using values given to all pixels in this image.