The role of photon scattering in voltage-calcium fluorescent recordings of ventricular fibrillation: *Supporting Material*

Martin J. Bishop, Alexander Rowley, Blanca Rodriguez,
Gernot Plank, David J. Gavaghan, Gil Bub

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1 Measurement of Dissociation: Mutual Information

Mutual Information (MI) is a robust signal processing technique which provides a non-linear measure of the statistical dependence between two variables, quantifying how much knowledge of one reduces our uncertainty in predicting the value of the other. MI can thus be applied to give a numerical measure of dissociation between to two time-varying signals, such as voltage and calcium recordings. For example, assume we have two signals of N data points: V_m^n, Ca^n ($n = 1 \rightarrow N$). From these data sets, a 2D scatter plot is produced $[V_m^n, Ca^n]$, which is then sub-divided, or binned, into a course-grained plot with grid dimensions $K \times K$, with columns $C_1 ... C_K$ and rows $R_1 ... R_K$ defining a bin, or grid element, by B_{ij}. Therefore, the probability of a certain point falling within a box B_{ij} is given by the probability of it falling within a row R_i multiplied by the probability of it falling within column C_j, provided that rows and columns are independent. MI then uses the discrepancy between this calculated probability relative to the actual probability that points lie within box B_{ij}. If the two signals are truly independent, then these probabilities are the same; if they are not independent, then the probabilities are different. The more they differ, the greater the association between the two signals.

Mathematically, the number of points lying in row R_i, column C_j and box B_{ij} are given by $\#R_i$, $\#C_j$ and $\#B_{ij}$, respectively. We can then define the probabilities of being within each of these as

$$P\left(R_i\right) = \frac{\#R_i}{N}, \qquad P\left(C_j\right) = \frac{\#C_j}{N}, \qquad P\left(B_{ij}\right) = \frac{\#B_{ij}}{N}. \tag{1}$$

MI is then defined to be

$$\mathrm{MI} = \sum_{i,j=1}^{K} P\left(B_{ij}\right) \times \log_2 \left[\frac{P\left(B_{ij}\right)}{P\left(R_i\right) P\left(C_j\right)} \right]. \tag{2}$$

2 Dependence Upon Specific MI Parameters

The purpose of this section is to investigate whether the specific choice of the different MI parameters, used in the calculation of the MI statistic above, affects the relative dissociation seen in the electrical and optical signals, as defined by the calculated MI value. Fig. S1 below shows the variation of maximum MI score as the decimation level (a) and the number of bins (b) parameters is varied for the case of ventricular fibrillation for the electrical (solid-line) and optical (dashed-line) signals. Note that previous default values of decimation factor and number of bins in the MI calculations were 15 and 10, respectively. Although in both cases the MI score changes significantly, importantly we see that the relative separation between the electrical and optical signals is preserved (other than at very small decimation levels and bin numbers). We can therefore conclude that the conclusions we have drawn regarding the relative differences in MI scores between electrical and optical signals are not overly sensitive to the specific MI parameters used in the calculation of the statistic.

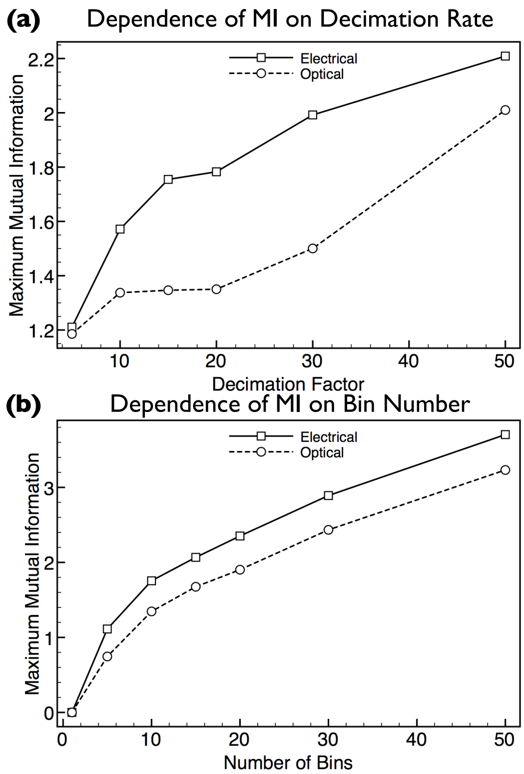

Figure 1: S1 - Dependence upon MI parameters. Variation in maximum MI during an episode of VF in the electrical (V_m/Ca, solid line) and optical (V_{opt}/Ca_{opt}, dashed-line) signals as a function of decimation factor (panel a) and bin number (panel b).