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Phase-alignment of delayed sensory signals by adaptive filters

Dennis J. McFarland
Wadsworth Laboratories, New York State Department of Health, Empire State Plaza, Albany, NY 12201. mcfarlan@wadsworth.org

Abstract

Correction of sensory transmission delays is an intractable problem because there is no absolute reference for calibration. Phase alignment is a practical alternative solution and can be realized by adaptive filters that operate locally with simple error signals.

Nijhawan suggests that the visual system compensates for delays, with the perceived position of a moving object being based on a type of guess as to the object's actual position. This would be adaptive, as it is necessary that the output of the visual system be synchronized with the environment and behavior. However there is really no way that any part of the nervous system can be calibrated to correct for transmission delays because there is no absolute reference available for calibration. As such, the calibration problem is intractable. This problem can be solved instead by aligning the relative phase of the signals in question. This is a common problem in engineering that has relatively simple and straightforward solutions.

Problems produced by transmission delays are frequently encountered in electrical engineering. Examples include cancellation of echoes produced in long-distance transmission lines and adaptive beam-forming from an array of sensors with delayed outputs (e.g., spatially separated sensors in a sonar system). These problems can be solved by means of adaptive filters with delayed inputs (Hayken 1996). The proper delay is selected by appropriate weighting on the delayed inputs. These weights are adjusted by some simple characteristic of the output, such as by minimizing the variance of the signal subject to the condition that the sum of the weights equals 1.

Adaptive filters capable of phase-aligning signals can be realized by simple operations that can be implemented either by algebraic equations or by a few elements of an artificial neural network. This means that the neural circuitry need not be complex. The cost function that tunes these filters can be very simple, so that it is not necessary to appeal to complex cognitive processes. Some characteristic of the fused signal, such as the variance, serves as an error signal to adjust the weights given to the delay elements. All that is required for phase alignment is some sort of recursive feedback of the output of a perceptual subsystem that adjusts the connections of the delayed inputs. The simplest design is a tapped-delay line filter, although there is no unique solution to this problem. The logical point for phase alignment would be the step in processing that precedes the fusion of the to-be-aligned signals, as this would minimize the length of the path required for the recursive feedback and ensure the fidelity of the error signal. If filters are tuned by the output of areas far removed from the site of sensor fusion, the error signal will not closely reflect the characteristics of the fusion product. Thus we would expect the site of phase alignment to be the local network involving both the site of fusion and the immediate sources of its to-be-aligned inputs.

To the extent that the phase-alignment problem is solved with adaptive filters, we should expect that there would be no absolute delay correction employed by perceptual systems. Rather, the phase correction would depend on the problems encountered during the recent history of the various perceptual subsystems. An understanding of how this process works might best be obtained by observing the plasticity in the calibration of perceptual subsystems (i.e., the statistics of the observer's environment). Fusion of audiovisual speech is an example.

Vatakis et al. (2007) measured judgments of the temporal order of auditory and visual speech tokens. Participants were concurrently exposed to audiovisual speech that was presented either in synchrony or with the auditory stream lagging by 300 msec. They found that exposure to asynchronous audiovisual speech shifted the point of subjective simultaneity in the temporal order task. These results demonstrate that even the brief exposure encountered in a typical experimental session is capable of recalibrating the relative phase of perceptual subsystems. Thus, phase alignment in this case is an adaptive process.

Phase alignment by adaptive filters can operate locally within a relatively simple network using simple error signals. As a result, the top-down input to perceptual systems does not need to involve complex cognitive processes from remote higher cortical regions.

Furthermore, the input is in the form of adjustments to the strength of synaptic weights that tune perceptual filters. This adjustment occurs in a slow post hoc manner so that changes resulting from any current mismatch do not affect on-line processing. This slow change would occur on a timescale much longer than that of individual perceptual events. This is in contrast to the view expressed by Nijhawan, in which prediction is based on an interaction of visual systems with information from areas much farther downstream.

Prediction is a difficult problem that is not explained by simply appealing to top-down input to perceptual processing streams. Phase alignment is a tractable problem with simple solutions. Prediction is based on a Cartesian view of the problem that considers the perception of motion to be the instantaneous value of a continuous variable that starts and stops a counter somewhere in the brain. Phase alignment involves a filter that integrates input from sensors across time to produce an output, the nature of which is adjusted by prior sensory experience.<C-Text ends>

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References [Dennis J. McFarland] [DJM]

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