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An implicit approximate normalization model for multi-sensory integration across reference frames

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Many brain processes (including multisensory integration and reference frame transformations) can be performed by probabilistic inference (PI). Divisive normalization (requiring intractable integral) has been proposed as a possible mechanism for implementing PI in the brain. Here, we propose an alternative, more physiologically feasible, mechanism to perform divisive normalization; implicit approximate normalization (IAN). We implemented a multi-layer feed-forward neural network using different neural coding schemes within the same network and trained it to perform multisensory integration across reference frames in one step using a standard pseudo-Newton method with preconditioned conjugate gradient descent. The performance of this network was comparable to a probabilistic population code network, but without requiring non-linear/divisive operations. IAN produces a wide range of behaviors similar to recorded activity in the brain: inverse effectiveness, the spatial correspondence principle, gain-like modulations, super-additivity, multisensory suppression, and modulation of neural activity by varying cue reliability. The strength of IAN is that it performs well with a fraction of the units required by explicit methods (i.e. in a network with two cues to be combined in 3-D and 100 units in each dimension, divisive normalization requires 10^12 while IAN requires 10^3 units). In conclusion, the results of this study demonstrate that normalization can be done in simple feed-forward networks of purely additive units without the requirement of explicit divisive normalization.