

## Real-Time Adaptive Color Segmentation by Neural Networks

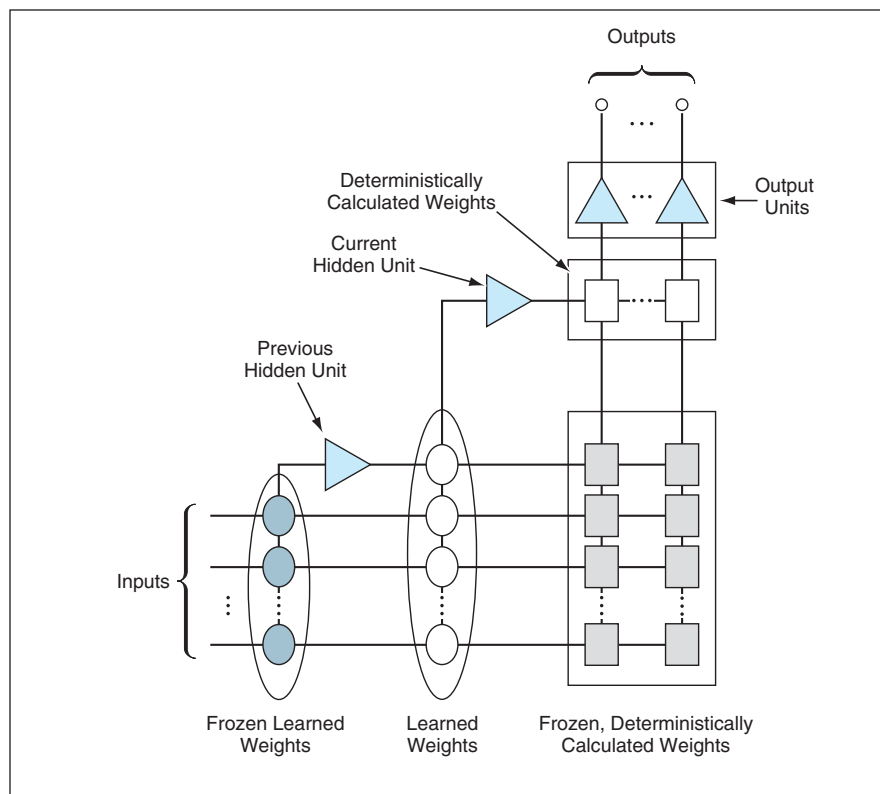
Changing images would be analyzed to detect features of interest.

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Artificial neural networks that would utilize the cascade error projection (CEP) algorithm have been proposed as means of autonomous, real-time, adaptive color segmentation of images that change with time. In the original intended application, such a neural network would be used to analyze digitized color video images of terrain on a remote planet as viewed from an uninhabited spacecraft approaching the planet. During descent toward the surface of the planet, information on the segmentation of the images into differently colored areas would be updated adaptively in real time to capture changes in contrast, brightness, and resolution, all in an effort to identify a safe and scientifically productive landing site and provide control feedback to steer the spacecraft toward that site. Potential terrestrial applications include monitoring images of crops to detect insect invasions and monitoring of buildings and other facilities to detect intruders.

The CEP algorithm is reliable and is well suited to implementation in very-large-scale integrated (VLSI) circuitry. It was chosen over other neural-network learning algorithms because it is better suited to real-time learning: It provides a self-evolving neural-network structure, requires fewer iterations to converge and is more tolerant to low resolution (that is, fewer bits) in the quantization of neural-network synaptic weights. Consequently, a CEP neural network learns relatively quickly, and the circuitry needed to implement it is relatively simple.

Like other neural networks, a CEP neural network includes an input layer, hidden units, and output units (see figure). As in other neural networks, a CEP network is presented with a succession of input training patterns, giving rise to a set of outputs that are compared with the desired outputs. Also as in other neural networks, the synaptic weights are updated iteratively in an effort to bring the outputs closer to target values. A distinctive feature of the CEP neural network and algorithm is that each update of synaptic weights takes place in conjunction with the addition of another hidden unit, which then re-



A CEP Neural Network, depicted here in simplified form, is well suited to real-time learning and to implementation in VLSI circuitry.

mains in place as still other hidden units are added on subsequent iterations. For a given training pattern, the synaptic weight between (1) the inputs and the previously added hidden units and (2) the newly added hidden unit is updated by an amount proportional to the partial derivative of a quadratic error function with respect to the synaptic weight. The synaptic weight between the newly added hidden unit and each output unit is given by a more complex function that involves the errors between the outputs and their target values, the transfer functions (hyperbolic tangents) of the neural units, and the derivatives of the transfer functions.

The adaptive color-segmentation process of a proposed CEP can be summarized as follows: The knowledge acquired by the network up to a given time,  $t_0$ , would be used in segmenting the image at the next increment of time,

$t_0 + \Delta t$ . The results of the segmentation at  $t_0 + \Delta t$  would then be used to update the knowledge pertaining to time  $t_0$ . This segmentation and updating would be performed repeatedly as new imagery was acquired.

On the basis of (1) computational simulations using representative terrain images and (2) the performances of prior CEP integrated circuits, it has been estimated that adaptive learning can be achieved in times of the order of milliseconds. An important issue that must be addressed in practical development is how often updates must be performed: The frequency of updates would directly affect the power demand of the proposed CEP circuitry.

*This work was done by Tuan A. Duong of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-30692*