Paper:

Visual Cortex Inspired Intelligent Contour Detection

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The present paper proposes a model for intelligent image contour detection. The model is strongly based on the architecture and functionality of the mammalian visual cortex. A pixel-to-feature transformation is performed on the input image, the result of which is a set of abstract image features, instead of another set of pixels. The contouring task is performed by a vast and complex network of simple units of computation that work together in a parallel way. The use of a large number of such simple units allows a clear structure that can be implemented on a special hardware to allow constant time computation.

Keywords: image contour detection, visual feature array, negative filtering

1. Introduction

The main goal of this paper is to present a cognitive model based on the visual cortex, which is able to perform image contouring in an intelligent way. Besides the possibilities of practical applications of the model, it also represents a different and rather new approach based on cognitive psychology and neurobiology, which aims to extend the limits of classical computation.

In order to show why cognitive models can give the necessary boost, consider the example where a test person has to determine whether there is a cat or something else in the shown image, and press a button according to the decision. Such a task is impossible for a computer to perform today, yet a human can do it reliably in half a second or less. This result becomes more shocking if we know that the “processing time” of the basic processing unit of the brain (a typical neuron) is in the range of milliseconds, while the basic processing unit (a logic gate) of a modern silicon-based computer is 5 million times faster. The answer for how the “slow” brain can solve this task lies in its special architecture and particular information representation and processing. It is thus our belief that in order to step beyond the borders of today’s computer systems’ architectures the basic way of information representation and processing has to be changed. For new ideas we turn to existing cognitive systems in biological architectures to study them, because they already bear the solutions that we are seeking for. A cognitive system is implemented in a biological neural network, where simple units of computation are connected in a very complex structure. Our research goal is to turn the cognitive information processing system into engineering models which can later be organized into a cognitive psychology inspired model running on a biology related computational architecture.

A cognitive process is an abstract concept which can be considered as an information processing function. A cognitive system is composed of many cognitive processes each responsible for a different task. By the complex structure of mutual interaction of the cognitive processes the cognitive system becomes very sophisticated with new limits of computation. A cognitive process only describes a functionality, but it does not say anything about the way of implementation, thus it can be implemented in many ways. One existing implementation of cognitive processes is the cerebral cortex of mammalian animals, where a very complex biological computational architecture provides the computational power for cognitive processes.

Such an architecture is built up by numerous, simple computational elements that can perform only primitive functions like addition, subtraction in a rather short time. These computational elements are connected to each other in a very complex network, like the neurons in the brain. The neural architecture can be much more efficient in certain tasks than the complex, classical algorithms, by virtue of the decomposition of the problem into thousands of simple independent operations which can be done simultaneously. The elaboration of such simple operations require simple hardware units that can be implemented in a chip with a clear and simple architecture. The resulting architecture is able to perform the computation in a fully parallel way, thus tremendously reducing the computational time. It seems thus to be promising to base the cognitive models on parallel architectures to achieve an efficient operation.

This paper introduces a model strongly based on the cognitive functions of the visual cortex for image contour detection. The model was elaborated on the analogy of the mammalian visual system. Each phase from the retina to the visual cortex is represented in the model by imitating the biological structures and cognitive functions in order to perform similar image transformations and operations. In classical image processing algorithms, such as edge detection using a sobel filter, both the input and the output are matrices containing pixels. These algorithms thus represent a pixel-to-pixel transformation between two matrices. Similarly to the neural networks in the cerebral cortex, the model proposed in this paper implements a pixel-to-feature transformation, where *feature* refers to a more abstract visual object, such as a line segment of a certain length and orientation, or a line crossing. The result of the transformation is thus a feature-level abstraction of the input image. The abstract features can also be re-transformed into the pixel level by a feature-to-pixel inverse transformation, allowing a visual representation of the feature-level abstraction. The re-transformation of features into pixels will exclude noise from the result, thus it can be used as a filtering technique, described later in this paper.

The rest of the paper is organized as follows. Section 2 gives an introduction to the visual pathway, how the brain processes an image. Section 3 describes the proposed architecture of the model for high speed image processing. Section 4 is devoted to the model evaluation and experimental results. The fundamental ideas of the hardware realization of our model is discussed in Section 5. Finally, Section 6 concludes the paper.

2. The Visual Pathway from the Retina to the Primary Visual Cortex

The main goal of this paper is to present a model of the visual pathway with a special respect on the primary visual cortex. The purpose of this section is to give an overview of the biological and cognitive aspects of early visual information processing, on which our model is based.

Visual processing begins in the retina. The photoreceptors that include 120 million rods and more than 5 million cones are located in the outer plexiform layer of the retina. The rods are sensitive to light intensity and are responsible for phototransduction [10], while cones are sensitive to the wavelength of the light [2]. These photoreceptors modulate the activity of the bipolar cells, which in turn connect with more than one million ganglion cells in each eye. The axons of the ganglion cells leave the eye at the optic disc and form the optic nerve, which carries information from the retina to the brain.

The bipolar cells and the ganglion cells are organized in such a way that each cell responds to light falling on a small circular patch of the retina, which defines the cell's *receptive field*. Both bipolar cells and ganglion cells have two basic types of receptive fields: on-center/off-surround and off-center/on-surround. The center and its surround are always antagonistic and tend to cancel each other's activity [1, 9]. On the other hand, the on/off or off/on arrangement of the receptive field makes ganglion cells more responsive to differences in the level of illumination between the center and surround of its receptive field. Uniform illumination of the visual field is less effective in activating a ganglion cell than is a well placed spot or line or edge passing through the center of the cell's receptive field.

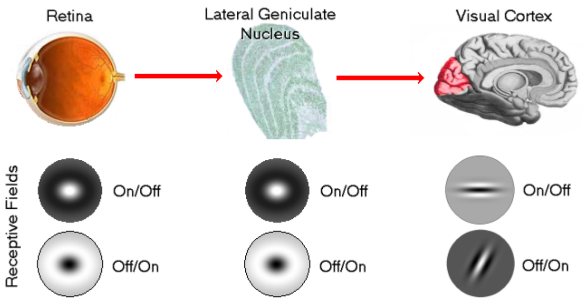

Fig. 1. The visual pathway from the retina through the lateral geniculate nucleus to the visual cortex. The shape of the corresponding classical receptive fields varies from circular in the retina and LGN to elongated in the cortex. Orientation selectivity occurs only in cortical neurons.

The main target of the axons of the ganglion cells are the lateral geniculate nucleus (LGN) of the thalamus, and the superior colliculus. The LGN is the main conduit to the primary visual cortex where conscious visual perception occurs. The superior colliculus is involved in guiding eye movements and other automatic visuo-motor responses. The primary visual cortex (which is also referred to as V1, the striate cortex, or area 17) populates approximately 2 billion neurons in a two-dimensional sheet about 2-3mm thick. Visual information processing totals up to a vast portion of cortical activity and is composed of more than a dozen separate areas. In macaque monkeys, the visual cortex constitutes about 50% of the surface area of the entire cerebral cortex, while in humans this fraction is about 20%. The primary visual cortex topographically maps the visual field, with neighboring neurons responding to neighboring parts of the visual field.

Neurons in the primary visual cortex can be classified in two major classes according to their response characteristics: simple-cells and complex cells [6]. Simple cells tend to receive afferent projections mostly from the LGN, while complex cells receive projections mostly from other cortical cells [11]. Both of these cells exhibit a property known as orientation selectivity, meaning that they do not respond simply to light or dark in the visual field, but more typically to bars or edges of light with a particular orientation [8].

The visual cortex has a columnar organization on the cellular level. In 1977, Hubel and Wiesel suggested that iso-orientation domains are packed in essentially linear parallel stripes, which Hubel [5] subsequently referred to as the "ice-cube" model. The model of Hubel, and later V1 models [3] suggest that cells in the visual cortex are organized in a 3D structure, where a location on the visual field and an input stimulus preference (e.g. orientation preference) can be assigned to each cell, as shown in **Fig.2**.

While simple cells respond to an oriented edge at a par-