The recent progress in physiological measurements has started to connect microscopic neural circuit function with macroscopic physiological phenomena. In such efforts, we have recognized the usefulness of neuronal models and constructive methods for analysis by numerical calculation. Our group previously constructed a theory and reported spatiotemporal calculation results of a confluence of membrane potential and its dependence on neuron's shape and configuration.
It has been revealed by recent physiological measurement and theoretical analysis that the nonlinear characteristic of the membrane ionic channel has a large influence on the firing property and the information coding. We previously suggested the temporal coincidence of action-potential pulses has more significant effects when the conductive-layer thickness reduces. The role of neuron's shape, however, has been unclear.

In this paper, we evaluate numerically the influence of the change of the neuron shape on the firing characteristics. We construct a new neuronal model of pyramidal cell at the CA3 hippocampus based on the compartmental model to analyze quantitatively the firing characteristics. We find the following facts. First, the soma shape affects the action potential frequency. The sharper the peak of the cone is, the higher the action potential frequency is when the rhythmic single action potential occurs at the soma. Secondly, soma is more sensitive to the signal from the apical dendrite if the peak of the cone at apical dendrite side is sharper. This fact means that pyramidal cell at CA3 is more sensitive to the synaptic current at the apical dendrite. This result is supported by the anatomical knowledge of the hippocampus. These facts lead to a hypothesis the shape is significant factor in coding the information.

The details are as follows. We construct a new cell model of a pyramidal cell at the CA3 hippocampus based on a compartmental model to evaluate what the shape affects. The cell model consists of two types of dendrites, soma and unmyelinated axon. The basal and apical dendrites are represented in bundles by equivalent cylinders. We construct three soma models divided into blocks and connect them by resistances instead of a single cylinder. We change the soma's shape on the condition that the total surface areas are almost same. One of the soma model is expressed a single cone. Radius is 12.5 mm and height is 75 mm. That is divided into 29 blocks. We call it model A. The other one is expressed as two different cones. Radii are 12.5 mm and heights are 25 and 60 mm respectively. The smaller cone is divided into 9 blocks and the bigger one is divided into 19 cones. We call it model B. The other one is expressed as two symmetrical cones. Radii are 12.5 mm and heights are 42.5 mm. Both the cones are divided into 14 cones. We call it model C. We estimate the effective thickness of conductive layer under the membrane at the soma as 0.8 - 0.9 mm. Each compartment is assumed to have a membrane property obtained by the voltage-clamp method for isolated hippocampus pyramidal cells. The distribution of ionic conductance densities includes six voltage- and/or calcium- dependent ionic channels with their kinetics obtained from current-clamp data.

The numerical calculations are conducted to analyze the average firing rate and firing timing.
In the analysis of the average firing rate, we assume the synaptic current NMDA type. We firstly stimulate the soma by some constant depolarizing currents. The three different firing modes, i.e., rhythmic burst, rhythmic burst with intercalated runs of fast spikes and rhythmic single action potential, are presented as the somatic injected current is changed. Low frequency bursting occurs when somatic injected currents are ranged at 0 - 0.3 nA. At the low frequency bursting, the burst frequencies are almost the same among all models. At the high frequency firing, the frequency of model A is slightly higher than that of model B when the somatic injected currents are ranged at 0.5 - 1.0 nA. The reason is that the slope of the frequency-current curves in model A is about 100 Hz/nA and is larger than that in model B. The frequencies of model A and model B are also higher than that of model C. The slope of the frequency-current curves in model B is about 80 Hz/nA and is almost the same as that in model C. Secondly we stimulate the distal apical dendrite by the dendritic injection of depolarizing currents. The frequency-current curves exhibit two ranges. At the small current injection ranged at 0 - 0.8 nA, repetitive burst at soma induces dendritic Ca spike at distal apical dendrite. The frequencies increase linearly at about 2 Hz/nA. At the bigger current injection, repetitive single action potentials occur at soma and repetitive single action potentials also occur at dendrite. The frequencies increase at about 10 Hz/nA.
In the analysis of the firing timing, we assume the synaptic current AMPA type. We stimulate the distal apical dendrite by the current at 0.8 nA (peak) with a duration of 5 ms. The firing time of model A is almost the same as that of model B. However, the firing time of model C is delayed in comparison with

that of model A and B.

As the results, following two facts are revealed. First, the soma shape affects the action potential frequency. The sharper the peak of the cone is, the higher the action potential frequency is when the rhythmic single action potential occurs at the soma. Secondly, soma is more sensitive to the signal from the apical dendrite if the peak of the cone at the apical dendrite side is sharper. This fact means that pyramidal cell at CA3 is more sensitive to the synaptic current at the apical dendrite. This result is supported by the anatomical knowledge of the hippocampus.
These facts lead to a hypothesis that the shape is significant factor in coding the information.