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Complex-valued neural networks fertilize electronics

The complex-valued neural networks are the networks that deal with complex-valued information by using complex-valued parameters and variables. They are extremely rich in variety. [1] In this chapter, we grasp the basic ideas lying in the complex-valued neural networks by glancing over an application example. Then we also obtain a bird's-eye view of their present and prospective application fields so that we can enjoy the flavor before we go deep into the world of the complex-valued neural networks. [2]

1.1 Imitate the brain, and surpass the brain

The art of the artificial neural networks is a technological framework in which we introduce and/or imitate the functions, constructions, and dynamics of the brain to realize an adaptive and useful information processing. The brain is able to manage both the pattern processing problems and the symbolic processing ones. For example, when we find a correct traveling route in a complex transportation network such as metro network in a large city, we first guess a possible route by a pattern processing and, afterward, we confirm the details and sequential consistency. The principle and the mechanism of the brain functions are still unclear in total. However, the accumulation of physiological experiments has brought many important suggestions.

The biological brain, including sensory neural networks such as retinal and cochlear networks, has various specific features. When it absorbs information

[1] Various features and applications are found, for example, in a series of special sessions in international conferences such as [1], [2], [3], [4], [5], [6], [7] .

[2] This Chapter is based on the article [8] (A.Hirose, Complex-valued neural networks fertilize electronics, Journal of the IEICE, 87 (6):447–449, June 2004). Chapters in the multiple-author book [9] are also helpful to extend the first impression of the complex-valued neural networks.

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of events occurring in the world, it reconstructs the information according to their meaning for the person. It also preserves the relation among the information meanings. The brain's manner to take in the information is roughly determined by the nature of the cells as well as the constructions of the nerve networks. Additionally the brain changes itself being influenced by the information presented by the environment. This change is the self-organization and / or learning in the neural system.

The purpose of the self-organization and learning lies in the reconstruction of the information representation in the brain so that the man can utilize the information as effectively as possible. It is known that it is significantly important for the human neural network to adopt a representation suitable for the purpose assigned to respective network modules, in particular to a module located close to human-environment interface. Therefore, the network of each module also possesses a construction suitable for processing respective information specific to visual, auditory, or olfactory signals. The cerebral cortex has, however, a more homogeneous structure, i.e., the six-layer structure, so that one part of the cortex can be substituting for another part when an inability occurs. But it also self-organizes according to input signals.

The modern electronics and communications provide us with a large variety of information. It is hence expected more and more in the engineering fields to develop new systems that process a wider range of information in more adaptive and effective manners just like we do, or better than we do. In other words, we need to build systems surpassing the brain by imitating the brain. Even in such cases, the effective self-organization and learning inevitably require the information representations suitable for the purposes.

1.2 Create a "Superbrain" by enrichment of the information representation

Let's consider an example. In these years, the measurement technology on the basis of the interference of waves makes remarkable progress. Assume that we have a coherent lightwave transmitter and phase-sensitive eyes, i.e., an interferometric radar function, so that we can *see* the phase of the reflected lightwave [10] as shown in Fig. 1.1.

When a reflecting object approaches to us, the number of the wave (wave tops or bottoms) between the object and our eyes reduces. That is, the phase of the reflected lightwave progresses. Contrarily, when the object goes away, the phase is retarded. In this way, phase of the reflected lightwave expresses the distance between the object and us. The fluctuation is related to the unevenness and roughness of the object surface. Then, as we *see* the object coherently, our brain self-organizes in such a special manner that we can *see* the environment in a phase-sensitive way.

That is, our brain looks the objective world adaptively on the basis of the amplitude and phase, i.e., "complex amplitude" or "phasor", For example,

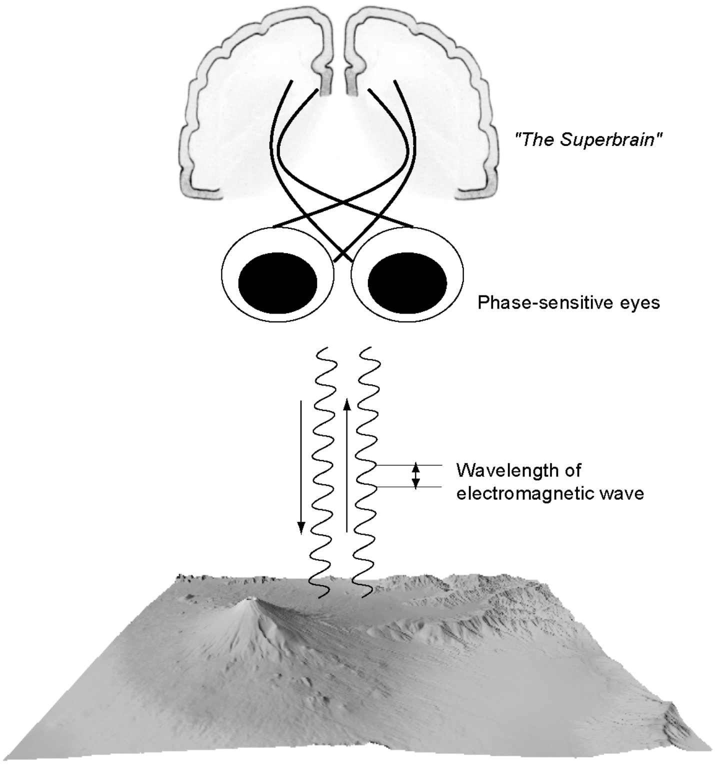

Fig. 1.1. Geographical profile acquisition using phase-sensitive eyes and a *superbrain* brought up with the special eyes. (Figure includes the data in Digital Map 50m Grid (Elevation), Geographical Survey Institute, with permission.)

we are on a plane and *see* Mt. Fuji and Lake Yamanaka beneath the craft. If we have phase-sensitive eyes, our brain takes in the information of the height of Mt. Fuji, the shape and roughness of its skirt, statistical unevenness of distance determined by vegetation, and the fluctuation *texture* in distance. Then the brain recognizes the state of the ground surface with a pattern processing method in complex-amplitude information space.

In Chapter 5, we present such an example of the phase-sensitive superbrain to see the region of Mt. Fuji and Lake Yamanaka. In Fig. 5.2 on Page 91, you find the data of reflection observation, while Fig. 5.6 on Page 96 shows the recognition results. Figure 5.6(a) was generated by a conventional neural network that sees only the intensity of the reflected wave. On the other hand, Fig. 5.6(b) is the result obtained by the phase-sensitive superbrain that sees the complex amplitude. The latter figure gives an impression completely different from that of the former one. Mt. Fuji is segmented as a mountain cluster, which is a useful result for human beings to live in the world. We have also succeeded in visualization of antipersonnel plastic landmines with this complex-amplitude superbrain brought up with the phase-sensitive eyes (Chapter 6).

One of the most important advantages of the complex-valued neural networks (CVNNs) is good compatibility with wave phenomena. The CVNNs are suitable for the processes related to complex amplitude such as the interferometric radar system mentioned above. In general, propagation and interference of electromagnetic wave are expressed by the magnitude of transmission and reflection, phase progression and retardation, superposition of fields, etc. These phenomena are expressed simply and naturally by the use of complex numbers. They are also related directly with the elemental processes in the CVNNs such as weighting at synaptic connections, i.e., multiplications in amplitude and shifts in phase, and summation of the weighted inputs.

1.3 Application fields expand rapidly and steadily

Regarding research history of the CVNNs, we can trace back to a Paper [11] written by Aizenberg et al. in 1971. They presented not only the possibility of adaptive information processing on the basis of complex numbers, but also an analogy between the timing of neural firing and phase information, which may be useful to realize workable systems. That is, they considered a coding of phase information by using the progress or retardation of pulse timing. This idea is indeed suggestive even from the viewpoint of present research situations. The most useful applications include the above-mentioned coherent electromagnetic system, where we pay attention to amplitude and phase of electromagnetic wave. In such a system, the amplitude corresponds to energy, whereas the phase does to progress or retardation of time. The CVNNs deal with the information directly related to such existence that forms the basis of physical world.

There are many other fields in which the CVNNs provide systems with appropriate information representations. Figure 1.2 is a diagram presenting application fields. Many are related to wave phenomena, e.g., active antennas in electromagnetism, communications and measurements using waves such as radar image processing, learning electron-wave devices, quantum computation, ultrasonic imaging, analysis and synthesis in voice processing, and so on. The wavelength-dependent dynamics of optical circuit leads to adaptive optical routers in optical wavelength-division-multiplexed communications, variable optical connections, frequency-domain parallel information processing, etc. The carrier-frequency-dependent neural behavior realizes both the adaptability and controllability in neural networks.

The compatibility of neural adaptability and controllability is closely related to context-dependent behavior and emergence of volition in neural networks and, hence, connected with so-called brainlike systems in the future. The periodicity in phase-information topology is applicable to systems that

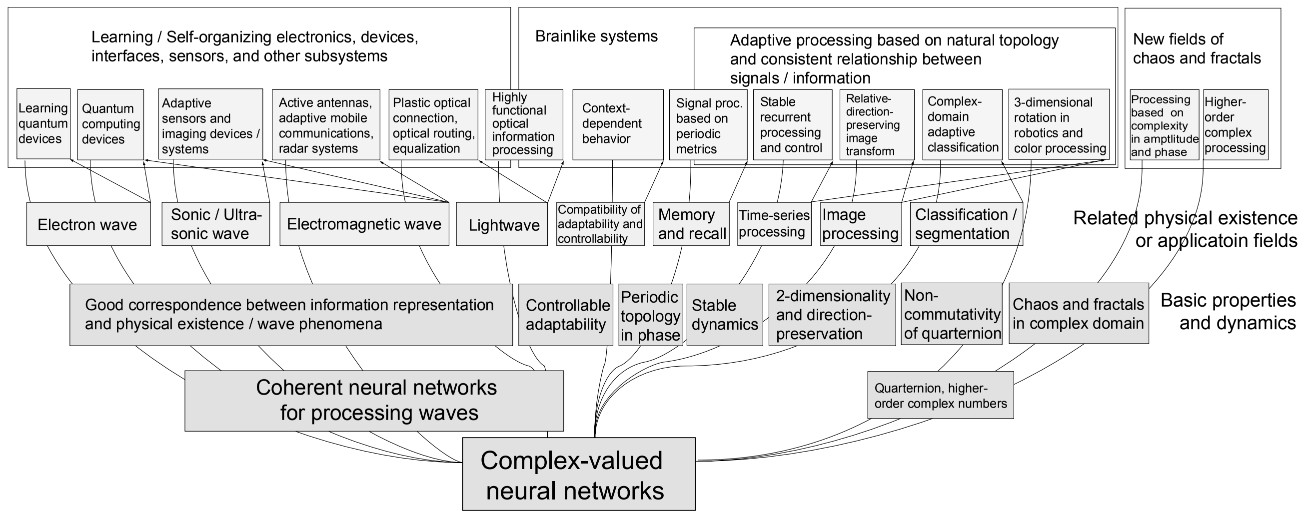

Fig. 1.2. Application fields of the complex-valued neural networks. Left-hand side: Items classified on the basis of physical existence. Right-hand side: Items classified on the basis of the features of neural dynamics. Details are explained in Chapter 3.3. (Reprinted from [8]: A.Hirose, "Complex-valued neural networks for more fertile electronics," Journal of the IEICE, 87(6):447–449, June 2004, with permission.)

process information naturally having a cyclic structure, e.g., adaptive controller of traffic lights with periodic behavior. Such a research directly brings comfort and safety to human beings. Other topics include new development in chaos and fractals, and use of quaternion and higher-order complex numbers.

1.4 Book organization

In this book, we present and discuss basic ideas and fundamentals of CVNNs in Part I. First, in Chapter 2, we describe the backgrounds and reasons why the art of the CVNNs becomes important more and more. Next, in Chapter 3, we present the features of CVNNs as well as in what applications they are especially useful. We also survey the history of CVNN researches. In Chapter 4, we explain the dynamics of processes, learning, and self-organization of CVNNs. We present dynamics of conventional (real-valued) neural networks first and, afterward, we extend them to those of CVNNs. Therefore, we expect that even a beginner in conventional neural networks can easily absorb the basics of CVNNs. However, please consult the books listed in chapters, if needed, for further assistance required in understanding conventional neural networks.

In Part II, we present several examples of applications in CVNNs, proposed by the author's research group, such as an interferometric radar imaging system and an adaptive lightwave information processing system. We describe the features of self-organization and learning in these systems, and we show the effectiveness of the CVNNs that deals with phase information in waves. The framework adopted in the systems is not only useful in imaging and sensing using other wave phenomena such as sonic and ultrasonic waves, but also promising future development, e.g., in adaptive neural devices on the basis of electron wave [12],[9]. Furthermore, we explain in what manner a CVNN yields volition and developmental learning. We wish the ideas described in this book inspire the readers with new ideas more and more.

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