神经网络
Neural Networks
第十四章

神经计算机

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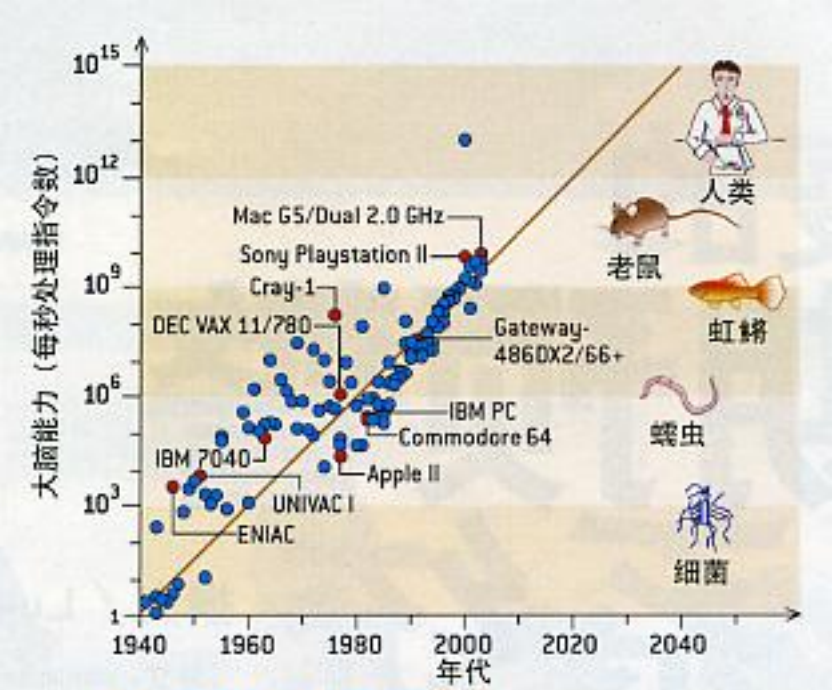
重大挑战

经过60多年的发展，计算机的运算速度达到几百万亿次，但是其智能水平极为低下。研究机器的高性能与人的高智能相结合，成为探索信息处理的高效能的有效途径。开展类脑计算机的研究并取得突破性进展，将对我国经济和社会可持续发展，国家安全和国防建设，信息产业的提升等带来重要的推动作用。



图中圆点代表1940年以来的120种顶级计算机．今天计算机的原始计算能力已经相当于一只虹鳉的大脑。大约在2040年，电脑将达到人类大脑的处理能力。

Cite from《Scientific American》, 2005 (3)

图灵Alan M. Turing

Alan Turing
(1912-1954)

1936年，年仅24岁的英国人图灵发表了著名的《论应用于决定问题的可计算数字》一文，提出思考实验原理计算机概念。图灵把人在计算时所做的工作分解成简单的动作，与人的计算类似，机器需要：

（1）存储器，用于贮存计算结果；

（2）一种语言，表示运算和数字；

（3）扫描；

（4）计算意向，即在计算过程中下一步打算做什么；

（5）执行下一步计算。

图灵Alan M. Turing

Alan Turing
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具体到一步计算，则分成：
（1）改变数字可符号；
（2）扫描区改变，如往左进位和往右添位等；
（3）改变计算意向等。图灵还采用了二进位制。这样，他就把人的工作机械化了。这种理想中的机器被称为“图灵机”。图灵机是一种抽象计算模型，用来精确定义可计算函数。图灵机由一个控制器，一条可以无限延伸的带子和一个在带子上左右移动的读写头组成。这个概念如此简单的机器，理论上却可以计算任何直观可计算函数。图灵在设计了上述模型后提出，凡可计算的函数都可用这样的机器来实现，这就是著名的图灵论题。

图灵Alan M. Turing

Alan Turing
(1912-1954)

- *On computable numbers with an application to the Entscheidungsproblem* (1936)

ON COMPUTABLE NUMBERS, WITH AN APPLICATION TO THE ENTSCHEIDUNGSPROBLEM

By A. M. TURING.

[Received 28 May, 1936.— Read 12 November, 1936.]

The "computable" numbers may be described briefly as the real numbers whose expressions as a decimal are calculable by finite means. Although the subject of this paper is ostensibly the computable *numbers*, it is almost equally easy to define and investigate computable functions of an integral variable or a real or computable variable, computable predicates, and so forth. The fundamental problems involved are, however, the same in each case, and I have chosen the computable numbers for explicit treatment as involving the least cumbrous technique. I hope shortly to give an account of the relations of the computable numbers, functions, and so forth to one another. This will include a development of the theory of functions of a real variable expressed in terms of computable numbers. According to my definition, a number is computable if its decimal can be written down by a machine.

In §§ 9, 10 I give some arguments with the intention of showing that the computable numbers include all numbers which could naturally be regarded as computable. In particular, I show that certain large classes of numbers are computable. They include, for instance, the real parts of all algebraic numbers, the real parts of the zeros of the Bessel functions, the numbers π, e, etc. The computable numbers do not, however, include all definable numbers, and an example is given of a definable number which is not computable.

Although the class of computable numbers is so great, and in many ways similar to the class of real numbers, it is nevertheless enumerable. In § 8 I examine certain arguments which would seem to prove the contrary. By the correct application of one of these arguments, conclusions are reached which are superficially similar to those of Gödel†. These results

† Gödel, "Über formal unentscheidbare Sätze der Principia Mathematica und verwandter Systeme, I", *Monatshefte Math. Phys.*, 38 (1931), 173–198.

John von Neumann

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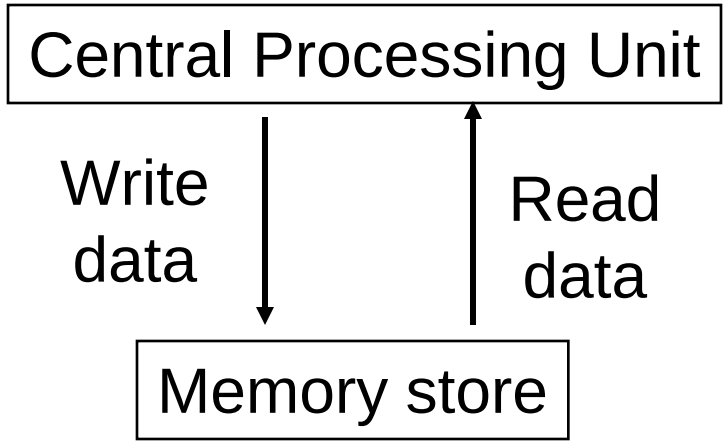
Mathematician: Game Theory, Quantum Mechanics, Theory of Computing...

Von Neumann 系统结构

Practical Implementation of Turing Machine



‘fetch-execute-store’ cycle

Repeat

- Fetch an instruction and any associated data from memory
- Execute the instruction
- Store the results in memory

Until...

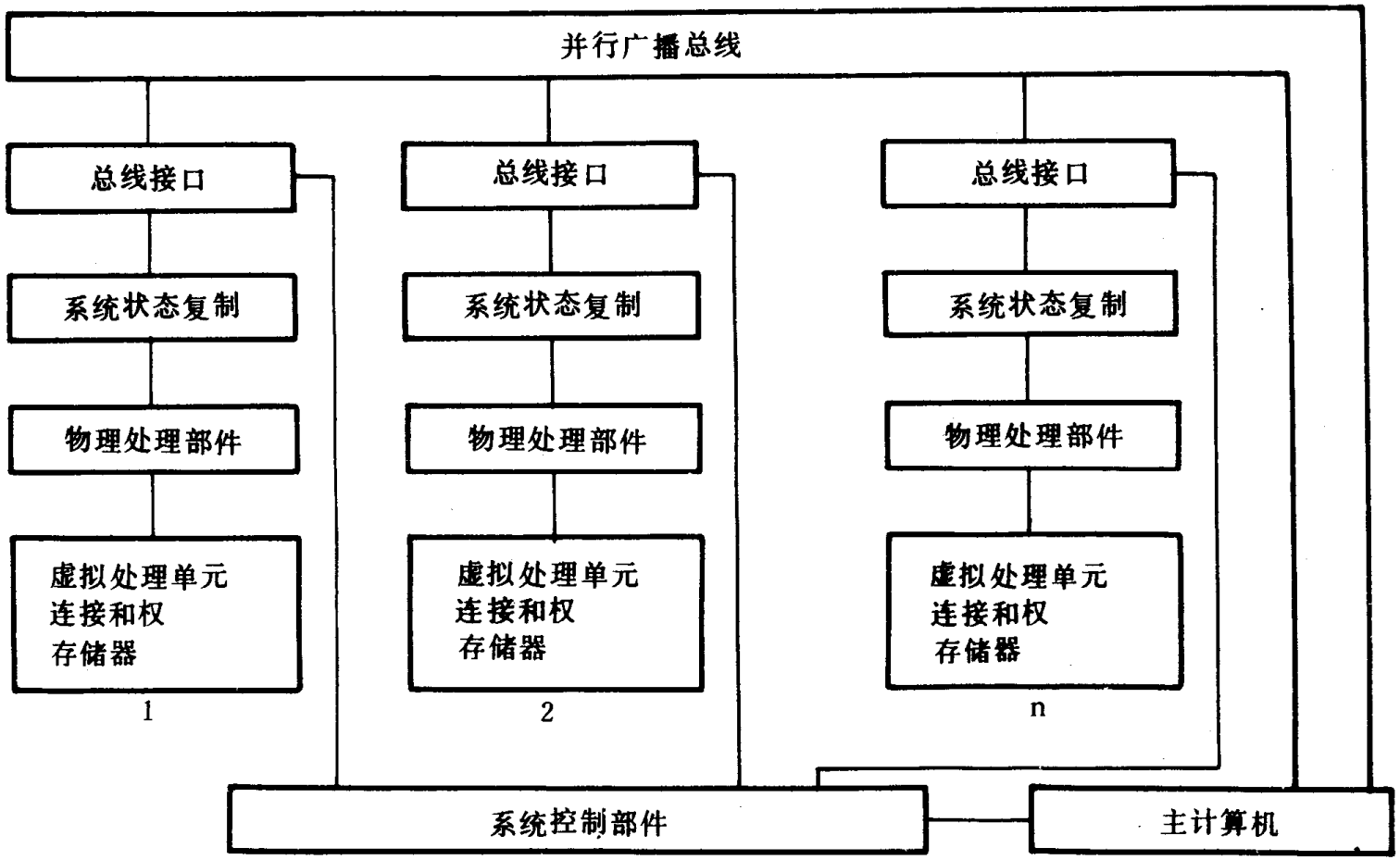
神经计算机

神经网络的研究取得了引人注目的进展，在此基础上，神经计算机系统也随之发展起来。

神经计算机是模拟人脑神经信息处理功能，通过并行分布处理和自组织方式，由大量基本处理单元相互连接而成的系统。

神经计算机本质上是一种处理单元互连的并行阵列，执行并发操作。每一个处理单元又与其它单元高度互连，并具有小容量局部存储器。

通用神经计算机体系结构



比较

	冯·诺依曼计算机	神经计算机
基本结构	采用的是冯·诺依曼体系结构	并行处理
	以精确的"0"和"1"的方式表示数字信息	能处理连续变化的模拟信息
	一般以 CPU 作为处理问题的核心	由大量简单的处理单元协同处理问题
运行模式	为寻求问题的精确解，常常遇到计算时间困难	在短时间内寻找好的，但不一定是最好的解
	注重算法，执行过程严格控制，结果可预料	注重变换，通过学习训练形成信息处理方法，结果难以预料
	由指定的存储器存储信息，能够轻易读出具有特定意义的数据信息	无特定的数据存储和数据存储器，以神经元之间的互连形式分布进行存储，可以通过部分信息而联想出事件的整体
	利用数字和逻辑进行二值逻辑判断	对模糊的、不完整或冗余、甚至矛盾的数据进行问题求解
功能	容错能力较弱	具有很强的容错能力
	擅长于科学与工程计算、过程控制与信息管理等领域	在视觉、语言、信息处理、机器人控制、模式识别等方面取得进展

Artificial Neural Network Chips

- Early neuromorphic architectures were artificial neural network chips
- Examples:
  - ETANN : (1989) Entirely analog chip that was designed for feed forward artificial neural network operation.
  - Ni1000 : (1996) Significantly more powerful than ETANN, however has narrower functionality

SYNAPSE-1 System Architecture

SYNAPSE-1 is a modular system arranged as a 2D array of MA16s, weight memories, data units, and a control unit

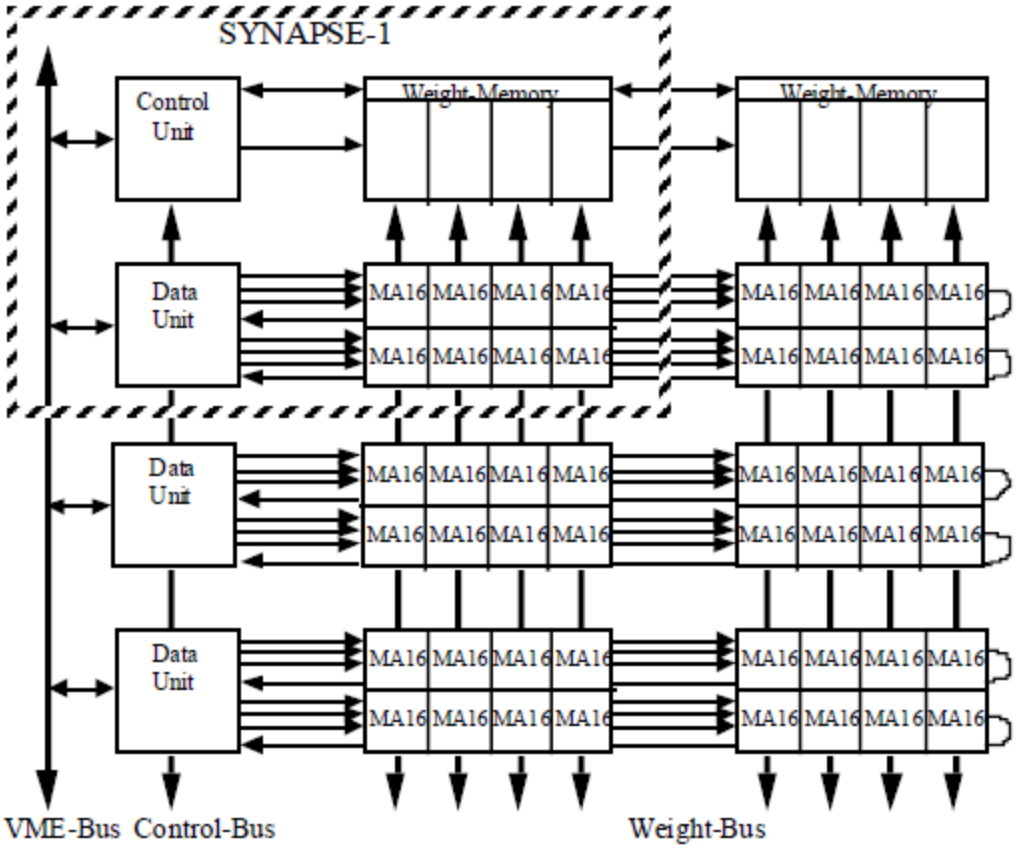


Image from [6]

Neurogrid

- (2005) Neurogrid is a multi-chip system developed by Kwabena Boahen and his group at Stanford University [9]
  - Objective is to emulate neurons
  - Composed of a 4x4 array of Neurocores
  - Each Neurocore contains a 256x256 array of neuron circuits with up to 6,000 synapse connections

The FACETS Project

- (2005) Fast Analog Computing with Emergent Transient States (FACETS)
  - A project designed by an international collective of scientists and engineers funded by the European Union
  - Recently developed a chip containing 200,000 neuron circuits connected by 50 million synapses.

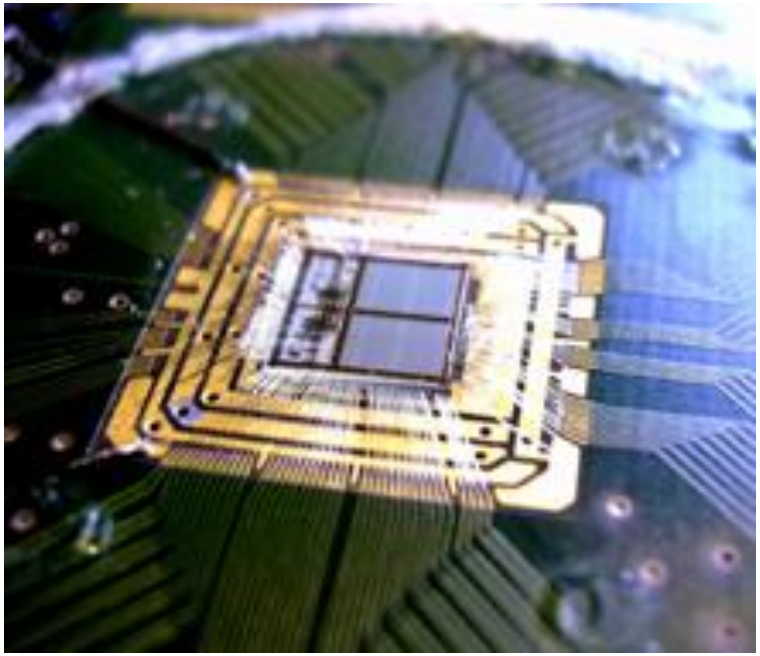


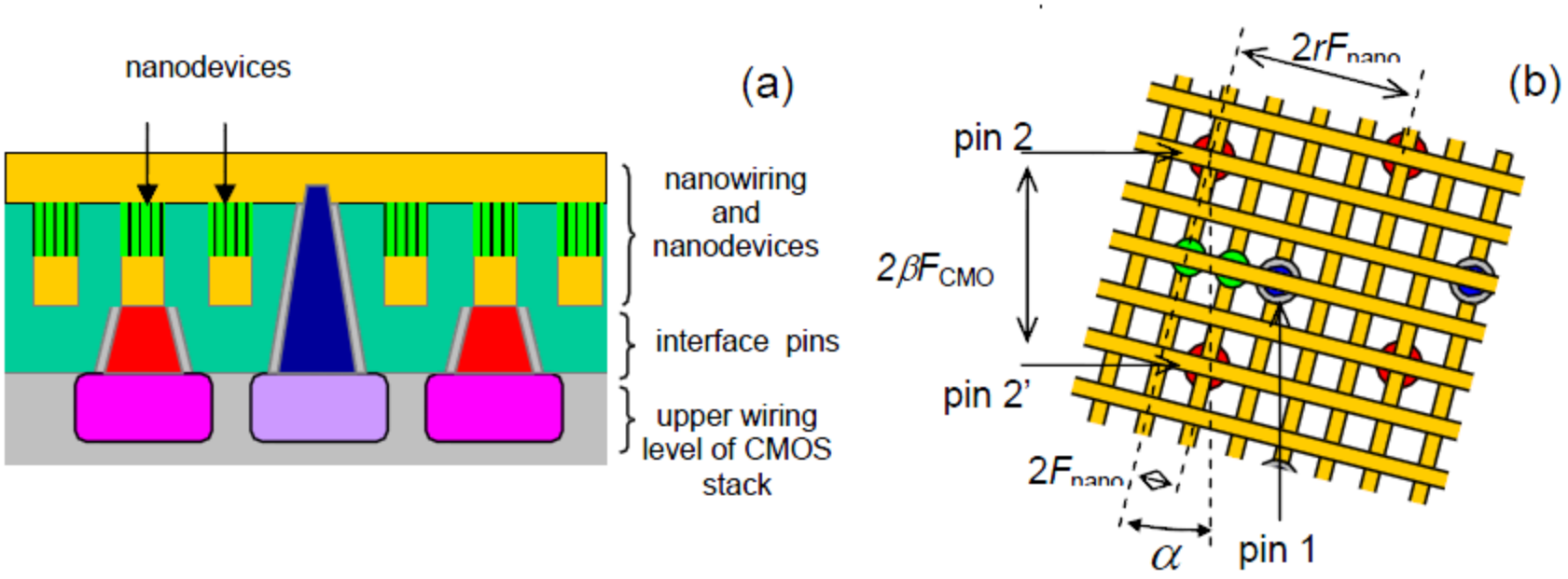
Image from [9]

Torres-Huitzil: FPGA Model

- Torres-Huitzil et. al (2005) designed an hardware architecture for a bio-inspired neural model for motion estimation.
  - Architecture has 3 basic components which perform spatial, temporal, and excitatory-inhibitory connectionist processing.
  - Observed approximately 100 x speedup over Pentium 4 processor implementation for 128x128 images

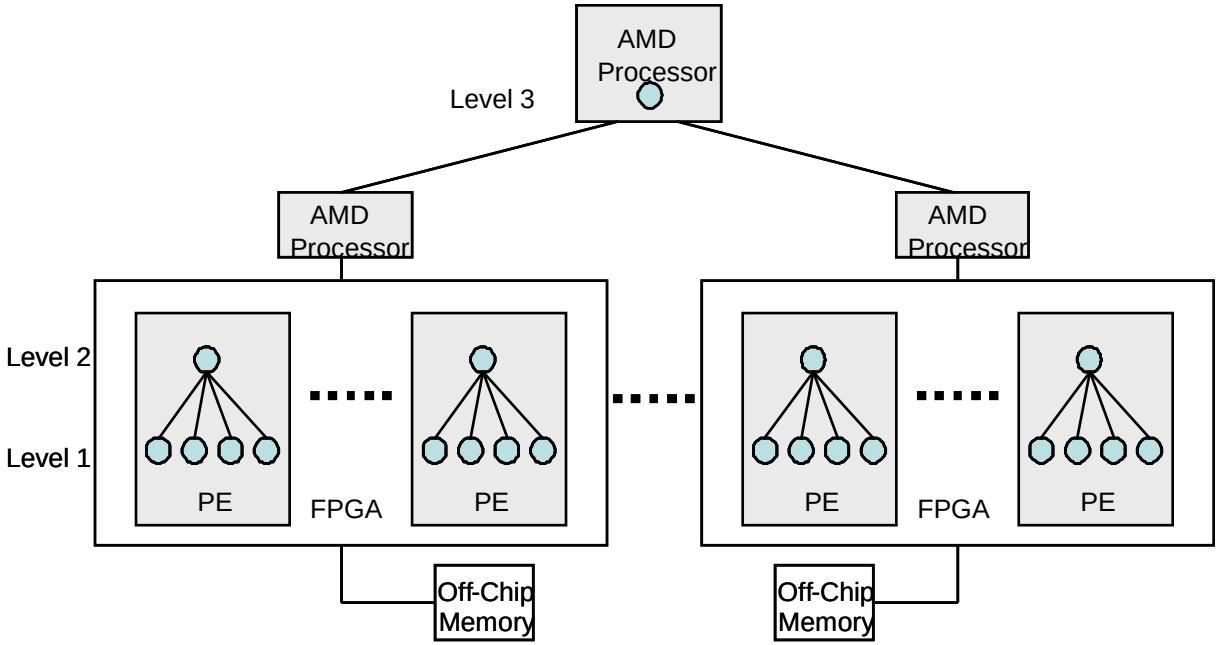
CMOL based design

- Developed by Dan Hammerstrom

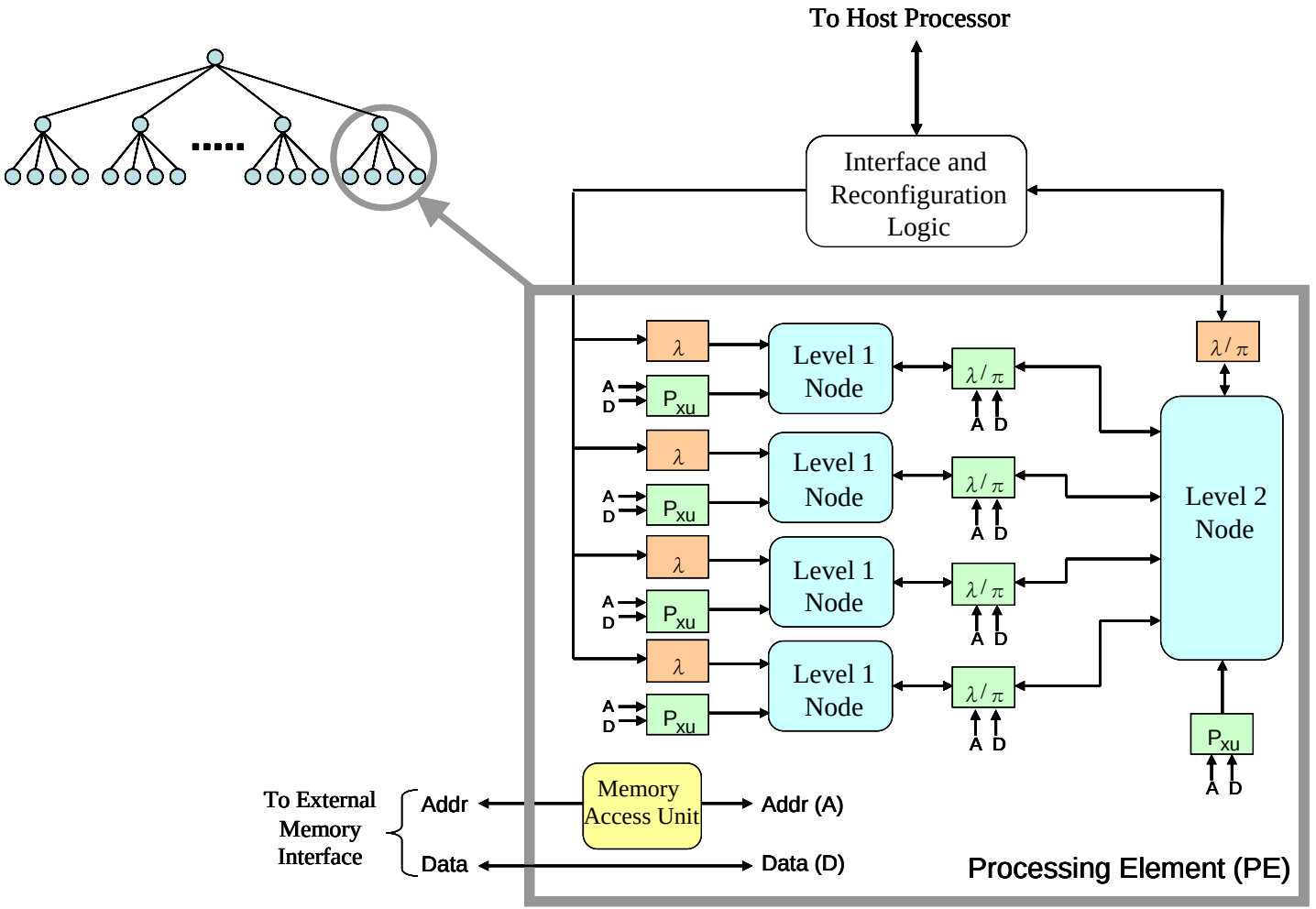


HTM on FPGAs

- Implemented on a Cray XD1



PEs on FPGA


To Host Processor
Interface and Reconfiguration Logic
λ
A D
Pxu
Level 1 Node
λ / π
Level 2 Node
Memory Access Unit
To External Memory Interface
Addr
Data
Addr (A)
Data (D)
Processing Element (PE)

Large Scale Simulations

- IBM:
  - Blue Brain Project: IBM & EPFL (Switzerland)
  - IBM Almaden Research Center
- Los Alamos National Lab
- Air Force Research Laboratory (Rome, NY)
- Academia:
  - Portland State University
  - Royal Institute of Technology (KTM, Sweden)

AFRL PS3 Cluster

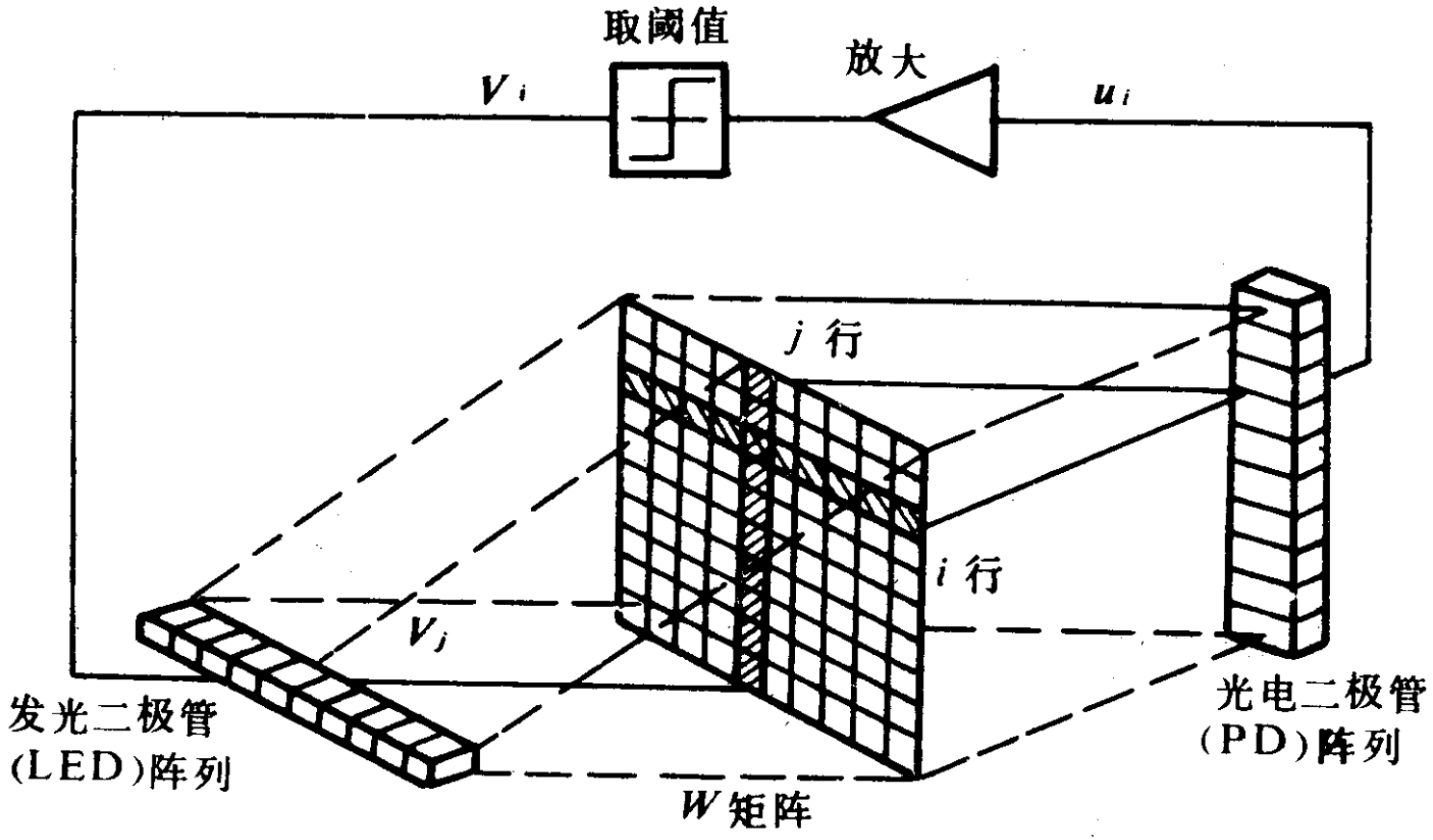
For more information

- Visit Institute of Neuromorphic Engineering:
  - http://www.ine-web.org/

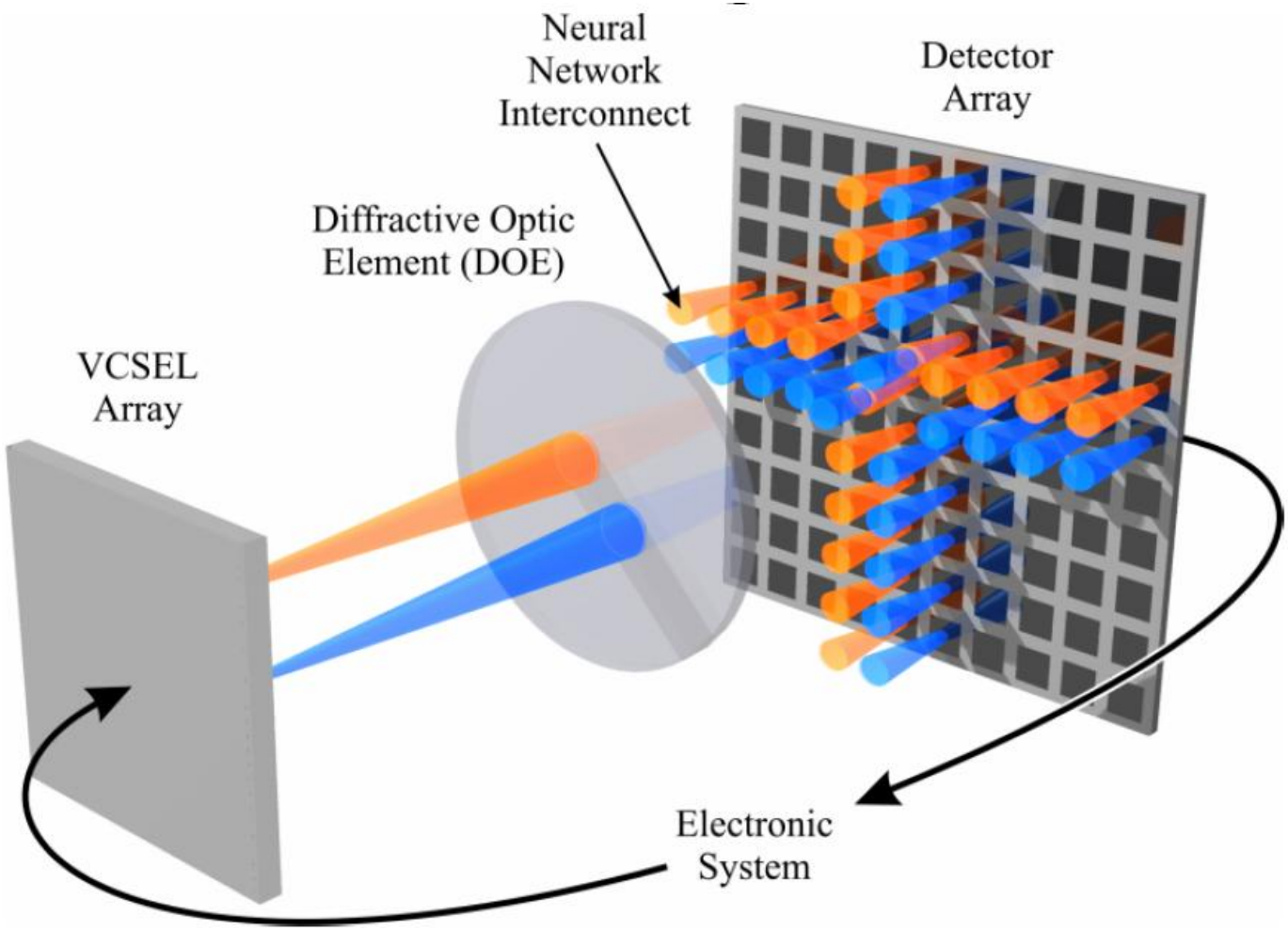
光神经计算机

光学元器件能实现大规模互连和并行处理，对实现神经计算机有着特别的吸引力。 过去20年中，光计算的工作，大部分集中在模拟系统方面，并且形成了光学的一个重要分支，称为光学信息处理。迄今，模拟光计算已得到了很大的发展，包括二维图像处理的范畴，向着更宽广的光计算方向发展，可以进行图像加、减和相乘，可以进行二维傅立叶变换、卷积运算，还可以进行矩阵运算以及偏微分方程模拟解的运算等多种运算。

光电神经计算机



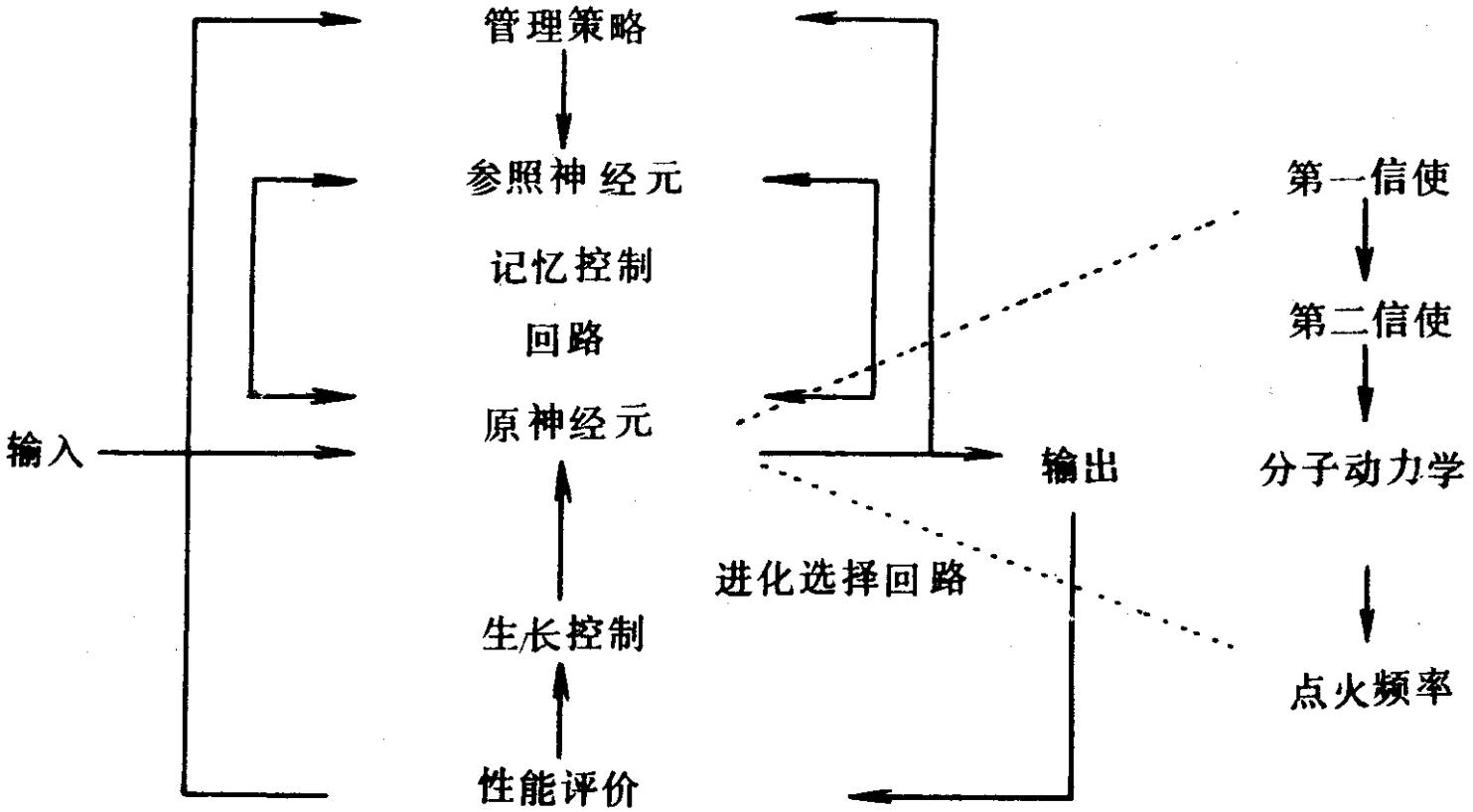
光电神经计算机


Neural
Network
Interconnect
Detector
Array
Diffractive Optic
Element (DOE)
VCSEL
Array
Electronic
System

分子神经计算机

自1983年美国公布研制生物芯片计算机的设想以来，引起各方面的研究兴趣，探讨制造生物芯片的原理和技术。生物芯片的概念主要来自分子生物学的两个方面，即象DNA那样的分子能够存储、复制和传递信息，和生物多聚体能够自主装配。科学家预言，在分子计算机中将利用生物材料和生物过程，制造和装配分子型电子元件。计算机将建立在沿原子链传播半导体孤子波的基础上，这种方式没有损耗，生物芯片几乎不产生热。

分子神经计算机的体系结构



神经计算机展望

光学技术与半导体技术的结合以及分子器件的研究，都是推动神经计算机实现的重要途径。如有可能将化学信息处理过程包括在分子器件构成的计算系统之中，神经计算机的实现将会出现新的前景。新型计算原理的实现，期待着新型器件的出现，一种非常有竞争前景的器件是纳米器件，包括量子结构纳米器件、自旋电子器件、超高密度存贮器件、分子器件、纳米生物器件和蛋白质芯片等。

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Thank You

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