Book Reviews

The Universal Constructor

Theory of Self-Reproducing Automata. JOHN VON NEUMANN. Edited by ARTHUR W. BURKS. University of Illinois Press, Urbana, 1966. 408 pp., illus. $10.

The scientific community is indebted to Arthur W. Burks for completing this unfinished work of the late John von Neumann. An immense effort must have gone into the collection of the fragmentary manuscripts, obtaining information from friends and co-workers of von Neumann, and completing the project without doing violence to the intentions of the author.

The volume begins with an editor's introduction, which consists of a very interesting discussion of the contributions von Neumann made to the development of modern computers. Part 1 consists of a series of lectures which were delivered at the University of Illinois in 1949 and which are now somewhat dated. But part 2 contains a complete design for an automaton that can reproduce itself, and it is this part that makes the volume a significant contribution to the scientific literature. I shall restrict my comments to this part.

The theory of computers must be traced back to a fundamental result by A. M. Turing, 30 years ago, establishing the possibility of a computer that is "universal." Such a computer, given appropriate instructions, can do anything any computer can do. Von Neumann wished to prove a companion result, to show that there exist universal construction automata. Indeed, the book concludes by showing the existence of an automaton that is a universal computer, a universal constructor, and able to reproduce itself.

For simplicity the model of the automaton is constructed in two dimensions. It is assumed that the plane is divided into square cells, all of which are alike. Each cell can be in one of 29 states, and construction is accomplished by changing the states of remote cells. A self-reproducing automaton imbedded in inert surroundings will through a long sequence of steps change the surroundings until a copy of itself exists at a remote location.

Sixteen of the states are used for transmission of information. They can be hooked up to build lines through which information travels in any desired direction. They transmit two types of signals, one of which is for ordinary transmission and the other is used to "kill," that is, to return a state to its inert status. Four states do most of the work, containing the logic of the system. Eight states may be viewed as embryonic, transitional states in the changing of an inert cell to an active one. And the 29th state is the inert one. The process has a discrete time-structure built into it. The state of any cell in the next moment is determined by its own state at the present, and by the state of its four neighboring cells. That is all the machinery that von Neumann requires.

He first shows how, with ingenuity, a wide variety of specialized organs may be built of these simple cells. Then he uses the components to build his universal automaton. The latter consists of three major parts. One is the construction unit (CU), which uses information supplied by its memory to construct a remote automaton. This is quite similar to a universal Turing machine. Indeed it can be constructed so that it also serves as a universal computer. The second part is the memory control unit (MC), which extracts information from the memory and changes this information. The memory itself is contained in a linear array (L), in a simple code. The array is manipulated by extendable arms under the control of MC.

The basic idea is really very simple: A universal construction automaton is designed to follow instructions, coded in its memory, to construct an automaton. It also has the ability to copy its own instructions. When such a unit is given *its own* description, it will copy itself together with these instructions, and will thus have reproduced itself. If the newly born automaton is then sent a starting signal, it will in turn reproduce itself. While this is a simple and ingenious idea, its complete implementation is a monumental task.

Burks deserves credit for the editing of a manuscript that was often no more than a sketch, for the correction of various minor errors, and for the completion of the design of the self-reproducing automaton. He has carefully preserved as much of the original manuscript as possible, and sections written by him are specially marked. Indeed, my one criticism is that the editor has sacrificed readability for historical accuracy.

An interesting philosophical question may be raised in connection with the model constructed. It is capable of parallel processing in the strongest sense—that is, a change may occur in every cell at every moment. Yet only a minute fraction of this capability is used in the construction, just as our computers do parallel processing only in a most trivial sense. Wouldn't a computer all of whose memory cells could be changed simultaneously be a vastly more powerful tool than our present machines? And does this furnish a clue to why the human mind is so incredibly efficient compared with computers?

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Molecules and Bulk Properties

Statistical Physics. GREGORY H. WANNIER. Wiley, New York, 1966. 544 pp., illus. $11.50.

In the hundred-odd years since its founding, the branch of physics which explains the properties and behavior of bulk matter through statistical properties of large numbers of molecules has been called by many different names, each of which emphasizes a particular aspect of the field. To Clausius it was the kinetic theory of heat. To Gibbs it was statistical mechanics. To Guggenheim it was statistical thermodynamics. Clausius' name reflects the preoccupation of the middle 19th century with heat engines. That of Gibbs reflects the late-19th-century point of view that any completely satisfactory physical theory must be a branch of analytical dynamics, while Guggenheim's emphasizes the calculation of equilibrium thermodynamic properties from properties of molecules.