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Editor: *Donlyn Lyndon, AIA, School of Architecture and Planning, Massachusetts Institute of Technology, Cambridge.* **Contents:** *Toward a Theory of Architecture Machines by Nicholas Negroponte; A Curriculum Structure by John Wade.*

Toward a Theory of Architecture Machines

BY NICHOLAS NEGROPONTE

When a designer supplies a machine with step-by-step instructions for solving a specific problem, the resulting solution is unquestionably attributed to the designer's ingenuity and labors. As soon as the designer furnishes the machine with instructions for finding a method of solution, the authorship of the results becomes ambiguous. Whenever a mechanism is equipped with a processor capable of finding a method *of finding a method of solution*, the authorship of the answer probably belongs to the machine.

If we extrapolate this argument, eventually the machine's creativity will be as separable from the designer's initiative as our designs and actions are from the pedagogy of our grandparents.

The Evolutionary Machine

This discussion is not about machines that necessarily can do architecture; it is a preface to machines that can learn about architecture and perhaps even learn about learning about architecture. Let us call such machines *architecture machines;* the partnership of an architect with such a device is a dialogue between two intelligent systems—the man and the machine—which are capable of producing an evolutionary system.[1]

Certainly computers are formidable clerks. They perform well when told exactly how to do something and they can remove drudgery by doing the dull repetitious design tasks. Is that not enough? Why ask a machine to learn, to associate courses with goals, to be self-improving and to be ethical? [2]

The answer is imbedded in the question. If a machine can be a self-improving evolutionary specie, it sports a better chance of making its computational and informational abilities relevant. Most computer-aided design studies are irrelevant inasmuch as they only present more fashionable and faster (though rarely cheaper) ways of doing what designers already do. And, since what designers already do does not seem to work, we will get inbred modus operandi that could make bad architecture even more prolific.

The general concern of machine-assisted architecture is twofold: First, architects cannot handle large scale problems, for they are too complex; second, architects ignore small scale problems, for they are too particular and individual (and, to them, trivial). As a result of both realities, "less than 5 percent of the housing built in the United States and less than 1 percent of the urban environment is exposed to the skills of the design professions." [3] In trying to combat these deficiencies, researchers are developing information systems, computer graphics and computing services that liberate the designer and allow him more time to do that which he really loves.

Such efforts would be meaningful only in a context where machines can learn to be adaptable and learn to be relevant. (And then these efforts might be unnecessary.) Ironically, an environmental humanism might only be attainable in

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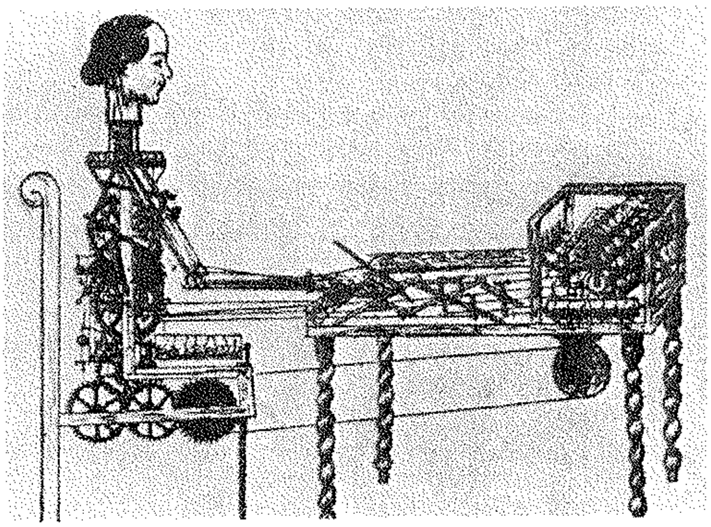
1. This issue will be discussed at length in Nicholas Negroponte's *The Architecture Machine*, Cambridge: MIT Press, late 1969. The preparation of the manuscript has been sponsored by Joint Center for Urban Studies of Harvard University and MIT: The reader should also refer to: Warren M. Brodey and Nilo Lindgren, "Human Enhancement Through Evolutionary Technology," *IEEE Spectrum*, September 1967, page 87.
2. Warren McCulloch, *Embodiments of Mind*, Cambridge: MIT Press, 1965. The reader should particularly look at "Towards Some Circuitry of Ethical Robots," in that volume.
3. John Eberhard, "A Humanist Case for the Systems Approach," AIA JOURNAL, July 1968.



cooperation with machines that have been thought to be inhuman devices—devices that can intelligently respond to the tiny, individual, constantly changing bits of information that reflect the identity of each urbanite as well as the coherence of the city. If this is true, then the first issue is: Can a machine deduce responses from a host of environmental data?

The Learning Machine

A 1943 theorem of McCulloch and Pitts states that a robot constructed with regenerative loops of a certain formal character is capable of deducing any legitimate conclusion from a finite set of premises.[4] One approach to such a faculty is to increase the probability of meaningfulness of the output (the design) generated from random or disorderly input (the criteria). Ross Ashby stated, "It has been often remarked that any random sequence, if long enough, will contain all answers; nothing prevents a child from doodling: $\cos^2 x + \sin^2 x = 1$."[5] In the same spirit, to paraphrase the British Museum/chimpanzee argument, a group of monkeys, while randomly doodling, can draw plans, sections and elevations of all the great works of architecture and do this in a finite period of time. As the limiting case, we would have a *tabula rasa* realized as a network of uncommitted design components (or uncommitted primates). Unfortunately, in this process, our protagonists will have built Levittown, Lincoln Center and the New York Port Authority Towers.

Surely some constraint and discrimination is necessary if the components are to converge on solutions with reasonable time. Components must assume some original commitment. As examples, five particular subassemblies would be part of an architecture machine: 1) a heuristic mechanism, 2) a rote apparatus, 3) a conditioning device, 4) a reward selector and 5) a forgetting convenience.

A heuristic is a method based on rules of thumb (or strategies) which drastically limit the search for a solution. A heuristic method does not guarantee a solution, let alone an optimal one. The payoff is in time and in the reduction of search for alternatives. Heuristic learning is particularly relevant to evolutionary machines, since it lends itself to personalization and change via talking to one specific designer or overviewing many designers. In an architecture machine, this heuristic element would probably be void of specific commitment when the package arrived at your office. Through architect-sponsored maturation, a resident mechanism would acquire broad rules to handle the exceptional information. The first time a problem is encountered, the machine would attempt to apply procedures relevant to apparently similar problems (or contexts). Heuristics gained from analogous situations would be the machine's first source of contribution to the solution of a new problem.

After repeated encounters, a rote apparatus would take charge. Rote learning is the elementary storing of an event or a basic part of an event and associating it with a response. When a situation is repeatedly encountered, a rote mechanism can retain the circumstance for usage when similar situations are next encountered. In architecture, such repetition of subproblems is extremely frequent: parking, elevators, plumbing, etc. Again, a rote mechanism lends itself to personalization. But, unlike the heuristic mechanism, this device would probably arrive originally with a small repertoire of situations it can readily handle.

Eventually, simple repetitious responses become habits (some good habits and some bad habits). More specifically acclimatized than a rote apparatus, a conditioning mechanism is an enforcement device that handles all the nonexceptional information. Habits, not thought, assist humans to surmount daily obstacles. Similarly, in a machine, beyond rote learning, design habitudes can respond to the standard events generated by the problem, by the heuristic mechanism or by the rote apparatus. Each robot would develop its own conditioned reflexes.[6] As with Pavlov's dog, the presence of habitual events will trigger predefined responses with little effort (no conscious memory recall) until the prediction fails; whereupon the response is faded out by frustration (evolution) and is handled elsewhere in the system.

A reward selector initiates no activities. In a Skinnerian fashion, the reward mechanism selects from any action that which the "teacher" likes.[7] The teacher (the designer, an overviewing apparatus, the inhabitants) must exhibit happiness or disappointment for the reward mecha-

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nism to operate. Or, to furnish this mechanism with direction, simulation techniques must evolve that implicitly (without the knowledge of the designer) test any environment. The design of this device is crucial; bad architecture could escalate as easily as good design. A reward selector must not make a machine the minion or bootlicker of bad design. It probably must evaluate, or at least observe, goals as well as results.

Finally, unlearning is as important as learning. A remark "its (the computer's) inability to forget anything that has been put into it . . ." [8] is simply untrue. Information can assume less significance over time and eventually disappear—exponential forgetting. Obsolescence occurs over time or through irrelevance. A technological innovation in the construction industry, for example, can make entire bodies of knowledge obsolete (which, as humans, we often hate surrendering). Or past procedures might not satisfy environmental conditions that have changed over time, thus invalidating a heuristic, rote response, or conditioned reflex.

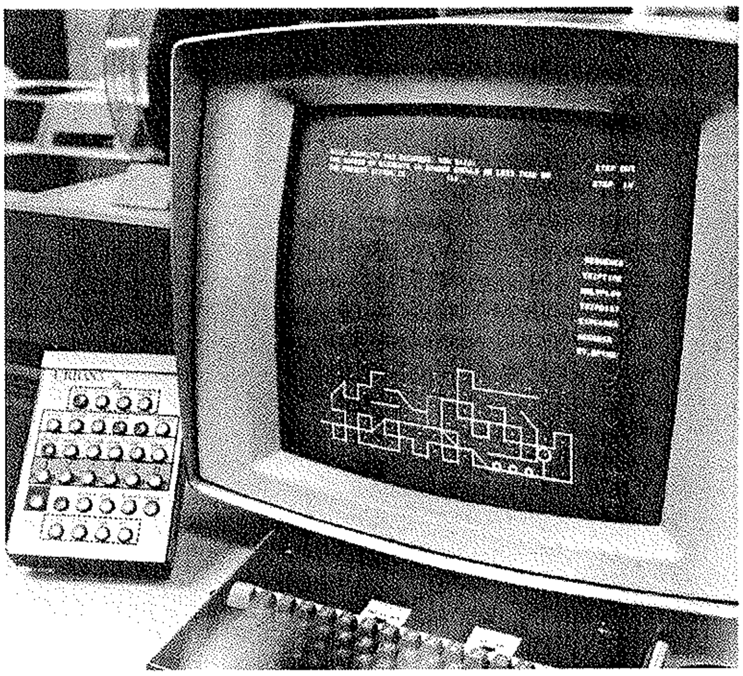
These five items are only pieces; the entire body will be an everchanging group of mechanisms that will undergo structural mutations, bear offspring,[9] and evolve, all under the direction of a steersman. Though this is not the place to describe monitoring devices or hardware configurations in detail, it is important to understand the general placement of parts. Located in residence with the architect would be the architecture machine with these five subassemblies. The machine would have local computing power and local memory and it would work 24 hours a day for a specific designer.

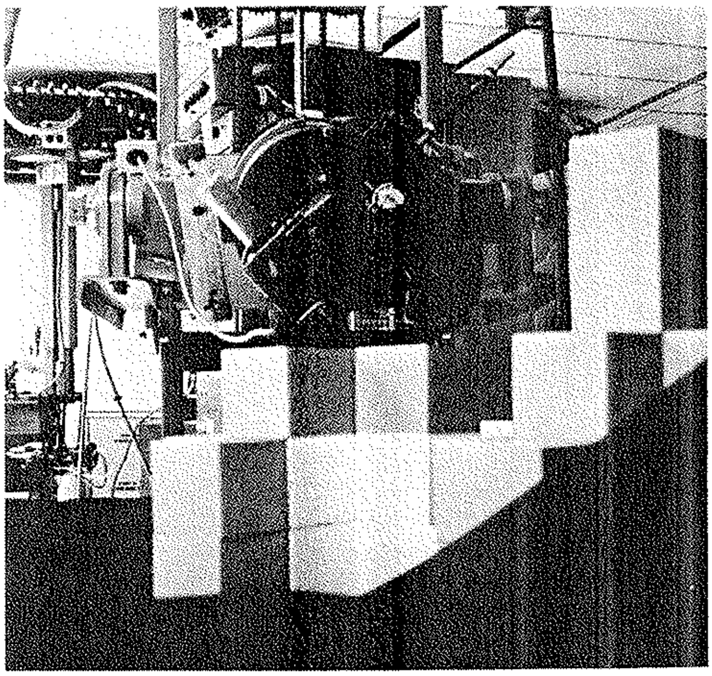
Away from the designer would be a parent machine to which all architecture machines could talk via telephone lines. This mechanism would have powerful processors and extensive memory (in the spirit of Sweets Catalogue, Graphics Standards, zoning laws, or all the demographic figures of the world). The architecture machines would talk to this parent device for three reasons: 1) to acquire large bursts of computing power, 2) to acquire stored information, 3) to communicate with other architects and other architecture machines. In other words, the configuration is one where many parts, human and mechanical, are communicating with themselves and with each other, while the consortium as a whole is somehow communicating with the real world.

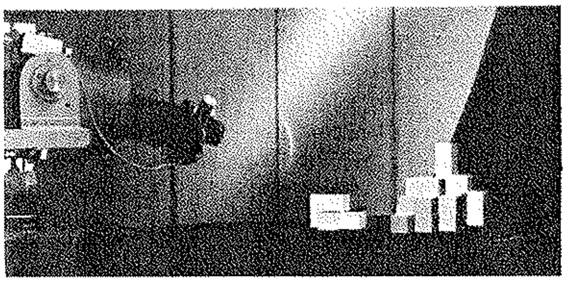
The Seeing Machine

Communication is the discriminatory response of an organism to a stimulus.[10] If we are to reckon with communication, beyond formal rhetoric or syntax (be it English or computer graphics), we must address ourselves to the versatility of the

4. Warren McCulloch and Walter Pitts, "A Logical Calculus for Ideas Immanent in Nervous Activity," *Bulletin of Mathematical Biophysics*, Vol. 5, Chicago University Press, 1943, pages 115-133.
5. Ross Ashby, "The Design of an Intelligence Amplifier," *Automata Studies*, edited by Claude Shannon and J. McCarthy, Princeton University Press, 1956.
6. Albert Uttley, "Conditional Probability and Conditioned Reflexes," *Automata Studies*, edited by Claude Shannon and J. McCarthy, Princeton University Press, 1956.
7. B. F. Skinner, *Science of Human Behavior*, New York: Macmillan Co., 1953.
8. Arthur R. Miller, "The National Data Center and Personal Privacy," *The Atlantic Monthly*, Vol. 220, November 1967.
9. The concept of simulated evolution through bearing offspring is covered at great length in Lawrence J. Fogel, Alvin J. Owens and Michael J. Wash, *Artificial Intelligence through Simulated Evolution*, New York: John Wiley & Sons, 1956.
10. Colin Cherry, *On Human Communication*, Cambridge: MIT Press, 1957.







discriminating mechanism—the interface.[11] In this case, the interface is the point of contact and interaction between a machine and the "information environment." The observation channel in which we are interested is where the processors become tangent to the real world by directly sensing it or by communicating with a human (who senses it).

For a machine to have an image of a designer, a design problem, or even a so-called design solution, three properties are necessary: an event, a manifestation, a representation. The event can be visual, auditory, olfactory, tactile, extrasensory or a motor command. The manifestation measures the event with the appropriate parameters (luminance, frequency, brain-wave-length, angle of rotation, etc.). The representation is the act of mapping the information into a receptacle that is compatible with the receiving organism's processing characeristics.[12] These three properties—event, manifestation, representation—form the interface.

In an architect-machine partnership perhaps the most relevant sensory interfaces are visual. Computer graphics techniques have become the paradigm for computer-aided architecture systems[13] but beyond inputting and outputting lines, points, characters and even halftones, architecture machines must have eyes (and ears and . . .). Setting aside the phantasmagoria of robot-designers, consider speaking with a machine that sees you. In our present culture the thought is foolish or frightening. To our children it will be an ordinary occurrence. To Mortimer Taube it is offensive.[14] To Marvin Minsky it is obvious.[15]

Oliver Selfridge is credited with the founding works in machine-vision.[16] His machine, "Pandemonium," observed many localized visual characteristics. Each local verdict as to what was seen would be voiced (thus pandemonium) and with enough pieces of local evidence from these *demons*, the pattern could be recognized. The more recent work of Seymour Papert and Marvin Minsky has extensively shown that such local information is not enough; certain general (or global) observations are necessary in order to achieve complete visual discrimination.[17]

Applying the Minsky-Papert eye, it is possible to build an architectural seeing machine by developing a simple device that will observe simple models.[18] Such a mechanism is the prelude to machines that someday will wander about the city seeing the city. In such a manner, architecture machines could acquire information beyond that which they are given and therefore would have the potential to challenge and to question. Furthermore, such data-acquisition avoids the mutations of transfer from real world to designer's sensors to designer's brain to designer's effectors to machine's sensors and so on. For this kind of data, the consequent losses of information at each transfer point are bypassed.

Such research is an exercise in learning through seeing (learning only those aspects which are indeed visually representable). The machine looks at a simple block-model, attempts to recognize what it has seen (using many layers of heuristics) and then extrapolates certain characteristics (probabilities, commonalities, intents, patterns, etc.). After the first model is recognized, the machine asks for a second and then a third, until it has seen 10 block-model solutions to 10 simple problem statements. Following the 10th solution, the machine will be given an 11th problem statement and asked to generate its own solution. In this experiment, the solution will be in the vernacular of forms presented in the original 10.

Even though such a machine is more of a mannerist than a student, the exercise is relevant inasmuch as it reverses the fashionable role of computers. Currently, a great deal of concern and research effort is placed on the machine-generation of form from a given statement of criteria (a statement that usually narrows the range of goals by being a solution-oriented verbal phrasing). For the eyes of an architecture machine, the problem is the opposite; given a form, generate the criteria . . . learn from the criteria and someday generate new forms. □

11. Extensive research has been undertaken to establish congenial architect-machine interfaces. URBAN5 is a computer system that illustrates some of the conveniences of graphical and natural language discourse. This has been reported in Nicholas Negroponte and Leon Groisser, "URBAN5," *Ekistics*, Vol. 24, September 1967.
URBAN5 is discussed at greater length in a forthcoming publication, Gary Moore (editor), *Proceedings of the First International DMG Conference* (held June 1968).
12. Stuart M. Silverstone, *Information Manipulation for the Evolution of Physical Environments*, Cambridge: Urban Systems Laboratory, MIT, Research Report (forthcoming).
13. Murray Milne (editor), *Proceedings of Computer Graphics in Architecture Conference* (held Spring 1968), New Haven (forthcoming).
14. Views that oppose the concept of machine-intelligence are extensively presented by Mortimer Taube, *Computers and Common Sense*, New York: McGraw-Hill, 1961. For further material, Hubert L. Dreyfus, *Alchemy and Artificial Intelligence*, Rand Corporation Paper, 1966, page 3244.
15. Marvin Minsky, "Artificial Intelligence," *Scientific American*, Vol. 215, September 1966. The entire issue provides material on the use of computers.
16. Oliver Selfridge and Ulric Neisser, "Pattern Recognition by Machine," *Computers and Thought*, edited by Edward A. Feigenbaum and Julian Feldman, New York: McGraw-Hill, 1963.
17. Marvin Minsky and Seymour Papert, *The Perceptron*, Cambridge: MIT Press, 1969. The book further expands on some of the myths of parallel processing.
18. Such work is being carried out by Anthony Platt, in cooperation with Seymour Papert, Leon Groisser and the author. The research is being conducted in Project MAC's Artificial Intelligence Laboratory under Ford Foundation sponsorship through MIT's Urban Systems Laboratory. The work is one of four experiments directed toward the actual construction of an architecture machine.