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HOW TO BUILD YOUR OWN SELF-PROGRAMMING ROBOT

Over-the-shoulder instructions on how to use the 8085 microprocessor to build Rodney Robot, a robot capable of thinking.

BY DAVID L. HEISERMAN

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Dedication

This book is dedicated to three personalities that have had the most influence on the project: my wife Judy, my son Paul, and my robot Rodney.

Other TAB books by the author:

No. 714 *Radio Astronomy for the Amateur*
No. 841 *Build Your Own Working Robot*
No. 971 *Miniprocessors: From Calculators to Computers*
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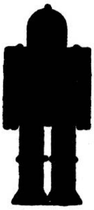

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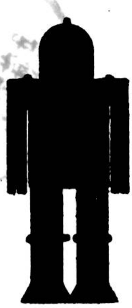
Preface



To my knowledge, this is the first practical, how-to book dealing with machine intelligence. Specifically, the book shows how to build a machine that learns to adapt to changing circumstances in its own environment. It is about a machine that programs itself to deal with problems of the moment and devise theories for dealing with similar problems in the future.

This little creature, dubbed *Rodney*, is a most remarkable machine in the present scheme of things. To be sure, there are a number of fascinating, robot-like machines roaming the workshops of amateur experimenters these days, but Rodney is in a class by himself.

Rodney is a self-programming machine, and as such, he develops a unique personality. No two Rodney machines behave exactly the same way. Wipe out the self-generated memory, and Rodney will develop another one that is bound to be somehow different from the first.

Rodney can exist quite well without any sort of direct human intervention. One exciting experiment with this machine is to wipe out its memory, roll it into a room with its battery charger, and close the door for a couple of days. Leave him alone in there for a month, if you want, but the machine won't be idle.

It will be snooping around its environment, building up its own impressions of what the world is like and developing ways to cope with it. When you finally open that door and step into the room, you will be facing a unique little personality.

Maybe you won't like certain aspects of that personality. Play with him for a while, though, and you can develop some theories on how to mold that personality into a more suitable format. Rodney is self-programmable, but he is trainable.

Building Rodney is, in itself, a valuable learning experience, but even that pales when compared with the opportunity to work with an intelligent little machine personality.

David L. Heiserman

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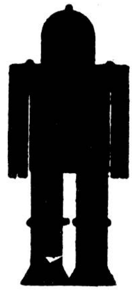

1 Robots, Machine Intelligence, and Rodney

I would really like to know the answer to one question; why are you reading this book? I will probably never know your answer; and, at this point, you might not know the answer yourself.

It is important to determine a good reason for reading this book, because your answer will most likely determine whether or not you will finish reading it. This is a tough book to read, and if your own curiosity about real robots and your own desire to build one for yourself aren't strong enough, you are likely to become discouraged with all the technical matters crammed between these two covers.

I'm not trying to discourage you from reading the book—heaven forbid! Rather, I'm hoping to help set the stage for a big project, and get you thinking along some lines that will help you do the job successfully.

This book does not make good armchair reading. There is too much to learn, think about, and do. A casual reader is bound to get lost or discouraged early in the going. So if you are hoping to find some casual reading about robots, you would do well to look around for a different kind of book on the subject.

But, if you are honestly interested in learning something truly significant about robots, or if you are interested in getting in on the ground floor of a new technology that promises to have some impact on all our lives in the near future, this is the right book for you.

WHAT'S SO TOUGH ABOUT THIS PROJECT?

There are two phases to this project: studying and understanding the material in this book and building the Rodney robot system itself. Both phases demand a certain kind of discipline that isn't altogether common these days. While I do attempt to make it all seem as simple and logical as possible, the real burden of understanding and carrying out the instructions is on your shoulders.

The study and understanding of this book will be difficult for many readers because it demands a certain level of acquaintance with digital electronics, microprocessors and related IC devices, and microprocessor programming. I am not saying you must have a college degree in electrical engineering and computer science to understand this book; but, if you aren't acquainted with the fundamental subjects I have listed here, you will have to find a few other books to help you. Such a book would be TAB's *Understanding Electronics*.

I would suggest finding a good book describing the fundamentals of digital electronics. Such a book will help you work your way through the theory of some of the logic circuits in the Rodney system. A good book would be TAB's *Digital/Logic Electronics Handbook*.

I also suggest picking up a copy of Intel's *MCS-85 User's Manual* and Texas Instrument's *TTL Data Book* and TAB's *Digital Interfacing With An Analog World*. All are available in most computer stores. Between these three books, you will have complete descriptions of all the IC devices used in the Rodney system, and the Intel book includes a complete summary of the machine-language programming procedures.

I am doing my part of the job by presenting the theory of operation of the circuits and programming in a fashion that is as logical as possible and as complete as is practical. And, with the aids just mentioned, the rest is up to you.

Even an individual with no background in digital electronics and microprocessor can work his way through this book, the equivalent of a full one-year course in these subjects.

There is, however, a whole different angle to the matter of studying and understanding this book. Much of the theory material deals with a topic that some would call artificial intelligence. Personally, I prefer to call it *machine intelligence*, a matter of semantics we needn't deal with at this time. You are going to be studying about an intelligent machine, and that means you will be dealing with some rather new and unusual ideas. As it is applied here, there are no other sources of information on machine intelligence. In fact, other books on artificial intelligence will prove to be a hinderance to understanding this one. You will be better off knowing nothing at all about artificial intelligence, because there won't be anything to confuse the matter and you won't have to unlearn old principles that don't apply very well to Rodney. So the *less* you already know about artificial intelligence and computer programs that work with it, the easier you will understand this book. It will be tough if you are starting out with some preconceived ideas about what artificial intelligence ought to be.

It is a good idea to read through the book first—all the way through. If nothing else, this first reading will point out what you must learn from other sources before getting really serious about the job. Then pick up any of the necessary aids and use them to help you understand the circuit theory and principles and the programming end of the job. Forget anything you might have learned about artificial intelligence, and study the book more thoroughly a second time. Only then will you be adequately prepared to start building the machine.

Building Rodney calls for some previous experience with constructing electronic circuits, especially IC circuits. You will have to know good soldering and wire-wrapping techniques, and of course, you will have to be able to follow schematics and wiring diagrams with confidence.

It isn't easy to pick up the necessary level of construction experience, something that comes only by doing it many times. Beginners would do well to find a friend or acquaintance who does have the necessary experience and can help get things going properly.

A CRITICAL TURNING POINT

Why *are* you still reading this book? Maybe you aren't so sure of the answer to that question any more. I have given you the "bad" news first, and some of you might be seriously thinking about giving up robotics for something less demanding such as fishing or gourmet cooking.

To this point you have only seen how tough the project is going to be, at least as it is filtered through the context of your own past experience. Any task this demanding must have a terrific payoff, else there would be no rational reason for carrying it any further. So, here comes the "good" news.

Rodney is a very, very special sort of machine, and before you finish reading this chapter, I hope you will see Rodney as a creature that effectively bridges the evolutionary gap between machines and animals. Just think about it—a creature that is certainly a man-made machine, and yet one that exhibits the fundamental characteristics (excepting reproductivity) of lower animals.

It is important to realize that Rodney is not merely a machine that mimics animal behavior. Researchers have been trying to build machines that mimic animal and human behavior for a long time now, and the results hardly justify all the work that must be put into the Rodney project.

Rodney is a unique creature in his own right. He often appears to behave as a simple animal, but that is incidental to the philosophy of the whole thing. Rodney belongs to a new class of machines that will soon fulfill the science-fiction fans' dream of what robots ought to be. Take a moment to consider what a real robot (*i.e.*, Rodney) ought to be.

WHAT IS A ROBOT?

The formative period of any new technology is an especially sensitive one. Mistakes or misconceptions in the early going can confuse and misdirect the efforts of well-meaning experimenters for years to come. Unless we are careful about laying the basic philosophical foundations of robotics now, we run the risk of wasting time, effort, and money developing machines and concepts that lead nowhere.

This is the time to get the basics of robotics straight; the logical starting point seems to be working up a good definition of *robot*. This is really getting down to basics, but there is a definite need for carrying an initial analysis to this extreme. The term *robot* is a coined expression that doesn't define itself as technical terms often do.

What many people think a robot should be, really isn't a robot at all. It is difficult for such people to understand the legitimate definition since they try force-fitting it to their existing misconceptions. For this reason, it is perhaps a good idea to spell out first what a robot is *not*—to tear down some old structures and make way for a more useful and exciting one.

What A Robot Isn't

There are two major classes of electromechanical contrivances making something of a stir in the popular media these days. Some of them are quite complex and very interesting machines, but they are not real robots. They are merely imitations—*parabots*, if you will.

One class of parabot calls for having a human operator manipulate the machine by remote control. Would-be roboticists must not be misled into believing any sort of remote-controlled machine that is manipulated by a human operator is any more vital to the evolution of machine technology than remote-controlled airplanes. Forget about any machine that relies on the in-line intervention of a human being. It isn't a robot.

The second major class of parabots simply replaces the remote human operator with a small computer system. It is certainly possible to play an endless variety of sterile computer programs through a cleverly interfaced set of mechanical gadgets, and end up with some fascinating effects. All this can be done, however, without really jumping the technological gap into the era of robotics.

Robot—A Matter of Semantics

When thinking about real robots, consider two alternate names, *cyborg* and *automaton*. These are the key expressions.

The term *cyborg* comes from the same root as *cybernetics*—the science of closed-loop feedback or servo systems pioneered by Norbert Wiener in the 1940s. A robot, then, must have cybernetic features, but that only expresses one aspect of how the job is done. It doesn't really say what a robot is—what separates it from any other class of automatic machinery in existence today.

Now, consider the term *automaton*. This word comes from the same root as *automatic*; what is even more meaningful is the fact it shares a common heritage with the word *autonomous*—and this word is the key to defining a robot.

A robot must be an autonomous machine, a machine capable of carrying out functions on its own. A typical computer system is not an autonomous machine. As sophisticated as some computers might be, they must interact with a human operator to do anything useful at all. A robot is not a slave, but a "free" machine. It is a free-will machine that can certainly obey the commands of a human operator, but only as long as those commands do not violate any higher-priority needs and desires.

Given a command or goal by a human operator, a true robot must be free to execute that command and achieve the goal, freely deciding exactly how to go about it. And, whenever the robot is not actively pursuing a goal set by its human operator, it must be free to determine and work toward goals of its own.

This is not a flight of fantasy, but a prime example of what a robot—an autonomous cyborg—can and must do. Any machine incapable of exhibiting autonomous behavior is not a robot at all.

Integrative Behavior Is The Key

The philosophy behind the construction of a truly autonomous cyborg, as incredible as the concept might seem at first, is not really difficult to implement these days. Buster III, described in *Build Your Own Working Robot* (TAB book No. 841), is an example of a lower-order robot. Buster III can operate without the need for direct human intervention; he can seek out his own battery charger and feed himself when the need arises; he can work his way around most kinds of physical barriers and generally interact with his environment in a fashion that clearly indicates some underlying intelligence.

Buster's brain is not a conglomeration of discrete, task-performing programs. The system is far more dynamic than is possible with the sort of thinking that goes into building parabots.

The brain of a true robot is an integrated network of simple and basic functions that are orchestrated according to on-line environmental conditions and the task set before the machine.

The Rodney system described in this book moves several steps higher on the scale of robot technology. This new machine not only reacts in a quasi-rational manner to its environment, but deals with that environment, even altering it if necessary and possible—*as judged by itself!*

HOW More Important Than WHAT

Putting together the basic working definition of a robot and the integrative techniques for implementing that definition, one central theme emerges: It is far more important at this point to think in terms of *how* a robot carries out its tasks than it is to become carried away with *what* it can or cannot do.

What really distinguishes man from other animals? Of course, we could point to an infinite variety of political, social, economic, and technological achievements through the history of mankind, but all these things merely reflect something deeper in the human makeup. The real essence of man is bound up in how his mind works, rather than what he does as a result.

Man is unique in his capacity for rational, imaginative, and often highly abstract thought. No other animal has the ability to think, judge, and interact with the environment on the same level as man does. *The thinking comes first, and the achievements are the result.*

A true robot is to other machines as man is to other animals. If roboticists can shed their current misconceptions and begin thinking in terms of an autonomous machine equipped with integrative reflex, decision-making, and goal-setting mechanisms, we can expect to see a new order of machine exhibiting a rich variety of behavioral modes that make other machines seem to be the lower-class mechanisms they really are.

IS RODNEY A REAL ROBOT?

The Rodney system is indeed an autonomous cyborg—a truly independent creature that does "its own thing." You, as Rodney's human owner, can interact with Rodney's free-will mechanisms. However, don't be surprised when Rodney treats you as a mere environmental factor, rather than an absolute master.

One of the philosophical mistakes I made when writing my book about Buster, *Build Your Own Working Robot*, was including some attractive remote control mechanisms. These mechanisms were really meant for testing purposes, but many reader/builders misinterpreted my intent. Rather than carrying the Buster project through to the point where he became an autonomous creature, a good many experimenters stopped at the point where they could get full control of the machine.

It certainly is exciting and a lot of fun to run Buster around the floor by manipulating a set of switches, but the scheme hardly qualifies as a real robot. It is rather an expensive, over-designed remote-controlled toy.

You will find it very difficult to play with Rodney in this fashion. Control switches are included, but mainly for programming purposes. Rodney simply cannot perform in an interesting way unless he is turned loose and allowed to pursue his own unique manner of dealing with the world around him.

At this point in the discussion, you should be getting at least an intuitive idea about what a robot should be and what Rodney is all about. By design, Rodney is an independent, free-willed creature that can operate from any one of three levels of machine intelligence.

THE EVOLUTION OF MACHINE INTELLIGENCE

Most of the so-called robots that exist today are mere shadows of what they could be. The world is primed for a major explosion in robot technology, but the people trying to light the fuse are using wet matches.

What is needed are dynamic, self-programming, general-purpose machines capable of setting and pursuing their own goals in the context of the world as the machines, themselves, perceive it. The film *Star Wars* portrays robots as free-willed machines that are fully capable of dealing with a complex environment in meaningful ways. Now that's the kind of robot people really want, and that's the kind of robot we must think about from now on.

Simple Yet Sophisticated

It is going to take some time and a lot of effort to evolve a machine as sophisticated as little Artoo-Detoo in *Star Wars*, but we have to start somewhere; I am convinced the starting point is a scheme called an *Alpha-Class robot*. An Alpha-Class robot is one whose responses are limited to basic reflex activity. One can include any number of sensory systems to sense light, sound, touch, and so on, but the responses are purely reflexive, and for the most part, random in nature.

My Buster machine includes the basic elements of an Alpha-Class robot, but Rodney more clearly exemplifies the character of an Alpha-Class mechanism. Rodney's responses include feeding (recharging his own battery) and a series of nine different motion patterns such as spinning clockwise or counterclockwise, moving slowly forward or backward with a slight turn, running fast forward, and so on.

Rodney's sensory system is limited to knowing when he has made contact with the feeder and sensing a stall condition when he is supposed to be moving. This machine responds to contact with the feeder by remaining motionless and absorbing energy as long as it is available. He responds to a stall condition by going through a series of quasi-random spinning and turning motions that continue until the stall condition is cleared.

Alpha-Class robots might seem too simple to be of any real importance. Indeed, they are simply little creatures, but they do not represent a trivial step in the evolution of real robots. They manage to survive quite well in a moderately complex environment just as their organic counterparts, one-celled creatures, have survived throughout earth's biological history.

Alpha-Class robots merely mark the starting point for the evolution of robot machines. A *Beta-Class robot* is slightly more intelligent than any Alpha-Class version. Beta robots have the same primitive reflex mechanisms, but they are also to *remember* reflex responses that work best under a given set of circumstances. So whenever a Beta-Class robot manages to extricate itself via a set of random responses from an undesirable environmental condition, it remembers the one response that worked and then uses it immediately whenever the same situation arises again. The responses are purely reflexive and random the first time around, but they become more rational as the machine gains experience with the world around it.

The number of sensory elements and motor responses can be extended indefinitely, but as long as the robot must encounter a given situation at least one time before learning and remembering the correct response, it remains a Beta-Class robot.

A *Gamma-Class robot* includes the reflex and memory features of the two lower-order machines, but it also has the ability to *generalize whatever it learns* through direct experience. Once a Gamma-Class robot meets and solves a particular problem, it not only remembers the solution, but generalizes that solution into a variety of similar situations not yet encountered. Such a robot need not encounter every possible situation before discovering what it is supposed to do; rather, it generalizes its first-hand responses, thereby making it possible to deal with the unexpected elements of its life more effectively.