PROGRAMMING THE TI-55 SLIDE RULE CALCULATOR

STEPHEN L. SNOVER
& MARK A. SPIKELL

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How to Program Your Programmable Calculator,

Brain Ticklers: Puzzles and Pastimes for Programmable Calculators and Personal Computers,

Mathematical Problem Solving with the Microcomputer.

Preface

Over 100 million hand-held calculators are estimated to be in the United States alone. Generally, these calculators fall into three broad categories—arithmetic, advanced function, and programmable calculators. The most powerful of these are the programmable calculators.

Recent technological breakthroughs have made these hand-held, computer-like calculators available at very inexpensive prices. Programmable calculators have a wide range of exciting uses, from performing everyday arithmetic to evaluating functions and solving advanced problems requiring decision-making.

If you are considering purchasing a more advanced calculator (or even your first one), perhaps the inexpensive TI 55 programmable calculator is just for you. Programmable calculators have all the features of nonprogrammable calculators and much more, as summarized in the following table:

	Ability		
Calculators	*Perform Arithmetic Computations*	*Evaluate Advanced Functions*	*Solves Problems Requiring Repeated Evaluations*
Arithmetic	X		
Advanced function	X	X	
Programmable	X	X	X

Who is this Book For?

Any person who wants to learn about programming the TI-55 and how to program it to solve problems will benefit from this book, especially:

- college students in engineering, business, science and mathematics,
- high school students interested in the mathematical sciences,
- teachers and professors who want a reference of problems that can be done on programmable calculators, micro-, or minicomputers,
- calculator enthusiasts who want to extend their problem solving ability, and
- persons interested in pre-experience for learning eventually to program computers.

What is the Purpose of this Book?

When you buy a TI-55 programmable calculator, you receive an owner's manual or text designed to show how to use the calculator, what its various special features are, and other relevant technical information. But you receive hardly any instruction on how to program the calculator or how to design programs to solve problems. Furthermore, you receive very few exercises and problems on which you can practice and develop programming skills. This book is carefully designed to complement the owner's manual by providing you with:

- information on how to design programs to solve problems on the TI-55 programmable calculator,
- over 125 carefully sequenced examples, exercises, and problems solvable on the TI-55 programmable calculator, micro-, or minicomputer, and
- insight on what programmable calculators can do and how they are used as problem-solving tools.

How Can You Use this Book?

If you own a TI-55 programmable calculator, you might use this book:

- as a self-study manual,
- as a text in a mini-course or continuing education course, or
- as a resource in a math club setting.

Even if you do not own one, you might use this book:

- as a self-study manual,
- as an aid in deciding whether to buy a programmable calculator,
- as a reference of exercises and problems solvable on programmable calculators, or
- as a library reference.

Which Programmable Calculator Should I Have to Get the Most Out of this Book?

Since the authors believe you can learn most rapidly by doing rather than by just reading, this book is written with a "hands on" approach. That is, if you have a programmable calculator at hand, you can follow the text and work through the examples on your calculator while you read. Because it is impossible to design a "hands on" book to be used with every one of the many programmable calculators presently available, this book is designed specifically to be used with the TI-55 programmable calculator.

Yet an important feature of this book is its adaptability. Both the programming techniques discussed in the text and the solutions to the problems are adapted to these other programmable calculators:

- Texas Instruments SR 56 and SR 52
- Texas Instruments TI-57, TI-58, and TI-59
- Sharp PC 1201 and 5100
- Hewlett-Packard HP 25 and HP 25C
- Hewlett-Packard HP 33E and HP 33C

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Introduction

Section 1: What Is A Programmable Calculator?

Today's hand-held calculators come in all sizes and types, but basically they can be grouped into three categories:

1. four-function calculators,
2. advanced-function calculators, like scientific and business calculators, and
3. programmable calculators.

In order to distinguish among these calculators, imagine that each is a "black box" with buttons and a display on the outside. Inside is a little man with a scratch pad and pencil who knows how to add, subtract, multiply, and divide.

The Four-Function Calculator

The cheapest of all the calculators, the four-function calculator is simply the black box already described. With this calculator you can perform the

four arithmetic operations—addition, subtraction, multiplication, and division.

Introduction

The Advanced-Function Calculator

Since more functions, such as $\boxed{\sqrt{x}}$ $\boxed{\tan}$ $\boxed{x^a}$ and $\boxed{e^x}$ appear on the advanced-function calculator, you might guess that it contains specially designed, or "hard-wired," circuitry inside the calculator for computing each such function. The little man inside the black box, you might guess, has been trained to compute each of these functions. Actually this is not the case. Building special circuitry for each additional function is far too expensive.

Instead, what really happens can be best described by extending the analogy of the little man in the black box. Because you pay more for your advanced-function calculator, the little man inside is provided with a helpful instruction booklet that tells him how to perform each advanced function, not directly, but as a sequence of the four arithmetic functions he already knows.

For example, suppose the square root function, $\boxed{\sqrt{x}}$, is pressed. The little man inside sees the button pressed, but on the inside the button reads "Page 2." He then opens the instruction booklet to page 2 and reads:

- *Step 1:* Copy the number from the display onto line 1 of the scratch pad. Then write a 1 on line 2.
- *Step 2:* Divide the number on line 2 into the number on line 1 and put the quotient on line 3.
- *Step 3:* Add the number on line 2 to the number on line 3 and then divide the sum by 2. Place the result on line 2 (erasing any number that was there before).
- *Step 4:* If the numbers on lines 2 and 3 are equal, put that value in the display and stop. Otherwise, go back to step 2 and repeat.

In the analogy, the little man in the box has no idea that he is calculating a square root, but that hardly matters. It is only necessary that page 2 is written properly and that he follows the steps letter perfect.

Each other function on the advanced function calculator is computed in a similar fashion, although its instructions are different and they appear on a separate page of the booklet.

The Programmable Calculator

When you purchase a programmable calculator, you buy most of the features of an advanced-function calculator plus the flexibility of being able to create (or program) your own functions.

The little man in the black box receives an instruction booklet with one page for each advanced function and with one additional *blank* page. The little man does either of two things with this blank page. If the calculator

is in the so-called "learn" or "program" mode, he records on the blank page any sequence of buttons that are pressed. Or if the calculator is in the "run" mode, he considers this page just like any other page and follows its instructions when the [2nd] [R/S] or run/stop sequence is pushed.

While the little man analogy may seem simplistic, it does indicate in nontechnical terms what a programmable calculator is. With a programmable calculator, you can perform most functions available on any advanced-function calculator with a single button. Furthermore, you can create or program your own functions and access them by just pressing the [2nd] [R/S] sequence.

Section 2: What Problems Can Programmable Calculators Solve?

To illustrate the wide range and variety of problems that can be solved on a programmable calculator, the following representative problems have been selected. You can find each of these problems together with their solutions in the text.

Programmable calculators can solve:

- from simple arithmetic:

$$24(1 + .05)^{300} = ?$$

to complex calculations:

$$\sum_{n=1}^{\infty} \frac{n^2}{2^n} = \frac{1}{2} + \frac{4}{4} + \frac{9}{8} + \frac{16}{16} + \frac{25}{32} + \frac{49}{64} + \ldots = ?$$

- from straightforward computations:
  Convert a temperature in degrees Fahrenheit to a temperature in degrees Celsius.
- to indirect computations:
  How many ways could you choose a committee of a president, vice-president, secretary, and a treasurer from a group of 10 people?
- from applications in business:
  If a new car dealer advertises an automobile at a delivery price of $5,272.50, how much does this car cost the dealer and how much profit is the dealer making?

  to applications in science:
  Suppose you have a large collection of n bricks, all the same size. Say each has unit length. If you stack them so that the top brick extends as far to the right of the bottom one as possible, can the top one overhang more than one unit length to the right of the bottom brick?

  to applications in recreational mathematics:
  Imagine a square-based pyramid of cannonballs with one cannonball on top and a square number of cannonballs on each layer. How many cannonballs are there in the top 10 layers? How many layers can be made from 10,000 cannonballs?

Section 3: The Evolution of Calculating Machines

Incredible as it may seem, man has been on earth for more than a million years while the programmable hand-held calculator has been here only since 1973! Man invented the first calculating machines some 5,000 years ago, but almost all advances leading to calculators as we know them today have occurred in the last 30 years.

To place the evolution of calculating machines in perspective, some of the major historical developments have been placed on the following time line, interspersed with other notable historical events:[1]

pre-3,000 B.C.	Abacus (performs +, −)
1456 A.D.	Movable type printing press
1617	Napier's bones (performs ×, ÷)
1642	Pascal calculating machine (+, −)
late 1600 s	Leibnitz calculator (+, −, ×, ÷, $\sqrt{\ }$)
about 1760	Industrial Revolution
1820	First reliable commercial calculating machine
1835	Mechanical programmable computing machine
1890	Electrical input reading computers
1939	Fully automatic calculator
1946	First digital computer, ENIAC
1957	Sputnik satellite
1958	Integrated circuit chip
1963	Desk-top computer, PDP-5
1969	First person to walk on the moon
1971	First hand-held calculator, Bowmar Brain
1973	First hand-held programmable calculator, HP 65
1975	HP 25
1976	HP 25C
1977	TI 57, 58, and 59
1978	Sharp 5100
1978	TI 55
1979	HP 19C, HP 29C
1980	HP 41C, HP 34C

Section 4: AOS and RPN Calculators

One way of distinguishing the types of programmable hand calculators is to scan the keyboard for an "equal" key. If there is one, your calculator is an Algebraic Operating System (AOS) calculator. Otherwise, it is most likely a Reverse Polish Notation (RPN) calculator.

What does it mean to say that a calculator is an AOS or RPN calculator? An AOS calculator allows you to enter calculations as they are generally written. For example, the computation of 3 + 4 is done by pressing the keys [3] [+] [4] and [=] in that order. With an AOS calculator, the + operation is not performed until the equal key is pressed.

[1] For a detailed historical presentation, you may consult the TI 57 owner's manual, *Making Tracks into Programming* (TI Learning Center, 1977), Chapter 12.

An RPN calculator, in contrast, uses the key stroke sequence [3] [↑] [4] [+] to perform the same calculation. In other words, RPN calculators perform the operations at the same time as the appropriate operation key is pressed.

Most persons prefer one type of calculator or the other; each has certain unique characteristics. AOS calculators allow you to enter arithmetic calculations from left to right as they are written algebraically. With RPN calculators, all data is entered before pressing any operation key. All programmable AOS calculators have parentheses while programmable RPN calculators do not. Some people feel that parentheses make programs more readable. Others feel that programs without parentheses are more efficient, that is, the programs often take fewer steps.

Two major American manufacturers, Texas Instruments and Hewlett-Packard, produce hand-held programmable calculators. Texas Instruments produces AOS calculators while Hewlett-Packard produces RPN calculators.

Section 5: The Texas Instruments Family of Calculators

The Texas Instruments family of calculators includes six programmables: SR 56, SR 52, TI 55, TI 57, TI 58, and TI 59. The SR 56 and SR 52, no longer manufactured, were the first programmables produced by Texas Instruments.

The SR 56 initially sold for about $100 and eventually fell in price to about $65. Features of this machine included 100 program memory steps, 10 memory registers, decision-making tests, and even subroutine capability. The SR 52 initially sold for about $295 and eventually fell in price to about $150. In addition to all of the features of the SR 56, this machine has 224 program memory steps, 20 memory registers, insert and delete editing capability, and magnetic cards for program storage.

The TI 55 programmable calculator has the greatest number of built-in special function keys of all the TI programmable calculators. It is programmable because it has the four programming key sequences [2nd] [R/S], [2nd] [Rst], [2nd] [Lrn], and [2nd] [Sst], as well as 32 programmable memory steps available for running "straight-line" programs. Although this calculator does not have decision tests and insert and delete editing features, it is still the best beginner's calculator by reason of its low cost and its capability of meeting most programmable needs.

The TI 57, 58, and 59 programmables have been designed for a wide range of users. The TI 57, selling for less than $50, includes 8 memory registers, 50 merged program steps (nearly the same as 100 nonmerged steps), the equivalent of 8 decision tests, insert and delete editing, labels, and subroutines. The TI 58 and 59 programmables are more advanced and come equipped with programmable read-only memory chips, called PROMs, which contain numerous programs already written. Both machines can be attached to the TI PC 100A printer, which sells for about $175. The TI 59, selling for about $200, has effectively twice the number

of memory registers and program steps as the TI 58, selling for about $100. Furthermore, the TI 59 can be used with magnetic cards.

Section 6: Possible Effects of Programmable Calculators On the Teaching of Mathematics

In June of 1976, the National Science Foundation and the National Institute of Education jointly sponsored a conference on badly needed research and development on hand-held calculators in school mathematics. The following observation from the conference report is significant: "Microelectronic technology is changing at an astonishing pace. Today's four-function calculator will soon be replaced, at the same price, by one with many more functions. Today's scientific calculator will be replaced soon by comparably priced programmable calculators. . . ."[2]

The observation has already been prophetic. Presently, programmable calculators are indeed available at remarkably low prices—prices so low, in fact, that teachers can give serious attention to considering the use of these machines in the school mathematics curriculum at every level.

Because the availability of inexpensive programmable calculators is such a recent phenomenon, educators have not yet been able to arrive at a consensus on what to do with these machines in the school curriculum. However, programmables could have an impact on the teaching of mathematics in a number of important ways.

- Topics from numerical methods, previously considered too advanced, can now be brought down to the level of high school mathematics. For example, programmable calculators greatly facilitate the study of limits of sequences and sums of series.
- Reading logarithm, trigonometric, power, and root tables is no longer necessary. Programmable calculators, in addition to having built-in function keys for obtaining this information, can be programmed to generate tables of related data for use as needed.
- The slide rule, long a significant tool for performing calculations, is now obsolete, because programmable calculators do everything a slide rule does—and much more. Programmable calculators also provide a degree of accuracy and a speed of computation not possible with slide rules.
- "Exhaustive searches" to generate data are now practical. The calculator can be programmed to search (or test) hundreds or thousands of special cases—a chore essentially impossible to do by hand. For example, consider the problem of finding all integer Pythagorean triples, $a^2 + b^2 = c^2$, with the hypotenuses, c, less than 100. Finding such triples by hand would be quite tedious and time-consuming. However, the calculator can find all such triples accurately and quickly.

In addition, the educational community can and should address other broader issues. The entire mathematics curriculum must be examined

[2] National Science Foundation and National Institute of Education, *Report of the Conference on Needed Research and Development on Hand-Held Calculators in School Mathematics*, (Washington, D. C., 20208: U.S. Department of Health, Education and Welfare, June, 1976).

and, where appropriate, redesigned to utilize the power of programmable calculators, micro-, and minicomputers. Among the pertinent issues are:

- How does the availability of programmable calculators affect the teaching of algebra? Geometry? Trigonometry? And other mathematics courses, especially calculus?
- Would teaching programming on programmable calculators be a useful topic for a senior level mathematics course?
- Could a unit on logic be designed around the decision-making capability of programmable calculators?
- At what age and in what course experiences should iterative techniques for solving equations (for example, the Newton–Raphson method) be introduced on programmable calculators?
- Is it possible for an exhaustive search to become an integral part of a mathematical proof? For example, is it permissible to combine an exhaustive search for $n \leq 10{,}000$ together with an analytical proof (valid only) for $n > 10{,}000$ to establish a proof for all positive integers, n?

Section 7: Programmable Calculators and Personal Computers

Scarcely a decade ago a four-function desk-top adding machine cost many hundreds of dollars. Now the cost of an equivalent four-function calculator is close to $10. In the near future, however, the prices need not continue to drop. Instead, the capabilities and flexibilities will increase in calculators that remain at certain price levels.

With the advent of the ROM or Read-Only Memory, calculators became cheap. With the RAM or Random Access Memory, calculators could memorize many locations worth of information—so programmable calculators became likewise inexpensive. Next the PROM, or Programmable Read-Only Memory, was introduced allowing much greater programmable flexibility.

In the next few years, man will witness a vast broadening of the flexibility and power of the hand-held calculator. With the bubble memory, a hand-held calculator will be able to memorize and process vast amounts of information. With the new varieties of I/O, or input/output, interfaces, the programmable calculator will be able to display its results on one's home television screen. In essence, the programmable calculator, available for a moderately low cost, will become a personal computer with almost all the power and flexibility of today's expensive computers.

The 1950s constituted the decade of the beginning computer. The 60s were the decade of time-sharing. The 70s comprise the decade of the hand-held calculator. The 80s will likely be the decade of the hand-held personal computer.