A Graphing Calculator for Mathematics and Science Classes

The HP 38G calculator allows teachers to direct students and keep them focused while they explore mathematical and scientific concepts. It features aplets, which are small applications that focus on a particular area of the curriculum and can be easily distributed from the teacher's calculator to the students'.

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The HP 38G calculator is a graphing calculator for students and teachers in mathematics and science classes. It features aplets, which are small applications that focus on a particular area of the curriculum and can be easily distributed from calculator to calculator. This allows the teacher to send an electronic story problem to each student in the class.

The HP 38G is built on the same software platform as the HP 48G family of graphing calculators,[1] but has a simpler user interface and feature set. Equations are entered using algebraic format rather than the reverse Polish notation (RPN) found in most HP calculators. The features of the HP 38G include:

- Graphical user interface
- Function, polar, parametric, stairstep, cobweb, histogram, scatter, and box and whisker plots
- Side-by-side split screen
- Tables
- Unlimited, scrollable history stack
- Symbolic equations
- HP Solve numeric root finder
- EquationWriter display
- Statistics functions
- Matrix operations
- User programming.

The hardware platform of the HP 38G is very similar to that of the HP 48G: they both have 32K bytes of RAM, 512K bytes of ROM, the same CPU and the same display (131 by 64 pixels). They both have a two-way infrared link for sending information to a printer and for transferring information between two calculators, and an RS-232 link for calculator-to-computer communications. An accessory that allows the calculator screen to be displayed with an overhead projector works with both the HP 48G and the HP 38G, but the HP 38G cable connector has been modified so that the overhead display accessory works with every HP 38G; no special handset is required.

The HP 48 case was redesigned to include a sliding plastic cover to make the HP 38G more durable for use by younger students. Also, two keys were removed to give visual emphasis to the navigation keys and to make the keyboard look less complicated.

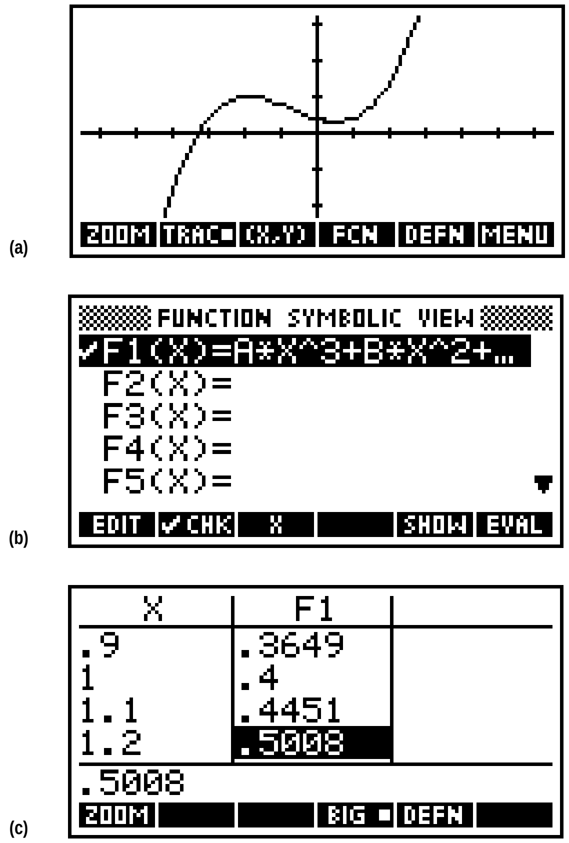
Designed for and with Teachers

We set out to design a graphing calculator for precalculus students and teachers. To help us do this, we formed an Education Advisory Committee consisting of eight high school, community college, and university teachers. We met with the teachers every few months, and between meetings we kept in touch by email.

The teachers told us that they want to allow students to explore mathematical and scientific concepts, and at the same time they need to direct the students and keep them focused. In our first meeting with the teachers, we compared this to the idea of a child's sandbox: the child is given toys for playing and exploration, but within a protected, specialized environment. Thus, one of our main goals with the calculator software design was to encourage exploration by limiting choices. This led us to the concept of *aplets*: an aplet is a small application that focuses on a particular problem.

HP 38G Aplets and Views

We based the design of aplets on the National Council of Teachers of Mathematics "three views": graphic, symbolic, and numeric. Each problem can be explored using these different representations. For example, a mathematical function can be expressed as a graph (Fig. 1a), in symbolic form (Fig. 1b), or using a table of numbers (Fig. 1c).



```
FUNCTION SYMBOLIC VIEW
✓F1(X)=A*X^3+B*X^2+…
 F2(X)=
 F3(X)=
 F4(X)=
 F5(X)=
```

X	F1
.9	.3649
1	.4
1.1	.4451
1.2	.5008

```
.5008
```

Fig. 1. *With the HP 38G calculator, a mathematical function can be expressed (a) as a graph, (b) in symbolic form, or (c) using a table of numbers.*

Aplets can be created by teachers (either directly on the HP 38G or with the assistance of a computer) and then “beamed” to the students’ calculators using infrared transfer. This way, a whole classroom full of students can have their calculators programmed identically at the beginning of a lesson. Then, the students can explore within the aplet on their own calculators.

Each aplet packages the formulas, settings, and other information associated with a particular problem. If the user wants to switch from one aplet to another, this can be done without disturbing any individual aplet’s settings, since they are compartmentalized.

Several aplets are built into the HP 38G. When the calculator is first turned on, these built-in aplets are empty. The user must add some information, such as equations, notes, or sketches to make these aplets come alive.

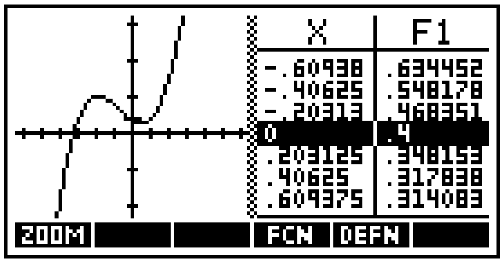
Using Aplets on the HP 38G

Six different types of aplets are built into the HP 38G: function, parametric, polar, sequence, statistics, and solve. Typically, a teacher will start with one of these aplet types, then customize it by adding particular functions that define a certain problem, together with settings, pictures, and text directions.

To start using a particular aplet that is already in the calculator, the student chooses it from the HP 38G library by pressing the **LIB** key. Continuing to explore the problem, the student may want to view the problem in different ways, and can do this by pressing the different view keys. **PLOT**, **SYMB**, and **NUM** display the graphic view, symbolic view, and numeric view, respectively. Additional views, such as split-screen views (Fig. 2), can be found by pressing the **VIEWS** key.

The student or teacher can customize the graphical, numeric, and symbolic views for a specific problem by using the setup screens. It is also possible to annotate the problem by typing some text into the note view or by adding a sketch to the sketch view.

The teacher and student can easily generate custom aplets that present new examples based on the built-in aplet types. An aplet is created by working with an aplet type and adding all of the customizing information that relates to a particular problem (see ***Article 7***).



X	F1
-.60938	.634452
-.40625	.548178
-.20313	.468351
0	.4
.203125	.348153
.40625	.317838
.609375	.314083

Fig. 2. *The plot-table view is a typical split-screen view.*

Main Components

The keyboard (Fig. 3) reflects the seven main components of the HP 38G's functionality (from top to bottom on the keyboard):

- Softkeys for accessing custom behavior defined by softkey labels along the bottom of the display
- View keys for moving among the possible representations of aplet data
- Library key for selecting the current topic of exploration with aplets
- Arrow keys for screen and menu navigation
- Home calculator keys for numeric entry and basic calculator operations
- Alpha keys for access to alphabetic characters
- Editing environments for creating, editing, and managing objects such as programs, matrices, lists, and notes.

Four of the key groupings are related as follows: first, a topic is chosen with the library key. Then, a way of looking at the problem is chosen with the view selection keys. Finally, the peculiarities of the problem view are manipulated with the softkeys and the arrow keys.

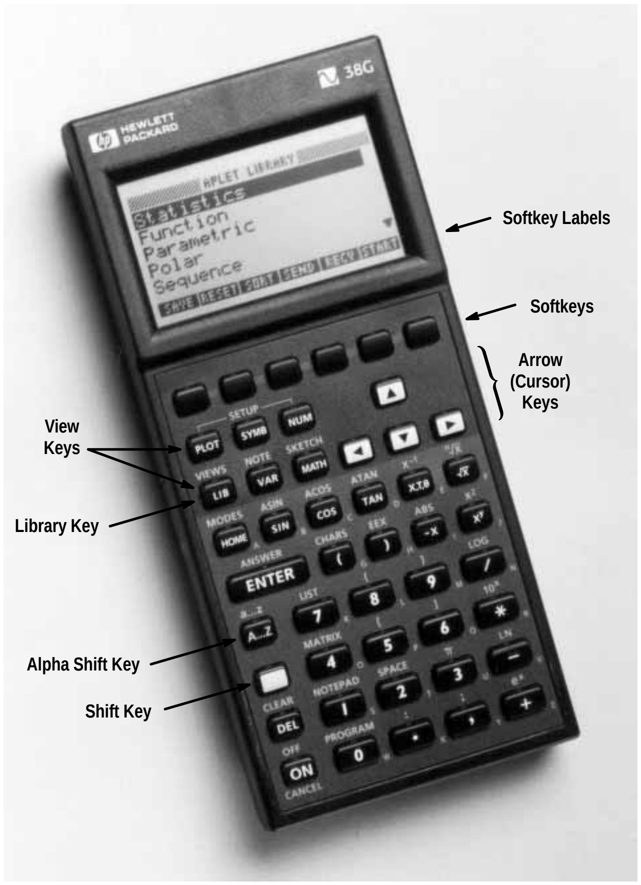


Fig. 3. *HP 38G calculator.*

Softkeys

The softkeys are the top row of unlabeled keys, which are associated with the dynamic menu labels displayed along the bottom of the screen. They give access to context-specific custom behavior. Unlike the HP 48G, there is no “next-row” key since all HP 38G softkey sets are limited to six items for the sake of simplicity.

View Keys

The view keys provide one-key access to the three National Council of Teachers of Mathematics representations of aplet data: graphical, numerical (tabular), and symbolic, plus annotation and sketch views for documenting a topic. Keys for setting up view parameters and managing split-screen views are also included.

- The plot view gives a conventional mathematical graphical representation. In most cases it looks like some flavor of plot output in the HP 48G.
- The numeric view is generally a table of sampled values. It is a derived form of the mathematical object (except for statistics, where it is the defining view).
- The symbolic view is generally an expression representing the mathematical object of interest. The variables are defined by the aplet. This view is the defining form of the mathematical object (except for statistics, where it is derived).
- The note view is a mini word processor that allows the user to create, edit, and view a text document associated with the aplet.
- The sketch view is a set of standard-sized GROBs (graphic objects in HP 48G terminology) that explain the “story” of the aplet. The user can create, edit, view, and animate pictures. Editing capabilities include lines, boxes, circles, text labels, and Etch-a-Sketch-style drawing.

Moving from view to view is the same as task switching, which means the user can always go on to the next task, but there is no concept of going back to somewhere, since tasks are not being nested.

The **LIB** key invokes the library, which is the aplet selection and management environment, in which different aplets (including those that are not built-in) can be started, exchanged with others, and created by saving the state.

The **VAR** key provides access to variables and the **MATH** key provides access to scientific functions and other operations and commands. These variables and operations are available whenever the user is using an edit line.

Invoking the **VAR** or **MATH** menu starts a subtask, which must be completed or cancelled, at which point the calculator is back where it was when the subtask was started.

The Library Environment

This environment gives high-level access to aplets. The user can select an aplet and manage the current collection of aplets. From within the library, the user can take a snapshot of a built-in aplet, giving it a name and a directory of its own. This is how aplets are generated for dissemination and how users show their work. Also, the user can import or export aplets from the library to another HP 38G or to a computer.

Arrow Keys

The arrow keys are used for all direction-oriented operations such as tracing a function plot, moving among fields in an input form, and selecting commands from a pop-up menu.

The shift key can be used as a modifier for the arrow keys that signals motion “all the way” in the direction indicated.

Home Calculator Keys

The home calculator environment gives a familiar tool with a nice graphical interface. The user invokes it by pressing the **HOME** key. Inputs are displayed on the left side of a line, with the results displayed on the right side of the next line.

The calculator keys are used to type numbers and to access basic scientific calculator functions. The **ENTER** key is used to terminate data entry, to select operations from menus, and in general, to make things happen. Some mathematical operations are available on the keyboard and other operations and commands are available through the **MATH** pop-up menu.

The **ANSWER** shifted key gives access to the variable called Ans, which always contains the last result.

Alpha Keys

The alpha shift key, **A...Z**, provides access to the alphabetic characters, which are labeled on the keyboard overlay. Pressing the **CHARS** shifted key invokes the character browser, which provides access to characters that are not on the keyboard.

Unlike the HP 48G, there is no alpha lock key to confuse the user. The user can either press and release the alpha shift key before pressing each alpha character key, or hold the alpha shift key down while pressing as many alpha character keys as desired. However, an alpha lock toggle softkey is provided in some editing environments.

Editing Environments

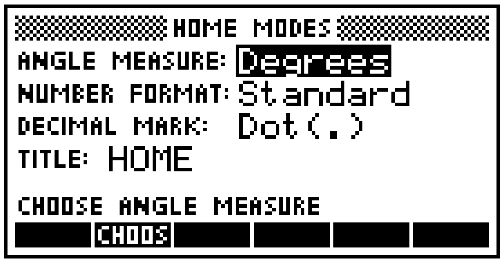
The HP 38G has specialized environments for managing programs, matrices, lists, and notes. When the user invokes one of the editing environments, a scrolling choose list of all the existing objects of that type appears, together with a softkey menu. From this environment, objects can be transferred between the HP 38G and a computer or another HP 38G.

- The program environment provides tools for creating, editing, storing, sending, receiving, and running programs. Variables can be accessed through the **VAR** pop-up menu. Mathematical operations can be accessed from the keyboard or through the **MATH** pop-up menu, and programming commands can be accessed through the commands section of the **MATH** pop-up menu.
- The matrix environment provides a two-dimensional matrix editor for creating, editing, viewing, sending, and receiving matrices.
- The list environment provides a list editor for creating, editing, viewing, sending, and receiving lists.
- The notepad environment provides an environment for creating, editing, viewing, saving, sending, and receiving text documents. The tools for editing notes in the notepad environment are identical to the editor for the note view. The documents created in the notepad environment are not bundled with an aplet as they are in the note view. The notepad environment can be used for tasks such as creating, storing, and viewing lists or notes.

User Interface

One of our goals for the HP 38G project was to leverage software from the HP 48G/GX calculator platform. For the HP 48G/GX we developed two primary general-purpose user interface tools: input forms and choose boxes.[1]

Input forms and choose boxes are interactive environments that are used to gather user input for a task. Input forms (see Fig. 4) are flexible, screen-sized dialog boxes similar to those in other graphical user interfaces. The appearance and use of input form fields resemble spreadsheet programs. Choose boxes (see Fig. 5) are either pop-up or screen-sized boxes optimized for selecting or working with one or more items from an arbitrarily long list. Input forms and choose boxes, along with some other user interface constructs, contribute to the improved ease of use that distinguishes the HP 48G/GX from its predecessor, the HP 48S/SX.



HOME MODES
ANGLE MEASURE: Degrees
NUMBER FORMAT: Standard
DECIMAL MARK: Dot(.)
TITLE: HOME
CHOOSE ANGLE MEASURE

Fig. 4. A typical input form.

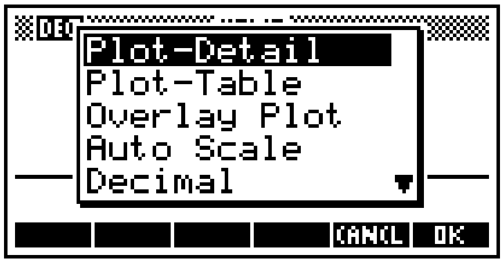


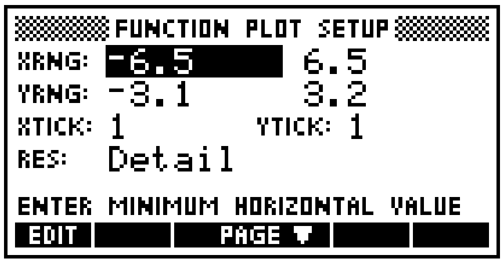
Fig. 5. A typical choose box.

In the HP 38G, we found that input forms and choose boxes were a good match for the needs of the utility environments and most of the nine views available for working with aplets.

Graphical User Interface Applications

Input forms are used in most aplet views for entering a mix of settings and values. They're also used for gathering input to complete a task. For example:

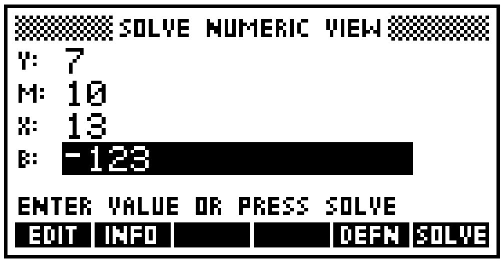
- The function aplet's plot setup view is an input form in which modes and parameters are specified (see Fig. 6).



FUNCTION PLOT SETUP
XRNG: -6.5 6.5
YRNG: -3.1 3.2
XTICK: 1 YTICK: 1
RES: Detail
ENTER MINIMUM HORIZONTAL VALUE

Fig. 6. The function aplet's plot setup view input form.

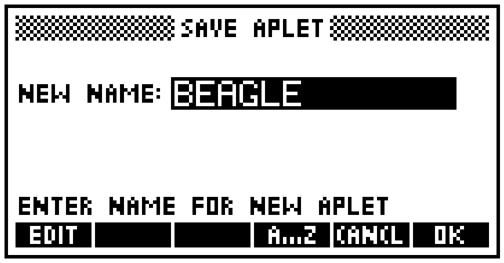
- The solve aplet's numeric view is an input form whose appearance varies according to the equation to be solved (see Fig. 7). The flexible layout and labeling of input form fields are employed to generate a custom input form each time the view is entered.



```
SOLVE NUMERIC VIEW
Y: 7
M: 10
X: 13
B: -123

ENTER VALUE OR PRESS SOLVE
EDIT INFO DEFN SOLVE
```

Fig. 7. *The solve aplet's numeric view, a dynamically generated input form.*

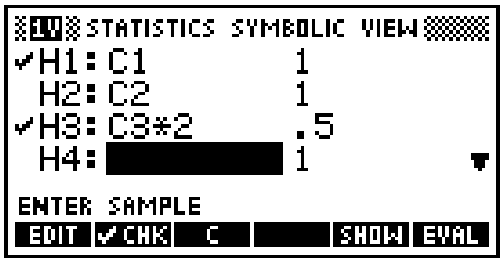
- When an aplet is to be saved, a simple input form is displayed to get the new aplet's name (see Fig. 8).



```
SAVE APLET

NEW NAME: BEAGLE

ENTER NAME FOR NEW APLET
EDIT A...Z CANCL OK
```

Fig. 8. *The aplet library's save-aplet input form.*

- The statistics symbolic view is a highly customized input form that scrolls to show more information than fits on one screen (see Fig. 9). Choose box elements, like the up and down arrows indicating more information is available offscreen, help suggest the operation of this hybrid view.

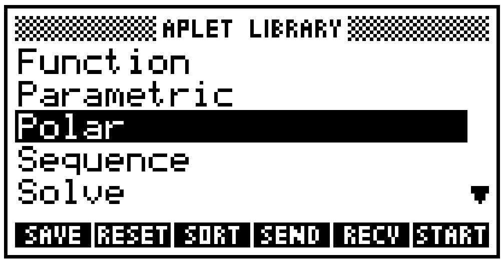


```
1V STATISTICS SYMBOLIC VIEW
✓H1: C1      1
 H2: C2      1
✓H3: C3*2    .5
 H4:         1

ENTER SAMPLE
EDIT ✓CHK C SHOW EVAL
```

Fig. 9. *The statistics aplet's symbolic view, a custom scrolling input form.*

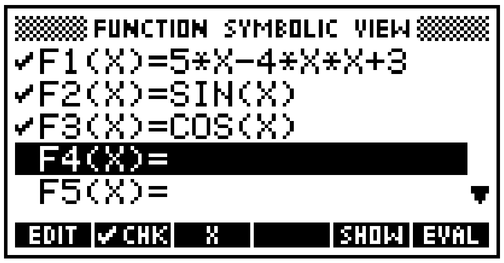
Choose boxes are used in a variety of views and utility environments wherever a list of related items needs to be managed. Here are a few examples of choose boxes in the HP 38G:

- The aplet library (see Fig. 10) is actually an elaborate choose box.
- Almost all symbolic views, such as the function aplet's symbolic view (see Fig. 11), are choose boxes.



```
APLET LIBRARY
Function
Parametric
Polar
Sequence
Solve
SAVE RESET SORT SEND RECV START
```

Fig. 10. *The aplet library, an elaborate choose box.*



```
FUNCTION SYMBOLIC VIEW
✓F1(X)=5*X-4*X*X+3
✓F2(X)=SIN(X)
✓F3(X)=COS(X)
 F4(X)=
 F5(X)=
EDIT ✓CHK X SHOW EVAL
```

Fig. 11. *The function aplet's symbolic view.*

- Choose boxes pop up within input forms like the **MODES** input form (see Fig. 12).
- The **VAR** and **MATH** menus (see Fig. 13) are two-column choose boxes that show categories of items plus the items in the selected category.

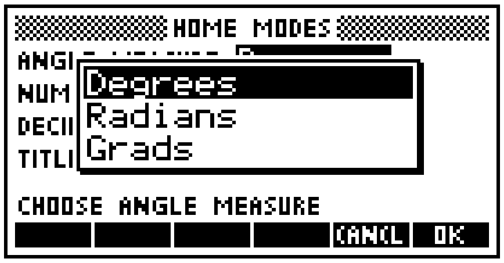


Fig. 12. *A pop-up choose box in the* **MODES** *input form.*

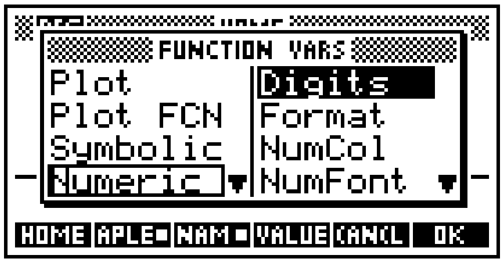


Fig. 13. *The* **VAR** *menu, a two-column choose box.*

As these examples illustrate, the look and feel of HP 48G/GX input forms and choose boxes remain largely unchanged in the HP 38G. However, substantial reengineering of the underpinnings of these tools was required to match other aspects of the HP 38G's use model, as discussed in the next section.

Topic Outer Loop

Many of the custom interfaces developed for the HP 48S/SX used an RPL-language tool we developed called the parameterized outer loop.[2] Parameterized outer loop applications depend on the parameterized outer loop for routine key and error handling and display management. The graphical user interface (GUI) elements introduced in the HP 48G/GX are also parameterized outer loop applications that automate routine matters of input entry, selection of options, and presentation of output.

In both the HP 48S/SX and the HP 48G/GX, the user interface was based on the notion of having a central environment (the user stack) from which other applications are launched and to which applications return when completed. All applications on these platforms, including parameterized outer loop applications like the GUI tools, are based on this "function call" model: they start, run for a while, then end, returning the flow of control to where they started. We call such applications *modal.*

New Model, New Tool

When we were investigating the use model for the HP 38G, it became apparent that the function call approach to application management would not suffice. The HP 38G is a tool for exploration, so we wanted to provide an environment that promotes wandering from one subject area to another, or in HP 38G terms, from one view or aplet to another.

To attain this goal we quickly determined that the modal nature of the parameterized outer loop and the applications based on it was too constraining, yet we weren't prepared to discard the wealth of useful tools and concepts we had built up from the parameterized outer loop foundation. Furthermore, we knew there were still plenty of times when the modal call-and-return interface would still apply, such as when pausing to get further input from the user before proceeding with a task. To accommodate all these needs, we developed the new *topic outer loop.*

Topic Outer Loop Overview

Where parameterized outer loop applications are designed to preserve the environment from which they're launched and later restore that environment, topic outer loop topics are optimized for rapidly setting up and switching from one topic to the next. Except with regard to the home environment from which the topic outer loop is originally launched and to which it ultimately returns—after running many topics, perhaps—the topic outer loop doesn't preserve or restore a previous user interface since there is none to go back to.

The most obvious examples of topic outer loop topics in the HP 38G are aplets, but many other environments with similar behavior are also topic outer loop topics—for example, the aplet library and the user program catalog (see Fig. 14).

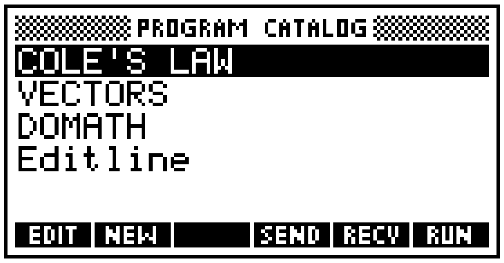
Like the parameterized outer loop on which it's based, the topic outer loop is launched from the calculator's system outer loop and temporarily redefines the current user interface until some exit condition is met. By design, the topic outer loop operates very similarly to the parameterized outer loop, but differs from the parameterized outer loop in two fundamental ways:

- To better support the standard two-tiered structure of HP 38G topics, the topic outer loop manages two nested user interface levels. The parameterized outer loop manages just one.
- The topic outer loop fully supports organized and efficient switching from one topic to another. The parameterized outer loop is designed to shut down completely before launching another application.

The operation of the topic outer loop for starting a topic can be summarized as follows:

```
If a topic outer loop is already running {

  Evaluate the old view exit handler
  Evaluate the old topic exit handler
  Set the topic entry and exit handlers
  Evaluate the topic entry handler
  Set the view entry and exit handlers
  Evaluate the view entry handler
  Set the remainder of the view user interface

}

Else {

  Save the home user interface

  If error in {

    Set the topic entry and exit handlers
    Evaluate the topic entry handler
    Set the view entry and exit handlers
    Evaluate the view entry handler
    Set the remainder of the view user interface

    If error in {

      While not done with the topic outer loop {
        Evaluate the view display object
        Read a key and get its custom definition
        If error in
          Evaluate the key definition
        Then
          Evaluate the error handler object
        }

      Evaluate the view exit handler
      Evaluate the topic exit handler

      }
    Then {
      Evaluate the view exit handler
      Evaluate the topic exit handler
      Error

      }

    }

  Then {

    Restore the saved home user interface
    Error

    }

  Restore the saved home user interface

}
```

The code setting up the topic specifies the user interface and other environment elements unique to the topic, such as the topic entry handler and the view display object, when it runs the topic outer loop. This is how the behavior of the topic outer


PROGRAM CATALOG

COLE'S LAW
VECTORS
DOMATH
Editline

Fig. 14. *The user program catalog, a topic outer loop utility environment.*

loop is customized. The topic outer loop is responsible for the key-display loop, low-level error handling, and juggling the topic and view entry and exit handlers and the saved home user interface.

When an event occurs that calls for running the topic outer loop, the topic outer loop may or may not already be running. As the first section of the topic outer loop overview illustrates, if a topic outer loop is already running, switching to a new topic is quick yet still gives the exiting topic an opportunity to shut down in an orderly fashion. Since it's common with the HP 38G to move from topic to topic without first returning home, this efficiency translates to faster performance.

Switching among views within the same topic is also common, and involves a similarly efficient set of operations:

```
Evaluate the old view exit handler
Set the view entry and exit handlers
Evaluate the view entry handler
Set the remainder of the view user interface
```

Reengineering the GUI Tools

Although very similar in specifications and use to the standard modal input form and choose box environments, versions of these environments based on the topic outer loop, which we call *modeless* environments, differ in the following ways:

- OK and cancel keys are nonfunctional.
- The default softkey set does not include OK and cancel keys.
- Task-switching keys are processed normally to allow task switching.
- The results returned by the input form or choose box engine always consist of the confirmed exit values. No flag indicating canceled or normal exit is returned.

To support modeless views and utility environments based on HP 48G/GX GUI tools, we adapted the input form and choose box engines to use the topic outer loop. However, modal input forms and choose boxes are also employed by the HP 38G. Rather than simply switch the engines from using the parameterized outer loop to using the topic outer loop, we modularized the components of the engines to enable the use of either. We then repackaged the modal versions of the engines to ensure backwards compatibility for existing code using them. To make modeless input form and choose box programming as straightforward as possible for programmers familiar with the modal versions, and yet still meet the requirements of the topic outer loop, we developed tools to translate traditional modal input form and choose box arguments and results to and from the specifications required for topic outer loop applications. This greatly simplified the reengineering of existing user interface code to make use of new modeless input forms and choose boxes. The process was largely mechanical, requiring only that the developer follow a few well-documented steps.

Aplets and Views

One of the key ideas of aplets is that they provide different ways of looking at a problem. For example, when exploring a story problem about speed and distance, the student can look at a symbolic expression, a table of numbers, a graph of the distance function, or even a diagram showing a tortoise and a hare. These different ways of looking at an aplet are called *views*. The topic outer loop manages the transitions between the views of an aplet. The views are implemented using the graphical user interface tools plus aplet data. The data associated with an aplet is encapsulated in a directory structure inherited from the HP 48G/GX.[1]

Aplet Structure

Associated with each aplet is a standard set of information. The topic outer loop uses this aplet information for aplet directory checking, topic switching, resetting, and so on. It's also used by the **VAR** menu and the **VIEWS** choose box. The standard information is:

- Topic ID
- Initial view
- Topic name

- Special views data
- Aplet-specific variables
- Topic entry procedure pointer
- Topic exit procedure pointer
- Topic reset procedure pointer
- Aplet directory checker procedure pointer.

An HP 38G aplet is a collection of aplet data and aplet views. Aplet data includes the aplet name, which is used in the library, real variables like Xmin and Xmax, which are set via the plot setup view, symbolic expressions, note text, and sketches. An aplet usually defines at least eight views: plot, symbolic, numeric, note, sketch, plot setup, symbolic setup, and numeric setup. The generic aplet contains items such as:

- Aplet name
- Aplet topic
- Attached library
- Plot view procedure pointer
- Symbolic view procedure pointer
- Numeric view procedure pointer
- Plot setup view procedure pointer
- Symbolic setup view procedure pointer
- Numeric setup view procedure pointer
- Note view procedure pointer
- Sketch view procedure pointer
- Xmin variable
- Ymin variable
- Other shared variables
- Aplet-specific variables
- List of symbolic expressions
- Array of independent values for numeric view
- List of strings for custom views
- Note text
- List of graphics objects for the sketch view.

For aplets built into the HP 38G, pointers like the plot view procedure pointer refer to code built into the 512K-byte ROM. New aplet types can include a RAM-based support library containing new view procedures. All aplets must contain a basic set of variables, but specific aplet types may implement additional optional variables.

View Structure

Each aplet view is managed by the topic outer loop, typically with the help of graphical user interface (GUI) tools like input forms. To customize its behavior, a view (or its GUI helper) specifies objects that are used while the view is visible. These include the view entry and exit handlers, the display handler, and the key handler, among others:

- Initialization procedure pointer
- Exit procedure pointer
- Display procedure pointer
- Key handler procedure pointer
- Non-view-specific-key-allowed flag
- Softkey menu description
- Error handler.

Symbolic View

Normally, the symbolic view is the defining view for an aplet. When the user starts an aplet, its symbolic view will be shown so the user can enter symbolic expressions or equations to be used in the aplet.

The symbolic view is the generalization of the HP 48G/GX `EQ` list. The `EQ` variable on the HP 48G is a list of unnamed symbolic expressions, which are plotted and traced together. The HP 38G breaks this into individual named symbolic expressions that have independent check marks. Expressions for a parametric function are further broken into real and imaginary parts. The expression for a sequence is broken into two initial terms and a recursive relation. This simplifies editing and selection of symbolic expressions. Giving expressions names in the symbolic view allows them to be reused in other expressions, home calculations, and programming.

Expressions entered in the symbolic view are checked for syntax errors and to a limited extent for semantic errors. Expressions defining a sequence are further classified and transformed into an internal form for cache-based iterative evaluation, saving both time and run-time RAM space. An EVAL menu key is provided in the symbolic view for constant expression evaluation, expression simplification, and function unfolding. Fig. 15 shows how the Fibonacci sequence can be defined and checked using ten keystrokes. (The EVAL menu key is shown when a command line is not active. It appears where OK appears in Fig. 15.)

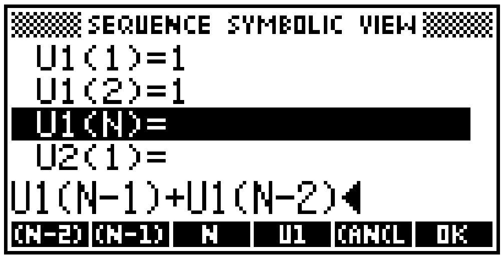

SEQUENCE SYMBOLIC VIEW
U1(1)=1
U1(2)=1
U1(N)=
U2(1)=
U1(N-1)+U1(N-2)

Fig. 15. *Using the symbolic view of the sequence aplet, the Fibonacci sequence can be defined and checked using ten keystrokes.*

The generic symbolic view is based on the choose box engine, which takes over display handling to maintain check marks on the left of the screen and takes over key mapping for dynamic menu changes and editing of expressions. Because of the different requirements for different aplets, the generic symbolic view is implemented as a derived instance of the symbolic view with several data fields and virtual routines to be overridden. The information for a symbolic view includes:

- Combine factor
- Total expression
- Group size
- Single-pick flag
- Softkey menu description
- Edit menu description
- Move focus procedure pointer
- Special initialization procedure pointer
- Edit terminator procedure pointer
- Expression checker
- Poststore procedure pointer.

For example, the sequence aplet combine factor is 3 (three terms define one sequence). The total expression is 30 (up to 10 sequences allowed). The group size is 3 (every three terms will share one check mark). The edit terminator procedure transforms definitions into internal form. The move focus procedure updates menu softkeys with the current sequence name. The expression checker rejects list or matrix expressions and initial terms that depend on the sequence independent variable n.

The symbolic view for the statistics aplet posed a new problem because we decided to show two expressions on one line, one for data and one for frequency, which is not supported by the choose box engine. The statistics symbolic view is implemented by customizing the input form to mimic a scrollable choose box with a check mark and two columns of data.

Setup Views

After expressions are set up, setup views are the natural places to go for setting the parameters for further explorations. The plot setup view is the main setup view, similar to the plot dialog box on the HP 48G, but enhanced with wider fields and a double-page design. The plot setup view, the symbolic setup view, and the numeric setup view are all based on the input form engine.

Plot View

The plot view is the most complicated of all aplet views. Students will spend most of their time here exploring the behavior of curves graphically and interactively.

The HP 38G takes the DRAW command in the HP 48G/GX plot window and improves it by implementing a "smart redraw." When switching back from other views, the picture, cursor position, and display mode are restored to the same state instantly, except when the defining parameters are changed. Plotting can be stopped and resumed later. When the user tries to move the cursor beyond the screen boundary, the graph shifts and redraws the scrolled-in portion. Zoom options are put into a choose box with more descriptive names. Instead of taking the current point as the first point, the box zoom prompts the user to select the first point. Tracing is improved and extended to statistics plots. Fig. 16 shows tracing on box and whisker plots.

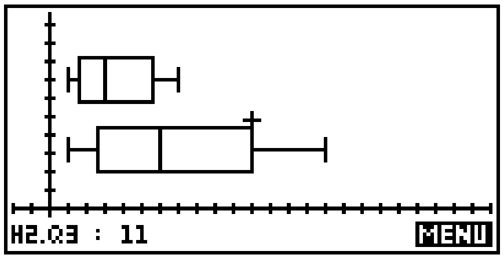


Fig. 16. *Box and whisker plot.*

For the function aplet, more areas of exploration are supported through the FCN menu key, which displays a choose box with choices of root, intersection, slope, area, and extremum. Fig. 17 shows the display for an area computation.

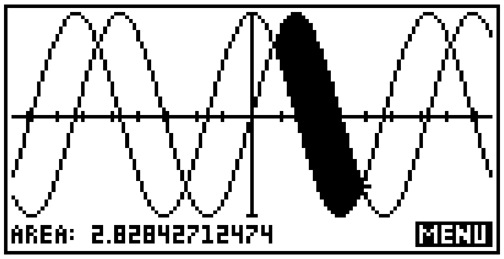


Fig. 17. *Area computation accessible via the FCN softkey.*

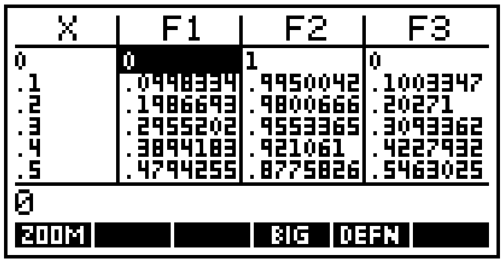
The plot view has overridable routines for curve drawing, curve tracing, FCN key handling, DEFN key handing, and other functions. For example, the function, parametric, and polar aplets share the same plot loop with different preprocessing, but the sequence aplet uses another plot loop for handling the discrete independent variable n.

For tracing, the sequence aplet implements four-way scrolling: the screen will scroll when the cursor is moved offscreen in all directions. The scatter plot overrides the FCN menu key to calculate and display a data-fitting curve. The information for a plot view includes:

- Draw procedure
- Independent variable ID
- Softkey menu description
- Display procedure pointer
- Key handler procedure pointer
- Pointer display procedure
- Draw axes flag
- Draw grid flag
- Axis labels
- Display coordinate procedure
- Tracing procedures
- Coordinate display procedures
- Equation display procedure.

Numeric View

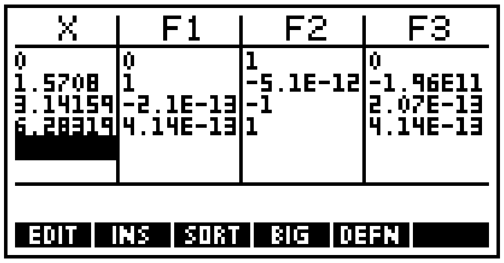
The numeric view lets a student explore the functions defined in the symbolic view in numeric form. The leftmost column displays values of the independent variable (except for statistics) and adjacent columns represent function results. There are two basic forms of the numeric view: automatic (Fig. 18) and build-your-own (Fig. 19). The automatic view displays a series of independent values with a starting value and a step specified by either the numeric setup view or the variables NumStart and NumStep.



X	F1	F2	F3
0	0	1	0
.1	.0998334	.9950042	.1003347
.2	.1986693	.9800666	.20271
.3	.2955202	.9553365	.3093362
.4	.3894183	.921061	.4227932
.5	.4794255	.8775826	.5463025

```
0
```

Fig. 18. *Automatic numeric view.*



X	F1	F2	F3
0	0	1	0
1.5708	1	-5.1E-12	-1.96E11
3.14159	-2.1E-13	-1	2.07E-13
6.28319	4.14E-13	1	4.14E-13

Fig. 19. *Build-your-own numeric view.*

The BIG menu key lets the student display the numbers using a larger font. The ZOOM key provides a series of options for changing the start and step values for the independent variable display.

When the cursor is moved to the upper or lower boundaries of the display the table scrolls to show adjacent values. The table can also be reset by entering a new value for the independent variable in the leftmost column.

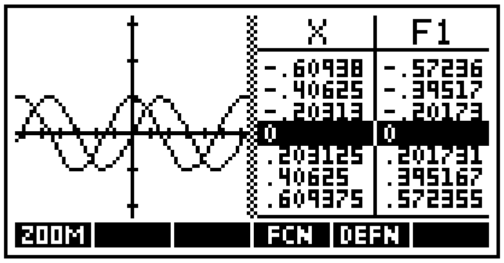
The build-your-own numeric view is useful for creating a table of interesting values. The values for the independent variable column in the build-your-own numeric view are accessible via the NumIndep variable.

The information for a numeric view includes:

- Initialization procedure pointer
- Numeric zoom choices
- Softkey menu description
- Display procedure pointer
- Key handler procedure pointer
- Split plot-table configuration information.

Plot-Table View

The split plot-table view allows a student to combine the plot and numeric views (Fig. 20).



X	F1
-.60938	-.57236
-.40625	-.39517
-.20313	-.20173
0	0
.203125	.201731
.40625	.395167
.609375	.572355

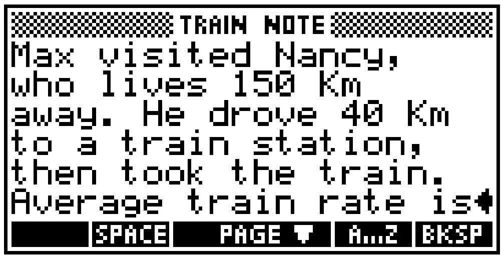
Fig. 20. *Plot-table view.*

This view is implemented primarily as a plot view, with the right side of the display being a small numeric view that updates to reflect the position of the plot cursor. As the student moves the cursor from one function to another, the right side of the table changes to reflect the function being traced. The DEFN menu key displays the current function at the bottom of the display. This lets the student display the symbolic, plot, and numeric views of a function all at once.

Note View

Besides main aplet views like plot view, symbolic view, and so on, auxiliary views like the note view and sketch view are provided to add textual and pictorial descriptions to an aplet. The note view (Fig. 21) can be used to edit and display a text string attached to an aplet. The note can provide information about the aplet's subject, a suggested sequence of exploration, or the supported keys. The note view is basically a word-wrapping text editor with a 6-line-by-22-character display.

Although the original HP 48G/GX edit line supports multiple-line editing, individual lines are handled independently. When more than 22 characters are inserted into a line, that line gets scrolled to the left without affecting the rest of the lines. The HP 38G note view is implemented independently from the edit line code. Direct display routines are coded to show a character or a string at a specified location without generating intermediate GROBs. System-level keyboard handling code is modified to implement a general blinking cursor display scheme. Besides the text string to be edited, the note editor maintains a linewidth array for word-wrapping bookkeeping.


TRAIN NOTE

Max visited Nancy, who lives 150 Km away. He drove 40 Km to a train station, then took the train. Average train rate is

Fig. 21. *Sample note view screen.*

Sketch View

Some people believe that a picture is worth a thousand words, so the HP 38G generalizes the HP 48G/GX's bitmap editing features to form an aplet sketch view. With the sketch view, the user can edit and display a set of bitmaps attached to an aplet. Holding down the page-down or page-up key shows a prestored animation sequence (Fig. 22).

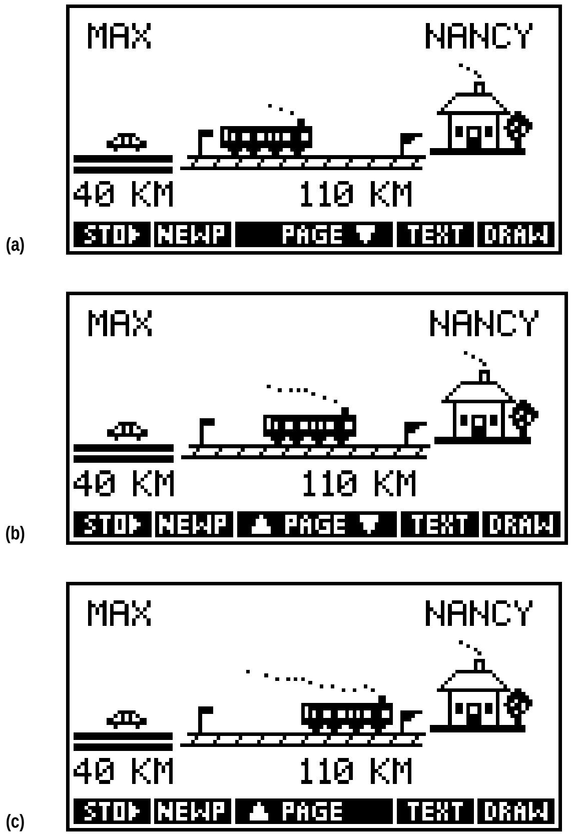

(a)
MAX
NANCY
40 KM
110 KM
STO▸ NEWP PAGE ▼ TEXT DRAW
(b)
MAX
NANCY
40 KM
110 KM
STO▸ NEWP ▲ PAGE ▼ TEXT DRAW
(c)
MAX
NANCY
40 KM
110 KM
STO▸ NEWP ▲ PAGE TEXT DRAW

Fig. 22. *An animation sequence in sketch view.*

Compared with the HP 48G/GX, the HP 38G limits the bitmap editing features and improves the user interface and implementation. The HP 38G implements a rubber band algorithm when the user drags the second point to define a line, rectangle, or circle. The circle drawing code uses a fast integer-based iterative algorithm. The user can drag a text string in the small or medium font to any location. The HP 38G can store a selected portion of a screen into a GROB variable and recall it. When bitmaps are stored back into an aplet directory, they are first trimmed to the minimum enclosing rectangle to save RAM space.

Additional Views

Each aplet type defines additional views available in the **VIEWS** menu. For example, the function aplet offers some hybrid views and some preconfigured plot views. Fig. 23 shows the function **VIEWS** menu.

In addition, a user can define a new set of special views that provide high-level tools for an aplet. Such a custom interface makes the aplet easier to explore and hides details of the calculator's operation.

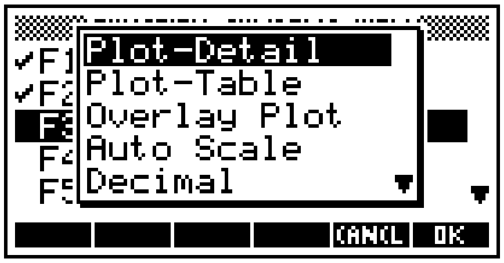


Fig. 23. *Function* VIEWS *menu.*

The Home Environment

The freeform home environment fills the traditional calculator role of supporting quick calculations. The user enters expressions in algebraic form and the value of the expression (usually a number) is returned.

Unlike aplets, the home environment provides access to all calculator resources, including lists, matrices, graphics objects, and programs.

The History Stack

The text of the input and the result are stored on a history stack (Fig. 24a). The user can review the items on the history stack and reuse those items as parts of the current input (Fig. 24b). Expressions and equations on the history stack can be shown in two-dimensional mathematical format (Fig. 24c).

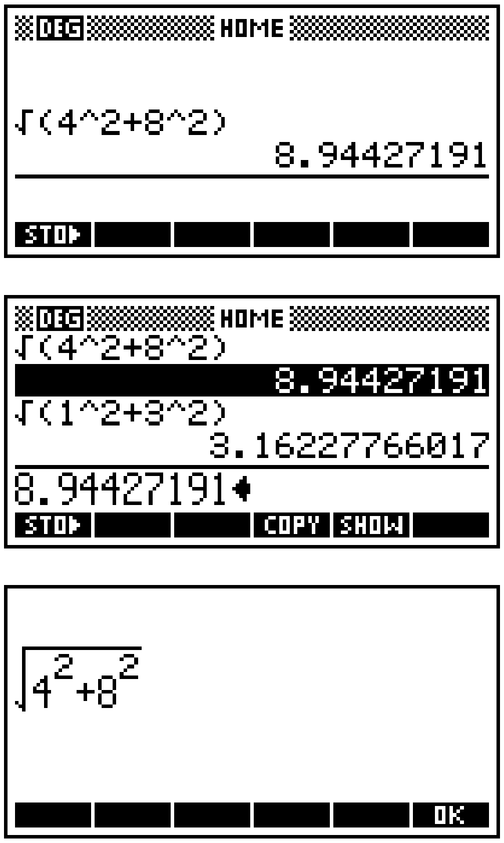
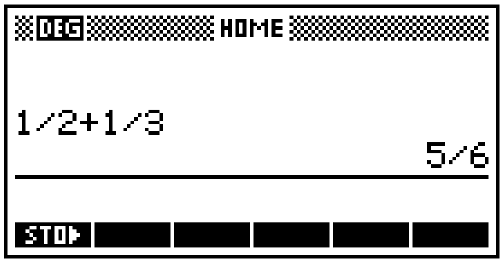


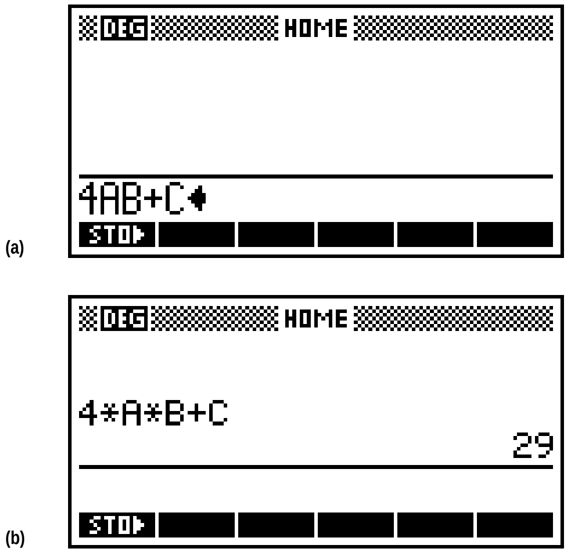
Fig. 24. *(a) History stack. (b) Previous result copied into the command line. (c) EquationWriter display of the same expression.*

The HP 38G includes special features to help beginners. To help students learn about fractions, the HP 38G has fraction number format, which uses continued fractions to convert results to rational form (Fig. 25). To help students unfamiliar with standard algebraic syntax, the HP 38G attempts to interpret ill-formed expressions as implied multiplication (Fig. 26).



```
1/2+1/3
                5/6
```

Fig. 25. Fraction number format.



```
4AB+C◆
```

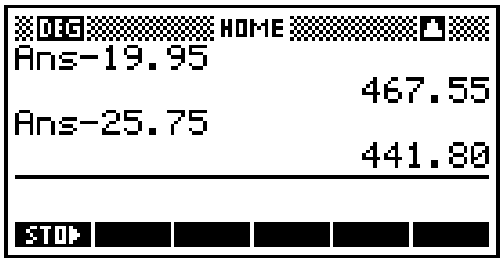
```
4*A*B+C
                 29
```

Fig. 26. (a) Implied multiply input. (b) Result.

The Variable Ans

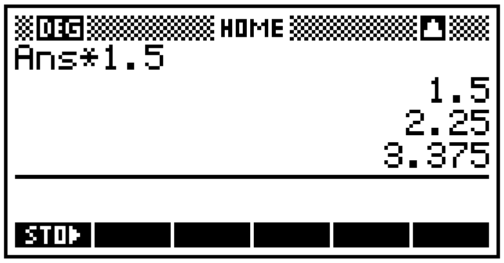
Each time the user inputs an expression, the value of the expression is stored in a variable named Ans. This current value of Ans is placed on the history stack, and the name Ans can be used in the next calculation. Even when the user enters a command that performs some action but doesn't return a value, the current value of Ans is placed on the history stack.

If the user starts an input with an infix function such as **+**, **–**, *****, or **/**, the calculator inserts the name Ans first. This saves keystrokes for tasks such as balancing a checkbook (Fig. 27). If the user presses **ENTER** without input, the previous input is repeated (Fig. 28). This saves keystrokes for iterative operations.



```
Ans-19.95
             467.55
Ans-25.75
             441.80
```

Fig. 27. Checkbook calculations in the home environment.



```
Ans*1.5
                1.5
               2.25
              3.375
```

Fig. 28. If the user presses **ENTER** without input, the previous input is repeated. This saves keystrokes for iterative operations.

The VAR and MATH Menus

To organize its extensive resources, the HP 38G presents the most-used variables and functions on the keyboard. Additional resources are available in the **VAR** and **MATH** menus. These two-column menus offer specific items in the right column, categories of items in the left column, and broader choices on menu keys.

In the **VAR** menu (Fig. 29) the user can choose to examine variables either from the current aplet or from the shared home variables. The user also can choose either the name or the value of a variable.

In the HP 38G most variables are strongly typed, that is, for many variables the value must be a specific type. For example, the variable X must contain a real number, Z1 must contain a complex number, and M2 must contain a matrix. Several classes of variables contain exactly ten variables, such as the ten complex variables Z1, Z2, ..., Z9, Z0 (Fig. 30).

Variables are used not only for mathematical objects, but also for modes. For example, storing the constant Degrees (whose numerical value is 1) into the variable Angle selects degrees angle mode.

The classes of home variables include complex numbers (Z1 to Z0), graphics objects (G1 to G0), aplets (user-selected names), lists (L1 to L0), matrices (M1 to M0), modes (fixed descriptive names), notepad (user-selected names), programs (user-selected names), and real numbers (A to Z, θ).

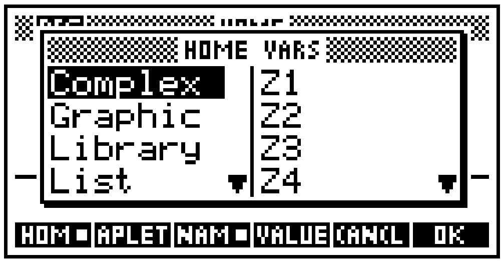


Fig. 29. VAR *menu of the home environment.*

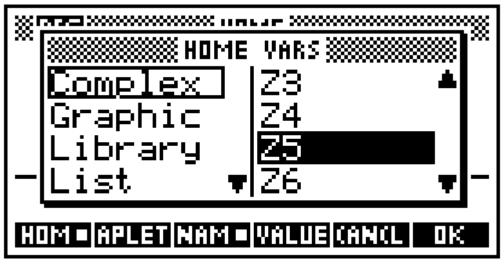


Fig. 30. Most variable values must be a specific type and several classes of variables contain exactly ten variables. For example, Z1 *to* Z0 *are complex variables.*

The **MATH** menu (Fig. 31) offers additional functions, commands, and constants not available on the keyboard. The categories of functions are: calculus functions, complex-number functions, constants, hyperbolic functions, list functions, loop functions, matrix functions, functions of polynomials, probability functions, real-number functions, statistics functions, functions for symbolic manipulation, tests, and trigonometric functions.

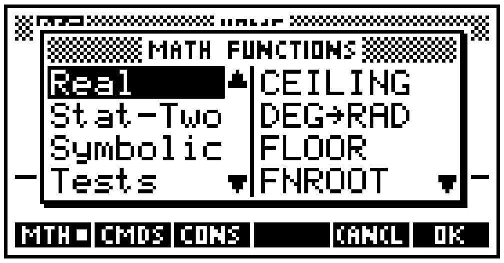
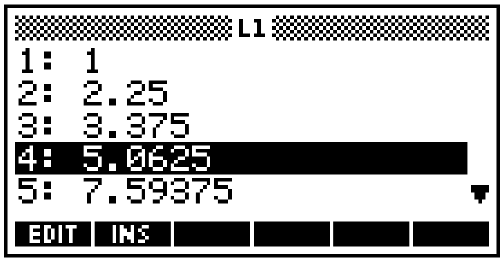


Fig. 31. MATH *menu.*

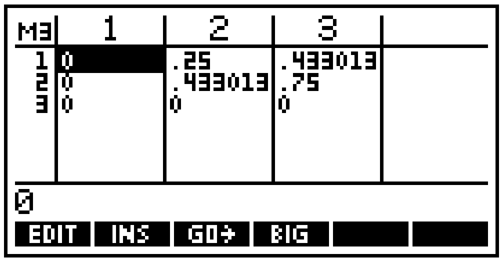
Lists and Matrices

For these composite variable types there are catalogs that report the variables' sizes, along with special editors to enter and modify the elements. The catalogs and editors are tasks, so the user can easily move among aplets, home, catalogs, and editors. The list editor (Fig. 32) is one-dimensional. The matrix editor is two-dimensional (Fig. 33).



```
1: 1
2: 2.25
3: 3.375
4: 5.0625
5: 7.59375
```

Fig. 32. The list editor is one-dimensional.



M3	1	2	3
1	0	.25	.433013
2	0	.433013	.75
3	0	0	0

Fig. 33. The matrix editor is two-dimensional.

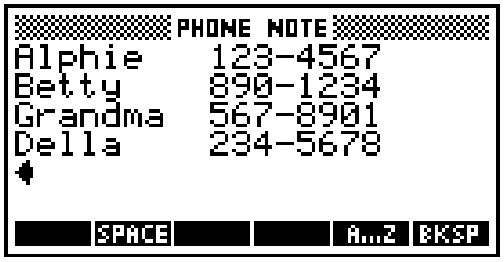
Lists and matrices can also be used as functions of an index value. For example, L1 is a list, while L1(2) is an expression whose value is the second element of L1.

Notes and Programs

For these text variable types there are catalogs that show the user-selected names and editors that allow freeform text input. The notepad holds simple text files such as phone lists (Fig. 34).

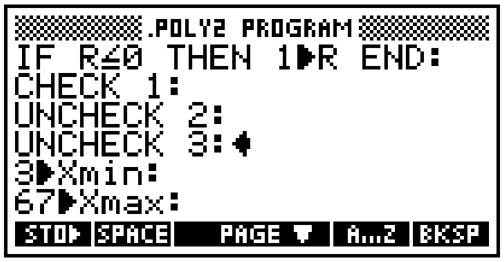
There is a program with the fixed name Editline, which holds the most recent input from the home environment. The user can choose to edit the most recent home input from within the program editor, or to execute the program Editline from the home environment by simply pressing **ENTER**.

Programs aren't parsed until the first time they're run. Because of this, and because the program editor is a task, the user can write a program a little at a time, leaving the program in an invalid state between editing sessions. Fig. 35 shows part of a program.



```
PHONE NOTE
Alphie    123-4567
Betty     890-1234
Grandma   567-8901
Della     234-5678
```

Fig. 34. *The notepad holds simple text files such as phone lists.*



```
.POLY2 PROGRAM
IF R≤0 THEN 1▶R END:
CHECK 1:
UNCHECK 2:
UNCHECK 3:
3▶Xmin:
67▶Xmax:
```

Fig. 35. *Part of a program.*

Commands that perform some action and return no result can appear only within programs (which includes Editline). The categories of commands are: commands to control aplets, branch commands, commands for scaled drawings, commands to manipulate graphics objects, loop commands, matrix commands, printing commands, prompt commands for input and output, and statistics commands.

Programs that Support Aplets

The most important purpose of programs in the HP 38G is to support the user-defined entries within the **VIEWS** menu (Fig. 36). Using the SETVIEWS command, the user specifies a number of special views that represent the tools for manipulating the aplet. These tools can be presented at a high level, using terms relevant to the particular aplet and hiding the actual methods of the calculator from the aplet user.

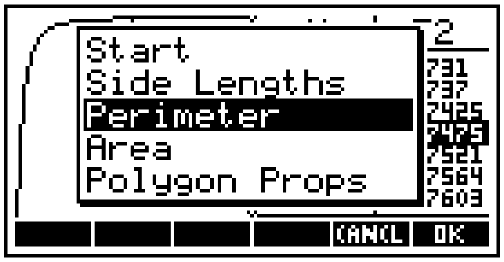


Fig. 36. ***VIEWS*** *menu with user-specified special views.*

The specification for each special view includes a prompt, which appears in the **VIEWS** menu. It also includes a program, which is run when the special view is selected, and a view specification, which determines the standard view (plot, symbolic, etc.) to be started when the program is done.

If an aplet has special views with start or reset prompts, pressing the menu keys START or RESET within the **LIB** catalog (Fig. 37) automatically selects the corresponding special view.

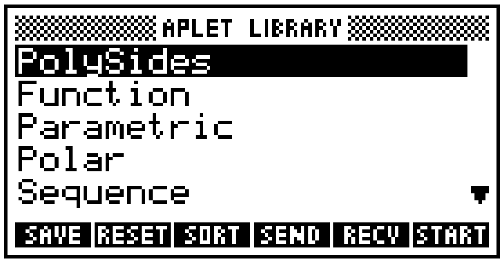


Fig. 37. ***LIB*** *catalog.*

While the prompt category of commands enables programmatic interaction with the user, the main goal of HP 38G programs is to modify the configuration variables of the current aplet. After the program runs, the standard view specified in the **VIEWS** menu starts, operating with the configuration left by the program. This approach has the advantage that the interface to the standard view is familiar to the user.

All the components needed for special views are automatically managed by the HP 38G. The menu of special views is stored as a part of the aplet, and the programs used by the special views are automatically transferred with the aplet.

This makes aplets simple to use: a single request gets the aplet and associated programs, and the **VIEWS** menu offers the high-level tools that allow the user to focus more on the content of the aplet and less on the calculator.

See the ***Sidebar*** for information about how the Distributed Software Team developed the HP 38G Calculator.

Acknowledgments

We would like to acknowledge the rest of the calculator software team: Helen Choy, Gabe Eisenstein, and Charles Patton. Youwen Wu worked closely with us to ensure quality. Diana Roy (learning products) and Kevin Myers and Cary McCallister (technical support) provided many valuable user interface design suggestions. Ron Brooks from our marketing department contributed input from educators. Our education advisory committee provided valuable day-to-day input on our design decisions and usability issues.

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1. D.K. Byrne, et al, "An Advanced Scientific Graphing Calculator," *Hewlett-Packard Journal*, Vol. 45, no. 4, August 1994, pp. 6-22.
2. T.W. Beers, et al, "HP 48SX Interfaces and Applications," *Hewlett-Packard Journal*, Vol. 42, no. 3, June 1991, pp. 13-21

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