Chapter 7
Equations and Computation

This chapter describes how to define and evaluate variables and functions. This chapter discusses only numerical equations. To learn how to use Mathcad's symbolic processing features, turn to Chapter 17, “Symbolic Calculation.”

The following sections make up this chapter:

Defining variables and functions

How to define variables and functions. How the relative placement of equations affects calculations.

Evaluating expressions

How to get a numerical answer.

Copying numerical results

How to copy numerical results from one worksheet to another or from Mathcad to other applications.

Controlling calculations

How to suppress the way Mathcad automatically updates the worksheet.

Disabling equations

Turning calculation or editing on and off for individual equations.

Error messages

What to do when Mathcad displays an error message.

Defining variables and functions

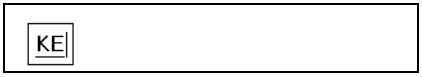
Whenever you type an equation into a worksheet, you are doing one of two things:

- You could be typing an expression and asking Mathcad to give you the answer. This is discussed in the next section, "Evaluating expressions."
- You could be typing a variable or function name and assigning some value to it. The remainder of this section discusses how to do this.

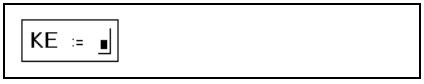
Defining a variable

A variable definition defines the value of a variable everywhere below the definition. To define a variable, you must follow these three steps:

- Type the variable name to be defined. Chapter 8, "Variables and Constants," contains a description of valid variable names.



- Press the colon (**:**) key. The definition symbol (**:=**) appears.



- Type an expression to complete the definition. This expression can include numbers and any previously defined variables and functions.

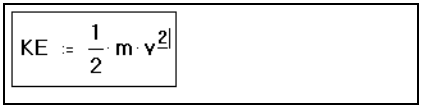


Figure 7-1 shows several examples of a variable definition. The left hand side of a "**:=**" can contain any of the following:

- A simple variable name like *x*.
- A subscripted variable name like v_i.
- A matrix whose elements are any of the above. For example:

$$\begin{bmatrix} x \\ y_1 \end{bmatrix}$$

- A function name with an argument list of simple variable names. For example, $f(x, y, z)$. This is described further in the next section.
- A superscripted variable name like $\mathbf{M}^{\langle 1 \rangle}$.

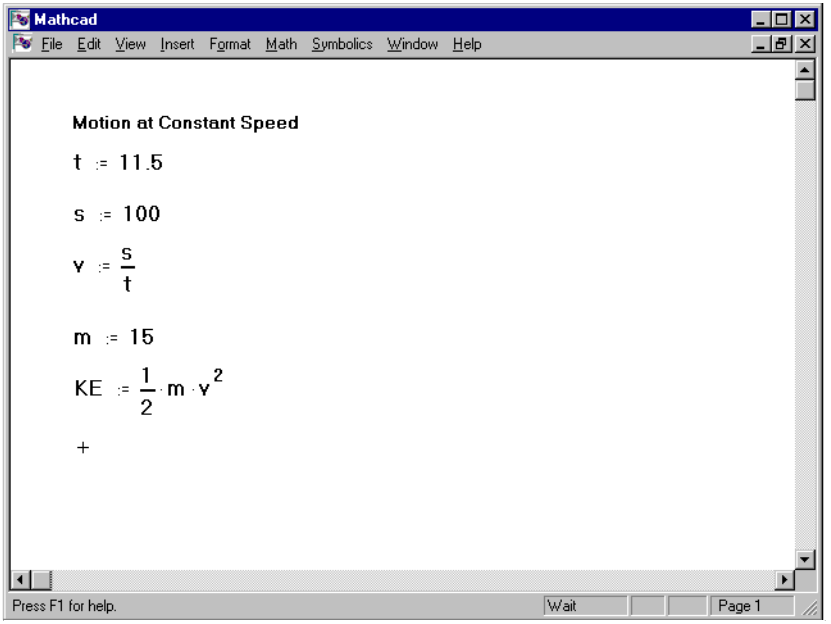


Figure 7-1: Defining variables.

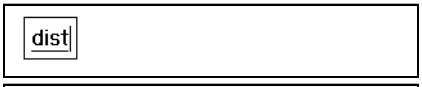
Defining a function

You can also define your own functions in Mathcad. Unlike a variable, the value of a function depends on the values of its arguments.

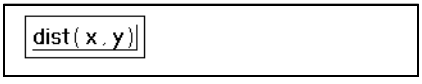
You define a function in much the same way you define a variable. The name goes on the left, a "**:=**" goes in the middle, and an expression goes on the right. The main difference is that the name includes an *argument list*. The example below shows how to define a function called dist(*x*, *y*) which returns the distance between the point (*x*, *y*) and the origin.

To type such a function definition:

- Type the function name.



- Type a left parenthesis followed by one or more names separated by commas. Complete this argument list by typing a right parenthesis.



It makes no difference whether or not the names in the argument list have been defined or used elsewhere in the worksheet. What is important is that these arguments *must be names*. They cannot be more complicated expressions.

- Press the colon (**:**) key. You see the definition symbol (**:=**).

- Type an expression to define the function. In this example, the expression involves only the names in the argument list. In general though, the expression can contain any previously defined functions and variables as well.

$$\text{dist}(x, y) := \sqrt{x^2 + y^2}$$

Once you have defined a function, you can use it anywhere below the definition, just as you would use a variable.

When you use a function in an equation, Mathcad:

- evaluates the arguments you place between the parentheses,
- replaces the dummy arguments in the function definition with the actual arguments you place between the parentheses,
- performs whatever arithmetic is specified by the function definition, and
- returns the result as the value of the function.

Figure 7-2 shows an example.

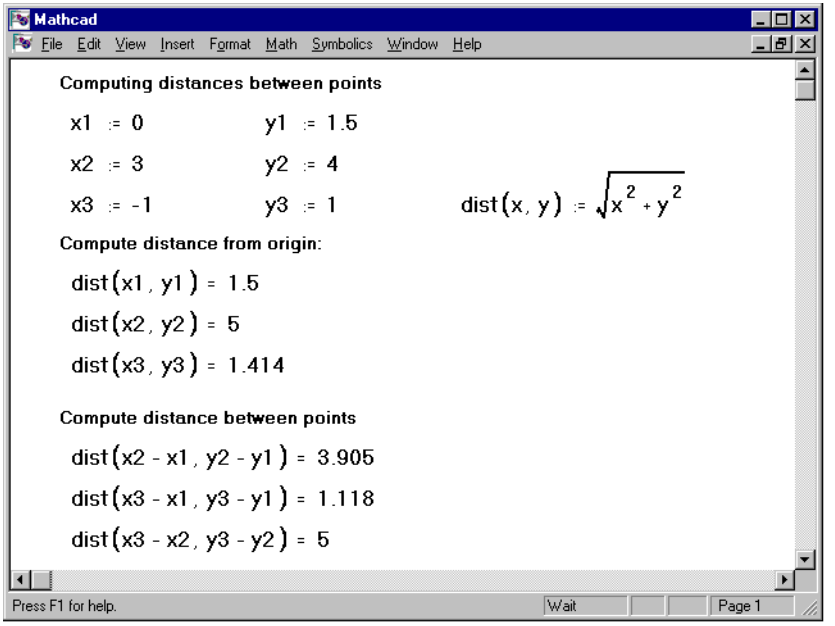


Figure 7-2: A user-defined function to compute the distance to the coordinate origin.

The arguments of a user function can represent scalars, vectors, or matrices. For example, you could define the distance function as

$$dist(\mathbf{v}) := \sqrt{v_0^2 + v_1^2}$$

This is an example of a function that accepts a vector as an argument, and returns a scalar result. See the section “Arrays and user-defined functions” in Chapter 10 for more information.

Note that function names are font sensitive. This means that the function **f**(*x*) is different from the function f(*x*). Figure 7-3 shows an example.

Mathcad's built-in functions are defined for all fonts (except the Symbol font), sizes, and styles. This means that **sin**(*x*), sin(*x*), and **sin**(*x*) all refer to the same function.

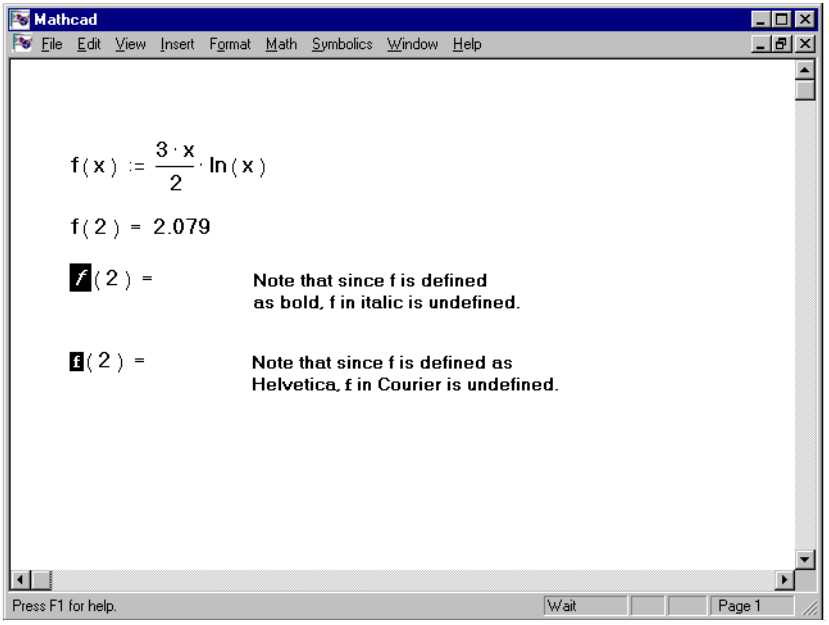


Figure 7-3: Function names are font sensitive. Undefined variables are marked in reverse video.

Variables in user-defined functions

When you define a function, you don't have to define any of the names in the argument list. This is because when you define a function, you are telling Mathcad *what to do* with the arguments, not what they are. When you define a function, Mathcad doesn't even have to know whether the arguments are scalars, vectors or matrices. All it needs to know is how many arguments there are and what to do with them. It is only when Mathcad actually *uses* a function that it needs to know what the arguments really are.

However, if in the process of defining a function you use a variable name that *is not* in the argument list, you must define that variable name above the function definition. The value of that variable at the time you make the function definition then becomes a permanent part of the function. This is illustrated in Figure 7-4.

When you evaluate a function, Mathcad:

- evaluates the arguments,

- substitutes their values on the right side of the function definition,
- evaluates the values of the other variables *at the point where the function is defined*,
- computes and returns a result.

If you want a function to depend on the value of a variable, you must include that variable as an argument. If not, Mathcad will just use that variable's fixed value at the point in the worksheet where the function is defined.

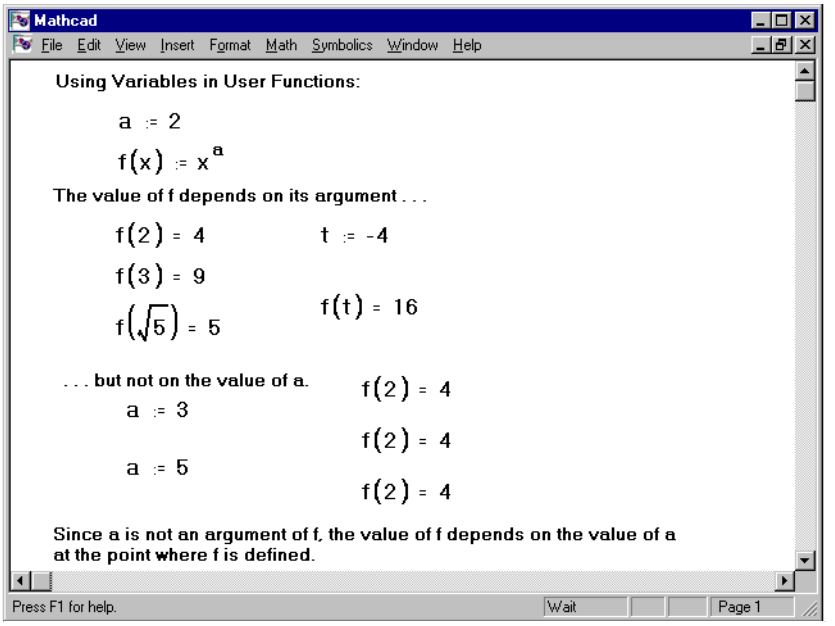


Figure 7-4: The value of a user function depends on its arguments.

Recursive function definitions

Mathcad supports *recursive* function definitions—you may define the value of a function in terms of a previous value of the function. As shown in Figure 7-5, recursive functions are useful for defining arbitrary periodic functions, as well as elegantly implementing numerical functions like the factorial function.

Note that a recursive function definition should always have at least two parts:

- An initial condition that prevents the recursion from going forever.
- A definition of the function in terms of some previous value(s) of the function.

If you do not specify an initial condition that stops the recursion, Mathcad will generate a "stack overflow" error message as described in "Error messages" on page 154.

Pro The programming operators in Mathcad Professional also support recursion. See the section "Programs within programs" in Chapter 18 for examples.

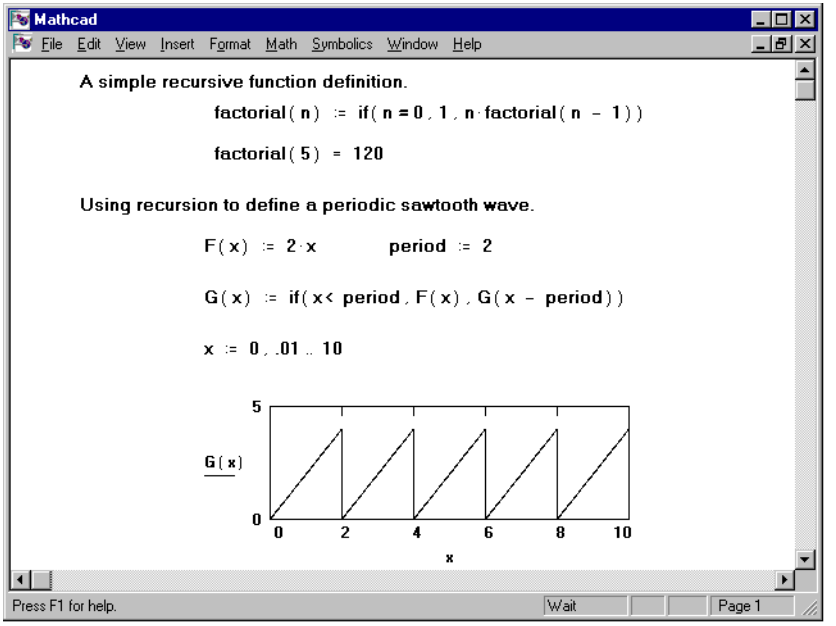


Figure 7-5: Mathcad allows recursive function definitions.

How Mathcad scans a worksheet

Mathcad scans a worksheet the same way you read it: left to right and top to bottom. This means that a variable or function definition involving a "**:=**" affects everything below and to the right of it.

To determine whether one equation is above or below another, Mathcad compares their *anchor points*. To see these anchor points, choose **Regions** from the **View** menu. Mathcad will display blank space in gray and leave regions white (or whatever your background color happens to be). Each region's anchor point will appear as a dot on the left.

Figure 7-6 shows an example of how not to place equations in a worksheet. In the first evaluation, both *x* and *y* are shown in red to indicate that they are undefined. This is because the definitions for *x* and *y* lie below where they are used. Because Mathcad scans from top to bottom, when it gets to the first equation, it has no idea what numbers to substitute in place of *x* and *y*.

The second evaluation, on the other hand, is below the definitions of *x* and *y*. By the time Mathcad gets to this equation, it has already assigned values to both *x* and *y*.

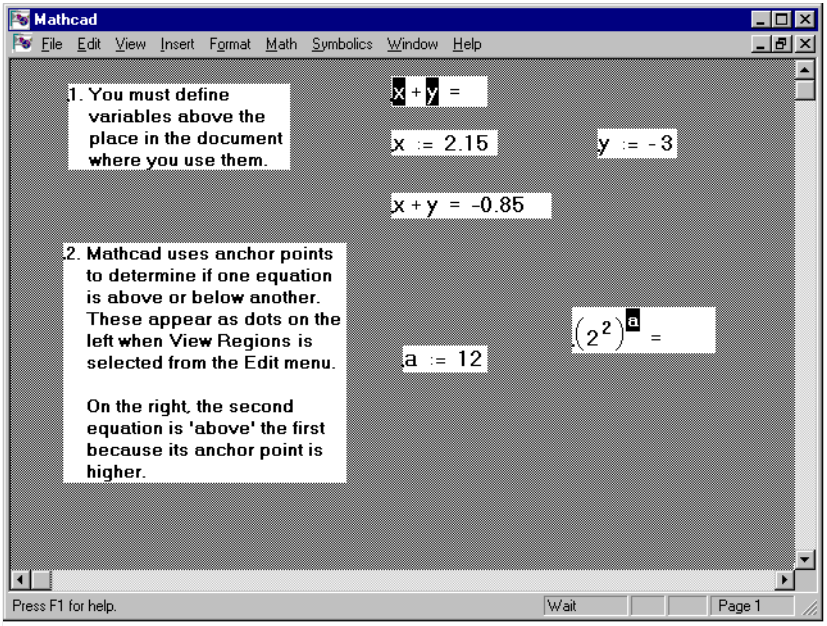


Figure 7-6: Mathcad evaluates equations from top to bottom in a worksheet. The small dot on the left side of each equation is an anchor point. Undefined variables are marked in reverse video.

You can define a variable twice in the same worksheet. Mathcad will simply use the first definition for all expressions below the first definition and above the second. For expressions below the second definition, Mathcad uses the second definition. Figure 7-7 illustrates a worksheet in which some variables are defined twice.

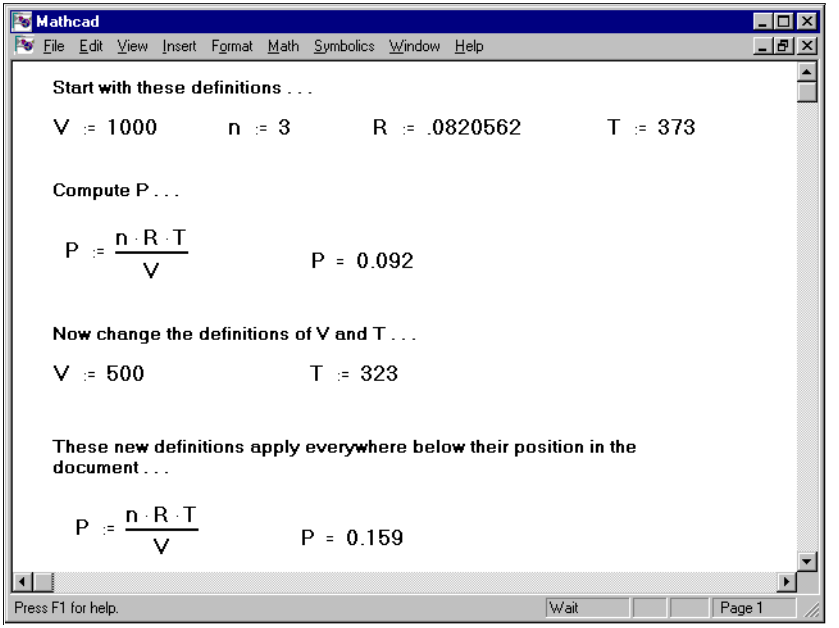


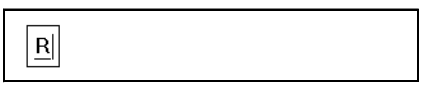
Figure 7-7: A worksheet in which V and T are both defined twice.

Global definitions

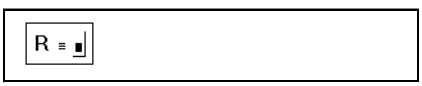
Global definitions are exactly like local definitions except that they are evaluated before any local definitions. If you define a variable or function with a global definition, that variable or function is available to all local definitions in your worksheet, regardless of whether the local definition appears above or below the global definition.

To type a global definition, follow these steps:

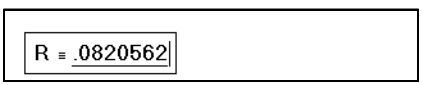
- Type a variable name or function to be defined.



- Press the tilde (**~**) key. The global definition symbol appears.



- Type an expression. The expression can involve numbers or other globally defined variables and functions.



You can use global definitions for functions, subscripted variables, and anything else that normally uses the definition symbol "**:=**". Just type a tilde instead of a colon, and Mathcad will show the global definition symbol "≡" in place of "**:=**".

This is the algorithm that Mathcad uses to evaluate all definitions, global and otherwise:

- First, Mathcad takes one pass through the entire worksheet from top to bottom. During this first pass, Mathcad evaluates global definitions only.

- Mathcad then makes a second pass through the worksheet from top to bottom. This time, Mathcad evaluates all definitions made with "**:=**" as well as all equations containing "=".

Figure 7-8 shows the results of a global definition for the variable *R* which appears at the bottom of the figure.

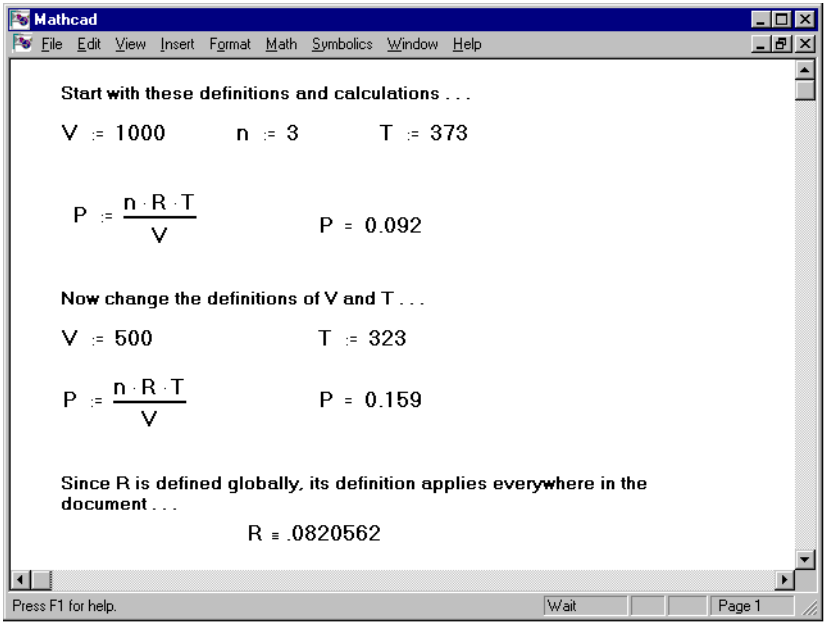


Figure 7-8: Using the global definition.

Although global definitions are evaluated before any local definitions, Mathcad evaluates global definitions the same way it evaluates local definitions: top to bottom and left to right. This means that whenever you use a variable to the right of a "≡":

- that variable must also have been defined with a "≡," *and*
- the variable must have been defined *above* the place where you are trying to use it.

Otherwise, the variable is marked in red to indicate that it is undefined.

It is good practice to allow only one definition for each global variable. Although you can do things like define a variable with two different global definitions or with one global and one local definition, this is never necessary and usually serves only to make your worksheet difficult to understand.

Evaluating expressions

To evaluate an expression, follow these steps:

- Type an expression containing any valid combination of numbers, variables and functions. Any variables or functions in this expression should be defined earlier in the worksheet.

$$\frac{1}{2}\cdot m\cdot v^2$$

- Press the "=" key. Mathcad computes the value of the expression and shows it after the equals sign.

$$\frac{1}{2}\cdot m\cdot v^2 = 567.108$$

Figure 7-9 shows some calculations using the definitions from Figure 7-1.

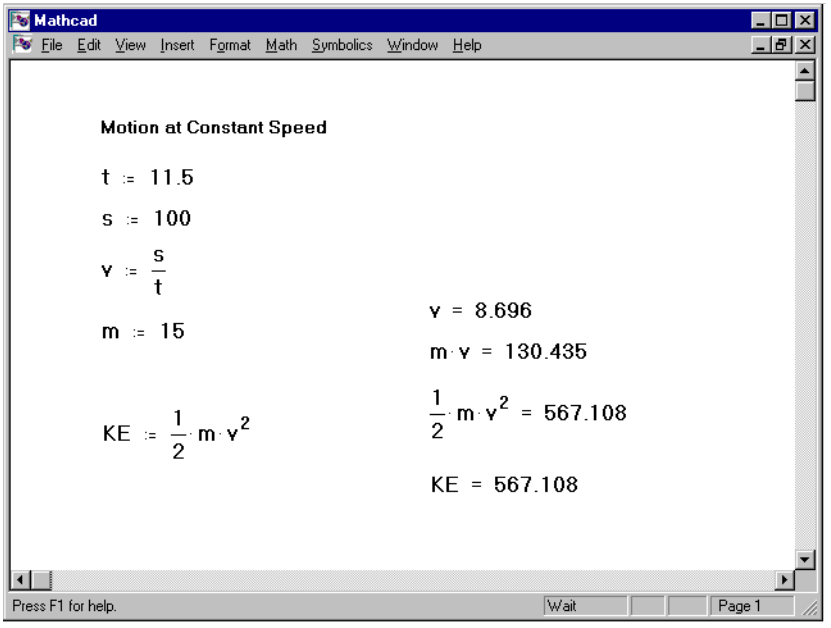


Figure 7-9: Calculations based on the variables defined in Figure 7-1.

Whenever you evaluate an expression, Mathcad shows a final placeholder at the end of the equation. You can use this placeholder for unit conversions, as explained in Chapter 9, "Units and Dimensions." As soon as you click outside the region, Mathcad hides the placeholder.

Copying numerical results

You can copy a numerical result and paste it either elsewhere in your worksheet or into another application. This allows you to copy an array of numbers directly from a spreadsheet or database into Mathcad where you can take advantage of its free-form interface and its advanced mathematical tools, and vice versa. Once you've performed the necessary computations, you can paste the resulting array of numbers back to where it came from or even into another application.

Copying a single number

To copy a single number appearing to the right of an equal sign:

- Click on the result to the right of the equal sign. This puts the result between the editing lines.
- Choose **Copy** from the **Edit** menu. This places the result on the clipboard.
- Click wherever you want to paste the result. If you're pasting into another application, choose **Paste** from that application's **Edit** menu. If you're pasting into a Mathcad worksheet, choose **Paste** from Mathcad's **Edit** menu.

The **Copy** command will copy the numerical result only to the precision displayed. To copy the result in greater precision, double-click on it and increase "Displayed Precision" on the Number Format dialog box. Note that **Copy** will not copy units and dimensions from a numerical result.

When you paste a numerical result into a Mathcad worksheet, it appears as:

- a math region consisting of a number if you paste it into empty space,
- a text string if you paste it into a text,
- a number if you paste it into a placeholder in a math region or if you paste it into text using the **Math Region** command on the **Insert** menu.

Copying an array of numbers

To copy an array (vector or matrix) appearing to the right of an equal sign:

- Click on the array to the right of the equal sign. This puts the array between the editing lines.
- Choose **Copy** from the **Edit** menu. This places the array on the clipboard.
- Click wherever you want to paste the result. If you're pasting into another application, choose **Paste** from that application's **Edit** menu. If you're pasting into a Mathcad worksheet, choose **Paste** from Mathcad's **Edit** menu.

When you paste an array into a Mathcad worksheet, it appears as:

- a vector or matrix if you paste it into empty space,

- a text string if you paste it into text,
- a vector or matrix if you paste it into a placeholder in a math region or if you paste it into text using the **Math Region** command on the **Insert** menu.

The **Copy** command will copy the numerical result to the precision with which it is displayed. You can view the current display settings by double-clicking on the result you want to copy and examining the dialog box. See Chapter 6, “Equation and Result Formatting,” to learn more about formatting numbers for display. Note that **Copy** will not copy units and dimensions.

Copying numbers from a scrolling output table

When you display results in a scrolling output table as described in the section “Displaying vectors and matrices” in Chapter 10, you may want to copy some of the numbers from the table and use them elsewhere.

To copy just one number from a scrolling output table, simply click on the number and choose **Copy** from the **Edit** menu. To copy more than one number from a scrolling output table:

- Click on the first number you want to copy.
- Drag the mouse in the direction of the other values you want to copy while holding the mouse button down.
- Choose **Copy** from the **Edit** menu.

To copy all the values in a row or column, click on the column or row number shown to the left of the row or at the top of the column. All the values in the row or column will be selected. Then choose **Copy** from the **Edit** menu.

After you have copied one or more numbers from a scrolling output table, you can paste them into another part of your worksheet or into another application. Figure 7-10 shows an example of a new matrix created by copying and pasting numbers from a scrolling output table. Note that if you copied and pasted more than nine rows or columns of numbers from the table, they will be displayed as a new scrolling output table.

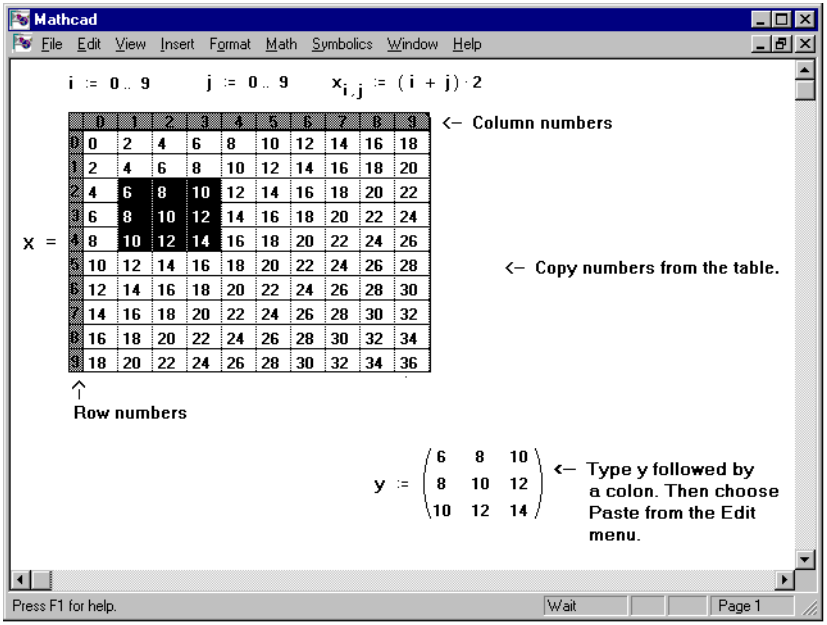


Figure 7-10: Creating a new matrix from numbers in a scrolling output table.

Controlling calculations

When you start Mathcad, you are in “automatic mode.” This means that Mathcad updates results in the worksheet window automatically. You can tell you're in automatic mode because the word “Auto” appears in the message line.

If you don't want to wait for Mathcad to make computations as you edit, disable automatic mode by choosing **Automatic Calculation** from the **Math** menu or by clicking the light bulb on the toolbar. The word “Auto” disappears from the message line and the checkmark beside **Automatic Calculation** disappears to indicate that automatic mode is now off.

Automatic window update

The word “Auto” on the message line indicates that you are in automatic mode. This means that:

- As soon as you press the equals sign, Mathcad displays a result.
- As soon as you click outside of an equation having a “**:=**” or a “≡, ” Mathcad performs all calculations necessary to make the assignment statement.

When you process a definition in automatic mode by clicking outside the equation region, this is what happens:

- Mathcad evaluates the expression on the right side of the definition and assigns it to the name on the left.
- Mathcad then takes note of all other equations in the worksheet that are in any way affected by the definition you just made.
- Finally, Mathcad updates any of the affected equations that are currently visible in the worksheet window.

Although the equation you altered may affect equations throughout your worksheet, Mathcad performs only those calculations necessary to insure that whatever you can see in the window is up-to-date. This optimization makes sure you don't have to wait for Mathcad to evaluate expressions that are not visible.

In automatic mode, if you print or move to the end of the worksheet, Mathcad automatically updates the whole worksheet.

Whenever Mathcad needs time to complete computations, the mouse pointer changes its appearance and the word "WAIT" appears on the message line. This can occur when you enter or calculate an equation, when you scroll, during printing, or when you enlarge a window to reveal additional equations. In all these cases, Mathcad evaluates pending calculations from earlier changes.

As Mathcad evaluates an expression, it surrounds it with a green rectangle. This makes it easy to follow the progress of a calculation.

To force Mathcad to recalculate all equations throughout the worksheet, choose **Calculate Worksheet** from the **Math** menu.

Manual window update

In manual mode, Mathcad does not compute equations or display results until you specifically request it to recalculate. This means that you don't have to wait for Mathcad to calculate as you enter equations or scroll around a worksheet.

Mathcad keeps track of pending computations while you're in manual mode. As soon as you make a change that requires computation, the word "Calc" appears on the message line, as shown in Figure 7-11. This is to remind you that the results you see in the window are not up-to-date and that you must recalculate them before you can be sure they are updated.

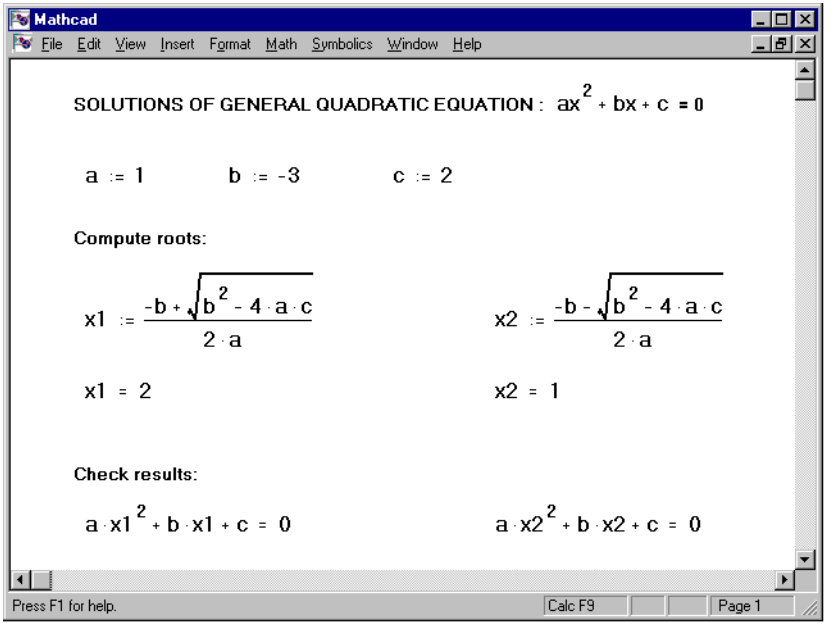


Figure 7-11: The word "Calc" on the message line indicates that recalculation is required.

You can update the screen by choosing **Calculate** from the **Math** menu. Mathcad performs whatever computations are necessary to update all results visible in the worksheet window. When you move down to see more of the worksheet, the word "Calc" reappears on the message line to indicate that you must recalculate to see up-to-date results.

To process the whole worksheet, including those portions not visible in the worksheet window, choose **Calculate Worksheet** from the **Math** menu.

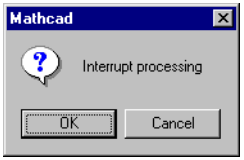
To switch back to automatic mode, choose **Automatic Calculation** from the **Math** menu. Mathcad updates the entire worksheet and displays the word "auto" on the message line.

When you print a worksheet in manual calculation mode, the results on the printout are not necessarily up-to-date. When you're in manual mode, make sure to choose **Calculate Worksheet** from the **Math** menu before you print.

Interrupting calculations

To interrupt a computation in progress:

- Press [**Esc**]. The dialog box shown below will appear.



- Click “OK” to stop the calculations or “Cancel” to resume calculations.

If you click “OK,” Mathcad displays a message on the message line to indicate that processing has been interrupted. The equation that was being processed when you pressed [**Esc**] is marked with an error message indicating that calculation has been interrupted. To resume an interrupted calculation, first click in the equation having the error message, then choose **Calculate** from the **Math** menu.

If you find yourself frequently interrupting calculations to avoid having to wait for Mathcad to recalculate as you edit your worksheet, you may wish to switch to manual mode. To do so, disable automatic mode by choosing **Automatic Calculation** from the **Math** menu. This will remove the checkmark from the menu. In manual mode, Mathcad recalculates only when you choose **Calculate** from the **Math** menu.

Starting in manual mode

The calculation mode—either manual or automatic—is a property saved in your Mathcad worksheet. If you often work in manual calculation mode, simply save your worksheets with Mathcad configured to work in manual mode; this way you do not have to disable automatic calculation each time you open your worksheets.

The calculation mode of Mathcad is also one of the properties saved in Mathcad template (MCT) files. As described in Chapter 4, “Worksheet Management,” you use Mathcad templates to save layout and formatting information to re-use in worksheets you later create. When you create a Mathcad template file, the template will be in manual mode if you previously removed the checkmark from **Automatic Calculation** on the **Math** menu; otherwise it will be in automatic mode.

You may also change the calculation mode of a template file from automatic to manual, or vice versa. For example, to change the calculation mode of an existing Mathcad template file from automatic to manual, do the following:

- Open the Mathcad template file, as described in the section “Worksheets and templates” in Chapter 4.
- Choose **Automatic Calculation** from the **Math** menu. This command puts Mathcad into manual mode. The checkmark beside this menu item should now be gone.
- Save the template file.

Thereafter, whenever you create a Mathcad worksheet based on this template, Mathcad will be in manual mode.

Disabling equations

You can *disable* a single equation so that it no longer calculates along with other regions in your worksheet, but you can still use Mathcad's equation editing, formatting, and display capabilities.

To disable calculation for a single equation in your worksheet, without affecting the calculation mode of the rest of the worksheet, follow these steps:

- Click on the equation you want to disable.
- Choose **Properties** from the **Format** menu, and click on the Calculation tab.
- Under "Calculation Options" place a check in the box next to "Disable Evaluation."
- Mathcad shows a small rectangle after the equation to indicate that it is disabled. An example is shown at right.

$$KE := \frac{1}{2} \cdot m \cdot v^2$$

You can edit a disabled equation just as you would any other equation. However, a disabled equation does not affect any other calculations, nor does it reflect changes you make to other equations in the worksheet.

To re-enable calculation for a disabled equation:

- Click on the equation to select it.
- Choose **Properties** from the **Format** menu, and click on the Calculation tab.
- Under "Calculation Options" remove the check in the box next to "Disable Evaluation."

Mathcad removes the small rectangle beside the equation.

Note: If you disable a plot or an output table, Mathcad freezes the display for the plot or table. Changes you make to other parts of the worksheet will not affect the plot or table. If you move a disabled equation that happens to be displaying a result, the result will disappear. If you move a graph, whatever is inside the graph will disappear.

Error messages

Mathcad may encounter an error when evaluating an expression. If it does, it marks the offending expression with an error message and highlights the offending name or operator in a different color (red).

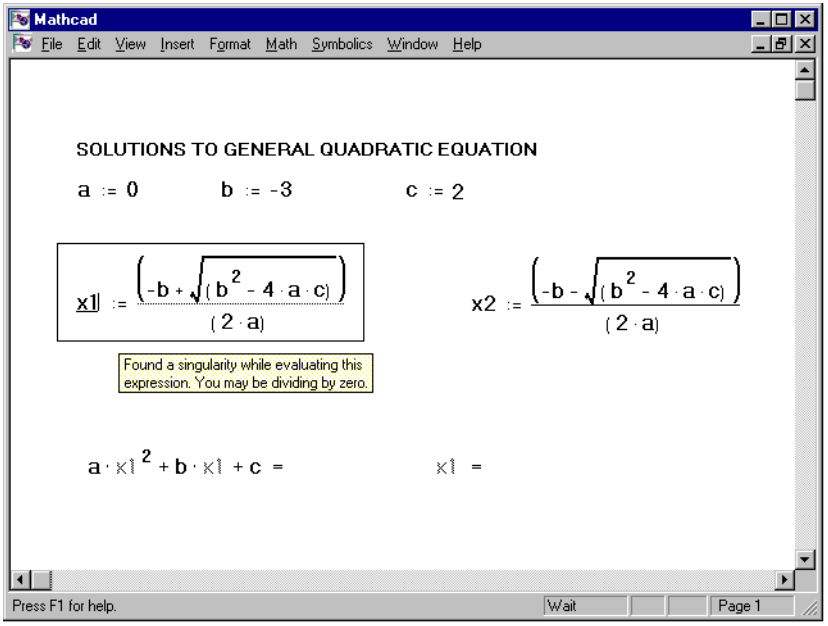


Figure 7-12: A worksheet containing an error message and several undefined variables.

An error message is visible only when you click on the associated expression. Figure 7-12 shows how an error message looks when you click on an expression. You'll always be able to get on-line help about the error message by clicking on it and pressing [**Shift**][**F1**].

Mathcad cannot process an expression containing an error. If the expression is a definition, the variable or function it is supposed to define will remain undefined. This can cause any expressions that reference that variable to be undefined as well. Mathcad indicates undefined variables and functions by displaying their names in red. In the example shown in Figure 7-12, an error in the definition of *x1* causes the variable to be undefined in three different places in the worksheet.

Note that in an expression in which zero is either a pre-factor or numerator (for example $0 \cdot x$ or $0/x$), Mathcad computes the result as zero, without evaluating or checking for errors in the *x* expression.

Fixing errors

If your worksheet contains several expressions with errors, as shown in Figure 7-12, this is what to do:

- Determine which expression with an error is closest to the top of the worksheet. This error is probably the cause of many of the other errors.
- If necessary, click on the error and press [**Shift**][**F1**] for help.

- If you anticipate time-consuming calculations, switch to manual mode as described in “Controlling calculations” on page 150. This will allow you to make numerous changes without having to wait for Mathcad to recalculate. When you are ready to recalculate, choose **Calculate** from the **Math** menu.

Once you have determined which expression caused the error, edit that expression to fix the error, or change the variable definitions that led to the error. When you click in the expression and begin editing, Mathcad removes the error message. When you click outside the equation (or in manual calculation mode, when you recalculate), Mathcad recomputes the expression. If you have fixed the error, Mathcad then recomputes the other expressions affected by the expression you changed.

Note that when you see an error message attached to an expression, it doesn't necessarily mean that you should edit that expression. More often than not, the error arises as a result of functions or variables defined farther up in the worksheet. Edit these other definitions to fix the error. For example, in Figure 7-12, all five errors are caused by a division by zero. To fix all five error messages at once, change the definition for *a* as shown in Figure 7-13.

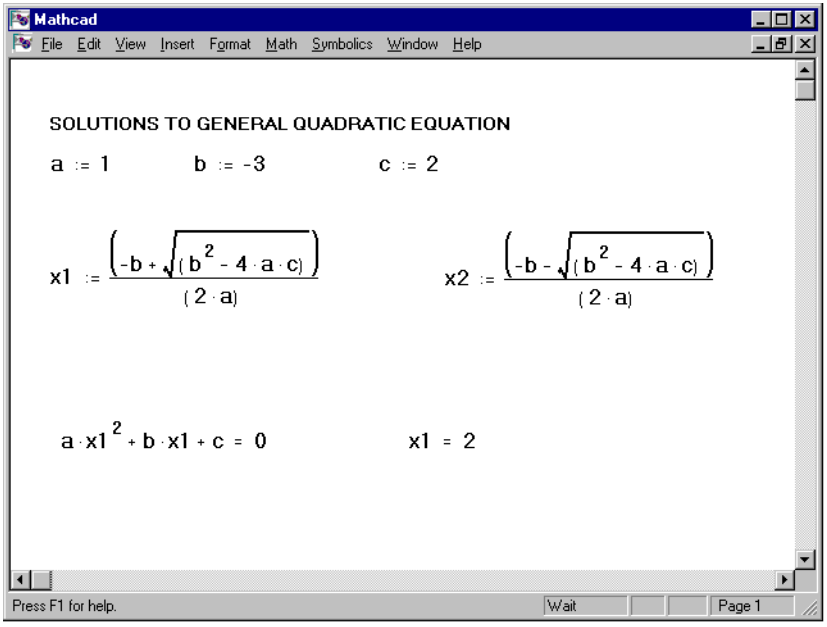


Figure 7-13: Changing the definition of the variable “a” fixes all errors at once.

A note about function definitions

When you define a function, Mathcad does not try to evaluate it until you use it later on in the worksheet. If there is an error, the use of the function is marked in error, even though the real problem may be in the definition of the function itself. Figure 7-14 shows two examples of this.

When a user-defined function is marked in error, be sure to check the function definition to find the actual source of error. Note that the second example in shows a recursive definition generating a “stack overflow” error message. Although Mathcad supports recursive function definitions, as described in “Recursive function definitions” on page 142, you must supply an initial condition in your function definition that prevents the recursion from going on forever.

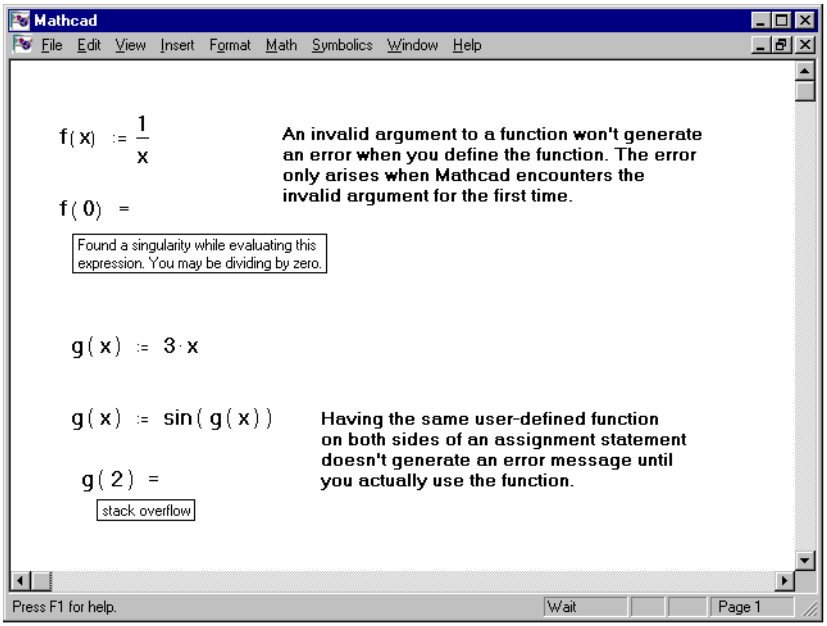


Figure 7-14: When an error message points to a function, go back and check the way the function was defined.