Chapter 11
Vectors, Matrices, and Data Arrays

This chapter describes techniques for creating, working with, and calculating with Mathcad arrays, including arrays of data you import from other sources. While ordinary variables (scalars) hold a single value, arrays hold many values. The following sections make up this chapter:

Creating arrays

Overview of techniques for creating arrays, including importing data and entering data into an input table.

Accessing array elements

Individual array entries, rows, and columns.

Displaying arrays

How Mathcad displays answers involving arrays.

Working with arrays

Calculating with arrays, graphing arrays, and exporting data.

Pro **Nested arrays**

Arrays in which the elements are themselves arrays.

Creating arrays

As introduced in "Inserting math" on page 46, one technique of creating an array is to use the **Matrix** command on the **Insert** menu to create an array of empty placeholders and then to enter expressions directly into the placeholders. This technique can only be used for small arrays, but it can be used to create arrays of any kind of Mathcad expression, not just numbers. This section describes this technique and other approaches for creating arrays of arbitrary size:

- Using range variables to fill in the elements. This technique is useful when you have some explicit formula for the array elements in terms of their indices.
- Using the File Read/Write component to import data from external files in a variety of formats.
- Entering numbers manually in a spreadsheet-like input table.

Unlike the Insert Matrix command, however, these procedures can be used *only* for creating arrays of numbers, as opposed to arbitrary math expressions.

Note The effective array size limit depends on the memory available on your system—usually at least 1 million elements. In no system is it higher than 8 million elements.

Insert Matrix command

To insert a vector or matrix in Mathcad, follow these steps:

- Click in either a blank space or on a math placeholder.
- Choose **Matrix** from the **Insert** menu, or click  on the Matrix toolbar. A dialog box appears, as shown at right.

- Enter the appropriate number of elements in the text boxes for "Rows" and "Columns." For example, to create a three-element vector, enter **3** and **1**.
- An array with blank placeholders appears in your worksheet.

Next, fill in the array elements. You can enter any Mathcad expression into the placeholders of an array created in this way. Simply click in a placeholder and type a

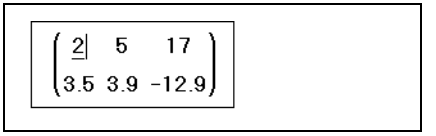
number or Mathcad expression. Use the [**Tab**] key to move from placeholder to placeholder.

Note Arrays created using the **Matrix** command on the **Insert** menu are limited to 100 elements.

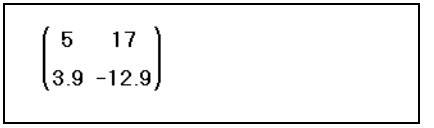
Changing the size of a vector or matrix

You can change the size of a matrix by inserting and deleting rows and columns:

- Click on one of the matrix elements to place it between the editing lines. Mathcad begins inserting or deleting with this element.



- Choose **Matrix** from the **Insert** menu. Type the number of rows and/or columns you want to insert or delete. Then press either "Insert" or "Delete." For example, to delete the column that holds the selected element, type **1** in the box next to "Columns," **0** in the box next to "Rows," and press "Delete."



Note If you insert rows or columns, Mathcad inserts rows *below* the selected element and inserts columns to the *right* of the selected element. If you delete rows or columns, Mathcad begins with the row or column occupied by the selected element and deletes rows from that element downward and columns from that element rightward. To insert a row above the top row or a column to the left of the first column, first place the entire matrix between the editing lines.

Creating arrays with range variables

As introduced in "Range variables" on page 125, you can use one or more range variables to fill up the elements of an array. If you use two range variables in an equation, for example, Mathcad runs through each value of each range variable. This is useful for defining matrices. For example, to define a 5×5 matrix whose i,jth element is $i + j$, enter the equations shown in Figure 11-1.

Recall that you enter the range variable operator by pressing the semicolon key (**;**) or clicking  on the Arithmetic toolbar. You enter the subscript operator by clicking  on the Matrix toolbar.

The $x_{i,j}$ equation is evaluated for each value of each range variable, for a total of 25 evaluations. The result is the matrix shown at the bottom of Figure 11-1, with 5 rows and 5 columns. The element in the ith row and jth column of this matrix is $i + j$.

Note To be used to define an array element, a range variable can take on only whole-number values.

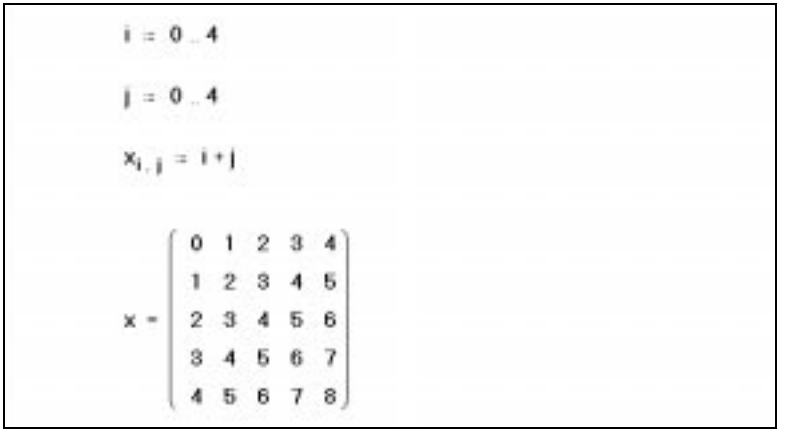


Figure 11-1: Defining a matrix using range variables.

Tip You can also define individual array elements using the subscript operator, as described in "Accessing array elements" on page 223.

Importing data

Mathcad provides the *File Read/Write component* to import data from a data file into a Mathcad array variable.

Note A component is a specialized OLE object that you insert into a Mathcad worksheet to create a link between the worksheet and either a data source or another application containing data. For more information on components, including specialized components for linking other computational applications dynamically to arrays in a Mathcad worksheet, see Chapter 16, "Advanced Computational Features.".

You can import data in a variety of file formats, including, among others:

- Excel (*.XLS)
- MATLAB (*.MAT)
- Lotus 1-2-3 (*.WK*)
- ASCII editors (*.DAT, *.CSV, *.PRN, *.TXT)

Tip Mathcad also provides a number of built-in functions for importing ASCII data files and image files. See "File access functions" on page 214.

To import data using the File Read/Write component:

- Click in a blank spot of your worksheet.
- Choose **Component** from the **Insert** menu.
- Choose File Read or Write from the list and click "Next." This launches the File Read or Write Wizard.
- Choose "Read from a data source" and press "Next" to continue through the Wizard.
- Specify the type of data file you want to read. Also enter the path to the data file or use the "Browse" button to locate it.
- Press "Finish." You'll see the File Read/Write component icon and the path to the data file. For example, if you specify a data file called DATA.TXT, you'll see the component at right.

In the placeholder that appears, enter the name of the Mathcad variable to which the data from the file will be assigned. When you click outside the component, the data file is read in and the data is assigned to the Mathcad array variable you entered into the placeholder. Each time you calculate the worksheet, Mathcad re-reads the data from the file you have specified. Figure 11-2 shows an example of importing data using the File Read/Write component.

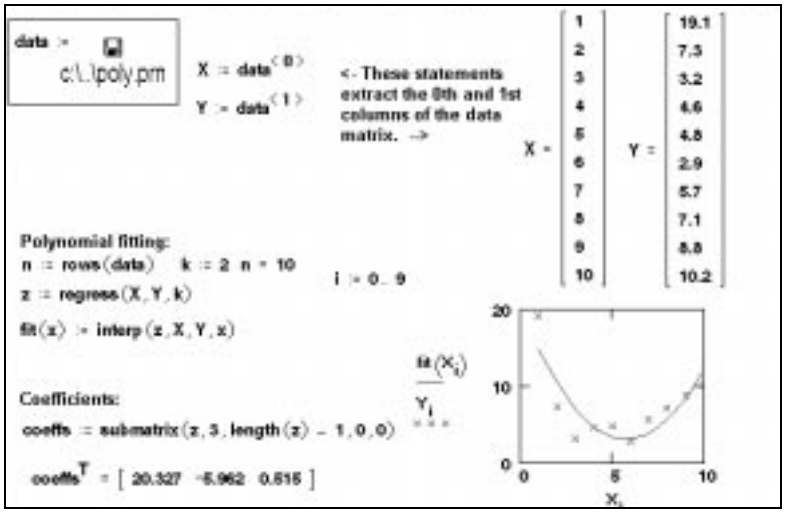


Figure 11-2: Importing data from a data file. Whenever you calculate the worksheet, the data file is read in.

To read in a different data file or a different type of data file:

- Click with the right mouse button on the component and select **Choose File** from the component pop-up menu.
- In the "Files of type" text box, choose the type of file you'd like to import. Use the dialog box to browse to the data file, select the data file, and click "Open."

Tip By default, Mathcad reads in the entire data file and creates an array with the variable name you provide. To read in only certain rows or columns of a data file, click once on the component to select it, then click with the right mouse button on the component and choose **Properties** from the pop-up menu. Use the Properties dialog box to specify the row and columns at which to start and stop reading.

Entering data into a table

To get the convenience of a spreadsheet-like interface for entering data, you can create an array using the Input Table component:

- Click in a blank spot in your worksheet and choose **Component** from the **Insert** menu.
- Select **Input Table** from the list and click "Next." The Input Table component is inserted into your worksheet.
- Enter the name of the Mathcad variable to which the data will be assigned in the placeholder that appears.
- Double-click the component and enter data into the cells. Each row must have the same number of data values. If you do not enter a number into a cell, Mathcad inserts 0 into the cell.

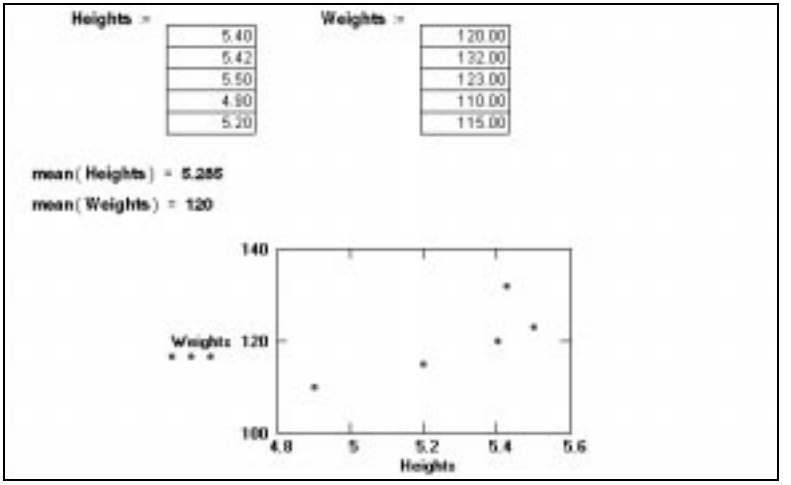


Figure 11-3: Using input tables to create arrays of data.

Figure 11-3 shows two input tables. Notice that when you create an input table, you're actually assigning elements to an array that has the name of the variable you entered into the placeholder.

When you double-click the table, you can edit the values in it. The scroll bars let you scroll through the table. To resize the table, move the cursor to one of these handles along the sides of the region so that it changes to a double-headed arrow. Then press and hold down the mouse button and drag the cursor to change the table's dimensions.

Tip You can copy data from an input table as follows: first select some data, then click with the right mouse button on the component and choose **Copy** from the pop-up menu. You can paste a single number from the Clipboard into the table by selecting a cell and choosing **Paste** from the pop-up menu. Choosing **Paste Table** from the pop-up menu overwrites the table with values in the Clipboard.

Importing once from a data file

You can use an input table to import data a single time from a data file. To do so:

- Insert an input table by following the instructions given above.
- In the placeholder that appears to the left, enter the name of the Mathcad variable to which this data will be assigned.
- Click with the right mouse button on the input table so that you see the pop-up menu.
- Choose **Import**.
- The Read from File dialog box appears. In the "Files of type" text box, choose the type of file you'd like to import. Use the dialog box to browse to the data file and click "Open."

The data from the data file appears in your worksheet in a table.

Note Unlike the File Read/Write component, the Import feature of an input table reads the data only when you choose **Import**, not each time you calculate the worksheet.

Accessing array elements

You can access all the elements of an array simply by using its variable name, or you can access the elements individually or in groups.

Subscripts

You access individual elements of a vector or matrix by using the subscript operator described in "Vector and matrix operators" on page 154. Insert the subscript operator by clicking x_n on the Matrix toolbar or by typing **[**. To access an element of a vector, enter one number in the subscript. To access a matrix element, enter two numbers separated by a comma. In general, to refer to the element in the *i*th row, *j*th column of matrix **M**, type **M[i,j**. To refer to the *i*th element of a vector, type **v[i**.

Figure 11-4 shows examples of how to define individual matrix elements and how to view them.

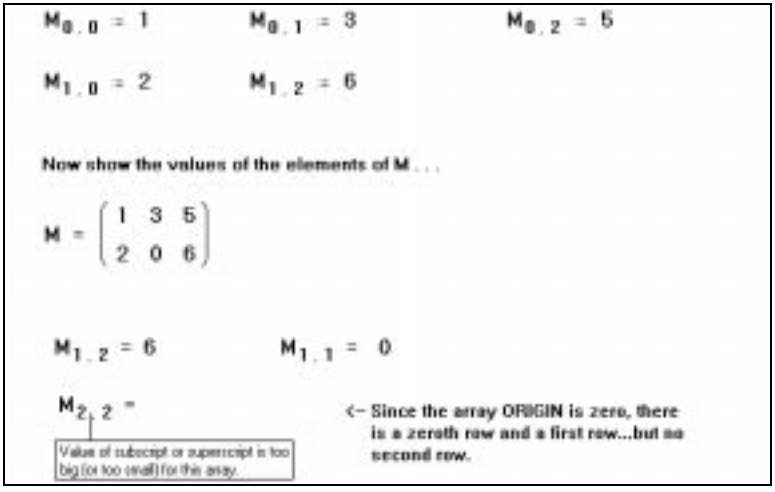


Figure 11-4: Defining and viewing matrix elements.

Note When you define vector or matrix elements, you may leave gaps in the vector or matrix. For example, if **v** is undefined and you define v_3 as 10, then v_0, v_1, and v_2 are all undefined. Mathcad fills these gaps with zeros until you enter specific values for them, as shown in Figure 11-4. Be careful of inadvertently creating very large vectors and matrices by doing this. Note also that vector and matrix elements by default are numbered starting with row zero and column zero unless the built-in variable ORIGIN has a value other than zero (see page 225).

You can use this kind of subscript notation in Mathcad to perform parallel calculations on the elements of an array. See "Doing calculations in parallel" on page 229.

Tip If you want to define or access a group of array elements at once, you can use a range variable in a subscript.

Accessing rows and columns

Although you can use a range variable to access all the elements in a row or column of an array, Mathcad provides a column operator for quickly accessing all the elements in a column. Click $M^{\langle\rangle}$ on the Matrix toolbar for the column operator. Figure 11-5 shows how to place the third column of the matrix **M** in the vector **v**.

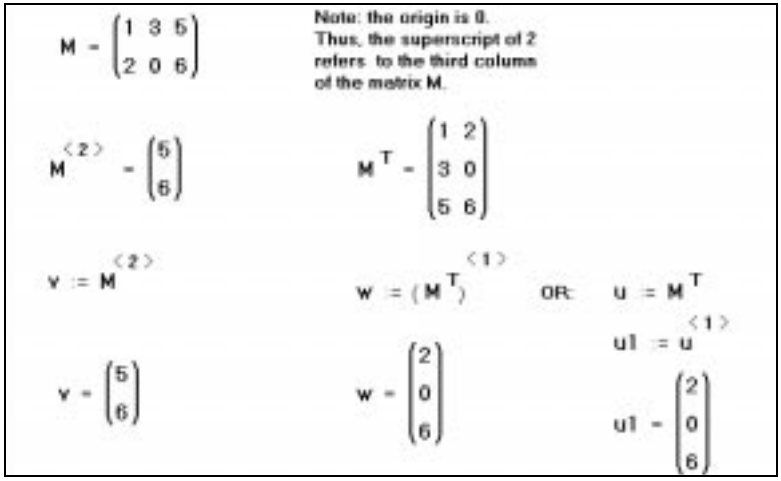


Figure 11-5: Extracting a column from a matrix.

To extract a single row from a matrix, transpose the matrix using the transpose operator (click M^T on the Matrix toolbar) and then extract a column using the column operator. This is shown on the right-hand side of Figure 11-5.

Changing the array origin

When you use subscripts to refer to array elements, Mathcad assumes the array begins at the current value of the built-in variable ORIGIN. By default, ORIGIN is 0, but you can change its value. See "Built-in variables" on page 121 for details.

Figure 11-6 shows a worksheet with the ORIGIN set to 1. If you try to refer to the zeroth element of an array in this case, Mathcad displays an error message.

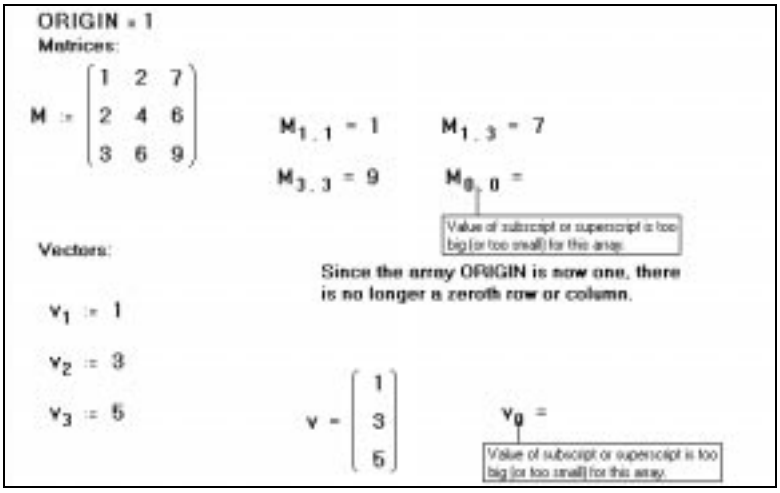


Figure 11-6: Arrays beginning at element one instead of at element zero.

Displaying arrays

As described in “Formatting results” on page 134, Mathcad automatically displays matrices and vectors having more than nine rows or columns as output tables rather than as matrices or vectors. Smaller arrays are displayed by default in traditional matrix notation. Figure 11-7 shows an example.

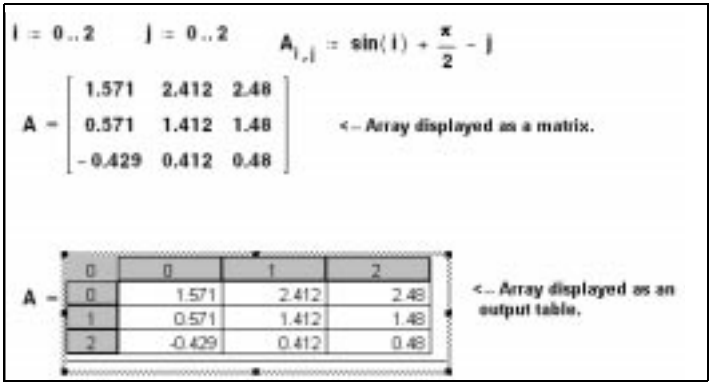


Figure 11-7: Displaying results in an output table.

Note An output table displays a portion of an array. To the left of each row and at the top of each column, there is a number indicating the index of the row or column. Click with the right mouse button on the output table and select **Properties** from the pop-up menu to control whether row and column numbers appear and the font used for values in the table. If your results extend beyond the table, a scroll bar appears along the appropriate edge of the table. You can scroll through the table using these scroll bars just as you would scroll through any window.

To resize an output table:

- Click the output table. You'll see handles along the sides of the table.
- Move the cursor to one of these handles so that it changes to a double-headed arrow.
- Press and hold down the mouse button and drag the cursor in the direction you want the table's dimensions to change.

Tip You can change the alignment of the table with respect to the expression on the left-hand side of the equal sign. Click with the right mouse button on the table, then choose one of the **Alignment** options from the pop-up menu.

Changing the display of arrays

Although matrices and vectors having more than nine rows or columns are automatically displayed as scrolling output tables, you can have Mathcad display them as matrices. To do so:

- Click on the scrolling output table.
- Choose **Result** from the **Format** menu.
- Choose Matrix in the "Matrix display style" drop-down box.
- Click "OK."

To display all the matrices and vectors of results in your worksheet as matrices (or as tables) regardless of their size, click "Set as Default" in the Result Format dialog box before clicking "OK."

Note Mathcad displays only the first 200 rows or columns in an array displayed as a matrix. An ellipsis is used to indicate that rows and columns are present but not displayed. Although Mathcad does not display these rows or columns, it continues to keep track of them internally.

Changing the format of displayed elements

You format the numbers in the array the same way you format other numerical results, as described in "Formatting results" on page 134. Just click on the displayed array and

choose **Result** from the **Format** menu, and modify the settings there. When you click "OK," Mathcad applies the selected format to all the numbers in the table, vector, or matrix. It is not possible to format these numbers individually.

Tip Double-clicking a result array is a shortcut for bringing up the Result Format dialog box.

Copying and pasting arrays

You can 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. Once you've performed the necessary computations, you can paste the resulting array of numbers back to its source or even into another application.

To copy just one number from a result array, simply click the number and choose **Copy** from the **Edit** menu, or click  on the Standard toolbar. Copying multiple numbers from a vector or matrix result differs depending on whether the array is displayed as a matrix or as an output table. See "Formatting results" on page 134 for more information on how vector and matrix results are displayed.

To copy a result array displayed as a matrix:

- Drag-select the array to the right of the equal sign to place the entire array between the editing lines.
- Choose **Copy** from the **Edit** menu. This places the entire 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, or click  on the Standard toolbar.

Note You may only paste an array into a math placeholder or into a blank space in a Mathcad worksheet.

When you display array results as a table, you can copy some or all of the numbers from the table and use them elsewhere:

- 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 are selected. Then choose **Copy** from the **Edit** menu.

After you have copied one or more numbers from an output table, you can paste them into another part of your worksheet or into another application. Figure 11-8 shows an example of a new matrix created by copying and pasting numbers from an output table.

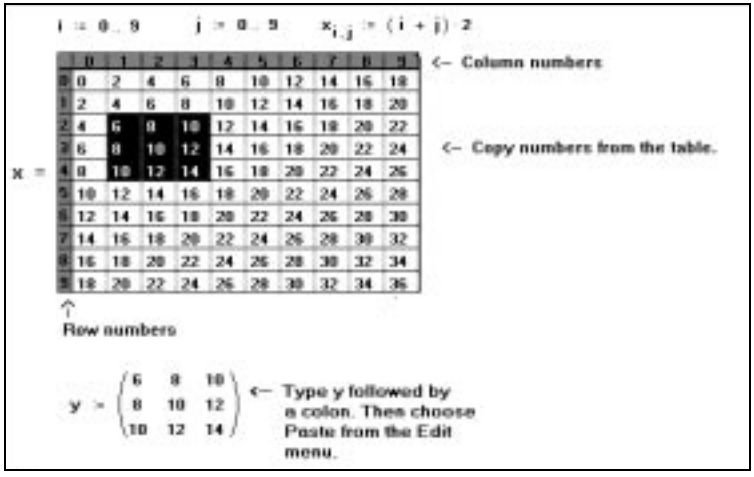


Figure 11-8: Copying and pasting results from an output table.

Working with arrays

Once you create an array, you can use it in calculations. There are many operators and functions designed for use with vectors and matrices. See “Vector and matrix operators” on page 154 and “Vector and matrix functions” on page 182 for an overview. This section highlights the vectorize operator, which permits efficient parallel calculations on the elements of arrays. You can also display the values of an array graphically or export them to a data file or another application.

Doing calculations in parallel

Any calculation Mathcad can perform with single values, it can also perform with vectors or matrices of values. There are two ways to do this:

- Iterate over each element using range variables. See for example “Creating arrays with range variables” on page 219.
- Use the *vectorize operator*, which allows Mathcad to perform the same operation efficiently on each *element* of a vector or matrix.

Mathematical notation often shows repeated operations with subscripts. For example, to define a matrix **P** by multiplying corresponding elements of the matrices **M** and **N**, you would write:

$$\mathbf{P}_{i,j} = \mathbf{M}_{i,j} \cdot \mathbf{N}_{i,j}$$

Note that this is not matrix multiplication, but multiplication element by element. It *is* possible to perform this operation in Mathcad using subscripts, but it is much faster to perform exactly the same operation with a vectorized equation.

Here's how to apply the vectorize operator to an expression like $\mathbf{M} \cdot \mathbf{N}$:

- Select the whole expression by clicking inside it and pressing [**Space**] until the right-hand side is surrounded by the editing lines.

- Click  on the Matrix toolbar to apply the vectorize operator. Mathcad puts an arrow over the top of the selected expression.

Properties of the vectorize operator

- The vectorize operator changes the meaning of the other *operators* and *functions* to which it applies. The vectorize operator tells Mathcad to apply the operators and functions with their scalar meanings, element by element. It does not change the meaning of the actual names and numbers. If you apply the vectorize operator to a single name, it simply draws an arrow over the name. You can use this arrow just for cosmetic purposes.
- Since operations between two arrays are performed element by element, all arrays under a vectorize operator must be the same size. Operations between an array and a scalar are performed by applying the scalar to each element of the array.
- You cannot use any of the following matrix operations under a vectorize operator: dot product, matrix multiplication, matrix powers, matrix inverse, determinant, or magnitude of a vector. The vectorize operator transforms these operations into element-by-element scalar multiplication, exponentiation, or absolute value, as appropriate.
- The vectorize operator has no effect on operators and functions that *require* vectors or matrices: transpose, cross product, sum of vector elements, and functions like *mean*. These operators and functions have no scalar meaning.

Tip A number of Mathcad's built-in functions and operators ordinarily take scalar arguments but *implicitly* vectorize arguments that are vectors (one-column arrays): they automatically compute a result element by element, whether you apply the vectorize operator or not. Functions that implicitly vectorize vector arguments include the trigonometric, logarithmic, Bessel, and

probability distribution functions. Operators that implicitly vectorize vector arguments include the factorial, square and *n*th root, and relational operators. You must continue to use the vectorize operator on arrays of other sizes with these functions and operators.

For example, suppose you want to apply the quadratic formula to three vectors containing coefficients *a*, *b*, and *c*. Figure 11-9 shows how to do this with the vectorize operator.

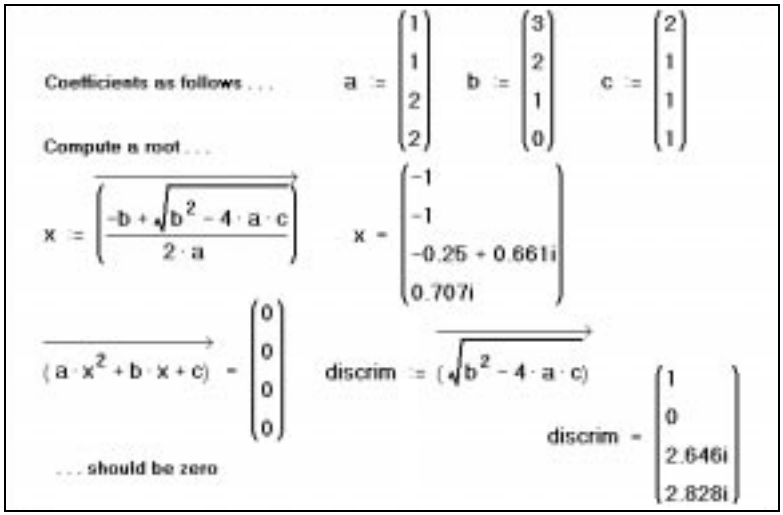


Figure 11-9: Quadratic formula with vectors and the vectorize operator.

The vectorize operator, appearing as an arrow above the quadratic formula in Figure 11-9, is essential in this calculation. Without it, Mathcad would interpret $\mathbf{a} \cdot \mathbf{c}$ as a vector dot product and also flag the square root of a vector as illegal. But with the vectorize operator, both $\mathbf{a} \cdot \mathbf{c}$ and the square root are performed element by element.

Graphical display of arrays

In addition to looking at the actual numbers making up an array, you can also see a graphical representation of those same numbers. There are several ways to do this:

- For an arbitrary array, you can use the various three-dimensional plot types discussed in Chapter 13, "3D Plots."
- For an array of integers between 0 and 255, you can look at a grayscale image by choosing **Picture** from the **Insert** menu and entering the array's name in the placeholder.
- For three arrays of integers between 0 and 255 representing the red, green, and blue components of an image, choose **Picture** from the **Insert** menu and enter the arrays' names, separated by commas, in the placeholder.

See Chapter 6, "Working with Graphics and Other Objects," for more on viewing a matrix (or three matrices, in the case of a color image) in the picture operator.

Exporting data

The File Read/Write component allows you to export the values stored in a Mathcad variable to a variety of file formats, including the following:

- Excel (*.XLS)
- MATLAB (*.MAT)
- Lotus 1-2-3 (*.WK*)
- ASCII editors (*.DAT, *.CSV, *.PRN, *.TXT)

Tip Mathcad also provides a number of built-in functions to export arrays as ASCII data files or image files. See "File access functions" on page 214.

To export data using the File Read/Write component:

- Click in a blank spot in your worksheet.
- Choose **Component** from the **Insert** menu.
- Select File Read or Write from the list and click "Next." This launches the File Read or Write Wizard.
- Choose "Write to a data source" and press "Next" to continue through the Wizard.
- Specify the type of data file you want to write. Also enter the path to the data file you want to write or click the "Browse" button to locate it.
- Press "Finish." You'll see the File Read/Write component icon and the path to the data file. For example, if you specify a data file called DATA.TXT, you'll see the component at right.

In the placeholder, enter the name of the Mathcad variable containing the data to be written to the data file. When you click outside the component, all the values in the array are written to the file you specified. Each time you calculate the worksheet, the data file is rewritten. See Figure 11-10 for an example.

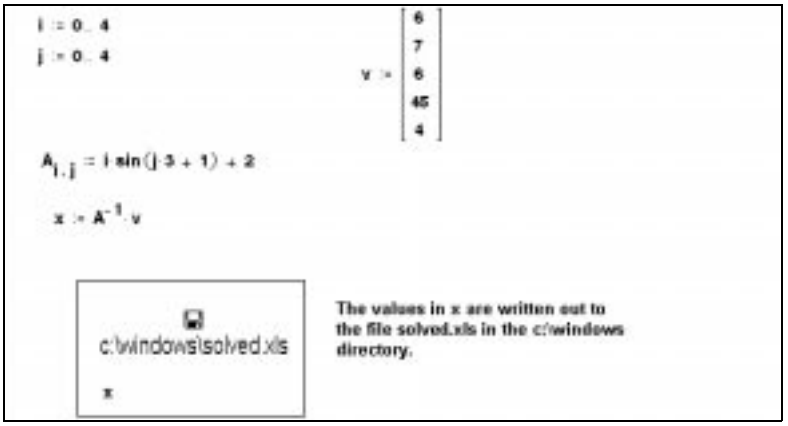


Figure 11-10: Exporting data with the File Read/Write component.

To change the name of the data file being created to or to change the type of file being created:

- Click once on the component to select it.
- Click with the right mouse button on the component and select **Choose File** from the pop-up menu to open the Write to File dialog box.
- Choose the type of file you'd like to create in the "Files of type" text box. Use the dialog box to browse to the folder in which the data file will be created and click "Open."

Tip When you display an array as an output table, as described in "Displaying arrays" on page 226, you can export data directly from the table. Click with the right mouse button on the output table, choose **Export** from the pop-up menu, and enter the name of the file that will receive the data. Unlike the File Read/Write component, the output table writes the data only when you choose **Export**, not each time you calculate the worksheet.

Nested arrays

Pro An array element need not be a scalar. In Mathcad Professional it's possible to make an array element itself be another array. This allows you to create arrays within arrays.

These arrays behave very much like arrays whose elements are all scalars. However, there are some distinctions, as described below.

Note Most of Mathcad's operators and functions do not work with nested arrays, since there is no universally accepted definition of what constitutes the correct behavior in this context. Certain operators and functions are nevertheless useful and appropriate for nested arrays. Functions that enumerate rows or columns, or that partition, augment, and stack matrices, can be applied to nested arrays. The transpose, subscript, and column array operators and the Boolean equal sign likewise support nested arrays.

Defining a nested array

You define a nested array in much the same way you would define any array. The only difference is that you cannot use the **Matrix** command from the **Insert** menu when you've selected a placeholder within an existing array. You can, however, click on a placeholder in an array and type the *name* of another array. Figure 11-11 shows several ways to define a nested array. Additional methods include using a file access function such as *READPRN* in the array of placeholders created using the Insert Matrix command, and using the programming operators in Mathcad Professional to build up an array whose elements are themselves arrays.

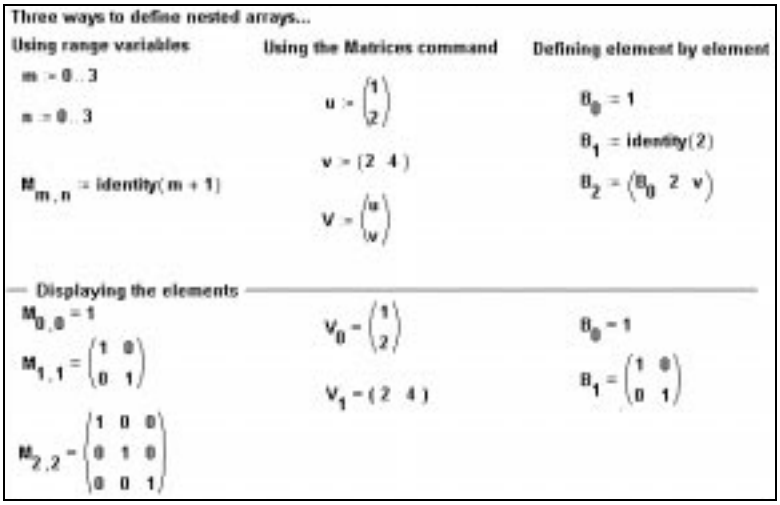


Figure 11-11: Defining nested arrays.

Note The display of a nested array is controlled by Display Styles settings in the Result Format dialog box (see page 134). You can expand a nested array when the array is displayed in matrix form; otherwise, whenever an array element is itself an array, you see bracket notation showing the number of rows and columns rather than the array itself. If the nested array is displayed as an output table, you can see the underlying array temporarily. Click on the array element, then click with the right mouse button and choose **Down One Level** from the pop-up menu. Choose **Up One Level** from the pop-up menu to restore the array element to non-expanded form.