MandelBrowser 2.0

0: Contents

I: About MandelBrowser

MandelBrowser is a graphics program for PowerMacs. It draws a mathematical object called the Mandelbrot Set. These images can be extraordinarily beautiful and complex. MandelBrowser will work on any PowerMac, but works best on monitors using thousands or millions of colors. Version 2.0 main addition is the Windows menu and the various tool windows. See the Change History for the other changes.

I've been writing fractal programs for a long time. In fact I learned how to write Macintosh programs by writing a fractal program called Mandella. Over the years Mandella turned into a pretty cool program and because of it and another program called LifeMaker I was able to get a job as a professional software developer.

There are still a lot of things I want to add to MandelBrowser. For example I want to experiment with a more visual interface for the maximum dwell, bailout, draw styles, etc. I also want to add a palette editor and support QuickTime and QuickDraw 3D.

MandelBrowser is freeware but cannot be used for any commercial purpose without my express written permission. This would include the program being sold by for-profit organizations. Bulletin board systems that charge by the hour are OK as are not-for-profit organizations. Images generated by MandelBrowser may be used however you please.

If you have any suggestions or bug reports please send them to me at jesjones@halcyon.com

II: Just what are fractals?

Euclidean geometry is concerned with objects such as points, lines, circles and 3-D shapes like spheres or planes. These objects are idealized versions of objects found in Nature. Classical geometry is limited to these sort of idealized objects and thus works poorly when it is used to describe real-world objects. As Mandelbrot says, "Clouds are not spheres, mountains are not cones, coastlines are not circles, and bark is not smooth".

Fractals, on the other hand, do model reality. Like natural objects fractals are not smooth and are often self similar. As an illustration consider a mountain. It is obviously not a smooth object. And it is self similar: if we examine part of the mountain we will see peaks and hills that are similar in appearance to the whole mountain.

Fractals vary in their degree of self similarity. For example Julia fractals (figure 3) are very self similar (and therefore rather boring). The Mandelbrot fractal (figure 2) is not nearly as self similar. If you examine it under magnification you can find an amazing number of different shapes including spirals, whirlpools, and stars. Here and there you will also find distorted replicas of the original fractal!

Fractals are quantified using the concept of dimension. Euclidean objects have an integer dimension. For example a line has a dimension of one, the plane has a dimension of two, and a sphere has a dimension of three. Fractals have either a fractional dimension or a dimension greater than their topological dimension.

As an example, consider the space filling curve in figure 1. This curve will eventually cover every point in the plane so it has a dimension of two. On the other hand, lines have a topological dimension of one so the curve is indeed a fractal. Figure 1 was drawn using a program called Hilbert.

Use Word 6.0c or later to

view Macintosh picture.
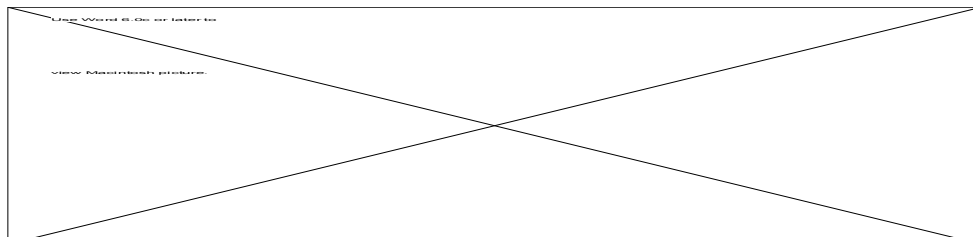
Figure 1 An example of a space-filling curve.

Fractals are used everywhere the natural world needs to be modeled or described. Scientists are using fractals to model nature, and computer scientists are using fractals to produce "natural" images. Some simple examples include the IFS fern and fractal mountains. Many of the special effects in movies are based on fractals. Barnsley is using fractals in a new image compression scheme. He has achieved compression ratios in excess of 10,000 to

1. Appendix 2 lists several books and articles describing how fractals are used in the real world. Barnsley's company, Iterated Systems, is also listed.

III: Computing Fractals

Most fractals are calculated using complex numbers. Complex numbers are numbers that have both a real and an imaginary component. Real numbers are the standard floating point numbers. Imaginary numbers are multiples of the square root of -1. Complex numbers are usually written as 3+5i where 3 is the real component and 5i is the imaginary component. "i" represents the square root of -1.

Complex numbers can be thought of as number pairs. In other words 3 + 5i can be written (3, 5). If we write them in this way it is natural to use the plane to represent complex numbers. This is called the complex plane. Each point on the plane corresponds to a complex number. The fractal windows in MandelBrowser can be thought of as windows into a section of the complex plane.

All of the standard arithmetic, trigonometric, and logarithmic functions can be extended so that they work on complex numbers. New functions can also be defined. One of the more important returns the magnitude of a complex number. If $z = x + yi$ then $Mag(z) = Sqrt(x^2 + y^2)$. This is a measure of the "size" of a complex number. It's also the distance from the origin to the point on the complex plane.

Unlike Mandella, MandelBrowser draws only one fractal: the Mandelbrot Set. The algorithm is very simple:

```
z := (0, 0);
c := a point on the complex plane
count := 0;
REPEAT
    z := z^2 + c
    count := count + 1;
UNTIL (Mag(z) > 2.0) OR (count = maxCount)
```

This procedure can be used to determine whether a point is outside the fractal. The fractal is, by definition, the set of all points where Mag(z) is never greater than two. If Mag(z) > 2 then z will increase without bound, i.e. it will "escape" to infinity. Points in the set typically fall into a loop and so never escape. Points within the set are, by convention, colored black. Points outside the set are colored according to either the count value or the final z value. The count variable is usually called a *dwell*.

It's important to notice that the algorithm above cannot be used to determine if a point is within the set. Since the loop is executed a finite number of times we can never be sure that the point won't escape. However if we increase maxCount the image will become a better and better approximation to the fractal. To determine if a point is really in the set we need to somehow check the z values to see if they have fallen in a loop.
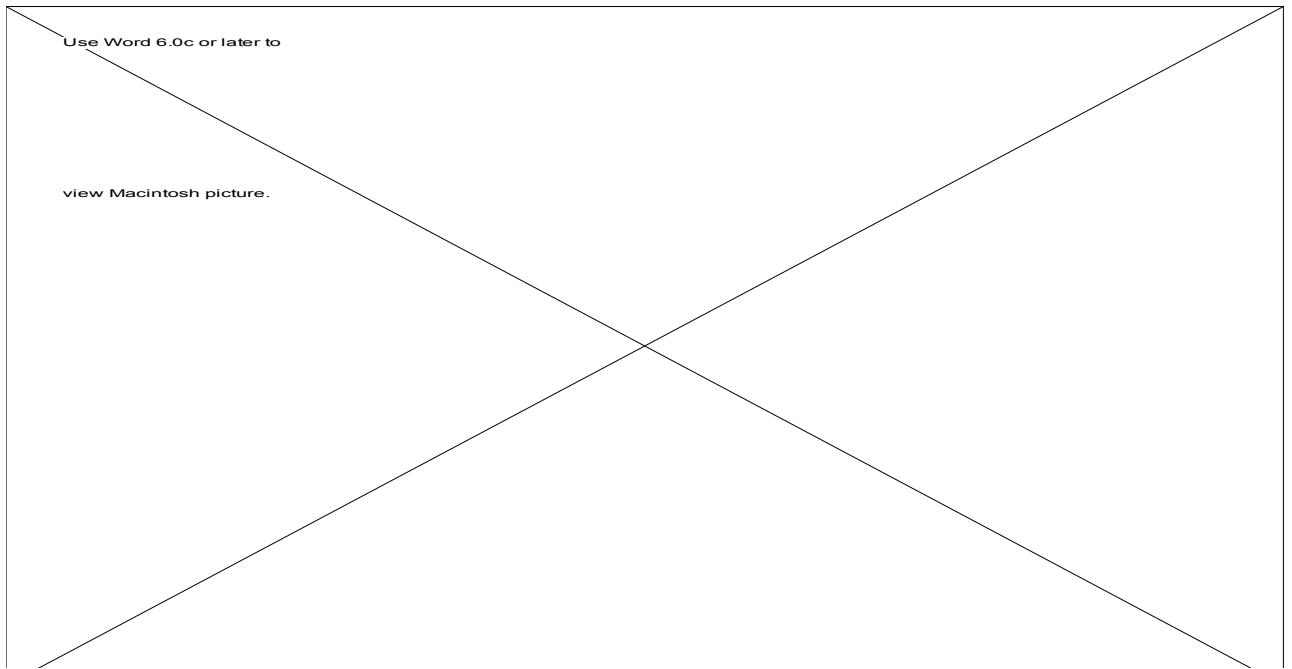
Figures 2 and 3 On the left the Mandelbrot Set. On the right a Julia fractal.

IV: Drawing the Fractals

MandelBrowser lets you open as many fractal windows as you have memory for. The front-most fractal window will be the first to be drawn. After it has been finished the window immediately behind the front-most window will be drawn. This process will continue until all the windows have been drawn.

MandelBrowser will continue drawing the fractal windows when it is placed in the background. The Draw For sub-menu in the Fractal menu can be used to adjust how long MandelBrowser spends calculating points before yielding time to the foreground application. If Draw For is set too high the foreground application will be slow in responding to the user (e.g. a word processor may take a moment to display text after you type it in).

MandelBrowser provides 16 ways to color the area outside the Mandelbrot Set and 11 ways to color the inside of the set. The outside draw styles are:

Level Sets This is the fastest method and the one most fractal programs use. Colors are chosen according to the dwell value.

Zebra Every other dwell is drawn using a special color yielding alternating stripes of color.

Continuous Potential This method generally produces the best looking images. It results in images where the colors shade very smoothly into each other. Most of the color plates in *The Beauty of Fractals* and *The Science of Fractal Images* use this method. However, it's slower than Level Sets and is a little more difficult to use since it uses a parameter called "slope". This number controls how quickly the colors reach the last color in the palette. Low slope values cause the colors to peak early. Higher slope values cause the colors to peak at the higher dwell values. Continuous Potential works best with a linear color map and a large Bailout value (say over a hundred).

Distance Estimator This method does some extra computation to determine how close a point is to the fractal. You can adjust the size of the filaments to make them larger or smaller. This is the slowest method and seems to work best when the image is drawn at a high resolution. *The Beauty of Fractals* and *The Science of Fractal Images* have some excellent black and white pictures of fractals drawn using the Distance Estimator.

Stalks This is a rather cool method. It draws stalks that curve and twist about the image. These stalks are drawn for points where z passes near the origin when the formula is iterated. You can adjust the size of the stalks by specifying how near the origin z must be for a stalk to be drawn.

Decomposition This is a rather weird method where the color of each pixel is adjusted according to the angle z makes with the origin. The result is very strange and occasionally even interesting.

Ratio This method uses the ratio of the real and imaginary components of the final z value to color the image. The results are similar to decomposition but usually look a little better.

Biomorph This method was developed by Pickover. It works well for images with low maxCounts. The results look a bit like invertebrates. It works by using a special color if both the real and imaginary components of the final z value are large.

Modulus In this method you enter the number of colors to use. For example, if you enter sixteen the first sixteen dwells will use sixteen evenly spaced colors from the palette. The next band of sixteen dwells will reuse those colors as will all the following bands.

Real Increments dwell by z.r and uses Level Sets.

Imag Increments dwell by z.i and uses Level Sets.

Mult Multiplies dwell by z.r/z.i and uses Level Sets.

Sum Increments dwell by z.r + z.i and uses Level Sets.

Solid Color The outside of the fractal is drawn in whatever color you select.

White The outside of the fractal is drawn in white.

Black The outside of the fractal is drawn in black.

The inside draw styles are:

Stalks Just like the outside method: it draws stalks for points where z passes near the origin when the formula is iterated. You can adjust the size of the stalks by specifying how near the origin z must be for a stalk to be drawn.

Decomposition This is a rather weird method where the color of each pixel is adjusted according to the angle z makes with the origin. The result is very strange and occasionally even interesting.

Ratio This method uses the ratio of the real and imaginary components of the final z value to color the image. The results are similar to decomposition but usually look a little better.

Mag The method uses the magnitude of the final z value to color the image.

Periodic Here points in the set are colored according to how long they take to become periodic. This method doesn't produce very striking images but it's kind of neat to see the period checker in action. (This is disabled since I haven't implemented the period checker yet).

Bof60 Colors are computed based on how close z passed to the origin.

Bof61 Colors are computed based on the dwell at which z passed closest to the origin.

ZMag Colored according to the product of the dwell and the magnitude of the final z value.

Solid Color The outside of the fractal is drawn in whatever color you select.

White The outside of the fractal is drawn in white.

Black The outside of the fractal is drawn in black.

V: The Menus

File

New
Creates a new fractal window showing the entire Mandelbrot Set. The initial window size can be changed using the Preferences menu item.

Open
Allows you to open MandelBrowser, Mandella, or Fractint files. Note that MandelBrowser files are PICTs.

Next File/Par
Lets you open the file after the one you opened last or the next par if you had opened a par file.

Close
Closes the front window. You can close all of the fractal windows by holding the option or command keys down when you select Close. Option-Close saves the windows before closing them. Command-Close doesn't save any of the windows. It will, however, ask you if you're sure you want to close the windows without saving.

Save
Saves the front window. If the option key is held down all of the windows are saved.

Save As

Saves the front fractal window. You may save the image (as a PICT file) or just the coordinates.

Revert

If the fractal was loaded from disk and changed you can select this to go back to the version on disk.

Page Setup
Print
Print One

Printing is disabled for now.

Quit

Quits the program.

Edit

Copy

Copies the fractal into the clipboard. (The other standard edit commands are disabled since they don't make much sense in MandelBrowser).

Select All

Selects all of the front window.

Constrain/Free Selection

Normally the selection rectangle can be of any size. If you select Constrain Selection the selection is constrained to a 4:3 aspect ratio. This means that any new windows created by the Extract or Magnify commands will also have a 4:3 aspect ratio.

Constrain By

This command is enabled after Constrain Selection is enabled. It allows you to change the aspect ratio used to constrain the selection rectangle.

Fractal

Outside Style

Submenu controlling how the area outside the fractal is drawn. See the Drawing the Fractals section for details.

Inside Style

Submenu controlling how the area inside the fractal is drawn. See the Drawing the Fractals section for details.

Color Mapping

Submenu controlling how dwells are mapped into the palette.

Math Precision

Submenu controlling the precision at which the fractals are computed. Higher precision numbers are automatically used as you zoom deeper.

Origin

Pops up a dialog allowing you to change the section of the complex plane used by the fractal. You can use center and width or specify the four corners.

Perturb

This is used to modify the initial z value (see Section III: Computing Fractals). If this is set to a non-zero value the Mandelbrot Set will become distorted.

Bailout

Changes the value at which points are considered to have "escaped". The default is two. Larger values result in images where the dwell values change more quickly.

Max Dwell

Changes the maximum number of times the Mandelbrot equation will be iterated. As you zoom into the Mandelbrot Set this number will have to be increased.

Image Size

Pops up a dialog allowing you to change the number of pixels used by the image. There are three options. Same Ratio ensures that the new size has the same aspect ratio as the old size. As you type in the width, the height will change to keep the ratio constant.

Same Area works like Same Ratio but keeps the total number of pixels constant. Free Form allows any window size to be entered. If the aspect ratio of the window changes, the portion of the complex plane used also changes to avoid distorting the image. This is done by expanding the amount of the complex plane shown.

Draw For

This submenu controls the amount of time MandelBrowser spends computing the fractals before responding to mouse clicks or other input. Larger times cause fractals to be drawn slightly faster but cause the program to be sluggish in responding to you. This time will also affect the performance of applications running concurrently with MandelBrowser.

View

Extract

Creates a new window using the coordinates defined by the selection rectangle.

Magnify

Resizes the front window and changes the coordinates to match the selection rectangle.

Scroll Up
Scroll Down
Scroll Left
Scroll Right

These commands scroll the image in the complex plane. In other words they shift the fractal so new, unexplored areas become visible. The arrow keys work just like the scroll commands.

Scroll Width

A submenu that controls how far the scroll commands scroll. The amounts are expressed in percents. For example, if you select %10, Scroll Up will scroll the fractal so that %10 of the image is new.

Zoom In
Zoom Out

Zooms in on the center of the fractal window so that the fractal covers less of the complex plane. It's usually better to use the Magnify command because you have more control over the area

zoomed into. However this can be handy when you want to undo the effect of a Zoom Out.

Zoom By

Zooms out of the center of the fractal window so that the fractal covers more of the complex plane. You can use this command to view the neighborhood around the original image.

Show Orbits

You can use this command to observe the behavior of points in the fractal. It shows the "orbits" of a point in the fractal. The orbit of a point is the trajectory of that point as it undergoes the Mandelbrot Set iteration. Points outside the set will escape to infinity. Points within the set will converge to a point or bounce between a few points.

Center Point

You can use this command to change the center of the fractal. Select Center Point and then click on a point within the fractal window. The image will shift so that the point you clicked on becomes the center of the fractal.

Palette

Palette List

Selecting a palette from the list causes that palette to be used in the front fractal window. Windows created with the New command use the Default palette. If there is no palette named Default the first palette is used. The palettes are saved in a file called "MandelBrowser Colors".

Add

Lets you add the palette being used by the front fractal window to the palette menu.

Delete

Lets you delete a palette from the list.

Window

Memory

Shows a window displaying the memory used by the front fractal, the memory used by all of the fractals, and the memory remaining. Like all of the tool windows, command-clicking on it brings up an options dialog.

Mouse
Shows a window displaying the pixel coordinate, the point on the complex plane, and the dwell of the pixel underneath the mouse.

Info
Shows a window displaying a bunch of information about the frontmost fractal..

Palette
Shows a window displaying the palette used by the frontmost fractal. Note that the displayed palette has a fixed size so if the fractal has too many colors some will be dropped in the palette window. You can set the number of colors displayed using the options dialog.

History
Shows a window displaying thumbnails for the last few fractals generated. The options dialog allows you to set the thumbnail size, the number of thumbnails to display, and the orientation of the window.

Fractal Windows
Lists the open fractal windows. The frontmost is marked with a checkmark. The one being drawn is marked with a hollow diamond (if it's different than the frontmost).

Stack Windows
Stacks the fractal windows.

Tile Windows
Tiles the fractal windows.

Next Window
Sends the frontmost fractal window to the back.

Color

Random Palette

Replaces the palette used by the front fractal window with a random palette.

Random Options

Allows you to change the way MandelBrowser creates random palettes. There are four parameters: Number of Colors is the number of colors used in random palettes. It can range from 2 to 99999. Complexity is the number of random colors used in the palette (the other colors are generated by linearly interpolating between the random colors). Saturation and Value affect the generation of the random colors. If Saturation is greater than one, the random colors will tend to be saturated. In other words, the colors will not be mixed with white - they will be pure hues. If Value is greater than one, the random colors will tend to be bright. The larger these numbers, the more the colors will tend towards the maximum saturation or value.

Import Palette

This is a submenu that allows you to choose a 'clut' resource or a Fractint map file to use for the front fractal window.

Add to Temp

This command assigns the palette in the front fractal window to a number key (1-9). The first temporary palette is assigned to the 1 key. Subsequent temporary palettes are assigned to the next open number. Pressing command-number key replaces the palette in the front window with a temporary palette.

Clear Temp

Removes all of the temporary palettes. You'll be asked if you're sure you really want to do this.

Save Temp

Saves the temporary palettes and their associated keys in a file.

Load Temp

Loads the temporary palettes from a file created with Save Temp.

VI: Change History

Version 2.0:

• Added the Memory, Mouse, Info, Palette, and History windows.
• Added the Stack Windows, Tile Windows, and Next Window commands.
• Added the Show Orbits command.
• Added the Windows menu.
• MandelBrowser will now ask if it should switch the monitor to thousands or millions of colors if there isn't a monitor at the correct depth. The old depth is restored when the app quits.
• The thumb in the fractal's scroll bars is now dynamic (ie the fractal scrolls as the thumb is dragged).
• MandelBrowser switches to 64-bit math a little sooner.
• The Center Point command now centers correctly.
• Line continuations are handled much better in FractInt par files.

Version 1.0:

• First public release.

Appendix 1: Shortcuts

Keys
Command-1 to 9	selects a temporary palette.
Command-0	clear all of the temporary palettes.
1-9	speeds up scrolling. 1 is normal speed. 9 is 9x faster.
Escape	is equivalent to pressing Cancel in a dialog or alert.
Command-.	is also equivalent to pressing Cancel in a dialog or alert.
'y' and 'n'	are equivalent to pressing Yes or No buttons.

File menu
Option-Close	closes all windows. If a window has been changed you'll be asked if you want to save it.
Command-Close	closes all windows without saving. You'll be asked if you're sure you want to do this.
Option-Save	saves all windows.
Option-Quit	saves all windows and quits.
Command-Quit	quits without saving any windows. You'll be asked to confirm that this is really what you want to do.

Note that the text in the file menu will change if you hold the option or command key down when you click in the menu bar. Also all of the floating tool windows have option dialogs you can access by holding the command key down and clicking on the window.

Appendix 2: Resources

Companies

Art Matrix, P.O. Box 880, Ithaca, New York, 14851. 1-800-PAX-DUTY.
This company sells videos, posters, tee-shirts, and slides of fractals.

Iterated Systems, 5550 Peachtree Parkway, Building A, Suite 545, Norcross, GA, 30092.
This is the company founded by Barnsley to create special purpose hardware using IFS fractals to compress images thousands of times.

John's Picks, P.O. Box E, Suisun City, CA, 94585.
John puts out a thirty page catalog three times a year containing books, posters, puzzles, and games relating to fractals, chaos, cellular automata, neural networks, computer graphics, the art of Escher, and much more.

Media Magic, P.O. Box 507, Nicasio, CA, 94946. (415) 662-2426.
This company sells books and videos about fractals, chaos, cellular automata, and so forth. They also sell postcards, tee-shirts, and posters.

Strange Attactions, 204 Kensington Park Rd, London, W11 1NR.
FAX (081) 459-7354.
Gregory Sams runs what he calls, "the worlds first chaos shop". He sells books, videos, posters, tee-shirts, mugs, post cards, etc. Greg uses Mandella to create his art-work and has created some excellent posters and tee-shirts.

Programs

Henderson Associates, *Hilbert*.
A nice little program that draws several different fractal curves.

Bourke, Paul, *FracHill*.
An excellent fractal mountain program. There are several ways to control the mountains, the mountains are drawn in color, and it can export the mountain to ray-shaders. FracHill requires a color, 68K Mac with an FPU.

Bourke, Paul, *LSystems*.
Another excellent program from Paul Bourke. This one uses a "string re-writing system" to draw both monster curves, trees, bushes, etc.

Davenport, Ben, *Julia's Nightmare*.

An impressive PowerPC fractal program allowing you to morph Julia fractals in real time.

Eberhardt, Thomas and Marc Parmet, *The Beauty of Fractals Lab*, Springer-Verlag. ISBN 3-540-14205-3.
A commercial fractal program for color, 68K Macs. It supports multiple windows, draws both the MandelClassic and JuliaClassic fractals, has a slick palette editor, and does an outstanding job drawing 3D fractals. Unfortunately, that is about all it does.

MicroSpot *MacPalette*, 20421 Stevens Creek Blvd, Suite 240, Cupertino, CA, 95014. (408) 253-2064.
Uses dithering to allow full color images to be printed on an ImageWriter II. A free demo is available.

Munafo, Robert, *Super MandelZoom*.
An older but still very nice black and white fractal program. It's lacking some important features but it has a very nice Mac-style interface and is very fast.

Nelson, Doug, *FDesign*.
An IFS program for IBM compatibles. I've never used this program but I have heard that it is excellent. It allows the user to construct IFS fractals using a mouse.

Platt, Dave, *MandelZot*.
A free fractal program for 68K Macs. It supports multiple windows, has a powerful palette editor, and draws several different fractal types.

Smith, Adam, *Floating Fractals*.
A fast, rather cool, program for 68K and PowerMacs.

Tyler, Bert, *Fractint*.
The fractal program for IBM compatibles. Bert wrote the original program and then released the code so other programmers could make additions. After several years of collaborative effort the program has grown into a true monster. It draws almost every fractal known to man and includes many different features.

Tyler, Bert, *Winfract*.
This is a subset of Fractint with an MS-Windows interface grafted on.

Books

Barnsley, Michael, *Fractals Everywhere*, San Diego: Academic Press, 1988.
This is an excellent text book about fractals suitable for junior or senior year mathematics students. The bulk of the book is devoted to iterated fractal systems (IFS fractals).

Devany, Robert and Linda Keen, eds, *Chaos and Fractals: The Mathematics Behind the Computer Graphics* Providence, RI: The American Mathematical Society, 1989.
> A book for professional mathematicians delving into strange attractors, Julia sets, the Mandelbrot Set, and IFS fractals.

Gleick, James, *Chaos: Making a New Science*, New York: Viking, 1987.
> An excellent popular account of the rise of the sciences of complexity.

Jones, Jesse, *Fractals for the Macintosh,* Corte Madera, CA: The Waite Group, 1993.
> This is a very cool book I wrote about Mandella.

Mandelbrot, Benoit, *The Fractal Geometry of Nature*, New York: W.H. Freeman & Co., 1983.
> This is Mandelbrot's attempt to show that much of the real world is fractal-like. This is not an easy book to read. It will be especially daunting for the mathematically unsophisticated. There are, however, lots of neat pictures.

Pagels, Heinz, *The Dreams of Reason: The Computer and the Rise of the Sciences of Complexity*, New York: Simon and Schuster, 1988.
> An interesting and wide-ranging look at how computers are revolutionizing the sciences.

Peitgen, H. O. and P.H. Richter, *The Beauty of Fractals: Images of Complex Dynamical Systems*, New York: Springer-Verlag, 1986.
> Lots of beautiful color plates and black and white figures of various fractals. There is also an appendix listing the coordinates and constants used by the color plates and many of the figures.

Peitgen, H. O. and P.H. Richter, eds, *The Science of Fractal Images*, New York: Springer-Verlag, 1988.
> This book contains a wealth of detail on various algorithms for generating fractals. However, it's targeted for a rather advanced audience and can be difficult to understand.

Pickover, Clifford, *Computers, Pattern, Chaos and Beauty: Graphics from an Unseen World*, New York: St. Martins Press, 1990.
> This is a really great book. Pickover covers a wide range of applications for computer graphics. His topics include: fourier series, image processing, fractals, chaos, spirals, and lots more. There are gorgeous pictures on nearly every page and Pickover includes algorithms for nearly every topic he discusses.

Pickover, Clifford, *Computers and the Imagination: Visual Adventures Beyond the Edge*, new York: St. Martins Press, 1991.

Like the book above, this book covers a large number of very different topics. Unlike the above book, there is little for the hacker who wants seeking algorithms for new graphics.

Rietman, Edward, *Exploring the Geometry of Nature*, Windcrest Books, 1989.
This is an easy introduction to chaos, strange attractors, and fractals. It's aimed at readers with a background in Calculus and includes many programs written in Basic.

Stevens, Roger, *Fractal Programming in C*, Redwood, CA: M&T Publishing, 1989.
This book seems to be aimed at beginning programmers who wish to write a fractal program. Half of the book is devoted to fractals curves like the Hilbert curve and the von Koch snow flake. The remainder covers the basics of drawing Mandelbrot, Julia, Newton, and IFS fractals.

Wegner, Tim and Mark Peterson, *Fractal Creations*, Mill Valley, CA: Waite Group Press, 1991.
Lots of neat color plates and black and white figures of various fractals. There is also an appendix listing the coordinates and constants used by the color plates and many of the figures.

Magazines

Algorithm, P.O. Box 29237, Westmount Postal Outlet, 785Wonderland Road, London, Ontario, Canada, N6K 1M6.
This is a small magazine started by Dewdney after he left *Scientific American*. It covers the sort of material his Recreational Computing column used to cover.

Amygdala, P.O. Box 219, San Cristobal, NM, 87564.
This is a newsletter about the Mandelbrot set and other fractals edited by Rollo Silver. It contains programming tips, new fractal types, alternate draw styles, program reviews, and book reviews.

articles

Barnsley, Michael, "A better way to compress images", *Byte*, Jan 1988.
A fascinating look at how Barnsley's company, Iterated Systems, is using fractals to compress images so that they are thousands of times smaller.

Dewdney, A.K., "A computer microscope zooms in for a close look atthe most complex object in mathematics", *Scientific American*, August 1985.
This is the article that started people writing fractal programs for micro-computers. It covers the Mandelbrot Set, "the most complex object in mathematics".

Dewdney, A.K., "Beauty and profundity: the Mandelbrot Set and a flock of its cousins called Julia", *Scientific American*, Nov 1987.
This is a follow up to the above article. It contains some additional discussion on the Mandelbrot Set and describes Julia sets.

Goldberger, Ary L., David Rigney, and Bruce West, "Chaos and fractals in human physiology", *Scientific American*, Feb 1990.
A fascinating article on how fractals and chaos apply to the human body. They present data showing that a healthy heart beats in a chaotic rhythm. On the other hand, diseased hearts beat in a periodic or completely random fashion.

Rothman, T., "God takes a nap", *Scientific American*, Oct 1988.
Describes Pluto's chaotic orbit.