

# Antplot: Visualising Long Binary Strings Using a Variation of Langton's Ant

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## Abstract

*Langton's ant is an interesting example of cellular automata, displaying both chaotic and emergent behaviour. This paper presents a simple integer-based numeric expression which generates the trajectory of Langton's ant on an infinite plane, and extends the technique so that binary strings of arbitrary length can be represented graphically. Patterns created by applying this technique to the mathematical constants e and pi are presented, together with those for a selection of long factorial and reciprocal values.*



## 1. Introduction

In its simplest form, Langton's ant moves across an infinite grid one square at a time, changing direction at every step according to the colour of the square it lands on. If the square is white, the ant changes the colour of the square to black and turns  $90^\circ$  to the right. If the square is black, the ant changes it to white and turns  $90^\circ$  to the left. Wikipedia has an animation which demonstrates the first few steps taken by the ant on an initially white grid, as well as an image of the trail left by the ant after 11000 steps [1].

The algorithm executed by the ant is quite a simple one, and it is not too surprising that it generates several symmetrical patterns for the first 475 hundred steps. However, the ant then traces a largely chaotic path up to the 9977<sup>th</sup> step, and thereafter it settles into a pattern which repeats every 104 steps. On an unbounded plane, this pattern repeats to infinity.

For the purposes of illustration, it is convenient to plot the ant trail on a non-white background, treating any squares which the ant has not yet visited as if they were white (thus when the ant lands on an unvisited square, it changes it to black and turns

right). This allows the full extent of the ant trail to be seen; otherwise the squares left as white by the ant would be indistinguishable from the ones it never visited. Figures 1 to 3 show the trail left by Langton's ant against a blue-grey background.

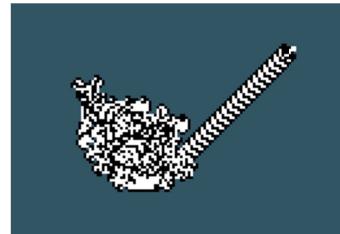


Figure 1: Langton's ant trail after 12000 steps



Figure 2: First 9977 steps of Langton's ant



Figure 3: 9978<sup>th</sup> to 12000<sup>th</sup> steps of Langton's ant

C.G. Langton originally devised his Ant as a part of his work on artificial life [2]. There have been numerous extensions to the basic algorithm based on multiple colours, bounded grids, multiple ants colliding with each other, and similar automata known as Turmites, but this discussion will be confined to the path taken by a single black-and-white ant.

The behaviour of the individual ant is far from intuitive. It obeys simple rules, yet traces an apparently chaotic path, then suddenly adopts a repetitive pattern which it follows for the remainder of its track as far as the grid allows. Could any mathematical construct other than the algorithm for 2-dimensional movement of Langton's ant produce identical behaviour?

Researcher Graham Medland has achieved just that by moving the ant on the surface of a torus instead of an infinite plane [3]. The sequential output of the algorithm is mapped to the grid using modulo arithmetic. This is similar to the way in which linear video memory addresses are sometimes mapped to a computer screen, i.e. going off any edge of the screen brings you back on the opposite edge. Interestingly, the expression which generates the ant trail takes the form of a wave equation. A script which implements the algorithm is available on Medland's website [4].

In this paper we explore a simpler mathematical expression for the path of the ant, expressed as a ratio of two integers. In an attempt to make sense of the result, the algorithm for Langton's ant is adapted so the large numbers involved can be visualised. This algorithm is then applied to a variety of other long numeric strings, with some interesting graphical results.



## 2. An Integer Expression for Langton's Ant

Take the first step of the ant as the most significant bit of a binary number; the second step as the next most significant, and so on. Where a pixel is turned black we set a 1, and where it is turned white we set a zero. The path of the ant thereby generates a string of 9977 bits with no obvious pattern, followed by a repeating string of 104 bits which carries on to infinity. Any infinitely recurring pattern of digits represents a rational number; we should therefore be able to express the path of Langton's ant as a ratio of two integers.

Let the string of binary digits representing the path of the ant be given the symbol L. If we choose to put the binary point after the first 9977 steps, then the part of the ant trail shown in figure 2 will generate a 9977-bit integer, which we call  $L_i$ . The remainder of the ant trail, as shown in figure 3 (but extended to infinity) is a binary recurring fraction which we call  $L_f$ . So:

$$L = L_i + L_f \quad (\text{Equation 1})$$

Conveniently, the recurring pattern in  $L_f$  is 104 bits long, which is exactly 13 bytes. In hexadecimal, the sequence of bytes is:

0x4F279E5E87B785EF0BD30CF349

The value of the fraction which has this recurring pattern can be found by dividing the above number by the following hexadecimal value:

0xFFFFFFFFFFFFFFFFFFFF

Both these integers are less than 128 bits long, so it is easy to use an online calculator to obtain the prime factorization of each. By doing so, we find that the highest common factor of both integers is 5. Since we only need the ratio of the two integers to calculate  $L_f$ , we can divide each by 5 to get:

$$L_f = C / B \quad (\text{Equation 2})$$

Where:

C = 0x0FD4B9461B24B463025D68FD75

and

B = 0x33333333333333333333333333333333

Combining equations 1 and 2, we get:

$$L = L_i + (C / B)$$

This can be re-expressed as:

$$L = (B \cdot L_i + C) / B$$

which we can write as:

$$L = A / B \quad (\text{Equation 3})$$

where:

$$A = B \cdot L_i + C \quad (\text{Equation 4})$$

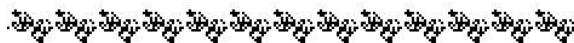
Equation 3 gives us an expression for the trail of Langton's ant as a ratio of two integers. The values of B and C given above have been used in equation 4 to give the following hexadecimal value for A:

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631812FC2C6A4B463025F9D8EC9530D6622F8EECA6FFBEE4D8B9CFDA4198639
A46F4EAD08E488FA8D20FC4527738D23960890DF7CE86F9FCEED173D9C3910
889C1241B66817021AA1PDE6167470B569FF31ED9BCCFE0CB95CB4E51CFE9C9
339D185834ECC6C85200113B28E958173CFF0CA14F938AF7660D1F1
1A0575D2C72E294C457AC6C8520013B28E958173CFF0CA14F938AF7660D1F1
83874F4E564B4728A6EDF82B6FB7ABE9A86B856783B35FC01DA63B870E48FEC4
3D0BC2F7050B62E7090572ZD35F1246195F33E82B6AAE223B1BCA6ECA85C6B1
4D99BDSF9BEA7E0C5219A7EAAACD36798E6PD3DC91A2727AC47AC262AB9224
1ED7E8860C19A056CABE4A41C34D26BCA65E450CBED062383E98A3969034
EE5B1CD1869C8204886BC63A7B1E2C21CF61699CE13D73F7E39E05729E40FAC
F7D39DF879A302843DC17BD8AC75FFF1E4A0D0F86EA39489267191E3B85D67
B62AB8F8846D8E125A0872B3C8BEE020C3CA9DAB610C27C5E99F5D31P30A
5401191CDEA91821E9456AAE3104D6553E0BB6DAAE285414D7DFFCS5D681D286
E5AFFB9820D57328348B3D5422A2E2F62A02711BD24FB74A9044111BDED8A6
2082B2F055981E6C6B8D303B42687B6C3EF272F65A983063A16F96FF51669
16ED4946658C145D128154C3E33B2501742C80E2CDCCE57C82D5EEF8479201DD
60040B17BEB4AC4D114048336F095AA164ABF0623C95CEA23EAA62BC2B73TC08
8437201B2B49BDF574FADA2079B6007DA2D40CC1B375694916F7E3AFD6
0700AA240910DC2AE2CFS835BBDC581A4A02D8020573F8483B5ECD579A9B3B
880104291055BC76365D482D35F1246195F33E82B6AAE223B1BCA6ECA85C6B1
AC85C958B64E523496886F57D35D76AFC0766B803B4C77OE2FAED1C7B5D
CC744B5E2388EEA2A8DC9F8BA0D7A0C5999B228A83B53148964B5FD5D58F34E24F
9E3CFB238EEA2A8DC9F8BA0D7A0C5999B228A83B53148964B5FD5D58F34E24F
AEA0AD513F0A94CB9021E2B167C2841B8A0D1823C87C9CA81B638E8469D2C87
D0BA8C427FACA5B8A659D23983A0658E67CCF176B5110A28A88E3A62F066D
13D7D7BD99067054D4415C7784FD6D21F93761CDEC1D42BE725D39CE88BF74F
7DDF2666G985B32S8156841617E100DBD921BCEA5BB6943A086C5D2B5A7F7449C094
292A4642E10855541617E100DBD921BCEA5BB6943A086C5D2B5A7F7449C094
9665A1679A7E8440E7750215F0BDBE83B6FD337687959994820E94892789CAA
499ACD73082D7910E4B25ECB181475F0382F4A616F4ED7A047941F43D48C1L0
6C950F4F69F53CA401965F63396406AD4F5AEEA6E7CE1FDF02A145834EFD8
28B05B35FA40F907B8C2548D7E389F4221F46B86159C93E83F38E0C990C93
96AF44B0A15862295DEC18BD91D7FDCC335B14E1C065A7A1F13AB5A8D37B484
20162A1C22DA1C133396B3A4AFC536BC28196E32D849992E89431431659
2D0D5C989E1ACCA2662926B98EC0A82B807A7B6655F6694A729B4B9E0B8C
EE0A77C6D6E5836865890162E2F5C4EACF27706D3F5560544ECA3FB8E0A3F5
E62D6EDC5E36DCD2393ACD7581C048837246B0856A1E69858F93A6562777C492
77C9B593B16E0CB9F11A056C5FFD60A0F99025C342C35908A232D85F06714
040AEB85PC6D23D1AE300D64B8ADB037C01B1CA890B9BFBC6E6FAD77BAE4EA7
10DD5266883B155D962345D

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This is an enormous integer (2520 hex digits) which makes for tedious reading. In decimal, its value is approximately  $9.336064 \times 10^{3033}$ . However, any patterns within its string of digits would be of interest. In the following sections, a graphical method is developed for verification of the value of A, and this same technique is then used to look for patterns within its value.



### 3. Verification of the Integer Expression for Langton's Ant

In order to verify that we have the correct values for A and B, we can use their values in equation 3, and see if the value we compute for L corresponds to the trail of Langton's ant. Doing this graphically requires a subtle but important modification to the plotting algorithm. Instead of controlling the ant direction and shading according to the previous colour of each square, we need to use the individual binary digits of an input value. If the input bit is 1, the ant shades the square black and turns 90° to the right. If the input bit is 0, the ant shades the square white and turns 90° to the left.

If we compute the value  $L = A / B$ , and feed the binary digits of L into the above algorithm, the output shown in figure 4 is obtained. The trail of Langton's ant is faithfully reproduced, with the length of the repeating pattern limited only by the arithmetic resolution to which the computation is performed.

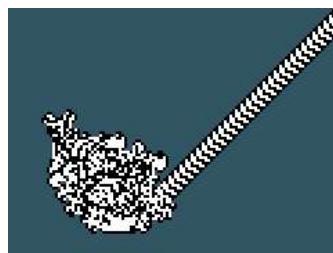
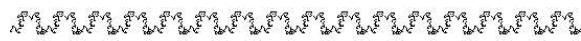


Figure 4:  $L = A / B$



### 4. Visualisation of Binary Strings

The algorithm developed in section 3 takes a 1-dimensional binary string as input, and generates 2-dimensional graphical output. We call this output the

antplot of the binary string. So far we have applied the algorithm to our calculated value of L, but what happens when we apply it to other values?

The obvious next choice of candidate for an antplot is the value of A. So far we have only viewed this as the long hexadecimal string in section 2. Using the antplot algorithm on the value gives the output shown in figure 5.

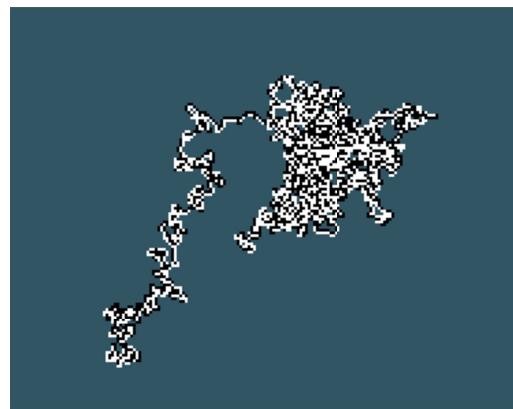


Figure 5: Antplot of A

What does this tell us about A? It is disappointing that there are no obvious patterns in the antplot; neither does the trail for A resemble the trail of Langton's ant. It is perhaps notable that there is a long narrow part of the trail leading to a patch which resembles a butterfly or flying squirrel, but antplots of numerous random binary strings have yielded similar forms. The tendency for observers to perceive objects in random patterns is known as pareidolia, as used to good effect in Rorschach inkblot tests. Further examples of antplots resembling familiar objects are presented in later sections.

For completeness, the antplot of the value B is presented in figure 6. The value consists of the hex digit 3 (or the binary digits 0011) repeated 26 times, so the ant makes pairs of right and left turns, and shades the squares appropriately leaving the trail shown.



Figure 6: Antplot of B



## 5. Antplots of Factorials

In an attempt to apply the antplot algorithm to other finite-length numeric strings, software has been written to generate factorials of integers up to about 20000. Only a small fraction of these factorials have been plotted, and almost all of those that have appear as fairly amorphous blobs, similar to antplots of random strings. However, a few have given notable results.

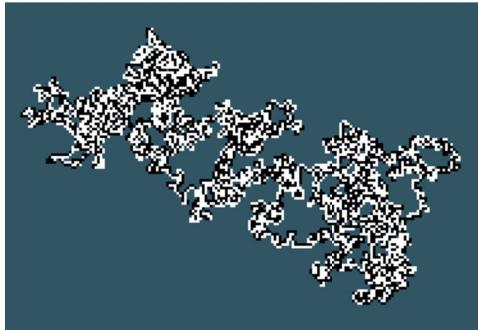


Figure 7:  $2047!$  or  $2048!$

The software increments an integer value and produces the corresponding factorial plot each time a key is pressed. Whenever the value is one less than a power of 2, it is observed that the antplot of the next factorial is identical. For example, the antplot shown in figure 7 is obtained for the factorials of 2047 and 2048.

The reason is that  $2048!$  is equal to the value  $2047!$  multiplied by 2048. Multiplying any binary value by a power of 2 is equivalent to shifting its digits to the left. This demonstrates that the antplot of any number depends only on the pattern of digits within it, and is not related to the magnitude of the number.

There is no obvious symmetry in any of the factorial antplots viewed so far for values above 5. Very few factorial antplots resemble any recognisable objects from the real world, probably due to this lack of symmetry. The only examples of pareidolia in antplots of factorials encountered by the author are shown in figures 8 (a dinosaur?) and 9 (a person kicking their leg?).

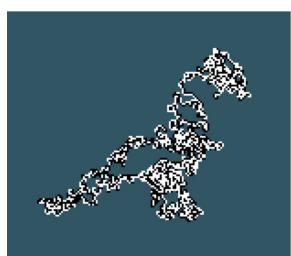


Figure 8:  $941!$

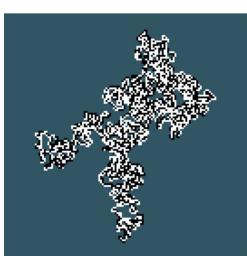


Figure 9:  $1316!$

It is worth noting that the direction taken by the ant at the start of the plot is arbitrary (up, down, left or right). Changing the initial direction could, for example, cause each of these figures to be rendered upside-down. Looking at the shapes in any other orientation tends to reduce or eliminate the pareidolia, demonstrating how arbitrary and subjective the phenomenon can be.



## 6. Antplots of e and Pi

So far the results presented have been for finite-length values, except for the recurring fraction calculated to prove the expression for Langton's ant as a ratio of two integers. In this section we turn our attention to two infinitely long irrational numbers.

Other graphical attempts have been made to find recognisable patterns in mathematical constants such as e (Euler's number) and pi. One method uses each digit of the number to control the angle through which a "turtle" turns at each step [5]. The turtle is a plotting device equivalent to our ant. The technique can be applied using any number base from 3 upwards. This is because the angle of turn is always a multiple of  $360^\circ$  divided by the number base. Using binary, the turtle would only turn forwards and backwards along a straight line.

In contrast, the antplot algorithm only works on a binary input string. Values for e and pi have been calculated to a length of over half a million bits, or decimal accuracy of nearly 158000 digits. The corresponding antplots are shown in figures 10 and 11.

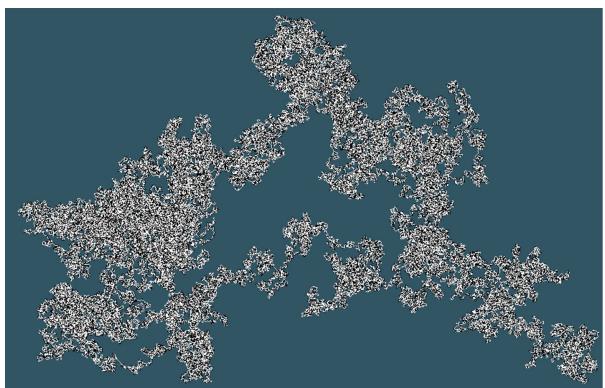


Figure 10: Antplot of Pi

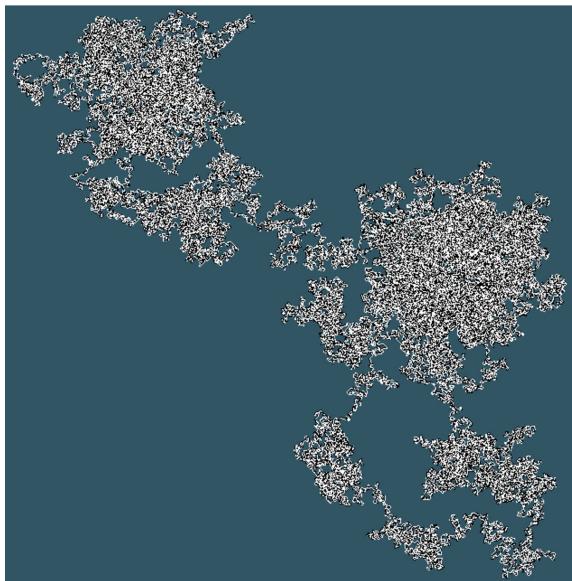
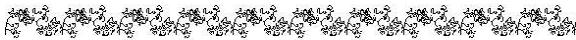


Figure 11: Antplot of Euler's number ( $e$ )

Like the antplots for most factorials, there are no instantly recognisable patterns. The antplot trails for  $e$  and  $\pi$  are not easily distinguishable from those for random bit sequences of similar length.

It must be remembered that the antplots in figures 10 and 11 are only for the first half-million or so binary digits of  $e$  and  $\pi$ . Extending the plots using more and more digits of precision could result in the ant trail looping back and overwriting what is already there. In such cases, the antplots obtained might not resemble the ones shown here. Similarly it is possible (though unlikely) that patterns have already arisen early on in the antplots, but these have been overwritten by later movements of the ant, so they are hidden in figures 10 and 11. There is no right answer for how long the plots should be to try to find patterns in irrational numbers.



## 7. Antplots of Reciprocals

Rational numbers are far more likely than irrationals to yield patterns in their antplots. The software which steps through factorials has been modified to step through reciprocals instead, resulting in antplots with much more structure and symmetry.

Antplots of reciprocals fall broadly into two types:- those which step-and-repeat to form lines which go off to infinity; and those which loop around to cover a finite area. Whether the antplot for the reciprocal of an integer forms a line or a loop

depends wholly on the length and bit values of the recurrent pattern in the reciprocal value.

### 7.1 Line Antplots

A selection of line antplots is shown in figure 12. The first two cases are very simple patterns. The third case looks like a spiral; in fact it is interesting how the antplot algorithm seems to shade the pattern to suggest a 3D shape. Numerous other values also give spiral patterns in their reciprocal antplots. In the fourth case ( $1/39893$ ), the ant steps and repeats a complex shape due to the relatively long recurring pattern of the fraction. The repeating motif resembles a bird of prey. The final example in figure 12 resembles a line of motorbike riders.

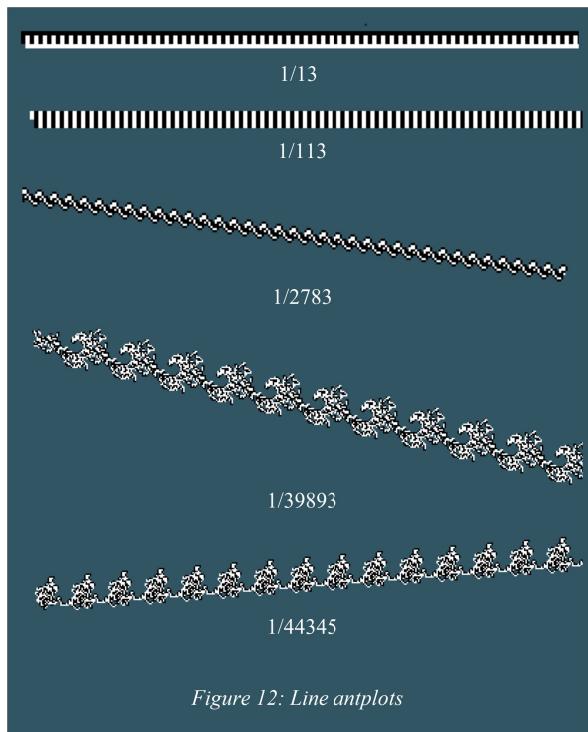


Figure 12: Line antplots

The separators between sections in this document were created from antplots of various reciprocals made against a white background. This leaves only the black squares visible.

In some cases the path of the ant is such that a repeated motif overwrites previous iterations of itself. This gives rise to the kind of effect shown in figure 13. Note the reflective symmetry of the repeated motif, as well as the fact that the black and white pixels are swapped in each half.

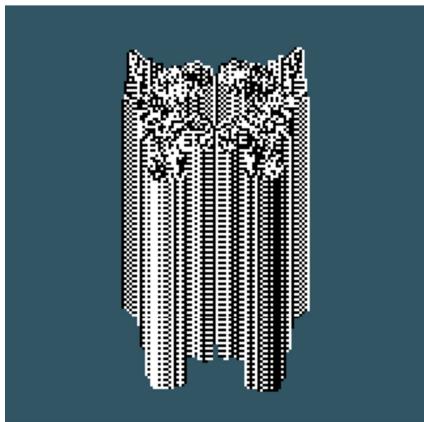


Figure 13: 1/84097 (Angels ascending?)

A similar phenomenon gives rise to the effect seen in figure 14, where each half of the line is entirely black or white, except for the edges. It may seem strange that this is generated by an ant which changes direction at every pixel, and colours it black or white according to the direction of turn. However, examination of just the first few hundred steps of the ant (figure 15) shows that the line is formed by a symmetrical shape which is replicated one pixel left and one pixel up at each step. This leaves the two halves of the line shaded as shown in figure 14.

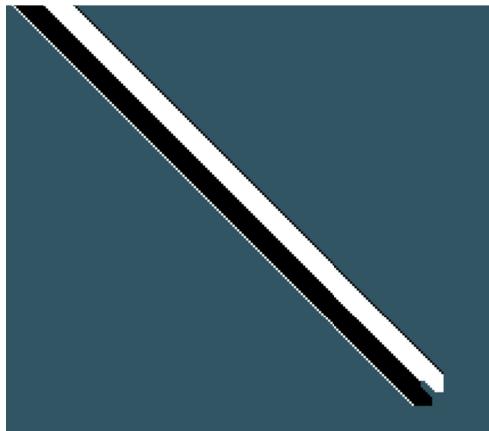


Figure 14: 1/16291



Figure 15: 1/16291 after 627 steps and 1918 steps

## 7.2 Loop Antplots

Many integers have a pattern in their reciprocal value which causes the ant trail to loop back on itself. Figure 16 shows a selection; these examples and many others show a rotational symmetry of order 4, which we might expect from the rules for movement of the ant on a square grid. There is a surprising degree of intricacy and texture in the figures though.

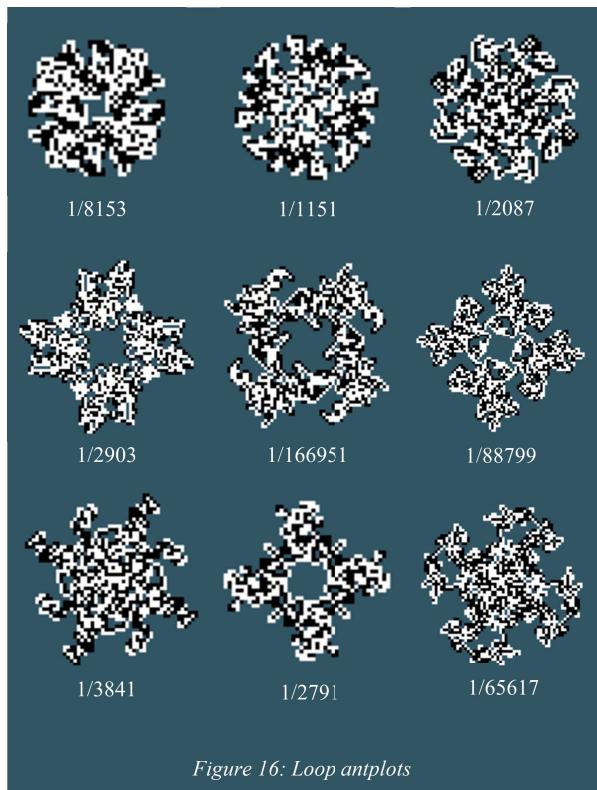
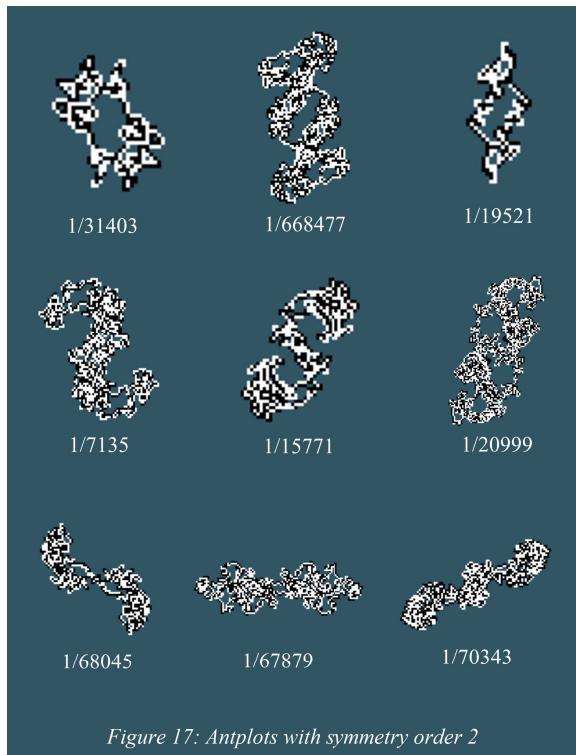


Figure 16: Loop antplots

All the labels shown on antplots in this document are the smallest integer values which will produce each pattern. Any power of two multiplied by the integer value will produce the same bit pattern in the reciprocal, and therefore the identical antplot, as explained in section 5.

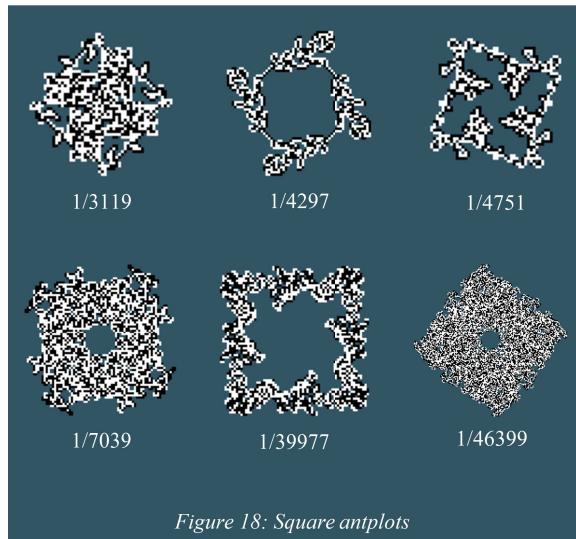
In some cases the antplot trail displays symmetry of order 2. A selection of these is shown in figure 17. It is a curious coincidence that the reciprocals of 7135 and 20999 both seem to generate an italic letter 'f', or an 'S' with an angled ring around its centre.



*Figure 17: Antplots with symmetry order 2*

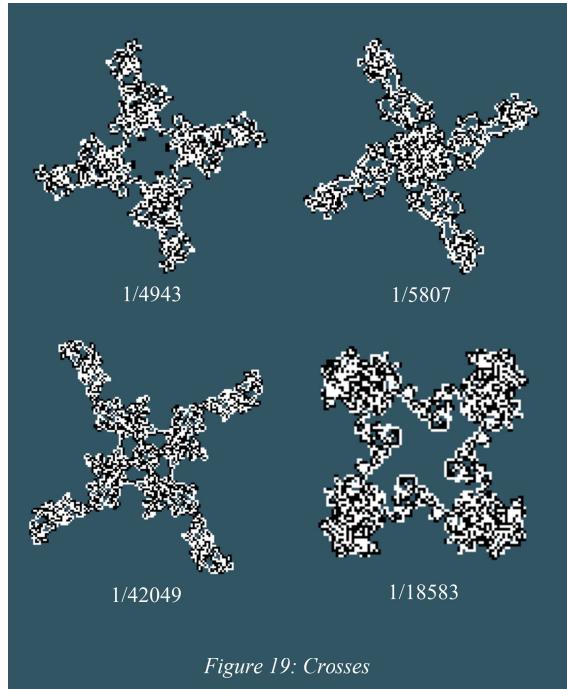
As yet no obvious relationship has been observed between integer values and whether the antplots of their reciprocals will produce lines or loops. Similarly it is not obvious from integers whose reciprocals produce loop antplots whether the plot will have order 2 or order 4 symmetry. It so happens that all the integer values used in figure 17 (order 2 symmetry) are non-prime, but those in figures 12 and 16 are mixtures of primes and non-primes.

When an antplot forms a loop with symmetry of order 4, it is often the case that the outline is close to being a square. Several such cases are shown in figure 18.



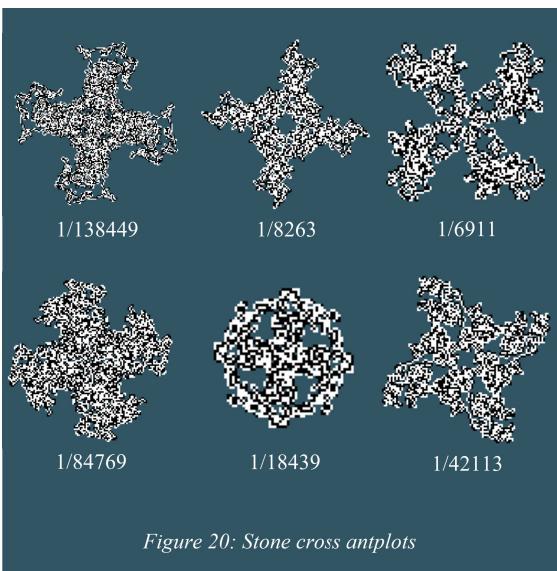
*Figure 18: Square antplots*

The other shape most commonly formed by loop antplots with symmetry of order 4 is a cross. A number of variations are shown in figures 19 and 20.



*Figure 19: Crosses*

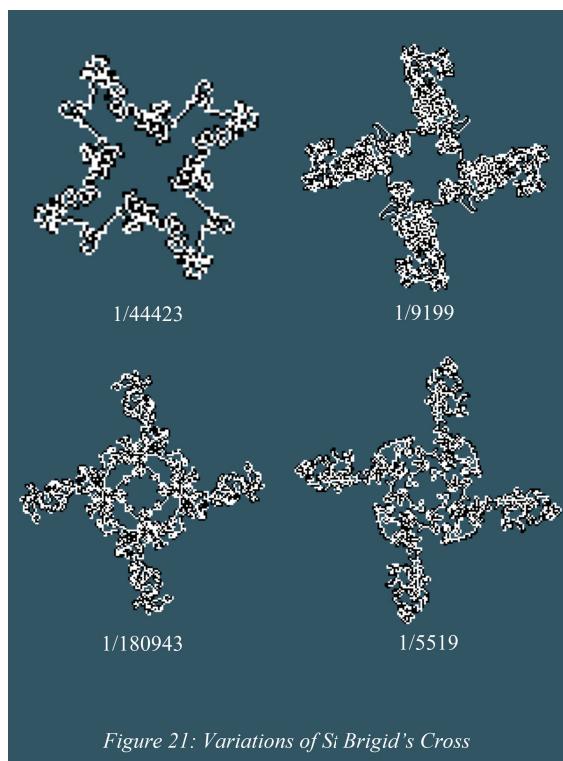
Figure 20 shows antplots which have been selected for their resemblance to ancient stonework. The close-packed black and white pixels give an impression of a rough granite-like texture, and an overall grey colour. Several of the shapes echo the form of Celtic or Anglo-Saxon gravestones; in particular the plot of 1/18439 resembles a Celtic cross.



*Figure 20: Stone cross antplots*

Another symbol which arises in stonework from ancient cultures is the swastika. It was mainly a symbol of good fortune or divinity long before its 20th-century adoption for political extremism. The antplot for the reciprocal of 271 (and power-of-two multiples of it) replicates the swastika very closely, though it is not reproduced here. In other cases (such as 32687, also not shown), the hole left in the middle of the shape is a swastika.

A similar shape is St Brigid's Cross; a cross with 4 off-centre arms, with Celtic or pagan origins. The shapes in figure 21 have been selected for their similarity to St Brigid's Cross. These antplots are also notable for a high degree of intricacy.



*Figure 21: Variations of St Brigid's Cross*

As in the case of the swastika, it is sometimes observed that the outline of one reciprocal antplot corresponds closely to the shape of the hole in another. An example of this can be seen where the outline of the antplot for 1/84769 (figure 20) is the same as the hole in the middle of the antplot for 1/5519 (figure 21).

The apparent similarity between antplots of reciprocals of integers and symbols from ancient history seems like a bizarre coincidence. However, there are very many more symbols from ancient cultures based on triangles and other shapes which antplots do not seem to generate.

Cross-shaped antplots probably resemble ancient artefacts due to similarities in the processes by which both are created. It is likely that ancient stonemasons

used a template to carve each quadrant of a cross, moving the template round 90° at a time to ensure rotational symmetry. The template is analogous to the recurring pattern of digits in a binary reciprocal. Suppose the recurring bit pattern is such that the ant traces it out and finishes pointing at 90° to its initial direction. The next 3 recurrences will cause the ant to trace the same shape arm in each quadrant, and each further recurrence will then overwrite what is already there with the identical pattern.



## 8. Software

The antplots presented in this document are a small fraction of those which can be generated. The author has spent many happy hours stepping through antplots in ascending sequences from integers chosen at random, and readers are invited to do the same, but be warned that the process can be addictive.

The source code of the software which generated all the antplots in this document is available to download [6]. It is written in Microsoft Visual C++, and makes use of certain intrinsic 64-bit functions, so porting to platforms other than x64 will likely require some modifications.



## 9. Conclusion

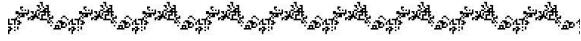
The antplot algorithm allows us to see patterns, if any exist, within long binary strings. It has been used to verify an integer expression for the trail of Langton's ant, but failed to show any interesting patterns in the values used in the expression.

Antplots of factorial integers, and of the irrational numbers e and pi, also failed to show any meaningful patterns. However, applying the antplot algorithm to rational numbers has provided a surprisingly rich set of graphical outputs.

Simple reciprocals of integers have been found to generate antplots of extraordinary complexity. Further investigation may establish a relationship between integer values and whether the antplots of their reciprocals form lines or loops. It may also be possible to relate values to the degree of symmetry in their reciprocal antplots.

Rational numbers other than reciprocals of integers can be expected to produce an equally rich set of antplots. The only one generated so far has

been the trail of Langton's ant from the ratio of two large integers. No single observer will ever be able to see all the reciprocal antplots, let alone those for all rational numbers. A vast space of visual patterns awaits those who wish to explore it.



## 10. References

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## Biographical Note

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