Using Fractals and *Turtle Geometry* to Visually Explain the Spread of a Virus to Kids: A STEM Multitarget Activity

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Abstract A lockdown was ordered in Spain on March 2020 due to the COVID-19 pandemic. The first author, advised by the second author, developed a tale and video (in Spanish) with a simplified explanation of virus propagation for their teenager son, justifying the need to stay at home. The tale and video relate the spread of the virus to fractal trees and aim to raise awareness about the transmission of the disease. The video is available from the web page of the *Instituto de Matemática Interdisciplinar* of the first author's university. The code was implemented in *Scratch 3* and takes advantage of the “Turtle Geometry” (there is an ulterior version using *Maple*, available from *Mapleprimes*). This article includes the English version of the original tale, describes the *Scratch 3* code, and details possible derived STEM activities. We plan to experiment them in the classroom during the 2020–2021 academic year.

Keywords Fractals · Epidemiology · Modeling and interdisciplinarity (aspects of mathematics education) · Computer science and society · Computer graphics

Mathematics Subject Classification 28A80 · 92D30 · 97M10 · 97P70 · 97R60

1 Introduction

1.1 Teaching Experience

The first author has taught computational mathematics to students of the School of Education of the *Universidad Complutense de Madrid* for 34 years:

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- within the frame of different subjects about using information and communication technology (ICT) in mathematics teaching,
- using different hardware¹ (Apple II, PC-AT, PC-386, PC-486,...) and languages:
 - * in the past: *Logo*, *Derive* and *The Geometer's Sketchpad*
 - * now: *Scratch*, *Maple* and *GeoGebra*

and also to postgraduates at the School of Mathematics of the same university along these years.

Meanwhile, the second author teaches at a School of Information and Communication Sciences of the *Universidad de Extremadura* and has a long experience in distance learning using different computational resources.

1.2 The Spark

We have a 14-year-old son that likes sciences and mathematics. In the beginning of the pandemic a lockdown of citizens was ordered in Spain. It is not easy to explain a kid of this age why he shouldn't meet his friends and relatives for some time and, even more, that he should stay at home.

Therefore we developed a simplified model and explanation of virus propagation [1] focused on the mathematical perspective (relating it to fractals) and social conscience.

The explanation is made visual by using the *Turtle Geometry* [2,3]. We believe that the almost forgotten *Turtle Geometry* still has many possible applications in different fields [4]. We developed in the 1990's *Pascal* [5], *Maple* [6] and *Derive* [7] implementations of the *Turtle Geometry*.

1.3 Development and Application

The simplified model of virus propagation was initially implemented in the computer language *Scratch 3* [8,9], that our son knew. It is well-known that *Turtle Geometry* is very well suited for drawing some kinds of fractals [2,10], and it is easy to implement a program that draws a fractal tree with any number of branches and any depth using it.

The number of branches can be related to the average number of animals infected by each ill animal and the depth can be related to the time that passes until the animals stop meeting each other. Moreover, the graphic cursor of *Scratch 3* (a cat) can be used to simulate the spread of the virus in a colony of cats.

This explanation was later recorded in a 5 minutes video and written in a tale (both of them in Spanish). Some colleagues liked the video and it is now available from the web page of the *Instituto de Matemática Interdisciplinar (IMI)* of the *Universidad Complutense de Madrid* [11].

The program has also been translated to *Maple* [12], using our implementation of *Turtle Geometry* [6] (that has a very good graphics resolution) and an adaptation of the tale is now available from *Mapleprimes'* web page [13]. The details and peculiarities of the *Maple* implementation were discussed after *ESCO2020* at the *Maple Conference 2020* [14,15].

The English translation of the original tale is included afterwards.

Although there are specialised papers relating virus propagation to fractals [16], we know of no other divulgation approach oriented to kids (or laymen in the topic).

As COVID-19 is a global pandemic, there are hundreds of papers on the topic. We could mention [17] as a summary of the different aspects of this disease.

The tale, together with the video are presented below as visual approaches to some STEM topics and a way to foster the awareness of the dangers of virus' spread.

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2 The Tale

An illustrated tale of fractals, cats and virus for kids

by

Eugenio Roanes Lozanoⁱ

Coco is a cat that returns sick to his town after a trip. You can see him in the photograph beside. He is suffering from a very contagious disease and he wants to meet his friends and family, since he has missed them so much. Coco doesn't know anything about *fractals*, he just wants to share some sardines with his family and to chase some mice with his mates later. Anyway, we'll use fractals and the computer language *Scratch* to show him why he shouldn't meet his family and friends, that he should remain isolated.

A fractal is a geometric object whose structure is repeated at any scale. An example in nature is Romanesco broccoli. Perhaps you have eaten it or have seen it at the market. There is a simple fractal in the following drawing: each branch is divided into two branches, always forming the same angle and decreasing in size in the same proportion. We could say that the tree drawn is of "depth 7" because there are 7 levels of branches.

Let us explain in a simplified way what happens if poor Coco meets his friends and family. In this illness a sick cat infects an average of two other cats. In all drawings Coco is in the center. If Coco has time to see his friends before all cats isolate themselves (but there is no time for Coco's friends to meet their friends), we have three sick cats:

If Coco meets his friends, and these in turn meet their friends before stopping meeting other cats (depth 2), the number of sick cats is 7:

If before isolation there is time for Coco to meet his friends once, these cats meet their friends, and the latter (friends of the friends of the first sick cat) meet their friends (depth 3) we have 15 sick cats...

At depth 4 we have 31 sick cats, and 63 sick cats at depth 5:

As you can see the illness propagates very fast. And the spread is faster if each cat infects an average of three cats instead of two. You have below the drawings corresponding to depths 1, 2, 3 and 4 (there are 4, 13, 40 and 121 infected cats, respectively):

And the growth is even faster if the average number of cats infected by each sick cat is 4 or 5: you have the depth 3 cases afterwards:

These are examples of what mathematicians call an exponential growth and it is clear that the higher the average number of cats infected by each sick cat, the worse the situation is.

Therefore, Coco should avoid meeting his mates and relatives for some time in order to prevent the illness from spreading... it is hard, but necessary. Anyway, many scientists are trying to obtain a vaccine for Coco's illness, so the cats expect to meet normally soon!

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Write to me if you want the code used.

Fig. 1 A fractal tree of depth 3 with 3 branches at each level. Note that, formally, the trunk of the tree shouldn't be drawn for the plot to be a fractal

3 The Scratch 3 Code

3.1 Drawing a First Fractal Tree

We would begin with a simplified example: how to draw a fractal tree with 3 branches at each level. In Fig. 1 you can find a tree of depth 3.

The *Scratch 3* code is simple (Fig. 2). The main procedure has two input:

- the depth of the tree,
- the length of the initial branches of the tree

and begins by clearing the screen and initiating the recursive subprocedure `Aux`.

Meanwhile, subprocedure `Aux` iterates the drawing of branches of the same level. If the depth of the tree hasn't been reached:

- moves forward the number of steps given by the second input to `Aux`,
- repeats three times:
 - turn $120^\circ = \frac{360^\circ}{3}$,
 - execute `Aux` with the first input increased in one and the second input (the length of the branches of the previous level) divided by two
- moves backwards the number of steps given by the second input to `Aux`).

3.2 Drawing the General Fractal Tree Used in the Tale

These procedures are slightly more complicated (Fig. 3). We have used another auxiliary procedure (`CS`), that clears the screen and resets the cat.

Fig. 2 Scratch 3 code that generates a fractal tree with three branches at each level and any depth

The main procedure has now three input (the average number of cats each ill cat infects by average is a new variable). *Scratch*'s cat is hidden to increase the drawing speed and stamped when it reaches a "leave" of the tree.

Aux procedure now includes a new conditional that avoids the cat to draw the "trunk" of the tree. And the angles to be turned are more complicated (360° divided by the number of branches and half this angle). Finally, the decrease in the length of the branches has been chosen to depend on the number of branches too.

4 STEM Applications

The tale and video have multiple STEM applications. Their initial goal was extracurricular: to foster the awareness of the dangers of virus' spread, and it is possibly their most important goal.

The implementation of Sect. 3.1 is appropriate to be reproduced by a Secondary School students or first year university students. Possibly, the implementation of Sect. 3.2 can be understood by many of such students. We planned to use this software with Secondary School students during the 2020–2021 academic year. Unfortunately, this hasn't been possible so far due to the restrictions derived from the pandemic. If the restrictions continue we'll use it with university students. The video was shown to a group of students from a pedagogy degree at the end of last academic year and was easily understood and very motivating [18].

The problem addressed has several STEM applications, that can be developed in the classroom:

Fig. 3 Scratch 3 code that generates the fractal trees reflecting the spread of the illness used in the tale

- revisiting angles' measures (mathematics),
- having a first glance to epidemics (biology),
- understanding what a fractal tree is (mathematics, computer science),
- relating fractal trees to structures in nature (biology),
- working with the *Turtle Geometry* (mathematics, computer science),
- understanding recursion (mathematics, computer science).

5 Conclusions

What began as something “for the family” has turned out to be a tale and video for a wider audience. Thinking more calmly about it, we believe it is eye-catching (and, therefore, motivating) for students of very different levels, and, moreover, has many different STEM applications.

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