
FractalComs

Workshop UPC - CIMNE

Universitat Politècnica de Catalunya

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BARCELONA

Workshop UPC – CIMNE

Related WP and tasks (from the Project Description)

WP3: Software simulation tool

Task 3.1: Advanced meshing of fractal structures

- b) Advanced adaptive meshing facilities will be developed for fractal domains (CIMNE). In a first phase, conventional meshing algorithms will be adapted to the requirements of the present project. In a second phase, the production of fractal meshes for the discretization of fractal domains will be evaluated and, if possible, the corresponding algorithms will be developed and coded.

Objectives

The objectives of the workshop were:

- Let CIMNE know the adaptive meshing needs for Fractal Antennas.
- Present the most basic concepts of Iterated Function Systems (IFS) to CIMNE.
- See what is possible to implement in GiD within the framework of the project. GiD is an advanced modelling and meshing software tool developed by CIMNE, that is available to all partners in FractalComs project.
- Establish the geometry parameters input for the new code to be developed in GiD.
- Define actions to do in task 3.1 b).

Iterated Function Systems (IFS)

Most pre-fractal structures can be built by using the concept of iterated function system (IFS). Every IFS iteration is defined by a set of Q affine transformations in the plane $\{\omega_q\}_{q=1}^Q : R^2 \rightarrow R^2$ which can be written as:

$$\begin{aligned} \omega_q(x) &= A_q x + t_q = \\ &= \begin{pmatrix} r_{q1} \cos \theta_{q1} & -r_{q2} \sin \theta_{q2} \\ r_{q1} \sin \theta_{q1} & r_{q2} \cos \theta_{q2} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} t_{q1} \\ t_{q2} \end{pmatrix} \end{aligned} \quad (1)$$

where x_1 and x_2 are the coordinates of point x . If $r_{q1} = r_{q2} = r_q$, with $0 < r_q < 1$, and $\theta_{q1} = \theta_{q2} = \theta_q$, the IFS transformation is a contractive similarity (angles are preserved) where r_q is the scale factor and θ_q is the rotation angle. The column matrix t_q is just a translation on the plane. Fig. 1 shows the Sierpinski fractal obtained from a single triangle after applying a set of transformations recursively.

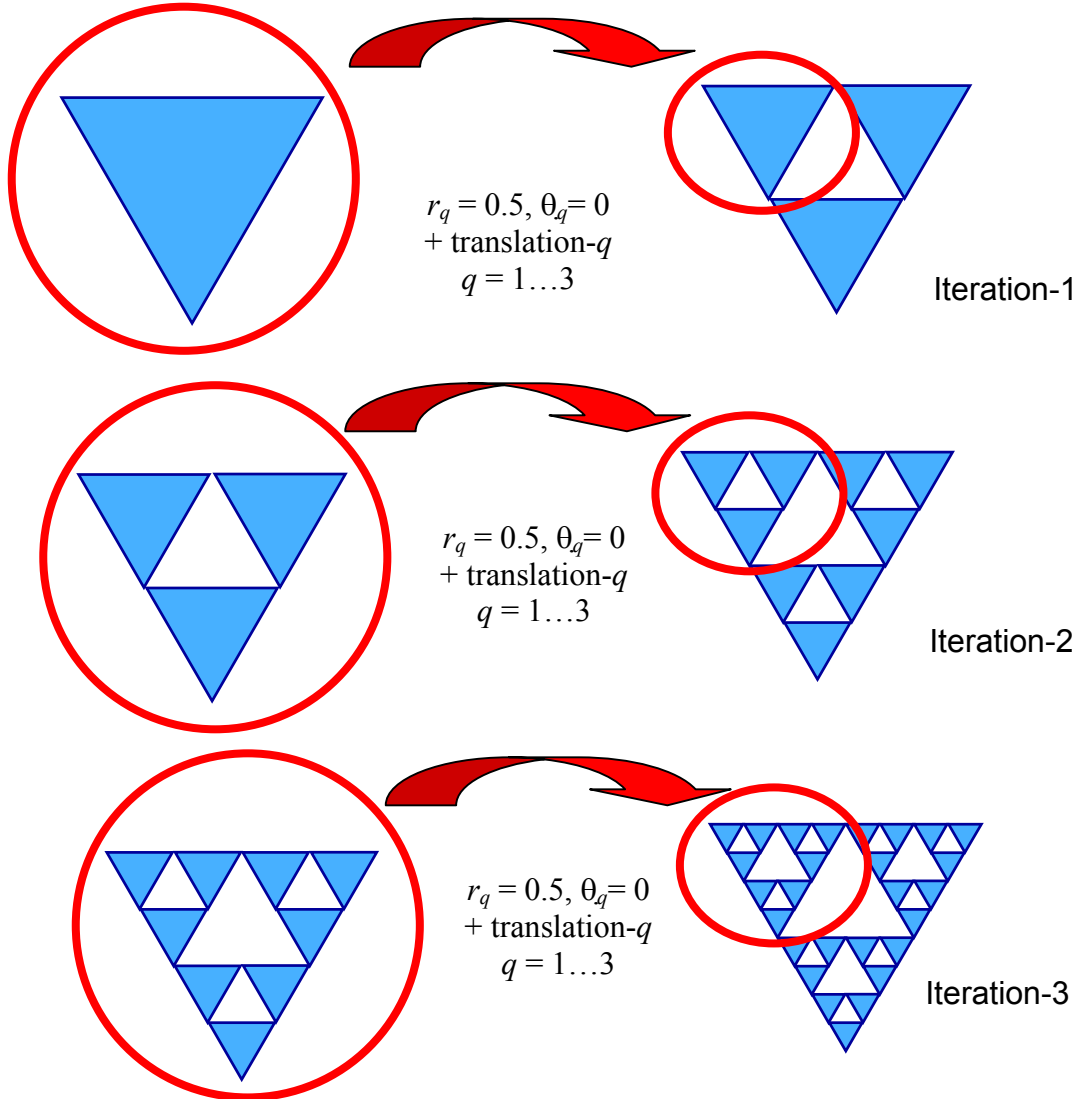


Fig. 1. Three iteration Sierpinski fractal obtained after a set of affine transformations.

Another example of pre-fractal surface structure generated by an IFS is the Koch island (Fig. 2). The surface is defined by three Koch curves. The initial segments of the Koch curves (iteration K0) are the sides of a triangle.

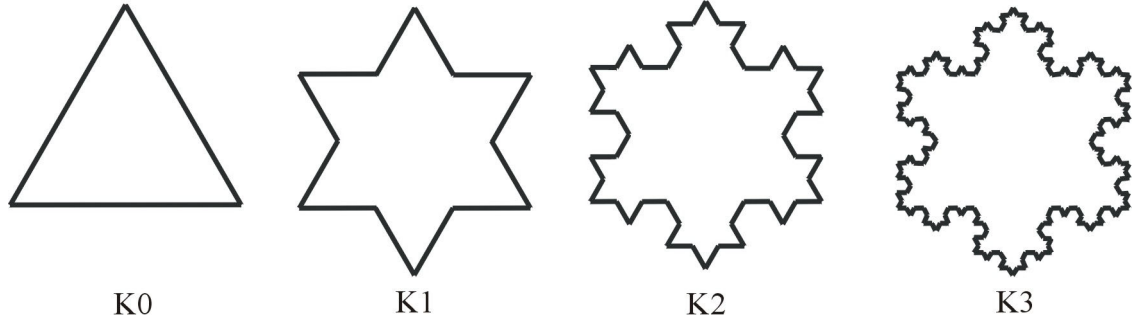


Fig 2. Koch island after three iterations

Element numbering

With the proper element numbering, that essentially results from assigning numbers to elements in the same order as they are created by the IFS iteration, the resulting linear system matrix has a very interesting block structure, as shown in Fig. 3. Submatrices 1A, 2A and 3A are identical. Besides, due to the recursive application of the IFS, each one of these submatrices has also redundant information: The diagonal blocks inside 1A, denoted as 1B, 2B and 3B, are also identical. The same can be observed in Fig. 3 c) for a finer level of zoom.

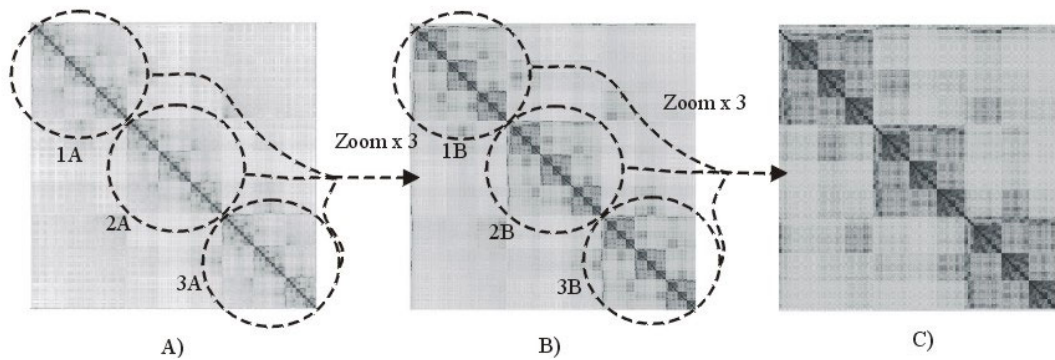


Fig. 3. Method of moments impedance matrix for a five iteration Sierpinski patch antenna. Grey scale shows the magnitude of the matrix elements. If the structure is generated by an IFS, the impedance matrix has plenty of redundant information: submatrices 1A, 2A and 3A are identical. Besides, due to the recursive application of the IFS, each one of these submatrices has also redundant information, as shown in images B and C.

Conclusions

GiD:

GiD is an advanced modelling and meshing software tool developed by CIMNE, that is available to all partners in FractalComs project. CIMNE is presently finishing the release of GiD version 7. The new fractal antennas adaptive meshing facilities will be implemented in version 7 after the official release.

Strip-wire fractal antennas:

Strip-wire antennas are strips obtained by extrusion of a Fractal curve in the direction perpendicular to the plane containing the curve, see Fig. 4.

Meshing this kind of structures is trivial. They will be modelled and meshed by MATLAB programs written by UPC. The models will be sent to UGR partner for simulation in the time domain.

Models and simulations of Koch monopoles will be presented at T0+6 progress meeting.

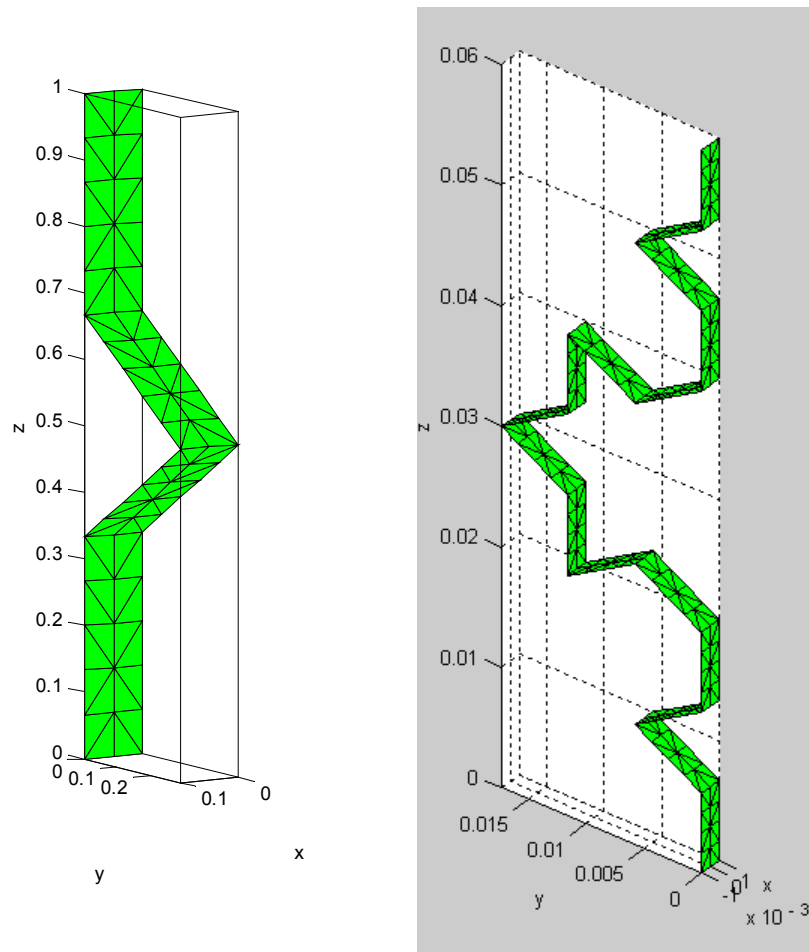


Figure 4: one-iteration Koch antenna (left) and two-iteration Koch antenna (right), both with the strip in the plane perpendicular to the Fractal curve

Strip Fractal antennas:

Strip antennas which have the strip in the same plane as the Fractal curve (usual printed planar antennas, see Fig. 5):

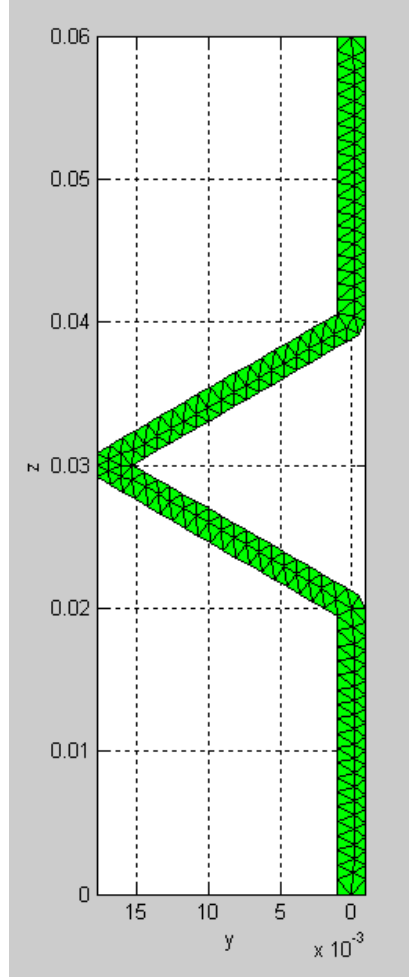


Figure 5: One-iteration strip Koch antenna with the strip in the same plane as the Fractal Curve. The model and the unstructured mesh have been generated with the present version of GiD.

Manual modelling and unstructured meshing of a strip Fractal antenna, like that of Fig. 5, is not feasible for FractalComs antennas simulation because:

- It is extremely tedious for a high number of IFS iterations
- The unstructured mesh of Fig. 5 does not result in a element numbering scheme that produces systems of equations where the matrix has IFS block properties (Fig. 3), which are essential for the optimisation of the simulation algorithms.

CIMNE will modify GiD for the automatic meshing of strip-wire antennas defined by an arbitrary IFS and an any number of iterations. The resulting mesh will lead to a system of equations matrix having the IFS block properties of Fig. 3.

The model and mesh input parameters will be, see Fig. 6:

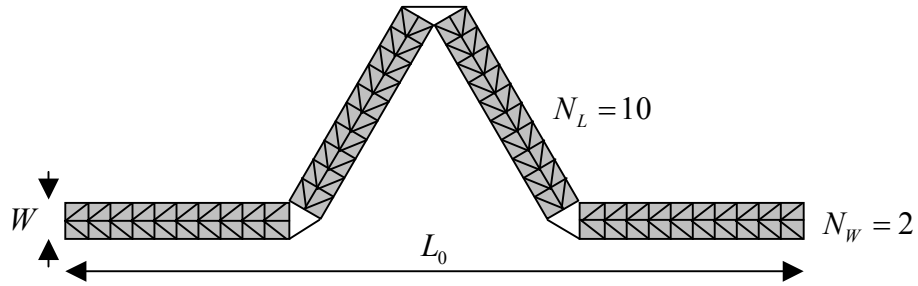


Figure 6: One-iteration Koch strip antenna (process of generation).

1. Initial segment length L_0
2. Strip width W
3. Number of triangles (number of nodes-1) along strip width ($N_W = 2$ in Fig. 6)
4. Number of triangles (number of nodes-1) along final segments length ($N_L = 10$ in Fig. 6)
5. Kind of strip bending (triangular or rectangular, see Fig. 7)

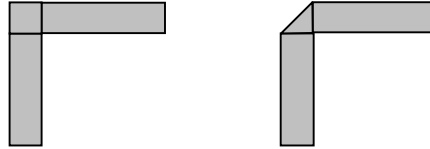


Figure 7: Kinds of strip bends

6. IFS definition parameters

The procedure to model and mesh the antennas will be:

1. Start with a rectangle meshed in $N_W \times N_L$ triangles and size $L_0 \times W$. At this stage, triangles will be very distorted.
2. Apply IFS transformations to the length-dimension of the rectangle. An additional contraction factor will be applied to the rectangles (wire segments) to avoid overlapping, taking care in connecting the rectangles by the corner nodes (see Fig. 6). After suffering a number of length-contractions equal to the number of IFS iterations, the mesh triangles will have a reasonable aspect ratio.
3. After all IFS iterations, the gaps at wire bends will be filled with rectangular or triangular patches (Fig. 7), and the patches will be meshed in $N_W \times N_W$ triangles.
4. Element numbering will be checked, and if necessary modified, for obtaining a linear system matrix with IFS block structure (Fig. 3).

CIMNE will do their best to have a mesh for at least the Koch strip antenna of an arbitrary number of iterations in early May, so that simulations are available for the T0+6 meeting in June.

Surface fractal antennas:

Surface fractal antennas, like the Sierpinski printed planar antenna of Fig. 1, need a triangle mesh having three important features:

- Connections between regions sharing a vertex, in order to allow the flow of electric current.
- Adaptive meshing in order to use smaller triangles to accurately model regions of the antenna with fast current variations.
- Element numbering scheme that produces systems of equations where the matrix has IFS block properties, which are essential for the optimisation of the simulation algorithms (Fig. 3).

Figure 8 shows a three-iteration Sierpinski antenna with uniform meshing. Some mesh triangles (marked in red color) have been added in order to allow the flow of current between different antenna regions. Note the small triangles at the feeding point in the coordinate origin (0,0).

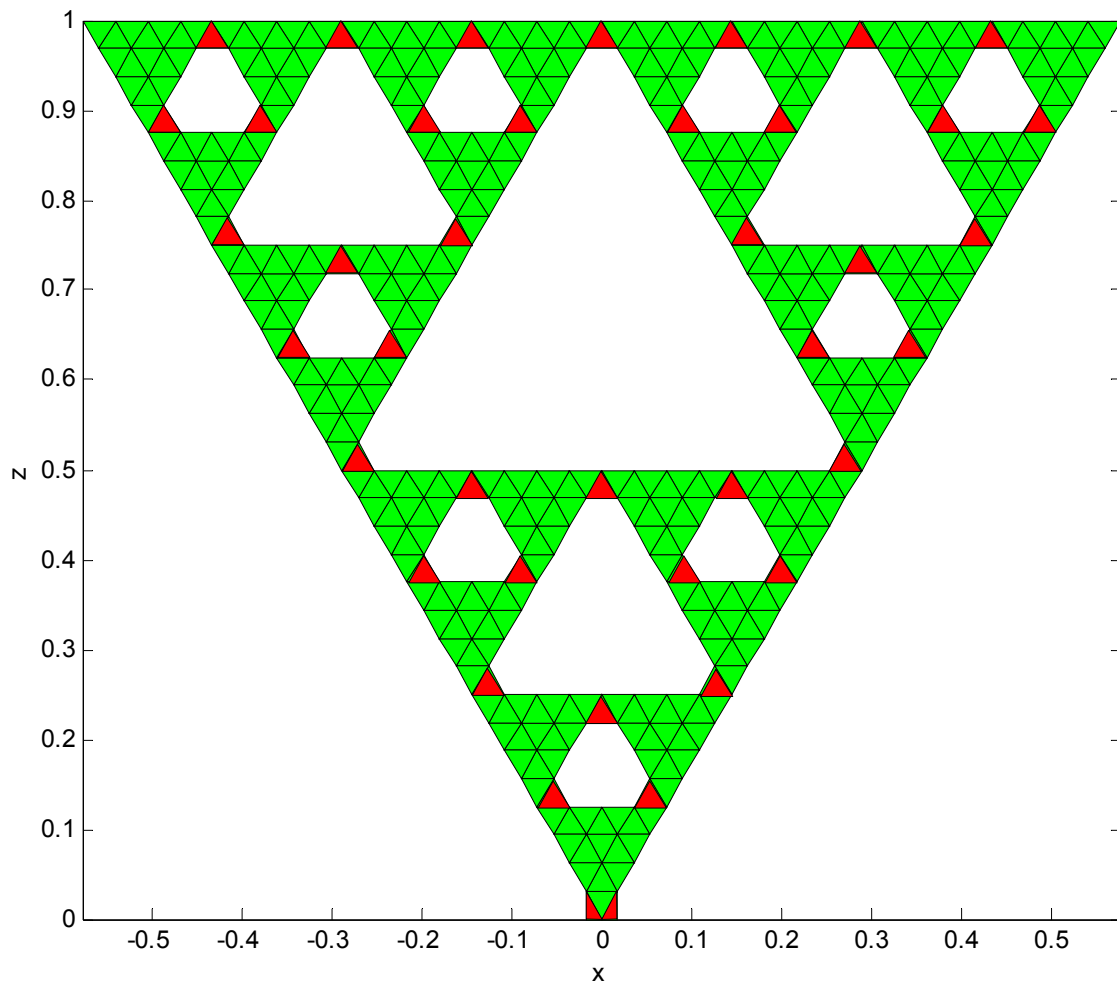


Figure 8: Three-iteration Sierpinski antenna with uniform meshing. Some mesh triangles have been added to allow the flow of current between different antenna regions (marked in **red** color). The number of triangles in this mesh is 473.

Figure 9 shows the same antenna with an adaptive mesh. The regions of the antenna where current variations are faster are meshed with a higher density of triangles. The size of the triangles at a given level is half the size at the immediate upper level. Note that the large connection mesh triangles distort the shape of the holes in the upper levels. These connection triangles are distorted when connecting levels with different mesh size. The number of triangles is now 593.

Note that the tiny connection triangles at the antenna feeding point -coordinates $(0,0)$ - have not been marked in red in Fig. 9.

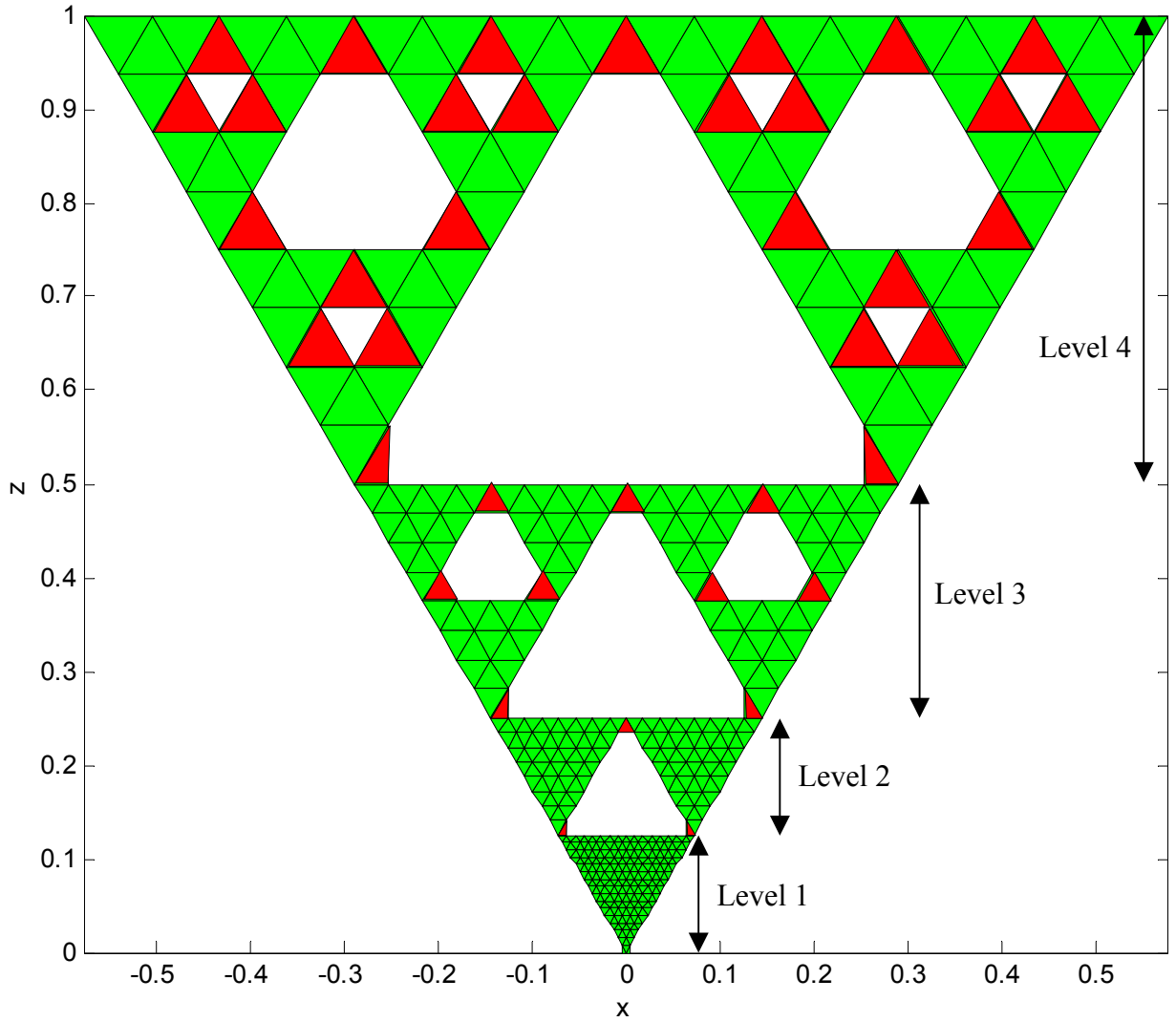


Figure 9: Three-iteration Sierpinski antenna with adaptive meshing. Some mesh triangles have been added to allow the flow of current between different antenna regions (marked in **red** color). The number of triangles in this mesh is 593. Due to the change of mesh size between different levels, some connection triangles are distorted.

The input parameters to model surface-Fractal antennas defined by an IFS and to create an adaptive mesh with connection triangles will be the following:

1. Shape of the original geometry that undergoes the IFS transformations (i.e. a triangle for the Sierpinski Fractal)
2. Size of the original geometry that undergoes the IFS transformations
3. IFS definition parameters
4. Number of IFS iterations
5. Number of triangles (nodes-1) along the size of the original geometry block in each one of the Fractal levels. For example, in Fig. 8 this parameter is equal to 4, 4, 4 (uniform meshing) and in Fig. 9 this parameter is equal to 2, 4, 8, 16.

The procedure to automatically model surface-Fractal antennas defined by an IFS and to create an adaptive mesh with connection triangles will be:

1. Model the shape of the original geometry that undergoes the IFS transformations (i.e. a triangle for the Sierpinski Fractal), according to parameters 1 and 2.
2. Mesh the original geometry that undergoes the IFS transformations. The number of triangles will be that corresponding to the coarsest level in adaptive meshing (parameter 5).
3. Create the pre-fractal structure by IFS iterations, according to parameter 3, with number of iterations equal to parameter 4.
4. Refine the mesh at each level according to parameter 5. The size of triangles is reduced by a factor two by dividing triangles in four.
5. Locate pairs of mesh triangles that share only one vertex. Add connection triangles attached to these vertices.
6. Element numbering will be checked, and if necessary modified, for obtaining a linear system matrix with IFS block structure (Fig. 3).

Cylindrical-wire Fractal antennas:

Cylindrical-wire fractal antennas are very difficult to model because a lot of surface-surface intersections must be computed. This kind of model is not essential for numerical simulations, since

- Most fractal antennas are printed strips
- Cylindrical wires can be modelled by one-dimensional wires and a radius parameter if some approximations are made in the electromagnetic computation code.

For that reason it was decided that meshing cylindrical wires would be the least priority task for CIMNE, and very possibly out of the framework of this project.

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