Parallel computing for processing and visualization of state space of nonlinear circuits

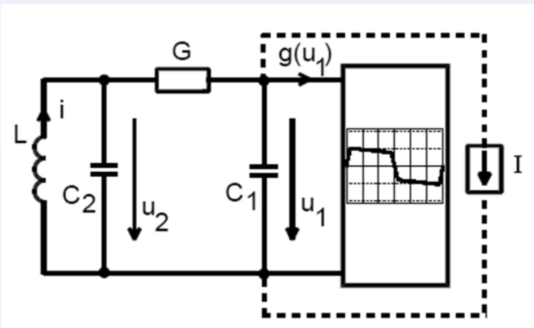
Zsolt Rácz

Technical University of Košice, Faculty of Electrotechnics and Informatics

Supervisor: Branislav Sobota, Consultant: Milan Guzan

Motivation

Research of chaotic behavior of non-linear deterministic dynamic systems has become one of the important scientific areas in recent decades. One of those systems is Chua's circuit, which is a simple autonomous circuit introduced by Leon O. Chua in 1983. It consists of a few simple circuit elements and a non-linear resistor, called Chua's diode.



Despite its simplicity, under certain conditions, Chua's Circuit can produce chaotic behavior and therefore it is an excellent tool to research chaotic phenomena. Its behavior can also be investigated by computer simulation, however, this is a relatively demanding numerical calculation, which was difficult to imagine a few decades ago.

The evolution of the internal state of non-linear dynamic systems is visualized by phase portraits. These portraits in certain systems (like Chua's Circuit) and certain parameters, depending on the system's initial conditions, can depict regular or chaotic trajectories. Knowing that, the following question may naturally rise: What separates chaotic trajectories in the state space from regular ones? Boundary surface gives us answer to this question.

To calculate the boundary surface of a certain circuit, the trajectory type has to be determined for every point of the state space (with certain gaps, depending on the desired precision), which can only be done by simulation. This is a computationally very intensive task.

Objectives

The main goal of this thesis was to design and implement a software solution that supports research of chaotic behavior taking place in Chua's circuit by being able to calculate and visualize trajectories and boundary surfaces on the state space. The emphasis was put on versatile **visualization** methods, high computational **performance** and **platform independence**.

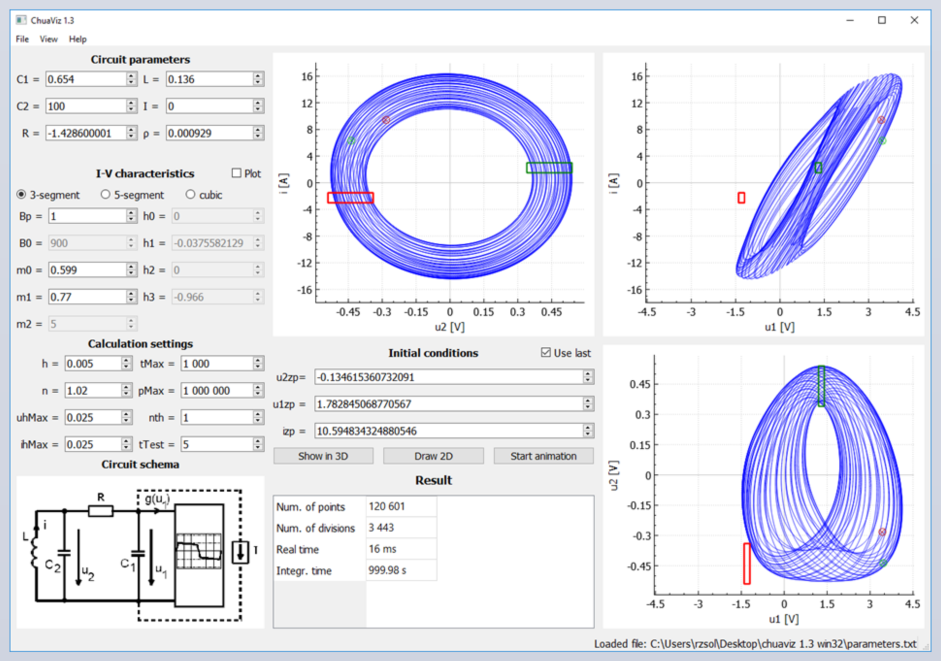
Based on the aforementioned requirements the following technologies have been chosen before starting the development:

- Programming language C++;
- Qt framework for user interface;
- Intel TBB for multi-threaded computations.

Further goals were to measure computing speed using different parameters and optimization techniques and to create more versions of the software that allow to compute various modifications of Chua's circuit.

Chuaviz – The application

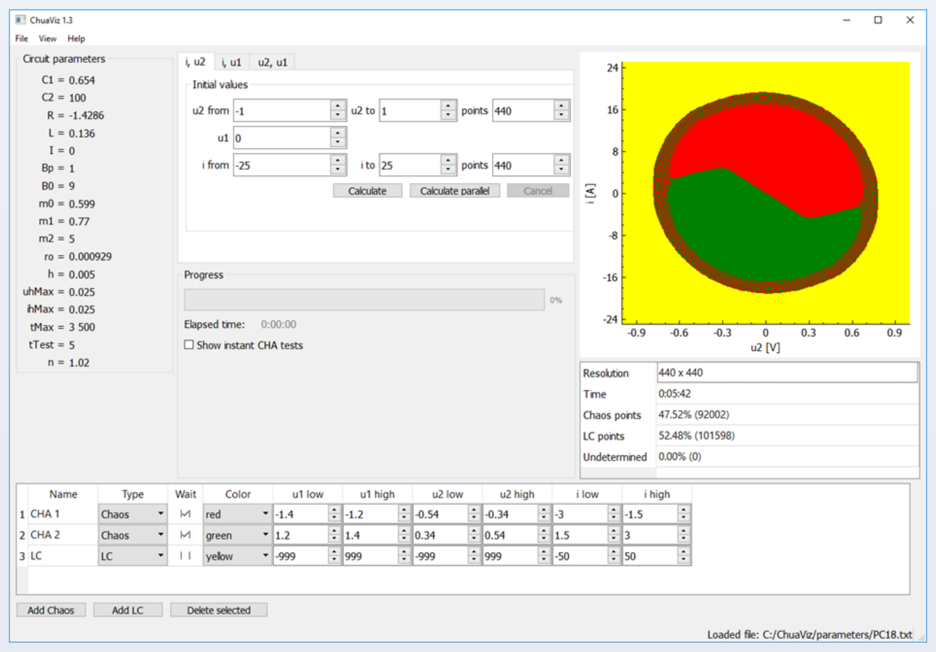
Based on these requirements and design choices, an application called Chuaviz was created. Its user interface provides three main switchable views. The first view can be seen on the picture below.



Calculation and visualization of a single trajectory in application Chuaviz.

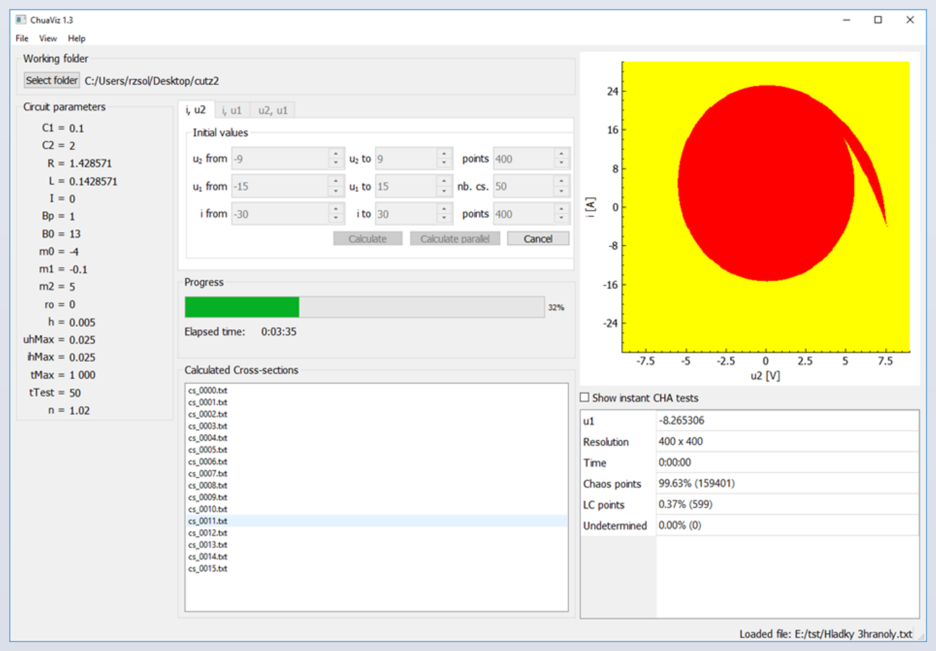
It allows to modify the parameters, perform the calculation of a single trajectory and visualize the result using 3 planes. The projected trajectory can then moved by dragging and zoomed by mouse scrolling.

The second view, which can be seen on the figure below is intended for the calculation and visualization of a single cross-section of the boundary surface. Among others it allows to define new and modify existing cuboids for chaotic and regular trajectories.



Boundary Surface calculation in Chuaviz.

The third view allows us to automatize calculation of multiple cross-sections of boundary surfaces in different, parallel planes. All of the calculated cross-sections are then saved into CSV files and can be visualized by Chuaviz at the time of calculation, or later. The most important advantages are parallel computation of cross-sections and possibility to continue interrupted calculations. This view can be seen on the picture below.

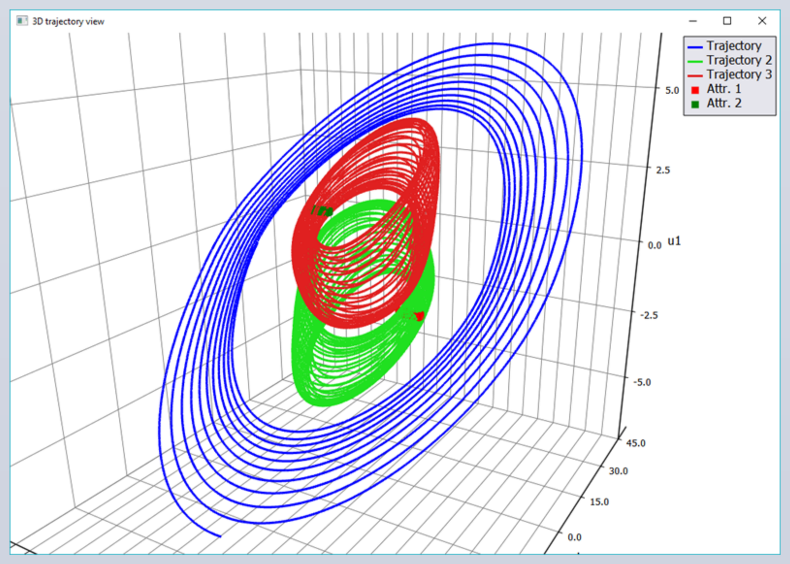


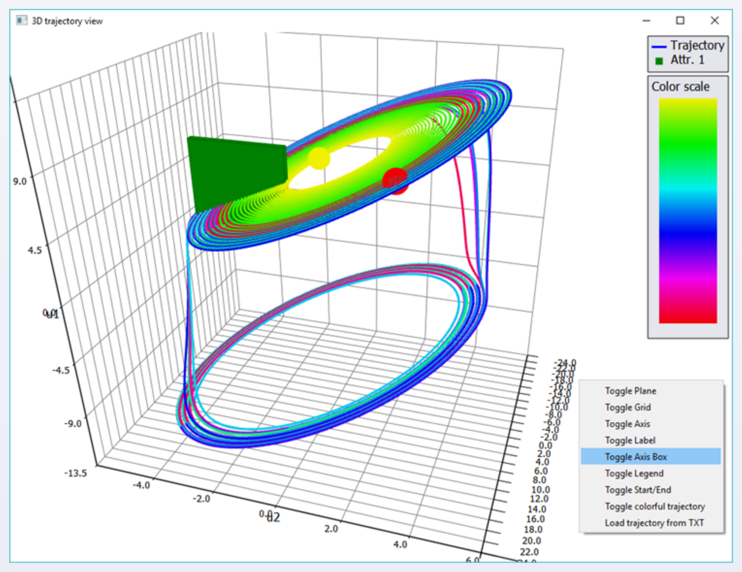
Batch calculation of Boundary Surfaces in Chuaviz.

The application, besides its main funcionality has the following features:

- Saving and loading circuit parameters into a file;
- Animated 2D plotting of the trajectory;
- Exportation of calculation results as CSV;
- Saving visualized trajectories and boundary surfaces as image files;
- 3D visualization of a single, or multiple trajectories.

The following pictures illustrate the feature of 3D visualization of multiple trajectories.





Performance improvements

Multiple ways have been studied and tested in order to improve computing performance of cross-sections of Boundary Surfaces. The most important are the following ones:

- Multi-threaded computing using all available CPUs;
- Variating calculation parameters;
- Positioning of cuboids for detecting attractor type;
- Using different compiler optimization levels;
- Compiling to concrete microarchitecture.

The following table presents the computation times of a certain cross-section on different computers using one and all CPU cores. It can be seen, that the application can take advantage of multiple cores, as on the Intel i7 with the most cores was the improvement the most significant.

CPU	Cores	1 core	All cores	Improvement
AMD Athlon, 2.7 GHz	2	2:54	1:27	2x
Intel Core 2, 2.83 GHz	4	2:24	0:38	3.79x
Intel i5, 2.2 GHz	2/4*	1:15	0:29	2.58x
Intel i7, 4 GHz	4/8*	1:06	0:14	4.71x

* - number of virtual cores

Benefits and conclusion

The main advantage of the developed application is that it has provided significant acceleration of calculation on any common, multi-threaded computer or multi-threaded laptop. During research using Chuaviz, new, unpublished attractors and boundary surface morphologies have been found. A part of the knowledge from this work has already been projected into two conference papers made available in the IEEE database.

The proposed app also allowed not only to display a gallery of chaotic attractors, but also their visualization without transient. In the future, the application could be deployed e.g. into the area of own calculation numbers or Ljapunov exponents, for which parallelization is a necessity.

Use of thesis results

Publications:

- Zsolt Rácz – Milan Guzan – Branislav Sobota. „Parallelizing Boundary Surface Computation of Chua's Circuit.“ *Radioelektronika 2017*.
- Milan Guzan – Zsolt Rácz – Branislav Sobota – Kristián Szerdahelyi. „Cross-Sections of Boundary Surface for Variations of Parameters in Chua's Circuit.“ *TSP 2017*.

In Master's theses:

- Peter Halachan. „3D vizualizácia hraničných plôch Chuaovho obvodu.“ Diplomová práca, TUKE, 2017.
- Patrik Kováč. „3D vizualizácia stavového priestoru autonómnych obvodov programom Paraview.“ Diplomová práca, TUKE, 2017.
- Kristián Szerdahelyi. „Hraničná plocha Chuaovho obvodu.“ Diplomová práca, TUKE, 2017.