RESEARCH ARTICLE

Interior Dual Optimization Software Engineering with Applications in BCS Electronics Superconductivity

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ABSTRACT

Interior optimization software and algorithms programming methods provide a computational tool with a number of applications. Theory and computational demonstrations/techniques were primarily shown in previous articles. The mathematical framework of this new method, (Casesnoves, 2018–2020), was also proven**.** The links among interior optimization, graphical optimization (Casesnoves, 2016–7), and classical methods in non-linear equations systems were developed. This paper is focused on software engineering with mathematical methods implementation in programming as a primary subject. The specific details for interior optimization computational adaptation on every specific problem, such as engineering, physics, and electronics physics, are explained. Second subject is electronics applications of software in the field of superconductors. It comprises a series of new BCS equation optimization for Type I superconductors, based on previous research for other different Type I superconductors previously published. A new dual optimization for two superconductors is simulated. Results are acceptable with low errors and imaging demonstrations of the interior optimization utility.

Key words: Electronics superconductors, graphical optimization, interior optimization methods, systems of non-linear equations

INTRODUCTION

The design of software for optimization subject to a mathematical problem constitutes a rather difficult task. This inconvenient gets higher when there are many constraints and several objective functions/subfunctions. In previous publications, the interior optimization method (IO) was presented and demonstrated.[3,4] Basically, it is a separation of variables method combined with graphical optimization 3D imaging/graphs.

Interior optimization is not designed exclusively for finding out a specific global minimum, local minimum, partial global minimum, or variants of these singular parameters. Not always in engineering and physics are necessary to find optimal values for a group of equations conditioned to particular constraints of a laboratory/industrial/specific problem. Then, IO provides with the facility to select desired optimal parameters in subsequent stages ordered and set applying the method of separation of variables.

This computational contribution is focused on programming methods for IO and dual IO. The electronics applications in superconductors constitute both a demonstrative part and a useful application at BCS superconductivity field.

In optimization with objective functions based on non-linear systems of equations,[5,6,8,24,28] or multiobjective parameters constraints and other conditions, the task is rather difficult. Specifically, this occurs in physics and engineering non-linear optimization problems.[6,7,9,13-17] Large-scale amount of empirical data for algorithms/models implementation has to be adapted/fitted to models that involve a high number of equations, non-linear many of them,[7,9,13] constraints added. One available useful method is stochastic optimization.

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These methods are based on random samples without taking all amounts of data. They can be used to save time and computational effort when the amount of data is large.

In previous contributions,[4-6,8,11,16] graphical optimization was presented and applied for engineering mathematical modeling, materials erosion models,[7,8] and physics of deformable solids dynamics. IO and dual IO software implementation are difficult because the task involves a number of vectors and matrices to be implemented/ordered in the program code. This, especially in dual IO, was a hurdle sorted with matrix algebra methods and is explained in Section III.

Graphical optimization involves the objective function visualization in 2D and 3D.[4,5,8,11,12,16] This implies that multiparameter formulas initially cannot be easily set for the 3D graphical optimization, unless a choice of 2 or 3 variables is done among several ones. This apparent difficulty was the base to develop interior optimization in previous contributions.[3,4] It is defined as interior graphical optimization/dual optimization method (Casesnoves, 2018).

The method was intended to be proven and set, at first, on simple equations at electronics physics field, namely, BCS algorithms.[3,4] Therefore, direct applications in electronics field for superconductors isotope effect and critical temperature are presented.[29]

In summary, this newly improved study shows an advanced contribution for the interior non-linear optimization method previously presented in Casesnoves.[3,4] However, it is focused on programming software and computational 3D imaging results. Computational base is explained/proven at the superconductors Type I area, Pt and Sn. The scheme of the method is shown, with a sharp proof in applications at this electronics field. The most important innovation is interior dual optimization.

MATHEMATICAL METHOD

The problem approached was previously explained.[3,4] For software implementation, IO and dual IO are a system of non-linear equations of several variables that have not, in general, unique solution.[3,4] If the objective optimization function becomes a number of non-linear functions,[12-14,27] such as

$$f_i(\vec{x}) = f_i(x_{1i}, x_{2i}, \& , x_{ni}) \qquad (1)$$

for i=1,....m and n≠m generally
subject to

$$
\begin{aligned}
a_{1i} &\le x_{1i} \le b_{1i} \\
a_{2i} &\le x_{2i} \le b_{2i} \\
a_{ni} &\le x_{ni} \le b_{n}
\end{aligned}
\qquad (2)
$$

or,

$$
\begin{bmatrix} a_{1i} \\ \cdot \\ \cdot \\ a_{ni} \end{bmatrix}
\le
\begin{bmatrix} x_{1i} \\ \cdot \\ \cdot \\ x_{ni} \end{bmatrix}
\le
\begin{bmatrix} b_{1i} \\ \cdot \\ \cdot \\ b_{ni} \end{bmatrix} ;
\qquad (3)
$$

These constraints are selected as simple here, in general, could be more complicated. Then, setting equations members such as

$$f_i(\vec{x}) = f_i(x_{1i}, x_{2i}, \& , x_{ni}) = 0$$

And objective function with L_1 Chebyshev Norm, for every f_i

$$\sum_{i=1}^{i=n} \left\| f_i\left(\vec{x}\right) \right\|_1 = 0 ; \text{ (Casesnoves, 2018)} \qquad (4)$$

For programming in the following section, a non-linear system of 100 equations was chosen, that is, $n = 100$.

IMPLEMENTATION OF METHOD IN SOFTWARE

The algebraic software developed for this contribution had various programming difficulties related to previous papers. The implementation of the algorithms on the programs with Chebyshev L_1 norm for objective function with matrices in dual interior optimization was complicated. Additional difficulties were the algebra changes in the subroutines to get functional the program for surface graphical optimization visualization. As it is detailed, (Sketch1), this requires mathematical changes – background. The software was developed in Matlab and is almost equivalent for FREEMAT also. Programming was selected to use subroutines that let rotate 3D images to obtain best visualization, (Sketch 2). With this tool, it was possible to see in images the sharp minimum zone to prove the mathematical statements. FreeMat also offers this possibility in 3D surfactal implementation. There are more types of software that can perform this task properly.

Range for surfactal simulations Delaunay tiles was 100. In previous contributions, higher values were taken for high accuracy.[2,3,4,6,8,11,13-16] However, optimization programs were designed for double precision, since were based on engineering software of extent number of previous publications.[3-17,22]

Sketch 1: Interior optimization/dual optimization matrix algebra programming			
Type of matrix	Dimensions	Setting	Numerical significance
Vector	[1,n]	To implement intervals	The length of the equations non-linear system
Vector	[1,n]	To implement intervals	To adapt the vector at matrix algebra (transpose)
Square matrix	[n,n]	At programming body	For surfactal construction of OF
Non-symmetrical matrix	[n,m]	At programming body	Intermediate matrix algebra calculations
Non-symmetrical matrix	[m,n]	At programming body	Intermediate matrix algebra calculations

To check complementarily the numerical results, both Fortran and F# subroutines in optimization were used. While Fortran proved to match the graphical optimization results, F# showed restrictions and, obviously, limits that discarded this type of language for accurate results in nonlinear optimization. These numerical data, although significant for verification, were not included in publication.

APPLICATIONS IN ELECTRONICS

In this section, a brief summary of superconductivity toward the transition equation and the isotope effect is presented. The superconductivity theory framework is rather extent and with large mathematical background. It involves quantum theory, molecular chemistry, materials physics, and other specialties. For the magnetic interaction of superconductor materials, the electromagnetic theory is wide and essential – rather difficult and not the objective of this contribution. All these areas converge together in superconductors theory and applications.

Superconductor developments in future stages of research involve a wide of theoretical and applied advances, namely, in new materials compounds for Type II superconductors. Second, technical aspects for optimal implementation/usage could be developed. Moreover, the new technical/industrial applications for the future constitute an advance area to be worked out. However, the most important industrial and scientific significances of superconductors are its essential property itself, resistivity zero at T_C. This fundamental property saves a loss of energy which constitutes the reason for their use/investigation. What is useful to prove interior optimization/dual optimization method are the simple equations of transition-temperature-critical and isotope effect.[1,3-5,18-20,24-26,29]

The applications of superconductors in nuclear physics based devices, medical technology are described extensively in literature. Main of them is hadrontherapy (protontherapy and/or carbon therapy) and nuclear magnetic resonance (NMR). Protontherapy[13] is a high precision dose delivery technique based on the advantage of Bragg peak radiation distribution. Carbon also shows a satisfactory dose delivery distribution compared to photons. Hadrontherapy constitutes an improvement of dosimetry compared to classical IMRT. These applications are related to the area of magnetic fields interaction with superconductors. Following possible/probable applications in the future are in investigation and development.

The classical critical temperature equation BCS for superconductors reads,
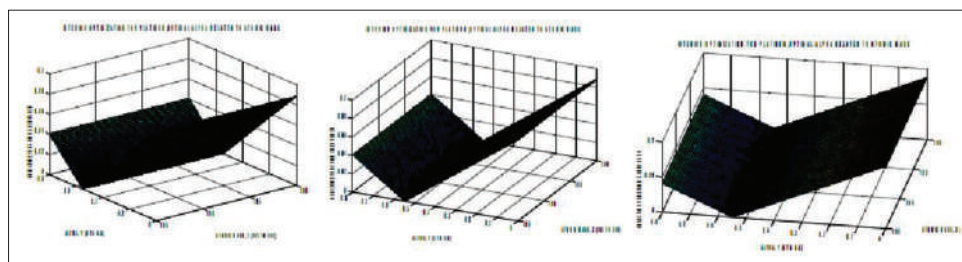
Sketch 2: Brief of interior optimization method matrix algebra programming. The particular characteristics for every type of matrix are explained. The setting on the program development is explained

$$M^\alpha T_C = K; (K=E \text{ in Figures}) \qquad (5)$$

Where, K (E) is a constant, M atomic mass (AMU), and T_C is critical temperature (Kelvin). From the stage when the solid reaches critical temperature, the superconductivity effect begins. T_C varies for every isotope element within a defined mass element, although not excessively in magnitude. This equation, although simple, remains useful. The evolution of this equation, for example, Kessel,[21] involves extent mathematical background and mathematical-physics theory. Taking decimal of Napierian logarithms, the Equation (5) can be linearized for setting graphics related to different isotopes with corresponding atomic proper mass. The linearization objective is to guess fast information about isotopic superconductivity characteristics. In the literature,[19,20,24-26,29] it is frequent data analysis of BCS equation with linearization plots for comparisons. The algorithm (4) was implemented with 100 equations and reads,

for (i=1,...n), i=100
$[M_i]^\alpha T_C - K_i = 0$, Tc fixed for simulations, and based on (4), it is set

minimize,

$$\left| [M_i]^{\pm} T_C - K_i \right| \qquad (6)$$

$$\text{for } i = 1, ... n \ ;$$

$A_i = [M_i]^\alpha$ for first stage of optimization, e. g., Figure 1
Where, i is the corresponding number within the range of simulations. For example, range of simulations for M is,[1,19,20,23,25]

$$M \in [198.0, 203.4] \qquad (7)$$

In the same way, range of constraints can be seen in axes ranges of Figures 1-7. That is, 100 divisions in Atomic Mass (M) interval for setting variables in the program. That range is for the Equation (7) that comprise the variation of atomic mass for all metal isotopes within. Therefore, with Equation (6), a non-linear system of equations is set. The variables are to get optimized. Extrapolation to large and complicated electronic physics equations, electronics, nuclear physics applications, or any type of system can be guessed from these mathematical formulas.

PT AND SN COMPUTATIONAL GRAPHICAL INTERIOR OPTIMIZATION RESULTS

This example/application deals with different superconductors compared to previous articles.[3,4] The results are shown in tables and graphics. The numerical applications are presented for Pt and Sn, because of their similarity in atomic mass. However, Pt and Sn differ significantly in T_C and isotopes distribution. Most of Sn isotopes correspond to AM 181, while Pt isotopes distribution shows almost the same percent for AM 194 and 195.

Residuals can be considered acceptable, although not of high precision accuracy. The time consuming for designing program is extremely short. The time for selecting optimal values is also very short with the Matlab graphical cursor. In engineering practice, this is a significant advantage that gives many options for fast on-site superconductivity data management at laboratory. Results confirm useful utility of Equation (5).

Table 1 shows the first stage of interior optimization. In X and Y axes, are set the constant K and the parameter A that comprises M^α. That is, A= M^α in Figure 1, X axis. The values are taken almost from all references related to Pt critical temperature for superconductors.[1,3,4,18-20,24-26,29] T_C value is fixed. At Z axis, it is deployed the objective function taking absolute value. It took about 15 min. Programs construction was performed in 2 h based on previous software[3-17] with matrix algebra modifications.

Table 2 shows the second stage of interior optimization. In X and Y axes, are set the constant α and the parameter M. That is, previously was optimized A = M^α. The values are taken almost from all references related to Pt critical temperature for superconductors. The objective function is taken in absolute value. These values were taken with the cursor in the most easy and simple way. It took about 10 min.

Table 3 shows the first stage of Sn interior

Table 1: Software engineering optimization

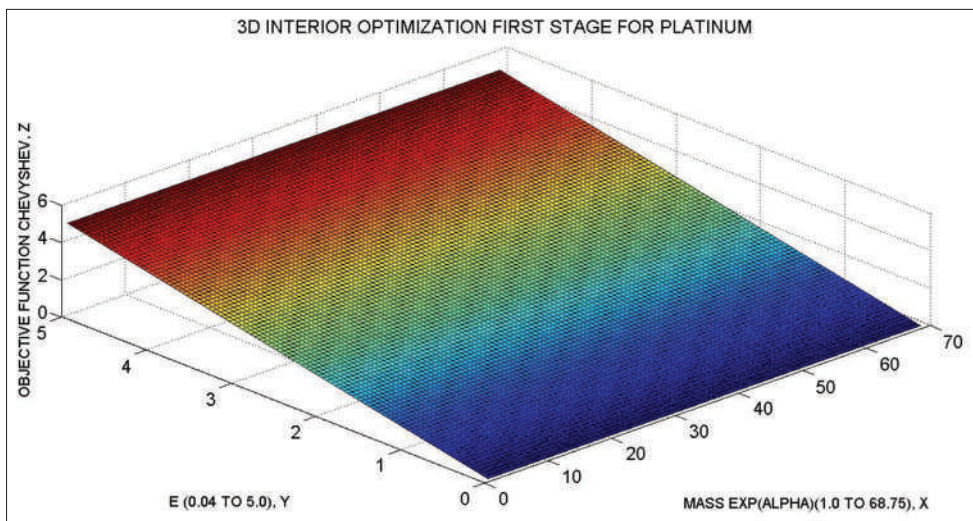| Pt numerical interior optimization results I		
Isotope type interval of atomic mass (UAM) and t_c	Parameter	Interval applied for programming
M ∈ [190, 198] T_C=0.0019 K	A=M^α	[1.0, 68.7594]
	$M^\alpha T_C$	[0.0019, 0.1306]
	E	[0.0019, 0.1306]
	Alpha	[0.001, 0.8]

Figure 1: The first stage of Pt interior graphical optimization. It was determined the optimal K (e) value and the optimal A = M^α value. Information and tools that can be used/obtained with imaging surfactal subroutines are detailed in Casesnoves.[3,4,8,11,12,16,22] The absolute value was taken at Chebyshev objective function
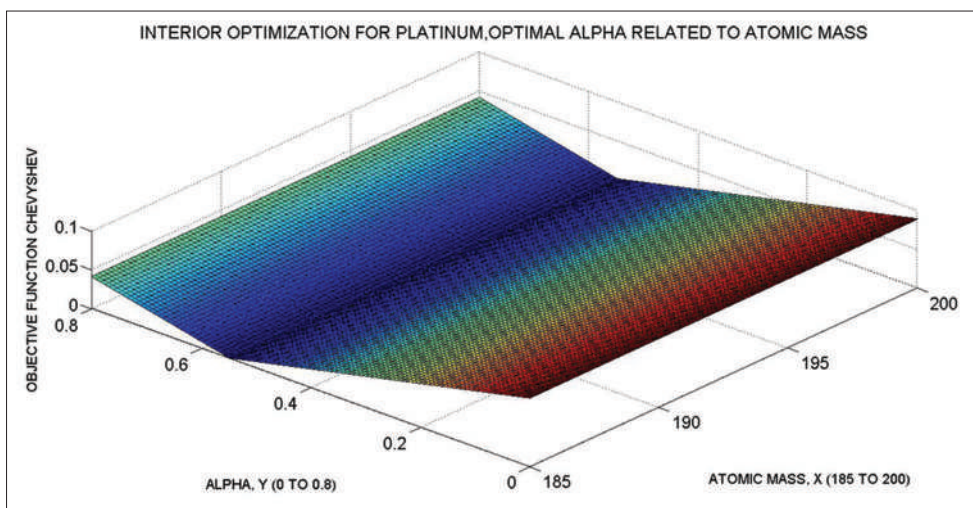

Figure 2: The second stage of interior graphical optimization. It was determined the optimal M value and the optimal α value. Information and tools that can be used/obtained with imaging surfactal subroutines are detailed in Casesnoves[3-5,8,11,12,16]

Figure 3: The first stage of Sn interior graphical optimization. Line of contact for global minima is not at center. It was determined the optimal K (e) value and the optimal A = M^α value. Sn is a more stable metal related to isotopes mass distribution. Information and tools that can be used/obtained with imaging surfactal subroutines are detailed in Casesnoves.[3,4,8,11,12,16] The absolute value was taken at Chebyshev objective function

Figure 4: The second stage of Sn interior graphical optimization. It was determined the optimal M value and the optimal α value. Information and tools that can be used/obtained with imaging surfactal subroutines are detailed in Casesnoves[3-5,8,11,12,16]
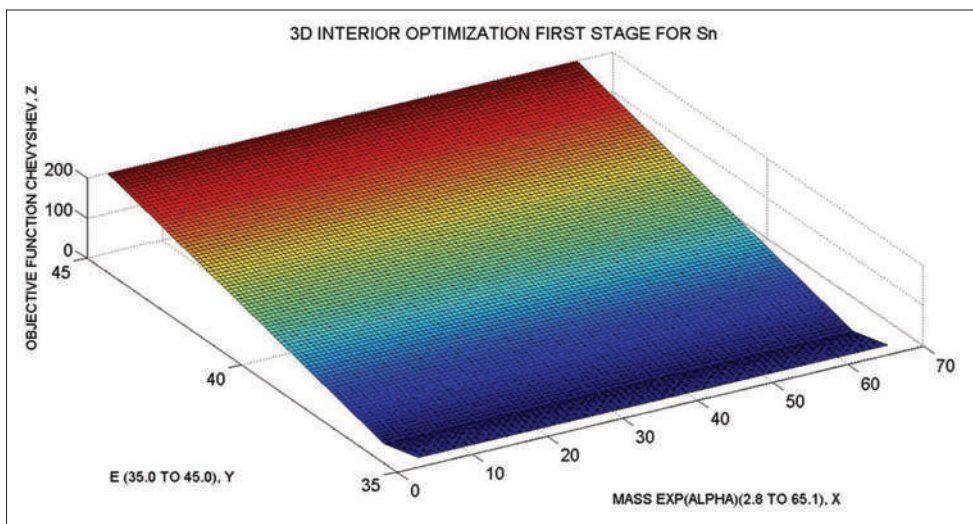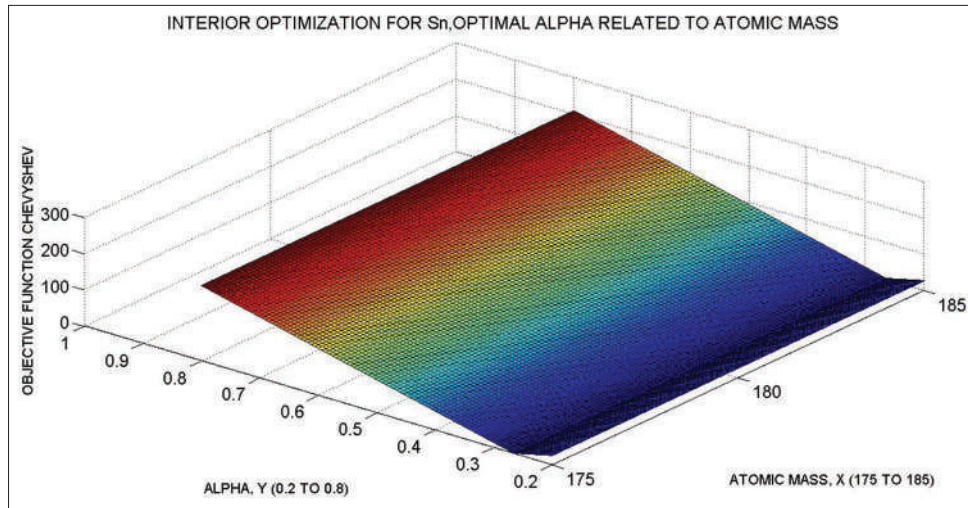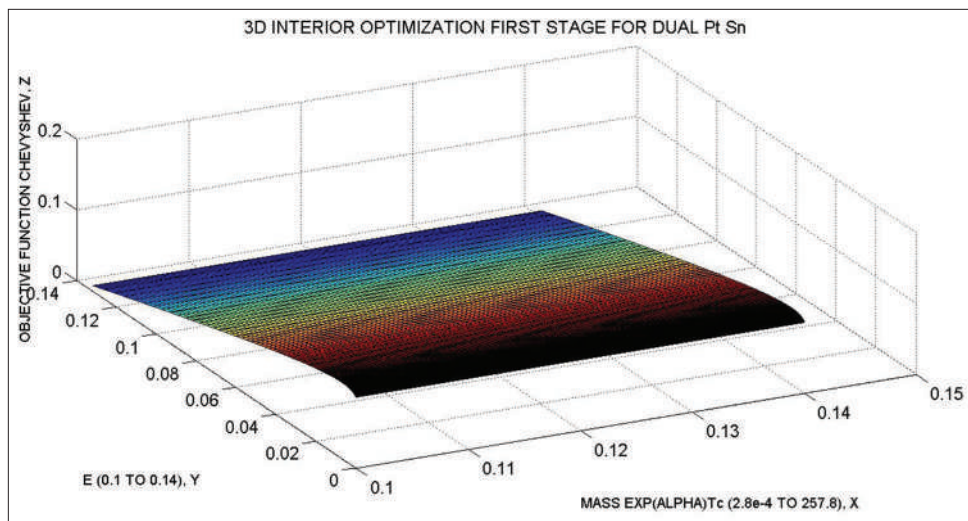

Figure 5: The first stage of interior graphical dual optimization. It was determined the optimal E value and the optimal $A = M^{\alpha} T_C$ values. The interval selected for T_C is [0.0001, 0.0019]. Intervals are in legends of Graphs 5, 6, and 7. Numerical results are shown in Table 6
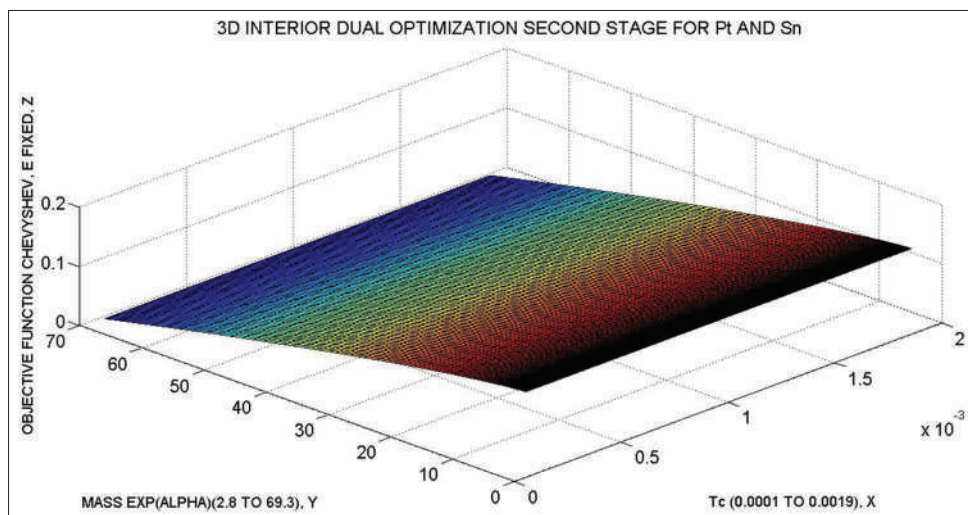

Figure 6: The second stage of interior graphical dual optimization. It was determined the optimal E value was fixed from the first stage, E = 0.1. Intervals are in legends of Graphs 5, 6, and 7. Numerical results are shown in Table 6
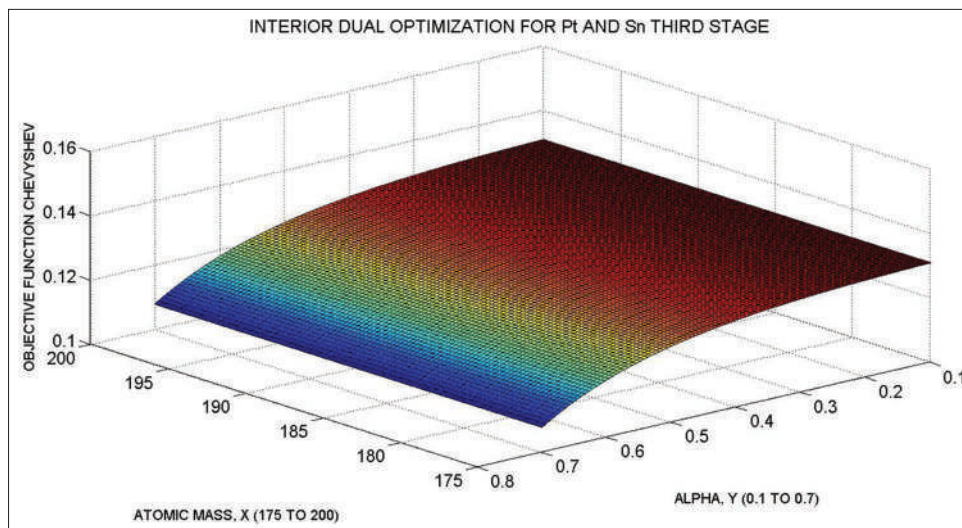
Figure 7: The third stage of interior graphical dual optimization. It was determined the optimal alpha value. Intervals are in legends of Graphs 5, 6, and 7. Numerical results are shown in Table 6. Note the smooth curvature of the surface. This mathematically implies that the OF is differentiable, derivable continuously. The homogeneity for all the isotope atomic masses is excellent with alpha value of 0.7

optimization. In X and Y axes, are set the constant K and the parameter A that comprises M^{α}. That is, $A = M^{\alpha}$ in Figure 1, X-axis. The values are taken almost from all references related to Sn critical temperature for superconductors.[1,3,4,18-20,24-26,29] T_C value is fixed. At Z axis, it is deployed the objective function taking absolute value. All these values were taken with the cursor in the most easy and simple way. It took about 15 min. Programs construction was performed in 2 h based on previous software[3-17] with matrix algebra modifications.

Table 4 shows the second stage of Sn interior optimization. In X and Y axes, are set the constant α and the parameter M. That is, previously was optimized $A = M^{\alpha}$. The values are taken almost from all references related to Sn critical temperature for superconductors. The objective function is taken in absolute value. These values were taken with the cursor in the most easy and simple way. It took about 12 min.

PT AND SN DUAL COMPUTATIONAL GRAPHICAL INTERIOR OPTIMIZATION SIMULATION RESULTS

This section deals with a theoretical simulation of BCS equation for two materials, Pt and Sn. They have similar atomic mass, although the isotopic distributions are different. It is extensively known that Pt has two isotopes with percentage similar, about 33% (194 and 195 UAM). On the contrary, Sn shows about 100% isotopic distribution at 180

Table 2: Software engineering optimization

Pt numerical interior optimization results II		
Optimization parameter	Numerical result	Residual
E	0.0901	0.0869
Alpha	0.5495	0.0002

Table 3: Software engineering optimization

Sn numerical interior optimization results I		
Isotope type interval of atomic mass (uam) and T_C	parameter	Interval applied for programming
M ∈ [175, 185] T_C=3.72 K	$A=M^{\alpha}$	[2.8094, 65.1234]
	$M^{\alpha} T_C$	[10.4508, 242.2592]
	E	[10.4508, 242.2592]
	Alpha	[0.2, 0.8]

Table 4: Software engineering optimization

Sn numerical interior optimization results II		
Optimization parameter	Numerical result	Residual
E	36.11	0.09618
Alpha	0.2667	0.09742

atomic mass isotope (UAM). The objective is to demonstrate the utility of interior optimization for several theoretical and experimental situations.

The purpose consists in a dual optimization with IO for both materials in three stages – namely, separation of variables. It is supposed, for instance, that at laboratory cables with powder of these two materials are being manufactured. That is, cables can be bent, since it is powder of both materials mixed. Therefore, cables could adapt on any convenient laboratory device. It is also supposed that in the mixture there is no interaction

between the two different powered metals. And also there is absence of electromagnetic fields at the set up device. The IO application, in this case, involves three subsequent stages. These steps are compulsory since Pt and Sn have different T_C. It is searched as follows:

Optimal T_C for both metals within an optimal range of T_C

Optimal E (K in some graphs/formulas of previous papers) in BCS equation for both metals

Optimal alpha value for BCS equation applicable on both metals

Pt has a T_C of 0.0019 K, while Sn T_C is 3.72 K. In simulation, is taken a range $T_C \in [0.0001, 0.0019]$. Therefore, once reached this range of temperatures, it is assured that the superconductivity effect will happen in both elements. The software engineering programming is more complicated and was done in double precision. Matrix Algebra changes are frequent and rather complicated. It was mandatory a strict order in programming sentences to avoid problems when running the program (Casesnoves software, 2020) and save functional time. In Tables 4 and 5, numerical results are presented. In graphs 5, 6, and 7, the sharp IO in three stages is shown and clearly demonstrated. Explanations of results are included at everyone. Just remark that this is a theoretical simulation based on rational experimental situations in laboratory. That is, the necessity of bending cables of powered superconductors for an eventual device settings/manufacturing.

Residuals can be considered acceptable at this first dual IO. The time consuming for designing program is about 5 s. The time for selecting optimal values is not short with the Matlab graphical cursor as there are three stages. In engineering practice, this simulation is a significant advantage that gives many options for fast on-site superconductivity dual-data management at laboratory. Results confirm useful utility of Equation (5).

Table 6 shows numerical results of dual interior optimization for Pt and Sn together. Residuals can be considered acceptable. The value of alpha is applicable for both metals at BCS equation. Optimal isotope mass that can fit better in BCS equation is 189.7 UAM for the first stage. At the third stage, all isotope masses, both Pt and Sn, $M \in [175.0, 200.0]$ are optimal with good residual, and alpha value 0.7.

Table 5 shows the development of optimization of parameters in dual interior optimization. These stages correspond with Figures 5-7. The numerical results for these parameters are shown in Table 6.

DISCUSSION AND CONCLUSIONS

The aim of this paper was different from previous contributions.[3,4] It is focused in software engineering techniques to implement the interior optimization. Therefore, the superconductors applications for Pt and Sn are confirmation examples of the method previously demonstrated. However, both Pt and Sn results can be considered acceptable. Dual simulation, (Casesnoves, 2019–2020), is a new tentative perspective for theoretical applications in electronics physics. The basic stages of IO were detailed with simulations and graphical optimization 3D imaging. In dual interior optimization, even some refinements were implemented.

Therefore, interior optimization method base with algorithms and mathematical definitions that were explained/presented formally in Casesnoves[3,4] was developed and proven for several elements of these different Type I superconductors. One important feature of this method is its speed in running time even working with double precision. The utility, although simple, of the BCS equation was proven for Pf and Sn. The matrix algebra programming is rather more difficult compared to previous contributions. This occurs in the dual IO program design. The difficulties were sorted using several combined code sentences. As a demonstration of the mathematical and practical engineering applications, electronics in superconductors equations were presented.

Table 5: Dual software engineering optimization

Numerical interior optimization results II		
Stage	Parameter fixed	Optimal parameter determined
First stage	E tentative	E
Second stage	E fixed	T_C
Third stage	T_C E	ALPHA

Table 6: Dual software engineering optimization

Numerical interior optimization results V Pt and Sn		
Stage of optimization	Optimal results for parameters	Objective function residual (Chebyshev optimization norm)
First stage	E=0.1317 M^α T_C=0.1388	0.008302
Second stage	T_C=0.0005909 M^α=69.31	2.48e-6
Third stage	Alpha=0.7 $M \in [175.0, 200.0]$ (UAM)	0.1076

Computational electronics simulations with 3D graphical optimization images were made correctly. Numerical results were explained in tables and schemes.

Numerical results for alpha in Pt are about ½. For Sn, the result of around 0.3 differs slightly from the literature value of 0.44. Dual alpha for both metals fits at 0.7 with a very good residual. In dual interior optimization, the optimal value $T_C \approx 0.0006$ K guarantees the superconducting effect for Pt and Sn at the same time.

In summary, original software engineering method of interior optimization/dual optimization was explained with a number of examples. Software techniques are supported by numerical results and 3D images/graphs.

Practical electronics applications in superconductor electronics field BCS equation are presented. The simulation of dual interior optimization was carried out as much realistic as possible. Nuclear physics applications in radiation therapy (hadrontherapy) and diagnostic imaging (NMR) emerge from these findings. Applications in other areas of electronic physics, physics, bioengineering, medical radiation-diagnosis technology, tribology, and engineering come from this interior optimization/dual optimization method.

SCIENTIFIC ETHICS STANDARDS

Interior graphical-optimization methods were created by Francisco Casesnoves on November 3, 2018, while he was preparing his Doctoral Thesis Defense and publishing some papers in IMRT radiation therapy. First implementation of algorithms and verification of simulations were carried out in the morning of April 1, 2020. Dual interior optimization was definitely implemented in October 16 about 14 pm. This third article has previous paper information and figures, whose inclusion is essential to make the contribution understandable. This study was carried out, and their contents are done according to the European Union Technology and Science Ethics. Reference, "European Textbook on Ethics in Research." European Commission, Directorate-General for Research. Unit L3. Governance and Ethics. European Research Area. Science and Society. EUR 24452 EN.[30] This research was completely done by the author, the software, calculations, images, mathematical propositions and statements, reference citations, and text are original for the authors. When anything is taken from a source, it is adequately recognized. Ideas from previous publications were emphasized due to a clarification aim.[30,31]

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Francisco Casesnoves is Engineering and Natural Sciences PhD by Tallinn University of Technology (started thesis in 2016, thesis defense/PhD earned Defense in December 2018, official graduate Diploma 2019), Estonia, and computational engineering/physics independent researcher at COE, MSc-BSc, Physics/Applied Mathematics (Public Eastern-Finland-University), Graduate with MPhil, in Medicine and Surgery (Public Madrid University Medicine School). Casesnoves studied always in public educational institutions. His education/scientific vocation was motivated very young, by Profs. Candida Navamuel and Isabel Vela, in Renaissance Humanism ideas – later on with the motivation manuscripts of Nobel and Von Helmholtz prizes Santiago Ramon y Cajal. His constant service to International Scientific Community and Estonian technological progress (2016 present) commenced in 1985 with publications in Medical Physics, with further specialization in optimization methods in 1997 at Finland – at the moment approximately 100 recognized publications with 50 papers. His main branch is Computational mathematical Non-linear/Inverse Optimization. His service to International Scientific community also comprises the publication of two recent books with Estonian affiliation, the first is the computational dynamics book, "The Numerical Reuleaux Method" (200 pages, first part book, 2019), the second is a sociological and medical philosophy book (300 pages, 2019). Casesnoves best achievement is the Numerical Reuleaux Method in dynamics and non-linear optimization. This Numerical Reuleaux Method constitutes, among others, an advance in Space Aerodynamics Computational Methods and Bioengineering. Casesnoves speaks, reads, and writes Estonian language at B1-2 levels, with corresponding official diplomas. Also participates/ registers in sporting Estonian activities such as Tallinn Marathon. Casesnoves played as defender and middle-fielder at Junior Madrid Football League, and as physician is supporting agnostic healthy life and all sporting activities. Casesnoves publications are always according to International Scientific Standards. He sets his medical technology papers, especially in cancer radiotherapy methods, always in open access for benefit and use of any public health system according to the Fundamental Right for health care. Recently has written new mathematical modeling radiotherapy articles affiliated to Estonia, Tallinn (2019). Casesnoves scientific service since 2016 to the Free and Independent Republic of

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