Distributed Evolutionary Design of HIFU Treatment Plans

Jakub Chlebik
Centre of Excellence IT4Innovations
Faculty of Information Technology
Brno University of Technology
Brno, Czech Republic
ichlebik@fit.vut.cz

Jiri Jaros
Centre of Excellence IT4Innovations
Faculty of Information Technology
Brno University of Technology
Brno, Czech Republic
jarosjir@fit.vutbr.cz

ABSTRACT

High-Intensity Focused Ultrasound (HIFU) is a modern and still evolving technique used to treat a variety of solid malignant cells in a well-defined volume. Using HIFU treatment allows a noninvasive and non-ionising approach, in comparison to more conventional cancer treatments, that can result in a multitude of complications after treatment.

In recent years, a realistic thermal model using patient-specific materials was introduced and an evolutionary strategy was employed to design a HIFU treatment plan. However, the execution times of such a model were too prohibitive to allow routine use. In this poster, we present the latest results of experiments carried on a further optimized fitness model using a distributed evolutionary algorithm. The experiments showed up to a total of 6 time decrease in evaluation time.

CCS CONCEPTS

• **Computing methodologies → Modeling and simulation**; *Parallel computing methodologies*; • **Theory of computation → Evolutionary algorithms**; • **Applied computing** → *Consumer health.*

KEYWORDS

Evolutionary strategy, Island model, Farmer-Workers model, HIFU, Treatment planning, k-Wave

ACM Reference Format:
Jakub Chlebik and Jiri Jaros. 2021. Distributed Evolutionary Design of HIFU Treatment Plans. In *2021 Genetic and Evolutionary Computation Conference Companion (GECCO '21 Companion), July 10–14, 2021, Lille, France.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3449726.3459550

1 INTRODUCTION

This section describes the encoding of the treatment plans and the objective function used to evaluate solutions, based on the tissue-realistic heat diffusion, developed as part of the k-Wave toolbox [6, 7].

Encoding and fitness. The driving force of the HIFU treatment is a coagulative thermal necrosis caused by raising the temperature of the focal region by tens of degrees [3]. The treatment of large target areas using HIFU requires multiple sonications to effectively cover this area. The amount of energy delivered during a single sonication is given by the length of the sonication, represented by a value of t_{on} and the length of the subsequent cooling interval t_{off}. If we consider 2D problems, one sonication can then be defined as follows:

$$S_i = (x_i, y_i, t_{on}, t_{off})$$

Optimization of a treatment plan is defined as finding the optimal consecutive sequence of targets for a given number of sonications, to destroy the targeted volume of a malignant tissue, while preserving its surrounding tissue. This calculation is composed of several stages, detailed in [1].

Equation 1 describes the process of calculation of the resulting fitness value.

$$f = \int_0^Y \int_0^X ((D * \overline{C}) + (P * C)))\, dx\, dy. \quad (1)$$

X and Y are domain sizes along the x and y axes, respectively. D is a target map specifying the malignant area, C is a binary mask representing the state of the tissue after the treatment, using the CEM_{43} metric [5]. $\overline{C}$ is a complementary mask for C and P is the prohibited area.

2 EXPERIMENTS

This section overviews the benchmarks used for experiments and the distributed evolution models employed. Results can be seen in Fig. 1 and 2.

Distributed computing models. Farmer-Workers (FW) is the most simplistic distributed computing model, using one large population spread across all computational nodes. Island-based (I) model uses multiple populations, one per island, and a periodic exchange of individuals across islands to maintain diversity in otherwise small populations. Each model uses 6 nodes (x6) and is compared against the standard sequential model (SQ) using the same size of the population as the FW model. For the optimization process, we decided to use state-of-the-art optimization algorithm CMA-ES [2]. This decision was based on empirical evidence comparing multiple evolutionary algorithms with different driving forces.

Setup. For each of the models, 15 independent runs were executed on two different benchmarks based on a realistic representative map of a biological medium, acquired from the open-source Austin-Woman voxel model [4]. Both can be seen in Fig. 3. Previous restriction of 48 hours [1] is now changed to a maximum of 8 hours per run. Lastly, experiments are performed for 6 (6x) and 20 (20x) sonications to cover a wider spectrum of HIFU treatment use-cases.

GECCO '21 Companion, July 10–14, 2021, Lille, France

ACM ISBN 978-1-4503-8351-6/21/07.
https://doi.org/10.1145/3449726.3459550

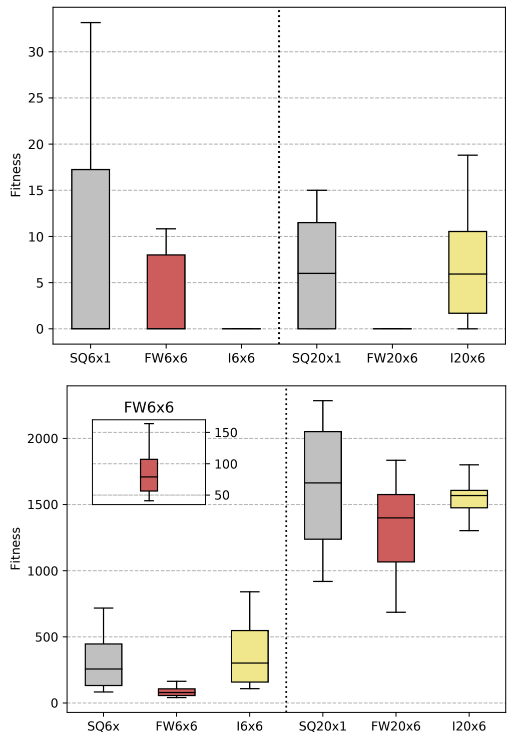

Figure 1: The end results of treatment planning for 6 and 20 sonications solving the monolithic target (top) and flower target (bottom).

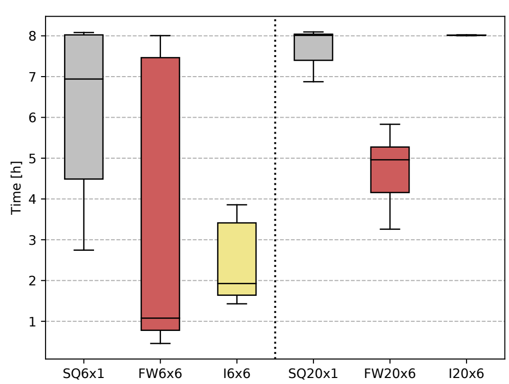

Figure 2: The time needed for each distributed model solving the monolithic use-case to end. All runs were capped at 8 hours maximum.

3 CONCLUSION

This poster has presented the results of our latest work on optimizing HIFU treatment plans. Thanks to the use of distributed evolution models, we were able to move a previous computational time limit of 48 hours to 8 hours without any loss in precision. This enabled the use of another realistic setting with a higher number of sonications. Next, a whole new use-case based on a real-life scenario was presented. Because of the difficulty in finding an optimal solution, using this newly introduced model was not previously feasible. The newly introduced flower target still requires more work done before realistic use. The monolithic target use-case is now solvable in a reasonable amount of time and is ready to transition to the 3D solving.

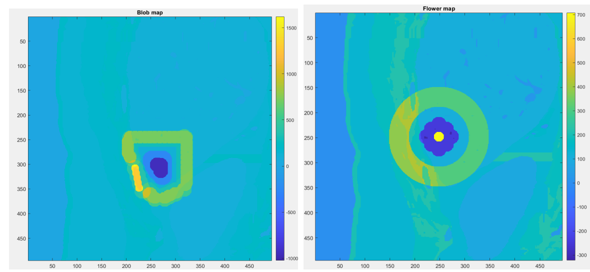

Figure 3: The visualisation of two used benchmarks, both using the AustimWoman liver lobe in the background. Left picture represents the standard monolithic target and the penalization area surrounding it.

ACKNOWLEDGMENTS

This work was supported by The Ministry of Education, Youth and Sports from the Large Infrastructures for Research, Experimental Development and Innovations project "IT4Innovations National Supercomputing Center – LM2018140". This work was supported by Brno University of Technology under project number FIT-S-20-6309.

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