

# Concurrent Wait-Free Red Black Trees

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**Abstract**—Our re-implementation of Natarajan, Savoie, and Mittal’s wait-free algorithm [1] seeks to not only imitate the concurrent data structure presented, but also transform it into a transactional data structure using the RSTM library. We are implementing a concurrently managed red-black tree using wait-free algorithms designed and presented in [?]. We will be writing these algorithms using C++ as our programming language. Concurrency during manipulation of a tree data structure is not plausible without additional (and creative) data structures because of the multiple instructions that rotations perform during the re-balancing of the tree. Using the techniques outlined in [?], we will have a concurrent algorithm that makes progress, is linearizable, and correct. Experiments run by the authors of this implementation prove that their solution provides “significantly better performance”[?] than other attempts that preceded it, including both attempts at concurrency and lock-based implementations.

## I. INTRODUCTION

This wait-free implementation of the Red Black tree data structure boasts `search()`, `insert()`, `update()`, and `delete()` functions, all executed utilizing single-word compare-and-swap instructions. The data structure’s concurrent implementation employs the use of “windows”, which are overlapping snapshots of the current state of the Red Black tree within the scope of the windows’ root node. Each of these windows is a balanced Red Black tree itself, and pushing a modified window into the windows’ origin will result in a correct, linearizable solution. This is because the window itself can be atomically swapped, where rotations are done inside a modified window, and using a single-word compare-and-swap, are placed back into the node where the window originated. This solution also strives for optimal concurrency by introducing an array that holds pending instructions (using the *announce* variable) and decides whether or not a thread will assist by checking for conflicts with its own update operation (using a *gate* variable, given to each record in the tree). An modify operation may also help during a search operation to ensure that the search operation eventually terminates [?]. This is necessary because this implementation avoids copying windows unnecessarily, and instead traversing to the next root when such a transaction would occur. These additions to the traditional sequential Red Black tree allow for an efficient algorithm that has outperformed other attempts at this implementation of the concurrent wait-free Red Black

tree data structure.

*Related Work:* There have been a few more recent attempts at this wait-free implementation of manipulating red-black trees concurrently. Notably, in 2014, there was a thesis written proposing that instead of a Top-Down approach to obtaining ownership of nodes within the tree, that working from Bottom-Up approach would “[allow] operations interested in completely disparate portions of the tree to execute entirely uninhibited”[?].

## II. CURRENT STATE, PROBLEMS, AND PLANNING

We do not foresee many changes between the given implementation in [?] and our own, because the psuedo code written in the document is easily translatable to actual C++ code. However, our own implementation’s class structure will diverge from their own, because we will be reverse engineering it from references in the algorithms provided.

Because we are developing in a multithreaded fashion in C++, we are using the POSIX Threads library (`pthread.h`) to create, join, and monitor our threads. For atomic operations such as Compare and Swap (CAS), and for utilization of atomic variables we will be using the C++ Standard Library (`std::atomic`). The usage of these libraries will be the tools we use to create the concurrent data structure.

As of right now, our task is to properly be able to handle the external record for a node’s value, as it is not being stored inside the node itself for this implementation. We have encountered some issues simply with translation of these algorithms, figuring out the best way to bring them into the code without sacrificing correctness. We struggled a bit with deciding whether keeping the decision made by the authors of this implementation to “assume the tree is never empty and always contains at least one node”[?]. For the purpose of getting our solution up and running, we are current following the practices of the authors.

Our plan of action for completing this project is to have a working solution for the concurrent data structure by the end of March. Moving forward onto part two from April till the final due date. In the event that we are able to complete both parts earlier than expected, we hope to conduct further testing and experimentation, possibly further improving upon our solution or rectifying any overlooked sections where our implementation is unoptimized.

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- A graph within a graph is an inset, not an insert. The word *alternatively* is preferred to the word *alternately* (unless you really mean something that alternates).
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TABLE I  
AN EXAMPLE OF A TABLE

One	Two
Three	Four

We suggest that you use a text box to insert a graphic (which is ideally a 300 dpi TIFF or EPS file, with all fonts embedded) because, in an document, this method is somewhat more stable than directly inserting a picture.

Fig. 1. Inductance of oscillation winding on amorphous magnetic core versus DC bias magnetic field

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity Magnetization, or Magnetization, M, not just M. If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write Magnetization (A/m) or Magnetization A[m(1)], not just A/m. Do not label axes with a ratio of quantities and units. For example, write Temperature (K), not Temperature/K.

## VI. CONCLUSIONS

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

## APPENDIX

Appendices should appear before the acknowledgment.

## ACKNOWLEDGMENT

The preferred spelling of the word acknowledgment in America is without an e after the g. Avoid the stilted expression, One of us (R. B. G.) thanks . . . Instead, try R. B. G. thanks. Put sponsor acknowledgments in the unnumbered footnote on the first page.

References are important to the reader; therefore, each citation must be complete and correct. If at all possible, references should be commonly available publications.

## REFERENCES

- [1] A. Natarajan, L. Savoie, & N. Mittal 2013, 'Concurrent Wait-Free Red Black Trees', The University of Texas at Dallas, Richardson, TX 75080, USA
- [2] V. Kubushyn 2014, 'Concurrent Localized Wait-Free Operations on a Red Black Tree', University of Nevada, Las Vegas
- [3] H. Poor, An Introduction to Signal Detection and Estimation. New York: Springer-Verlag, 1985, ch. 4.
- [4] B. Smith, An approach to graphs of linear forms (Unpublished work style), unpublished.
- [5] E. H. Miller, A note on reflector arrays (Periodical styleAccepted for publication), IEEE Trans. Antennas Propagat., to be published.
- [6] J. Wang, Fundamentals of erbium-doped fiber amplifiers arrays (Periodical styleSubmitted for publication), IEEE J. Quantum Electron., submitted for publication.
- [7] C. J. Kaufman, Rocky Mountain Research Lab., Boulder, CO, private communication, May 1995.
- [8] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, Electron spectroscopy studies on magneto-optical media and plastic substrate interfaces(Translation Journals style), IEEE Transl. J. Magn.Jpn., vol. 2, Aug. 1987, pp. 740741 [Dig. 9th Annu. Conf. Magnetism Japan, 1982, p. 301].
- [9] M. Young, The Techincal Writers Handbook. Mill Valley, CA: University Science, 1989.
- [10] J. U. Duncombe, Infrared navigationPart I: An assessment of feasibility (Periodical style), IEEE Trans. Electron Devices, vol. ED-11, pp. 3439, Jan. 1959.
- [11] S. Chen, B. Mulgrew, and P. M. Grant, A clustering technique for digital communications channel equalization using radial basis function networks, IEEE Trans. Neural Networks, vol. 4, pp. 570578, July 1993.
- [12] R. W. Lucky, Automatic equalization for digital communication, Bell Syst. Tech. J., vol. 44, no. 4, pp. 547588, Apr. 1965.
- [13] S. P. Bingulac, On the compatibility of adaptive controllers (Published Conference Proceedings style), in Proc. 4th Annu. Allerton Conf. Circuits and Systems Theory, New York, 1994, pp. 816.
- [14] G. R. Faulhaber, Design of service systems with priority reservation, in Conf. Rec. 1995 IEEE Int. Conf. Communications, pp. 38.
- [15] W. D. Doyle, Magnetization reversal in films with biaxial anisotropy, in 1987 Proc. INTERMAG Conf., pp. 2.2-12.2-6.
- [16] G. W. Juette and L. E. Zeffanella, Radio noise currents n short sections on bundle conductors (Presented Conference Paper style), presented at the IEEE Summer power Meeting, Dallas, TX, June 2227, 1990, Paper 90 SM 690-0 PWRS.
- [17] J. G. Kreifeldt, An analysis of surface-detected EMG as an amplitude-modulated noise, presented at the 1989 Int. Conf. Medicine and Biological Engineering, Chicago, IL.
- [18] J. Williams, Narrow-band analyzer (Thesis or Dissertation style), Ph.D. dissertation, Dept. Elect. Eng., Harvard Univ., Cambridge, MA, 1993.

- [19] N. Kawasaki, Parametric study of thermal and chemical nonequilibrium nozzle flow, M.S. thesis, Dept. Electron. Eng., Osaka Univ., Osaka, Japan, 1993.
- [20] J. P. Wilkinson, Nonlinear resonant circuit devices (Patent style), U.S. Patent 3 624 12, July 16, 1990.