

Turning Manual Concurrent Memory Reclamation into Automatic Reference Counting

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Abstract

Safe memory reclamation (SMR) schemes are an essential tool for lock-free data structures and concurrent programming. However, manual SMR schemes are notoriously difficult to apply correctly, and automatic schemes, such as reference counting, have been argued for over a decade to be too slow for practical purposes. A recent wave of work has disproved this long-held notion and shown that reference counting can be as scalable as hazard pointers, one of the most common manual techniques. Despite these tremendous improvements, there remains a gap of up to 2x or more in performance between these schemes and faster manual techniques such as epoch-based reclamation (EBR).

In this work, we first advance these ideas and show that in many cases, automatic reference counting can in fact be as fast as the fastest manual SMR techniques. We generalize our previous Concurrent Deferred Reference Counting (CDRC) algorithm to obtain a method for converting any standard manual SMR technique into an automatic reference counting technique with a similar performance profile. Our second contribution is extending this framework to support weak pointers, which are reference-counted pointers that automatically break pointer cycles by not contributing to the reference count, thus addressing a common weakness in reference-counted garbage collection.

Our experiments with a C++ library implementation show that our automatic techniques perform in line with their manual counterparts, and that our weak pointer implementation outperforms the best known atomic weak pointer library by up to an order of magnitude on high thread counts. All together, we show that the ease of use of automatic memory management can be achieved without significant cost to practical performance or general applicability.

CCS Concepts: • Computing methodologies → Concurrent algorithms.

Keywords: automatic memory reclamation, concurrency, smart pointers, lock-free

1 Introduction

Manually managing memory for concurrent programs is notoriously difficult and prone to errors. One solution is to

only work in fully garbage-collected languages but this is not always possible, and comes with its own performance problems, often yielding no control to the user. On the other hand, manually managing memory can be challenging even for sequential programs, but the concurrent setting makes it significantly more difficult. In particular, concurrent programs can suffer from read-reclaim races [12] with potentially disastrous results. For example, one thread could overwrite a location containing a pointer to an object, and then reclaim the memory for that object since it is not being referred to anymore. Another thread executing concurrently could read the location just before it is overwritten. It could then access the contents of the object, which by now might have been reclaimed and perhaps even been reallocated for another use, or returned to the operating system.

Over the past two decades, researchers have developed a broad set of techniques to avoid such read-reclaim races. The goal of these techniques is to delay the destruction and reclamation on an object until it can be ensured that no thread can still access the object. These techniques are generally referred to as *safe memory reclamation* (SMR), and include approaches such as read-copy-update (RCU) [10], epoch-based-reclamation (EBR) [8], hazard-pointers [19], pass-the-back [13], pass-the-pointer [4], interval-based reclamation (IBR) [30], Hyaline [25], and others [2, 27]. All these approaches replace the destruction of an object with a retire operation, which delays the actual destruction until it is safe.

The SMR approaches differ in how they ensure the reclamation and destruction is safe. The approaches can be partitioned broadly into two classes. *Protected-region techniques*, such as RCU, EBR, IBR, and hyaline, protect regions of code, while *protected-pointer techniques*, such as hazard-pointers, pass-the-back, and pass-the-pointer, are based on protecting individual pointers. The protected-region techniques tend to be faster since they only need a memory fence on every critical region instead of every read, but require more space due to longer delays between a retire and reclamation. Both classes of manual techniques, however, are difficult to use and can lead to subtle and hard to reproduce bugs. As evidence, Anderson et al. [1] noted several instances where manual techniques of both kinds were applied incorrectly to concurrent data structures.

An alternative approach for memory management in languages without built-in garbage collection (or even with)

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Table of Contents Turning A Manual Into An Automatic

1. Understanding the eBook Turning A Manual Into An Automatic
 - The Rise of Digital Reading Turning A Manual Into An Automatic
 - Advantages of eBooks Over Traditional Books
2. Identifying Turning A Manual Into An Automatic
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Turning A Manual Into An Automatic
 - User-Friendly Interface
4. Exploring eBook Recommendations from Turning A Manual Into An Automatic
 - Personalized Recommendations
 - Turning A Manual Into An Automatic User Reviews and Ratings
 - Turning A Manual Into An Automatic and Bestseller Lists
5. Accessing Turning A Manual Into An Automatic Free and Paid eBooks
 - Turning A Manual Into An Automatic Public Domain eBooks
 - Turning A Manual Into An Automatic eBook Subscription Services
 - Turning A Manual Into An Automatic Budget-Friendly Options

6. Navigating Turning A Manual Into An Automatic eBook Formats
 - ePub, PDF, MOBI, and More
 - Turning A Manual Into An Automatic Compatibility with Devices
 - Turning A Manual Into An Automatic Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Turning A Manual Into An Automatic
 - Highlighting and Note-Taking Turning A Manual Into An Automatic
 - Interactive Elements Turning A Manual Into An Automatic
8. Staying Engaged with Turning A Manual Into An Automatic
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Turning A Manual Into An Automatic
9. Balancing eBooks and Physical Books Turning A Manual Into An Automatic
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Turning A Manual Into An Automatic
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Turning A Manual Into An Automatic
 - Setting Reading Goals Turning A Manual Into An Automatic
 - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Turning A Manual Into An Automatic
 - Fact-Checking eBook Content of Turning A Manual Into An Automatic
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
 - Integration of Multimedia Elements

- Interactive and Gamified eBooks

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