

# 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)

<sup>\*</sup>Authors are listed in alphabetical order.

# Turning A Manual Into An Automatic

**Geoff Coffey, Susan Prosser**



## Turning A Manual Into An Automatic:

Technical Manual United States. War Department,1959      Boiler Operator's Handbook, Second Edition P.E. Heselton,2020-11-26 This book was written specifically for boiler plant operators and supervisors who want to learn how to lower plant operating costs as well as how to operate plants of all types and sizes more wisely It is newly revised with guidelines for HRSGs combined cycle systems and environmental effects of boiler operation Also included is a new chapter on refrigeration systems that addresses the environmental effects of inadvertent and intentional discharges of refrigerants Going beyond the basics of keeping the pressure up the author explains in clear terms how to set effective priorities to ensure optimal plant operation including ensuring safety and continuity of operations preventing damage managing environmental impact training replacement plant operators logging and preserving historical data and operating the plant economically      **CNC Control Setup for Milling and Turning** Peter Smid,2010 This unique reference features nearly all of the activities a typical CNC operator performs on a daily basis Starting with overall descriptions and in depth explanations of various features it goes much further and is sure to be a valuable resource for anyone involved in CNC      Boiler Operator's Handbook Carl Buzzuto,2021-12-28 With the increased interest in climate impacts sustainability and efficiency more responsibility is being placed on boiler operators to help improve performance and reduce emissions This third edition of the Boiler Operator s Handbook is intended to help such operators in the quest for improved operability and performance of their boilers and their plants The theme of this book is to operate wisely The goal is to instill not only know how but know why The main details have been provided by the original author Mr Ken Heselton This updated version has been somewhat expanded to include a wider range of examples and some of the more recent environmental requirements To illustrate these points topics include multi boiler operations understanding the plant load maintenance issues and controls Every plant is different However it is hoped that with the information provided in this book the wise operator will be able to address the various unique issues posed by the specific plant and provide timely solutions to meet the present day requirements

*Managing Computer Numerical Control Operations* Mike Lynch,1995 Provides the ideas guidelines and techniques you need to capture the full potential of your CNC equipment Nearly every aspect of CNC operations is addressed and the book is organized so you can use it as a step by step guide to efficient CNC utilization or as a shop floor reference for continuous improvement Hundreds of specific utilization boosting techniques are detailed      AF Manual United States. Department of the Air Force,1964      Lloyd's Register Technical Association Session 1985-1986 Lloyd's Register Foundation,1985-01-01 The Lloyd s Register Technical Association LRTA was established in 1920 with the primary objective of sharing technical expertise and knowledge within Lloyd s Register Publications have consistently been released on a yearly basis with a brief interruption between 1938 and 1946 These publications serve as a key reference point for best practices and were initially reserved for internal use to maximise LR s competitive advantage Today the LRTA takes a fresh approach focusing on

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**Manual, Valve Repair and Maintenance for Naval Service** United States. Navy Department. Bureau of Ships,1949

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