

Our Approach

$$\text{SMR impl} \models \text{SMR spec}$$

Data structure + SMR spec \models Property

Data structure + SMR spec \models ABA Freedom

Data structure + Garbage Collection \models Property



[POPL'19]

with Roland Meyer



Decoupling Lock-Free Data Structures from Memory Reclamation for Static Analysis

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Verification of concurrent data structures is one of the most challenging tasks in software verification. The topic has received considerable attention over the course of the last decade. Nevertheless, human-driven techniques remain cumbersome and notoriously difficult while automated approaches suffer from limited applicability. The main obstacle for automation is the complexity of concurrent data structures. This is particularly true in the absence of garbage collection. The intricacy of lock-free memory management paired with the complexity of concurrent data structures makes automated verification prohibitive.

In this work we present a method for verifying concurrent data structures and their memory management separately. We suggest two simpler verification tasks that imply the correctness of the data structure. The first task establishes an over-approximation of the reclamation behavior of the memory management. The second task exploits this over-approximation to verify the data structure without the need to consider the implementation of the memory management itself. To make the resulting verification tasks tractable for automated techniques, we establish a second result. We show that a verification tool needs to consider only executions where a single memory location is reused. We implemented our approach and were able to verify linearizability of Michael&Scott's queue and the DGLM queue for both hazard pointers and epoch-based reclamation. To the best of our knowledge, we are the first to verify such implementations fully automatically.

CCS Concepts: • **Theory of computation** → **Data structures design and analysis**; **Program verification**; *Shared memory algorithms*; *Program specifications*; *Program analysis*;

Additional Key Words and Phrases: static analysis, lock-free data structures, verification, linearizability, safe memory reclamation, memory management

ACM Reference Format:

Roland Meyer and Sebastian Wolff. 2019. Decoupling Lock-Free Data Structures from Memory Reclamation for Static Analysis. *Proc. ACM Program. Lang.* 3, POPL, Article 58 (January 2019), 31 pages. <https://doi.org/10.1145/3290371>

1 INTRODUCTION

Data structures are a basic building block of virtually any program. Efficient implementations are typically a part of a programming language's standard library. With the advent of highly concurrent computing being available even on commodity hardware, concurrent data structure implementations are needed. The class of lock-free data structures has been shown to be particularly efficient. Using fine-grained synchronization and avoiding such synchronization whenever possible results in unrivaled performance and scalability.

Unfortunately, this use of fine-grained synchronization is what makes lock-free data structures also unrivaled in terms of complexity. Indeed, bugs have been discovered in published lock-free

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Data structure + SMR impl \models Property





Our Approach

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~~$Data\ structure + SMR\text{ spec} \models Property$~~

$Data\ structure + Garbage\ Collection \models Property$

$Data\ structure + SMR\text{ spec} \models ABA\text{ Freedom}$

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Experiments



Data Structures	SMR	ABA Freedom	Linearizability
Treiber's stack	EBR	16s ✓	— ✓
	HP	19s ✓	— ✓
Michael&Scott's queue	EBR	44m ✓	— ✓
	HP	120m ✓	— ✓
DGLM queue	EBR	63m ✓	— ✓
	HP	117m ✓	— ✓