

A Novel Parallel Triangle Counting Algorithm with Reduced Communication

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Abstract—Counting and finding triangles in graphs is often used in real-world analytics for characterizing the cohesiveness and identifying communities in graphs. In this paper, we present novel sequential and parallel triangle counting algorithms based on identifying horizontal-edges in a breadth-first search (BFS) traversal of the graph. The BFS allows our algorithm to drastically reduce the number of edges examined for set intersections. Our new approach is the first communication-optimal parallel algorithm that asymptotically reduces the communication on massive graphs such as from real social networks and synthetic graphs from the Graph500 Benchmark. In our estimate from massive-scale Graph500 graphs, our new algorithms reduces the communication by 21x on a scale 36 and by 176x on a scale 42. Because communication is known to be the dominant cost of parallel triangle counting, our new parallel algorithm, to our knowledge, is now the fastest method for counting triangles in large graphs.

Index Terms—Graph Algorithms, Parallel Algorithms, High Performance Data Analytics

I. INTRODUCTION

Let $G = (V, E)$ be an undirected graph with $n = |V|$ vertices and $m = |E|$ edges. A *triangle* in the graph is a set of three vertices $\{v_a, v_b, v_c\} \in V$ such that $\{(v_a, v_b), (v_a, v_c), (v_b, v_c)\} \in E$. *Triangle counting* is defined as finding the number of unique triangles in G and is one of the fundamental problems in graph analytics. In this paper we consider the problem of both counting and finding triangles in G . Triangle counting is used in graph analytics such as clustering coefficients [1], k-truss [2], and triangle centrality [3], and its importance is recognized by its use in high performance computing benchmarks such as Graph500 [4] as well as in future architecture systems design (e.g. IARPA AGILE [5]).

Triangle counting has been studied extensively in the literature for both sequential and parallel algorithms. Latapy [6] provides an extensive literature of sequential triangle counting and finding algorithms. The fastest sequential triangle counting algorithm for sparse graphs due to Itai and Rodeh [7] runs in

$\Theta(m^{3/2})$ time and $\Theta(n^2)$ space, which is cost-prohibitive for practical use on large graphs.

Triangle counting algorithms are often based on techniques such as list intersection, matrix multiplication and subgraph matching [8]. The three main list intersection based triangle counting algorithms are summarized as: the node iterator, the edge iterator and the forward algorithm (detailed in Section III).

Cohen [9] designed a novel map-reduce parallelization of triangle counting that generates *open wedges* between triples of vertices in the graph, and determines if a closing edge exists that completes a triangle. Most parallel approaches for triangle counting [10], [11] partition the sparse graph data structure across the compute nodes, and follow this strategy of generating open wedges that are sent to other compute nodes to find whether or not a closing edge exists. As such, the running time of parallel triangle counting is often dominated by the communication time for these open wedges.

In fact, most parallel triangle counting algorithms are based on generating open wedges (also known as 2-paths) and checking whether or not a closing edge exists. This approach results in an overabundance of communication because each graph edge is sent repeatedly, the repetition factor being the degree of one of its endpoints. One way to view our new approach is that rather than send all open wedges in the graph, we reverse this and send potential closing edges once, resulting in asymptotically less communication. In this paper, we present novel sequential and parallel triangle counting algorithms. Our contributions include:

- A new sequential triangle counting and finding algorithm that runs in $O(m \cdot d_{\max})$ time and $O(n + m)$ space, where d_{\max} is the maximal degree of a vertex $v \in V$. The algorithm uses breadth-first search to identify horizontal-edges, and uses the intersection of the endpoints of each horizontal-edge to determine triangles.
- A novel communication-optimal parallel algorithm for triangle counting and finding that asymptotically reduces the communication from all prior parallel approaches. The new approach has a total communication volume of $O(m)$ and is the first parallel algorithm to achieve this.

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The Parallel Triangle A Story Of Coming To Terms With Sexual Indentity

**The Johns Hopkins Hospital, Lauren
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The Parallel Triangle Terry Pinaud, 2002-12 This is a masterfully composed story of an American missionary kid growing up amongst the Luo people in Kenya attending a boarding school in the midst of the Mau Mau Emergency and straddling diverse cultures on two continents Skoda is an extraordinarily keen observer with great intellectual curiosity and verbal dexterity The end result is beautiful prose which intertwines deeply personal experiences with detailed historical geographic and cultural information In closing Skoda rewards the reader with A Code of Behavior and A Declaration of Rights designed for universal application To refer to this book only as a personal memoir is to minimize the daring scope of its content yet it is Skoda's personality and personal life experiences that enhance every page *Virginia Woolf and the Power of Story* Linda Nicole Blair, 2017-03-05 From novels to films our everyday lives are filled with stories that comfort and connect us and enable new ways of thinking One of the most innovative writers in modern history Virginia Woolf changed the landscape of fiction and challenged our notions of what it means to be human Her novels invite readers to envision a world in which stories have the power to effect positive change This book explores the phenomenon of Story as practiced by Woolf interpreting her work in the context of literary Darwinism a critical approach focusing on patterns of innate human behavior **The Encyclopedia of Twentieth-Century Fiction, 3 Volume Set** Brian W. Shaffer, 2011-01-18 This Encyclopedia offers an indispensable reference guide to twentieth century fiction in the English language With nearly 500 contributors and over one million words it is the most comprehensive and authoritative reference guide to twentieth century fiction in the English language Contains over 500 entries of 1000-3000 words written in lucid jargon free prose by an international cast of leading scholars Arranged in three volumes covering British and Irish Fiction American Fiction and World Fiction with each volume edited by a leading scholar in the field Entries cover major writers such as Saul Bellow Raymond Chandler John Steinbeck Virginia Woolf A S Byatt Samuel Beckett D H Lawrence Zadie Smith Salman Rushdie V S Naipaul Nadine Gordimer Alice Munro Chinua Achebe J M Coetzee and Ng g Wa Thiong o and their key works Examines the genres and sub genres of fiction in English across the twentieth century including crime fiction Sci Fi chick lit the noir novel and the avant garde novel as well as the major movements debates and rubrics within the field such as censorship globalization modernist fiction fiction and the film industry and the fiction of migration diaspora and exile **Teaching Gender and Sexuality at School** Tara Goldstein, 2018-12-17 In a set of compelling letters to teachers Tara Goldstein addresses a full range of issues facing lesbian gay bisexual transgender and queer LGBTQ students and families at elementary and secondary school Goldstein talks to teachers about how they can support LGBTQ students and families by normalizing LGBTQ lives in the curriculum challenging homophobic and transphobic ideas and building an inclusive school culture that both expects and welcomes LGBTQ students and their families Moving and energizing Teaching Gender and Sexuality at School provides readers with the knowledge and resources they need to create safer and more positive classrooms and discusses what it takes to build authentic trusting

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Hollywood Fantasies of Miscegenation Susan Courtney, 2021-12-07 Hollywood Fantasies of Miscegenation analyzes white fantasies of interracial desire in the history of popular American film From the first interracial screen kiss of 1903 through the Production Code s nearly thirty year ban on depictions of miscegenation to the contemplation of mixed marriage

in *Guess Who's Coming to Dinner* 1967 this book demonstrates a long popular yet underexamined record of cultural fantasy at the movies With ambitious new readings of well known films like D W Griffith's 1915 epic *The Birth of a Nation* and of key forgotten films and censorship documents Susan Courtney argues that dominant fantasies of miscegenation have had a profound impact on the form and content of American cinema What does it mean Courtney asks that the image of the black rapist became a virtual cliché while the sexual exploitation of black women by white men under slavery was perpetually repressed What has this popular film legacy invited spectators to remember and forget How has it shaped our conceptions of and relationships to race and gender Richly illustrated with more than 140 images *Hollywood Fantasies of Miscegenation* carefully attends to cinematic detail revising theories of identity and spectatorship as it expands critical histories of race sex and film Courtney's new research on the Production Code's miscegenation clause also makes an important contribution inviting us to consider how that clause was routinely interpreted and applied and with what effects

The Harriet Lane Handbook Johns Hopkins Hospital, Kristin Arcara, Megan Tschudy, 2011-06-08 Trusted by generations of residents and practitioners *The Harriet Lane Handbook* from The Johns Hopkins University remains your first choice for fast accurate information on pediatric diagnosis and treatment Now even more convenient to carry it's your go to resource for a wealth of practical information including the latest treatment and management recommendations immunization schedules procedures and therapeutic guidelines as well as a unique comprehensive drug formulary New information on dermatology treatments eczema complications lead poisoning and signs of child abuse keeps you completely up to date You'll also have easy access to the entire contents online with frequent updates to drug information treatment protocols vaccination schedules and downloadable images at www.expertconsult.com Benefit from time tested practical wisdom from the first book written by residents for residents reviewed by expert faculty at The Johns Hopkins Hospital and essential for all health care professionals who treat children Find information quickly and easily even in the most demanding circumstances with a modified outline format Rely on the most dependable drug information available with the thoroughly updated one of a kind pediatric formulary Ensure accurate and efficient diagnosis and treatment with all new coverage of dermatology treatments eczema complications and lead poisoning as well as new CDC immunization schedules vaccine abbreviations and full color images of the signs of child abuse Access the complete contents online at www.expertconsult.com including frequent updates to the trusted and comprehensive Pediatric Drug Formulary Carry it more easily in your pocket with its smaller more concise format still delivering the same high quality information you can refer to with confidence but in a more convenient size

The Harriet Lane Handbook E-Book The Johns Hopkins Hospital, Lauren Kahl, Helen K Hughes, 2017-04-02 Written by residents for residents and reviewed by expert faculty at The Johns Hopkins Hospital Lauren Kahl MD and Helen K Hughes MD MPH *The Harriet Lane Handbook* 21st Edition remains your 1 source of pediatric point of care clinical information Updated and expanded content as well as increased online coverage keeps you fully current with new guidelines practice

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The Labyrinth of Universality

Hena Maes-Jelinek,2006 The complete sixth series of the BBC comedy sketch show hosted by Ronnie Barker and Ronnie Corbett which in its heyday was as much of a British institution as roast beef and Yorkshire pudding Each programme begins and ends with the pair seated behind a desk reading quick fire news reports In between in a packed programme tonight there are sketches drama serials musical routines and a rambling monologue from Ronnie Corbett before the pair finally sign off with their famous catchphrase It s goodnight from me And it s goodnight from him Goodnight

Textbook of Pediatric

Rheumatology E-Book James T. Cassidy,Ross E Petty,Ronald M. Laxer,Carol B Lindsley,2010-10-15 Textbook of Pediatric Rheumatology examines the full spectrum of rheumatologic diseases and non rheumatologic musculoskeletal disorders in children and adolescents detailing the presentation differential diagnosis course management and prognosis of every major condition Drs James T Cassidy Ross E Petty Ronald M Laxer and Carol B Lindsley discuss recent developments in diagnosis treatment genetics immunology imaging and more Diagnose and treat effectively through exhaustive reviews of the complex symptoms and signs and lab abnormalities that characterize these clinical disorders Choose treatment protocols based on the best scientific evidence available today Apply the knowledge and experience of the leading experts in the field Keep current with coverage of new topics including macrophage activation syndrome pediatric sarcoidosis uveitis imaging and occupational and physical therapy Tap into detailed discussions of recent advances in the field new research on the immunologic mechanisms of inflammatory disease and new developments on biologic treatments for arthritis in ten new chapters Master complex concepts and key techniques with a full color design and full color illustrations

Judging the

Boy Scouts of America Richard J. Ellis,2014-05-23 As Americans we cherish the freedom to associate However with the freedom to associate comes the right to exclude those who do not share our values and goals What happens when the freedom of association collides with the equally cherished principle that every individual should be free from invidious discrimination This is precisely the question posed in Boy Scouts of America v James Dale a lawsuit that made its way through the courts over the course of a decade culminating in 2000 with a landmark ruling by the U S Supreme Court In

Judging the Boy Scouts of America Richard J Ellis tells the fascinating story of the Dale case placing it in the context of legal principles and precedents Scouts policies gay rights and the culture wars in American politics The story begins with James Dale a nineteen year old Eagle Scout and assistant scoutmaster in New Jersey who came out as a gay man in the summer of 1990 The Boy Scouts citing their policy that denied membership to avowed homosexuals promptly terminated Dale s membership Homosexuality the Boy Scout leadership insisted violated the Scouts pledge to be morally straight With the aid of the Lambda Legal Defense Fund Dale sued for discrimination Ellis tracks the case from its initial filing in New Jersey through the final decision of the U S Supreme Court in favor of the Scouts In addition to examining the legal issues at stake including the effect of the Supreme Court s ruling on the law of free association Ellis also describes Dale s personal journey and its intersection with an evolving gay rights movement Throughout he seeks to understand the puzzle of why the Boy Scouts would adopt and adhere to a policy that jeopardized the organization s iconic place in American culture and finally explores how legal challenges and cultural changes contributed to the Scouts historic policy reversal in May 2013 that ended the organization s ban on gay youth though not gay adults *The Advocate* ,2003-01-21 The Advocate is a lesbian gay bisexual transgender LGBT monthly newsmagazine Established in 1967 it is the oldest continuing LGBT publication in the United States Chris Claremont J. Andrew Deman,2025-09-25 Chris Claremont b 1950 is best known for his landmark sixteen year author run on Uncanny X Men This is the longest author run in Marvel Comics history one that saw X Men go from a title on the verge of cancellation to one of the most popular comics for over a decade and eventually a multibillion dollar film franchise While Claremont s influence on popular culture is becoming more widely recognized this volume offers an in depth exploration of how his life shaped his work and the deep sources of inspiration behind his iconic characters and storylines From Britain to Israel to the New York demimonde Claremont s relationships education upbringing collaborations and faith all contribute to his voice and to the creations that he shaped The story of Chris Claremont is the story of a creator who achieved popular success whilst making significant artistic contributions to his chosen medium including the first African American superheroine the first Black superhero team leader the first canonically Jewish Marvel superhero extensive queer subtext notable BDSM imagery the first superhero team with a strong female roster and the best selling single issue comic of all time This volume celebrates an extraordinary career and marvels at how Claremont accomplished all of this within mainstream comics **Truman Capote** Sterling Professor of Humanities Harold Bloom,2014-05-14 Presents a collection of critical essays on the works of Truman Capote **Evaluation for a Caring Society** Merel Visse,Tineke A. Abma,2018-02-01 This book highlights views on responsive participatory and democratic approaches to evaluation from an ethos of care It critically scrutinizes and discusses the invisibility of care in our contemporary Western societies and evaluation practices that aim to measure practices by external standards Alternatively the book proposes several foci for evaluators who work from a care perspective or wish to encourage a caring society This is a society that sees evaluation and

care as a continuously unfolding relational practice of moral political learning contributing to life sustaining webs At one level is the evaluator s immediately responsive and interpersonal encounter with the personal troubles of social actors most visible as Mills originally pointed out in an individual s biography and in those social settings directly open to the individual s lived experience At another level the sociological and political level the evaluator operates at what Mills called the arena of public issues where immediate personal troubles are seen not only as problems encountered by individuals but as the result of structural and political arrangements in society evaluation for a caring society is thought to operate at both levels Thomas A Schwandt Professor Emeritus University of Illinois at Urbana Champaign The intricate relationship between evaluation and care is hardly addressed by evaluators or caregivers This book fills a gap as it focuses on the relationship between evaluation and care and provides a multitude of examples of evaluation as a caring practice the book can serve as an antidote to the present day haste in social practices and contribute in form and content to developing an evaluation practice which may foster a caring society Guy Widdershoven Professor of Philosophy and Ethics of Medicine and head of the Department of Medical Humanities at VU University Medical Center VU University Amsterdam The Century Dictionary: The Century dictionary ,1895 **The Hanging Figure** Christopher Morris,2002-07-30 Adopts a figural and deconstructive approach to suspense focusing on representations of hanging figures in the films of Alfred Hitchcock **Framing Hitchcock** Sidney Gottlieb,Christopher Brookhouse,2002 An engaging look at Alfred Hitchcock s work from all angles culled from an authoritative source of Hitchcock film commentary In its ten year history the Hitchcock Annual has established itself as a key source of historical information and critical commentary on one of the central figures in film history and arguably one of the most important artists of the twentieth century Fans of Alfred Hitchcock both scholars and general readers alike will be entertained and informed by this selection of writings which offers an overview of the current thinking on the filmmaker and his work The articles span his career and cover a wide range of topics from archeological investigations uncovering new details about his working methods and conditions to incisive analyses of the films themselves The collection begins with rare insights into Hitchcock s early years including his work in Germany and his silent film Easy Virtue which with its metaphoric play on the concept of being framed dramatizes aspects of the human condition to which Hitchcock returned repeatedly Commentators explore a variety of themes including the centrality of kissing shots and sequences in nearly all the films and images of women s handbags as elements of suspense and sexual tension in such films as Dial M for Murder and Psycho Other essays examine the influence of Vertigo The Birds and Frenzy on Fran ois Truffaut the remaking of Psycho and feminist interpretations of Shadow of a Doubt Interviews with Jay Presson Allen and Evan Hunter illuminate Hitchcock s working relationship with screenwriters actors and actresses Written by established as well as emerging critics of Hitchcock this fascinating collection will help shape future appreciation and interpretation of an enormously important and influential filmmaker

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