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# On-Chip Photonic Interconnects

A Computer Architect's Perspective

# On Chip Photonic Interconnects A Computer Architect S Perspective Matthew Ferrens

**Christopher J. Nitta, Matthew  
Farrens, Venkatesh Akella**



## **On Chip Photonic Interconnects A Computer Architect S Perspective Matthew Ferrens:**

*On-Chip Photonic Interconnects* Christopher J. Nitta, Matthew Farrens, Venkatesh Akella, 2022-06-01 As the number of cores on a chip continues to climb architects will need to address both bandwidth and power consumption issues related to the interconnection network Electrical interconnects are not likely to scale well to a large number of processors for energy efficiency reasons and the problem is compounded by the fact that there is a fixed total power budget for a die dictated by the amount of heat that can be dissipated without special and expensive cooling and packaging techniques Thus there is a need to seek alternatives to electrical signaling for on chip interconnection applications Photonics which has a fundamentally different mechanism of signal propagation offers the potential to not only overcome the drawbacks of electrical signaling but also enable the architect to build energy efficient scalable systems The purpose of this book is to introduce computer architects to the possibilities and challenges of working with photons and designing on chip photonic interconnection networks

**Power-Efficient Computer Architectures** Magnus Sjölander, Margaret Martonosi, Stefanos Kaxiras, 2022-05-31 As Moore s Law and Dennard scaling trends have slowed the challenges of building high performance computer architectures while maintaining acceptable power efficiency levels have heightened Over the past ten years architecture techniques for power efficiency have shifted from primarily focusing on module level efficiencies toward more holistic design styles based on parallelism and heterogeneity This work highlights and synthesizes recent techniques and trends in power efficient computer architecture Table of Contents Introduction Voltage and Frequency Management Heterogeneity and Specialization Communication and Memory Systems Conclusions Bibliography Authors Biographies

**FPGA-Accelerated Simulation of Computer Systems** Hari Angepat, Derek Chiou, Eric S. Chung, James C. Hoe, 2022-05-31 To date the most common form of simulators of computer systems are software based running on standard computers One promising approach to improve simulation performance is to apply hardware specifically reconfigurable hardware in the form of field programmable gate arrays FPGAs This manuscript describes various approaches of using FPGAs to accelerate software implemented simulation of computer systems and selected simulators that incorporate those techniques More precisely we describe a simulation architecture taxonomy that incorporates a simulation architecture specifically designed for FPGA accelerated simulation survey the state of the art in FPGA accelerated simulation and describe in detail selected instances of the described techniques Table of Contents Preface Acknowledgments Introduction Simulator Background Accelerating Computer System Simulators with FPGAs Simulation Virtualization Categorizing FPGA based Simulators Conclusion Bibliography Authors Biographies

**Die-stacking Architecture** Yuan Xie, Jishen Zhao, 2022-05-31 The emerging three dimensional 3D chip architectures with their intrinsic capability of reducing the wire length promise attractive solutions to reduce the delay of interconnects in future microprocessors 3D memory stacking enables much higher memory bandwidth for future chip multiprocessor design mitigating the memory wall problem In addition heterogenous

integration enabled by 3D technology can also result in innovative designs for future microprocessors This book first provides a brief introduction to this emerging technology and then presents a variety of approaches to designing future 3D microprocessor systems by leveraging the benefits of low latency high bandwidth and heterogeneous integration capability which are offered by 3D technology

*Single-Instruction Multiple-Data Execution* Christopher J. Hughes, 2022-05-31 Having hit power limitations to even more aggressive out of order execution in processor cores many architects in the past decade have turned to single instruction multiple data SIMD execution to increase single threaded performance SIMD execution or having a single instruction drive execution of an identical operation on multiple data items was already well established as a technique to efficiently exploit data parallelism Furthermore support for it was already included in many commodity processors However in the past decade SIMD execution has seen a dramatic increase in the set of applications using it which has motivated big improvements in hardware support in mainstream microprocessors The easiest way to provide a big performance boost to SIMD hardware is to make it wider i e increase the number of data items hardware operates on simultaneously Indeed microprocessor vendors have done this However as we exploit more data parallelism in applications certain challenges can negatively impact performance In particular conditional execution non contiguous memory accesses and the presence of some dependences across data items are key roadblocks to achieving peak performance with SIMD execution This book first describes data parallelism and why it is so common in popular applications We then describe SIMD execution and explain where its performance and energy benefits come from compared to other techniques to exploit parallelism Finally we describe SIMD hardware support in current commodity microprocessors This includes both expected design tradeoffs as well as unexpected ones as we work to overcome challenges encountered when trying to map real software to SIMD execution

**Parallel Processing, 1980 to 2020** Robert Kuhn, David Padua, 2022-05-31 This historical survey of parallel processing from 1980 to 2020 is a follow up to the authors 1981 Tutorial on Parallel Processing which covered the state of the art in hardware programming languages and applications Here we cover the evolution of the field since 1980 in parallel computers ranging from the Cyber 205 to clusters now approaching an exaflop to multicore microprocessors and Graphic Processing Units GPUs in commodity personal devices parallel programming notations such as OpenMP MPI message passing and CUDA streaming notation and seven parallel applications such as finite element analysis and computer vision Some things that looked like they would be major trends in 1981 such as big Single Instruction Multiple Data arrays disappeared for some time but have been revived recently in deep neural network processors There are now major trends that did not exist in 1980 such as GPUs distributed memory machines and parallel processing in nearly every commodity device This book is intended for those that already have some knowledge of parallel processing today and want to learn about the history of the three areas In parallel hardware every major parallel architecture type from 1980 has scaled up in performance and scaled out into commodity microprocessors and GPUs so that every personal and embedded device is a

parallel processor There has been a confluence of parallel architecture types into hybrid parallel systems Much of the impetus for change has been Moore's Law but as clock speed increases have stopped and feature size decreases have slowed down there has been increased demand on parallel processing to continue performance gains In programming notations and compilers we observe that the roots of today's programming notations existed before 1980 And that through a great deal of research the most widely used programming notations today although the result of much broadening of these roots remain close to target system architectures allowing the programmer to almost explicitly use the target's parallelism to the best of their ability The parallel versions of applications directly or indirectly impact nearly everyone computer expert or not and parallelism has brought about major breakthroughs in numerous application areas Seven parallel applications are studied in this book *Photonic Interconnects for Computing Systems* Gabriela Nicolescu, Mahdi Nikdast, Sébastien Le

Beux, 2022-09-01 In recent years there has been a considerable amount of effort both in industry and academia focusing on the design implementation performance analysis evaluation and prediction of silicon photonic interconnects for inter and intra chip communication paving the way for the design and dimensioning of the next and future generation of high performance computing systems *Photonic Interconnects for Computing Systems* provides a comprehensive overview of the current state of the art technology and research achievements in employing silicon photonics for interconnection networks and high performance computing summarizing main opportunities and some challenges The majority of the chapters were collected from presentations made at the International Workshop on Optical Photonic Interconnects for Computing Systems OPTICS held over the past two years The workshop invites internationally recognized speakers on the range of topics relevant to silicon photonics and computing systems Technical topics discussed in the book include Design and Implementation of Chip Scale Photonic Interconnects Developing Design Automation Solutions for Chip Scale Photonic Interconnects Design Space Exploration in Chip Scale Photonic Interconnects Thermal Analysis and Modeling in Photonic Interconnects Design for Reliability Fabrication Non Uniformity in Photonic Interconnects Photonic Interconnects for Computing Systems presents a compilation of outstanding contributions from leading research groups in the field It presents a comprehensive overview of the design advantages challenges and requirements of photonic interconnects for computing systems The selected contributions present important discussions and approaches related to the design and development of novel photonic interconnect architectures as well as various design solutions to improve the performance of such systems while considering different challenges The book is ideal for personnel in computer photonic industries as well as academic staff and master graduate students in computer science and engineering electronic engineering electrical engineering and photonics High-Speed Photonics Interconnects Lukas Chrostowski, Krzysztof Iniewski, 2013-04-05 Dramatic increases in processing power have rapidly scaled on chip aggregate bandwidths into the Tb/s range This necessitates a corresponding increase in the amount of data communicated between chips so as not to limit overall system performance To meet the

increasing demand for interchip communication bandwidth researchers are investigating the use of high speed optical interconnect architectures Unlike their electrical counterparts optical interconnects offer high bandwidth and negligible frequency dependent loss making possible per channel data rates of more than 10 Gb/s High Speed Photonics Interconnects explores some of the groundbreaking technologies and applications that are based on photonics interconnects From the Evolution of High Speed I/O Circuits to the Latest in Photonics Interconnects Packaging and Lasers Featuring contributions by experts from academia and industry the book brings together in one volume cutting edge research on various aspects of high speed photonics interconnects Contributors delve into a wide range of technologies from the evolution of high speed input/output I/O circuits to recent trends in photonics interconnects packaging The book discusses the challenges associated with scaling I/O data rates and current design techniques It also describes the major high speed components channel properties and performance metrics The book exposes readers to a myriad of applications enabled by photonics interconnects technology Learn about Optical Interconnect Technologies Suitable for High Density Integration with CMOS Chips This richly illustrated work details how optical interchip communication links have the potential to fully leverage increased data rates provided through complementary metal oxide semiconductor CMOS technology scaling at suitable power efficiency levels Keeping the mathematics to a minimum it gives engineers researchers graduate students and entrepreneurs a comprehensive overview of the dynamic landscape of high speed photonics interconnects

*Photonic Network-on-Chip Design* Keren Bergman, Luca P. Carloni, Aleksandr Biberman, Johnnie Chan, Gilbert Hendry, 2013-08-13 This book provides a comprehensive synthesis of the theory and practice of photonic devices for networks on chip It outlines the issues in designing photonic network on chip architectures for future many core high performance chip multiprocessors The discussion is built from the bottom up starting with the design and implementation of key photonic devices and building blocks reviewing networking and network on chip theory and existing research and finishing with describing various architectures their characteristics and the impact they will have on a computing system After acquainting the reader with all the issues in the design space the discussion concludes with design automation techniques supplemented by provided software

**Silicon Photonics for High-Performance Computing and Beyond** Mahdi Nikdast, Sudeep Pasricha, Gabriela Nicolescu, Ashkan Seyed, Di Liang, 2021-11-16 Silicon photonics is beginning to play an important role in driving innovations in communication and computation for an increasing number of applications from health care and biomedical sensors to autonomous driving datacenter networking and security In recent years there has been a significant amount of effort in industry and academia to innovate design develop analyze optimize and fabricate systems employing silicon photonics shaping the future of not only Datacom and telecom technology but also high performance computing and emerging computing paradigms such as optical computing and artificial intelligence Different from existing books in this area Silicon Photonics for High Performance Computing and Beyond presents a comprehensive overview of the current state of the art

technology and research achievements in applying silicon photonics for communication and computation. It focuses on various design development and integration challenges, reviews the latest advances spanning materials, devices, circuits, systems, and applications. Technical topics discussed in the book include Requirements and the latest advances in high performance computing systems, Device and system level challenges, and latest improvements to deploy silicon photonics in computing systems. Novel design solutions and design automation techniques for silicon photonic integrated circuits, Novel materials, devices, and photonic integrated circuits on silicon, Emerging computing technologies and applications based on silicon photonics, Silicon Photonics for High Performance Computing and Beyond presents a compilation of 19 outstanding contributions from academic and industry pioneers in the field. The selected contributions present insightful discussions and innovative approaches to understand current and future bottlenecks in high performance computing systems and traditional computing platforms and the promise of silicon photonics to address those challenges. It is ideal for researchers and engineers working in the photonics, electrical, and computer engineering industries, as well as academic researchers and graduate students. M.S. and Ph.D. in computer science and engineering, electronic and electrical engineering, applied physics, photonics, and optics.

*Photonic Computing Breakthroughs* Mei Gates, 2025-01-08

*Photonic Computing Breakthroughs* offers a comprehensive exploration of the revolutionary shift from electronic to light-based computing, focusing on how this transition promises to overcome current limitations in data processing speed and computational power. The book expertly navigates through three transformative developments: the merger of photonic circuits with semiconductor technology, the evolution of optical interconnects in data centers, and the emergence of photonic neural networks. This technical yet accessible work demonstrates how photonic computing represents a fundamental paradigm shift rather than merely an incremental improvement in computing architecture. The book's systematic approach begins with essential photonic principles and progresses through real-world implementations to future applications. Starting with foundational concepts like wave-guided light manipulation and optical switching mechanisms, it builds toward sophisticated discussions of silicon photonics integration and hybrid electro-optical systems. Particularly noteworthy is its coverage of the silicon photonics breakthrough in the early 2000s, which marked a turning point in making photonic computing commercially viable. Through detailed case studies and research evidence from leading institutions, the book examines practical applications in data centers, high-frequency trading systems, and scientific computing installations. It thoughtfully addresses technical challenges such as photonic-electronic interfaces and thermal management while maintaining a balanced perspective on competing implementation strategies. This comprehensive treatment makes it an invaluable resource for electronics engineers, computer scientists, and technology professionals seeking to understand and leverage the potential of light-based computing.

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