Raj Joshi, Ph.D.

CONTACT INFORMATION

Email: rajjoshi@comp.nus.edu.sg
Phone: +65 9353 9356
Website: rajkiranjoshi.github.io | Google Scholar

ADDRESS:
412 Commonwealth Ave W,
#03-3027, Singapore 120412

RESEARCH SUMMARY

I am passionate about designing and building networked systems. My Ph.D. work focused on network monitoring and fault-tolerance for datacenter networks using programmable switches. Currently, I am working as well as supervising research projects in the areas of 5G RAN/core and distributed systems.

EDUCATION

Doctor of Philosophy, (Ph.D.), Computer Science *Aug '15 – Apr '23*
School of Computing, National University of Singapore (NUS)
Advisor: Dr. Ben Leong. Also collaborated closely with Dr. Mun Choon Chan.

- Thesis: In-Network Techniques for Highly Reliable Datacenter Networks
- Graduate Courses: Advanced Topics in Networking, Distributed Systems, Network Security, Systems Support for Continuous Media, Advanced Topics in Data Mining, The Art of CS Research.
- Cumulative G.P.A.: 4.92 / 5.0

Bachelor of Engineering (Hons.), Computer Science *2009 – 2013*
Birla Institute of Technology and Science (BITS), Pilani, India

- Thesis: Design and Implementation of Mobile Aerial Nodes (exchange at NUS)
  Advisor: Dr. Ben Leong
- Cumulative G.P.A.: 9.09 / 10.0

Higher Secondary School Certificate Examination *2009*
Maharashtra State Board of Secondary & Higher Secondary Education, India

- Ranked 1st with a score of 96% among 100,000+ students in the Kolhapur Board in Science stream.

RESEARCH EXPERIENCE

Research Fellow, National University of Singapore *Jul '23 – Present*
Working on 5G, distributed systems, and Internet measurement projects at the NUS School of Computing:

- Supervising and working closely with Ph.D. students and research assistants for setting research directions, determining project milestones, and guiding prototype implementation/experimentation.
- Guided work on a paper (under submission) where we demonstrate a scalable and efficient implementation of the UPF's ATSSS function (5G-WiFi convergence) using programmable switches. Our solution costs 225× less and consumes 84.7× less power compared to a server-based solution.
- Leading the deployment of a P4Campus-like infrastructure for Internet measurements at the NUS School of Computing (with Ben Leong).
- Part of the team building a µSecond-Scale live TCP migration system (with Jialin Li).
- Starting a new project to improve wireless packet corruption handling at the MAC (HARQ) and RLC layers of the 5G network stack (with Mun Choon Chan).

Graduate Research Assistant, National University of Singapore *Aug '15 – Jun '23*
Key highlights of my work experience as a Ph.D. student as well as a graduate research assistant at the NUS School of Computing:

- Started the line of research using programmable switches at NUS that has led to more than 8 full papers (4 tier-1) to date.
- Developed a light-weight and efficient microburst monitoring solution that reduced the data collection and processing overhead by 10x compared to the (then) state-of-the-art.
- Developed in-network techniques to mitigate the impact of link failures in datacenter networks and improved the application tail flow completion time (FCT) under failures by up to 50 times.
- Co-developed a novel technique using programmable switches for slicing in 5G fronthaul networks resulting in tail FCT improvement by up to 4 times for latency-sensitive traffic.
- Co-developed a dataplane time synchronization protocol that synchronizes the dataplane hardware clocks to within 10's of nanoseconds.
- Enabled large-scale evaluation of our solutions by designing and building 2 simulators (packet-level and topology-level) for datacenter networks.
- Reviewed/sub-reviewed 37 research papers.
- Contributed to writing grant proposals that brought in ∼USD 1.25M research funding in total.
- Managed 3+ research grants including budgeting and cash flow management.
- Built vendor relationships, managed communication and facilitated procurement of standard and customized research equipment.
- Built and managed a shared testbed that facilitated multiple networking research projects.

- Interviewed and hired 6 interns as well as visiting students.
- Advised and mentored 7 interns (2 remote) and supervised 3 undergraduate theses.

Industry Experience

Member of Technical Staff, Adobe Systems India Pvt. Ltd. *Jul '13 – Jul '15*

I was part of the software engineering team responsible for the Adobe PDF Print Engine, a rendering platform that enables high quality digital printing of Adobe PDF documents. Specifically I worked on the following modules:

- **Color management workflows:** Color management workflows involving Adobe Color Engine, Adobe Graphics Manager and ICM2-based Color Conversion Modules (CMMs). Gained in-depth understanding of PDF's transparent imaging model including transparency composition, blending and overprinting.
- **JPEG2000** and **JDF**: Worked on Adobe's implementation of ISO/IEC 15444 and Job Description Format (JDF). Ensured critical performance and handled security issues.

Received the ***Special Contribution Award*** in recognition of my work.

Awards and Honors

- Best Paper Awards: SOSR 2019, ICNP 2019
- NUS School of Computing Research Excellence Award 2023 for significant and sustained research achievements throughout the course of Ph.D. study.
  (Awarded to 10 best-performing students across 300+ Ph.D. students in Computer Science.)
- NUS School of Computing Research Achievement Award 2020 for outstanding research performance over the past academic year.
- Facebook Research Networking Systems Award '19 (USD 50,000). Co-PI for the proposal 'Record & Replay: Framework for Network-Wide Monitoring and Debugging' with PI Dr. Mun Choon Chan.
- President's Graduate Fellowship 2015-16 awarded to candidates at NUS who show exceptional promise or accomplishment in research.
- Adobe Systems Special Contribution Award in recognition of my engineering contributions to the Adobe PDF Print Engine.
- Summer Research Fellowship 2012 awarded jointly by the Indian National Science Academy (INSA), National Academy of Sciences India (NASI) and the Indian Academy of Sciences (IAS).
- Merit-cum-Need scholarship at BITS Pilani for all 8 semesters.
- Dhirubhai Ambani Undergraduate Scholarship awarded by the Reliance Foundation to meritorious students at the Higher Secondary School Certificate Examination.
- State Merit Scholarship awarded by Govt. of Maharashtra (India) to top-ranking students at the Higher Secondary School Certificate Examination.

Publications

Junction: Enabling 5G-WiFi Convergence at Scale with Programmable Switches
Under Submission
Xin Zhe Khooi, Cha Hwan Song, Satis Kumar Permal, Nishant Budhdev, Raj Joshi, Mun Choon Chan

Masking Corruption Packet Losses in Datacenter Networks with Link-local Retransmission
[SIGCOMM '23]
Raj Joshi, Cha Hwan Song, Xin Zhe Khooi, Nishant Budhdev, Ayush Mishra, Mun Choon Chan, Ben Leong

Network Load Balancing with In-network Reordering Support for RDMA
[SIGCOMM '23]
Cha Hwan Song, Xin Zhe Khooi, Raj Joshi, Inho Choi, Jialin Li, Mun Choon Chan

Capybara: µSecond-Scale Live TCP Migration
[ACM APSys '23]
Inho Choi, Nimish Wadekar, Raj Joshi, Joshua Fried, Dan R. K. Ports, Irene Zhang, Jialin Li

LinkGuardian: Mitigating the impact of packet corruption loss with link-local retransmission
[ACM APNet '22]
Raj Joshi, Qi Guo, Nishant Budhdev, Ayush Mishra, Mun Choon Chan, Ben Leong

Hop-On Hop-Off Routing
[ACM APNet '22]
Jialong Li, Yiming Lei, Federico De Marchi, Raj Joshi, Balakrishnan Chandrasekaran, Yiting Xia

FSA: fronthaul slicing architecture for 5G using dataplane programmable switches
[ACM MOBICOM '21]
Nishant Budhdev, Raj Joshi, Pravein Govindan Kannan, Mun Choon Chan, Tulika Mitra

Debugging Transient Faults in Data Centers using Synchronized Network-wide Packet Histories
[USENIX NSDI '21]

Pravein Govindan Kannan, Nishant Budhdev, Raj Joshi*, and Mun Choon Chan*
*equal contribution

Conjecture: Existence of Nash Equilibria in Modern Internet Congestion Control
[ACM APNet '21]
Ayush Mishra, Jingzhi Zhang, Melodies Sim, Sean Ng, Raj Joshi, and Ben Leong

Slicing 5G Fronthaul Networks using Programmable Switches
[ACM CoNEXT '20, Posters & Demos]
Nishant Budhdev, Raj Joshi, Pravein Govindan Kannan, and Mun Choon Chan

The Great Internet TCP Congestion Control Census
[ACM SIGMETRICS '20]
Ayush Mishra, Xiangpeng Sun, Atishya Jain, Sameer Pande, Raj Joshi, and Ben Leong

SQR: In-network Pkt Loss Recovery from Link Failures for Highly Reliable Datacenter Networks
[IEEE ICNP '19] ***Best Paper Award!***
Ting Qu, Raj Joshi*, Mun Choon Chan, Ben Leong, Deke Guo, Zhong Liu*
*equal contribution

TimerTasks: Towards Time-driven Execution in Programmable Dataplanes
[ACM SIGCOMM '19, Posters & Demos]
Raj Joshi, Ben Leong, Mun Choon Chan

P4TrafficTool: Automated Code Generation for P4 Traffic Generators and Analyzers
[ACM SOSR '19, Posters & Demos]
Deepanshu Jindal, Raj Joshi, Ben Leong

Precise Time-synchronization in the Data-Plane using Programmable Switching ASICs
[ACM SOSR '19] ***Best Paper Award!***
Pravein Govindan Kannan, Raj Joshi, Mun Choon Chan

BurstRadar: Practical Real-time Microburst Monitoring for Datacenter Networks
[ACM APSys '18]
Raj Joshi, Ting Qu, Mun Choon Chan, Ben Leong and Boon Thau Loo

EleTrack: Ultra-Low-Power Retrofitted Monitoring for Elevators
[EWSN '18]
Mobashir Mohammad, Raj Joshi, Mun Choon Chan

HaptiColor: Interpolating Color Information as Haptic Feedback to Assist the Colorblind
[ACM CHI '16]
Marta G. Carcedo, Soon Hau Chua, Simon Perrault, Pawel Wozniak, Raj Joshi, Mohammad Obaid, Morten Fjeld, Shengdong Zhao

Feasibility Study of Mobile Phone WiFi Detection in Aerial Search and Rescue Operations
[ACM APSys '13]
Wei Wang, Raj Joshi, Aditya Kulkarni, Wai Kay Leong and Ben Leong

Contributed Research Grants

- Efficient and Scalable Network Security and Performance Monitoring for 5G Networks, NUS-NCS Joint Laboratory for Cyber Security (2023), SGD 520k, with Mun Choon Chan.
- Active and Passive Monitoring of Realtime Internet and 5G Evolution, Singapore Ministry of Education Tier-2 (2023), SGD 444k, with Ben Leong.
- A Buffer-Regulation-Based Approach to Achieving Low-Latency TCP (2020), Singapore Ministry of Education Tier-1, SGD 130k, with Ben Leong.
- Leveraging Data-Plane Programmability for Scalable & Resilient Network Services (2020), Singapore Ministry of Education Tier-2, SGD 489k, with Mun Choon Chan.
- Record & Replay: Framework for Network-Wide Monitoring and Debugging (2019), Facebook Research, USD 50k, with Mun Choon Chan.
- Towards High-Fidelity Datacenter Network Monitoring with Programmable Dataplanes (2018), Singapore Ministry of Education Tier-1, SGD 53k, with Mun Choon Chan and Ben Leong.

Professional Service

- **Program Committee (Reviewer):** SOSP Artifact Evaluation (2023), IEEE INFOCOM (2022, 2024), IFIP Networking (2023), NUS Computing Research Week (Fall 2020)
- **Contributed Reviews (Sub-reviewer):** NSDI (2024), ACM IMC (2023), IEEE ICNP (2021, 2022, 2023), IEEE INFOCOM (2021, 2023, 2024), ACM APNet (2021), ACM HotNets (2017, 2020), ACM Multimedia (2020), IEEE SECON (2017)
- **Other:** Instructor for P4 Tutorial at SIGCOMM'19

Mentoring and Advising

- Undergraduate Summer Interns (N=5)
- Undergraduate Theses (N=3)
- Remote Interns (N=2)

Teaching Experience

Teaching Assistant, CS5229: Advanced Computer Networks *Aug '21 – Dec '21*
Instructor: Dr. Ben Leong
A graduate level course at NUS that covers advanced topics in networking. Included a hands-on project to reproduce results from a popular research paper.

Teaching Assistant, CS5248: Systems Support for Continuous Media *Aug '17 – Dec '17*
Instructor: Dr. Roger Zimmermann
A graduate level course at NUS that covers major aspects of video and audio streaming systems. Included a hands-on project to build an end-to-end DASH streaming system from scratch.
- Mean student rating: 4.4 / 5.0

Teaching Assistant, CS1010X: Programming Methodology *Jan '17 – Jun '17*
Instructor: Dr. Ben Leong *Jan '16 – Jun '16*
An undergraduate level course at NUS that introduces freshmen to the fundamental concepts of problem solving by means of computing and programming using the Python programming language.
- Mean student rating: 4.6 / 5.0 *(Jan '17 – Jun '17)*; 4.8 / 5.0 *(Jan '16 – Jun '16)*

Undergraduate Research Experience

School of Computing, National University of Singapore *Jan '13 – Jul '13*
Undergraduate Thesis: *Design and Implementation of Mobile Aerial Nodes*
Advisor: Dr. Ben Leong
Designed and built wireless nodes that could fly autonomously using multi-rotor UAV platform. Interfacing a WiFi-enabled computer with a UAV flight controller was the key contribution. Subsequently conducted a measurement study of signal propagation in aerial WiFi links. Also investigated WiFi scanning patterns and WiFi power consumption in mobile devices.
(This work was supported by the Singapore Ministry of Education tier 1 grant 251RES1204)

Tata Institute of Fundamental Research (TIFR), Mumbai, India *May '12 – Jul '12*
Summer Internship Project: *Evaluation of a Clustered Regression Prediction Setup*
Advisor: Dr. Onkar Dabeer
Using Python numpy-scipy tools, implemented a local regression scheme. Verified the scheme's accuracy and performance in solving a clustered regression prediction setup by using NASDAQ stock and Indian rainfall data.
(Supported by the Indian Academy of Sciences (IAS) Summer Research Fellowship 2012)

Indian Space Research Organization (ISRO), Dehradun, India *May '11 – Jul '11*
Summer Internship Project: *GIS Customization for 3D Terrain Visualization*
Advisor: PLN Raju, Scientist G.
Developed a 3D overlay and visualization add-in for ArcGIS Explorer. It enabled 3D animation of time-lapse geo-spatial data for policy planning and other studies at the Indian Institute of Remote Sensing (IIRS under the purview of ISRO).

Technical Skills

Networking	P4, Intel P4 Studio, DPDK, Scapy, Pcap++, MoonGen, Mininet
Programming	C, C++, Java, Arduino
Scripting	Python, Bash shell, PHP
Mobile and Web Technologies	Android, Django, HTML, CSS, JavaScript

Extracurricular Activities

- Nominated member of the Graduate Student Panel for Student Discipline at the National University of Singapore.
- Steering committee member of the team organizing Alumni Research Talks, a student-industry-research symposium which features research talks and discussions in Computer Science by BITS alumni currently in graduate schools or pursuing industry research. So far, the five successful editions of the event have been generously supported by Microsoft Research, LinkedIn, Google, eBay-PayPal and NetApp.
- Served as President for Embryo, a student driven initiative that organizes video lectures and mini-courses providing students exposure to current research trends in addition to classroom learning.