

Computer Architecture

Why Is It So Exciting Today?

Onur Mutlu

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19 February 2022

Kesisen Yollar Kariyer Sohbetleri

SAFARI

ETH zürich

Carnegie Mellon

Brief Self Introduction



■ Onur Mutlu

- ❑ Full Professor @ ETH Zurich ITET (INFK), since Sept 2015
- ❑ Strecker Professor @ Carnegie Mellon University ECE (CS), 2009-2016, 2016-...
- ❑ Started the Comp Arch Research Group @ Microsoft Research, 2006-2009
- ❑ Worked @ Google, VMware, Microsoft Research, Apple, Intel, AMD
- ❑ PhD in ECE from University of Texas at Austin in 2006
- ❑ <https://people.inf.ethz.ch/omutlu/> omutlu@gmail.com

■ Research and Teaching in:

- ❑ **Computer architecture, systems, hardware security, bioinformatics**
- ❑ Memory and storage systems
- ❑ Robust & dependable hardware systems: security, safety, predictability, reliability
- ❑ Hardware/software cooperation
- ❑ New computing paradigms; architectures with emerging technologies/devices
- ❑ Architectures for bioinformatics, genomics, health, medicine, AI/ML
- ❑ ...

SAFARI

SAFARI Research Group

safari.ethz.ch

Think BIG, Aim HIGH!

<https://safari.ethz.ch>

Onur Mutlu's SAFARI Research Group

Computer architecture, HW/SW, systems, bioinformatics, security, memory

<https://safari.ethz.ch/safari-newsletter-april-2020/>



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SAFARI Newsletter April 2020 Edition

- <https://safari.ethz.ch/safari-newsletter-april-2020/>



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Think Big, Aim High



Dear SAFARI friends,

2019 and the first three months of 2020 have been very positive eventful times for SAFARI.

SAFARI Newsletter January 2021 Edition

- <https://safari.ethz.ch/safari-newsletter-january-2021/>



Newsletter
January 2021

*Think Big, Aim High, and
Have a Wonderful 2021!*



Dear SAFARI friends,

Happy New Year! We are excited to share our group highlights with you in this second edition of the SAFARI newsletter (You can find the first edition from April 2020 [here](#)). 2020 has

SAFARI Newsletter December 2021 Edition

- <https://safari.ethz.ch/safari-newsletter-december-2021/>

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SAFARI Research Group

Think Big, Aim High

ETH zürich



View in your browser
December 2021

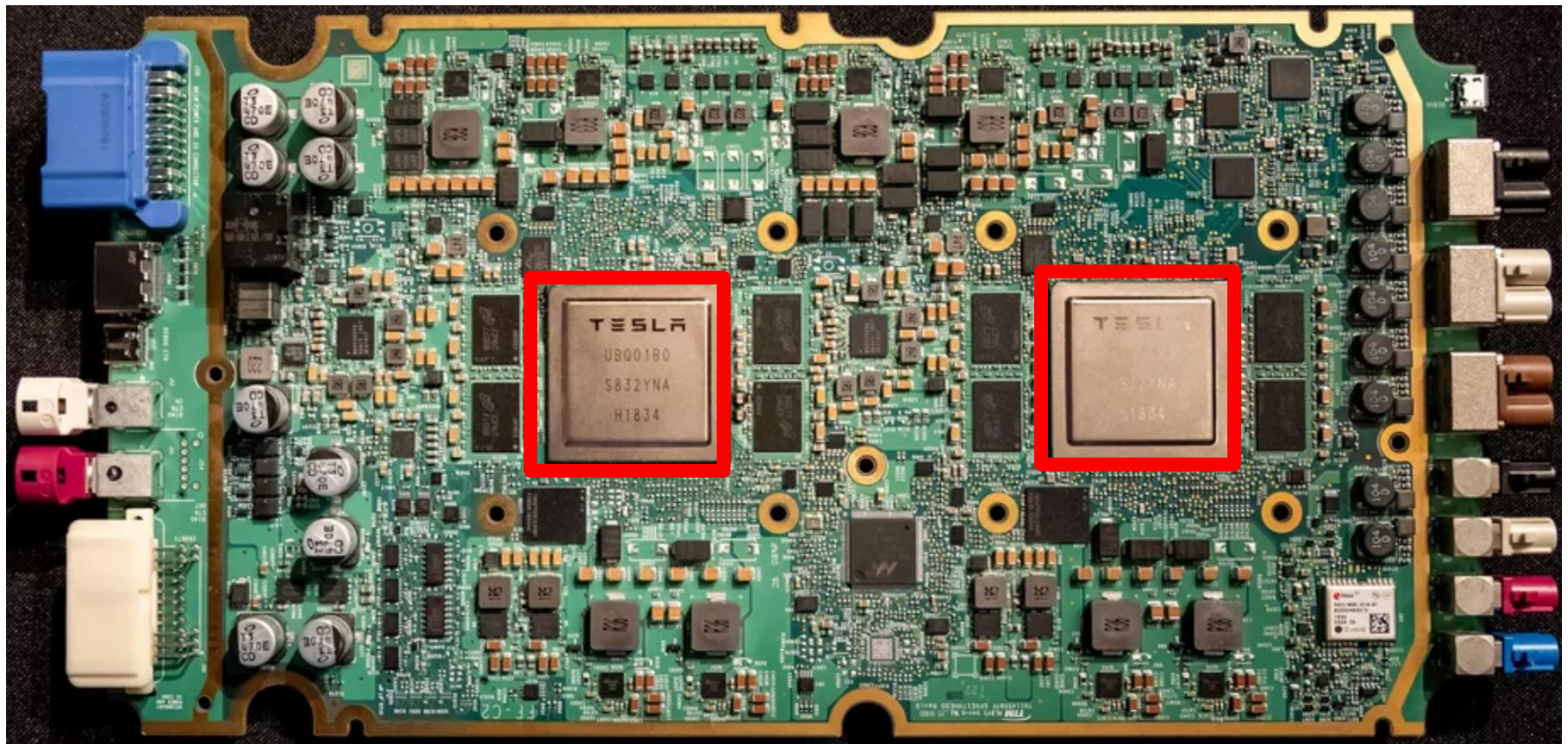


Many Interesting Things
Are Happening Today
in Computer Architecture

**Performance
and
Energy Efficiency**

TESLA Full Self-Driving Computer (2019)

- ML accelerator: 260 mm², 6 billion transistors, 600 GFLOPS GPU, 12 ARM 2.2 GHz CPUs.
- Two redundant chips for better safety.



Google TPU Generation I (~2016)

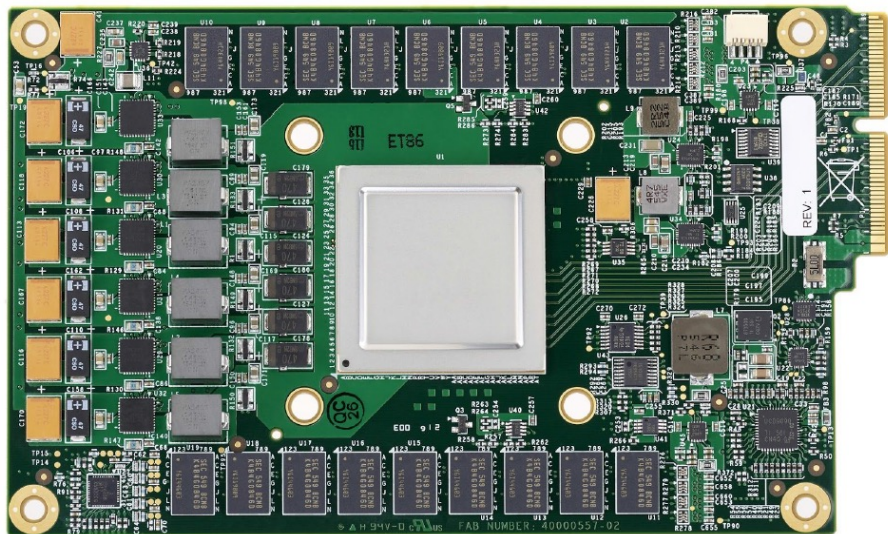


Figure 3. TPU Printed Circuit Board. It can be inserted in the slot for an SATA disk in a server, but the card uses PCIe Gen3 x16.

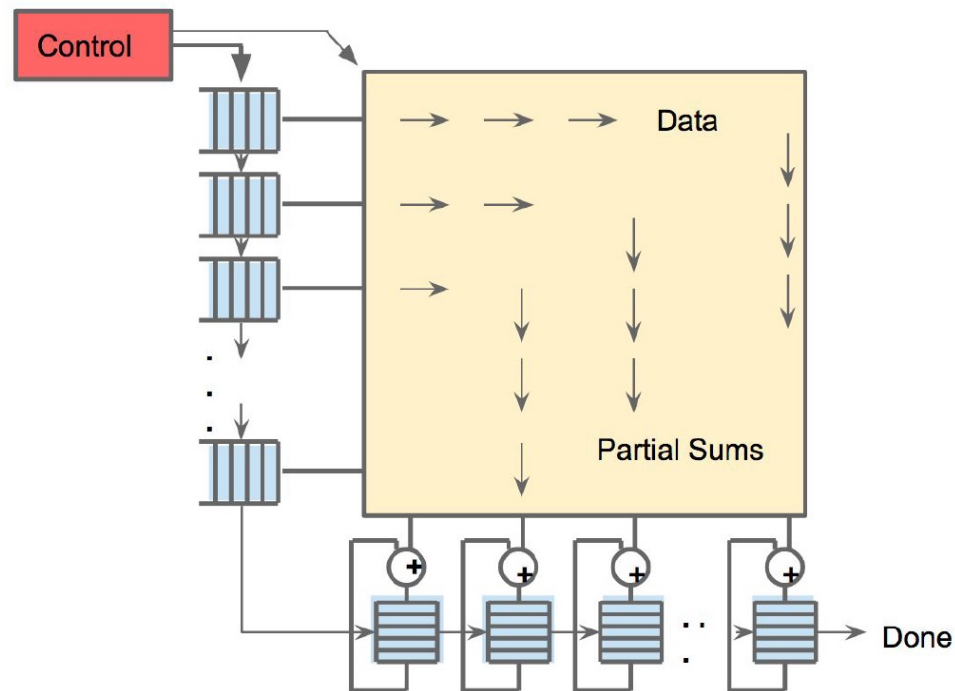
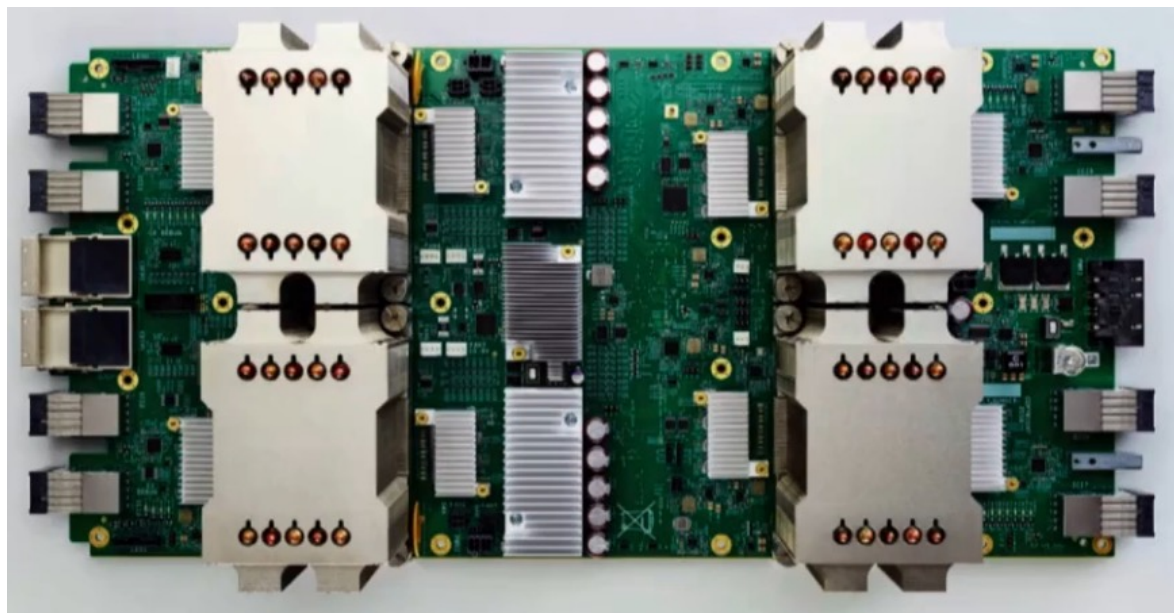


Figure 4. Systolic data flow of the Matrix Multiply Unit. Software has the illusion that each 256B input is read at once, and they instantly update one location of each of 256 accumulator RAMs.

Jouppi et al., “In-Datacenter Performance Analysis of a Tensor Processing Unit”, ISCA 2017.

Google TPU Generation II (2017)



<https://www.nextplatform.com/2017/05/17/first-depth-look-googles-new-second-generation-tpu/>

4 TPU chips
vs 1 chip in TPU1

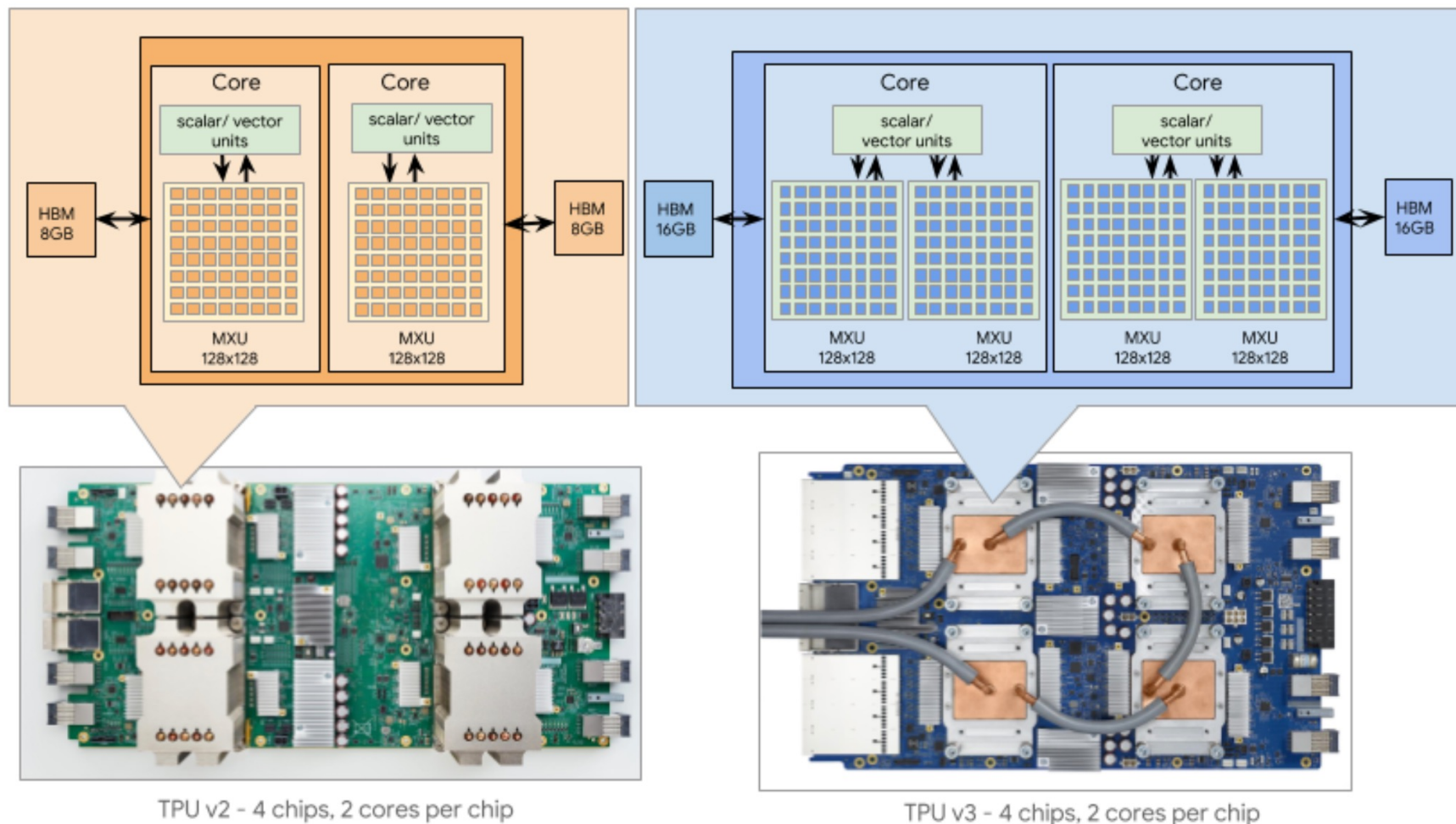
High Bandwidth Memory
vs DDR3

Floating point operations
vs FP16

45 TFLOPS per chip
vs 23 TOPS

Designed for training
and inference
vs only inference

Google TPU Generation III (2019)

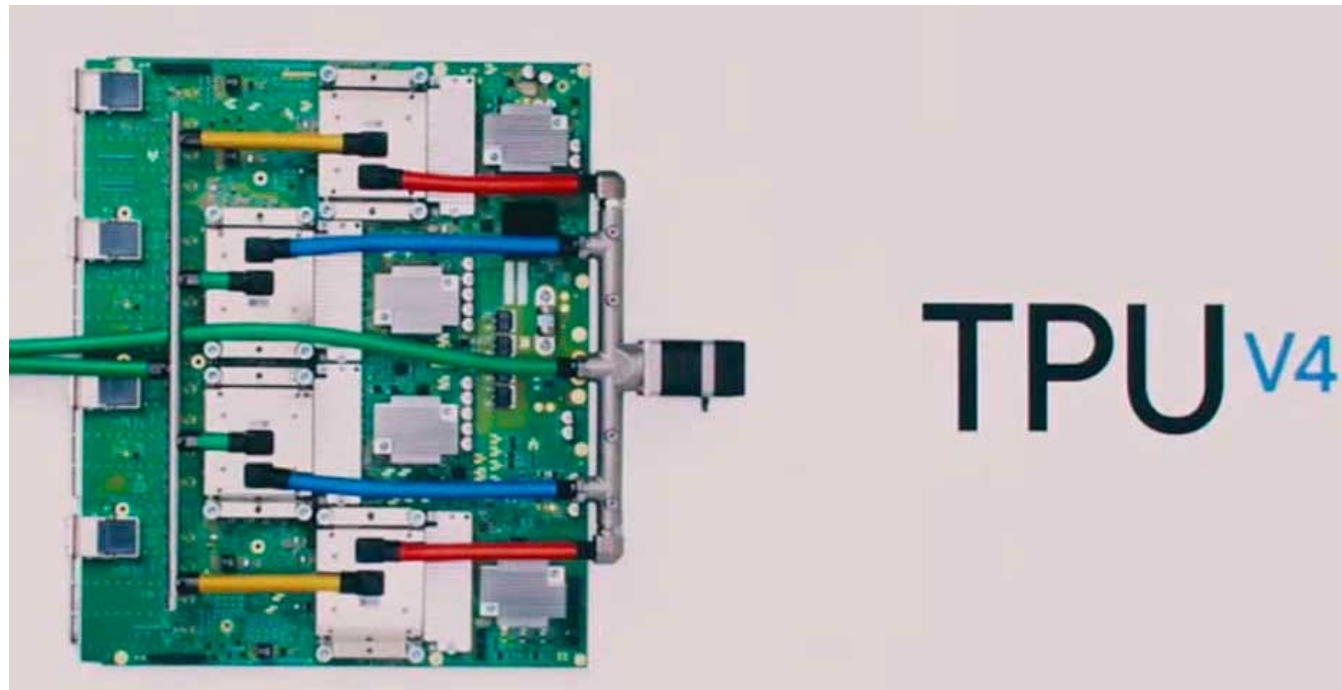


32GB HBM per chip
vs 16GB HBM in TPU2

4 Matrix Units per chip
vs 2 Matrix Units in TPU2

90 TFLOPS per chip
vs 45 TFLOPS in TPU2

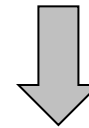
Google TPU Generation IV (2021)



New ML applications (vs. TPU3):

- Computer vision
- Natural Language Processing (NLP)
- Recommender system
- Reinforcement learning that plays Go

250 TFLOPS per chip in 2021
vs 90 TFLOPS in TPU3

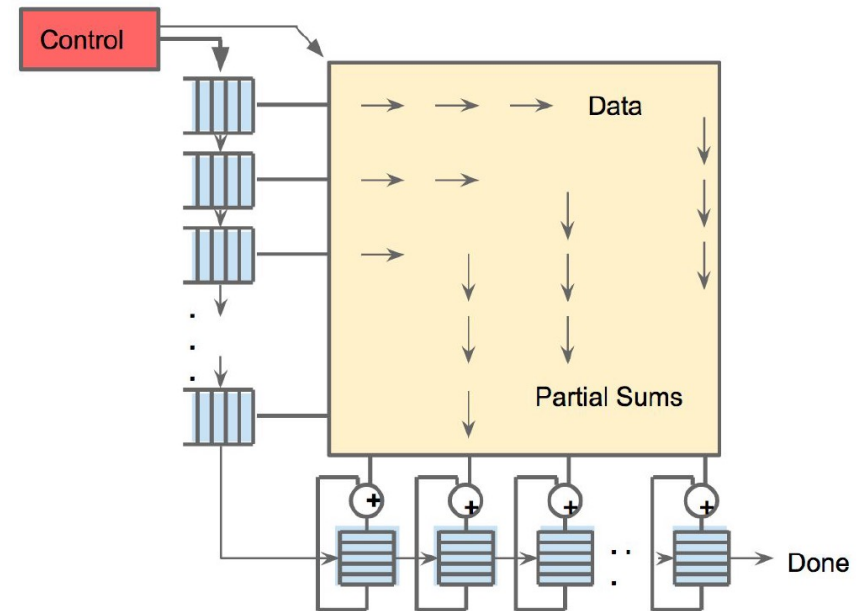


1 ExaFLOPS per board

<https://spectrum.ieee.org/tech-talk/computing/hardware/heres-how-googles-tpu-v4-ai-chip-stacked-up-in-training-tests>

An Example Modern Systolic Array: TPU (II)

As reading a large SRAM uses much more power than arithmetic, the matrix unit uses systolic execution to save energy by reducing reads and writes of the Unified Buffer [Kun80][Ram91][Ovt15b]. Figure 4 shows that data flows in from the left, and the weights are loaded from the top. A given 256-element multiply-accumulate operation moves through the matrix as a diagonal wavefront. The weights are preloaded, and take effect with the advancing wave alongside the first data of a new block. Control and data are pipelined to give the illusion that the 256 inputs are read at once, and that they instantly update one location of each of 256 accumulators. From a correctness perspective, software is unaware of the systolic nature of the matrix unit, but for performance, it does worry about the latency of the unit.



Jouppi et al., “In-Datacenter Performance Analysis of a Tensor Processing Unit”, ISCA 2017.

An Example Modern Systolic Array: TPU (III)

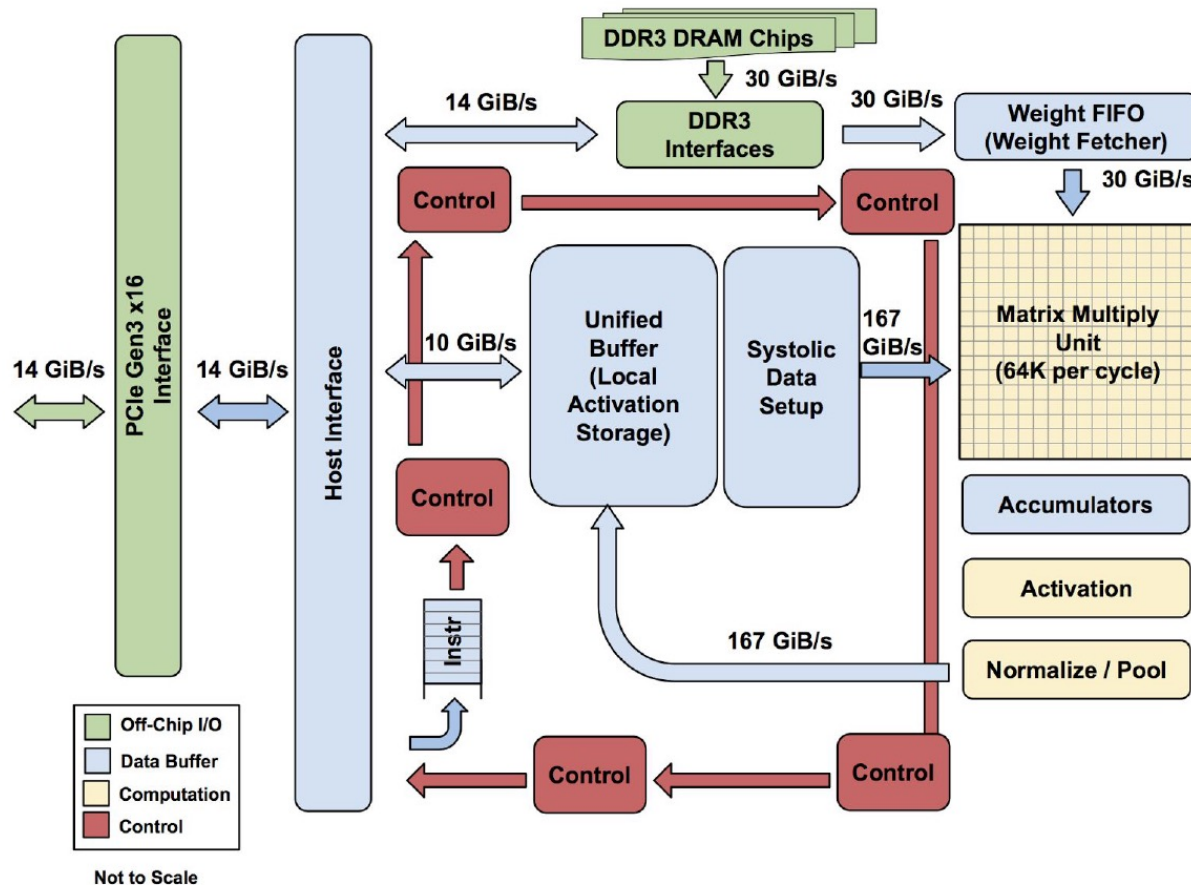
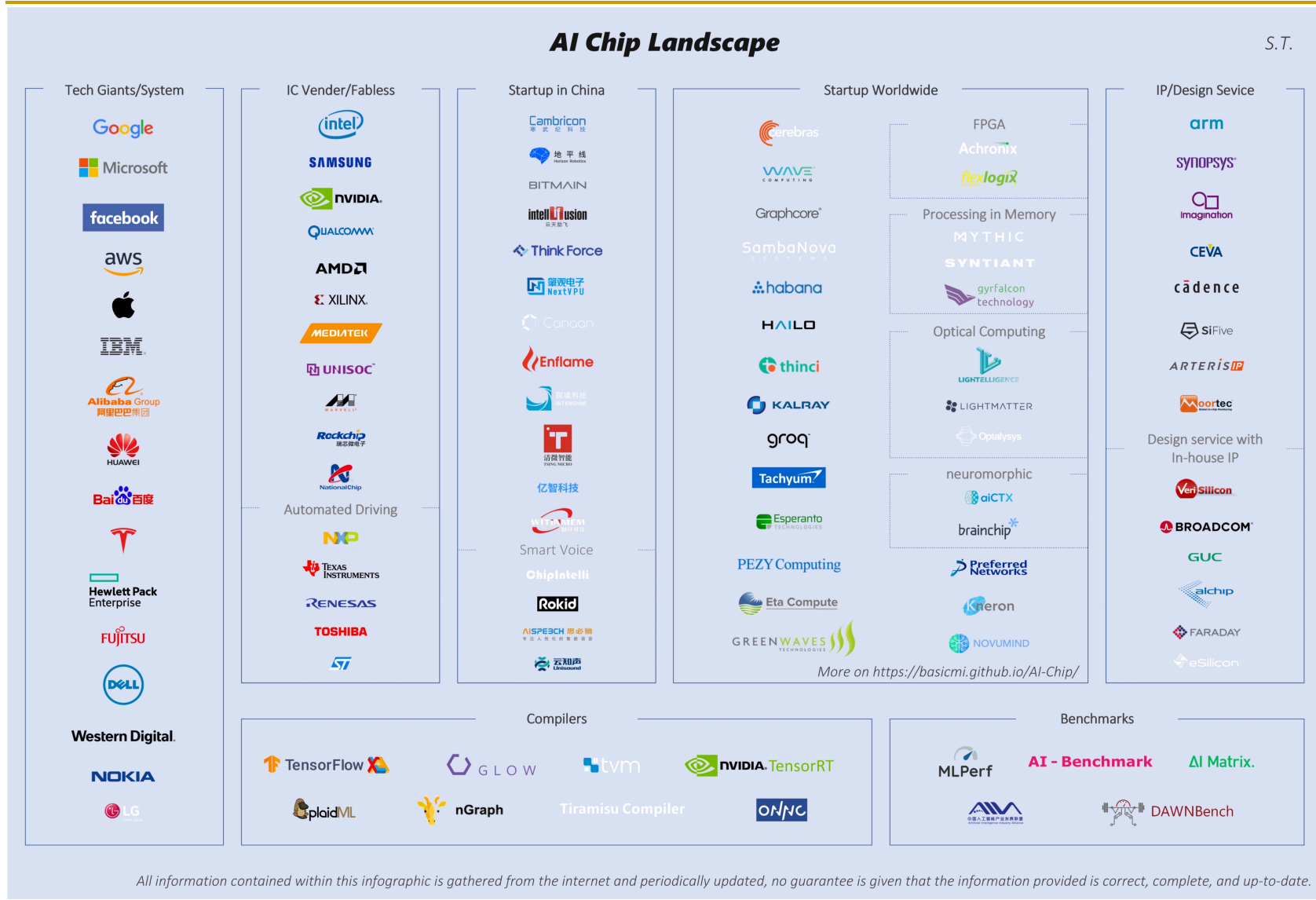


Figure 1. TPU Block Diagram. The main computation part is the yellow Matrix Multiply unit in the upper right hand corner. Its inputs are the blue Weight FIFO and the blue Unified Buffer (UB) and its output is the blue Accumulators (Acc). The yellow Activation Unit performs the nonlinear functions on the Acc, which go to the UB.

Many (Other) AI/ML Chips

- Alibaba
- Amazon
- Facebook
- Google
- Huawei
- Intel
- Microsoft
- NVIDIA
- Tesla
- Many Others and Many Startups...
- **Many More to Come...**

Many (Other) AI/ML Chips (2019)



Many (Other) AI/ML Chips (2021)

■ MLPerf results available ■ AI-Benchmark results available

AI Chip Landscape

V0.7 Dec., 2019

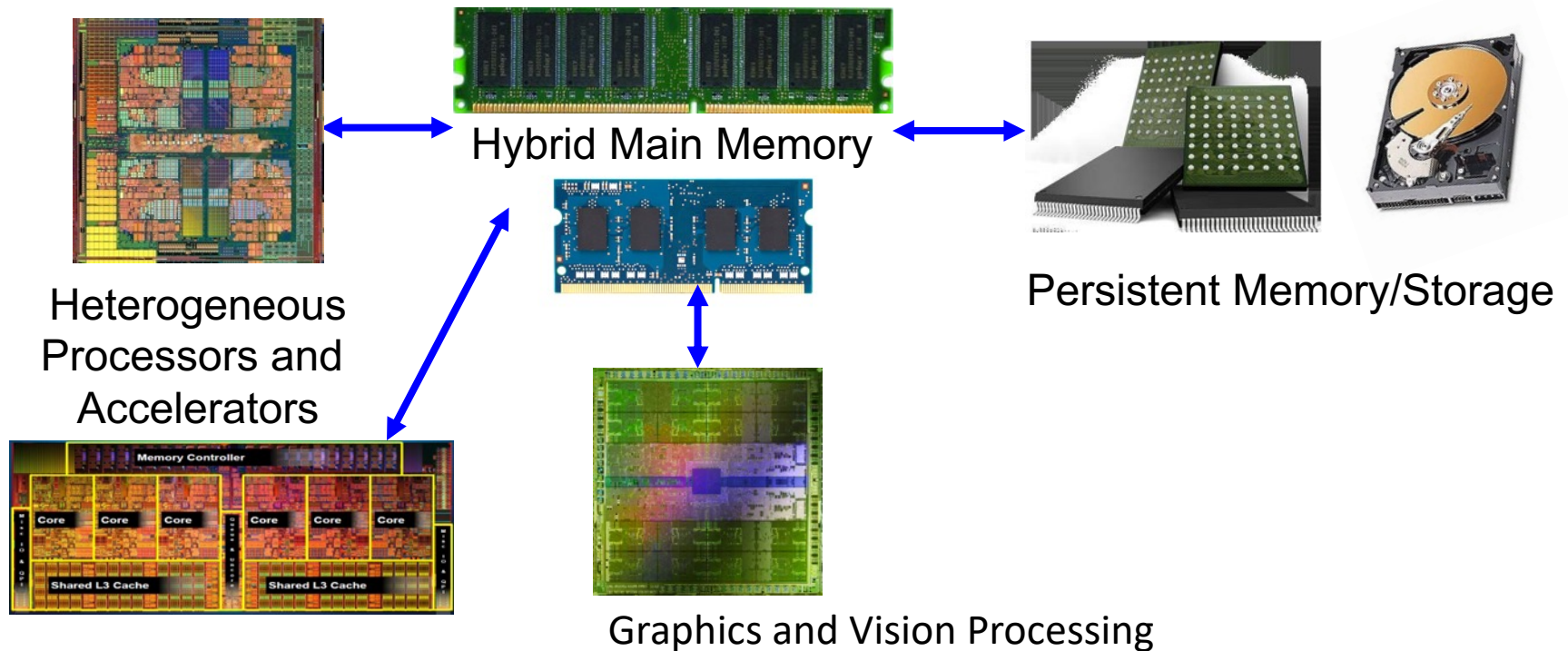
S.T.



All information contained within this infographic is gathered from the internet and periodically updated, no guarantee is given that the information provided is correct, complete, and up-to-date.

Current Research Mission

Computer architecture, HW/SW, systems, bioinformatics, security



Build fundamentally better architectures

Four Key Current Directions

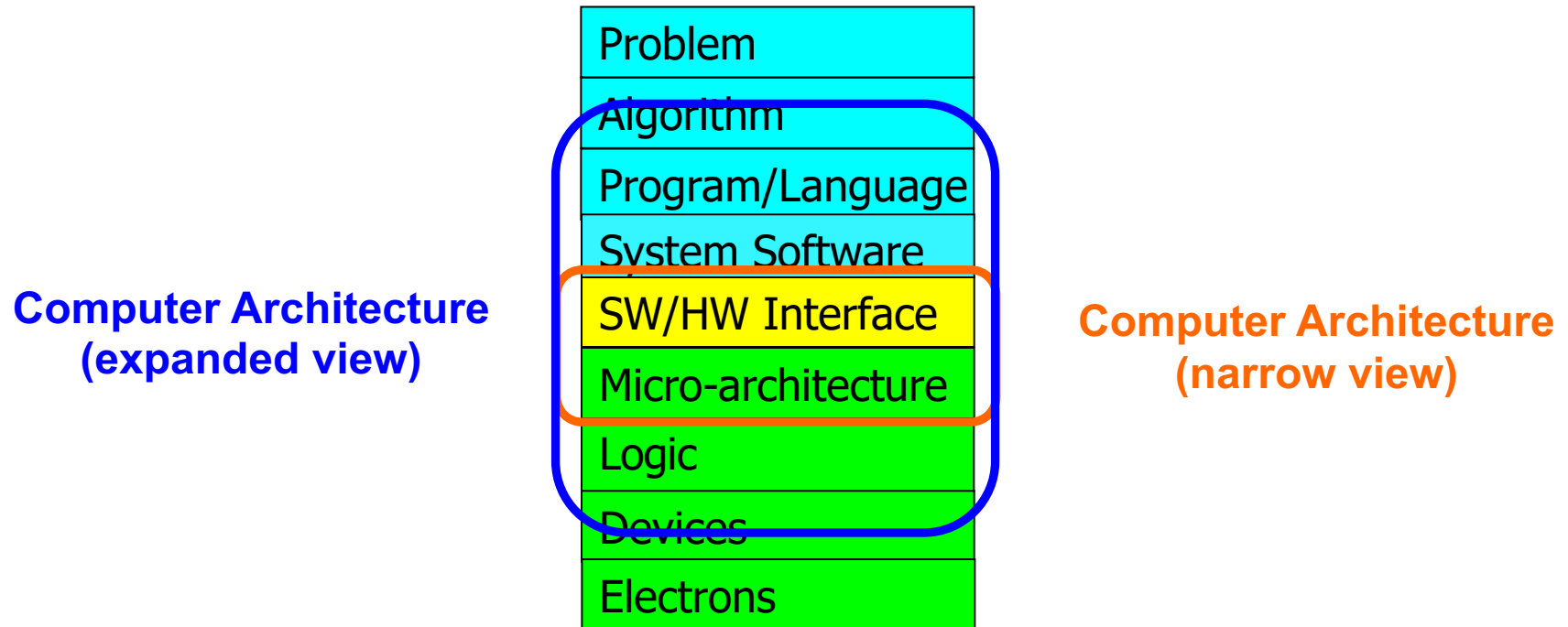
- Fundamentally **Secure/Reliable/Safe** Architectures
- Fundamentally **Energy-Efficient** Architectures
 - **Memory-centric** (Data-centric) Architectures
- Fundamentally **Low-Latency and Predictable** Architectures
- Architectures for **AI/ML, Genomics, Medicine, Health, ...**

Data-centric

Data-driven

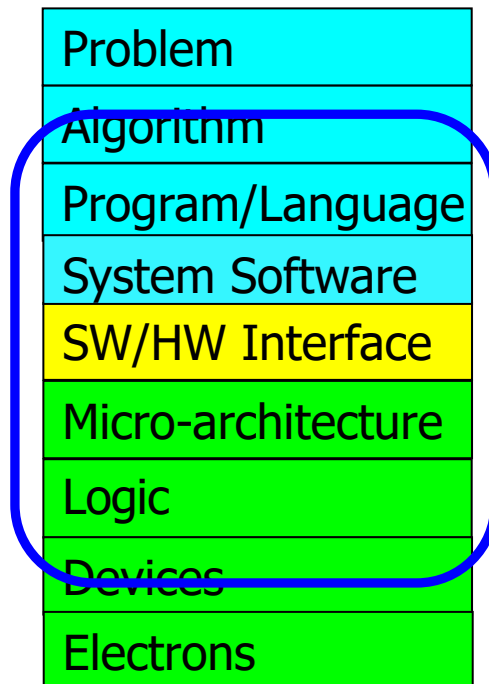
Data-aware

The Transformation Hierarchy



To achieve the highest **energy efficiency** and **performance**:

we must take the expanded view
of computer architecture

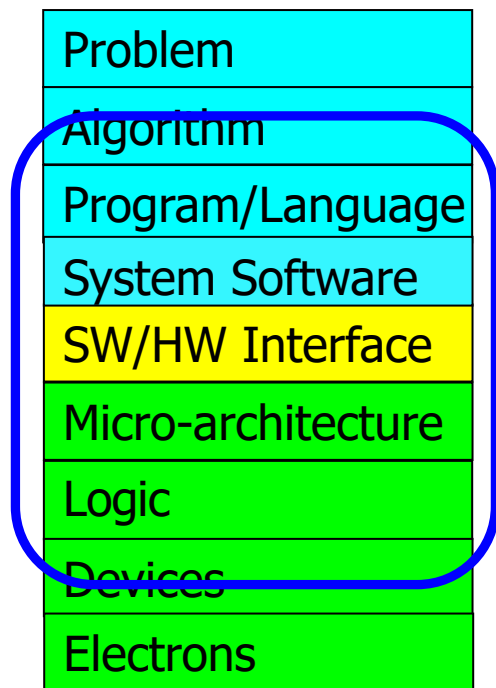


Co-design across the hierarchy:
Algorithms to devices

Specialize as much as possible
within the design goals

Current Research Mission & Major Topics

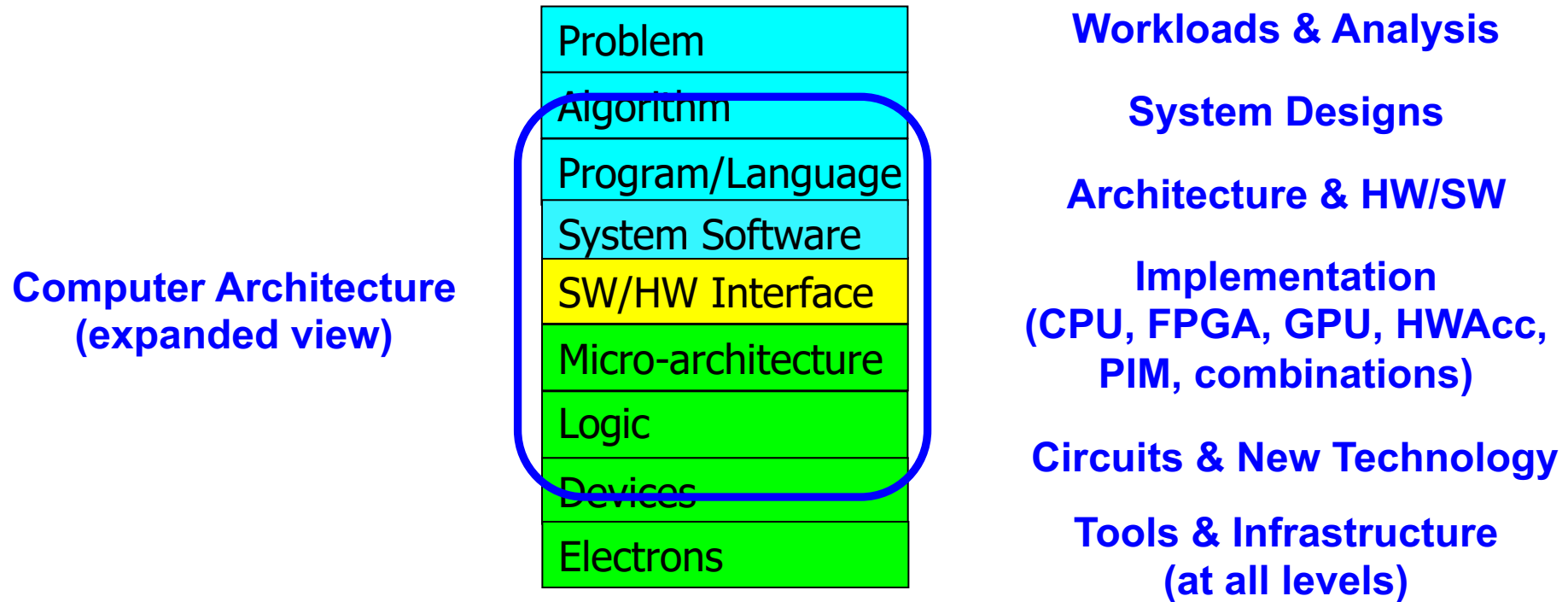
Build fundamentally better architectures



**Broad research
spanning apps, systems, logic
with architecture at the center**

- Data-centric arch. for low energy & high perf.
 - Proc. in Mem/DRAM, NVM, unified mem/storage
- Low-latency & predictable architectures
 - Low-latency, low-energy yet low-cost memory
 - QoS-aware and predictable memory systems
- Fundamentally secure/reliable/safe arch.
 - Tolerating all bit flips; patchable HW; secure mem
- Architectures for ML/AI/Genomics/Health/Med
 - Algorithm/arch./logic co-design; full heterogeneity
- Data-driven and data-aware architectures
 - ML/AI-driven architectural controllers and design
 - Expressive memory and expressive systems

Research Across the Computing Stack



New Genome Sequencing Technologies

Nanopore sequencing technology and tools for genome assembly: computational analysis of the current state, bottlenecks and future directions

Damla Senol Cali ✉, Jeremie S Kim, Saugata Ghose, Can Alkan, Onur Mutlu

Briefings in Bioinformatics, bby017, <https://doi.org/10.1093/bib/bby017>

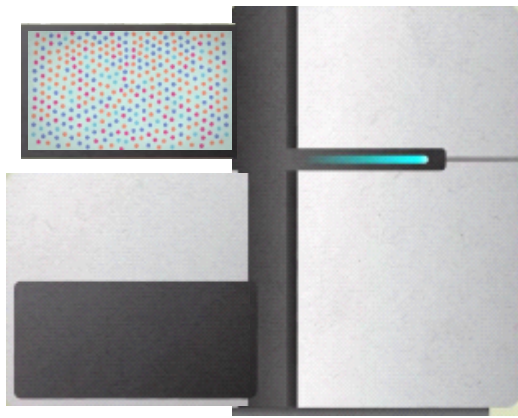
Published: 02 April 2018 **Article history** ▼



Oxford Nanopore MinION

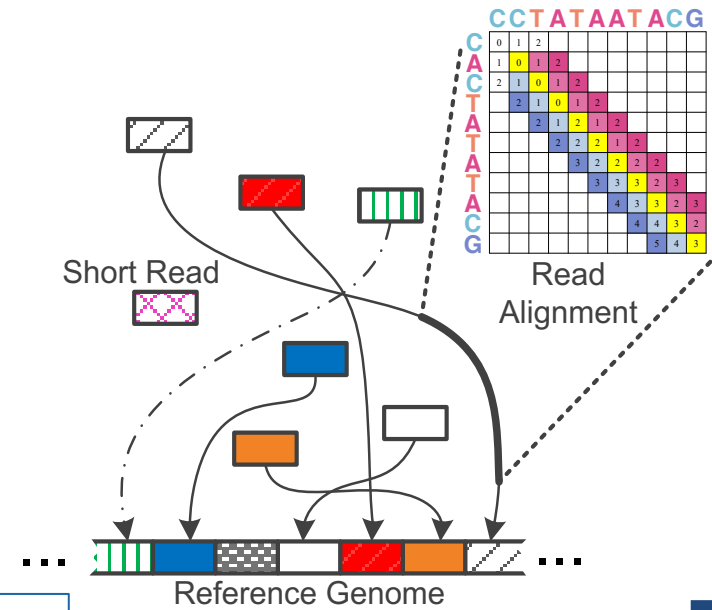
Senol Cali+, “**Nanopore Sequencing Technology and Tools for Genome Assembly: Computational Analysis of the Current State, Bottlenecks and Future Directions**,” *Briefings in Bioinformatics*, 2018.

[[Open arxiv.org version](#)]



Billions of Short Reads

ATATATACGTACTAGTACGT
 TTTAGTACGTACGT
 ATACGTACTAGTACGT
 CGCCCCTACGTA
 ACGTACTAGTACGT
 TTAGTACGTACGT
 TACGTACTAAAGTACGT
 TACGTACTAGTACGT
 TTTAAACGTA
 CGTACTAGTACGT
 GGGAGTACGTACGT



1 Sequencing

Genome Analysis

2 Read Mapping

reference: TTTATCGCTTCCATGACGCAG

read1: ATCGCATCC

read2: TATCGCATC

read3: CATCCATGA

read4: CGCTTCCAT

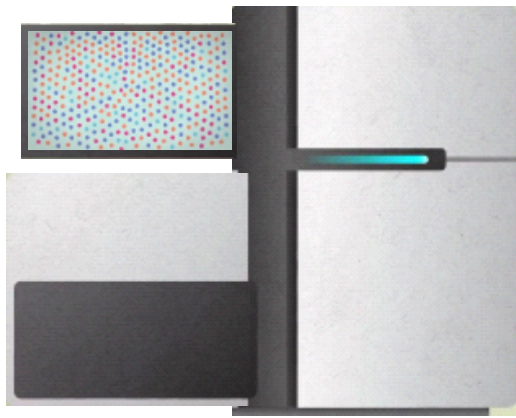
read5: CCATGACGC

read6: TTCCATGAC



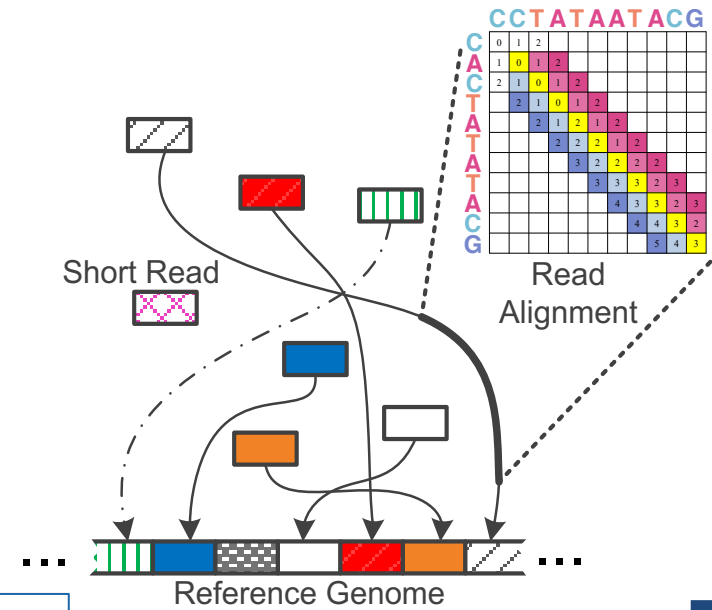
3 Variant Calling

4 Scientific Discovery



Billions of Short Reads

ATATATACGTACTAGTACGT
 TTTAGTACGTACGT
 ATACGTACTAGTACGT
 CGCCCCTACGTA
 ACGTACTAGTACGT
 TTAGTACGTACGT
 TACGTACTAAAGTACGT
 TACGTACTAGTACGT
 TTTAAACGTA
 CGTACTAGTACGT
 GGGAGTACGTACGT



1 Sequencing

Genome Analysis

2 Read Mapping

Data → performance & energy bottleneck

read4: CGCTTCCAT
 read5: CCATGACGC
 read6: TTCCATGAC



3 Variant Calling

4 Scientific Discovery

Future of Genome Sequencing & Analysis

Mohammed Alser, Zülal Bingöl, Damla Senol Cali, Jeremie Kim, Saugata Ghose, Can Alkan, Onur Mutlu
["Accelerating Genome Analysis: A Primer on an Ongoing Journey"](#) IEEE Micro, August 2020.



MinION from ONT

Accelerating Genome Analysis: A Primer on an Ongoing Journey

Sept.-Oct. 2020, pp. 65-75, vol. 40

DOI Bookmark: [10.1109/MM.2020.3013728](https://doi.org/10.1109/MM.2020.3013728)

FPGA-Based Near-Memory Acceleration of Modern Data-Intensive Applications

July-Aug. 2021, pp. 39-48, vol. 41

DOI Bookmark: [10.1109/MM.2021.3088396](https://doi.org/10.1109/MM.2021.3088396)



SmidgION from ONT

Accelerating Genome Analysis [IEEE MICRO 2020]

- Mohammed Alser, Zülal Bingöl, Damla Senol Cali, Jeremie Kim, Saugata Ghose, Can Alkan, and Onur Mutlu,
["Accelerating Genome Analysis: A Primer on an Ongoing Journey"](#)
[IEEE Micro \(IEEE MICRO\)](#), Vol. 40, No. 5, pages 65-75, September/October 2020.
[\[Slides \(pptx\)\(pdf\)\]](#)
[\[Talk Video \(1 hour 2 minutes\)\]](#)

Accelerating Genome Analysis: A Primer on an Ongoing Journey

Mohammed Alser

ETH Zürich

Zülal Bingöl

Bilkent University

Damla Senol Cali

Carnegie Mellon University

Jeremie Kim

ETH Zurich and Carnegie Mellon University

Saugata Ghose

University of Illinois at Urbana–Champaign and
Carnegie Mellon University

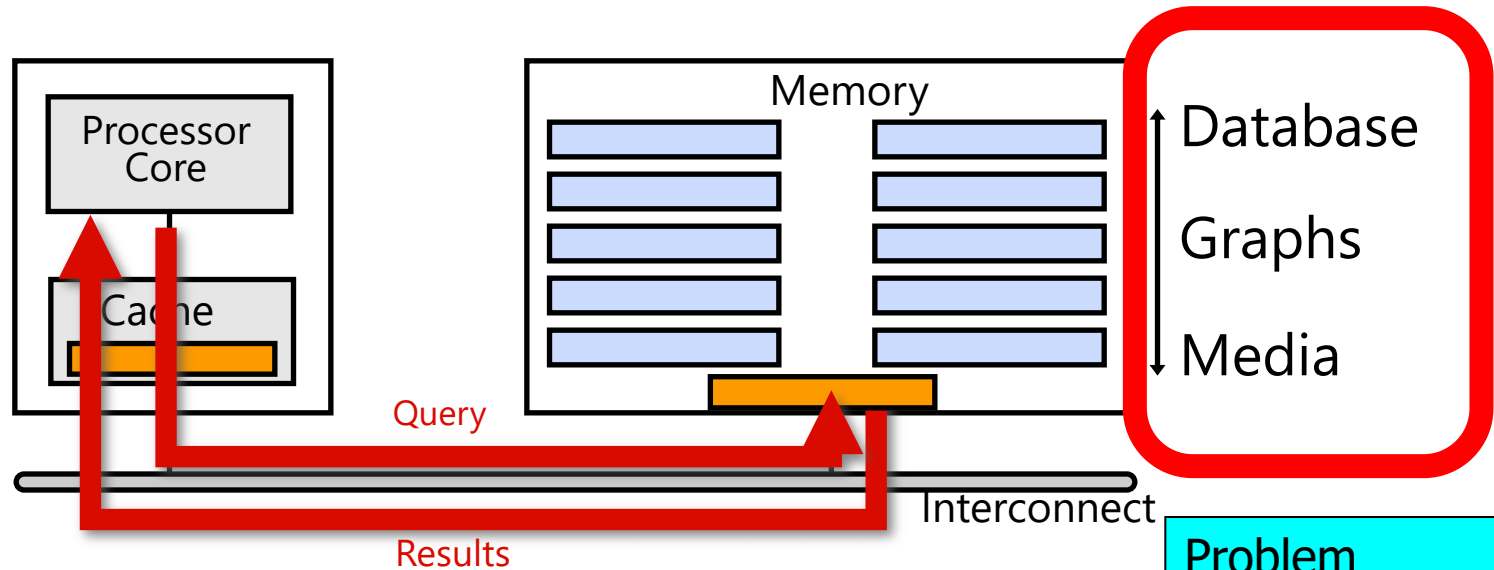
Can Alkan

Bilkent University

Onur Mutlu

ETH Zurich, Carnegie Mellon University, and
Bilkent University

Goal: Processing Inside Memory Systems



- Many questions ... How do we design the:
 - ❑ compute-capable memory & controllers?
 - ❑ processor chip and in-memory units?
 - ❑ software and hardware interfaces?
 - ❑ system software, compilers, languages?
 - ❑ algorithms and theoretical foundations?

Problem

Algorithm

Program/Language

System Software

SW/HW Interface

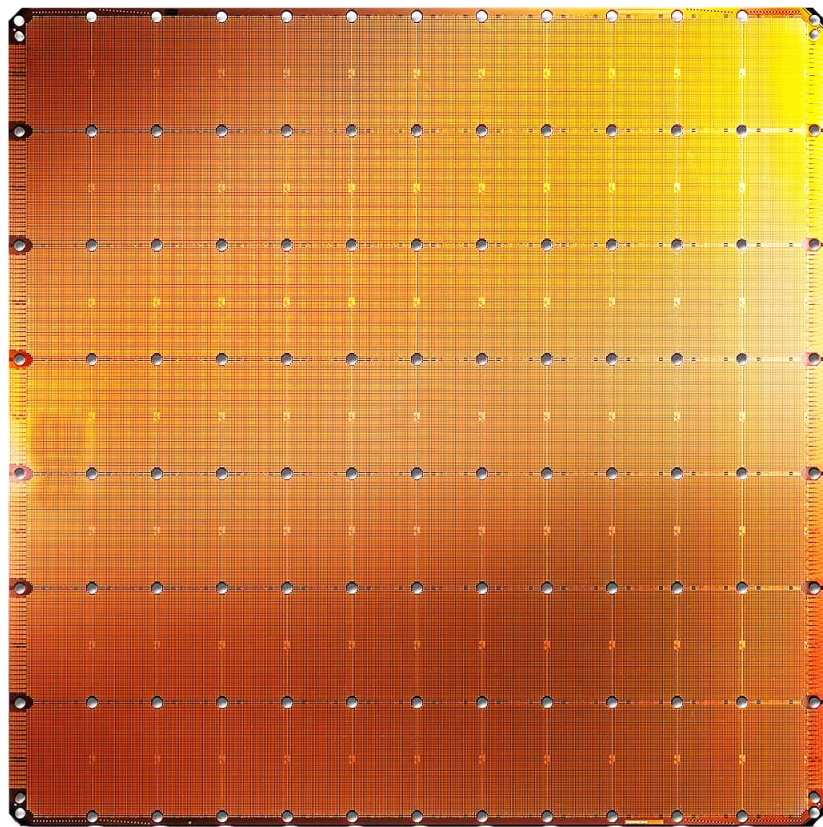
Micro-architecture

Logic

Devices

Electrons

Cerebras's Wafer Scale Engine (2019)



Cerebras WSE

1.2 Trillion transistors

46,225 mm²

- The largest ML accelerator chip
- 400,000 cores



Largest GPU

21.1 Billion transistors

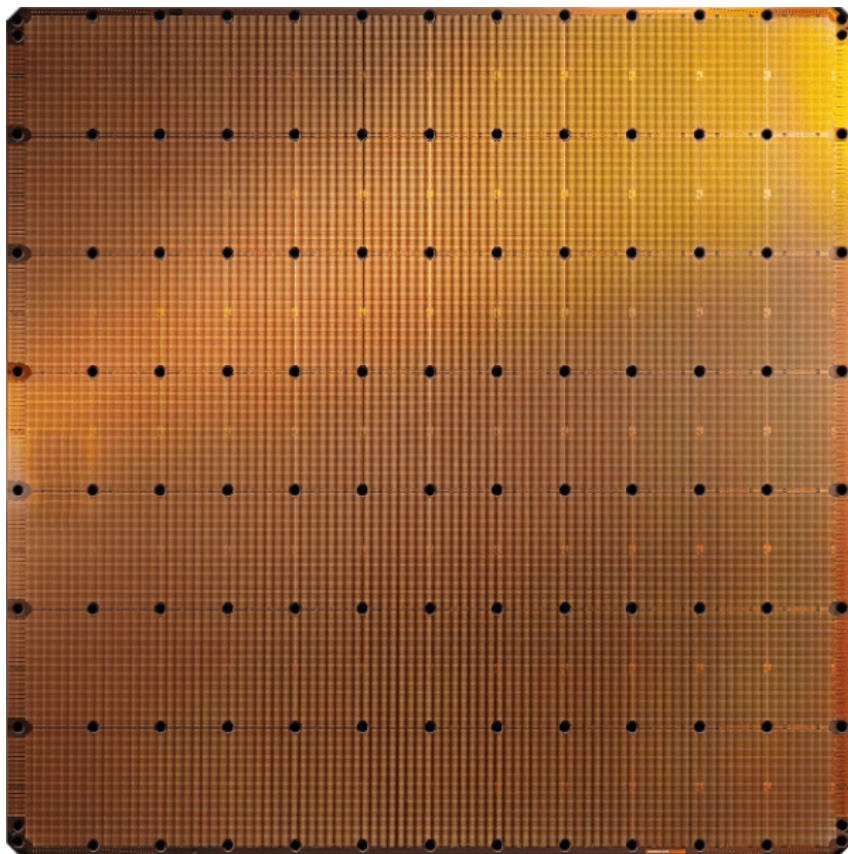
815 mm²

NVIDIA TITAN V

<https://www.anandtech.com/show/14758/hot-chips-31-live-blogs-cerebras-wafer-scale-deep-learning>

<https://www.cerebras.net/cerebras-wafer-scale-engine-why-we-need-big-chips-for-deep-learning>

Cerebras's Wafer Scale Engine-2 (2021)



Cerebras WSE-2
2.6 Trillion transistors
46,225 mm²

- The largest ML accelerator chip (2021)
- 850,000 cores



Largest GPU
54.2 Billion transistors
826 mm²

NVIDIA Ampere GA100

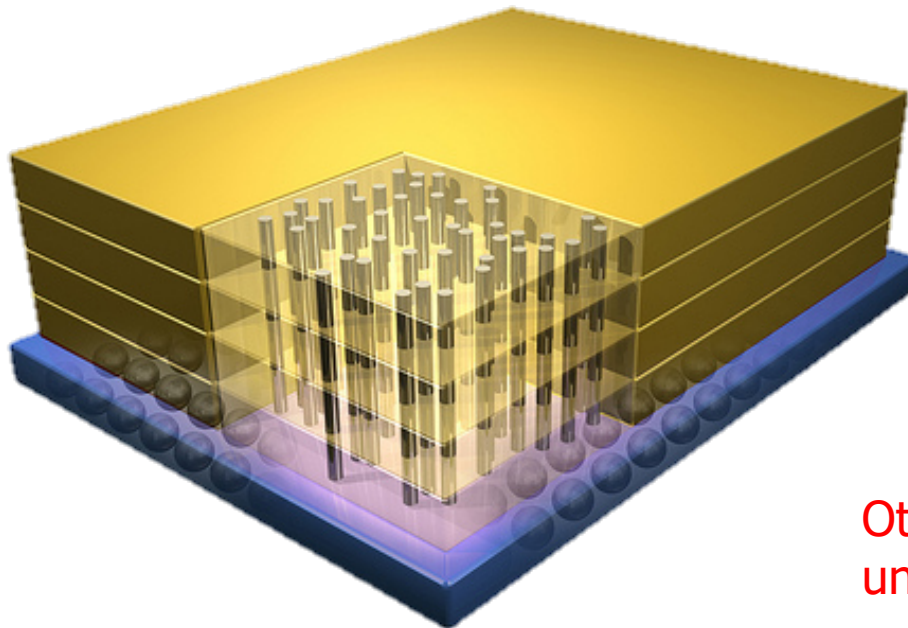
<https://www.anandtech.com/show/14758/hot-chips-31-live-blogs-cerebras-wafer-scale-deep-learning>

<https://www.cerebras.net/cerebras-wafer-scale-engine-why-we-need-big-chips-for-deep-learning/>

Opportunity: 3D-Stacked Logic+Memory



Hybrid Memory Cube
C O N S O R T I U M



Memory

Logic

Other "True 3D" technologies
under development

SAFARI PhD and Post-Doc Alumni

- <https://safari.ethz.ch/safari-alumni/>
- Minesh Patel (ETH Zurich), MICRO 2020 and DSN 2020 Best Paper Awards; ISCA Hall of Fame 2021
- Damla Senol Cali (Bionano Genomics), SRC TECHCON 2019 Best Student Presentation Award
- Nastaran Hajinazar (ETH Zurich)
- Gagandeep Singh (ETH Zurich), FPL 2020 Best Paper Award Finalist
- Amirali Boroumand (Stanford Univ → Google), SRC TECHCON 2018 Best Student Presentation Award
- Jeremie Kim (ETH Zurich), EDAA Outstanding Dissertation Award 2020; IEEE Micro Top Picks 2019; ISCA/MICRO HoF 2021
- Nandita Vijaykumar (Univ. of Toronto, Assistant Professor), ISCA Hall of Fame 2021
- Kevin Hsieh (Microsoft Research, Senior Researcher)
- Justin Meza (Facebook), HiPEAC 2015 Best Student Presentation Award; ICCD 2012 Best Paper Award
- Mohammed Alser (ETH Zurich), IEEE Turkey Best PhD Thesis Award 2018
- Yixin Luo (Google), HPCA 2015 Best Paper Session
- Kevin Chang (Facebook), SRC TECHCON 2016 Best Student Presentation Award
- Rachata Ausavarungrun (KMUNTB, Assistant Professor), NOCS 2015 and NOCS 2012 Best Paper Award Finalist
- Gennady Pekhimenko (Univ. of Toronto, Assistant Professor), ISCA Hall of Fame 2021; ASPLOS 2015 SRC Winner
- Vivek Seshadri (Microsoft Research)
- Donghyuk Lee (NVIDIA Research, Senior Researcher), HPCA Hall of Fame 2018
- Yoongu Kim (Software Robotics → Google), TCAD'19 Top Pick Award; IEEE Micro Top Picks'10; HPCA'10 Best Paper Session
- Lavanya Subramanian (Intel Labs → Facebook)
- Samira Khan (Univ. of Virginia, Assistant Professor), HPCA 2014 Best Paper Session
- Saugata Ghose (Univ. of Illinois, Assistant Professor), DFRWS-EU 2017 Best Paper Award
- Jawad Haj-Yahya (Huawei Research Zurich, Principal Researcher)

Research & Teaching: Some Overview Talks

<https://www.youtube.com/onurmutlulectures>

■ Future Computing Architectures

- https://www.youtube.com/watch?v=kgiZISOcGFM&list=PL5Q2soXY2Zi8D_5MGV6EnXEJHnV2YFBjI&index=1

■ Enabling In-Memory Computation

- https://www.youtube.com/watch?v=njX_14584Jw&list=PL5Q2soXY2Zi8D_5MGV6EnXEJHnV2YFBjI&index=16

■ Accelerating Genome Analysis

- https://www.youtube.com/watch?v=r7sn41IH-4A&list=PL5Q2soXY2Zi8D_5MGV6EnXEJHnV2YFBjI&index=41

■ Rethinking Memory System Design

- https://www.youtube.com/watch?v=F7xZLNMIY1E&list=PL5Q2soXY2Zi8D_5MGV6EnXEJHnV2YFBjI&index=3

■ Intelligent Architectures for Intelligent Machines

- https://www.youtube.com/watch?v=c6_LgzuNdkw&list=PL5Q2soXY2Zi8D_5MGV6EnXEJHnV2YFBjI&index=25

■ The Story of RowHammer

- https://www.youtube.com/watch?v=sgd7PHQQ1AI&list=PL5Q2soXY2Zi8D_5MGV6EnXEJHnV2YFBjI&index=39

Online Courses & Lectures

■ **First Computer Architecture & Digital Design Course**

- ❑ Digital Design and Computer Architecture
- ❑ Spring 2021 Livestream Edition:
https://www.youtube.com/watch?v=LbC0EZY8yw4&list=PL5Q2soXY2Zi_uej3aY39YB5pfW4SJ7LIN

■ **Advanced Computer Architecture Course**

- ❑ Computer Architecture
- ❑ Fall 2020 Edition:
<https://www.youtube.com/watch?v=c3mPdZA-Fmc&list=PL5Q2soXY2Zi9xidyIgBxUz7xRPS-wisBN>



Onur Mutlu Lectures

16.9K subscribers

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Popular uploads ▶ PLAY ALL




How Computers Work
(from the ground up)

1:33:25



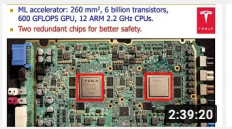
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Architecture: Lecture 1:...

49K views • 1 year ago




Computer Architecture -
Lecture 1: Introduction and...

36K views • 3 years ago



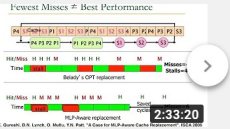
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Lecture 1: Introduction and...

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Computer Architecture -
Lecture 1: Introduction and...

30K views • 8 months ago



Design of Digital Circuits -
Lecture 1: Introduction and...

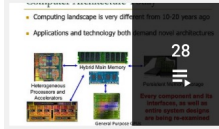
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Lecture 2: Fundamentals,...


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First Course in Computer Architecture & Digital Design 2021-2013




Livestream - Digital Design and
Computer Architecture - ETH...

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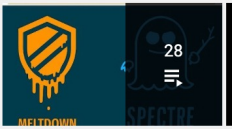
Digital Design & Computer
Architecture - ETH Zürich...

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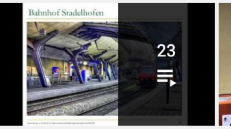
Design of Digital Circuits - ETH
Zürich - Spring 2019

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Design of Digital Circuits - ETH
Zürich - Spring 2018

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Digital Circuits and Computer
Architecture - ETH Zürich - ...

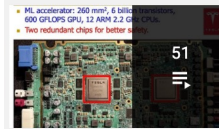
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Spring 2015 -- Computer
Architecture Lectures -- ...

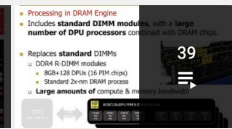
Carnegie Mellon Computer Architec...
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Advanced Computer Architecture Courses 2020-2012




Computer Architecture - ETH
Zürich - Fall 2020

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Computer Architecture - ETH
Zürich - Fall 2019

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Computer Architecture - ETH
Zürich - Fall 2018

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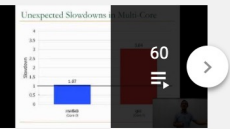
Computer Architecture - ETH
Zürich - Fall 2017

Onur Mutlu Lectures
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Fall 2015 - 740 Computer
Architecture


Carnegie Mellon Computer Archite...
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Fall 2013 - 740 Computer
Architecture - Carnegie Mellon


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Special Courses on Memory Systems



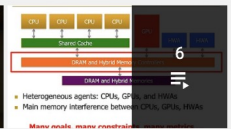
Memory Technology Lectures

Onur Mutlu Lectures
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Champéry Winter School 2020 -
Memory Systems and Memory...

Onur Mutlu Lectures
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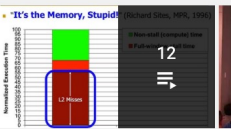
Perugia NIPS Summer School
2019

Onur Mutlu Lectures
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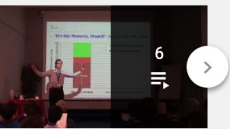
SAMOS Tutorial 2019 - Memory
Systems

Onur Mutlu Lectures
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TU Wien 2019 - Memory
Systems and Memory-Centric...

Onur Mutlu Lectures
VIEW FULL PLAYLIST



ACACES 2018 Lectures --
Memory Systems and Memory...

Onur Mutlu Lectures
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Research Talks

<https://www.youtube.com/onurmutlulectures>

DDCA (Spring 2021)



<https://safari.ethz.ch/digitaltechnik/spring2021/doku.php?id=schedule>

https://www.youtube.com/watch?v=LbC0EZY8yw4&list=PL5Q2soXY2Zi_uej3aY39YB5pfW4SJ7LIN

Bachelor's course

- 2nd semester at ETH Zurich
- Rigorous introduction into "How Computers Work"
- Digital Design/Logic
- Computer Architecture
- 10 FPGA Lab Assignments

Trace: · schedule

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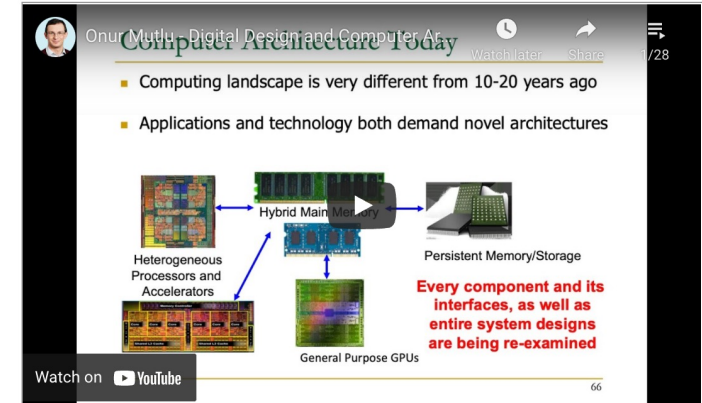
- Lectures/Schedule
- Lecture Buzzwords
- Readings
- Optional HWs
- Labs
- Extra Assignments
- Exams
- Technical Docs

Resources

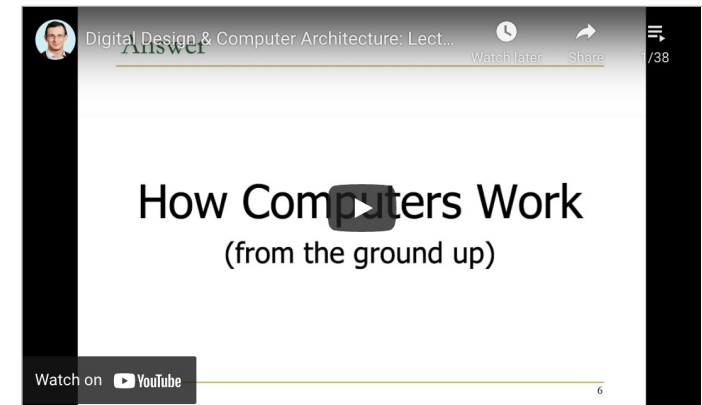
- Computer Architecture (CMU) SS15: Lecture Videos
- Computer Architecture (CMU) SS15: Course Website
- Digitaltechnik SS18: Lecture Videos
- Digitaltechnik SS18: Course Website
- Digitaltechnik SS19: Lecture Videos
- Digitaltechnik SS19: Course Website
- Digitaltechnik SS20: Lecture Videos
- Digitaltechnik SS20: Course Website
- Moodle

Lecture Video Playlist on YouTube

Livestream Lecture Playlist



Recorded Lecture Playlist



Spring 2021 Lectures/Schedule

| Week | Date | Livestream | Lecture | Readings | Lab | HW |
|------|------------|--------------|---|------------------------------------|-----|----|
| W1 | 25.02 Thu. | YouTube Live | L1: Introduction and Basics 02:00 (PDF) 02:00 (PPT) | Required Suggested Mentioned | | |
| | 26.02 Fri. | YouTube Live | L2a: Tradeoffs, Metrics, Mindset 02:00 (PDF) 02:00 (PPT) | Required | | |
| | | | L2b: Mysteries in Computer Architecture 02:00 (PDF) 02:00 (PPT) | Required Suggested Mentioned | | |
| W2 | 04.03 Thu. | YouTube Live | L3a: Mysteries in Computer Architecture II 02:00 (PDF) 02:00 (PPT) | Required Suggested Mentioned | | |

Comp Arch (Fall 2020)

- <https://safari.ethz.ch/architecture/fall2020/doku.php?id=schedule>
- <https://www.youtube.com/watch?v=c3mPdZA-Fmc&list=PL5Q2soXY2Zi9xidyIgBxUz7xRPS-wisBN>

- Master's level course
 - ❑ Taken by Bachelor's/Masters/PhD students
 - ❑ Cutting-edge research topics + fundamentals in Computer Architecture
 - ❑ 5 Simulator-based Lab Assignments
 - ❑ Potential research exploration
 - ❑ Many research readings

Computer Architecture - Fall 2020

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- Computer Architecture FS19: Course Webpage
- Computer Architecture FS19: Lecture Videos
- Digitaltechnik SS20: Course Webpage
- Digitaltechnik SS20: Lecture Videos
- Moodle
- Piazza (Q&A)
- HotCRP
- Verilog Practice Website (HDLBits)

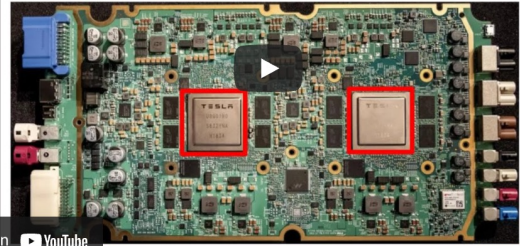
Lecture Video Playlist on YouTube

Lecture Playlist

Computer Architecture - Lecture: Introduction

ML accelerator: 260 mm², 6 billion transistors, 600 GFLOPS GPU, 12 ARM 2.2 GHz CPUs.

Two redundant chips for better safety.



Watch on YouTube

<https://www.youtube.com/watch?v=c3mPdZA-Fmc&list=PL5Q2soXY2Zi9xidyIgBxUz7xRPS-wisBN>

Fall 2020 Lectures & Schedule

| Week | Date | Lecture | Readings | Lab | HW |
|------|---------------|---|------------------------|--------------|-------------|
| W1 | 17.09 Thu. | L1: Introduction and Basics CORA (PDF) PPT YouTube Video | Described Suggested | | HW 0 Out |
| | | L2a: Memory Performance Attacks CORA (PDF) PPT YouTube Video | Described Suggested | Lab 1 Out | |
| | 18.09 Fri. | L2b: Data Retention and Memory Refresh CORA (PDF) PPT YouTube Video | Described Suggested | | |
| | | L2c: Course Logistics CORA (PDF) PPT YouTube Video | | | |
| W2 | 24.09 Thu. | L3a: Introduction to Genome Sequence Analysis CORA (PDF) PPT YouTube Video | Described Suggested | | HW 1 Out |
| | | L3b: Memory Systems: Challenges and Opportunities CORA (PDF) PPT YouTube Video | Described Suggested | | |
| | 25.09 Fri. | L4a: Memory Systems: Solution Directions CORA (PDF) PPT YouTube Video | Described Suggested | | |
| | | L4b: RowHammer CORA (PDF) PPT YouTube Video | Described Suggested | | |
| W3 | 01.10 Thu. | L5a: RowHammer in 2020: TRRespass CORA (PDF) PPT YouTube Video | Described Suggested | | |
| | | L5b: RowHammer in 2020: Revisiting RowHammer CORA (PDF) PPT YouTube Video | Described Suggested | | |
| | | L5c: Secure and Reliable Memory CORA (PDF) PPT YouTube Video | Described | | |

Computer Architecture - Fall 2021

Search

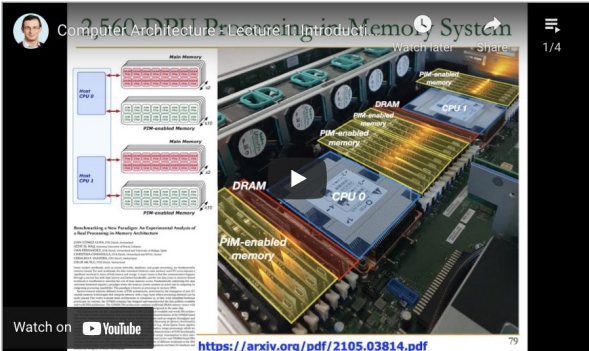
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Lecture Video Playlist on YouTube


[Livestream Lecture Playlist](#)



Watch on

<https://arxiv.org/pdf/2105.03814.pdf>

[Recorded Lecture Playlist](#)



Watch on

<https://www.youtube.com/watch?v=Ucp0TTmvsQE&t=4236>

Fall 2021 Lectures & Schedule

| Week | Date | Livestream | Lecture | Readings | Lab | HW |
|------|------------|------------------------------|---|------------------------|------------------------|-------------|
| W1 | 30.09 Thu. | YouTube Live | L1: Introduction and Basics aaa(PDF) aaa(PPT) | Required Mentioned | Lab 1 Out | HW 0 Out |
| | 01.10 Fri. | YouTube Live | L2: Trends, Tradeoffs and Design Fundamentals aaa(PDF) aaa(PPT) | Required Mentioned | | |
| W2 | 07.10 Thu. | YouTube Live | L3a: Memory Systems: Challenges and Opportunities aaa(PDF) aaa(PPT) | Described Suggested | | HW 1 Out |
| | | | L3b: Course Info & Logistics aaa(PDF) aaa(PPT) | | | |
| | | | L3c: Memory Performance Attacks aaa(PDF) aaa(PPT) | | Described Suggested | |
| | 08.10 Fri. | YouTube Live | L4a: Memory Performance Attacks aaa(PDF) aaa(PPT) | Described Suggested | Lab 2 Out | |
| | | | L4b: Data Retention and Memory Refresh aaa(PDF) aaa(PPT) | Described Suggested | | |
| | | | L4c: RowHammer aaa(PDF) aaa(PPT) | Described Suggested | | |


- <https://safari.ethz.ch/architecture/fall2021/doku.php?id=schedule>
- **Youtube Livestream:**
 - ❑ https://www.youtube.com/watch?v=4yfkM_5EFgo&list=PL5Q2soXY2Zi-Mnk1PxjEIG32HAGILkTOF
- **Master's level course**
 - ❑ Taken by Bachelor's/Masters/PhD students
 - ❑ Cutting-edge research topics + fundamentals in Computer Architecture
 - ❑ 5 Simulator-based Lab Assignments
 - ❑ Potential research exploration
 - ❑ Many research readings

Seminar (Spring'21)

■ https://safari.ethz.ch/architecture_seminar/spring2021/doku.php?id=schedule

■ https://www.youtube.com/watch?v=t3m93ZpLOyw&list=PL5Q2soXY2Zi_awYdjmWVIUegsbY7TPGW4

- Critical analysis course
 - Taken by Bachelor's/Masters/PhD students
 - Cutting-edge research topics + fundamentals in Computer Architecture
 - 20+ research papers, presentations, analyses


Seminar in Computer Architecture - Spring 2021

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Past Course Materials

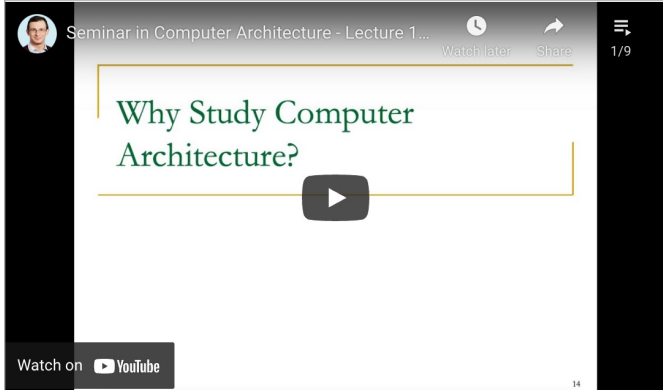
- Fall 2020
- Spring 2020
- Fall 2019
- Spring 2019

Resources

- Computer Architecture
 - Fall 2020
 - Fall 2020: Lecture Videos
 - Fall 2019
 - Fall 2019: Lecture Videos
 - Fall 2018
 - Fall 2018: Lecture Videos
- Digital Design and Computer Architecture
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 - Spring 2020: Lecture Videos
 - Spring 2019
 - Spring 2019: Lecture Videos

Lecture Video Playlist on YouTube

Lecture Playlist



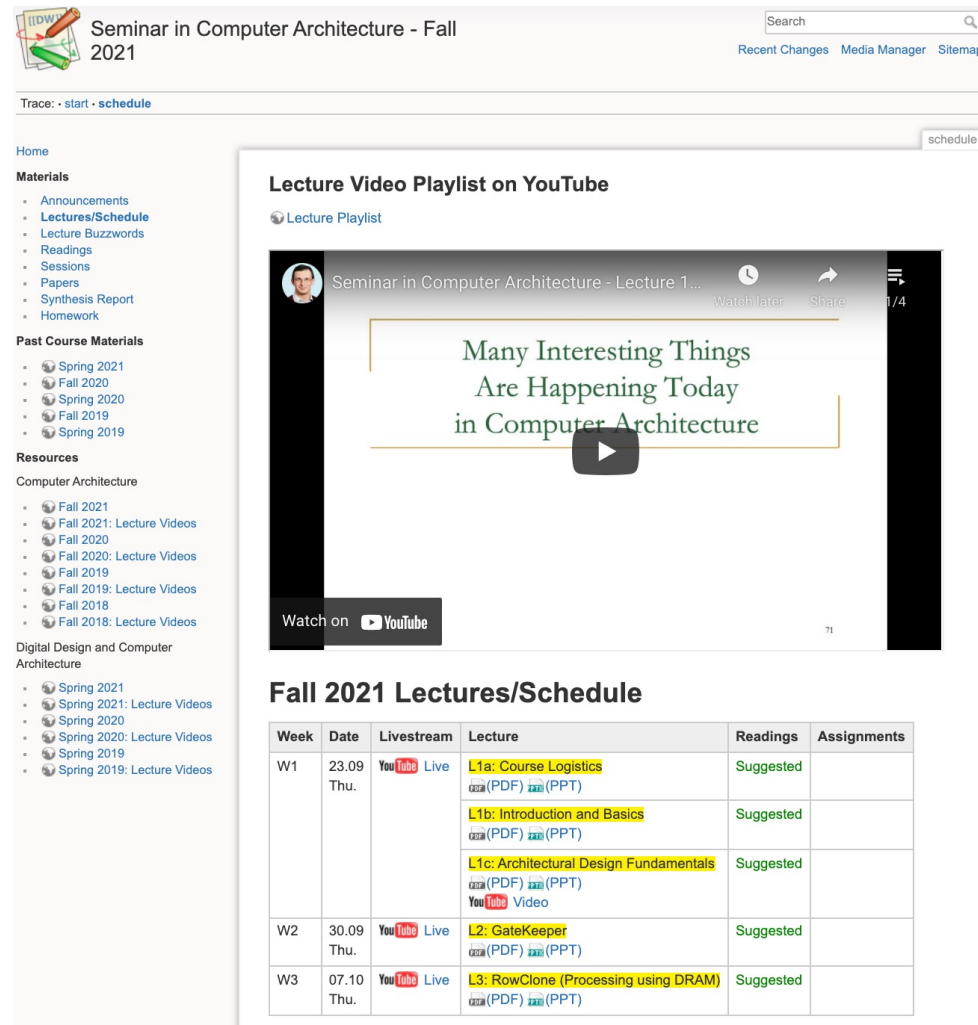
Watch on YouTube

Spring 2021 Lectures/Schedule

| Week | Date | Livestream | Lecture | Readings | Assignments |
|------|------------|------------------|---|-----------|-------------|
| W1 | 25.02 Thu. | YouTube Live | L1a: Introduction and Basics <small>PDF (PPT)</small> Optional Lecture: Design Fundamentals <small>PDF (PPT)</small> L1b: Course Logistics <small>PDF (PPT)</small> | Suggested | |
| W2 | 04.03 Thu. | YouTube Live | L2: Example Review: RowClone <small>PDF (PPT)</small> | Suggested | |
| W3 | 11.03 Thu. | YouTube Live | L3: Example Review: Memory Channel Partitioning <small>PDF (PPT)</small> | Suggested | |
| W4 | 18.03 Thu. | YouTube Live | L4: Example Review: GateKeeper <small>PDF (PPT)</small> | Suggested | |
| W5 | 25.03 Thu. | YouTube Premiere | S1.1: Spectre Attacks: Exploiting Speculative Execution, S&P 2019 <small>PPT (PDF)</small> S1.2: BlockHammer: Preventing RowHammer at Low Cost by Blacklisting Rapidly-Accessed DRAM Rows, HPCA 2021 <small>PPT (PDF)</small> | Mentioned | |
| W6 | 01.04 Thu. | YouTube Live | S2.1: D-RaNGe: Using Commodity DRAM Devices to Generate True Random Numbers with Low Latency and High Throughput, HPCA 2019 <small>PPT (PDF)</small> S2.2: ComputeDRAM: In-Memory Compute Using Off-the-Shelf DRAMs, MICRO 2019 <small>PPT (PDF)</small> | Mentioned | |
| W7 | 15.04 Thu. | | S3.1: PIM-Enabled Instructions: A Low-Overhead, Locality-Aware Processing-in-Memory Architecture, | Mentioned | |

Seminar (Current)

- https://safari.ethz.ch/architecture_seminar/fall2021/doku.php?id=schedule
- **Youtube Livestream:**
 - https://www.youtube.com/watch?v=4TcP297mdsI&list=PL5Q2soXY2Zi_7UBNmC9B8Yr5JSwTG9yH4
- Critical analysis course
 - Taken by Bachelor's/Masters/PhD students
 - Cutting-edge research topics + fundamentals in Computer Architecture
 - 20+ research papers, presentations, analyses



Seminar in Computer Architecture - Fall 2021

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- Spring 2021
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- Fall 2019
- Spring 2019

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- Fall 2020: Lecture Videos
- Fall 2019
- Fall 2019: Lecture Videos
- Fall 2018
- Fall 2018: Lecture Videos

Digital Design and Computer Architecture

- Spring 2021
- Spring 2021: Lecture Videos
- Spring 2020
- Spring 2020: Lecture Videos
- Spring 2019
- Spring 2019: Lecture Videos

Lecture Video Playlist on YouTube

Lecture Playlist

Seminar in Computer Architecture - Lecture 1...

Many Interesting Things Are Happening Today in Computer Architecture

Watch on YouTube

Fall 2021 Lectures/Schedule

| Week | Date | Livestream | Lecture | Readings | Assignments |
|------|------------|--------------|---|-----------|-------------|
| W1 | 23.09 Thu. | YouTube Live | L1a: Course Logistics L1b: Introduction and Basics L1c: Architectural Design Fundamentals | Suggested | |
| W2 | 30.09 Thu. | YouTube Live | L2: GateKeeper | Suggested | |
| W3 | 07.10 Thu. | YouTube Live | L3: RowClone (Processing using DRAM) | Suggested | |

Hands-On Projects & Seminars Courses

- https://safari.ethz.ch/projects_and_seminars/doku.php



SAFARI Project & Seminars Courses
(Spring 2021)



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Projects

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- [Ramulator](#)
- [Accelerating Genomics](#)
- [Mobile Genomics](#)
- [Processing-in-Memory](#)
- [Heterogeneous Systems](#)
- [SSD Simulator](#)

[start](#)

SAFARI Projects & Seminars Courses (Spring 2021)

Welcome to the wiki for Project and Seminar courses SAFARI offers.

Courses we offer:

- Understanding and Improving Modern DRAM Performance, Reliability, and Security with Hands-On Experiments
- Designing and Evaluating Memory Systems and Modern Software Workloads with Ramulator
- Accelerating Genome Analysis with FPGAs, GPUs, and New Execution Paradigms
- Genome Sequencing on Mobile Devices
- Exploring the Processing-in-Memory Paradigm for Future Computing Systems
- Hands-on Acceleration on Heterogeneous Computing Systems
- Understanding and Designing Modern NAND Flash-Based Solid-State Drives (SSDs) by Building a Practical SSD Simulator

PIM Course (Current)

Fall 2021 Edition:

- https://safari.ethz.ch/projects_and_seminars/fall2021/doku.php?id=processing_in_memory

Youtube Livestream:

- <https://www.youtube.com/watch?v=9e4Chnwdovo&list=PL5Q2soXY2Zi-841fUYYUK9EsXKhQKRPyX>

Project course

- Taken by Bachelor's/Master's students
- Processing-in-Memory lectures
- Hands-on research exploration
- Many research readings

PIM Review and Open Problems
Processing in Memory Course: Meeting 1: Ex...

Watch later Share 1/10

A Modern Primer on Processing in Memory

Onur Mutlu^{a,b}, Saugata Ghose^{b,c}, Juan Gómez-Luna^a, Rachata Ausavarungnirun^d

SAFARI Research Group

^aETH Zürich
^bCarnegie Mellon University
^cUniversity of Illinois at Urbana-Champaign
^dKing Mongkut's University of Technology North Bangkok

Onur Mutlu, Saugata Ghose, Juan Gomez-Luna, and Rachata Ausavarungnirun, "A Modern Primer on Processing in Memory" Invited Book Chapter in *Emerging Computing: From Devices to Systems - Looking Beyond Moore and Von Neumann*, Springer, to be published in 2021.

Watch on YouTube <https://arxiv.org/pdf/1903.03988.pdf> 108


Fall 2021 Meetings/Schedule

| Week | Date | Livestream | Meeting | Learning Materials | Assignments |
|------|------------|--|--|---|-------------|
| W1 | 05.10 Tue. | YouTube Live | M1: P&S PIM Course Presentation PDF (PDF) PPT (PPT) | Required Materials Recommended Materials | HW 0 Out |
| W2 | 12.10 Tue. | YouTube Live | M2: Real-World PIM Architectures PDF (PDF) PPT (PPT) | | |
| W3 | 19.10 Tue. | YouTube Live | M3: Real-World PIM Architectures II PDF (PDF) PPT (PPT) | | |
| W4 | 26.10 Tue. | YouTube Live | M4: Real-World PIM Architectures III PDF (PDF) PPT (PPT) | | |
| W5 | 02.11 Tue. | YouTube Live | M5: Real-World PIM Architectures IV PDF (PDF) PPT (PPT) | | |
| W6 | 09.11 Tue. | YouTube Live | M6: End-to-End Framework for Processing-using-Memory PDF (PDF) PPT (PPT) | | |
| W7 | 16.11 Tue. | YouTube Live | M7: How to Evaluate Data Movement Bottlenecks PDF (PDF) PPT (PPT) | | |
| W8 | 23.11 Tue. | YouTube Live | M8: Programming PIM Architectures PDF (PDF) PPT (PPT) | | |
| W9 | 30.11 Tue. | YouTube Live | M9: Benchmarking and Workload Suitability on PIM PDF (PDF) PPT (PPT) | | |
| W10 | 07.12 Tue. | YouTube Live | M10: Bit-Serial SIMD Processing using DRAM PDF (PDF) PPT (PPT) | | |

Open-Source Artifacts

<https://github.com/CMU-SAFARI>

Open Source Tools: SAFARI GitHub



SAFARI Research Group at ETH Zurich and Carnegie Mellon University


Site for source code and tools distribution from SAFARI Research Group at ETH Zurich and Carnegie Mellon University.

📍 ETH Zurich and Carnegie Mellon ... 🔗 <https://safari.ethz.ch/> ✉ omutlu@gmail.com

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Pinned

Customize your pins

 **ramulator** Public ⋮


A Fast and Extensible DRAM Simulator, with built-in support for modeling many different DRAM technologies including DDRx, LPDDRx, GDDRx, WIOx, HBMx, and various academic proposals. Described in the...

● C++ ☆ 250 🍴 130

 **prim-benchmarks** Public ⋮

PRIM (Processing-In-Memory benchmarks) is the first benchmark suite for a real-world processing-in-memory (PIM) architecture. PRIM is developed to evaluate, analyze, and characterize the first publ...

● C ☆ 18 🍴 8

 **DAMOV** Public ⋮

DAMOV is a benchmark suite and a methodical framework targeting the study of data movement bottlenecks in modern applications. It is intended to study new architectures, such as near-data processin...

● C++ ☆ 12 🍴 1

📁 Repositories

Type ▾ Language ▾ Sort ▾ New

Pythia

A Customizable Hardware Prefetching Framework Using Online Reinforcement Learning.

● C++ ☆ 0 🍴 1 🔄 0 📄 0 Updated yesterday

BurstLink

☆ 0 🍴 0 🔄 0 📄 0 Updated 21 days ago

<https://github.com/CMU-SAFARI/>

47

Repositories 45 Packages People 12 Projects

Find a repository...

Type ▾

Language ▾

Sort ▾

COVIDHunter

COVIDHunter 🦠📊: An accurate and flexible COVID-19 outbreak simulation model that forecasts the strength of future mitigation measures and the numbers of cases, hospitalizations, and deaths for a given day, while considering the potential effect of environmental conditions. Described by Alser et al. (preliminary version at <https://arxiv.org/abs/2003.09471>...

simulation epidemiology covid-19 covid-19-data covid-19-tracker
 reproduction-number covidhunter

Swift MIT 1 5 0 0 Updated 9 hours ago

SNP-Selective-Hiding

An optimization-based mechanism 🧠🔒 to selectively hide the minimum number of overlapping SNPs among the family members 👨👩👧👦 who participated in the genomic studies (i.e. GWAS). Our goal is to distort the dependencies among the family members in the original database for achieving better privacy without significantly degrading the data utility.

gwas genomics data-privacy differential-privacy
 genomic-data-analysis laplace-distribution genomic-privacy

MATLAB 0 0 0 0 Updated 10 hours ago

SneakySnake

SneakySnake 🐍 is the first and the only pre-alignment filtering algorithm that works efficiently and fast on modern CPU, FPGA, and GPU architectures. It greatly (by more than two orders of magnitude) expedites sequence alignment calculation for both short and long reads. Described in the Bioinformatics (2020) by Alser et al. <https://arxiv.org/abs/2003.09471>...

fpga gpu smith-waterman needleman-wunsch
 sequence-alignment long-reads minimap2

VHDL GPL-3.0 6 31 0 1 Updated on May 12

ramulator

A Fast and Extensible DRAM Simulator, with built-in support for modeling many different DRAM technologies including DDRx, LPDDRx, GDDRx, WIOx, HBMx, and various academic proposals. Described in the IEEE CAL 2015 paper by Kim et al. at http://users.ece.cmu.edu/~omutlu/pub/ramulator_dram_simulator-ieee-cal15.pdf

C++ MIT 121 237 47 4 Updated on May 11

Top languages

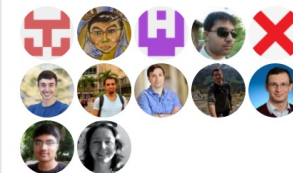
C++ C C# AGS Script
 VHDL

Most used topics

dram reliability
 error-correcting-codes
 experimental-data
 pre-alignment-filtering

People

12 >



<https://github.com/CMU-SAFARI>

Papers, Talks, Artifacts

- All are available at

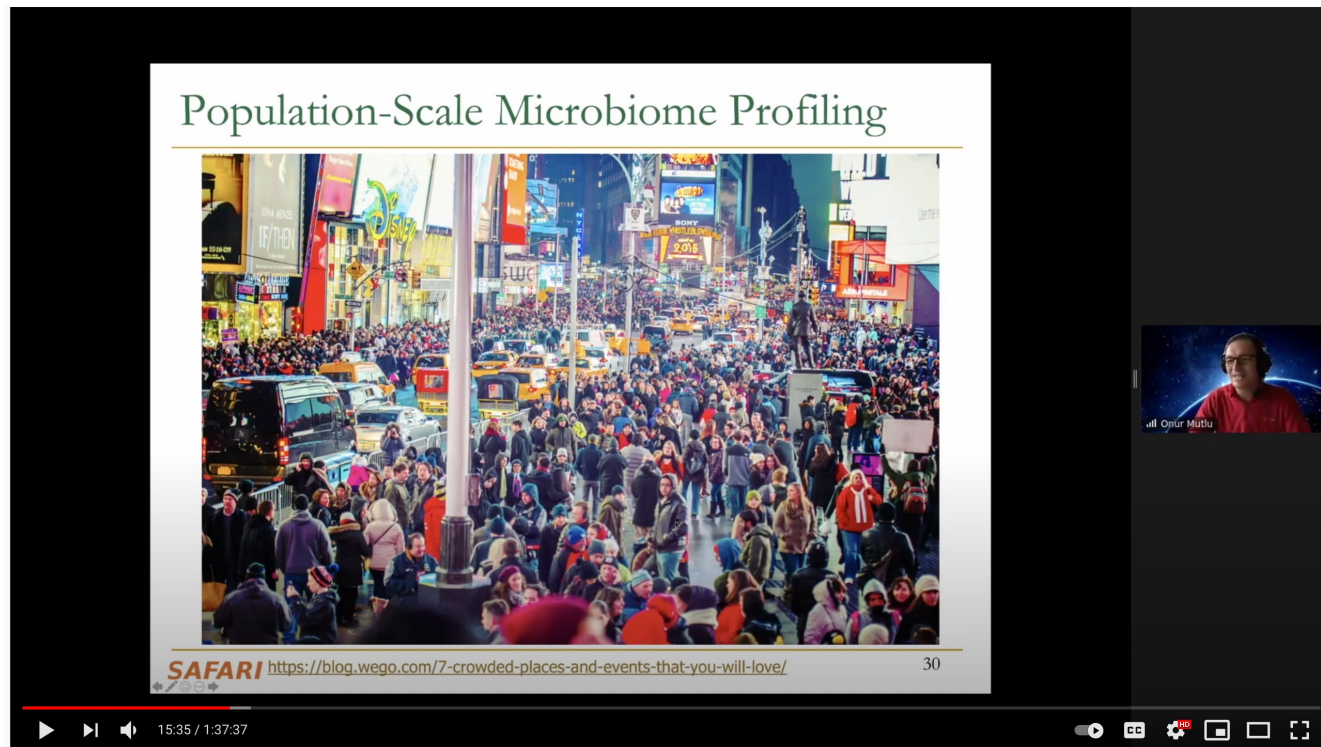
<https://people.inf.ethz.ch/omutlu/projects.htm>

<https://www.youtube.com/onurmutlulectures>

<https://github.com/CMU-SAFARI/>

More on Fast & Efficient Genome Analysis ...

- Onur Mutlu,
"Accelerating Genome Analysis: A Primer on an Ongoing Journey"
Invited Lecture at [Technion](#), Virtual, 26 January 2021.
[[Slides \(pptx\)](#) ([pdf](#))]
[[Talk Video](#) (1 hour 37 minutes, including Q&A)]
[[Related Invited Paper \(at IEEE Micro, 2020\)](#)]



Onur Mutlu - Invited Lecture @Technion: Accelerating Genome Analysis: A Primer on an Ongoing Journey

740 views • Premiered Feb 6, 2021

35 0 SHARE SAVE ...

SAFARI



Onur Mutlu Lectures
15.9K subscribers

ANALYTICS

EDIT VIDEO

Detailed Lectures on Genome Analysis

- **Computer Architecture, Fall 2020, Lecture 3a**
 - **Introduction to Genome Sequence Analysis** (ETH Zürich, Fall 2020)
 - <https://www.youtube.com/watch?v=CrRb32v7SJc&list=PL5Q2soXY2Zi9xidyIgBxUz7xRPS-wisBN&index=5>
- **Computer Architecture, Fall 2020, Lecture 8**
 - **Intelligent Genome Analysis** (ETH Zürich, Fall 2020)
 - <https://www.youtube.com/watch?v=ygmQpdDTL7o&list=PL5Q2soXY2Zi9xidyIgBxUz7xRPS-wisBN&index=14>
- **Computer Architecture, Fall 2020, Lecture 9a**
 - **GenASM: Approx. String Matching Accelerator** (ETH Zürich, Fall 2020)
 - <https://www.youtube.com/watch?v=XoLpzmN-Pas&list=PL5Q2soXY2Zi9xidyIgBxUz7xRPS-wisBN&index=15>
- **Accelerating Genomics Project Course, Fall 2020, Lecture 1**
 - **Accelerating Genomics** (ETH Zürich, Fall 2020)
 - <https://www.youtube.com/watch?v=rgjl8ZyLsAg&list=PL5Q2soXY2Zi9E2bBVAgCqLgwiDRQDTyId>

SAFARI Live Seminars (I)


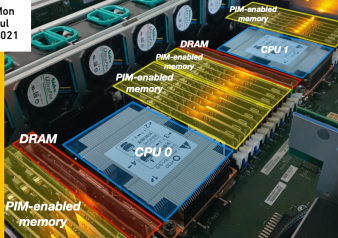
SAFARI Live Seminars in Computer Architecture

Dr. Juan Gómez Luna, ETH Zurich

Understanding a Modern Processing-in-Memory Architecture: Benchmarking and Experimental Characterization

SAFARI
SAFARI Research Group

12 Mon Jul 2021


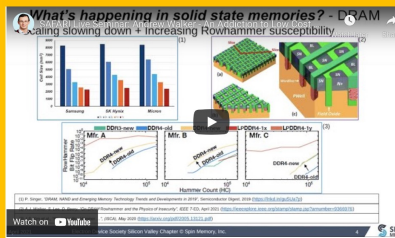
SAFARI Live Seminars in Computer Architecture

Dr. Andrew Walker, Schiltron Corporation & Nexgen Power Systems

An Addition to Low Cost Per Memory Bit – How to Recognize It and What to Do About It

SAFARI
SAFARI Research Group

19 Mo Jul 2021


SAFARI Live Seminars in Computer Architecture

Geraldo F. Oliveira, ETH Zurich

DAMOV: A New Methodology and Benchmark Suite for Evaluating Data Movement Bottlenecks

SAFARI
SAFARI Research Group

22 Do Jul 2021



Near-Data Processing (2/2)

UPMEM (2019) Samsung HBM-PIM (2021)

Near-DRAM-banks processing for general-purpose computing

0.9 TOPS compute throughput¹

1.2 TFLOPS compute throughput²

The goal of Near-Data Processing (NDP) is to mitigate data movement

SAFARI


SAFARI Live Seminars in Computer Architecture

Gennady Pekhimenko, University of Toronto

Efficient DNN Training at Scale: from Algorithms to Hardware

SAFARI
SAFARI Research Group

5 Do Aug 2021



DNN Training vs. Inference

Step 1 - Forward Pass (makes a prediction)

Step 2 - Backward Pass (calculates error gradients)

Generated in the forward pass

Used in the backward pass

DNN training requires stashing feature maps for the backward pass (not required in inference)


SAFARI Live Seminars in Computer Architecture

Jawad Haj-Yahya, Huawei Research Center Zurich

Power Management Mechanisms in Modern Microprocessors and Their Security Implications

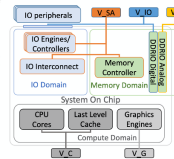
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Overview of a Modern SoC Architecture

- 3 domains in modern thermally-constrained mobile SoC: Compute, Memory, IO
- Several voltage sources exist, and some of them are shared between domains
- IO controllers and engines, IO interconnect, memory controller, and DDRIO typically each has an independent clock




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Ataberk Olgun, TOBB & ETH Zurich

QUAC-TRNG: High-Throughput True Random Number Generation Using Quadruple Row Activation in Commodity DRAM Chips

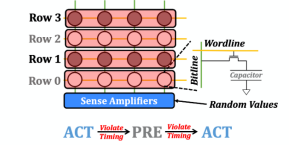
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Using QUAC to Generate Random Values

Use QUAC to activate DRAM rows that are initialized with conflicting data (e.g., two '1's and two '0's) to generate random values



ACT **PRE** **ACT**

SAFARI **kasirga**


SAFARI Live Seminars in Computer Architecture

Minesh Patel, ETH Zurich

Enabling Effective Error Mitigation in Memory Chips That Use On-Die ECCs

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21 Tues Sep 2021



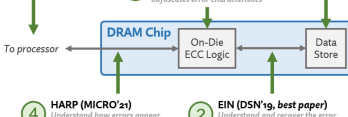
Position Paper (Ongoing) Arguing for increased transparency of DRAM reliability characteristics

REAPER (ISCA'17) Understand the basic properties of DRAM data-retention errors

BEER (MICRO'20, best paper) Determine exactly how on-die ECCs adjust error characteristics

HARP (MICRO'21) Understand how errors appear and how to identify at-risk bits

EIN (DSN'19, best paper) Understand and recover the error characteristics beneath on-die ECC




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Christina Giannoula, National Technical University of Athens

Efficient Synchronization Support for Near-Data-Processing Architectures

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NDP Synchronization Solution Space

Shared Memory

Message-passing

Hardware Cache Coherence

Remote Atomics

Specialized Hardware Support

Software-based Schemes

Specialized Hardware Support

NDP Systems: SynCron (HPCA'21)


SAFARI Live Seminars in Computer Architecture

Jawad Haj-Yahya, Huawei Research Center Zurich

Security Implications of Power Management Mechanisms in Modern Processors, Current Studies and Future Trends

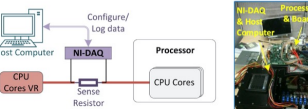
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Experimental Methodology

- We experimentally study three modern Intel processors
 - Haswell, Coffee Lake, and Cannon Lake
- We measure voltage and current using a Data Acquisition card (NI-DAQ)



SAFARI

<https://safari.ethz.ch/safari-seminar-series/>

SAFARI Live Seminars (II)

SAFARI Live Seminars in Computer Architecture

Nastaran Hajinazar, ETH Zurich

Data-Centric and Data-Aware Frameworks for Fundamentally Efficient Data Handling in Modern Computing Systems

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SAFARI Research Group


27 Wed Oct 2021

Overview of Our Approach

Data and the **efficient computation of data** should be the ultimate priority of the system

- **Data-Centric Architectures**
 - Enable computation with minimal data movement
 - Compute where data resides
- **Data-Aware Architectures**
 - Understand what they can do with and to each piece of data
 - Make use of different properties of data to improve performance, efficiency, etc.

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SAFARI Live Seminar: Nastaran Hajinazar 27 Oct 2021

Posted on October 1, 2021 by ewent

Join us for our [SAFARI Live Seminar](#) with [Nastaran Hajinazar](#).

Wednesday, October 27 at 7:00 pm Zurich time (CEST)

SAFARI Live Seminars in Computer Architecture

Damla Senol Cali, Bionano Genomics

Accelerating Genome Sequence Analysis via Efficient Hardware/Algorithm Co-Design


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7 Sun Nov 2021

Our Goal & Approach

- **Our Goal:**
Accelerating genome sequence analysis by **efficient hardware/algorithm co-design**
- **Our Approach:**
 - (1) Analyze the **multiple steps** and the **associated tools** in the genome sequence analysis pipeline,
 - (2) Expose the **tradeoffs** between accuracy, performance, memory usage and scalability, and
 - (3) Co-design **fast and efficient algorithms** along with **scalable and energy-efficient customized hardware accelerators** for the key bottleneck steps of the pipeline

Damla Senol Cali SAFARI 10



SAFARI Live Seminar: Damla Senol Cali 07 Nov 2021

Posted on October 18, 2021 by ewent

Join us for our [SAFARI Live Seminar](#) with [Damla Senol Cali](#).

Sunday, November 07 at 6:00 pm Zurich time (CEST)

SAFARI Live Seminars in Computer Architecture

Gennady Pekhimenko, University of Toronto

Machine Learning Tools in Action

ETH zürich
SAFARI
SAFARI Research Group

8 Mo Nov 2021

RL-Scope: Cross-Stack Profiling for Deep Reinforcement Learning Workloads



SAFARI Live Seminar: Gennady Pekhimenko 08 Nov 2021

Posted on November 1, 2021 by ewent

Join us for our [SAFARI Live Seminar](#) with [Gennady Pekhimenko](#).

Monday, November 08 at 4:00 pm Zurich time (CET)

SAFARI Live Seminars in Computer Architecture

Serghei Mangul, Mangul Lab, USC

Opportunities and challenges of computational data-driven immunology

SAFARI
SAFARI Research Group
ETH zürich

11 Thu Nov 2021

Opportunities and challenges of computational data-driven immunology

Serghei Mangul, Ph.D
Assistant Professor,
University of Southern California

<https://mangul-lab.usc.edu/ethz/>



SAFARI Live Seminar: Serghei Mangul 11 Nov 2021

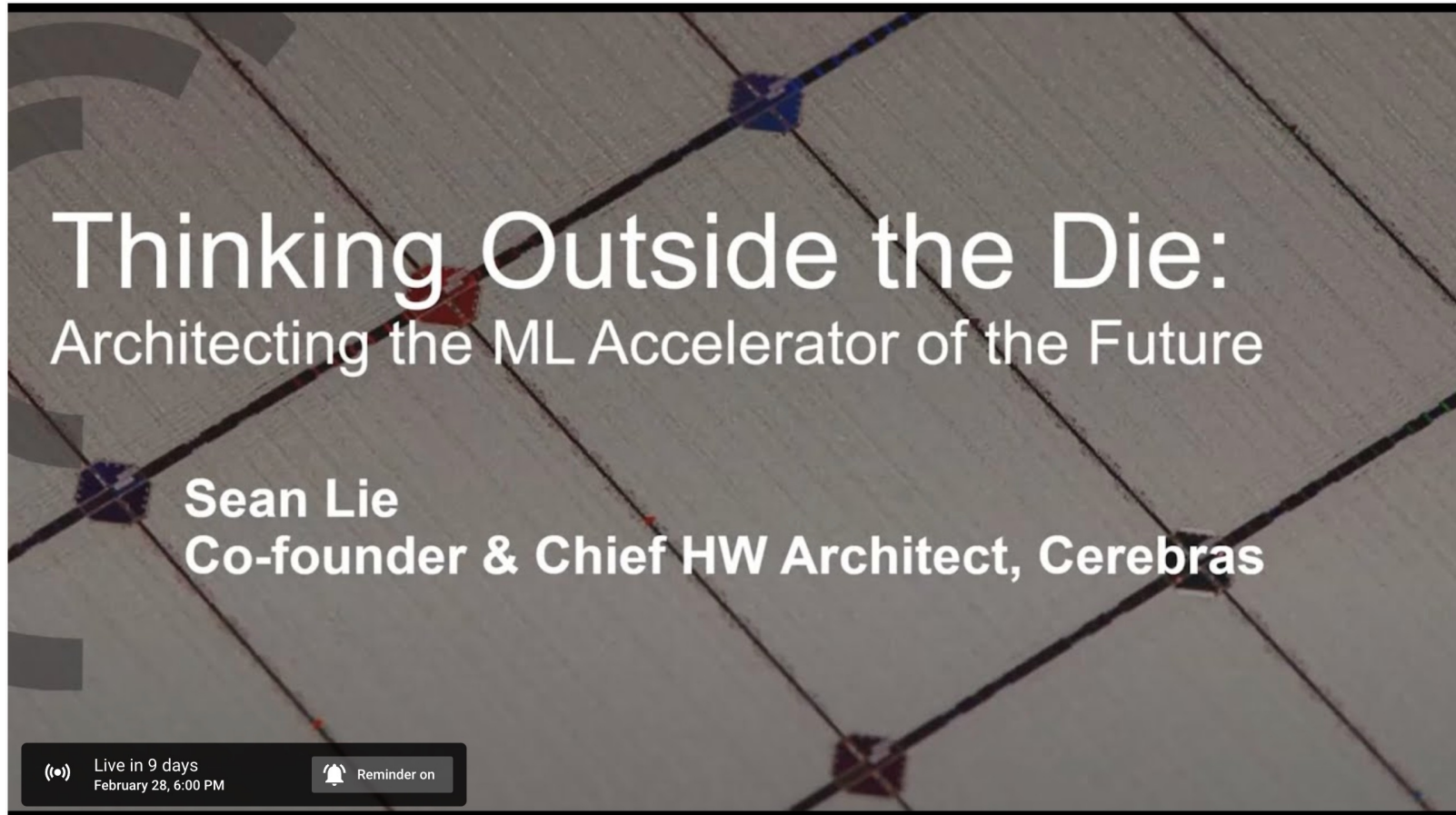
Posted on November 5, 2021 by ewent

Join us for our [SAFARI Live Seminar](#) with [Serghei Mangul](#).

Thursday, November 11 at 11:00 am Zurich time (CET), ETH Zentrum ETZ K91

Upcoming SAFARI Live Seminar (Feb 28)

<https://www.youtube.com/watch?v=x2-qB0J7KHw>



SAFARI Live Seminar - Thinking Outside the Die: Architecting the ML Accelerator of the Future

1 waiting • Scheduled for Feb 28, 2022

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Onur Mutlu Lectures
22.6K subscribers

ANALYTICS

EDIT VIDEO

A Long Talk on Our Research & Teaching



The video player shows a presentation slide with the following content:

Applying to Grad School
& Doing Impactful Research

Onur Mutlu
omutlu@gmail.com
<https://people.inf.ethz.ch/omutlu>
13 June 2020
Undergraduate Architecture Mentoring Workshop @ ISCA 2021

Logos for SAFARI, ETH zürich, and Carnegie Mellon are displayed at the bottom of the slide.

Below the video player, the YouTube interface shows:

Arch. Mentoring Workshop @ISCA'21 - Applying to Grad School & Doing Impactful Research - Onur Mutlu
1,563 views • Premiered Jun 16, 2021

Onur Mutlu Lectures
17.2K subscribers

Panel talk at Undergraduate Architecture Mentoring Workshop at ISCA 2021
(<https://sites.google.com/wisc.edu/uar...>)

Engagement icons show 74 likes and 1 comment. Buttons for SHARE, SAVE, ANALYTICS, and EDIT VIDEO are visible.

An Interview on Computing Futures



Interview with Onur Mutlu @ ISCA 2019 on computing research & education (after Maurice Wilkes Award)

6,749 views • Oct 19, 2019

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Onur Mutlu Lectures
19.1K subscribers

ANALYTICS

EDIT VIDEO

Computer Architecture

Why Is It So Exciting Today?

Onur Mutlu

omutlu@gmail.com

<https://people.inf.ethz.ch/omutlu>

19 February 2022

Kesisen Yollar Kariyer Sohbetleri

SAFARI

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