Digital Design & Computer Arch.

Lecture 2a: Tradeoffs, Metrics, Mindset

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ETH Zürich
Spring 2021
26 February 2021
Let’s Start with Some Puzzles

a.k.a. Computer Architecture resembles Building Architecture
What Is This?

Source: https://www.flickr.com/photos/tambako/2286064777/in/photostream/
What About This?
What Do the Following Have in Common?
Gare do Oriente, Lisbon

Milwaukee Art Museum
Athens Olympic Stadium
City of Arts and Sciences, Valencia

Florida Polytechnic University (I)

Source: http://www.architectmagazine.com/design/buildings/florida-polytechnic-university-designed-by-santiago-calatrava_o
Oculus, New York City

What do All Those Have in Common with Bahnhof Stadelhofen?
**Answer: All Designed by a Famous Architect**

- ETH Alumnus, PhD Civil Engineering

- “The train station has several of the features that became signatures of his work; straight lines and right angles are rare.”

**Santiago Calatrava Valls** (born 28 July 1951) is a Spanish architect, structural engineer, sculptor and painter, particularly known for his bridges supported by single leaning pylons, and his railway stations, stadiums, and museums, whose sculptural forms often resemble living organisms.[1] His best-known works include the Milwaukee Art Museum, the Turning Torso tower in Malmo, Sweden, the Margaret Hunt Hill Bridge in Dallas, Texas, and the Museum of Tomorrow in Rio de Janeiro.

Your First Comp. Architecture Assignment

- Go and find the closest Calatrava building to this classroom
  - For the ones who like a challenge, find the furthest building that was designed by Calatrava to his classroom 😊

- Appreciate the beauty & out-of-the-box and creative thinking

- Think about tradeoffs in the design
  - Strengths, weaknesses, goals of design

- Derive principles on your own for good design and innovation

- Due date: **Any time during this course**
  - Later during the course is better
  - Apply what you have learned in this course
  - Think out-of-the-box
But First, Today’s First Assignment
Find The Differences of This and That
This
That

Source: http://cookiemaqik.deviantart.com/art/Train-station-207266944 - Göttingen, DE
Many Tradeoffs Between Two Designs

- You can list them after you complete the first assignment...
Aside: Evaluation Criteria for the Designs

- Functionality (Does it meet the specification?)
- Reliability
- Space requirement
- Cost
- Expandability
- Comfort level of users
- Happiness level of users
- Aesthetics
- Security
- ...

- How to evaluate goodness of design is always a critical question → “Performance“ evaluation and metrics
A Key Question

How was Calatrava able to design especially his key buildings?

Can have many guesses

- (Ultra) hard work, perseverance, dedication (over decades)
- Experience
- Creativity, Out-of-the-box thinking
- A good understanding of past designs
- Good judgment and intuition
- Strong skill combination (math, architecture, art, engineering, …)
- Funding ($$$), luck, initiative, entrepreneurialism
- **Strong understanding of and commitment to fundamentals**
- **Principled design**
- ...

(You will be exposed to and hopefully develop/enhance many of these skills in this course)
Principled Design

“To me, there are two overriding principles to be found in nature which are most appropriate for building:

- one is the optimal use of material,
- the other the capacity of organisms to change shape, to grow, and to move.”

*Santiago Calatrava*

“Calatrava's constructions are inspired by natural forms like plants, bird wings, and the human body.”

Source: http://www.arcspace.com/exhibitions/unsorted/santiago-calatrava/
A Principled Design

Zoomorphic architecture

From Wikipedia, the free encyclopedia

**Zoomorphic architecture** is the practice of using animal forms as the inspirational basis and blueprint for architectural design. "While animal forms have always played a role adding some of the deepest layers of meaning in architecture, it is now becoming evident that a new strand of biomorphism is emerging where the meaning derives not from any specific representation but from a more general allusion to biological processes."[1]

Some well-known examples of Zoomorphic architecture can be found in the TWA Flight Center building in New York City, by Eero Saarinen, or the Milwaukee Art Museum by Santiago Calatrava, both inspired by the form of a bird’s wings.[3]
What Does This Remind You Of?

Design

Calatrava said that the Oculus resembles a bird being released from a child's hand. The roof was originally designed to mechanically open to increase light and ventilation to the enclosed space. Herbert Muschamp, architecture critic of *The New York Times*, compared the design to the Bethesda Terrace and Fountain in Central Park, and wrote in 2004:

Source: https://en.wikipedia.org/wiki/World_Trade_Center_station_(PATH)
Santiago Calatrava's design for the World Trade Center PATH station should satisfy those who believe that buildings planned for ground zero must aspire to a spiritual dimension. Over the years, many people have discerned a metaphysical element in Mr. Calatrava's work. I hope New Yorkers will detect its presence, too. With deep appreciation, I congratulate the Port Authority for commissioning Mr. Calatrava, the great Spanish architect and engineer, to design a building with the power to shape the future of New York. It is a pleasure to report, for once, that public officials are not overstating the case when they describe a design as breathtaking.[43]
However, Calatrava's original soaring spike design was scaled back because of security issues. The *New York Times* observed in 2005:

“In the name of security, Santiago Calatrava's bird has grown a beak. Its ribs have doubled in number and its wings have lost their interstices of glass.... [T]he main transit hall, between Church and Greenwich Streets, will almost certainly lose some of its delicate quality, while gaining structural expressiveness. It may now evoke a slender *stegosaurus* more than it does a bird.”[^45]
Stegosaurus

From Wikipedia, the free encyclopedia

For the pachycephalosaurid of a similar name, see Stegoceras.

Stegosaurus (/stɛɡəˈsoʊrəs/)[1] is a genus of armored dinosaur. Fossils of this genus date to the Late Jurassic period, where they are found in Kimmeridgian to early Tithonian aged strata, between 155 and 150 million years ago, in the western United States and Portugal. Several

Source: https://en.wikipedia.org/wiki/Stegosaurus
However, Calatrava's original soaring spike design was scaled back because of security issues. The New York Times observed in 2005:

“In the name of security, Santiago Calatrava's bird has grown a beak. Its ribs have doubled in number and its wings have lost their interstices of glass.... [T]he main transit hall, between Church and Greenwich Streets, will almost certainly lose some of its delicate quality, while gaining structural expressiveness. It may now evoke a slender stegosaurus more than it does a bird.”[45]

The design was further modified in 2008 to eliminate the opening and closing roof mechanism because of budget and space constraints.[46]

The Transportation Hub has been dubbed "the world's most expensive transportation hub' for its massive cost for reconstruction—$3.74 billion dollars.[48][58] By contrast, the proposed two-mile PATH extension
The Lecture Was Slightly Different
When I Was at CMU
What Is This?

Source: https://roadtrippers.com/stories/falling-water
Fallingwater or Kaufmann Residence is a house designed by architect Frank Lloyd Wright in 1935 in rural southwestern Pennsylvania, 43 miles (69 km) southeast of Pittsburgh.[4] The home was built partly over a waterfall on Bear Run in the Mill Run section of Stewart Township, Fayette County, Pennsylvania, in the Laurel Highlands of the Allegheny Mountains.

Time cited it after its completion as Wright's "most beautiful job";[5] it is listed among Smithsonian's Life List of 28 places "to visit before you die."[6] It was designated a National Historic Landmark in 1966.[3] In 1991, members of the American Institute of Architects named the house the "best all-time work of American architecture" and in 2007, it was ranked twenty-ninth on the list of America's Favorite Architecture according to the AIA.

Source: https://en.wikipedia.org/wiki/Fallingwater
Find The Differences of This and That
This

Source: http://www.fallingwater.org/
That
A Key Question

- How was Wright able to design his masterpiece?
- Can have many guesses
  - (Ultra) hard work, perseverance, dedication (over decades)
  - Experience
  - Creativity, Out-of-the-box thinking
  - A good understanding of past designs
  - Good judgment and intuition
  - Strong skill combination (math, architecture, art, engineering, ...)
  - Funding ($$$), luck, initiative, entrepreneurialism
  - Strong understanding of and commitment to fundamentals
  - Principled design
  - ...

- (You will be exposed to and hopefully develop/enhance many of these skills in this course)
A Quote from The Architect Himself

- “architecture [...] based upon principle, and not upon precedent”

Source: http://www.fallingwater.org/
A Principled Design

Organic architecture

From Wikipedia, the free encyclopedia

Organic architecture is a philosophy of architecture which promotes harmony between human habitation and the natural world through design approaches so sympathetic and well integrated with its site, that buildings, furnishings, and surroundings become part of a unified, interrelated composition.

A well-known example of organic architecture is Fallingwater, the residence Frank Lloyd Wright designed for the Kaufmann family in rural Pennsylvania. Wright had many choices to locate a home on this large site, but chose to place the home directly over the waterfall and creek creating a close, yet noisy dialog with the rushing water and the steep site. The horizontal striations of stone masonry with daring cantilevers of colored beige concrete blend with native rock outcroppings and the wooded environment.
A Key Question

- How was Wright able to design his masterpiece?

Can have many guesses

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- Principled design
- ...

(You will be exposed to and hopefully develop/enhance many of these skills in this course)
Takeaways

- It all starts from the basic building blocks and design principles

- And, knowledge of how to use & apply them

- Underlying technology might change (e.g., steel vs. wood)
  - but methods of taking advantage of technology bear resemblance
  - methods used for design depend on the principles employed
The Same Applies to Processor Chips

- There are **basic building blocks** and **design principles**

- AMD Barcelona
  4 cores

- Intel Core i7
  8 cores

- Sun Niagara II
  8 cores

- Nvidia Fermi
  448 “cores”

- IBM Cell BE
  8+1 cores

- IBM POWER7
  8 cores

- Intel SCC
  48 cores, networked

- Tilera TILE Gx
  100 cores, networked
The Same Applies to Computing Systems

- There are **basic building blocks** and **design principles**
The Same Applies to Computing Systems

- There are **basic building blocks** and **design principles**
Different Platforms, Different Goals

Source: https://iq.intel.com/5-awesome-uses-for-drone-technology/
Different Platforms, Different Goals

Source: https://taxistartup.com/wp-content/uploads/2015/03/UK-Self-Driving-Cars.jpg
Different Platforms, Different Goals

Source: http://sm.pcmag.com/pcmag_uk/photo/g/google-self-driving-car-the-guts/google-self-driving-car-the-guts_dwx8.jpg
Different Platforms, Different Goals

Source: https://fossbytes.com/wp-content/uploads/2015/06/Supercomputer-TIANHE2-china.jpg
Different Platforms, Different Goals

**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.
Different Platforms, Different Goals

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

https://youtu.be/Ucp0TTmvqOE?t=4236
Different Platforms, Different Goals

- The largest ML accelerator chip
- 400,000 cores

Cerebras WSE
1.2 Trillion transistors
46,225 mm²

Largest GPU
21.1 Billion transistors
815 mm²

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
UPMEM Processing-in-DRAM Engine (2019)

- Processing in DRAM Engine
- Includes **standard DIMM modules**, with a **large number of DPU processors** combined with DRAM chips.

- Replaces **standard** DIMMs
  - DDR4 R-DIMM modules
    - 8GB+128 DPUs (16 PIM chips)
    - Standard 2x-nm DRAM process
  - **Large amounts of** compute & memory bandwidth

Samsung Function-in-Memory DRAM (2021)

- FIMDRAM based on HBM2

**Chip Specification**

- 128DQ / 8CH / 16 banks / BL4
- 32 PCU blocks (1 FIM block/2 banks)
- 1.2 TFLOPS (4H)
- FP16 ADD / Multiply (MUL) / Multiply-Accumulate (MAC) / Multiply-and- Add (MAD)

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**ISSCC 2021 / SESSION 25 / DRAM / 25.4**

25.4 A 29nm 6GB Function-In-Memory DRAM, Based on HBM2 with a 1.2TFLOPS Programmable Computing Unit Using Bank-Level Parallelism, for Machine Learning Applications

Young-Cheon Kwon1, Suk Han Lee1, Jaehoon Lee1, Sang-Hyuk Kwon1, Je Min Ryu1, Jong-Pil Son1, Seongil O1, Hak-Soo Yu1, Hae Suk Lee1, Soo Young Kim1, Youngmin Cho1, Jin Guk Kim1, Jongyoon Choi1, Hyun Sung Shin1, Jin Kim1, Beng Seng Phuah1, Hyung Min Kim1, Myeong Jun Song1, Ahn Choi1, Daeho Kim1, Soo Young Kim1, Eun-Bong Kim1, David Wang1, Shin Hae Sung Kang1, Yu Hwan Roh1, Seungwoo Seo1, Joon Ho Song1, Jayoun Youn1, Kyomin Sohn1, Nam Sung Kim1

1Samsung Electronics, Hwasung, Korea
2Samsung Electronics, San Jose, CA
3Samsung Electronics, Suwon, Korea
Basic Building Blocks

- Electrons
- Transistors
- Logic Gates
- Combinational Logic Circuits
- Sequential Logic Circuits
  - Storage Elements and Memory
- ...
- Cores
- Caches
- Interconnect
- Memories
- ...

...
Reading Assignments for This Week

- Chapter 1 in Harris & Harris
- Supplementary Lecture Slides on Binary Numbers
- Chapters 1-2 in Patt and Patel
Major High-Level Goals of This Course

In Digital Circuits & Computer Architecture

- Understand the basics
- Understand the principles (of design)
- Understand the precedents

Based on such understanding:
- learn how a modern computer works underneath
- evaluate tradeoffs of different designs and ideas
- implement a principled design (a simple microprocessor)
- learn to systematically debug increasingly complex systems
- Hopefully enable you to develop novel, out-of-the-box designs

The focus is on basics, principles, precedents, and how to use them to create/implement good designs
Why These Goals?

- Because you are here for a Computer Science degree

- Regardless of your future direction, learning the principles of digital design & computer architecture will be useful to
  - design better hardware
  - design better software
  - design better systems
  - make better tradeoffs in design
  - understand why computers behave the way they do
  - solve problems better
  - think “in parallel”
  - think critically
  - ...

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Course Info and Logistics
Course Info: Instructor

Onur Mutlu

- Full Professor @ ETH Zurich ITET (INFK), since September 2015
- Strecker Professor @ Carnegie Mellon University ECE/CS, 2009-2016, 2016-
- PhD from UT-Austin, worked at Google, VMware, Microsoft Research, Intel, AMD
- [https://people.inf.ethz.ch/omutlu/](https://people.inf.ethz.ch/omutlu/)
- [omutlu@gmail.com](mailto:omutlu@gmail.com) (Best way to reach me)
- [https://people.inf.ethz.ch/omutlu/projects.htm](https://people.inf.ethz.ch/omutlu/projects.htm)

Research and Teaching in:

- Computer architecture, computer systems, hardware security, bioinformatics
- Memory and storage systems
- Hardware security, safety, predictability
- Fault tolerance, robust systems
- Hardware/software cooperation
- Architectures for bioinformatics, health, medicine, intelligent decision making
- ...
Course Info: Lecturer & PhD Assistants

- Head Assistant
  - Dr. Juan Gómez Luna

- Vice-Head Assistant
  - Hasan Hassan

- Lecturer
  - Dr. Frank Gurkaynak

- (Other) Key Assistants and Guest Lecturers
  - Dr. Jisung Park
  - Dr. Mohammed Alser
  - Dr. Lois Orosa
  - Minesh Patel
(Other) Key Assistants and Guest Lecturers (cont.)

- Dr. Jawad Haj-Yahya
- Dr. Haiyu Mao
- Dr. Behzad Salami
- Jeremie Kim
- Giray Yaglikci
- Can Firtina
- Geraldo De Oliveira Junior
- Rahul Bera
- Konstantinos Kanellopoulos
- Nika Mansouri Ghiasi
- Gagandeep Singh
Course Info: Student Assistants

- Roknoddin Azizibarzoki
- Anaïs Berkes
- François Costa
- Haocong Luo
- Lukas Gygi
- Lara Lazier
- Chris Mnuk
- Daniel Nezamabadi
- Bernard Pranjic
- Nina Richter
- João Dinis Sanches Ferreira
- Diego de los Santos
- Roberto Starc
- Kosta Stojiljkovic
Course Info: Lab Assistants (I)

- Tuesday 16-18
  - TBD

- Wednesday 16-18
  - TBD
Course Info: Lab Assistants (II)

- **Friday 8-10**
  - TBD

- **Friday 10-12**
  - TBD
If You Need Help

- Post your question on Piazza Q&A Forum
  - https://piazza.com/class/klgb5v5se8d4y7
  - Preferred for technical questions

- Write an e-mail to:
  - digitaltechnik@lists.inf.ethz.ch
  - The instructor and all assistants will receive this e-mail

- Come to office hours
  - We will provide Zoom links
  - TBD
Where to Get Up-to-date Course Info?

- Website:
  - [https://safari.ethz.ch/digitaltechnik/](https://safari.ethz.ch/digitaltechnik/)
  - Lecture slides and videos
  - Readings
  - Lab information
  - Course schedule, handouts, FAQs
  - Software
  - Plus other useful information for the course
  - Check frequently for announcements and due dates
  - This is your single point of access to all resources

- Your ETH Email
- Lecturers and Teaching Assistants
Lecture and Lab Times and Policies

- Lectures:
  - Thursday and Fridays, 14:00-16:00
  - YouTube livestream: [https://youtu.be/LbC0EZY8yw4](https://youtu.be/LbC0EZY8yw4)
  - Zoom link provided via Moodle
  - Attendance is for your benefit and is therefore important
  - Some days, we will have guest lectures and exercise sessions

- Lab sessions:
  - See online
  - You should definitely attend the lab sessions
    - In-class evaluation (70%) and mandatory lab reports (30%)
  - Labs will start on March 9th
  - Lab information and handouts are here:
Lab Organization

Groups

- Choose your preferred group in Moodle
  - Due 03.03.2021 at 11:59pm

- Choose your partner
  - Due 03.03.2021 at 11:59pm

Lab grades from previous years

- Choose among (due 26.02.2021 at 11:59pm):
  - 1) I will use my lab grades from previous years, and I won't do the labs this year
  - 2) I will use my lab grades from previous years, but I will do the labs this year
  - 3) I won't use my lab grades from previous years. I will do the labs this year
Final Exam

- 180-minute written exam

- Find examination rules in Course Catalogue

- Also in the first page of previous exams

- Some exam questions are similar to questions in Optional HWs
  - Optional HWs are optional, but highly recommended
Reading Assignments for This Week

- Chapter 1 in Harris & Harris

- Chapters 1-2 in Patt and Patel

- Supplementary Lecture Slides on Binary Numbers
Reading Assignments for Next Week

- Combinational Logic chapters from both books
  - Patt and Patel, Chapter 3
  - Harris and Harris, Chapter 2

- Check course website for all future readings
  - Required
  - Recommended
  - Mentioned