Digital Design & Computer Arch.

Lecture 2a: Tradeoffs, Metrics, Mindset

Prof. Onur Mutlu

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 Malmö, 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 those 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

Source: By Toni_V from Zurich, Switzerland - Stadelhofen2, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=4087256
That

Source: http://cookiemagik.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

- (Very) 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/
Gare do Oriente, Lisbon, Revisited

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  [ edit ]

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)
Strengths and Praise

“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.\[43\]”

Source: https://en.wikipedia.org/wiki/World_Trade_Center_station_(PATH)
Design Constraints and Criticism

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.... The 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.”

Source: https://en.wikipedia.org/wiki/World_Trade_Center_station_(PATH)
Stegosaurus

From Wikipedia, the free encyclopedia

For the *pachycephalosaurid* of a similar name, see Stegoceras.

Stegosaurus (/ˈstɛɡəˌsɔːrəs/) 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

The Postcranial Skeleton of an Exceptionally Complete Individual of the Plated Dinosaur Stegosaurus stenops
Design Constraints: Noone is Immune

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

Source: https://en.wikipedia.org/wiki/World_Trade_Center_station_(PATH)
The Lecture Was Slightly Different When I Was at CMU
What Is This?

Source: https://roadtrippers.com/stories/ Falling-water
Fallingwater

From Wikipedia, the free encyclopedia

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/
This
That
A Key Question

How was Wright able to design his masterpiece?

Can have many guesses

- (Very) 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
  - (Very) 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
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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, enhance 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**

<table>
<thead>
<tr>
<th>Processor Chip</th>
<th>Cores</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMD Barcelona</td>
<td>4</td>
<td>8 cores</td>
</tr>
<tr>
<td>Intel Core i7</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>IBM Cell BE</td>
<td>8+1</td>
<td></td>
</tr>
<tr>
<td>IBM POWER7</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Sun Niagara II</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Nvidia Fermi</td>
<td>448</td>
<td>“cores”</td>
</tr>
<tr>
<td>Intel SCC</td>
<td>48</td>
<td>cores, networked</td>
</tr>
<tr>
<td>Tilera TILE Gx</td>
<td>100</td>
<td>cores, networked</td>
</tr>
</tbody>
</table>
The Same Applies to Computing Systems

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

source: [http://www.sia-online.org](http://www.sia-online.org) (semiconductor industry association)
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.

Different Platforms, Different Goals

- ML accelerator: 260 mm$^2$, 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

[3D Chip Structure of HBM with FIMDRAM]

**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)

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

25.4 A 20nm 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 Kwon, Suk Hun Lee, Jaeheon Lee, Sang-Hyuk Kwon,
  Je Min Ryu, Jong-Pil Goon, Seongil O, Hak-Soo Yu, Hensuk Lee,
  Soo Young Kim, Youngmin Cho, Jin Guk Kim, Jongyoon Choi,
  Hyun-Sung Shin, Jin Kim, BengSeng Phua, HyoungMin Kim,
  Myeong Jin Song, Ahn Cho, Daeho Kim, SooYoung Kim, Eun-Bong Kim,
  David Wang, Shinhwa Kang, Yuwan Ro, Seungwoo Seo, JoonHo Song,
  Jaeyoun Yoon, Kyomin Sohn, Nam Sung Kim

'Samsung Electronics, Hwasung, Korea
'Samsung Electronics, San Jose, CA
'Samsung 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
- Chapters 1-2 in Patt and Patel
- Supplementary Lecture Slides on Binary Numbers
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
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 (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
- ...

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Course Info: Instructor
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
Course Info: PhD Assistants

- (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](https://piazza.com/class/klgb5v5se8d4y7)
  - Preferred for **technical** questions

- Write an e-mail to:
  - [digitaltechnik@lists.inf.ethz.ch](mailto: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 playlist: [https://www.youtube.com/watch?v=LbC0EZY8yw4&list=PL5Q2soXY2Zi_uej3aY39YB5pfW4SJ7LIN](https://www.youtube.com/watch?v=LbC0EZY8yw4&list=PL5Q2soXY2Zi_uej3aY39YB5pfW4SJ7LIN)
  - Zoom link provided via Moodle
  - Attendance is for your benefit and is therefore important
  - Some days, we may 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 and Past Exams
  - Optional HWs are optional, but highly recommended
  - Solving past exams could also be useful
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
Future Lectures and Assignments

- You can also anticipate (and study) future lectures and assignments based on Spring 2020 schedule:
  - https://www.youtube.com/watch?list=PL5Q2soXY2Zi_FRrIoMa2fUYWP GiZUBQo2&v=AJBmIaUneB0&feature=emb_logo

- An example of “Last Time Prediction”
  - Speculative Execution
    - The concept of doing something before knowing it is needed
  - A key concept we will cover in the design of microprocessors