Seminar in Computer Architecture

Lecture 1c: Architectural Design Fundamentals

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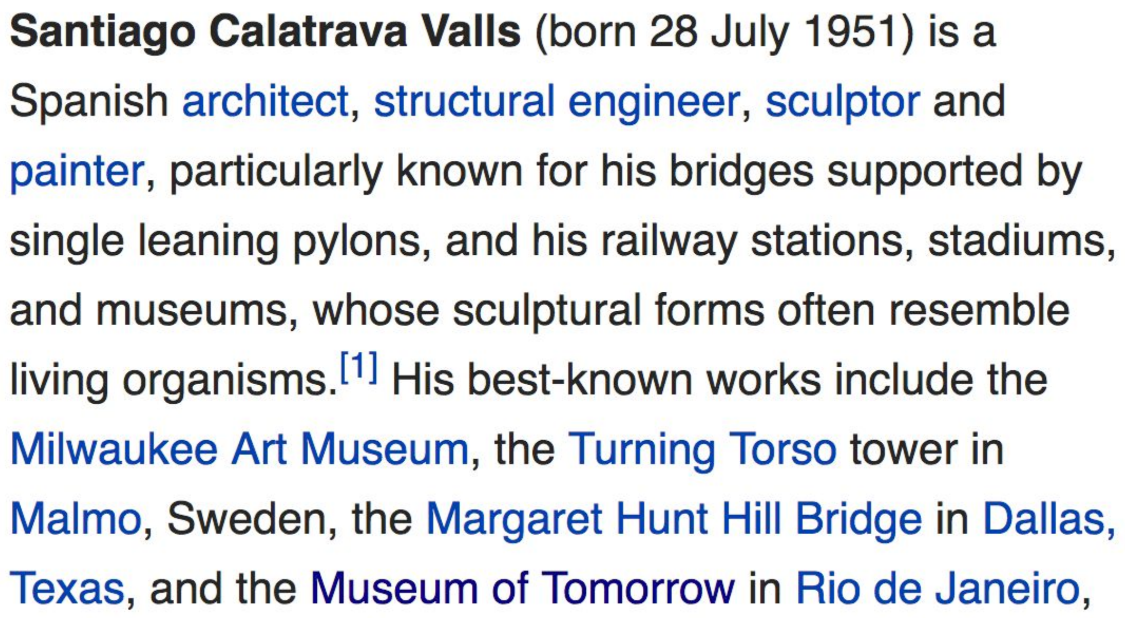
Let's Start with Some Fundamentals

Question: What Is This?

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

Answer: The First Major Piece of a Famous Architect

- **Bahnhof Stadelhofen:** "The train station has several of the features that became signatures of his work; straight lines and right angles are rare."
- ETH Alumnus, PhD in Civil Engineering


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,

Source: By 準建築人手札網站 Forgemind ArchiMedia - Flickr: IMG_2489.JPG, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=31493356, https://en.wikipedia.org/wiki/Santiago_Calatrava

Compare To This

Source: http://cookiemagik.deviantart.com/art/Train-station-207266944

Question 2: What Is This?

Source: https://www.dezeen.com/2016/08/29/santiago-calatrava-oculus-world-trade-center-transportation-hub-new-york-photographs-hufton-crow/

Answer: Masterpiece of a Famous Architect

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.... [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]

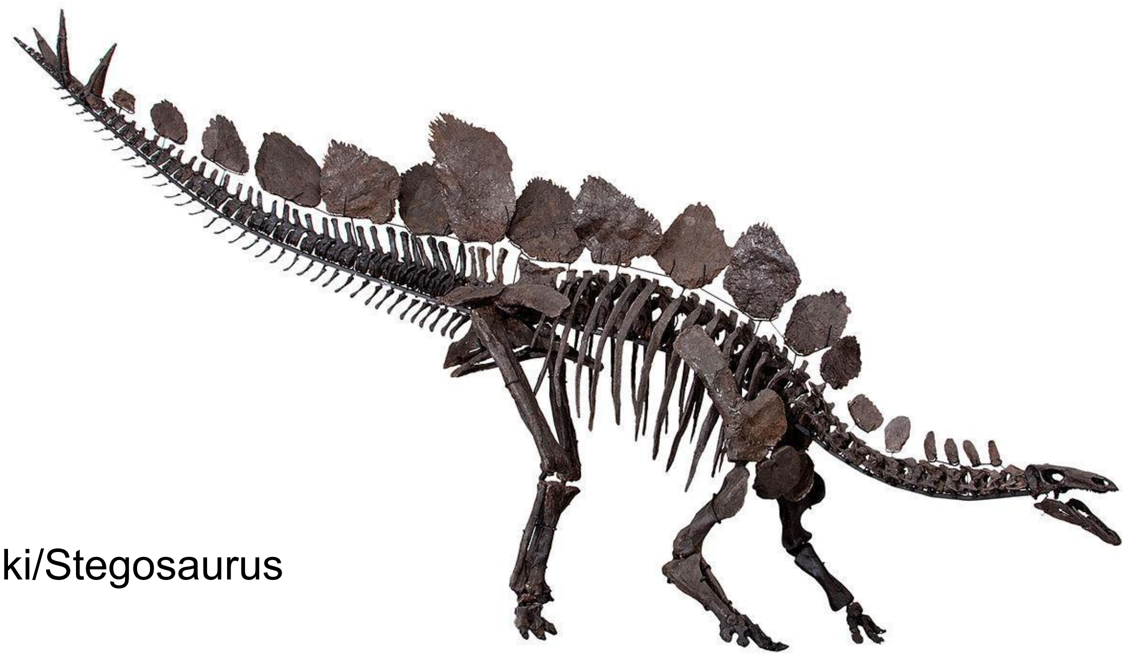
Source: https://en.wikipedia.org/wiki/World_Trade_Center_station_(PATH)

Stegosaurus

From Wikipedia, the free encyclopedia

For the pachycephalosaurid of a similar name, see Stegoceras.

Stegosaurus (/ˌstɛɡəˈsɔːrəs/[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

Susannah Maidment et al. & Natural History Museum, London - Maidment SCR, Brassey C, Barrett PM (2015) The Postcranial Skeleton of an Exceptionally Complete Individual of the Plated Dinosaur Stegosaurus stenops (Dinosauria: Thyreophora) from the Upper Jurassic Morrison Formation of Wyoming, U.S.A. PLoS ONE 10(10): e0138352. doi:10.1371/journal.pone.0138352

Design Constraints: Noone is Immune

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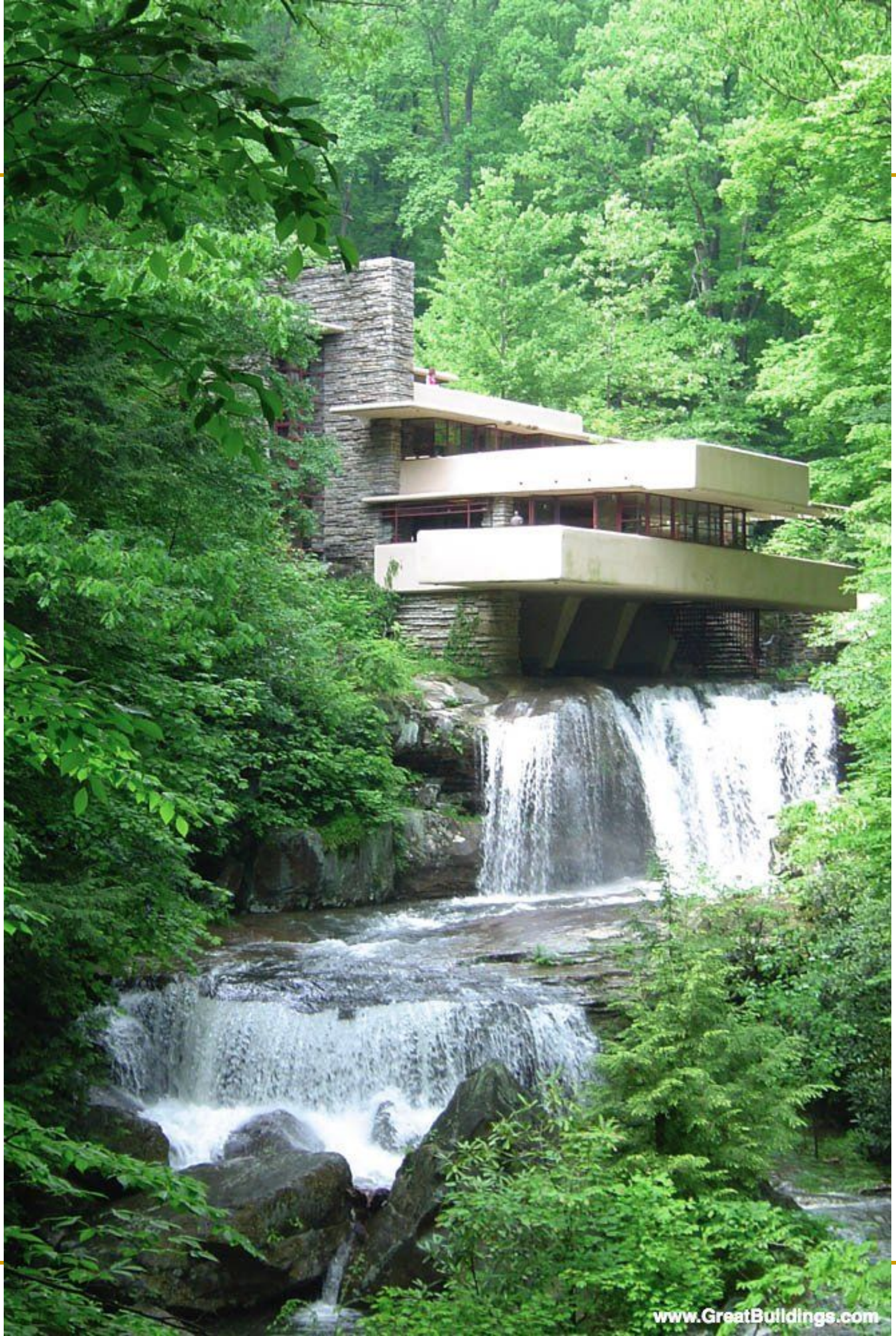
The design was further modified in 2008 to eliminate the opening and closing roof mechanism because of budget and space constraints.[46]

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)

Question: What Is This?


www.GreatBuildings.com

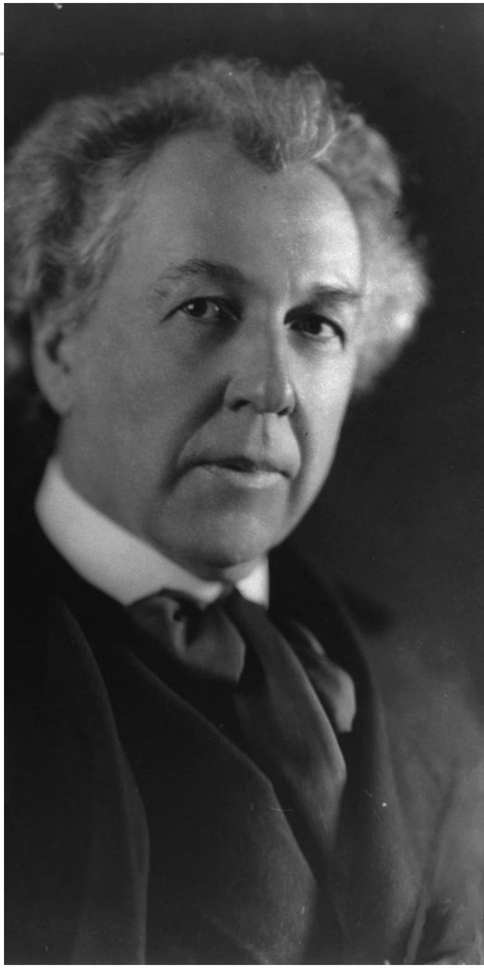
Answer: Masterpiece of Another Famous Architect

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

Your First Comp Arch Assignment

- Go and visit Bahnhof Stadelhofen
  - Extra credit: Repeat for Oculus
  - Extra+ credit: Repeat for Fallingwater

- Appreciate the beauty & out-of-the-box and creative thinking
- Think about tradeoffs in the design of the Bahnhof
  - 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

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

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
- …

- How to evaluate goodness of design is always a critical question.

A Key Question

- How was Calavatra 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/

Gare do Oriente, Lisbon, Revisited

Source: By Martín Gómez Tagle - Lisbon, Portugal, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=13764903

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?

Source: https://www.dezeen.com/2016/08/29/santiago-calatrava-oculus-world-trade-center-transportation-hub-new-york-photographs-hufton-crow/

What About This?

Source: De Galván - Puente del Alamillo.jpg on Enciclopedia.us.es, GFDL, https://commons.wikimedia.org/w/index.php?curid=15026095

A Quote from The Other Famous Architect

- "architecture […] based upon principle, and not upon precedent" (Frank Lloyd Wright)

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.

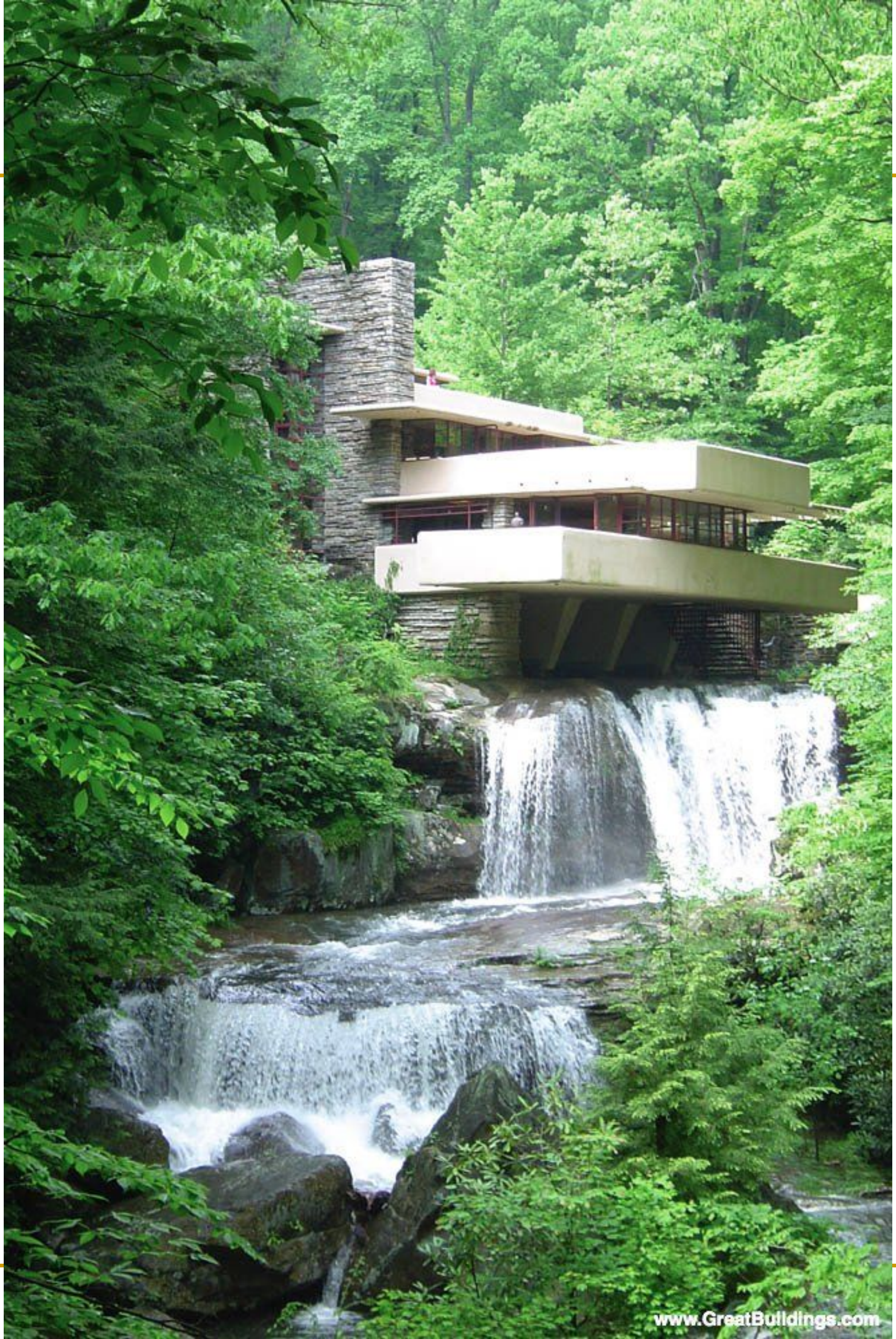
A well-known example of organic architecture is Fallingwater, the residence Frank Lloyd Wright designed for the Kaufmann family in rural Pennsylvania. Wright had many choices to locate a home on this large site, but chose to place the home directly over the waterfall and creek creating a close, yet noisy 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.

Another View

Source: https://roadtrippers.com/stories/falling-water

Yet Another View

Source: By Carol M. Highsmith - http://www.loc.gov/pictures/collection/highsm/item/2010630255/, Public Domain, https://commons.wikimedia.org/w/index.php?curid=29385254


www.GreatBuildings.com

Major High-Level Goals of This Course

- Understand the principles
- Understand the precedents

- Based on such understanding:
  - Enable you to evaluate tradeoffs of different designs and ideas
  - Enable you to develop principled designs
  - Enable you to develop novel, out-of-the-box designs

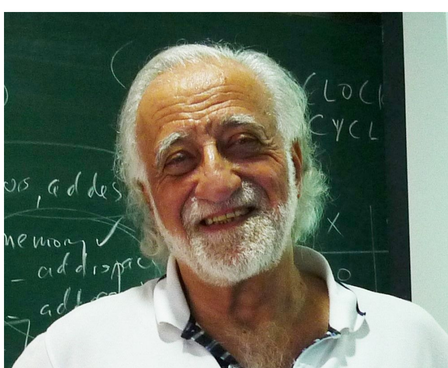
- The focus is on:
  - Principles, precedents, and how to use them for new designs

- In Computer Architecture

Role of The (Computer) Architect

Role of the Architect

- -- Look Backward (Examine old code)
- -- Look forward (Listen to the dreamers)
- -- Look Up (Nature of the problems)
- -- Look Down (Predict the future of technology)



from Yale Patt's lecture notes

Role of The (Computer) Architect

- Look backward (to the past)
  - Understand tradeoffs and designs, upsides/downsides, past workloads. Analyze and evaluate the past.
- Look forward (to the future)
  - Be the dreamer and create new designs. Listen to dreamers.
  - Push the state of the art. Evaluate new design choices.
- Look up (towards problems in the computing stack)
  - Understand important problems and their nature.
  - Develop architectures and ideas to solve important problems.
- Look down (towards device/circuit technology)
  - Understand the capabilities of the underlying technology.
  - Predict and adapt to the future of technology (you are designing for N years ahead). Enable the future technology.

Takeaways

- Being an architect is not easy
- You need to consider **many** things in designing a new system + have good intuition/insight into ideas/tradeoffs

- But, it is fun and can be very rewarding
- And, enables a great future
  - E.g., many scientific and everyday-life innovations would not have been possible without architectural innovation that enabled very high performance systems
  - E.g., your mobile phones
  - E.g., self-driving vehicles

- This course will enable you to become a good computer architect

So, I Hope You Are Here for This

Comp. Systems

"C" as a model of computation

Programmer's view of how a computer system works

- How does an assembly program end up executing as digital logic?
- What happens in-between?
- How is a computer designed using logic gates and wires to satisfy specific goals?

Architect/microarchitect's view: How to design a computer that meets system design goals.

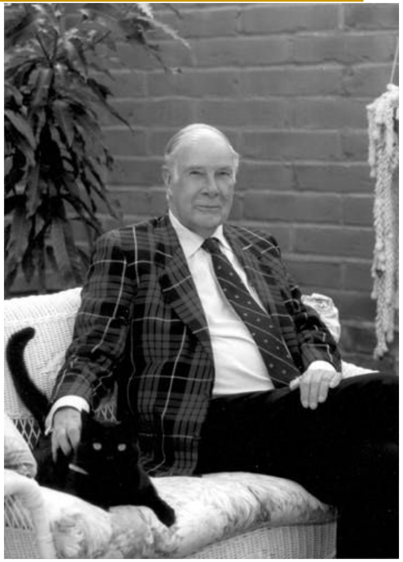
Choices critically affect both the SW programmer and the HW designer

HW designer's view of how a computer system works

Digital logic as a model of computation

Digital Design

Levels of Transformation



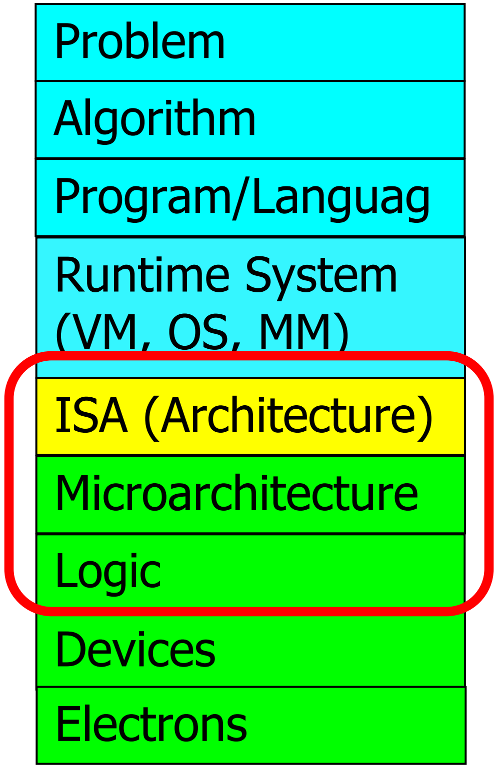
"The purpose of computing is [to gain] insight" (*Richard Hamming*)
We gain and generate insight by solving problems
How do we ensure problems are solved by electrons?

Algorithm

Step-by-step procedure that is **guaranteed to terminate** where **each step is precisely stated** and **can be carried out by a computer**

- **Finiteness**
- **Definiteness**
- **Effective computability**

Many algorithms for the same problem



ISA
(Instruction Set Architecture)

Interface/contract between SW and HW.

What the programmer assumes hardware will satisfy.

Microarchitecture
An implementation of the ISA

Digital logic circuits
Building blocks of micro-arch (e.g., gates)

Aside: A Famous Work By Hamming

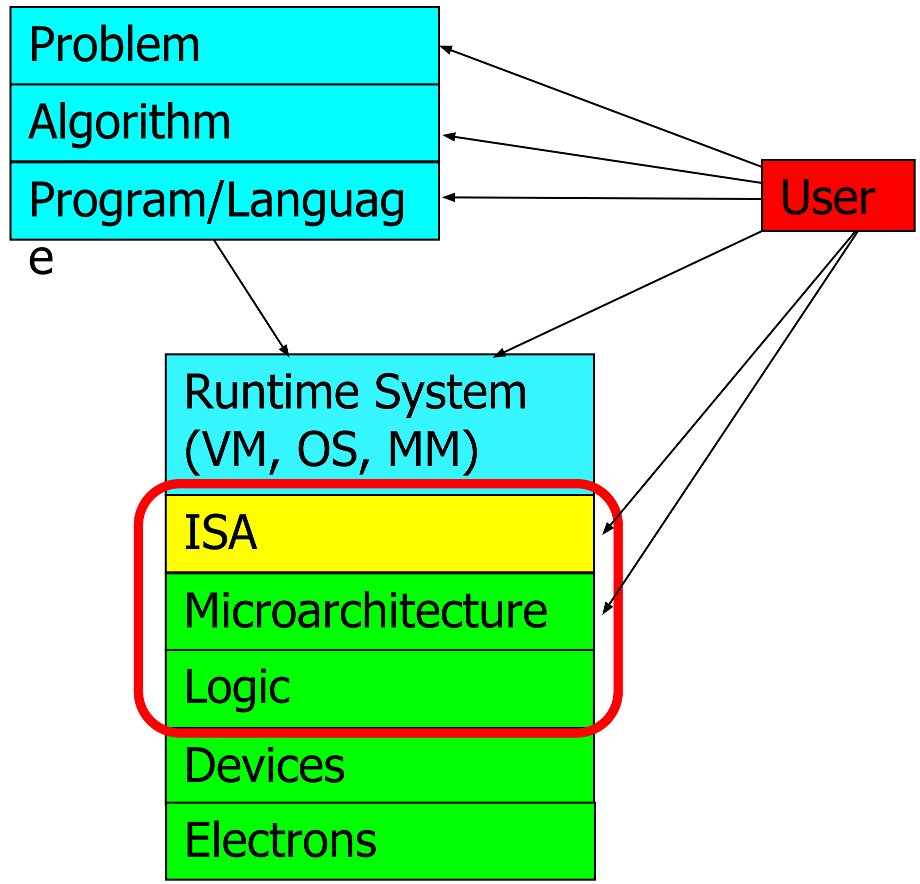
- Hamming, "Error Detecting and Error Correcting Codes," Bell System Technical Journal 1950.

- Introduced the concept of Hamming distance
  - number of locations in which the corresponding symbols of two equal-length strings is different
- Developed a theory of codes used for error detection and correction

- Also see:
  - Hamming, "You and Your Research," Talk at Bell Labs, 1986.
  - http://www.cs.virginia.edu/~robins/YouAndYourResearch.html

Levels of Transformation, Revisited

- A user-centric view: computer designed for users



- The entire stack should be optimized for user

The Power of Abstraction

- Levels of transformation create abstractions
  - Abstraction: A higher level only needs to know about the interface to the lower level, not how the lower level is implemented
  - E.g., high-level language programmer does not really need to know what the ISA is and how a computer executes instructions
- Abstraction improves productivity
  - No need to worry about decisions made in underlying levels
  - E.g., programming in Java vs. C vs. assembly vs. binary vs. by specifying control signals of each transistor every cycle
- Then, why would you want to know what goes on underneath or above?

Crossing the Abstraction Layers

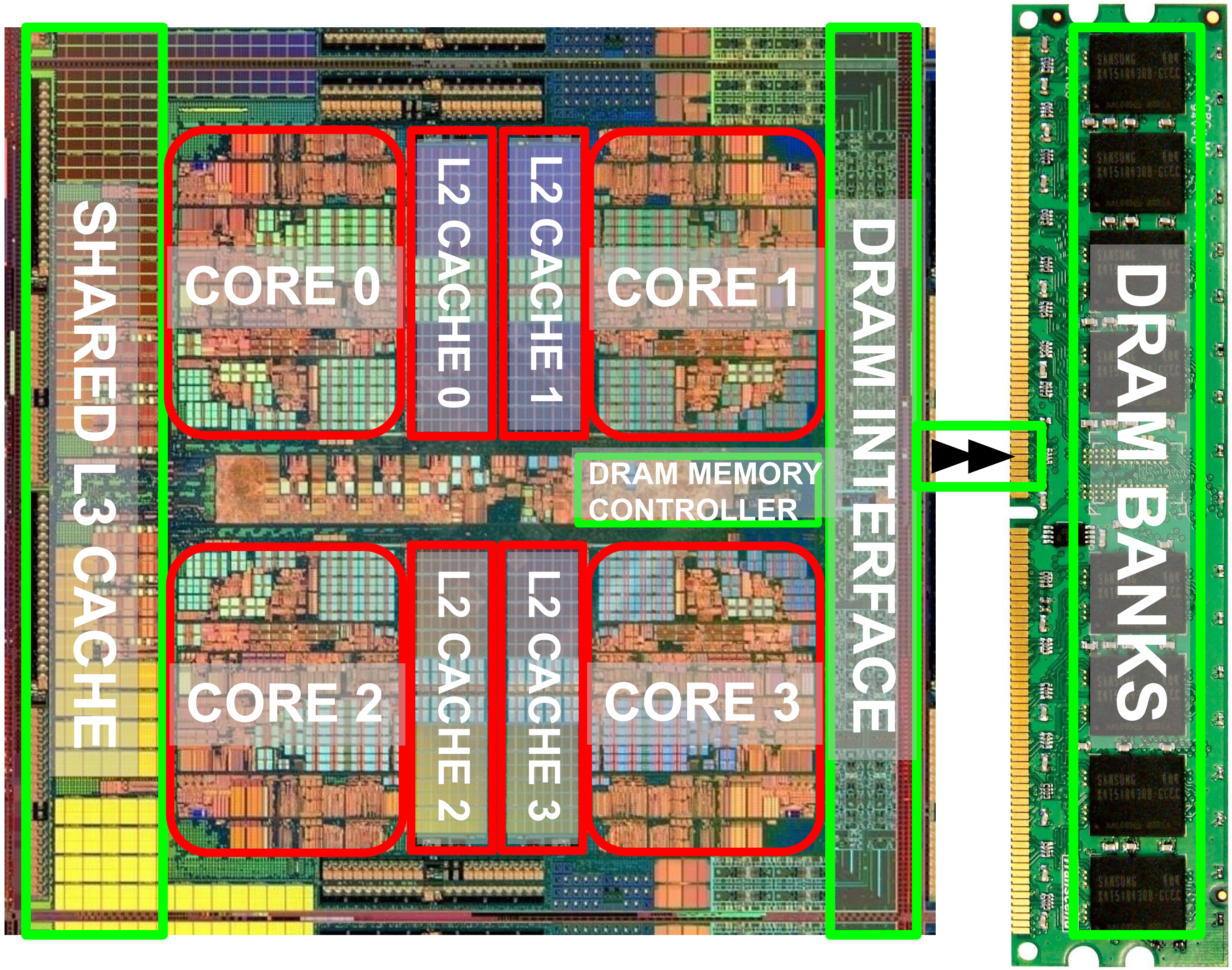
- As long as everything goes well, not knowing what happens underneath (or above) is not a problem.
- What if
  - The program you wrote is running slow?
  - The program you wrote does not run correctly?
  - The program you wrote consumes too much energy?
  - Your system just shut down and you have no idea why?
  - Someone just compromised your system and you have no idea how?
- What if
  - The hardware you designed is too hard to program?
  - The hardware you designed is too slow because it does not provide the right primitives to the software?
- What if
  - You want to design a much more efficient and higher performance system?

Crossing the Abstraction Layers

- Two key goals of this course are
  - to understand how a processor works underneath the software layer and how decisions made in hardware affect the software/programmer
  - to enable you to be comfortable in making design and optimization decisions that cross the boundaries of different layers and system components

An Example: Multi-Core Systems

Multi-Core
Chip



*Die photo credit: AMD Barcelona

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