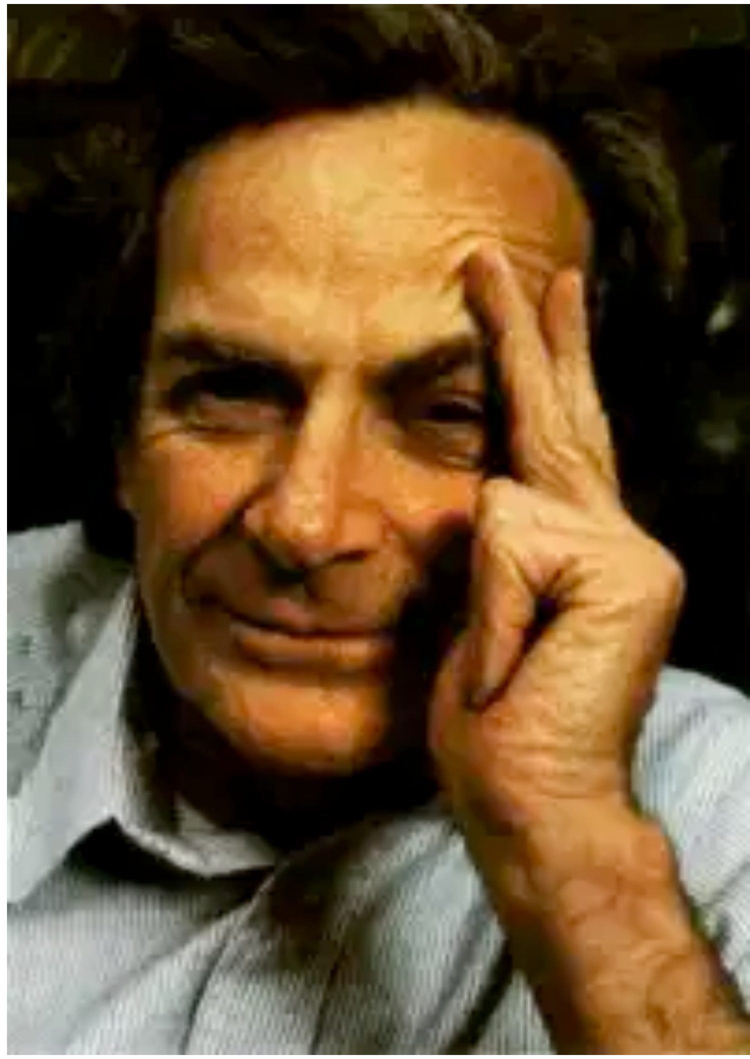
EE260 (F): Quantum Computing & Computer Architectures

Hung-Wei Tseng

Brief History of Quantum Computing

- 1959 — Richard Feynman states the possibility of using quantum effects for computation
- 1980 — Paul Benioff published paper on quantum Turing machines
- 1981 — Feynman urged the world to build a quantum computer. "Nature isn't classical...and if you want to make a simulation of nature, you'd better make it quantum mechanical…"
- 1993 — an international group of six scientists, showed that perfect quantum teleportation is possible
- 1994
  — Dan Simon showed another computational problem that a quantum computer has an exponential advantage over any classical computers.
  —Peter Shor discovered a quantum algorithm, which allows a quantum computer to factor large integers exponentially much faster than the best known classical algorithm. Shor's can theoretically break many of the Public-key cryptography systems in use today



Brief History of Quantum Computing

- 2009 — Yale created first solid-state quantum processor, a 2-qubit superconducting chip
- 2011
  — scientists from Australia and Japan made a breakthrough in quantum teleportation, successfully transferring quantum data with full transmission integrity
  — D-Wave announced first commercial quantum annealer
- 2012 — the first quantum teleportation from one macroscopic object to another was reported by scientists at the University of Science and Technology of China
- 2013 — Google announced that it was launching the Quantum AI Lab
- 2014 — Edward Snowden showed the NSA is running a $79.7 million research program titled "Penetrating Hard Targets", to develop a quantum computer capable of breaking vulnerable encryption
- 2015 — NASA publicly displayed the world's first fully operational quantum computer, D-Wave Systems
- 2017 — IBM Research scientists successfully "broke the 49-qubit simulation barrier"
- 2018 — IBM, Intel, and Google each reported testing quantum processors containing 50, 49, and 72 qubits
- 2019 — Google announced it had achieved quantum supremacy - marking a huge milestone in the advancement of practical quantum computing

Quantum Computer

- A computer exploits its internal states through special quantum mechanical properties such as superposition and entanglement

Categories of Quantum Computers

- Analog
- Digital Gate Based
- Measurement-based

Analog QC

- Gradually evolves the state of a quantum system using quantum operations that smoothly change the system such that the information encoded in the final system corresponds to the desired answer with high probability.
- When the restriction is lifted and the system is allowed to interact with the thermal environment, it is referred to as "quantum annealing"
- Whether or not existing quantum annealing devices achieve universal quantum computation or any quantum speedup remains unclear.

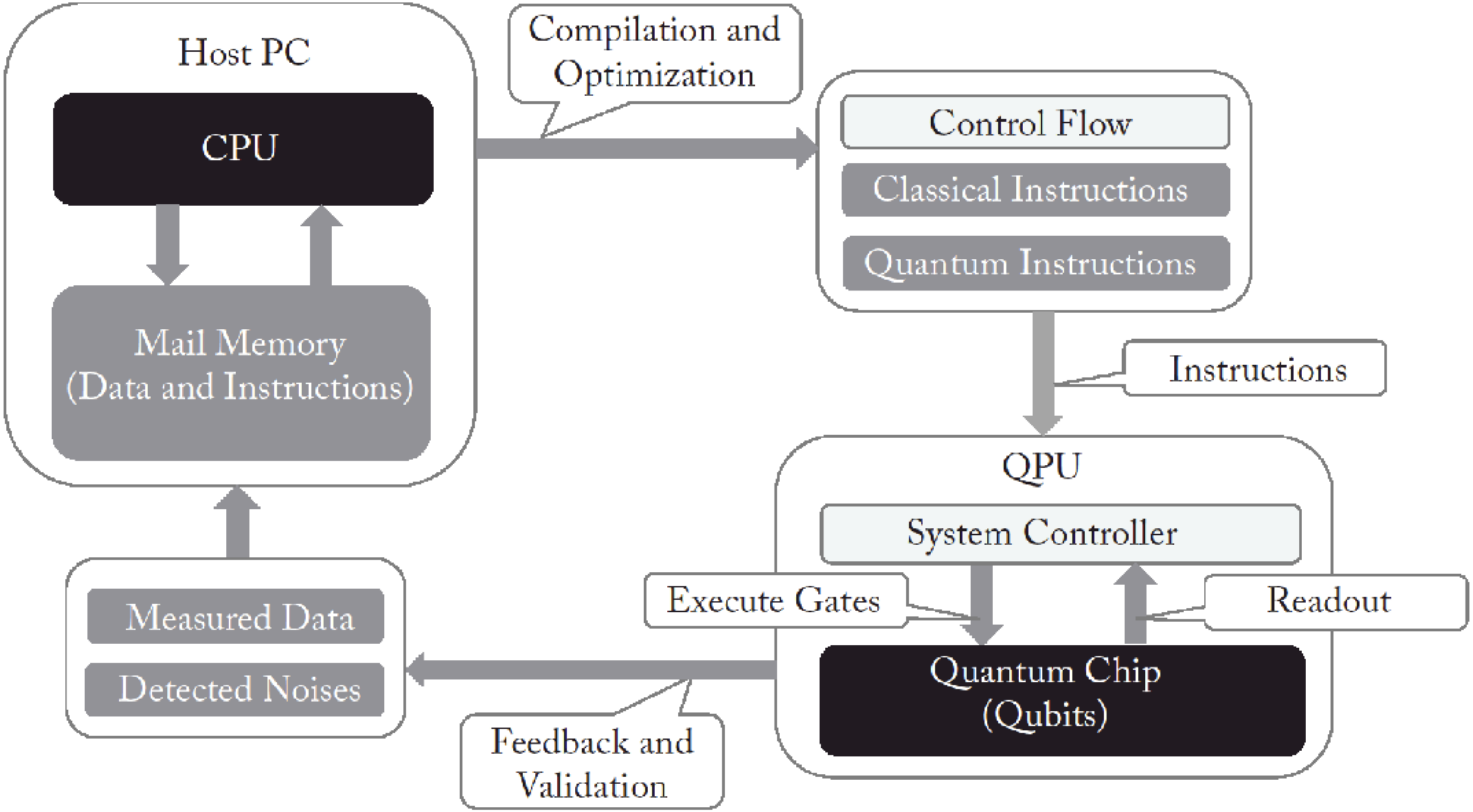
Digital QC

- Information is encoded onto a discrete and finite set of quantum bits (qubits)
- Quantum operations are broken down to a sequence of a few basic quantum logic gates.
- More sensitive to noise from the environment than an analog QC — lead to the cost of error correction

Measurement-based QC

- Initializes a number of qubits in the cluster state.
- The computation process involves measuring (in some measurement basis) some of the qubits in the cluster state.
- The output of the computation is the measurement bit-string outcome and the remaining state of the qubits that are not measured.
  - possibly conditioned on the outcomes of previous measured qubits

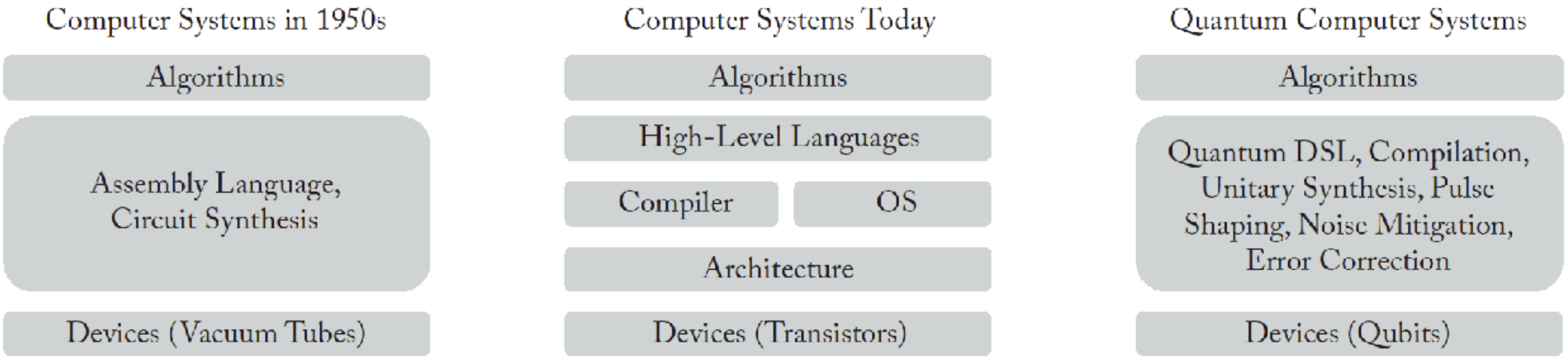
Quantum Computer Architecture



Regarding QPUs

- A hardware accelerator for modern computers — not a replacement
- The host processor controls every move of a QPU
- A well-isolated physical system
  - Encodes a sufficiently large number of qubits
  - Controls these qubits with extremely high speed and precision in order to carry out computation
  - Must reliably address and control qubits and correcting errors.

System Stack



Quantum Technologies

Quantum Technologies

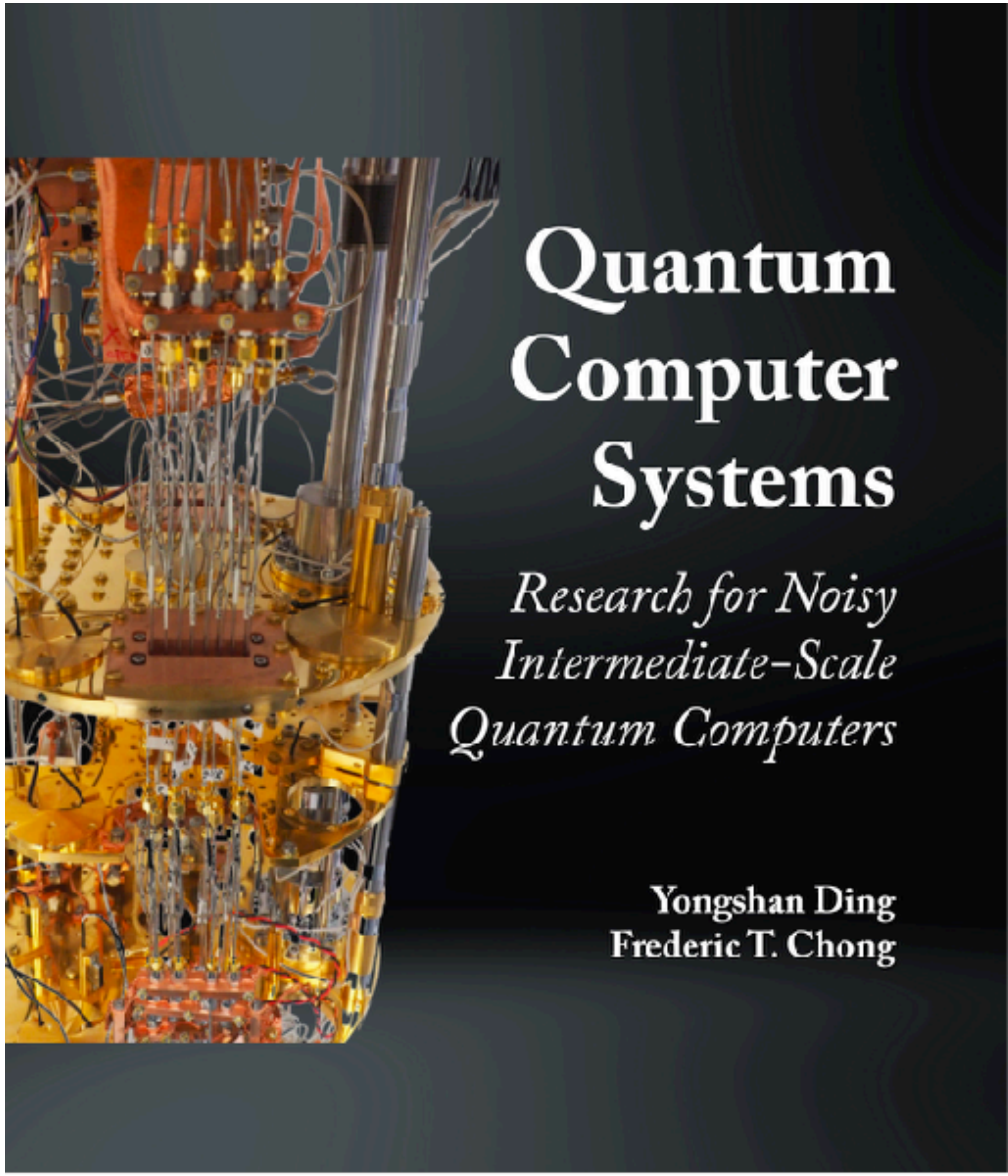
- Quantum Communication
- Quantum Computation
- Quantum Simulation
- Quantum Sensing

Quantum Computer Systems

- Quantum Algorithms
- Quantum Programming Languages
- Quantum Compilation
- Unitary Synthesis
- Microarchitecture and Pulse Control
- Quantum Hardware

What the class is going to cover?

- A "study-group" of
  Quantum Computer Systems: Research for Noisy Intermediate-Scale Quantum Computers. Yongshan Ding and Frederic T. Chong. Synthesis Lectures on Computer Architecture
  - Free download through UCR VPN by accessing https://doi.org/10.2200/S01014ED1V01Y202005CAC051
- Also three research papers
- Each of us should signup for exact one presentation throughout the quarter
  - Sign up for your presentation slot — https://calendar.google.com/calendar/u/0/selfsched?sstoken=UUpRMXREUlVDM3FwfGRlZmF1bHR8OWFlMjZmODk4OWYwMjEwMWNlYmZhMGE3MzEyMjgwNTI
  - Please do as soon as you can! We need the first presenter next Tuesday!



Schedule — on the website

escalab.org/classes/ee260f-2021sp/

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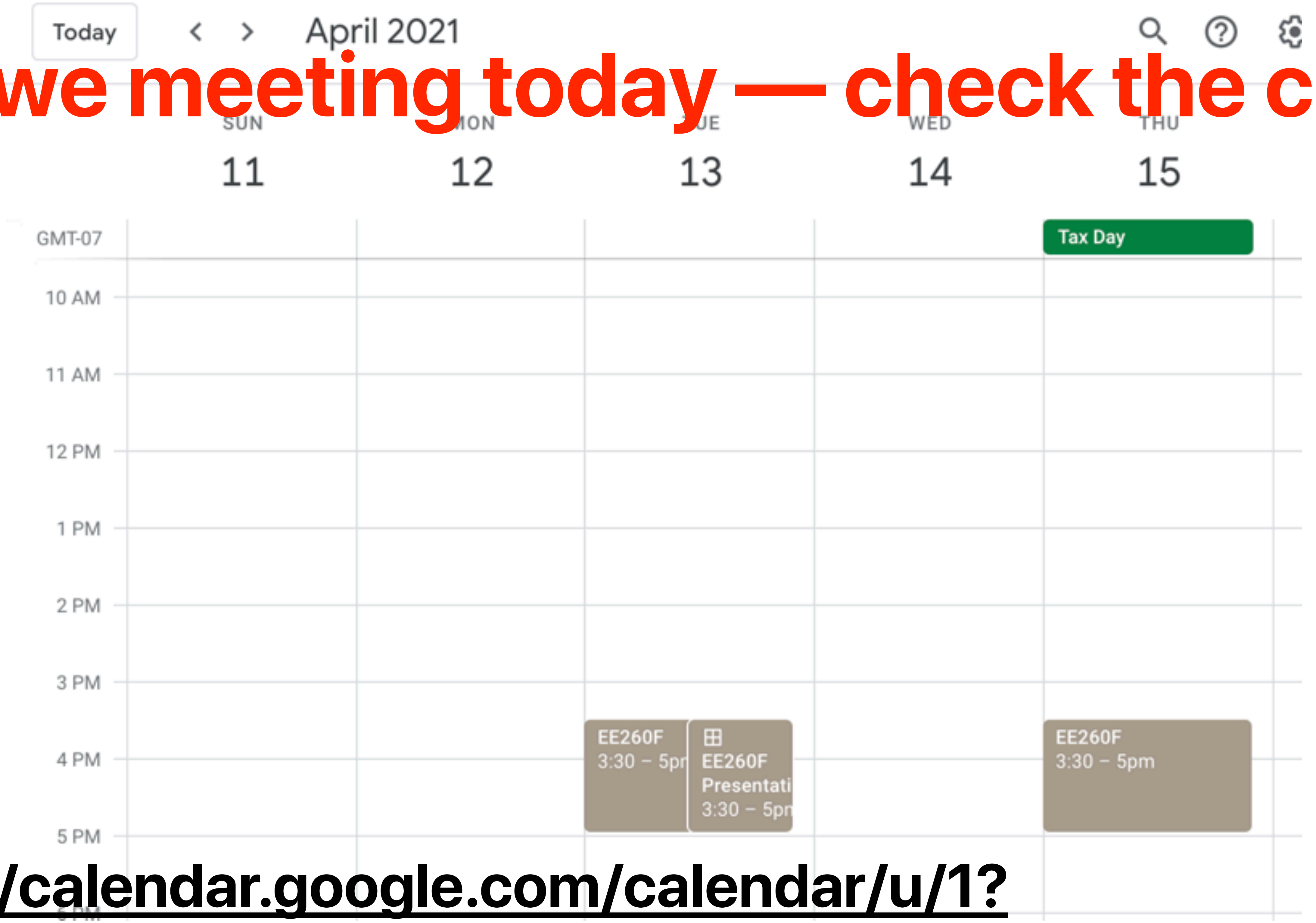
Schedule and Slides

	Topic	Reading
3/30/2021	Intro	Ding/Chong Chapter 1
4/1/2021		Ding/Chong Chapter 2
4/6/2021		Ding/Chong Chapter 3
4/8/2021		
4/13/2021		Ding/Chong Chapter 4
4/15/2021		
4/20/2021		Ding/Chong Chapter 5
4/22/2021		
4/27/2021		Ding/Chong Chapter 6
4/29/2021		

https://www.escalab.org/classes/ee260f-2021sp/

Are we meeting today — check the calendar



- https://calendar.google.com/calendar/u/1?cid=dWNyLmVkdV82N2FianBmNXFya3Nvb25uYmQyamlkcWZuNEBn91cC5jYWxlbmRhci5nb29nbGUuY29t

Logistics

- You should try your best to prepare for the presentation
  - Check https://www.escalab.org/classes/ee260f-2021sp/ for slides and the topic of the week
  - Send me your slides after your presentation
- Starting from week 2, we will meet ever Tuesday and meet on Thursday only when necessary (e.g., the presentation of a chapter cannot finish in one lecture)
  - Subscribe to the calendar for the most up-to-date meeting schedule https://calendar.google.com/calendar/u/1?cid=dWNyLmVkdV82N2FianBmNXFya3Nvb25uYmQyamlkcWZuNEBncm91cC5jYWxlbmRhci5nb29nbGUuY29t
- You should try to ask questions
- You should think about what research can be done along the line of topics learned from this quarter
  - Turn in a 2-page research proposal at the end of the quarter

Questions?