"The best theory is inspired by practice. The best practice is inspired by theory."



Introductory Lecture Chi-Ning Chou @ 2022 January Mini-Course "What is Computation? From Turing machines to Black Holes and Neurons"

- Donald Knuth



What is Computation? Introductory Lecture

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- Donald Knuth

Speaking of Computation, What Do We Precisely Mean?

Biology

Physics

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Biology

Physics

What is Computation? From Turing Machines to Blackholes and Neurons

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Biology

Physics

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Computation Has Become an Interdisciplinary Notion!

But Why Should I Care?

You Don't Have to Care, But...

If you have one (or more) of the following...

- Curiosity in knowledge Passion in learning Love in deep and broad thinking • Wide range of interests

together in this mini-course!

Welcome to a journey of crossdisciplinary exploration

Then I sincerely invite you to reexamine the essence of computation

Overview on this Mini-Course

Please save your questions to the end!

Main Instructor

Name: Chi-Ning Chou **Brief intro:** I'm a 5th year Ph.D. student advised by Professor Boaz Barak at Harvard University. My home field is theoretical CS while I'm broadly interested in math, physics, biology, and especially their interconnections. Outside academics, I love sports, classical music, and cooking :)

Introduction to our guest speakers and teaching staff soon!

Biology

16

Mathematics

Three Modules

Physics

Biology

Why these three?

Why Math?

9478=0 h= 4.3219 marz 1001 2454.56 D(x)00 4.31447 r=X)=NM 1.10 55 men 6883 =(3'+2e).Ve X=9.2 lin(x) 010115 InT(m) = log 010002 011002 s(544.32) - DJ(2) = 5.454 O O Inle: NO)/H(2) = 5.6545 O - hethore here and and the second of the s

Why Math?

Why Math?

 $(2q^{2}e^{2})^{u/2}(n/u)^{u/2} \cdot \alpha^{(o+\eta)/k}C^{u}(n/\kappa)^{\kappa}(u/\sqrt{n\eta})^{\eta}(u/n)^{o} \cdot C_{2}^{h'}(sn/h'^{2})^{h'/4} \cdot h \cdot 2^{k\kappa} \cdot (h^{2}/(sn))^{h/4}$ $\leq C_4^u C_5^h \alpha^{(o+\eta)/k} \cdot (n/u)^{u/2} \cdot (n/\kappa)^{\kappa} \cdot (u/\sqrt{n\eta})^{\eta} \cdot (u/n)^o \cdot (sn/h'^2)^{h'/4} \cdot (h^2/(sn))^{h/4}$ (Using $h' \leq h \leq 2^h$, $\kappa \leq u$, $C_4 \triangleq \sqrt{2}e \cdot q \cdot C \cdot 2^k$, $C_5 \triangleq 2C_2$) $\leq C_4^u C_6^h \alpha^{(o+\eta)/k} \cdot (n/u)^{u/2} \cdot (n/\kappa)^{\kappa} \cdot (u/\sqrt{n\eta})^{\eta} \cdot (u/n)^o \cdot (sn/h^2)^{-(h-h')/4}$ $= C_4^u C_6^h \alpha^{(o+\eta)/k} \cdot (n/u)^{u/2} \cdot (n/\kappa)^{\kappa} \cdot (u/\sqrt{n\eta})^{\eta} \cdot (u/n)^o \cdot (sn/h^2)^{-(u+\kappa-(\eta+o))/4}$ $= C_4^u C_6^h \alpha^{(o+\eta)/k} \cdot (nh^2/(su^2))^{u/4} \cdot (h^2 n^3/(s\kappa^4))^{\kappa/4} \cdot (su^4/(n\eta^2 h^2))^{\eta/4} \cdot (su^4/n^3 h^2)^{o/4}$ $= C_4^u C_6^h \alpha^{(o+\eta)/k} \cdot (h^2/(\varepsilon u^2))^{u/4} \cdot (h^2 n^2/(\varepsilon \kappa^4))^{\kappa/4} \cdot (\varepsilon u^4/(\eta^2 h^2))^{\eta/4} \cdot (\varepsilon u^4/(n^2 h^2))^{o/4}$ $\leq C_4^u C_6^h \alpha^{(o+\eta)/k} \cdot (h^2/u^2)^{u/4} \cdot (h^2 n^2/(\kappa^4))^{\kappa/4} \cdot (u^4/(\eta^2 h^2))^{\eta/4} \cdot (u^4/(n^2 h^2))^{o/4}$ **Constructions** + $\kappa - (\eta + o) \le 0$ and **Otations** $\leq (e^2 C_4)^u C_6^h \alpha^{(o+\eta)/k} \cdot (h/u)^{u/2} \cdot (hn/(u^2))^{\kappa/2} \cdot (u/h)^{\eta/2} \cdot (u^2/(nh))^{o/2}$ (Using $(u/\kappa)^{\kappa} \leq e^u$ and $(u/\eta)^{\eta} \leq e^u$) $= (e^2 C_4)^u C_6^h \alpha^{(o+\eta)/k} \cdot (h/u)^{u/2} \cdot (u/h)^{\eta/2} \cdot (u^2/(nh))^{(o-\kappa)/2}$ $\leq (e^2 C_4)^u C_6^h \alpha^{(o+\eta)/k} \cdot (h/u)^{u/2} \cdot (u/h)^{\eta/2} \cdot (u/h)^{(o-\kappa)/2}$ $\leq (e^2 C_4)^u C_6^h \alpha^{(u-h)/k} \cdot (h/u)^{u/2} \cdot (u/h)^{\eta/2} \cdot (u/h)^{(o-\kappa)/2}$ (Using $\alpha \leq 1$ and $u - h \leq \eta + o$) $= (\alpha^{1/k} e^2 C_4)^u (C_6/\alpha^{1/k})^h (h/u)^{u/2} \cdot (u/h)^{\eta/2} \cdot (u/h)^{(o-\kappa)/2}$

I encourage you to follow your instinct and feel the underlying story like watching an art movie!

Why Math?

Module I: The mathematical foundation of computation

Fundamentals

Departure: Reasoning about Computation via Mathematics

Module I: The Mathematical Foundation of Computation

"If we understand an idea then it is only by mathematically recreating it." – Misha Gromov

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Lecture I.a (Jan. 10 11am-11:50am ET)

Modern approach

Modern Developments: Models, Resources, Reductions

Module I: The Mathematical Foundation of Computation

"Every new body of discovery is mathematical in form, because there is no other suidance we can have. Charles Darwin Chi-Ning Chou @ 2022 January Mini-Course "What is Computation? From Turing Machines to Black Holes and Neurons

Lecture I.b (Jan. 11 10am-10:50am ET)

Philosophy

Reflection: Turing Machine and Reality

Module I: The Mathematical Foundation of Computation

As far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality.

Albert Einstein

Lecture I.c (Jan. 17 10am-10:50am ET)

Why Physics? Module II: Computations in the physical world

"The essence of math lies in its freedom."

- Georg Cantor

Why Physics? Module II: Computations in the physical world

I encourage you to focus on the different world views and postulates physicists used for studying reality!

Module II: Computations in the Physical World

Classical approach

After the Falling Apple: **Classical and Statistical Mechanics**

Module II: Computations in the Physical World

"Nature is pleased with simplicity. And nature is no dummy.

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– Isaac Newton

Lecture II.a (Jan. 12 10am-10:50am ET)

Modern approach

Two Extremes: Quantum and Gravitational Theories

Module II: Computations in the Physical World

"As far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain they do not refer to reality. – Albert Einstein

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Lecture II.b (Jan. 13 10am-10:50am ET)

Philosophy

The Road to Reality: **New Insights from Computation?**

Module II: Computations in the Physical World

"Science is a differential equation. Religion is a boundary condition."

Lecture II.c (Jan. 19 10am-10:50am ET)

Why Biology? Module III: Computations in the biological world

I encourage you to enjoy the many examples we are going to see throughout the lectures and build up your own story!

Module III: Computations in the Biological World

Many Examples

Entering the Living World: Algorithms & Computations in Biology

Module III: Computations in the Biological World

"In the first place, there can be no living science unless there is a widespread instinctive conviction in the existence of an Order of Things. and, in particular, of an Order of Nature."

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- Alfred Whitehead

Lecture III.a (Jan. 12 11am-11:50am ET)

Evolution & Brain

Two Mysteries: Evolution and Neuroscience

Module III: Computations in the Biological World

"Natural science, does not simply describe and explain nature; it is part of the interplay between nature and ourselves. Werner Heisenberg

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Lecture III.b (Jan. 14 10am-10:50am ET)

Philosophy

Challenges and Hopes: A Tango between Biology & Computation Module III: Computations in the Biological World

"All models are wrong, but some are useful."

- George Box

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Lecture III.c (Jan. 20 10am-10:50am ET)

An Example of the Intersection of the Three

2C8BAC58E28C0 DF3A78D6C7308 24E48C99E98D1 77E9FB9FB6843 EDDED4A80C26

C7EC84655773F 552273D34D745 6386E0E56B049 3A9D9B40728D 6F40D84E9C93E

What's Covered and What's Not?

Consciousness

Creativity

Art

Math Appreciations

Intelligence

"Our knowledge can only be finite, while our ignorance must necessarily be infinite." - Karl Popper

Coding theory

Game theory Examples Physics Information Computation **Stories** Cryptography Biology Learning

If you are familiar with the materials

l encourage you to...

- Focus on how the high-level big pictures connect to each other.
- Be critical to the narrative I give.
- Think about how to explain the same materials to nonprofessionals.

If you are unfamiliar with the materials

I encourage you to...

- Grasp the high-level stories before understanding all details.
- Build up "feeling" and "intuition" on the topics you find interesting.
- Come up with some takeaways for each lecture you attend.

In either case, feel comfortable to share your thoughts!

Goals

"Hmmm, Shiba is dumb, I like Schrödinger's cat better"

Goals

"Can you axiomatize a cat? If so maybe I'll consider to take care of Shiba when you are on vacation"

Mathematics

Goals

Physics

Biology

This is just the beginning of a lifelong journey!

- Zoom:

- Would be great to see your beautiful faces :)
- For technical support or clarification questions, send a zoom message to the teaching staff (marked as co-host). I won't frequently check zoom message.

- Online Q&A:

- Due to the large attendance, please **don't interrupt the lecture** in the middle. Instead, ask questions through vevox (will introduce it shortly). The teaching staff will answer some urgent clarification questions for you through zoom chat.
- There will be several question break during each lecture and I'll answer some top-rated questions on vevox.

- Scribe notes:

- Scribe notes are "shared notes" among students for the lectures and talks.
- I encourage people to sign up and you will be credited in the final report!

Meanwhile, let us know how to improve your learning experience!

Quick Logistics

Guest Speakers for Module I

"Efficiency of Algorithms and the Sorites Paradox"

Lijie Chen (Jan. 11 11am-12pm ET)

Guest Speakers for Module II

"Quantum Correlation: the Resource to Make Quantum Machine More Powerful"

Xun Gao (Jan. 13 11am-12pm ET)

"Quantum Machine Learning from Algorithms to Reality"

Khadijeh Sona Najafi (Jan. 14 11am-12pm ET)

Guest Speakers for Module III

"Into the Unknown: (De)constructing Creativity in the Age of Human-Machine Partnership"

Angel Hsing-Chi Hwang (Jan. 17 11am-12pm ET)

"A Road to Totality: Between Art and Computation"

Brabeeba Wang (Jan. 20 11am-12pm ET)

"Animal Intelligence: Flexible Computation Under Uncertainty"

(Jan. 19 11am-12pm ET)

Aman

Pawan

Teaching Staff Thank you all for volunteering!

Reijo (Jan. 11 2pm-3pm ET)

"Undecidability of the Halting Problem and Gödel's incompleteness Theorem"

Prahlad (Jan. 12 9am-10am ET)

"The Four Color Theorem"

Sowmya (Jan. 18 10am-11am ET)

"Basic of Quantum Computing and Future Direction"

Avantika (Jan. 18 11am-12pm ET)

"Quantum Complexity Theory"

Mostafa

Aaron

Erick (Jan. 13 2pm-3pm ET)

Simone (Jan. 14 2pm-3pm ET)

"Information Geometry"

"Simulated Annealing"

Salvador (Jan. 19 2pm-3pm ET)

Kartikeya (Jan. 20 9am-10am ET)

"Quantum Computing from a Condensed Matter Perspective"

"DNA Computing, Cellular Automata, and Beyond"

Math

Physics

It's time for a screenshot (required by the school) now, it'd be nice to have your camera on 🙂

Biology

CS

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Online Q & A Platform

E

Get Started

ID: 199-577-624

Or scan the QR code with your

(2) In future lecture, teaching staff will regularly post the link in zoom chat.

phone

Join at: vevox.app

Type this in your browser

(1) If you want to show your name, feel free to attach it to the end of your question.

(3) Try to ask a question or like a question there!

Brief Q & A

Feel free to take a break and see you at 11am ET!

Brief Q & A

- **Q:** Will all the lectures be recorded?
- A: Yes, the recording link will be sent out once available and in long term will be posted somewhere publicly.
- **Q:** Is there any homework?
- **A:** No, but there will be food for thought questions at the end of each lecture.
- **Q:** When will the slides be posted?
- **A:** Slides will be posted on the course website after the lecture.
- **Q:** How advanced is the advanced section?

A: Each advanced section will focus on a more specific topic and dive into certain level of details. The target audience is advanced undergraduate students and early-year graduate students (not necessarily in relevant area).

Departure: Reasoning about Computation via Mathematics

Module I: The Mathematical Foundation of Computation

"If we understand an idea then it is only by mathematically recreating it." – Misha Gromov

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Lecture I.a happens at 11am ET!

Coffee Chat

"When everyone says the same thing about some complex topic, what should come to your mind is, wait a minute, nothing can be that simple. Something's wrong. That's the immediate light that should go off in your brain when you ever hear unanimity on some complex topic."

– Noam Chomsky

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Coffee chat happens at 2pm ET!

* Many icons in the slides were made by Freepik from www.flaticon.com

