Many Interesting Things

by

Christian Ivan Cardozo-Aviles

Submitted to the Department of Electrical Engineering and Computer Science
in partial fulfillment of the requirements for the degree of

Master of Engineering in Electrical Engineering and Computer Science

at the

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Abstract

I designed and implemented ES.S10: Many Interesting Things, a novel freshman seminar that introduces students to topics many of them will encounter in classes later on in their undergraduate careers. Topics were presented with a light workload and no formal assignments or exams, in such a way that students' intrinsic motivation was able to serve as the guiding force for the class. The seminar ran through the Spring term of 2018 and covered computer architecture, strobe photography, probability, quantum computation, machine learning, computer vision, and cosmology. Student feedback was favorable and the class was adopted as a freshman advising seminar for the Fall term of 2018.

Thesis Supervisor: Leigh H. Royden
Title: Professor

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Acknowledgments

It's astounding how many of the things we come to see as fundamental to our lives start as happy little coincidences. We end up so immersed in something that we forget just how precious the circumstances that gave rise to it were. Here's to the painters of that big picture.

Looking back to the night I happened to be at ESG when you approached me with a random math question, Ari, I realize that if we hadn't talked that night, things might have turned out very differently, and I might be writing a very different type of thesis. Thanks for being you. I'm thrilled you'll be coming back to MIT!

Paola, grazie per avermi incoraggiato a iniziare ES.S10. I still remember the first e-mail I sent you when I had this idea, and I'm incredibly grateful for your support since. Dave, danke für deine Freundschaft im Stammtisch, and for being around to reason together about the class. You win!

Leigh, thank you for having me in your vision for ESG. I'm immensely humbled and excited by the opportunity of working with yet another wonderful bunch of students this coming year.

Chrissy, you are one of a kind. I look forward to any trip to CopyTech, and I cherish our friendship like you can't imagine. Thanks for your help every time I came down with something to print for this class.

Natalie, you're an angel. Thank you for being my laughter and my common sense. No sabes cuanto te quiero.

I thank my parents, Beatriz Aviles and Ivan Cardozo, for their continued support. Mami, gracias por darme la idea de averiguar si esto podría ser una tesis. Papi, gracias por las conversaciones y filosofías. De verdad que me saqué la lotería teniendolos a ustedes. Los quiero mucho. I thank my stepfather, Donato Medina, for his support as well. Kico, ahora estas en la tesis del flaco salsita.

I also thank my grandmother, Beba, without whom I probably wouldn't have made it here. Abuela, te quiero mucho. Estoy seguro que Hershey te tiene en su corazon mientras come sus treats en el cielo.

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Lastly, a special thanks to the inaugural class of ES.S10:

Many Interesting Things, Spring 2018
Linh Nguyen
Samantha Seaman
Sheila Kennedy-Moore
Rolando Rodarte
Sarah Moseson
Emily Chen
Suzie Byun
Rionna Flynn
Tianyu Cindy Luo
Anne Harrington
Sharon Lin
Sheila Baber
Xinhe Midori Zhou
Melody Phu
Jessica Titensky
Alexander Miller

Thank you all for taking a chance on this pilot. We probably didn't win the lottery in class, but I *know* I won the lottery with you guys. I can't wait to see what you do in the years ahead!

To all, with love,

Christian Cardozo

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Chapter 1

Introduction

The first year at MIT is one of marked transition for all involved. First-year students come in from diverse backgrounds, ethnicities, and homes, but nearly all have one thing in common: they were regarded as the very best, or nearly the very best, by the institutions they came from, a notion backed up by exam and class scores [1]. Their proficiencies at home led them to be known as the "smart one" or the "nerd" back home, often to their delight. It is perhaps fundamental human nature to identify with the things at which we excel, and for the developing adolescents who gain admission to the Institute, it is often with their perceived brilliance that they enter our ecosystem.

This brilliance, once the thing that set them apart from their peers, once the thing that might even have lent a fair amount of development to their feelings of self-efficacy, becomes—to much shock—nothing. Their intelligence remains, but no longer able to be inflated by comparison. If anything, comparison weakens; somehow, at MIT there always seems to be somebody more brilliant than oneself. This presents many freshmen—the recipients of unrivaled privilege in the eyes of outsiders—with an internal conflict they might never have expected to face: they are not the "smartest" any longer. The rigor of the curriculum at MIT then sets in, and students face problem sets, exams, deadlines, office hours, and peers to work with and witness working, some too easily for comfort.

This buildup of academic pressure, coupled with the potential frailty of self-efficacy to tackle it, leads some to break and others to grow, but it is incontrovertibly something all MIT students have faced at one point or another. Many students do eventually come to be at peace with themselves by not regarding themselves on the basis of their academic performance or their perceived intelligence, but instead in terms of the things that make them unique even in the Institute's vast sea of intellect. This development is crucial, and though it may have come by a number of hard knocks, it may serve a student well in facing problems further on in life. In the time that this development occurs, however, students may have taken a number of formative classes in their majors, classes whose substance they were unable to appreciate in the midst of intense pressure and self-discovery. It is not uncommon to hear a student describe a class in which they had little to no idea what was going on, suffering through problem sets and exams and surviving only by the skin of their teeth, traumatized so much by the material that they are afraid to approach it in future classes. Such topics are often not nearly as intangible as they seem to be in times of stress, but their perception as being intangible and pressure-inducing can repel students from them for the duration of their academic career.

1.1 Inspiration

In October of 2017, a student came to me for guidance in writing an extra credit problem for a multivariable calculus problem set. She wanted to know if she could make a connection between double integration and art that was not simply finding the volume of some sculpture. After a minute of thought, the following equation came to mind, taken from the laws of probability as I learned them in 6.041: Probabilistic Systems Analysis in the fall of my third year at MIT:

$$P(a < x < b,\, c < y < d) = \int_c^d \int_a^b p(x,y)\, dxdy \tag{1.1}$$

That is, double-integrating the joint probability distribution of two random variables yields the total probability that the variables lie in a particular range [2]. It occurred to me that one might model the perception of colors by two animals, or two people, by some sort of probability distribution. Describing hypothetical scenarios to the increasingly excited student, I realized that I carry considerably more context for the things I learned as a freshman *now* than I did when I was a freshman, but that when I did take classes that gave me that context, the pressure of problem sets and exams quickly overwhelmed my qualitative appreciation of the material, in such a way that I was learning things solely for the sake of completing assignments rather than for the sake of the material itself, deadline after deadline.

It occurred to me that it would be highly valuable if one could get a "sneak peek" of some of the really interesting classes at MIT as a freshman and without the pressure of actually being in those classes. This is the genesis of my idea.

1.2 Initial Thoughts

Immediately following that moment of inspiration, I put together a list of what I deemed to be the most foundational Course VI classes I had taken in my time at the Institute:

6.004: Computation Structures, taken Spring 2015
6.041: Probabilistic Systems Analysis, taken Fall 2015
6.036: Machine Learning, taken Spring 2017

I also considered classes I had found to be interesting and supplementary to the foundational classes:

6.163: Strobe Project Laboratory, taken Spring 2016
8.370: Quantum Computation, taken Fall 2016
6.819: Advances in Computer Vision, taken Fall 2017

Particularly with regard to the foundational classes, I recalled that the initial interest they had kindled in me was often quickly overwhelmed by their workload. It may not be a criticism, but a circumstance that the "firehose" nature of MIT courseloads can often come at the expense of peace. Whilst under regular academic pressures, it is easy to lose sight of what made a class interesting or appealing to begin with.

My goal was to provide students relief from the Institute's academic intensity, yet still teach them valuable material they will go on to use in future classes. I set out to design a course without formal problem sets, projects, or other assignments of any sort, a course which would give an early but non-burdensome start to the interesting classes at MIT. Its motto would be "No prereqs, no psets, no pressure." Its title: "Many Interesting Things."

Chapter 2

Beginnings

After approval, the preparation of Many Interesting Things proceeded in the months between November and January 2018. Here, I detail the first considerations that went into the class's material and how this material came to be organized.

2.1 ESG

I first proposed the idea of Many Interesting Things to Paola Rebusco, academic administrator of MIT's Experimental Study Group (ESG), a freshman learning community. Established in 1969, ESG offers an alternative way of taking the General Institute Requirements (GIRs): rather than take them in large classes, typically with hundreds of classmates at a time, students take the GIRs with a cohort of fifty to fifty-five students. As a result, individual classes in ESG are typically of five to ten students, allowing them to take ownership of their learning in ways that sitting in a large lecture hall would hardly do. Students and instructors in ESG are often on a first-name basis, and though the classes are of the same rigor as any at MIT, students tend to feel capable of tackling their workloads thanks to the tight-knit community that tends to evolve. Part of this is thanks to the fact that ESG is not just a program, it is also a physical space. Located in the sixth floor of MIT's building 24, it tends to bring students together as they're working on assignments. Forming pset groups is an organic and integral part of the ESG experience; it happens seamlessly. Another central component to the ESG ethos is peer teaching, with many students coming back to the program as TAs for classes they took there.

2.1.1 Past Experience

I was a student in ESG in the 2013-2014 academic year, and stayed on as a teaching assistant for multivariable calculus (ES.1802) for the next three years of my undergraduate career. In the Fall term of 2017, as I was developing Many Interesting Things, I served as a lecturer for ES.1802. In my time with ESG, I've gotten to know it as a sandbox for educational experiments. Such classes as CMS.333: Production of Educational Videos and ES.S70: Electricity and Magnetism with Python have gotten their start in ESG and spread to adoption in the mainstream MIT curriculum. It seemed to me the most appropriate setting for an endeavor to enhance the first-year experience.

2.1.2 Gauging Interest

Throughout November, I described the class to upperclass colleagues in Course VI and other departments, and many of them told me they wished they had had the opportunity to take such a class in their freshman year. I also brought up the ideas of Many Interesting Things to students in my 18.02 section and at office hours, describing the "no prereqs, no psets, no pressure" concept and the proposed content of the class. All expressed interest and a few outright told me they would absolutely register for such a class if it was offered.

Armed with the possibility that a class like Many Interesting Things could tap into the foundations of students' experiences at the Institute, I began to develop a more concrete list of topics for the class.

2.2 Topics

The original topic set for ES.S10 is shown here in Table 2.1, including corresponding MIT subject numbers and compatible GIRs.

Table 2.1: Original ES.S10 topic set

Topic	MIT Subject Number	Corresponding GIR	Relevant Material from GIR
Machine Learning	6.036	18.02	Multivariable chain rule, linear algebra
Probability	6.041	18.02	Functions of multiple variables
Quantum Computation	8.370	18.02	Linear algebra
Computer Vision	6.819	18.02	Linear algebra
Strobe Photography	6.163	18.02, 8.02	Integration, wave mechanics
Computer Architecture	6.004	8.02	Circuit analysis
Relativity	8.033	8.01, 18.02	Linear algebra, frames of reference
Cosmology	8.942	8.01	Wave mechanics

2.2.1 Division of Topics

I split these topics into two categories: major and minor. Major topics are those I deemed to be most central to an exploration of Course VI's essential and growing fields: Computer Architecture, Probability, Machine Learning, and Computer Vision.

Minor topics are those I deemed to be particularly interesting but slightly more unconventional choices in Course VI: Strobe Photography, Quantum Computation, Relativity, and Cosmology.

2.2.2 Many Interesting Talks

In addition to the major and minor topics, I established a project component to the class titled "Many Interesting Talks." The talks would be five-minute, TED Talk-style presentations given by students in the class on any topic of their choosing. I saw this as a way for students to add to the experience by talking about "interesting things" of their own choosing, be they from classes at MIT or any other experiences or interests.

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2.3 Scheduling

ES.S10 was planned to span thirteen classes, each two hours in length once a week. In scheduling the class, I allocated two class meetings per major topic and one per minor topic and alternated them to keep things light. In further keeping with the class's goal of being a *relief,* I decided on holding it on Friday afternoons. This way, I hoped, students would be more likely to see the class as something to look forward to at the end of each week.

The finalized ES.S10 calendar is included here in Table 2.2. There was also originally a planned section of relativity, but due to the class's registration size, I ultimately removed it to make room for more student talks (see section 2.2.2).

Table 2.2: Initial schedule

#	Date	Interesting Thing	Course
1	9-Feb	Computer Architecture—Part I	6.004
2	16-Feb	Computer Architecture—Part II	6.004
3	23-Feb	Strobe Photography	6.163
4	2-Mar	Probability—Part I	6.041/18.600
5	9-Mar	Probability—Part II	6.041/18.600
6	16-Mar	Quantum Computation—Part I	8.04
7	23-Mar	Quantum Computation—Part II	8.370
8	6-Apr	Machine Learning—Part I	6.036
9	13-Apr	Machine Learning—Part II	6.036
10	20-Apr	Computer Vision	6.819
11	27-Apr	Cosmology	8.942
12	4-May	Many Interesting Talks—Part I	
13	11-May	Many Interesting Talks Part II and Conclusion	

This calendar is part of the class's syllabus, which is attached in the Appendix.

2.4 Promoting the Class

Toward the end of the Fall 2017 term, I began producing a set of posters for the class. The first is attached here in Figure 2-1.

Figure 2-1: First ES.S10 poster

I first introduced the poster to ESG and then, by Leigh and Paola's suggestion, distributed it to the UAAP and the OME—MIT's Offices of Undergraduate Advising and Academic Programming and Minority Education, respectively. Between the last week of Fall 2017 and the end of IAP 2018, I also produced a series of topic-specific promotional posters for the class, included here in Figure 2-2.

Figure 2-2: Topic-specific ES.S10 posters for machine learning and strobe photography.

2.4.1 Pre-registration

At the end of the pre-registration period, twelve students had registered for the class, and about two-thirds of them were actually *not* ESG freshmen! News about the class

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appeared to have spread by word-of-mouth, and I was occasionally approached about the class by students outside of ESG. It was pleasing to discover that the class had an appeal with students both in and out of building 24.

2.4.2 Registration

By the start of the semester, eighteen students were registered: four listeners and thirteen for-credit. About half were from ESG, and all were freshmen. It is in this configuration that the Spring term of 2018, and ES.S10: Many Interesting Things, would begin.

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Chapter 3

Pedagogy

The pedagogy with which I approached ES.S10 was largely inspired by my experiences teaching in Brazil, Taiwan, and Hong Kong in 2017. Teaching introductory subjects is already delicate, but it gains a dimension of complexity when English cannot be relied on as the most useful means of communication. Seemingly a constraint, lack of language compelled me to consider alternative, less technical and more *universal* ways of impressing key concepts upon students, and, put into practice, these ultimately worked far better than I could have imagined.

3.1 Easing into Material

Introducing such topics as computer architecture and machine learning is a sensitive matter, a walk along a thin tightrope for the attention and comprehension of one's students. First among many things to consider, one does not want to make a subject seem esoteric, nor reinforce any student's existing view that it is esoteric. From personal experience and conversations I had with students in Taiwan and MIT, I noted that a large reason for students' dislike of a class they've taken is the memory of *how* it was taught. When a menacing topic such as, say, convolution, is brought up to a class all-at-once, an overwhelmed student may instinctively respond by closing themself up to the topic, also all-at-once, saying to themself, "I don't get it," and precluding their understanding. It won't be until they take an exam for the class and are forced to try to make sense of that topic that they begin to realize it was more their fear than the topic itself that had stopped them from looking deeper into it. In order to dissolve any student's preconceived notions that a topic is esoteric and they "won't get it," I believe one must make one's *treatment* of the subject completely new, so that it is *genuinely* introductory to every student. This way, even students who've already learned something and disliked it in the past have an opportunity to, sometimes even unknowingly, give it a fresh start.

I tested these ideas in teaching computer programming in Taiwan; the first half of the class was a discussion, not of computers, but of the way we, as humans, think: often in terms of "ifs", "whiles", and "fors." It was *after* this that I revealed that this is precisely how we program a computer. The results were pleasing: students weren't clueless *or* afraid when it came time to type their thoughts into a Python interpreter. By the end of the class, many students were exclaiming that this had been one of their most enjoyable and informative classes!

This sort of *easing*, or gentle movement from a big picture to an actual technical topic, is, I believe, particularly effective at keeping students engaged because it keeps the purpose and initial wonder of each class in sight.

This was at the core of my intention for ES.S10, to *ease* students into the topics they might see later on in their undergraduate careers, and it guided my approach to each class.

3.2 Quality over Quantity

Though easing students into an introductory topic is an end in itself, once one has accomplished it, it's best to hang on tightly before proceeding. One should not assume right away that students are ready to hear everything there is to know about a topic. Technical difficulty must be incremented gradually; otherwise one runs the risk of dismantling their students' delicately-captured attention with overly sudden complications.

I actually learned this lesson firsthand, the first time I taught electronics, while in

Brazil. I had spent an hour carefully introducing students to the components of an electric circuit using an analogy with flowing water. Things seemed to be going well; students' questions indicated that they were fairly confident in their understanding, so I proceeded to the final part of the class, for which there remained thirty minutes: having them use what they had learned about programming and circuits to build a circuit on an Arduino, a device many of the students had never seen before. Disaster ensued, with many students feeling too lost to even start. I realized that I had made the irreversible mistake of over-estimating a good rate of progression and sent students' self-efficacy plummeting by packing too much into the class.

When teaching introductory subjects, I realized, the best practice may well be to err on the side of slowness. If students seem to catch on, then one can speed up that progression, but in general starting slow is the safest way to ensure all students stay on board.

Recalling Brazil, I resolved to contain the amount of material in Many Interesting Things to students' comfort levels. As I stated in the class's syllabus, our calendar would be tentative and flexible. "We [would] proceed with freedom to make it our own in the weeks ahead" because a smaller number of topics properly covered would be worth significantly more than many topics briskly covered. ES.S10 would *not* be an attempt to condense all of 6.004, 6.041, and 6.036 into thirteen classes. It would be a selective *sampling* of material from each of those classes. Students would then have the freedom to look further into these topics at their own leisure.

3.3 A Class as a Dialogue

During one of the first classes I taught in Hong Kong, I noticed that many students were very reserved; I could tell they had questions, but they seemed extremely hesitant about asking them. After that first class, I got together with a few students to hear more about their experiences and, in the process, I learned about some of the nuances of Hong Kong's educational system. Coming from a place like MIT, where students are generally free to speak with professors and question everything, it was fascinating to hear how much more rigid things in Hong Kong seemed to be. For one, much of the educational system revolves around rote memorization, inherently shunting critical thinking. Additionally, the students told me, teachers and professors in Hong Kong are typically regarded as infallible, such that asking them to clarify anything or questioning their answers is extremely discouraged; they rarely take kindly to it. I realized that the students were probably seeing me just as they saw their other teachers: as an omniscient being that could never be wrong or questioned. To address this, I structured the remainder of my classes in Hong Kong as discussions. I levelled with students and ensured I wasn't reinforcing any notions that I was like the teachers that they had been used to having. The outcome was just as I had hoped; we got to form more of a community around the classroom, and students even invited me out on trips with them!

While perhaps an extreme case, these students' intrinsic fear of asking questions reminded me a bit of the all-too-common MIT scenario where a struggling freshman is overwhelmed but too fearful to speak up to a professor or TA. I reasoned that complementary to a relaxed pace of material is a relaxed *presentation* of that material. The class should feel like a meeting among friends and colleagues, a dialogue rather than a discourse by a detached central figure.

Granted, I had already developed a notion and practice of this from my time teaching in ESG, but recalling my experience in Hong Kong made it doubly evident that this perspective must be integral to ES.S10. I would make it clear to students that, glad as I was to answer questions, I would be just as open to having my answers questioned. We would reason through each class *together*.

3.4 Resulting Fundamentals

Recapping, with lessons learned abroad and at home in mind, I converged on a pedagogical definition of what I intended for ES.S10: a relaxed, community-like setting for easing into a sampling of interesting material from Course VI and beyond.

Chapter 4

ES.S10 in Practice, Part I

The first section of ES.S10 was held on Friday, February 9, 2018. I welcomed students to the class and we all sat down together, going around and introducing each other. After some icebreaking, I distributed the syllabus, reviewed the class's calendar, and took a moment to remind students that they should always feel free to ask questions. "There is no dumb question," I said. "I struggled through these classes. Who am I to say this is easy?" All this in mind, we began our first topic.

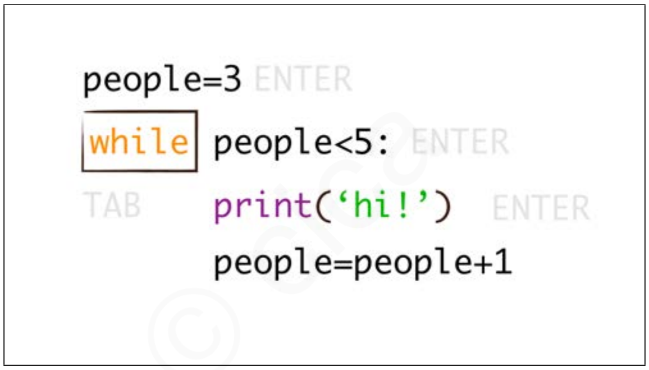
All ES.S10 sections were guided by presentations I produced on Apple Keynote, which facilitated the animations and general visual flow I intended for the class. Excerpts from some slides can be found here, and all slides are included in the appendix.

4.1 Computer Architecture, Part I

To introduce computer architecture, and in the spirit of easing into material, I began with an introduction to programming. I carried out the class much like I did in Taiwan, building up to how computers "think" by discussing how we human beings think and make decisions. In particular, we contemplated the things that might go through the mind of a baby. I pulled up an image of a baby I had met while in Lisbon, Portugal in 2017 and used it as a discussion point for the importance of "if."

Figure 4-1: The Portuguese baby.

Once the discussion had advanced, I put up a shortlink to an online Python interpreter and students were all able to discuss together while working individually on code. It was reassuring to see that responses were very similar to what I had experienced in Taiwan.



```
people=3
while people<5:
      print(‘hi!’)
      people=people+1
```

Figure 4-2: Sample programming exercise.

Students who had never programmed before quickly warmed up to it, and a few even exclaimed about continuing to have fun with this after class. After we got through our introduction to programming, I brought up a fundamental question: How do we go from *thinking* in terms of "if," "while," and "for" to being able to *program* in terms of "if," "while," and "for?" That is, what is inside of a computer that makes this possible? I reminded the class that the answers to all of our "ifs," "whiles," and "fors" had boiled down to checking if something was true or false. With this, I brought up the most basic electronic circuits: a short circuit and open circuit.

When we flip on the lights in a room, I explained, we're simply "switching" the circuit containing those lights from open to closed. A transistor, I explained, is a little digital switch, switching between an open circuit and a short circuit based on an input. The input, rather than a hand to a light switch, is a voltage to a gate, and we can make it high or low, analogous to true or false, one or zero. I then introduced two kinds of transistors, the NMOSFET and the PMOSFET, and discussed how they function as complements of each other: one opens with a high voltage, while the other closes.

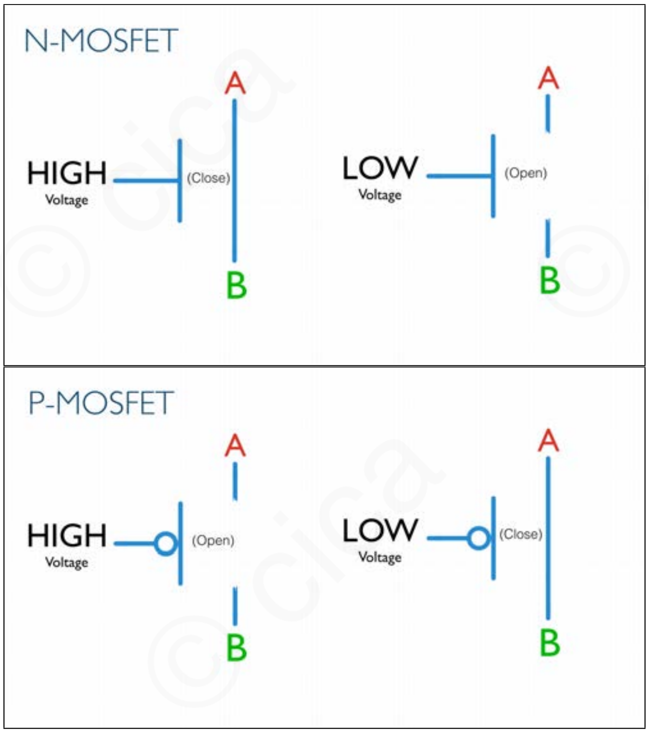


Figure 4-3: NMOSFET and PMOSFET responses to inputs.

Once we understood these basics, I put an NMOSFET and PMOSFET together to form our first digital logic gate: a NOT gate. Together, we reasoned through what its input-output table would look like and then, just as with the online Python interpreter, I displayed a shortlink, this time to the Jade online circuit simulator used in 6.004. Students were able to directly put together two transistors and make the circuit we had talked about. Once they were comfortable with their inverters, I discussed additional logic gates: the AND and OR gates.

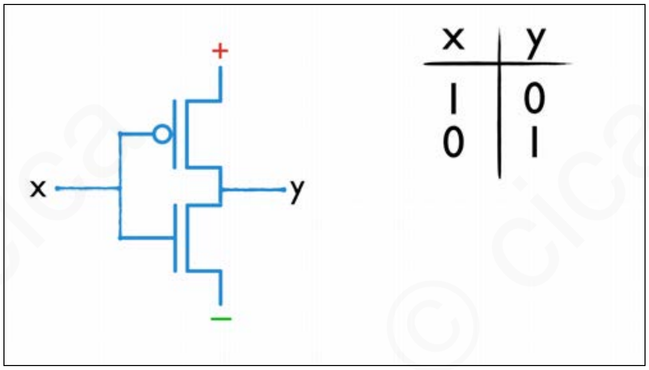


Figure 4-4: Inverter as it appears in the circuit simulator, alongside its truth table.

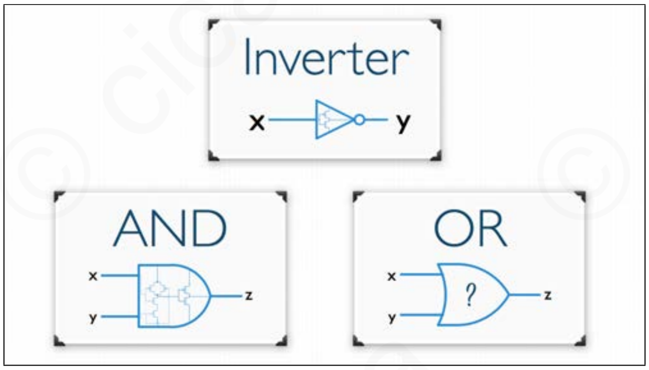


Figure 4-5: Overview of logic gates, with the OR gate's internal transistor configuration left as an exercise to students.

Moving ahead, I said that while it was great that we now knew what to do with high and low voltages, we had a grander goal in mind: doing computations with them. In order to do so, I stated, we had to think in terms of *multiple* bits. I reminded students of the numbers we had seen since Kindergarten, in base ten, and how using binary values allows us to represent numbers in a new base, base two. Rather than a hundreds place, a tens place, and a ones place, we have a fours place, a twos place, and a ones place. Sequences of binary numbers are the fundamental strings we perform computations on. What kinds of computations? At this point, I reminded students once more of Kindergarten and how we added numbers in base ten. Adding numbers in base two, I explained, is very similar. We ended the class with a few elementary base ten and base two additions.

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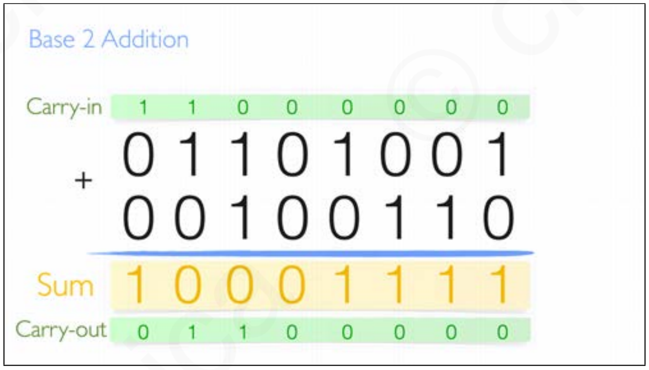
4.2 Computer Architecture, Part II

In the second computer architecture class, we reviewed our progression from transistors to logic gates and returned to looking at addition in bases ten and two.

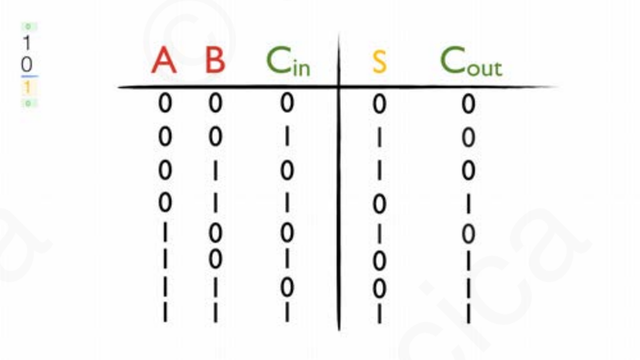


Base 2 Addition

Carry-in	1	1	0	0	0	0	0	0
	0	1	1	0	1	0	0	1
+	0	0	1	0	0	1	1	0
Sum	1	0	0	0	1	1	1	1
Carry-out	0	1	1	0	0	0	0	0

Figure 4-6: Addition in base two.

We ran through a few examples together and showed how addition is simply another binary logic function, for which we can make a truth table and design the corresponding circuit. We derived this truth table together, and I then gave students time to find the corresponding logic expression and put together the corresponding gates in the online application.



A	B	C_{in}	S	C_{out}
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

Figure 4-7: One-bit adder truth table.

I showed students that we had already begun a series of abstractions, moving from individual transistors to logic gates to, now, adders, and that we would be able to continue doing this by stringing together adders to form multiple-bit adders, bitshifters, and circuits that would perform multiplication and division. Putting all of those pieces together, we can make a circuit to perform all arithmetic and logic functions: the Arithmetic and Logic Unit (ALU).

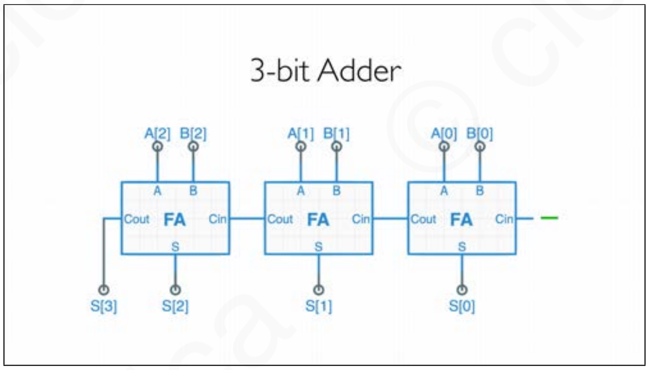


Figure 4-8: Sample three-bit adder.

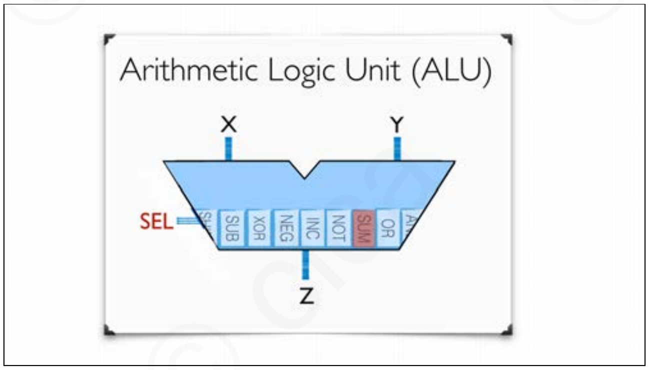


Figure 4-9: Arithmetic and Logic Unit (ALU).

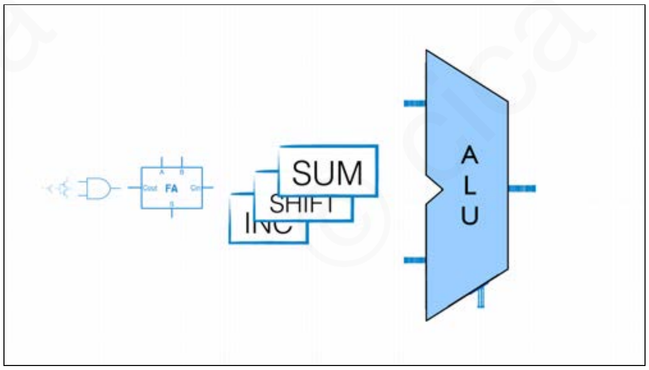


Figure 4-10: Progression of abstractions, from individual transistors to the ALU.

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I talked about how this, along with memory and a program counter, formed the basis for the central processing unit (CPU) of a computer. By the end of the class, we had pieced together a very basic form of the same CPU derived in 6.004 as taught by Chris Terman of EECS.

At this point, I invited in Philip Murzynowski, a former 18.02 student who had built his own 8-bit computer. He connected it to power and showed students some of its basic operations, all in terms of the concepts we had arrived at in class. With this, we concluded our discussion on computer architecture.

4.3 Strobe Photography

As a respite from the more technical class on computer architecture, I next held a section on strobe photography. I borrowed four Nikon D5300 DSLR cameras from the MIT Edgerton Center's strobe laboratory, where I also serve as a teaching assistant, and brought them into class. I taught students the basic parameters of a photographic exposure: shutter speed, aperture, and ISO sensitivity. Cameras in hand, I gave students some time to solidify these concepts and take their own photographs. After this, we ventured into a talk on strobes and the basic principle of timing a flash with an ultrafast event of interest. I demonstrated the results in a photograph I had taken of a balloon mid-pop a couple of years ago.

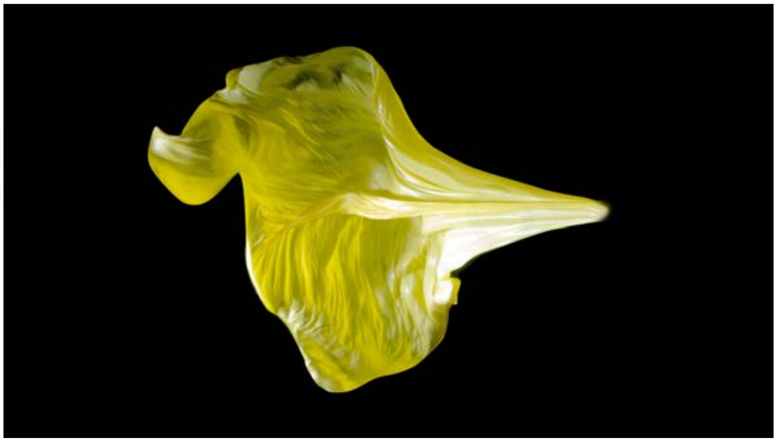


Figure 4-11: Balloon pop photograph I had taken.

After our dive into theory was through, I led students to the Edgerton strobe laboratory and they successfully took photographs of a balloon pop and a water balloon striking a surface.

Figure 4-12: Strobe photograph of water balloon upon impacting a table, taken by ES.S10 students.

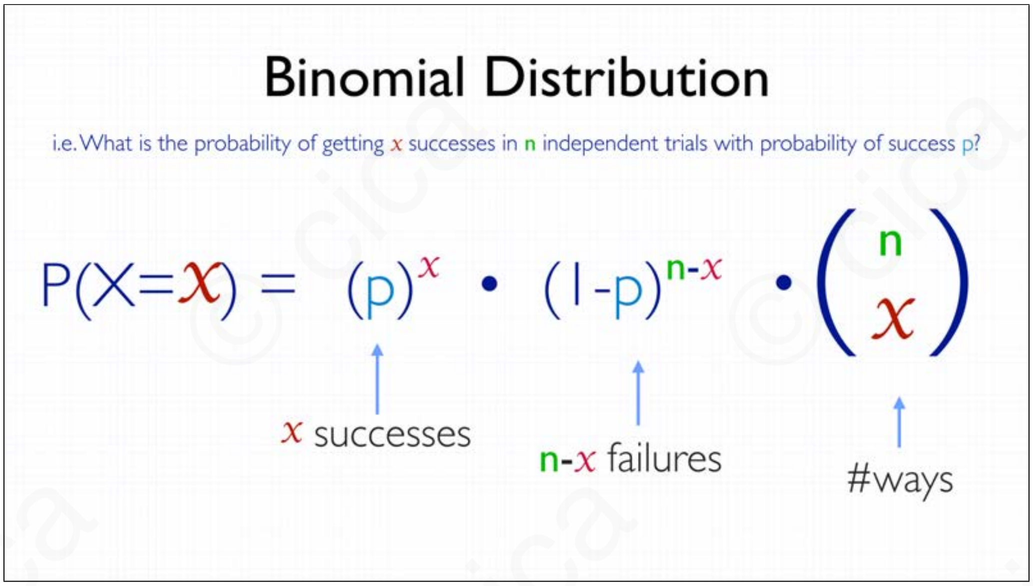
4.4 Probability, Part I

Moving back into a more technical subject, probability, I began the class by discussing events and the unions and intersections of sets of events using everyday scenarios. We also drew a connection to computer architecture: a union of events is similar in principle to an OR gate, and an intersection is similar to an AND gate. From there, I introduced probability as the likelihood of a particular event and spent a while on the fundamental axioms:

> -The probability of any event is at least zero and at most one.
> -The probability of the sample space is one.
> -If two events are mutually exclusive, the probability of their union is the sum of their probabilities.

I then pulled out a set of Massachusetts lottery tickets, which I had picked up from a local convenience store, and asked students to each fill one out and consider the likelihood that that ticket would win the lottery. This eased us into thinking about combinatorics, factorials, and counting. By the end of the activity, we were—for better or worse—much less eager to try playing the lottery!

Drawing inspiration from our talk on combinatorics, we continued by deriving the binomial distribution and doing another activity: independently drawing cards from a deck and counting the number of red cards.



Binomial Distribution

i.e. What is the probability of getting x successes in n independent trials with probability of success p?

$$P(X=x) = (p)^{x} \cdot (1-p)^{n-x} \cdot \binom{n}{x}$$

x successes

n-x failures

#ways

Figure 4-13: Deriving the binomial distribution.

A student opened a deck, still in its original box and wrapping, and shuffled it several times over. We then took fifteen independent draws. To the students' surprise, we found that all of the cards drawn were red. Students used the binomial distribution to verify that this was unusual and, indeed, we found the likelihood to be far, far down the distribution's tail.

This was when I revealed that prior to the class, I had discreetly cut several card boxes' cellophane wrap and switched their contents so that one box had exclusively red cards. That, I said, was the box they had been drawing from. On this light note, and to much laughter, I ended the first probability class.

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4.5 Probability, Part II

In the second week of the probability class, I discussed probability distributions in more detail, including the topic that had inspired the class to begin with: the probability density function and its integration. I also brought in a 3D-printed Galton Table to simulate a binomial process and the resulting look of a binomial distribution. I then discussed what happens when we take the continuous approximation to the binomial distribution: the Gaussian distribution, which would follow us into quantum mechanics and even computer vision. I graphed a few one and two-dimensional Gaussians and gave an early preview of the Gaussian blur filter for images, which we'd look at more in computer vision. With this, I concluded our foray into probability and our fifth class.

Chapter 5

Fifth-week Feedback

At the end of the fifth class, I asked students to take a few minutes to fill out anonymous feedback forms about how they felt the class going so far. I left the room to give them time and space, and later returned to pick up an envelope with the completed forms. Here are a few excerpts from students' feedback:

> "I love the open, discussion-style environment."
>
> "Keynote presentations have very good, helpful animations that make more difficult subject material easier to visualize."
>
> "I love the presentation slides. They are dynamic and clear, and not overloaded with information."
>
> "The experiments are extremely helpful, and Christian takes his time putting concepts into the way people normally think. I wish more classes at MIT were like this. I've learned more in this class than many of my GIRs."
>
> "I would like supplemental materials for additional learning about the topics presented in class."

> "Excellent class. Not having to worry about psets and midterms helps me learn better because I am relaxed."
>
> "This class is so much fun that I'd be okay with having psets (in maybe a different iteration of the class) to help retain some of the information I get during class."
>
> "Every minute spent in this class is worth it! Great organization, use of media (I wonder how long it takes Christian to come up with these slides), always engaging, hands-on component is refreshing."

5.1 Reflection

It was beyond reassuring to hear that the class was progressing well. Every bit of intention I had put into the delivery and content seemed to be paying off, and I was particularly struck by how some students even wouldn't mind having to do work for this class. To me, in particular, it shed light on the power of intrinsic motivation. Here was a class with no formal assignments, yet students were consistently comfortable and relaxed to the point of being *okay* with more work. I had never heard or felt anything like that! With regard to the class's pace, the majority of students reported it to be "just right," so it appeared that they generally appreciated the relaxed rhythm and its conductivity to their learning.

While I would need more time to consider whether or not to make problem sets for the class, the bit of feedback I was able to most quickly respond to was the request for supplementary material. I added a "supplementary items" section to the class webpage and attached numerous links to applets, notes, and videos from in and out of MIT on each of the topics we had covered. For all future topics, I would post supplementary material and slides immediately after each class.

Chapter 6

ES.S10 in Practice, Part II

Thanks to the fifth week evaluations, I had a more concrete notion of how ES.S10 was going. With these lessons learned, I pressed on into the latter half of the term.

6.1 Quantum Computation, Part I

Having done a primer on probability, we were set to begin quantum mechanics and quantum computation. I began with an in-class version of the double slit experiment for particles and waves. For the particle version of the experiment, we used squash balls and the classroom's partitions to set up two gaps for the balls to pass through when tossed. Each student closed their eyes and threw a ball at the partitions, and we then looked at the distribution of balls at the other side of the gaps. As expected, we found that they were concentrated in two large clumps aligned with the gaps. I then brought in a wave table I borrowed from the physics department and we performed the wave version of the experiment. We noted the interference fringes that formed evenly at the other side of the slits.

Figure 6-1: In-class particle version of the double slit experiment. The "slits" are the two gaps in between the dark classroom partitions, here seen on the left of the image.

I explained that if we were to perform the double-slit experiment with electrons, we would actually obtain a wave-like interference pattern at the other side of the slits. We observe particles, but they behave like waves. "The mechanics of a quantum object are not deterministic," I said. "They are probabilistic," and we now had the mathematical machinery to take this on thanks to our previous two sections on probability! I proceeded by laying down the fundamental principles:

> -A quantum object's wavefunction tells us about the likelihood of it having a particular position or momentum.
>
> -The norm squared of an object's wavefunction is its probability density function, and we can integrate accordingly.
>
> -A quantum object exhibits a superposition of states until observed.

We derived equations for the mean and variance of a quantum object's position/momentum and, thanks to a student's question about Heisenberg's Uncertainty Principle, we also talked about the Fourier Transform and used it to derive the Heisenberg relation, which students found particularly interesting. I also briefly discussed quantum tunneling and its relevance to flash memory, which had come up in computer architecture.

I then dwelled on the notion of quantum superposition, which I framed in terms of basis vectors. We have been seeing basis vectors all along, I told the class, as î and ĵ in two-dimensional space in 18.02. Just as a vector has components in both î and ĵ, a quantum object has components in multiple mutually exclusive basis states, right up until the moment we observe it.

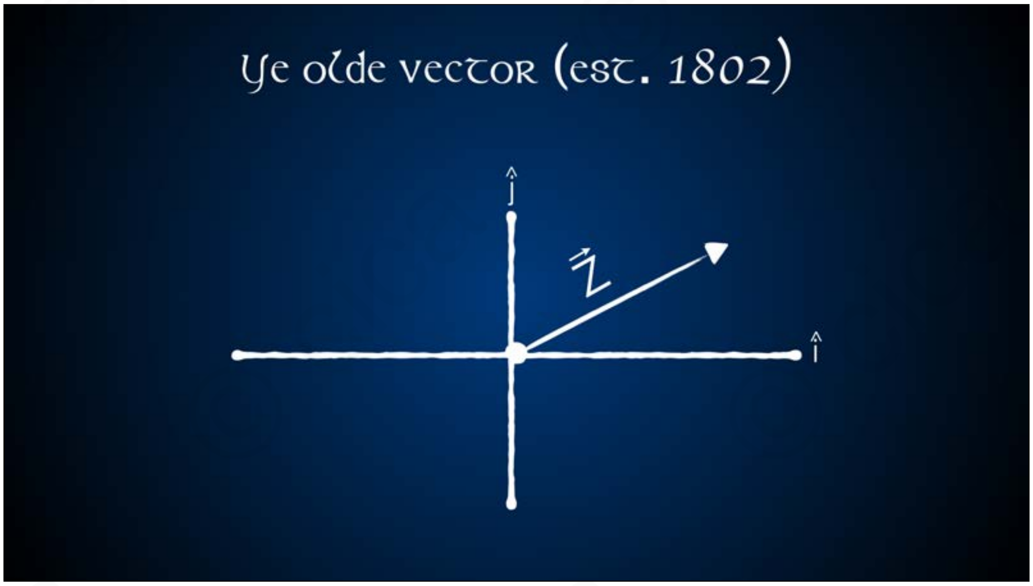


Figure 6-2: Showing the decomposition of a vector into its bases.

Schrödinger's cat, for instance, is in a quantum superposition of the dead and alive states until somebody takes a look:

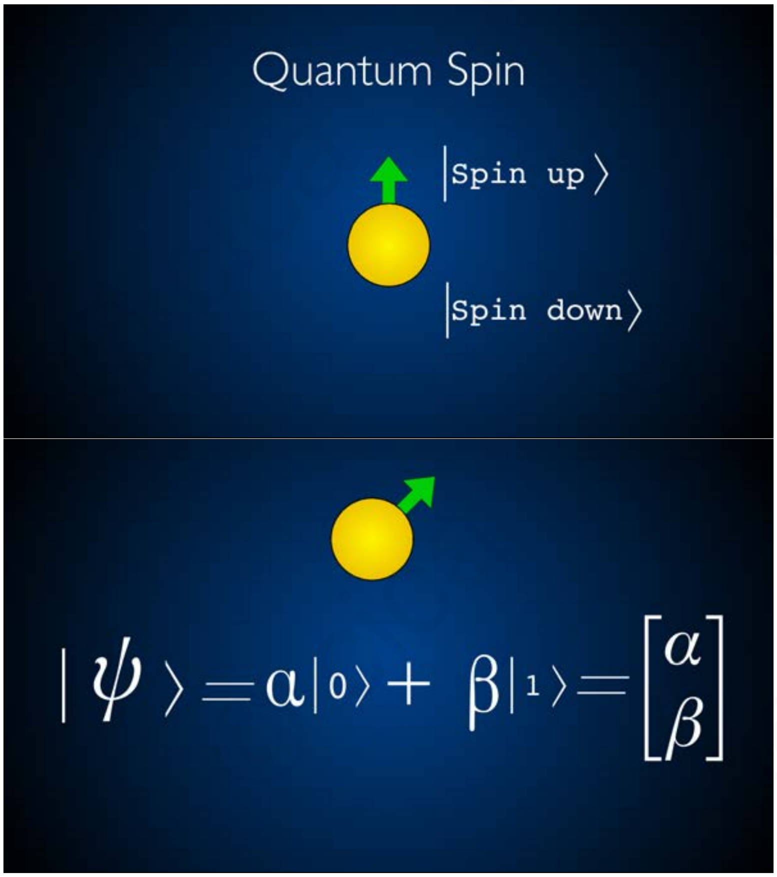
$$|\psi\rangle \;=\; \alpha\,|\text{alive}\rangle + \beta\,|\text{dead}\rangle \tag{6.1}$$

I proposed that a current quantum state for our class might involve the basis states $|\text{donuts}\rangle$ and $|\text{no donuts}\rangle$, and ended with the *observation* that I had indeed bought donuts for the class.

6.2 Quantum Computation, Part II

Our second quantum computation class was, in practice, our first, as we had spent the previous class laying the groundwork for it by discussing purely quantum mechanics.

I began with a review of quantum superposition, which would be fundamental to our discussion of computation. I told students that a quantum bit, or qubit, is a quantum object in a superposition of states $|0\rangle$ and $|1\rangle$, which typically represent spin up and spin down, respectively. I contrasted this with the classical bit we had learned about in computer architecture, which could only be either high or low voltage.



Quantum Spin

$|\text{Spin up}\rangle$

$|\text{Spin down}\rangle$

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle = \begin{bmatrix} \alpha \\ \beta \end{bmatrix}$$

Figure 6-3: Showing the decomposition of a qubit into its basis states.

Because a quantum state is a superposition of basis states, one can think of it as just a two dimensional vector, to which, just as in 18.02, we can apply transformations by matrix multiplication. A transformation is simply a rotation. With this, I was able to introduce the Bloch Sphere as the allowable universe of states of a qubit. A quantum logic gate is simply a device that performs a transformation on a qubit.

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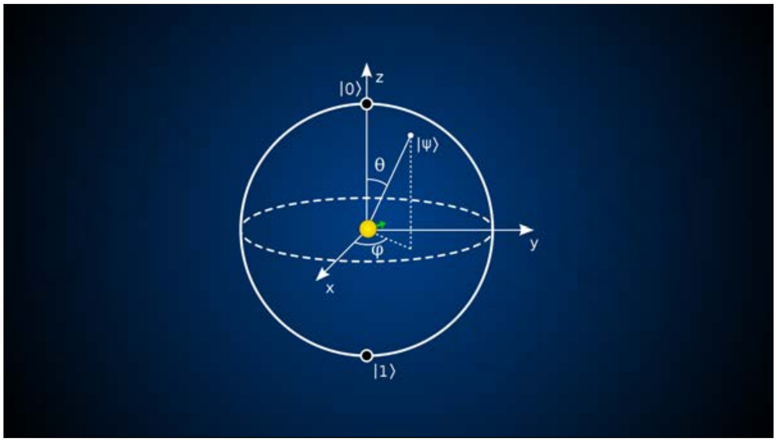

Figure 6-4: The Bloch sphere.

I then lightly described some of the computationally difficult problems we face and how such quantum algorithms as Shor's Algorithm could cause a revolution if we develop a quantum computer that can implement them. Lastly, I played a Google-produced video about the D-Wave quantum computer and ended the class.

6.3 Machine Learning, Part I

Considering its ever-increasing relevance, I felt that a basic understanding of machine learning should definitely be more widespread in this day, so it was among the subjects I was most excited to introduce to freshmen when planning the class.

I began the first machine learning class by tying back to the question we had looked at when starting computer architecture: How do we human beings think? I then raised the question: Is it possible for computers to ever "think" the way we do? To start us off, I discussed how we can encode information about an object in terms of feature vectors and labels. A feature vector might, say, contain somebody's height and weight. A label corresponding to that feature vector would be a discrete classification, say $+1$ for male and -1 for female. A large task of machine learning, I explained, is to find correlations between feature vectors and labels, so that we can classify feature vectors for which we *don't* have labels.

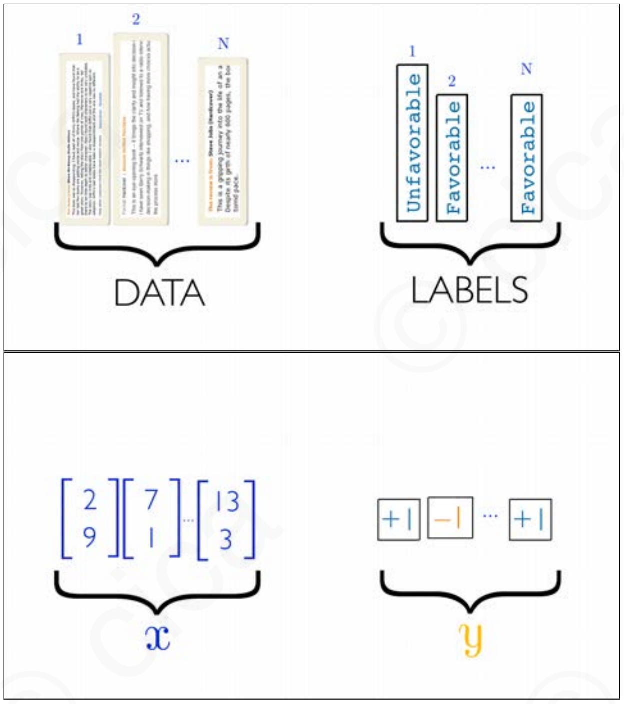

Figure 6-5: Showing the representation of data in terms of feature vectors and labels.

Just as with quantum computation, I seized the opportunity to bring a geometric perspective on vectors, this time by demonstrating the use of two-dimensional feature vectors to label Amazon reviews as favorable or unfavorable. These two dimensions were the number of times the words "glad" and "awful" were said in a given review. I then showed how, in two dimensions, a linear classification simply meant finding the equation of the line which separates the feature vectors into two categories and classifies the most feature vectors correctly.

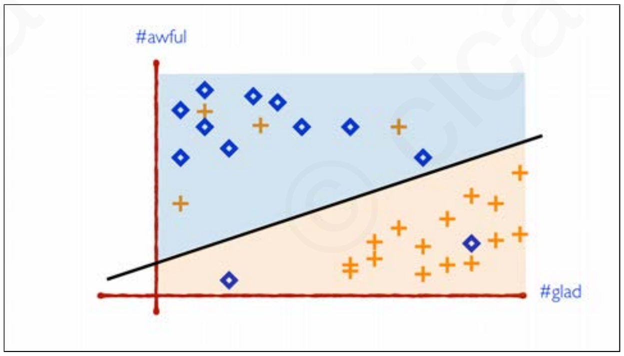

Figure 6-6: Showing two-dimensional linear classification.

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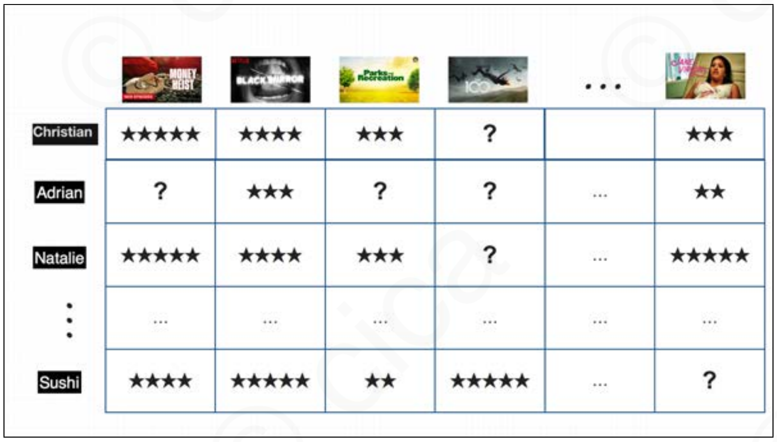
With this, I introduced the perceptron algorithm for linear classification and demonstrated it in action using an applet. I expanded by discussing how we are by no means limited to two dimensions; we can extend our scope to high-dimensional feature vectors. I demonstrated this using an Amazon review classifier I had written in 6.036, which used feature vectors of one dimension per English word.

The next topic I covered, albeit briefly, was low-rank matrix factorization, which plays a large role in recommender systems. This was very simple to invoke applications for, with Netflix being perhaps the most close-to-home for students. We looked at a large matrix of users and show reviews and discussed how the low-rank matrix factorization algorithm could be used to infer ratings for users on shows they have not yet seen and hence produce recommendations.



					...	
Christian	★★★★★	★★★★	★★★	?		★★★
Adrian	?	★★★	?	?	...	★★
Natalie	★★★★★	★★★★	★★★	?	...	★★★★★
⋮	...	...	...	...	...	...
Sushi	★★★★	★★★★★	★★	★★★★★	...	?

Figure 6-7: Motivating recommender systems using Netflix as an example.

In the remaining few minutes of class, I teased an introduction to the ultimate attempt to mimic the way humans think: artificial neural networks. We would continue this the next week.

6.4 Machine Learning, Part II

For the second machine learning class, I recapped linear classification and recommender systems and returned to neural networks. I described the foundations of a fully-connected network: neurons, weights, and activation functions.

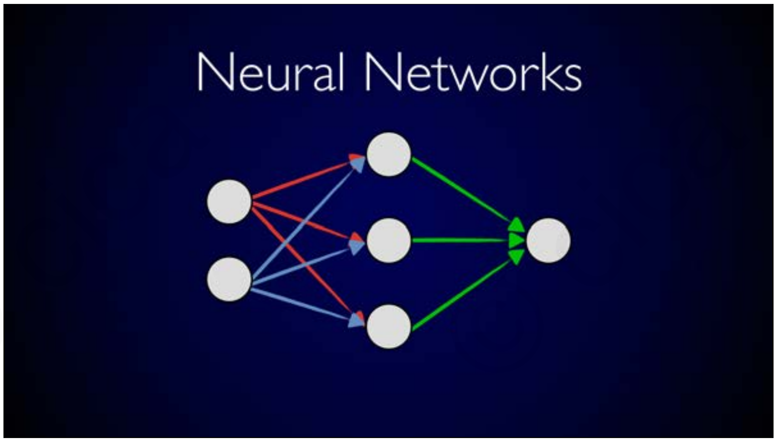


Figure 6-8: Introductory slide on neural networks.

I then introduced the way neural networks' weights are trained: the backpropagation algorithm. This was particularly exciting because it could be described in the context of level curves, the gradient, and the chain rule, all of which students had seen in multivariable calculus. This allowed them a fairly intuitive understanding! At this point, we dove into an online neural network applet, the TensorFlow Neural Network Playground, and students were able to get their hands dirty seeing how weights and classifications evolve over training.

I ended the class with a guest speaker, Magnus Johnson, an MIT junior and software developer who was developing a neural network application for iOS devices. He gave a live demo of his application and students were able to beta test it on their own devices ahead of its release.

6.5 Computer Vision

Just as prevalent as machine learning to the scope of popular and relevant Course VI topics is, I believe, computer vision. One particularly beautiful thing about it is that, like strobe photography, it is inherently very visual, and that presents a unique opportunity for students to *experience* the content in more ways than a traditional, more textual topic.

I started the class by showing a few image files on my computer. I said that underneath it all, we were looking at numbers. That is, an image is simply a matrix of numbers representing a brightness value at each pixel. From this, I linked students to an online MATLAB interpreter, and they were able to analyze images on their computers, see the underlying matrices, and increment or decrement their values. Together, we saw how such operations as changing brightness or tuning color are simply the results of incrementing or decrementing the values of a matrix.

After covering these basics, I moved on to convolution. This was a subject I wanted to be particularly careful about due to the somewhat uninviting nature of the word "convolution." I wanted to ensure students weren't "turned off," so I kept things particularly interactive here: I took a sheet of paper and moved it around an image on the projector screen, visually walking through how a convolution is applied by centering a filter matrix on each pixel of an image, taking the sum of the elementwise product of the filter and the image pixels it overlaps, and making that sum the new value of that pixel.

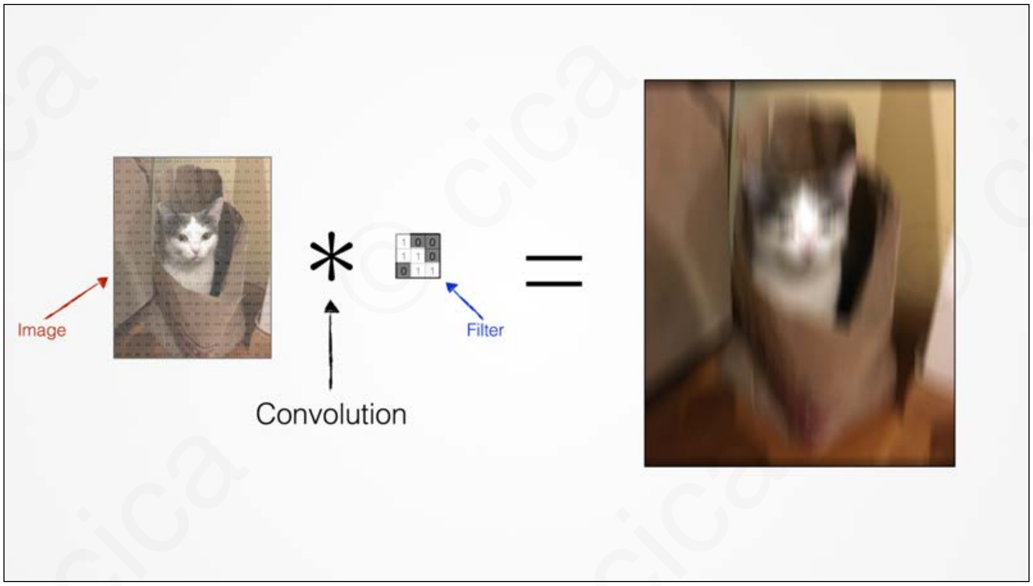


Figure 6-9: Demonstrating convolutional filtering.

I told students that convolution didn't have to be as difficult as the name implied and added that one main value of filtering is that it brings out particular features in an image. Features, as we've seen, can be powerful in machine learning tasks.

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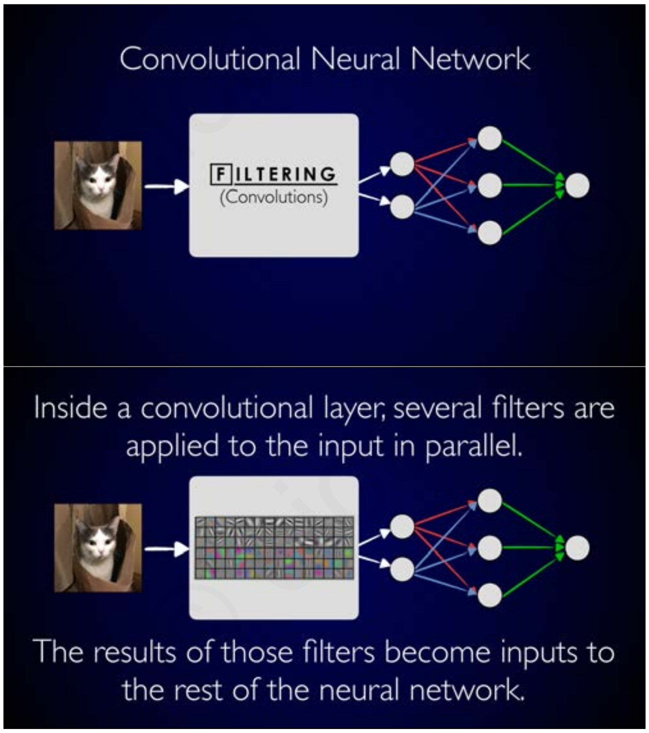
Having discussed convolution, I was now ready to introduce convolutional neural networks, a topic which intimidated me greatly when I was in 6.036, but that I felt could be simplified by simply looking at the convolutional network as a union of two components: a convolutional layer that just applies a sequence of filters, and then a regular, fully-connected neural network like what we had discussed in the previous machine learning class. The convolutional layers of a convolutional neural network essentially do some preprocessing so that the remainder of the neural network, the fully-connected layer, has an easier time digesting the input.



Convolutional Neural Network

Inside a convolutional layer, several filters are applied to the input in parallel.

The results of those filters become inputs to the rest of the neural network.

Figure 6-10: Introductory slides on convolutional neural networks.

I described how training a convolutional neural network was essentially the same as we had learned for a regular network, only that in a convolutional network, we have an additional set of numbers to optimize: the individual values inside each of the convolutional filters. When we train a convolutional neural network, we tune the filters to detect features of interest.

Lastly, I gave a demonstration of AlexNet, a widely-used and top-performing convolutional neural network, and used it to classify images.

6.6 Cosmology

The final section I covered in ES.S10 was on cosmology, a topic I had never really taken a formal class on, but developed an interest in as an undergraduate and learned enough to produce an educational video, Cosmology for the Science Enthusiast, which went on to be published by the magazine of the American Geosciences Institute at the end of my freshman year.

I began the class with a discussion of how our individual perspectives of Earth's size might have evolved when we each first looked out the window of an airplane. I then talked about how, despite seeming so large to us, the Earth is actually quite small next to the sun, and the sun is actually quite small next to other stars. A student then pulled up an applet that allows one to scroll through the smallest and largest scales in the universe, and we used it as a talking point for how Cosmology is the study of *everything*. Everything that has ever existed or will ever exist is inextricably tied to the origin and development of the cosmos. To begin to tame this topic, I said, we might well begin somewhere calm: a pond. I discussed the ripples in a pond made by the drop of a stone, and how the spacings between those ripples would be different if made by an object that moves. This allowed me to introduce the Doppler Effect and point out that it's not exclusive to sound; light behaves in precisely the same way. Light moving toward us is slightly higher-frequency (blueshifted), and light moving away from us is slightly lower-frequency (redshifted).

Figure 6-11: Showing the Doppler Effect in a moving car.

I then discussed the emission spectra of certain gases and stated how in the 1920s, astronomers pointed their telescopes at distant galaxies and found that their emission spectra were all redshifted. That is, they all seemed to be moving away from us, in all directions. This must mean that the universe is expanding. From this, I moved to turning the cosmic clock backwards. If the universe is expanding with time, then if we go far back enough, we find that at the beginning of time, 13.7 billion years ago, the universe was a single, infinitesimally small point: the singularity. From here, I re-ran the cosmic clock forward, discussing the Big Bang, the initial annihilation between matter and antimatter, and how an imbalance of a billionth between the two led to the survival of the universe past the annihilation phase. I then moved ahead to how gravity brought the universe's primordial masses of hydrogen gas tighter and tighter together to produce stars, which went on to fuse even heavier elements within. When these stars collapsed, they released the heavy elements they had fused out into the cosmic void, and now gravity could bring them together to shape things like planets, planets like our own Earth. I closed the class on the same quote with which I closed Cosmology for the Science Enthusiast: "We who now study the universe are the universe."

6.7 Many Interesting Talks, Parts I and II

The end of Cosmology marked the last of the material I would be presenting for the class and the start of students' taking the wheel. The next two sections were the Many Interesting Talks. Together we enjoyed presentations on a diverse set of topics, from the mechanics of bubble tea to microelectromechanical systems (MEMS) to the mathematics of origami. On Friday, May 11, 2018, ES.S10: Many Interesting Things came to an end.

Chapter 7

Closing Feedback

At the start of the last class meeting on May 11, I had asked students to write about their experiences and their most valuable takeaways from ES.S10. Here are a few excerpts, one from each topic:

> "I had always been curious on how computers actually dealt with zeros and ones, and building up to a computer from scratch was a profound experience."

> "Learning how a camera works was very useful for my 12.409 class when we did astrophotography."

> "I really liked the spatial depiction of probability; it was very helpful in 6.036 to know about expected value."

> "Most interesting was quantum tunneling and how we store information in computers."

> "We did the double slit experiment later in 8.02 and this seminar helped me understand a lot."

> "I thought the guy who came in and shared his app was so cool."
>
> "Nice job in describing convolutional neural networks in a super accessible way. I had no idea it was so easy to do basic image manipulation in MATLAB!"
>
> "Really nice visuals of the universe in presentation."
>
> "I knew nothing about neural networks, but feel like I have a strong understanding of the concept now."

7.1 Reflection

Though I'm still awaiting the release of the MIT online course evaluations, these preliminary closing comments seem to be in a similar spirit to those from the fifth week. It was particularly striking to hear how students were already using what they had learned in ES.S10 in other classes, such as 8.02, 12.409, and 6.036! It lent credit to the notion that that list of classes will continue to grow as ES.S10's first students go on to their next three years at the Institute.

Chapter 8

Conclusion

In the final weeks of ES.S10, I was approached by Leigh Royden, director of ESG, with an offer to stay at MIT as an instructor and continue teaching Many Interesting Things as a freshman advising seminar. It is with great joy that I announce I've accepted this offer. Many Interesting Things is in many ways unique, but it is also in concert with the emergent MIT-wide initiative to improve the first-year experience, and I am thrilled to have the opportunity to continue this work.

In the past week, I've begun the design of a second ES.S10-like course that will introduce programming in the spirit of 6.0001/6.0002, but with project-based ties to more advanced Course VI classes such as 6.004, 6.009, 6.036, and 6.819. I've also met with Amitava "Babi" Mitra, executive director of the MIT New Engineering Educational Transformation (NEET), to discuss the niche of a class like Many Interesting Things. It is my hope that we will engage in fruitful collaborations as the next academic year dawns. In the months ahead, I would like to define a concrete set of intended learning outcomes (ILOs) for ES.S10 and develop a means of assessing them. Student comments formed a basis for measuring the class's success, and I would like to add to those measures. I also plan to design a set of optional homework assignments to accompany each topic of the class, allowing students to choose an additional way to interact with the material.

With all of this said, here ends the pilot term of ES.S10: Many Interesting Things. Thank you!

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Appendix A

Original Syllabus and Posters

v4

ES.S10: Many Interesting Things

Spring 2018

Fridays 3-5PM
24-621

Christian Cardozo
cica@mit.edu

Motivation:

There is a surprising amount of *context* for the things we learn in our first year at the Institute. However, sometimes, when we go on to take the classes that *reveal* that context to us, the pressures of their deadlines, exams, and psets can get in the way of our qualitative understanding and appreciation of their material. Have you ever found yourself thinking more about deadlines than actual ideas? You're not alone! Such is the genesis of Many Interesting Things: a "sneak peek" of some of the interesting classes at MIT without the pressure of actually being in them—learning for learning's sake.
No prereqs, no psets, no pressure.

The Interesting Things (in order of appearance):

1. Computer Architecture
2. Strobe Photography
3. Probability
4. Quantum Computation
5. Cosmology
6. Machine Learning
7. Computer Vision
8. Relativity

Many Interesting Talks:

By no means is our list of Interesting Things all-encompassing! Our last class in May will feature a series of 5-minute, TED-style talks, an opportunity for *you* to add to the experience with topics *you've* found interesting anywhere—in classes, out of classes, on Wikipedia, et cetera!

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Office hours:

“Formally ordained” office hours to be arranged. That said, I tend to be around!

Tentative calendar:

This is a tentative, and very flexible, calendar. We will proceed with freedom to make it our own in the weeks ahead.

#	*Date*	*Interesting Thing*	*Course*
1	2/9	Computer Architecture—Part I	6.004
2	2/16	Computer Architecture—Part II	6.004
3	2/23	Strobe Photography	6.163
4	3/2	Probability	6.041/18.600
5	3/9	Quantum Computation—Part I	8.04
6	3/16	Quantum Computation—Part II	8.411
7	3/23	Cosmology	8.942
8	4/6	Machine Learning—Part I	6.036
9	4/13	Machine Learning—Part II	6.036
10	4/20	Computer Vision	6.819
11	4/27	Relativity—Part I	8.033
12	5/4	Relativity—Part II	8.033
13	5/11	Many Interesting Talks and Conclusion	

“You are a wonderful creation. You know more than you think you know, just as you know less than you want to know.” —*Oscar Wilde*

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Passing ES.S10:

To pass Many Interesting Things, you should have no more than *two* unexcused absences, and deliver a talk as part of Many Interesting Talks.

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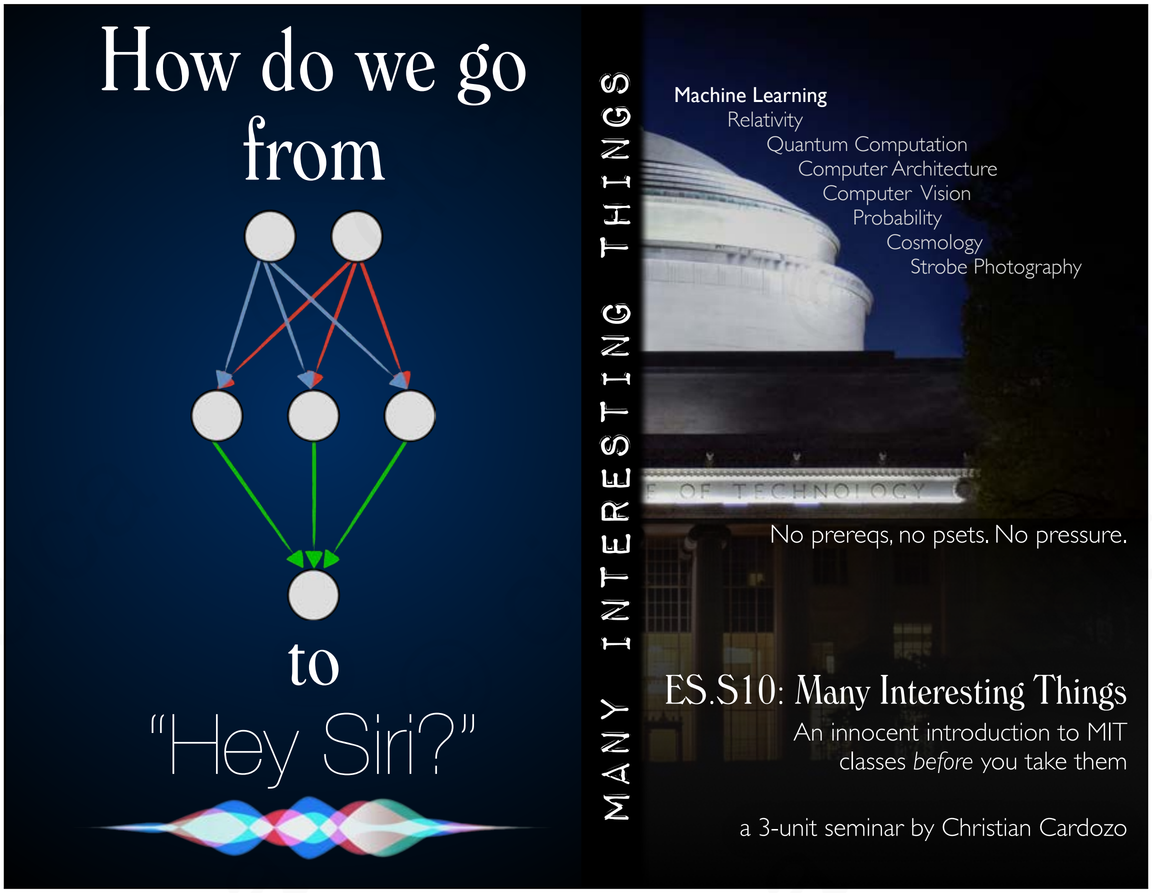


How do we go from

to

“Hey Siri?”

MANY INTERESTING THINGS

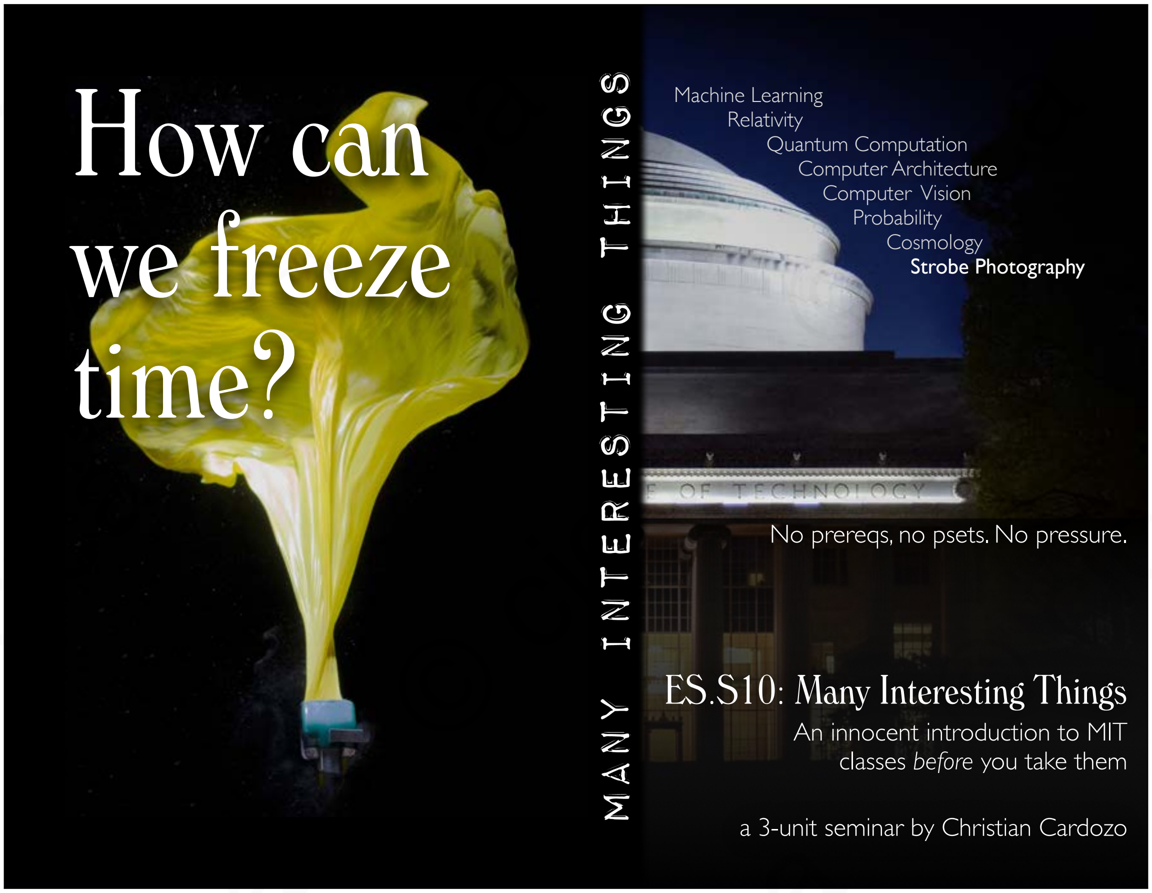
Machine Learning
Relativity
Quantum Computation
Computer Architecture
Computer Vision
Probability
Cosmology
Strobe Photography

No prereqs, no psets. No pressure.

ES.S10: Many Interesting Things

An innocent introduction to MIT classes *before* you take them

a 3-unit seminar by Christian Cardozo



How can we freeze time?

MANY INTERESTING THINGS

Machine Learning
Relativity
Quantum Computation
Computer Architecture
Computer Vision
Probability
Cosmology
Strobe Photography

No prereqs, no psets. No pressure.

ES.S10: Many Interesting Things

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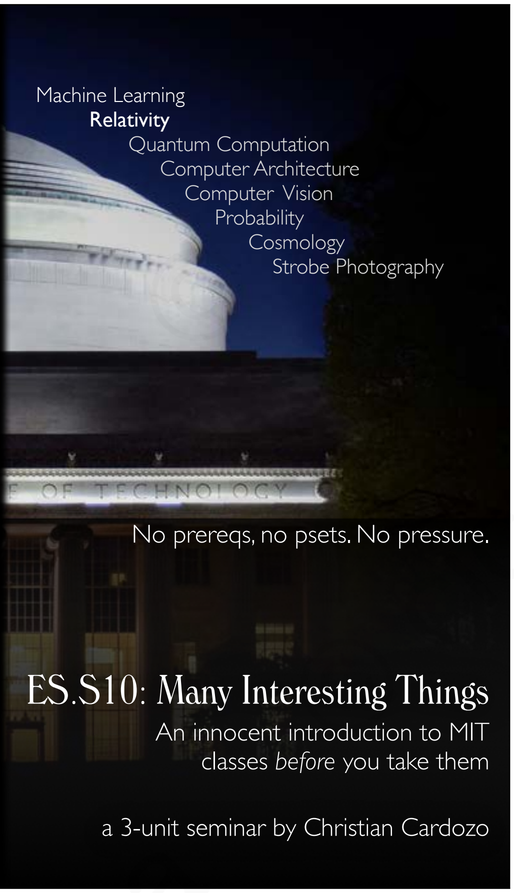
Discover the universe's

MANY INTERESTING THINGS



Machine Learning

Relativity

Quantum Computation

Computer Architecture

Computer Vision

Probability

Cosmology

Strobe Photography

No prereqs, no psets. No pressure.

ES.S10: Many Interesting Things

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Appendix B

Fifth-week Feedback Forms

ESG Fifth Week Feedback: Instructors

Subject number (e.g. ES.1801, ES.802, etc.)	ES.S10						
Instructor name	Christian						
Your first and last name (optional)							
How clearly does your instructor explain new material? (1=not at all clearly, 7=extremely clearly)	1	2	3	4	5	6	7
							7
Do you have any specific feedback on the clarity and organization of the presentation (oral, board work, use of multimedia)?	The expeiments are extremely helpful, and he takes his time putting conceps into the way people normally think						
The pace of the class is… (1=too slow, 4=just right, 7=too fast)	1	2	3	4	5	6	7
				4			
Average hours spent per week on this subject outside of the classroom	0						
On a scale from 1 to 7, how would you rate your instructor? (1=terrible, 7=fabulous)	1	2	3	4	5	6	7
							7
Do you have any overall comments? (e.g. strengths, areas for improvement, class format, problem sets, tests, schedule, etc.)	I wish more classes at MIT were like this... I've learned more in this class than many of my GIRs						

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ESG Fifth Week Feedback: Instructors

Subject number (e.g. ES.1801, ES.802, etc.)	ES.S10						
Instructor name	Christian						
Your first and last name (optional)							
How clearly does your instructor explain new material? (1=not at all clearly, 7=extremely clearly)	1	2	3	4	5	6	7
							✓
Do you have any specific feedback on the clarity and organization of the presentation (oral, board work, use of multimedia)?	Awesome combo of slides and board. Love the animations						
The pace of the class is… (1=too slow, 4=just right, 7=too fast)	1	2	3	4	5	6	7
				✓			
Average hours spent per week on this subject outside of the classroom	0 ? Except sharing videos with friends						
On a scale from 1 to 7, how would you rate your instructor? (1=terrible, 7=fabulous)	1	2	3	4	5	6	7
							✓
Do you have any overall comments? (e.g. strengths, areas for improvement, class format, problem sets, tests, schedule, etc.)	Love the passion. Might be helpful of there's reading informally assigned as previews of each class, so don't feel so clueless in the beginning But the class is exciting as it is right now.						

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ESG Fifth Week Feedback: Instructors

Subject number (e.g. ES.1801, ES.802, etc.)	ES.510						
Instructor name	christian cordao						
Your first and last name (optional)	Linh Nguyen						
How clearly does your instructor explain new material? (1=not at all clearly, 7=extremely clearly)	1	2	3	4	5	6	7
							✓
Do you have any specific feedback on the clarity and organization of the presentation (oral, board work, use of multimedia)?	· The PPTs are so fun + well-designed + thought-out!						
The pace of the class is… (1=too slow, 4=just right, 7=too fast)	1	2	3	4	5	6	7
					✓		
Average hours spent per week on this subject outside of the classroom	0						
On a scale from 1 to 7, how would you rate your instructor? (1=terrible, 7=fabulous)	1	2	3	4	5	6	7
							✓
Do you have any overall comments? (e.g. strengths, areas for improvement, class format, problem sets, tests, schedule, etc.)	· I love the open, discussion style environment · maybe more discussions w/ peers in small groups so we get to know each other better						

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ESG Fifth Week Feedback: Instructors

Subject number (e.g. ES.1801, ES.802, etc.)	ES.510						
Instructor name	Christian Cardozo						
Your first and last name (optional)							
How clearly does your instructor explain new material? (1=not at all clearly, 7=extremely clearly)	1	2	3	4	5	6	[✓ 7]
							X
Do you have any specific feedback on the clarity and organization of the presentation (oral, board work, use of multimedia)?	Keynote presentations have very good/ helpful animations that make ~~confusing~~ more difficult subject material easier to visualize (demonstrations, graphs, etc.)						
The pace of the class is… (1=too slow, 4=just right, 7=too fast)	1	2	3	4	5	6	7
				X			
Average hours spent per week on this subject outside of the classroom	0 (no psets, no pressure)						
On a scale from 1 to 7, how would you rate your instructor? (1=terrible, 7=fabulous)	1	2	3	4	5	6	7
							X
Do you have any overall comments? (e.g. strengths, areas for improvement, class format, problem sets, tests, schedule, etc.)	This isn't a criticism of the class, but more of an observation - ~~it would be really~~ this class is so much fun that I'd be okay with having psets (in maybe a different iteration of the class) to help retain some of the information that I get during class. Obviously this would involve a redefinition of the class itself, but if Christian wanted to teach this with more units and a bit more rigorously, I think he definitely could.						

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ESG Fifth Week Feedback: Instructors

Subject number (e.g. ES.1801, ES.802, etc.)	ES.S10						
Instructor name	Christian Cardozo						
Your first and last name (optional)							
How clearly does your instructor explain new material? (1=not at all clearly, 7=extremely clearly)	1	2	3	4	5	6	7
							✓
Do you have any specific feedback on the clarity and organization of the presentation (oral, board work, use of multimedia)?	I love the presentation slides. They are dynamic and clear (not overload with information).						
The pace of the class is… (1=too slow, 4=just right, 7=too fast)	1	2	3	4	5	6	7
				✓			
Average hours spent per week on this subject outside of the classroom	1						
On a scale from 1 to 7, how would you rate your instructor? (1=terrible, 7=fabulous)	1	2	3	4	5	6	7
							✓
Do you have any overall comments? (e.g. strengths, areas for improvement, class format, problem sets, tests, schedule, etc.)	I love seeing how passionate my instructor is about what he does. It's very inspiring and gives me hope that I can find my way beyond this class.						

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ESG Fifth Week Feedback: Instructors

Subject number (e.g. ES.1801, ES.802, etc.)	ES.S10						
Instructor name	Christian Cardozo						
Your first and last name (optional)							
How clearly does your instructor explain new material? (1=not at all clearly, 7=extremely clearly)	1	2	3	4	5	6	7
						✓	
Do you have any specific feedback on the clarity and organization of the presentation (oral, board work, use of multimedia)?	Great powerpoints Good use of the board Cool demonstrations						
The pace of the class is… (1=too slow, 4=just right, 7=too fast)	1	2	3	4	5	6	7
		✓					
Average hours spent per week on this subject outside of the classroom	0						
On a scale from 1 to 7, how would you rate your instructor? (1=terrible, 7=fabulous)	1	2	3	4	5	6	7
							✓
Do you have any overall comments? (e.g. strengths, areas for improvement, class format, problem sets, tests, schedule, etc.)	I would like supplemental materials for additional learning about the topics presented in class. I know there's no psets, but maybe optional readings would be good.						

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ESG Fifth Week Feedback: Instructors

Subject number (e.g. ES.1801, ES.802, etc.)	ES.S10						
Instructor name	Christian Cardozo						
Your first and last name (optional)	Rolando Rodarte						
How clearly does your instructor explain new material? (1=not at all clearly, 7=extremely clearly)	1	2	3	4	5	6	7
							✓
Do you have any specific feedback on the clarity and organization of the presentation (oral, board work, use of multimedia)?	The use of interactive videos and presentation really helps me learn the material						
The pace of the class is… (1=too slow, 4=just right, 7=too fast)	1	2	3	4	5	6	7
				✓			
Average hours spent per week on this subject outside of the classroom	1 (doing research about topics)						
On a scale from 1 to 7, how would you rate your instructor? (1=terrible, 7=fabulous)	1	2	3	4	5	6	7
							✓
Do you have any overall comments? (e.g. strengths, areas for improvement, class format, problem sets, tests, schedule, etc.)	Excellent class, not having to worry about psets and midterms helps me learn the material better because I am relaxed						

ESG Fifth Week Feedback: Instructors

Subject number (e.g. ES.1801, ES.802, etc.)	ES.S10						
Instructor name	Christian						
Your first and last name (optional)							
How clearly does your instructor explain new material? (1=not at all clearly, 7=extremely clearly)	1	2	3	4	5	6	7
							✓
Do you have any specific feedback on the clarity and organization of the presentation (oral, board work, use of multimedia)?	the slides are well made						
The pace of the class is… (1=too slow, 4=just right, 7=too fast)	1	2	3	4	5	6	7
			✓				
Average hours spent per week on this subject outside of the classroom	0						
On a scale from 1 to 7, how would you rate your instructor? (1=terrible, 7=fabulous)	1	2	3	4	5	6	7
							✓
Do you have any overall comments? (e.g. strengths, areas for improvement, class format, problem sets, tests, schedule, etc.)	very interesting, just as the name promised						

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ESG Fifth Week Feedback: Instructors

Subject number (e.g. ES.1801, ES.802, etc.)	ES. 510						
Instructor name	Christian						
Your first and last name (optional)	Sheila Kennedy-Moore						
How clearly does your instructor explain new material? (1=not at all clearly, 7=extremely clearly)	1	2	3	4	5	6	7
						✓	
Do you have any specific feedback on the clarity and organization of the presentation (oral, board work, use of multimedia)?	I like the demos						
The pace of the class is… (1=too slow, 4=just right, 7=too fast)	1	2	3	4	5	6	7
				✓			
Average hours spent per week on this subject outside of the classroom	0						
On a scale from 1 to 7, how would you rate your instructor? (1=terrible, 7=fabulous)	1	2	3	4	5	6	7
							✓
Do you have any overall comments? (e.g. strengths, areas for improvement, class format, problem sets, tests, schedule, etc.)	Overall This class has been interesting						

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ESG Fifth Week Feedback: Instructors

Subject number (e.g. ES.1801, ES.802, etc.)	ES. S10 (M.I.T)						
Instructor name	Christian						
Your first and last name (optional)	Sheila						
How clearly does your instructor explain new material? (1=not at all clearly, 7=extremely clearly)	1	2	3	4	5	6	7
							×
Do you have any specific feedback on the clarity and organization of the presentation (oral, board work, use of multimedia)?	- Great organization, use of media (I wonder how long it takes Christian to come up w/ the slides), always engaging, hands-on component is refreshing.						
The pace of the class is… (1=too slow, 4=just right, 7=too fast)	1	2	3	4	5	6	7
							×
Average hours spent per week on this subject outside of the classroom	2						
On a scale from 1 to 7, how would you rate your instructor? (1=terrible, 7=fabulous)	1	2	3	4	5	6	7
							×
Do you have any overall comments? (e.g. strengths, areas for improvement, class format, problem sets, tests, schedule, etc.)	Every minute spent in this class - is worth it! - There is always something new to learn in this class -						

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ESG Fifth Week Feedback: Instructors

<table>
<tr><td>Subject number (e.g. ES.1801, ES.802, etc.)</td><td colspan="7">ES.S10</td></tr>
<tr><td>Instructor name</td><td colspan="7">Christian Cardozo</td></tr>
<tr><td>Your first and last name (optional)</td><td colspan="7"></td></tr>
<tr><td rowspan="2">How clearly does your instructor explain new material? (1=not at all clearly, 7=extremely clearly)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>✓</td><td></td></tr>
<tr><td>Do you have any specific feedback on the clarity and organization of the presentation (oral, board work, use of multimedia)?</td><td colspan="7"></td></tr>
<tr><td rowspan="2">The pace of the class is… (1=too slow, 4=just right, 7=too fast)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td></td><td></td><td></td><td>✓</td><td></td><td></td><td></td></tr>
<tr><td>Average hours spent per week on this subject outside of the classroom</td><td colspan="7">0 – 1</td></tr>
<tr><td rowspan="2">On a scale from 1 to 7, how would you rate your instructor? (1=terrible, 7=fabulous)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td>✓</td></tr>
<tr><td>Do you have any overall comments? (e.g. strengths, areas for improvement, class format, problem sets, tests, schedule, etc.)</td><td colspan="7"></td></tr>
</table>

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ESG Fifth Week Feedback: Instructors

Subject number (e.g. ES.1801, ES.802, etc.)	ES.510						
Instructor name	Christian						
Your first and last name (optional)							
How clearly does your instructor explain new material? (1=not at all clearly, 7=extremely clearly)	1	2	3	4	5	6	7
							7
Do you have any specific feedback on the clarity and organization of the presentation (oral, board work, use of multimedia)?	love the presentation and delivery						
The pace of the class is… (1=too slow, 4=just right, 7=too fast)	1	2	3	4	5	6	7
				✓			
Average hours spent per week on this subject outside of the classroom	0 ?						
On a scale from 1 to 7, how would you rate your instructor? (1=terrible, 7=fabulous)	1	2	3	4	5	6	7
							7
Do you have any overall comments? (e.g. strengths, areas for improvement, class format, problem sets, tests, schedule, etc.)	enjoy the material, could we do more over film and see real world projects involving and implementing what we learn in class ☺						

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Appendix C

Final Feedback Forms

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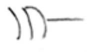
Computer architecture

baby → coding doesn't have to be complicated
if, when . . .

circuits and /or gates
if remember what we did on our computers the most



Strobe photography

exposure, how open the lens is, changing variables affects ~~to~~ how much information we capture
↳ how long you open the lens → how much light comes in

I remember using the camera. It was interesting to see the strobe lab

Probability

Gaussian ; I remember the funny conditions ~~[illegible]~~/senarios we had, how events over lap

Quantum Mechanics / computation

- I remember the double slit experiment
- the water wave demonstration
- complex equation, probability distribution
- quantum tunneling and how we store information in computers, how long this lasts /how this can be improve most interesting

Machine Learning

- neural ~~net~~ networks, looking at how they can learn with the website
- student who came in and showed us his app
- it was interesting to see how adding more layers and filters altered performance.

Computer vision

I liked how you tied it back to the Gaussian filter and earlier lessons about the sort of grid of light values that make up an image.

I remember most the images of that were different depending on the distance viewed at

Cosmology -> absent

upon reflection, the most memorable part were the interactive parts, (actively coding etc) but the most interesting were the ideas that we discussed – the ideas that were complex ~~that~~ I could understand to a degree because of the lessons you gave.

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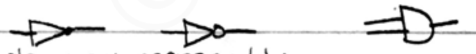
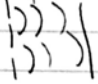
neural network

Computer Architecture I:
- most memorable:  (n/or)
  - the baby was also very memorable
  - seeing what was underneath computer

Strobe Photography:
- most memorable: the pictures we took of water balloon/ being in the cool photo lab and getting to take cool strobe photos ourselves

Probability
- seeing all the computation that goes behind probabilites
- understanding type of problems to approach w/ probability
- program that showed probability graph

Quantum Mechanics/Computation
- quantum mechanics w/ doing the experiment in the room. the partition across the room + we all threw balls + saw how uncommon it was to go through, then when we had the high tech machine and saw the dual properties of light in person



↳ we did this later in 8.02 as experiment and this seminar helped me understand a lot

Machine Learning
- Neural Networks!
- I thought the guy who came and shared his app was so cool
- Knew nothing about neural networks but feel like I have strong understanding of concept now

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Computer Vision
- missed this class

Cosmology
- Universe
- Your video you made as a freshman? at MIT

Many Interesting Talks I:
- Bubble Tea! went to one of the places that was recommended + it was delicious

Computer Architecture

Memorable – The Portugese baby!

Takeaway – The pathway from logic gates all the way up to a full computer/CPU

logic gates ⇒ transistors (each input(s) → binary output!)

Strobe Photography (N/A, not present)

Probability

memorable – something about Sabrina failing her exam??

– The 3D printed demo (balls falling through pegs)

Takeaway – Physical Demonstration of ~~probabi~~ normal distribution! – testing actual cases.

Quantum Mechanics

memorable – Electron tunnelling!! when they go through walls (with 10% chance)

– The balls / life size double slit experiment

takeaway – Electrons + quantum particles act in really interesting ways + modeling is complicated(?)

Quantum Computation (not present)

Machine learning / ~~Computer Vision~~ Computer Vision

memorable – The website that could do rapid simulations, identifying patterns

– Amazon mechanical Turk!

takeaways – Training sets to neural networks teach + create "filters" that process information in a way different from human brains

– The ~~teaching level~~ training rate(?) (?) affects how successful ~~a~~ training can be – can cause over correcting or taking really long to adapt.

Cosmology

- The universe is really big. → that to scale website of the universe / solar system
- Doppler effect, red shift
- Telescopes?

memorable takeaways

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Many Interesting Things - Most memorable moment
- Key Takeaways to remember - What did you do, post-class?

① Computer Architecture.

→ [illegible]

Key Takeaway

→ Working on transistors → I had ~~not thought of~~ had always been curious on how computers actually deal w/ the "0s and 1s" → and building up the computer from scratch (w/ the actual gates) was a profound experience and made me appreciate the computer I have.

"The humble transistor"

~~Key takeaway → computers base decision~~

M^3 → ~~Portuguese Bar~~ | Building a computer from scratch → working on the [illegible]. example - Circuitboard online and trying to match it up to the

[illegible] portuguese baby

② Strobe photography

- $\boxed{M^3}$. Popping balloons in the Strobe lab, dropping objects in front of very bright lights.

Key Takeaways → learning how a camera works - from the photons hitting the sensors to aperture and ISO → this was very useful for my 12.409 class when we took astron[illegible]-photography. [finally, how to use a camera that isn't my phone!)

③ Probability

$\boxed{M^3}$ → The playing card trick → I still have that King of hearts pinned in my dorm room.

Key Takeaways Gens converge over many, many trials → flipping coins digitally thousands of times.

④ Quantum mechanics

$\boxed{M^3}$ → throwing balls through the double slit experiment, Also deriving some of the wave equations, looking at a "wave" simulation -

Key Takeaways → going over the particle-wave duality of a particle,

⑤ Quantum computing → I wasn't here for this class (null).

⑥ Machine Learning

M³ looking at how Amazon reviews can be broken down into their word components and arranged in a matrix for evaluation, creating neural nets with many, many layers

Key Takeaway Machine Learning relies extensively on matrices and identifying whether a new piece of information lies w/in a certain category based on past data → neural nets are comprised of different layers with weights associated w/ each neuron, ~~[illegible]~~

~~Probability~~

↖ new ways of organizing data so that they are separable

⑦ Computer Vision

M³ handwriting recognition, working w/ the online computer vision program that worked w/ spirals → actually seeing the layers
→ looking at an image as a matrix of pixels w/ values.

Key Takeaway Computer Vision breaks things apart into components of different characteristics (such as gradients, curves) → and can detect edges.

⑧ Cosmology

M³ watching that video Christian made ~~[illegible]~~ his freshman year

Key Takeaway We are very small in this universe.

Most memorable moment		Key takeaways / What did you find most interesting
1. computer 2. Architecture	We got to play with the software that 6.004 uses and arranging NAND Gates are fun	Information can be found everywhere. computer is just a machine of digitalized information
3. Strobe Photography	The ballon picture was cool	photography is about art & science !
4. Probability* 5.	A lot of formulas. A lot of applications.	Probability is what connects math and the real world together
6. Quantum 7. Stuff	Reminds me of the first month of 5.111.	Quantum stuff gives people a new perspective of looking at everything.
8. Machine Learning. 9.	Machine learning has a lot of linear algebra in it.	Machine learning is going to change people's life just like how computer science did

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10	Computer Vision	We analyzed Amazon comments	Computer Vision it's an application of Machine Learning that's used in image / video recognition
11.	Cosmology	Christian's video from freshman year	The universe still has a lot to be explored

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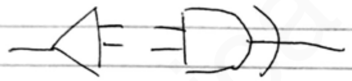
① Most memorable moment
② Key takeaways / what I found interesting

1. Computer Architecture
② Gates

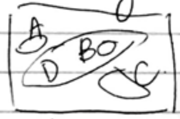


① Website where we simulated how to put together the gates.

② Python - while, for, if loop

2. Strobe Photography
① Drop the balloon!! Pop pop pop
② How filter works as a matrix that is covered ~~by~~ on each pixel of the picture
② Did not know how the light and sound triggers the camera
② Exposure, shutter speed

3. Probability
①



Different universe

② and, or statements translate to symbols
- $A \cup B$, $A \cap B$

4. Quantum Mechanics & Computation
① Double slit experiment ② Magnus' projects
② Probability density, indeterministic nature

5. Machine Learning & Computer Vision
① Christian's project of face recognition ② MATLAB!
② Training neural networks to identify things, recognize faces...

6. Cosmology

① Christian's young documentary celeb photo

② We see things not in its present state due to the time it takes for light to travel from objects far away to our eyes

② Website where we scroll through items of various sizes & scale

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