Commencement address to the Department of Mathematics at the University of Illinois at Urbana-Champaign

Remarks by Nigel Goldenfeld, May 11 2008

Professor Katz, members of the mathematics department faculty, Class of 2008, family members and guests:

Happy Mothers Day: We can never say thank you enough. Why don't we take a moment to show our appreciation to our Mothers, without whom none of us would be here today. OK, thank you.

A couple of weeks ago, your Department Head, Sheldon Katz, asked me if I would deliver the Commencement Address to the Mathematics Department. My first reaction was to try and find a tactful reason to refuse. "But I'm not even a mathematician", I protested, "I'm a physicist!". Never mind, he responded: we like to get an interdisciplinary flavor for our Commencement Speeches. Now, I should point out that Sheldon has a third time appointment in the Physics Department --- to those of you who have your calculators out and never got beyond fractions that's 33.3333333 percent. And so I shrugged my shoulders resignedly, at least as best as one can do while sending an email, and accepted. I thought that maybe it was part of some grand plan to have Physics stage what the CIA likes to call a "Palace Coup" and take over Mathematics. But that didn't really make much sense. After all, why bother? We already stole the Crown Jewels, when a card-carrying Physicist --- Edward Witten at Princeton's Institute for Advanced Study --- won the 1990 Fields Medal, which is generally regarded as the closest thing to a Nobel Prize in Mathematics.

So --- why me? And then I had it: Sheldon had diagnosed me as having a severe case of what Sigmund Freud would have called "Math Envy". After all, when I was a student at Cambridge --- the "real" Cambridge, I might add --- I formally registered in Natural Sciences, but actually took many courses in Mathematics. I always had the sneaking suspicion that mathematicians were smarter than physicists, and sitting in the back of the class rooms in the Art School where the maths lectures were held, I became convinced of it. When I've had occasion to walk through Altgeld Hall, here at U of I, I've occasionally peaked in through the door to watch your classes: you all seemed very diligent to me, listening carefully, and presumably even taking notes of what the lecturer was presenting. In Cambridge in the 1970's, nothing could have been further from the truth: the students would lounge around indolently, reading the newspaper impudently, chatting and even grooming themselves. Now to a Cambridge mathematician of that era, grooming oneself meant basically arranging one's hair to have the highest possible fractal dimension, eating candy, which with the graceful habits of mathematics students means smearing the remains of a chocolate bar over one's jeans, and --- how shall I put this in polite company --- exhibiting inordinate interest in the contents of one's nasal cavities. Despite this

ostentatious show of indifference to the educational mission of Cambridge University, these students performed brilliantly on the notoriously difficult examinations, and many went on to have stellar careers in both academia and the real world. The most distinguished of my cohort, by the way, was Simon Donaldson, with whom I attended lectures on the mathematics of Einstein's general theory of relativity. Simon went on to win the Fields Medal and also the Crafoord Prize, which is awarded by the Royal Swedish Academy of Sciences for research in areas that are not covered by the Nobel Prize. Interestingly, Simon's work explored the properties of surfaces in four dimensions by using equations that were first formulated by physicists to describe nuclear forces. All of which is a very roundabout way of saying that there are very close ties between physics and mathematics --- it's not just that both fields involve arcane algebra and symbolic logic. Somehow, the structures of mathematics find their natural expression in physics, and *vice versa*. And so, that's one reason why I am here addressing you today. There are others, which I will get to later.

Well, you didn't come here to hear a post-graduation lecture on the profundities of mathematics; you've all earned your degree, and the only "after-sales" service that you should expect from the University of Illinois is the polite but persistent reminder from the Alumni Association of the importance of making gifts to the University, when you become rich and famous. Which I am sure many of you will become. You see, I think --- I hope --- that you are all going to be wonderfully and spectacularly successful in your lives. And that brings me to what I really want to talk to you about today ...

Superheroes! Look outside. It's warm-ish. Sunny. Time for summer. And that means T-shirts, shorts and sandals; beer on the back porch; barbecues; and of course that staple of the American summer experience: the blockbuster movie. Anyone here been to see "Ironman"? Fantastic, isn't it? Great story, great acting, brilliant special effects, and the hero is a geek who got his degree in engineering from MIT at the age of 17. Too bad that he became a weapons designer, but halfway through the movie he turns into a good guy. Superheroes are part and parcel of the American mythology and experience. And (as they say) now, more than ever, we need superheroes if we are to face the challenges of the 21st century! But not just any superheroes, with bulging muscles, testosterone-powered egos and exotic genetic defects. What we need is a new breed of superhero, one more at home with a pen than a sword, with smarts, passion and a sense of justice. A superhero with a brain. And I think that if you rise to the challenge, as I hope some of you will, we'll look back with pride, not just on the athletic feats of the Fighting IIlini, but on the achievements of you young people, mathematicians, but athletes in your own way. A group that we might perhaps call the Thinking Illini.

So, I want to tell you some stories: some Amazing Stories if you will. Stories that really defy comprehension, because they sound so improbably apocalyptic ... yet they are happening right now. These are stories about catastrophic events that were avoidable, but they happened anyway, because someone didn't do the math.

And listen up --- because this is important: this is your homework assignment for extra credit, this is where many of you will one day find yourselves in a position to make a difference, because you will be able to do the math. In your own lives in your own ways, big and small, you'll have opportunities to do the math, however simple, and make better judgments than others might. It's your sacred responsibility, and it's one way that you can make the world better.

Here's my first story, and it's one of the reasons why I am an appropriate person to be addressing you today. It's about (yawn) sub-prime mortgages, of all things. So I'm sure you've heard that the world's economy is going down the tubes, that we're in a recession, and that it's a tough job market out there for people like, well, you. If you've been too plugged into Facebook, MySpace and YouTube to notice, just ask your parents. The culprit is the sub-prime mortgage meltdown, banks lending your money to people who bought houses they couldn't afford, and now can't pay back their loans. Boring grown-up stuff, right? Wrong! This is all about probability theory and statistics; and if there is one thing that this department is well-known for, it's probability and statistics. Here's how the world's most highly-paid bankers, government officials and hedge-fund managers missed some elementary mathematical statistics, and lost hundreds of billions of dollars as a result.

My story starts nearly 20 years ago, when my first Ph.D graduate student, culminated a very successful research career at the University of Illinois, the University of Chicago and the University of California by accepting his first job: not as a professor of theoretical physics, but as a quantitative analyst at the premier investment bank, Goldman Sachs. What had I taught him that made him so valuable to an investment bank?, I asked him. Well, he said, first and foremost, was the ability to explain very complex and technical topics in a simple and concise way. But what really got him the job was his knowledge of computer simulation using Monte Carlo methods and techniques to solve singular differential equations. His job was to compute the price and assess the risk of so-called derivative securities, such as stock options, that are basically very complicated legal contracts whose value derives from something that can be measured or traded, like a stock, or the weather in Brazil.

As I started to learn about all this, I quickly realized that the financial economists hadn't a clue about how to solve their equations, and so I started a software company to make products that would help banks, hedge funds, pension funds, University endowment funds etc. to accurately price these financial instruments, to be able to trade them correctly and to figure out their risk using probability theory. The mathematical challenge was fun: how to quickly do integrals of singular functions in thousand-dimensional spaces? We met the challenge, and the company still exists today and is doing quite nicely, thank you. However, the more I looked into it, the more I realized that what I was doing was helping people get the wrong answer faster! You see, not only did the financial economists not know how to solve their equations, they also didn't know how to write them down properly in the first place! They assumed that all the statistics

of stock market fluctuations were governed by what you and I would call Normal statistics, described by Gaussian probability distributions. But when you look at the real world data, you find that it is basically not true, at least when you look out to the tails of the distribution describing rare events. These rare events are the famous stock market crashes, like the dot-com crash, the Asian market crash, the Russian default. The sort of disaster that should occur once in a hundred years --- but which happens every 5 years or so. I started putting articles about this on our company's web site, but the sales people eventually asked me to stop. The reason: telling Wall Street that its market models were all wrong was bad for business.

So what was Wall St. doing wrong? They use a statistic called "value-at-risk", which basically answers the question "how much could the bank lose 99 out of every hundred days?". Sounds reasonable, doesn't it? But the problem is that it does not say what happens on the other day, the day that's one-in-a-hundred. Not only does it not tell you what happens then, it basically assumes the risk is zero on that day. But in fact, it's the one-in-a-hundred days when all the action takes place. The real answer was: the risk is infinite, but Wall Street calculated zero. Zero is not equal to infinity (unless you are a physicist doing renormalization group theory!). Wall Street gave itself a false sense of security by making a parachute that opens all the time, except when you are falling out of an airplane.

So, there we have it: a global financial disaster, affecting the lives of many hundreds of millions of people, that could have been averted by a superhero trained as you have been. Yes, Wall St has mathematical geniuses working for it; but mostly they don't manage the money or make the important decisions. Some of you, I hope, will go out into the real world, and one day attain positions of influence. When you do, I urge you to remember what you learned here at the University of Illinois, and, please, <u>do the math</u>.

My second story is much shorter, and I don't know the ending yet. No one does. It's about something else that is super. But not super-good. Super-bad. The enemy is invisible and inside everyone of you right now. The enemy is "superbugs": bacteria that kill but can't be killed. Superheroes, if you will, of the microbial world. These superbugs are immune to antibiotics, those wonder drugs that turned strep throat from a fatal illness into a mild inconvenience, and nearly banished tuberculosis from the world. About 60 years ago or so, we started war on microbes with the widespread use of penicillin, followed by many other antibiotics of varying strengths and capabilities. Today, at the dawn of the 21st century, we know how this war turned out. We lost. Like the Martians in H.G. Wells' famous science-fiction story "The War of the Worlds", we were beaten by microorganisms.

And how exactly did we lose the war against microbes? Not inadequate knowledge of biochemistry. Not inadequate knowledge of epidemiology. No --- it was not <u>doing the math</u>. Here's the problem. Back in the 1940's, people knew

that microbes would respond to antibiotics by evolving resistance, and they assumed that this would take millions of years. After all, evolutionary time scales are always millions of years, right? Wrong! In the early 1950's, it was discovered that microbes have the ability to swap their genes, kind of like trading the music on your iPod over the internet to your friends. Microbes swap genes of all sorts, including those that confer resistance to antibiotics. This process short-circuits the usual mechanism of Darwinian evolution, and along with the massive overdosing of the planet with antibiotics, for example by putting them in our food supply, has led to the widespread evolution of antibiotic resistant bacteria, not in millions of years, but in only a few decades.

That's an appalling mathematical error, and is causing a massive health care crisis which is only going to get worse in your lifetime. Evolution matters, and so does doing the math. Even today, as far as I know, no one can properly do the calculation for how the microbial world responds to antibiotics, and figure out how we made an error of 6 orders of magnitude in the speed of evolution. Even worse --- how do we get out of this fix? What is the right way to slow this down? How can we avoid it happening again? And how should we treat bacterial infections in the 21st century? No one really knows. Maybe one of you, the Thinking Illini, will do the math.

I want to end by bringing the strands of this talk together to give you some parting advice. First, and perhaps mainly to those of you who will go on into research. You've all heard of the expression "Pure Mathematics", right? The abstruse intellectual constructs that are some of the highest achievements of the human mind, along with the music of Beethoven, Mozart and Chopin, for example. Some of you received degrees today in pure mathematics. Well, I have some news for you --- it probably doesn't really exist. I'll stick my neck out and make a bold claim: there is probably no mathematics that can't be used to describe the physical or perhaps the biological world. Edward Witten and my classmate Simon Donaldson taught us that physics can be used to reveal mathematical truth. And time and time again, we have seen abstract mathematical concepts finding their home in science: from Riemann's differential geometry that formed the basis for Einstein's general theory of relativity to the exciting possible application of braid groups to design quantum computers based upon the fractional quantum hall effect.

Godfrey Harold Hardy, one of the most famous pure mathematicians of the 20th century, famously wrote:

> "*I have never done anything 'useful'. No discovery of mine has made, or is likely to make, directly or indirectly, for good or ill, the least difference to the amenity of the world.*"

But his name is irrevocably linked with a fundamental and exceedingly useful result in population genetics, the so-called Hardy-Weinberg principle. And his work on abstract number theory has recently found application in nuclear physics

and in describing the thermodynamics of ultra-cold atoms forming the weird state of matter known as Bose-Einstein condensation. For every mathematical construct that can exist, there is a realization of that somewhere in the physical universe. It is the job of scientists, like me, and perhaps some of you, to find those realizations. The only meaningful distinction between styles of mathematics is Applied Mathematics, and Mathematics that has yet to be applied.

Now, some advice. Take a look at me, in these fine robes; take a look at your neighbour, or your son or daughter, sister or brother. Take a look at yourself. Don't we look splendid? Don't we look like "Caped crusaders", don't we look like Superheroes? Well, we do ... but don't wear these robes to work! You'll look like a complete bozo!

Thinking Illini: I salute you and your accomplishments: those that brought you here today, and those that you will make in the years ahead. I bid you farewell from this Garden of Eden, the groves of Academe. Go forth into the world and have brilliant, wonderful and happy lives.

And please, if you only remember one thing about this day, let it be this: there are three sorts of mathematicians: those who can count and those who can't.

Be one of those who counts! Do the Math! And be Super!