“So long, and thanks for the Ph.D.!”

a.k.a.

“Everything I wanted to know about C.S. graduate school at the beginning but didn’t learn until later.”

The 4th guide in the Hitchhiker’s guide trilogy (and if that doesn’t make sense, you obviously have not read Douglas Adams)

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TL;DR (Executive Summary)

A computer science graduate school survival guide, intended for prospective or novice graduate students. This guide describes what I wish I had known at the start of graduate school but had to learn the hard way instead. It focuses on mental toughness and the skills a graduate student needs. The guide also discusses finding a job after completing the Ph.D. and points to many other related web pages.

- This guide covers the traits and skills that separate the star graduate students from the ordinary ones.
- If you don’t have a good reason for pursuing the Ph.D., then get a Master’s degree instead.
- A Ph.D. program is very different from getting a Bachelor’s degree, and you must treat it as a strange type of job. Initiative, tenacity, flexibility, interpersonal skills, organizational skills, and communication skills are all critical and not things that universities typically test for in selecting incoming students.
- A Ph.D. is a means to an end: employment in a startup, commercial business, government or industrial research lab, or academia. This guide explains the characteristics of these four career choices.
- If you spend 15 minutes reading the rest of this guide, you might increase your chances of successfully completing the Ph.D. and finishing earlier.

Introduction

“To know the road ahead, ask those coming back.”
- Chinese proverb

In February 1995, on a beautiful sunny day with clear Carolina blue skies, I turned in the final, signed copy of my dissertation. The graduate school staff member did some last-minute checks on the document and pronounced it acceptable. After six and a half years of toil and sweat, I was finally done!

While walking back to the C.S. department building, I was sorely disappointed that the heavens didn't part, with trumpet-playing angels descending to announce this monumental occasion. Upon hearing this observation, Dr. Fred Brooks (one of my committee members) commented, "And the sad fact is, you're no smarter today than you were yesterday." "That's true," I replied, "but the important thing is that I am smarter than I was six and a half years ago."

I wrote the first version of this guide two years after graduating, after reflecting upon my graduate student career. One thought that has repeatedly struck me is how much easier graduate school might have been if somehow, magically, some of the things I knew when I turned in my dissertation I could have known when I first entered graduate school. Instead, I had to learn those the hard way. Of course, for many topics this is impossible: the point of graduate school is to learn those by going through the experience. However, I believe other lessons can be taught ahead of time. Unfortunately, such guidance is rarely offered. While I had to learn everything the hard way, new graduate students might benefit from my experiences and what I learned. That is the purpose of this guide.

Very little of this guide discusses technical matters. Technical skills, intelligence and creativity are certainly strong factors for success in graduate school. For example, I doubt there is a C.S. graduate student who didn't at one point wish he or she had a stronger mathematical background. However, it's beyond the scope of this guide to tell you how to be technically brilliant, as the following joke implies:

> *The Feynman Problem Solving Algorithm*
> 1) Write down the problem.
> 2) Think very hard.
> 3) Write down the solution.

You don't have to be a genius to do well in graduate school. You must be reasonably intelligent, but after a certain point, I think other traits become more important in determining success.

This guide covers the character traits and social skills that often separate the "star" graduate students from the ordinary ones. Who are the students who are self-motivated, take initiative, find ways around obstacles, communicate well both orally and in writing, and get along well enough with their committee and other department members to marshal resources to their cause? Which students seem to know "how the system works" and manage to get things done? These traits are hardly unique to succeeding in graduate school; they are the same ones vital to success in academic or industrial careers, which is probably why many of the best graduate students that I knew were ones who had spent some time working before they came back to school.

This document is aimed at junior C.S. graduate students, but these observations are probably broad enough to apply to graduate education in other technical fields. My conclusions are certainly colored by my particular experiences (doing my dissertation work in interactive computer graphics in the Computer Science department of the University of North Carolina at Chapel Hill) but I think they are fairly general in application and should be of interest to readers at other schools and other C.S. specialties. Obviously, these are only my opinions and may not represent the views of other sane individuals or organizations. Some points may be controversial, but if they weren't this would not be interesting reading. Parts of this document come from two informal talks I gave at UNC about "the Ph.D. job hunt" and "observations from spending one year in industrial research." Both talks had larger audiences than any informal *technical* talk I gave at UNC, which told me that students are definitely interested in these subjects!

This guide does not discuss how to be accepted for admission into graduate school. I have never been a professor, so I do not have insights to share on how professors decide which students to admit. For

one professor's view, read Matt Might's advice on getting into graduate school.

Why get a Ph.D.?

"Being a graduate student is like becoming all of the Seven Dwarves. In the beginning, you're Dopey and Bashful. In the middle, you are usually sick (Sneezy), tired (Sleepy), and irritable (Grumpy). But at the end, they call you Doc, and then you're Happy."

- yours truly

The most basic question every Ph.D. student must know the answer to is: "Why the hell am I doing this?"

It's a good question. The hours are long. The pay is low, with minimal benefits. After graduation, Ph.D. salaries are higher than B.S. and M.S. salaries, but the difference doesn't make up for the income lost by staying in school longer. The M.S. has a better "bucks for the time invested" ratio than the Ph.D. does. And in terms of social status, a graduate student doesn't rank very high on the ladder.

If you do not have an acceptable answer to this question, then don't get a Ph.D. ***I repeat: if you do not have a rock-solid reason for getting the Ph.D., then it is better that you leave with a Master's.***

Why? Completing a Ph.D. is a long, hard road with many potholes and washed out bridges along the way. You may run over some land mines and have to stop and turn around and explore other routes. If the goal is important enough to you, then these obstacles will not prevent you from completing your journey. But if you don't know why you are on this road, then you will get discouraged and will probably leave without finishing, having wasted years of your life.

I faced this situation after the first time I took the Doctoral Written Exam (which at the time was the entrance examination into the Ph.D. program). I missed passing it by just 4 percentage points. I then had to decide whether or not to try again next semester (committing myself again to spending months getting ready for the test) or to just leave with an M.S. degree.

I didn't come to graduate school with the Ph.D. as the primary goal. So this test result forced me to answer the basic question "Why the hell am I doing this?" After much soul searching, I found my answer and decided to take the test again, passed it, and went on to get my Ph.D.

I got the Ph.D. because I wanted to get a research position after leaving graduate school. I wanted to work with the state of the art and extend it. I did not want to "bring yesterday's technology one step closer to tomorrow." I wanted a job that would I find interesting, challenging and stimulating. While an M.S. would give me a chance at landing a research position, the Ph.D. would give me a much better chance. And I did not want to live with regrets. If I took the Doctoral Written Exam again and failed again, then I could say that it wasn't meant to be and move on with my life. I would have no regrets because I had given it my best shot and was not able to make it. However, if I left with an M.S. without taking the test a second time, and five years later I was in a job that was boring and uninteresting, then I would have to lie awake every night for the rest of my life wondering "What if?" What if I had taken the test again and passed? Would I then be in the job that I really wanted? That was not a situation I wanted to be in. I did not want to live the rest of my life regretting what might have been.

In hindsight, I think one of the main reasons I successfully completed the Ph.D. was the fact that I *didn't* pass the exam on the first try. It's ironic, but life sometimes works in strange ways. That initial failure caused me to answer the basic question, providing the mental fortitude to keep going despite the hurdles and problems I would later face.

My answer is you should get a Ph.D. if it is required for your goals after graduate school, such as becoming a professor or a researcher in academia, government or industry. Your answer may differ from mine. As long as you have an answer that you believe in passionately, then that's enough. If you don't have an answer, then save yourself a lot of grief and don't get the Ph.D.

The best answer to this question I have ever seen comes from William Lipscomb, a Nobel Prize winner in chemistry. He said, *"With a Ph.D. you will have a better chance of spending the rest of your life doing what you want to do, instead of what someone else wants you to do."*

Tim Hopper created a site that interviews many people who provide their opinions about why someone should or should not pursue a Ph.D.

Academia is a business

"Remember the Golden Rule: Those who have the gold make the rules."

Academia is a business, and "graduate student" is a job title. This is especially true at private universities. Academia is very peculiar type of business. It is certainly not the Real World and does not work in the same way that the ordinary corporate world does. However, it is a business nonetheless and as a graduate student, you must treat it that way. Graduate school made a lot more sense and became much easier for me after I realized this. If you think of graduate school as an "Ivory Tower" free of politics, money problems, and real-world concerns, you are going to be severely disappointed. If you don't believe me, read *The Idea Factory* by Pepper White (listed in the references) for one account of graduate life at MIT.

A few graduate students are independently wealthy or have fellowship and scholarship money that cover all their expenses in graduate school. Such students are rare, however. Most of us needed financial support, in the form of Teaching Assistantships or Research Assistantships (RA's). In general, RA's are more desirable to students since those can directly fund the research you need to finish.

Where does the money come from to fund RA's? Your professors have to raise funds from external organizations. These include government agencies such as the National Science Foundation (NSF), Defense Advanced Research Projects Agency (DARPA), the Office of Naval Research (ONR), and others. Private companies also fund some university research, and as government funding has become harder to get. private sources have become more important. For example, Intel spends tens of millions of dollars a year funding university research centers. These organizations don't just give money away as charity. They expect their money to accomplish something. Increasingly these days, this takes the form of a contract for a working demonstration that must be shown at the end. That means once the money is delivered, your professors must come through with the working demonstration. It is rare that they do this by themselves. Instead, they find some very capable, young, self-motivated people who are willing to work long hours for small amounts of pay. In other words, they fund RA's.

The RA job is crucial to the academic business. If the RA's cannot successfully conduct the research, then the demonstration will not work in the end and the funding agencies may not be happy. They may choose to not fund your professor in the future, which will bring his or her research program to a halt. And there are many professors and other researchers chasing too few research dollars these days; it is a competitive market. Thus, each professor wants the best students available. These students are the most capable ones who can get the research done required to fulfill the funding contracts.

That means you must treat an RA like a job. You must prove to your professors that you are capable of getting the work done, being a team player, communicating your results, and most of the other

characteristics needed to do well in regular jobs. That's why many of the upcoming sections in this guide sound like ones written for the regular workplace.

What do you get out of this? At the start, you may have to do tasks specifically related to the funding contracts. But eventually your professor must be flexible enough to fund your own specific research program that leads to the completion of your dissertation. Your stipend and tuition waiver should be enough to live on frugally without going into debt. You will learn the state of the art in your chosen speciality and conduct cutting-edge research on a subject that you find interesting and enjoyable. If you don't find this compensation sufficient, then you shouldn't be in graduate school in the first place.

The bottom line: realize that academia is a peculiar kind of business and the role you play in this enterprise. If you do your job well (and have good negotiation and interpersonal skills, as discussed in future sections), both your needs and your professors' needs will be met. But don't enter an RA position thinking that the computers, research equipment, staff members and other resources that you are provided with are your birthright. Don't take them for granted! Most of those exist only because your professors have been able to raise the money to provide those to you. In turn, you must fulfill your end of the deal by doing great research with those resources. If you don't do your job well, don't be surprised if your professors choose to not fund you in the future. They do not *have* to provide you with an RA job or let you use the computing equipment they acquired. And the student who has no funding, no tuition reimbursement and no access to required computing resources is the student who leaves the university that semester.

How do you make sure you are one of those best, highly desired RA's? Read on!

Graduate school is a different ballgame

"Don't let school get in the way of your education."
- Mark Twain

"The IQ test was invented to predict academic performance, nothing else. If we wanted something that would predict life success, we'd have to invent another test completely."
- Robert Zajonc

If you go through a Ph.D. program, you will find graduate school a very different world from undergraduate school. If you just get an M.S., then graduate school may not be much different from undergrad (depending on where you get your degree), except that the courses are deeper and more advanced. But for a Ph.D. student, graduate school is a whole new ballgame. The students who do well are the ones who learn this earlier rather than later and make the necessary adjustments.

Jason Hong has an article on this theme called Ph.D. Students Must Break Away From Undergraduate Mentality (ACM digital library subscription required for access).

Graduate school is not primarily about taking courses. You will take classes in the beginning but in your later years you probably won't have any classes. People judge a recently graduated Ph.D. by his or her research, not by his or her class grades. And, without any offense to my professors, most of what you learn in a Ph.D. program comes outside of classes: from doing research on your own, attending conferences, and discussions with your fellow students. Success in graduate school does not come from completing a set number of course units but rather from successfully completing a research program.

Graduate school is more like an apprenticeship where each student has his or her own project, and the masters may or may not be particularly helpful. It's like teaching swimming by tossing students into the deep end of the pool and seeing who makes it to the other end alive and who drowns. It's like training clock designers by locking students inside a clock factory with some working clocks and lots of clock parts and machines for building clocks. However, the instructions are at best incomplete and even the masters themselves don't know exactly how to build next year's models.

Excelling in a Ph.D. program requires different skills than doing well in undergrad. Undergraduate education tests you through class projects (that do not last more than a semester), essays, midterms and finals. For the most part, you work alone. Your professor may not know your name. Every other student in your class takes the same tests or does similar projects. But in a Ph.D. program, you must select and complete a unique long-term research program. For most of us, this means you have to learn *how* to do research and all that entails: working closely with your professors, staff and fellow students, communicating results, finding your way around obstacles, dealing with politics, etc.

Carl Vogel suggests the most important personality traits of successful graduate students are being inquisitive, disciplined, obsessive and delusional (certain that their research programs will uncover something new and important).

I'm not saying that tests and grades are completely unimportant in graduate school. One of the two biggest hurdles in completing a Ph.D. is passing the qualifying exam. (The other is finding an acceptable dissertation topic.) But because graduate school is not nearly as exam-based as undergraduate education and requires different skills, the GRE and undergraduate grades are not as good an indicator of who will excel and who will drop out as admission committees seem to think. Those tests do not measure creativity, tenacity, interpersonal skills, oral presentation skills, and many other important traits.

The next several sections discuss these traits.

Initiative

"The difference between people who exercise initiative and those who don't is literally the difference between night and day. I'm not talking about a 25 to 50 percent difference in effectiveness; I'm talking about a 5000-plus percent difference, particularly if they are smart, aware, and sensitive to others."
- Stephen R. Covey, *The 7 Habits of Highly Effective People*

The dissertation represents a focused, personal research effort where you take the lead on your own, unique project. If you expect that your advisor is going to hold your hands and tell you what to do every step of the way, you are missing the point of the dissertation. Ph.D. students must show initiative to successfully complete the dissertation. This does not mean that guidance from professors is unimportant, just that this guidance should be at a reasonably high level, not at a micromanaging level. If you never do any tasks except those that your professor specifically tells you to do, then you need to work on initiative.

At UNC, there is a famous anecdote about a former UNC graduate student named Joe Capowski. Many years ago, UNC got a pair of force-feedback mechanical arms to use with molecular visualization and docking experiments. The problem was how to move them to UNC. These mechanical arms were large, heavy beasts, and were in Argonne National Labs in Chicago, IL. Unfortunately, there was a trucker's strike going on at the time. Joe Capowski, on his own initiative (and without telling anyone), flew out to Argonne, rented a truck, drove the mechanical arms all the way back to North Carolina, and then handed the computer science department the bill! Many years later, Joe Capowski ran for the

Chapel Hill city council and won a seat. Prof. Fred Brooks gave him an endorsement. I still remember the words Dr. Brooks said: “I may not agree with his politics, but I know he’ll get things done.” (Thanks to Jim Lipscomb for corrections to this anecdote.)

While the Joe Capowski anecdote is perhaps a bit extreme, it does show that it is often better to ask forgiveness than permission, provided you are not becoming a “loose cannon.” Certain universities (e.g. MIT) are good at fostering a “can do” attitude among their graduate students, and therefore they become more assertive and productive. One of the hallmarks of a senior graduate student is that he or she knows the types of tasks that require permission and those that don’t. That knowledge will come with experience. Generally, the senior graduate students have the most freedom to take initiative on projects. This privilege has to be earned. The more that you have proven that you can work independently and initiate and complete appropriate tasks, the more your professors will leave you alone to do what you want to do.

Tenacity

“Let me tell you the secret that has led me to my goal. My strength lies solely in my tenacity.”
- Louis Pasteur

You don’t need to be a genius to earn a Ph.D. (although it doesn’t hurt). But nobody finishes a dissertation without being tenacious. A dissertation usually takes several years to complete. This can be a culture shock to former undergraduates who have never worked on a project that lasted longer than one quarter or semester (at the end of which, whatever the state of the project, one declares victory and then goes home). No one can tell you in advance exactly how long the dissertation will take, so it’s hard to see where the “end of the road” lies. You will encounter unexpected problems and obstacles that can add months or years to the project. It’s very easy to become depressed and unmotivated about going on. If you are not tenacious about working on the dissertation, you won’t finish.

Tenacity means sticking with things even when you get depressed or when things aren’t going well. For example, I did not enjoy my first year of graduate school. I didn’t tell anyone this until after leaving UNC. I was not on a project and was focused on taking classes, some of which I didn’t do all that well in. I didn’t feel a part of the Department, and really wondered whether or not I fit in. Still, I stuck with it and when summer rolled around and I got a job in the Department, I became much more involved in research and enjoyed graduate school much more. Part of earning a Ph.D. is building a “thick skin” so you are not so fragile that you will give up at the first sign on any difficulties.

One lesson I learned as a graduate student is the best way to finish the dissertation is to do something every day that gets you closer to being done. If all you have left is writing, then write part of the dissertation *every day*. If you still have research to do, then do part of it *every day*. Don’t just do it when you are “in the mood” or feeling productive. This level of discipline will keep you going through the good times and the bad and will ensure that you finish.

Flexibility

“Back in graduate school, I’d learned how to survive without funding, power, or even office space. Grad students are lowest in the academic hierarchy, and so they have to squeeze resources from between the cracks. When you’re last on the list for telescope time, you make your observations by hanging around the mountaintop, waiting for a slice of time between other observers. When you need an

electronic gizmo in the lab, you borrow it in the evening, use it all night, and return it before anyone notices. I didn't learn much about planetary physics, but weaseling came naturally."

- Clifford Stoll, *The Cuckoo's Egg*

Flexibility means taking advantage of opportunities and synergies, working around problems, and being willing to change plans as required. As a graduate student, you are on the bottom of the academic totem pole. Even undergraduates can rank higher, especially at private universities (because they actually pay tuition!) You cannot *order* anybody to do anything. In general, you will be in the position of reacting to big events rather than controlling them. Therefore, you must be flexible in your approach and research program.

For example, you may not have as much access to a piece of laboratory equipment as you would like, or maybe access is suddenly cut off due to events beyond your control. What do you do? Can you find a replacement? Or reduce the time needed on that equipment? Or come in at odd hours when no normal person uses that equipment? Or redefine the direction of your project so that equipment is no longer required?

Events can be good as well as bad. The difference between the highly effective graduate student and the average one is that the former recognizes those opportunities and takes advantage of them. I had nothing to do with bringing Gary Bishop to UNC. But after he arrived, I realized my research would progress much faster if he became my advisor so I made the switch and that was a big help to my graduate student career. Opportunities for synergy and serendipity do occur, but one has to be flexible enough to recognize them and take advantage of them.

Interpersonal skills

"For humans, honesty is a matter of degree. Engineers are always honest in matters of technology and human relationships. That's why it's a good idea to keep engineers away from customers, romantic interests, and other people who can't handle the truth."

- Scott Adams, *The Dilbert Principle*

"I can calculate the motions of the heavenly bodies, but not the madness of people."

- Isaac Newton

Computer Science majors are not, in general, known for their interpersonal skills. Some of us got into this field because it is easier to understand machines than people. As frustrating as computers can be, they at least behave in a logical manner, while human beings often do not. However, your success in graduate school and beyond depends a great deal upon your ability to build and maintain interpersonal relationships with your advisor, your committee, your research and support staff and your fellow students. This does not mean you must become the "life of the party." I am not and never will be a gregarious, extroverted person. But I did make a serious effort to learn and practice interpersonal skills, and those were crucial to my graduate student career and my subsequent jobs in industrial research.

Why should this matter, you may ask? If one is technically brilliant, shouldn't that be all that counts? The answer is no, because the situation is different from your undergraduate days. In both graduate school and in business, you must depend upon and work with other people to achieve your goals To put this in perspective, I have excerpted the following from an article called "Organizations: The Soft and Gushy Side" by Kerry J. Patterson, published in the Fall 1991 issue of *The Bent:*

I first learned of the capricious, human side of organizations some 15 years ago while studying the careers of engineers and scientists. The research design required that I spend eight hours a day in one-on-one interviews. For two hours I'd ask “career” questions of an engineer, chemist, physicist, or applied mathematician -- all of whom worked for a Fortune 500 firm. During these 120 minutes, the subjects talked about the perils of the organizations. Two hours was scarcely enough time to share their stories. All energetically discussed their personal careers. Most had been frustrated with the “soft and gushy” side of organizations. Some had figured out the system and learned to master it. Others had not.

As part of the research design, we asked to talk to low, medium, and high performers. This in itself was an interesting exercise. To determine performance rankings, we would place in front of a senior manager the names of the 10-50 people within his or her organization. Each name would be typed neatly in the middle of a three-by-five card. After asking the manager to rank the employees from top to bottom, the managers would then go through a card sort. Typically the executive would sort the names into three or four piles and then resort each pile again. Whatever the strategy, the exercise usually took only minutes. Just like that, the individual in charge of the professionals in question was able to rank, from top to bottom, as many as 50 people. It rarely took more than three minutes and a couple of head scratches and grunts. Three minutes. Although politics may appear ambiguous to those on the receiving end, those at the top were able to judge performance with crystal clarity.

This performance ranking (conducted by individuals not involved in the interviews) was then used as a dependent measure. Those of us conducting the interviews attempted to surface information (independent measures) that would predict the ranking. What about a scientist’s career would lead to a top ranking? What trashed a perfectly good career? Surely scientific prowess would have an impact. And it did.

But technological prowess wasn’t as predictive as another factor. We discovered that we could tell what performance group the interviewees belonged to within a minute or two by their attitudes toward people and politics. Individuals who were ranked low by their managers spoke of organizational politics as if it were poison. They were exceptionally annoyed by the people side of the business. They frequently stated they would rather be left alone to conduct their research untrammeled by human emotions. They characterized the social side of organizations as “soft and gushy.” They sounded like Spock turned bitter.

Top performers, in contrast, found a way to work within the political system. They hadn’t exactly embraced politics. They didn’t appear like that toothy kid you knew back in college who lived to fight political battles. They didn’t come off as glad-handling sales folks. These were professional scientists who were often top ranked in their field. They looked and talked liked scientists. The difference between them and those ranked at the bottom of the totem pole was clear. They had found a way to make peace with organizations, people, and politics. They climbed to the top of their field by mastering both hard things and soft and gushy people.

Engineers and scientists aren’t the only ones who find the human side of the organizations to be annoying. As we expanded our research to include professors, accountants, and other professionals, the findings were remarkably similar. All found political machinations to be distasteful. It’s just that some had found a way to master the social aspects -- the top performers.

Students usually look down on politics, but politics in its most basic, positive form is simply the art of getting things done. Politics is mostly about who is allowed to do what and who gets the resources (money, people, equipment, etc.) To succeed in your research, you will need resources, both capital

and personnel. Interpersonal skills are mandatory for acquiring those resources. If you are incapable of working with certain people or make them mad at you, you will not get those resources and will not complete your research.

Furthermore, people who complete a Ph.D. generally have careers where they take leadership roles. Leadership requires good interpersonal skills to convince and motivate others to think a certain way or to take certain actions. If you do not have good interpersonal or “soft” skills, the amount of influence you will have will be restricted to yourself. Your potential will be limited.

Here is an example of how relationships are important: As a graduate student, which group of people did I try my best to avoid offending? Was it my committee? No, because healthy disagreements and negotiations with your advisor and committee are crucial to graduating within a reasonable amount of time. Nor was it my fellow students, because I did not need help from most of them, and most of them did not need me. The critical group was the *research and support staff*. These include the research faculty and all the various support positions (the system administrators, network administrators, audio-visual experts, electronic services, optical and mechanical engineers, and above all, the administrative assistants). *I needed their help to get my research done, but they did not directly need me.* Consequently, I made it a priority to establish and maintain good working relationships with them.

Cultivating interpersonal relationships is mostly about treating people with respect and determining their different working styles. Give credit where credit is due. Acknowledge and thank them for their help. Return favors. Respect their expertise, advice and time. Apologize if you are at fault. Realize that different people work in different ways and are motivated by different things -- the more you understand this diversity, the better you will be able to interact and motivate them to help you. For certain people, offering to buy them dinner or giving them free basketball tickets can work wonders.

A true example: at one point in my research, I needed to make significant modifications to some low-level code in the graphics computer called “Pixel Planes 5.” Doing this required expertise that I did not have, but another graduate student named Marc Olano did. How should I tap into Marc’s expertise and get the changes I needed done?

The wrong way is to go up to Marc, explain the problem, and get him to make the changes. Marc doesn’t need the changes done; I do. Therefore, I should do most of the work. Expecting him to do the work shows disrespect of his time.

What I actually did was to explain the problem to Marc and he sketched out a possible solution. Then I ran off and worked on my own for a few days, trying to implement the solution. I got part of it working, but ended up getting stuck on another part. Only at that point did I go back to Marc and ask him for help. By doing this, I showed that I respected his time and wanted to minimize his burden, thus making him more willing to help me. Months later, when he and Jon Cohen needed my help in setting up a system to demonstrate some of their software, I was more than happy to return the favor.

Interpersonal interaction is a huge subject and goes far beyond my description here. All I can really do in this section is (hopefully) convince you that these skills are vital to your graduate student career and encourage you to learn more if you need to improve these skills. I still have a lot to learn myself. I recommend reading *The 7 Habits of Highly Effective People* and *Type Talk* (both listed in the References section) as starting points. The magazine article “How to be a star engineer” (listed in the References) also touches on this subject.

Scott Adams (the creator of Dilbert) wrote an interesting book called How to Fail at Almost Everything and Still Win Big: Kind of the Story of My Life where he describes systems and skills that correlate with life success. Those include psychology and understanding people.

Organizational skills

"Failing to plan is planning to fail."

Since academia is a type of business, you will have responsibilities that you must uphold. You will be asked to greet and talk with visitors, give demos, show up to meetings, get projects done on time, etc. If you are not well organized, you will have a difficult time meeting those obligations. A technically brilliant student will be greatly hampered if he or she exhibits an "absent minded" personality and develops a reputation for being disorganized.

There are many different time management and organization skills, and you can find many books on those at your local bookstore. This guide is not going to describe them. Find one that works for you and use it. I can highly recommend Stephen Covey's book, listed in the references. Another book is Getting Things Done by David Allen. But whatever system you pick, just make sure it works for you. I have never found anyone else who uses my filing scheme, but it is effective for me (by minimizing the combined time of putting away and locating a piece of information). All that really matters is whether or not it works.

One metaphor I found useful is the following: Organize your tasks as if you were juggling them. Juggling several balls requires planning and skill. You must grab and toss each ball before it hits the ground. You can only toss one ball at a time, just as you can only work on one task at a time. The order in which you toss the balls is crucial, much as the order of working on tasks often determines whether or not you meet all your deadlines. Finally, once you start a task (grab a ball) you want to get enough done so you can ignore it for a while (throw it high enough in the air so it won't come down for a while). Otherwise you waste too much time in context switches between tasks. Do you see jugglers try to keep each ball at the same height above the ground, frantically touching every ball every second?

Randy Pausch (who was a professor at Virginia and CMU) has a set of notes on time management. Three words in his guide summarize the most vital step: Kill your television. He asks you to keep your priorities straight. What is the most important thing to a Ph.D. student? It should be finishing the dissertation, not watching every episode of your favorite TV series. That doesn't mean dropping everything else in life, but it does mean knowing what takes priority and allocating time accordingly.

Taking advantage of opportunities

"The Chinese call luck opportunity and they say it knocks every day on your door. Some people hear it; some do not. It's not enough to hear opportunity knock. You must let him in, greet him, make friends and work together."

- Bernard Gittelson

I have been asked several times on how to get a good mentor or how to get professors or others in positions of power to give them opportunities that can further their careers.

The best way is to get yourself noticed in a positive way, so that professors or others in positions to hand out opportunities will decide it is worth spending time mentoring you or to offer you such opportunities. And then you must do the work necessary to exploit those opportunities.

Let me share a personal story about this. When I was a graduate student at UNC Chapel Hill, a group of us drove up to the University of Virginia to visit Randy Pausch's group. Not surprisingly, Randy asked some of us to give talks. I was one of those students. After my presentation, Randy commented that he never knew that I was such a dynamic speaker.

It was probably because of that presentation that later on I was invited to join a group of speakers teaching a course at the SIGGRAPH conference. Randy was one of those speakers. They were teaching a class on Virtual Reality and wanted me to be the last speaker and talk about Augmented Reality. I accepted. This meant creating a set of notes to include with the course. I decided I would try to define, characterize and summarize the field of Augmented Reality (this was back in 1995 when the field was small enough that this was a reasonable goal for such a document!). After we taught the course, Steven Feiner, who was another professor in that course, suggested that I update my notes and submit them to a new MIT Press journal called *Presence: Teleoperators and Virtual Environments.* So I did the work to change my notes into a journal paper and it was accepted and published.

That paper ended up becoming the single most cited reference in the field of Augmented Reality. The definition of "Augmented Reality" I provided in that paper became accepted by the research community, and researchers cited my paper when they wanted to explain that their paper was on the topic of Augmented Reality. It opened other opportunities for me, such as serving on the Steering Committee of the premier research conference in the field, and was probably one reason I was honored as an IEEE Fellow.

I did not plan any of this. Luck definitely was a factor. But the key points are:

- I did something that got myself noticed in a positive way by top professors in my field.
- Because I showed potential, they decided to take a chance on me by providing opportunities.
- And most importantly, I did the work to exploit these opportunities.

Now that I am a senior researcher, I see things from the perspective of those professors. If someone does something that shows potential or catches my attention, I am much more willing to invest time in such a person or to steer opportunities his or her way.

Don't go around demanding to be mentored or to receive opportunities. Show that you are worth it, make sure that people in positions to grant things are aware of your potential, and when you get opportunities, put in the necessary effort.

Communication skills

"What is written without effort is, in general, read without pleasure."
- Samuel Johnson

"Present to inform, not to impress; if you inform, you will impress."
- Frederick P. Brooks, Jr.

As a student, I was always amazed that articles written about business consistently put good communication skills at or near the top of the list of skills that employers want to see but often didn't find in candidates. Now, as someone who has worked in industry for a long time and also hired people, I can confirm this is true.

Communication skills, both written and oral, are vital for making a good impression as a Ph.D. student and as a researcher. At a minimum, you have to defend your dissertation with an oral presentation. But you should also expect to write technical papers and reports, give presentations at conferences, and give demonstrations to groups of visitors. If you can write and speak well, you will earn recognition and distinguish yourself from other graduate students. This is especially true when giving presentations in front of important visitors or at major conferences.

Conversely, if you cannot communicate well, then your career opportunities after graduation will be limited. Professors spend most of their time communicating: teaching, fundraising, guiding graduate students, and documenting their results (through papers, videos, slidesets, etc.). In industry, we need people who can communicate well so they can work in teams, learn what businesses and customers need, present their results, raise funds, and transition to leadership roles in project and personnel management. If you are technically brilliant but are incapable of communicating or working with other people, then your results will be limited to what you can accomplish alone and your career growth will have a low ceiling, both in industry and academia.

Unfortunately, not all graduate students receive training in giving presentations or writing technical documents (which are different from English essays). These are skills that can be learned! Don't worry if giving presentations and writing papers are not something that comes naturally to you. I was not very comfortable giving oral presentations when I started graduate school, so I made a concerted effort to learn how to do so, by taking classes, reading about the subject, and practicing. It's not easy, but it's well worth the investment. If you need practice, try giving informal talks at research luncheons, joining Toastmasters, and studying good speakers to see what they do.

Covering everything about this subject would fill a guide by itself, and would probably be better explained in a video rather than a written document. But here are a few basic points:

- Organization counts. Within the first few paragraphs or first few minutes, tell me why I should read your paper or listen to your talk. Make it clear where we are going and what we have already covered.
- Make the text in your slides large enough so that people sitting in the back can read them. For large presentation halls, this usually means no more than 6-7 lines per slide and 28 point type minimum. You'd be surprised how many experts on visualization (especially tenured professors!) give presentations with unreadable slides.
- Variety retains interest. Vary your pace, tone, and volume. Emphasize the important points. Look around the room. Throw in some video, pictures, or live examples.
- Don't stand in front of the screen and block everyone's view. You'd be surprised how often people do this without realizing it.
- Point out the limitations of your work. That helps your credibility. Similarly, credit others where appropriate.
- Make friends with the A/V crew! Running A/V is a thankless job. If everything runs smoothly, well, that's what was supposed to happen so nobody says anything. But if anything goes wrong, the entire audience looks back at the control room. *Help the A/V people help you.* Always check in early and test the equipment. Tell them what you are going to do in your presentation (e.g., I'm running 3 video segments). Make sure you know how everything works long before you come up to the podium. And thank the A/V crew for their help after you are done!

Confidence is the key to giving a good presentation. And the way to gain confidence is to give good presentations. When you're just starting out, this is a Catch-22. However, once you become good enough, this turns into a positive feedback cycle that can make giving talks a pleasure.

If you want to see an example of an excellent talk, please watch The Last Lecture by Randy Pausch (video available on YouTube). I knew Randy personally, and I had the difficult task of having to speak directly after him, not once but twice. Randy gave the talk of his life in The Last Lecture but I will tell you that was not an aberration. He was a superb speaker, and someone we can all learn a lot from. One time, after I spoke at the University of Virginia, Randy told me that he hadn't realized I was such a

dynamic speaker. I replied that it hadn't come naturally for me, unlike Randy who was a naturally talented speaker. For me, I had to work hard at it. But I am proof that with hard work, one can develop good presentation skills and get noticed by someone like Randy.

A good reference on how to communicate in a compelling manner is the book Made to Stick: Why Some Ideas Survive and Others Die by Chip and Dan Heath. They give concrete approaches for crafting a message in a way that people will remember.

Writing papers and getting them published is vital for Ph.D. students who want to get research positions after graduation. Your ability to write well significantly improves the chances that your paper will be accepted. When I was a young graduate student and reviewed a paper that I didn't understand, I thought "Gee, I must be dumb." Today I will read the same paper and think "Boy, this is a lousy paper. The authors did not do a good job explaining and presenting their work." Such a reaction is enough for me to reject the paper.

Where do you submit your papers? Your professors will help you with this choice, but in general I would suggest shooting for the best conferences or journals where you think it has a reasonable chance of being accepted. It's not much more work to write, submit and present a paper in a highly respected venue than in less respected venues. And if you don't shoot for the top you'll never know if it would have made it. The field of computer graphics is a bit unusual in that the most desirable place to publish is a conference (SIGGRAPH), rather than a journal (although SIGGRAPH papers now are published in a journal called Transactions on Graphics). Be aware that journals can take years to publish submitted papers; the turn-around time is much faster in a conference.

Finally, don't forget to communicate with your professors and your teammates. Keep your committee appraised of your progress. One thing I do (which few others do) is write short (1 screenfull) status reports, which I religiously e-mailed to my professors and team members on a weekly basis. These serve as an efficient way of keeping everyone up to date on what I'm doing. They are also a good way for me to record my progress. If I need to remember what I got done during a six month period, I have plenty of old status reports that I can read. You'd be amazed how appreciative professors and managers are of this simple practice. I also throw in a different humorous quote at the end of each week's report to reward people for reading it.

When you are working in the lab and you reach a milestone or achieve a result, let people know about it! Bring in your professors and fellow students and show it off! That's a win-win situation. It lets others know that you are making progress and achieving results, and you get valuable feedback and advice.

Choosing an advisor and a committee

"Some students in the lab are only nominally supervised by a thesis advisor. This can work out well for people who are independent self-starters. It has the advantage that you have only your own neuroses to deal with, not your advisor's as well."

- from "How to do research at the MIT AI Lab"

The choice of an appropriate advisor is crucial to successfully completing the Ph.D. Your advisor must be someone who can cover your area of specialization and someone you can get along with. When I started graduate school, I thought the advisor - student relationship was supposed to be very close, both professionally and socially. In reality, the relationship is whatever the professor and the student choose to make of it. It can be close, with invited dinners at the professor's home, or it can be distant, e.g. meeting occasionally to remind the professor that the student is still alive.

One basic question in choosing an advisor is whether to pick a junior (non-tenured) or a senior (tenured) professor. Non-tenured professors tend to travel less and are generally more available. It is difficult to get help from an advisor who is never in town. Non-tenured faculty have fewer advisees that you have to compete with to get time with the professor. They are more likely to be personally involved with your research -- writing code, spending time in the lab at midnight, etc. Non-tenured faculty must be energetic and hard working if they want to be awarded tenure, and this work habit can rub off on their students. However, tenured faculty have several advantages as well. They are usually the ones with most of the money and resources to support you. They do not have to compete with their students for publications and recognition. The advisee does not run the risk of having his or her advisor not getting tenure and leaving the university. Tenured faculty are more experienced with “how the game works” and thus may be better sources of guidance, personal contacts, jobs after graduation, etc.

I ended up with a non-tenured professor (actually, he was not even on the tenure track at the time) as my advisor, but also put several tenured professors on my committee, including some of the most senior ones in my specialty. In that way, I got the best of both worlds: the day-to-day attention from the primary advisor, combined with the resources and experience of the committee.

Professors develop reputations amongst graduate students. Some are known to graduate their Ph.D. students rapidly. Others are impossible to get hold of, so their students take forever to finish or leave without graduating. Some dictate what their advisees have to do, while others are accommodating of student interests. Ask around. What you learn may be revealing. And if circumstances change to make another professor a more appropriate match to your needs, don’t be afraid to switch if that is an overall win.

When picking a committee, you want to make sure they can cover all areas of your thesis. You also want to make sure that it is likely that all the committee members will be available for meetings! Including too many professors who travel often will make it difficult to get all five or six together in one room for a three hour oral exam or proposal meeting. When scheduling such meetings, start by finding times when the difficult-to-reach professors are in town, and then add in the other committee members.

Balance and Perspective

“Life goes by so fast, that if you don’t stop and look around, you might miss it.”
- from the film *Ferris Bueller’s Day Off*

“Generally speaking, people provide better maintenance for their cars than for their own bodies.”
- Scott Adams, *The Dilbert Future*

When I was in graduate school, my top priority was crystal clear to me: getting out with a Ph.D. Other people described me as “focused like a laser beam” on that goal. In retrospect, I may have been too focused. There *is* more to life than graduate work. Keeping your health and your sanity intact are both vital to achieving the primary goal of getting out.

Repetitive Strain Injury (RSI) is a major occupational hazard in our industry. Carpal Tunnel Syndrome is just one type of RSI. If you do not know how to set up your workspace for good ergonomics, *learn now!* The Pascarelli reference at the end of this guide is a good book on this subject. Over a dozen of my friends and coworkers have been inflicted with this problem. In severe cases, RSI can be a career-ending injury. If you can’t type, it’s rather difficult to write papers, computer programs, presentations, etc. Don’t let this happen to you! Prevention is the way to go. When lifting weights, I exercise to strengthen my shoulders and wrists as an additional preventative step.

Earning a Ph.D. is like running a marathon. You have to learn to pace yourself and take care of your body if you want to reach the finish line. Unfortunately, students often act like sprinters trying to run a marathon. They are highly productive for a while, but then fall by the wayside because they aren't eating correctly, exercising, taking time out to recharge their batteries, etc. You maximize your long-term productivity by not ignoring those other aspects. While I was in graduate school, I took time out to travel up and down the East Coast, from Boston down to Orlando. That was an important part of keeping my stress down and recharging my batteries. I also did some running and circuit training for exercise. For shorter breaks, I shot nerf basketballs at a tiny hoop mounted in the graphics lab and kept a guitar in my office. Figure out what works for you.

It's easy to lose perspective while in graduate school. You are surrounded by so many other smart, hard working people that it is easy to feel inferior and lose self esteem and confidence. But without an underlying confidence that you *do* have what it takes to complete a dissertation, it's too easy to drop out when the going gets tough instead of sticking it through. I found it useful to keep in touch with the "real world," to remind myself that the graduate student population is not representative of humanity in general and to keep my perspective. You got into graduate school because you have already shown to your professors that you have potential and skills that are not typical among most college students, let alone most people -- don't forget that.

I freely admit that this section reflects my personal bias that balance in life is important. For some people, focusing on work to the exclusion of almost everything else is how they achieve excellence. Jim Lipscomb, who was a graduate student before me at UNC, describes the traits that enabled his father, William Lipscomb, to win a Nobel Prize. However, I chose a different set of priorities and have not regretted that choice. Decide for yourself what is most important in your life.

The Ph.D. job hunt

On résumés: "The closest to perfection a person ever comes is when he fills out a job application form."
- Stanley Randall

Real World, The (n.): Where a computer science student goes after graduation; used pejoratively ("Poor slob, he got his degree and had to go out into the REAL WORLD."). Among programmers, discussing someone in residence there is not unlike talking about a deceased person.
- the fortune program

"Never forget this primary rule: Graduate school is not your job; graduate school is a means to the job you want. Do not settle in to your graduate department like a little hamster burrowing in the wood shavings. Stay alert with your eye always poised for the next opportunity, whatever it is: to present a paper, attend a conference, meet a scholar in your field, forge a connection, gain a professional skill."
- Dr. Karen Kelsky

"Startups are business experiments performed with other people's money."
- Antonio Garcia Martinez, from the book Chaos Monkeys

Ideally, the job hunt begins years before you graduate. Networking is very important: while you are in the middle to late phases of your graduate studies, try to get yourself noticed by professors and industry people *at other sites*. One way to do this is to offer to give a talk about your work at another site. This is not that difficult to do, since most research places love to host seminars and bring in fresh ideas. Attending conferences and working elsewhere during the summer are other ways to get

exposure. Make friends with graduate students and personnel at other schools. Make and carry your own business cards. Schmooze with important visitors during major site visits. For about two years, I ran the informal “Graphics Lunch” symposia at UNC. That means I was the point of contact for many speakers who visited UNC and that helped me make contacts. There is also a “star” system that exists. Certain outstanding graduate students can get labeled as “stars” by their professors and that can be an enormous help in getting an interview at CMU or other prestigious locations. It’s nice if you can get on that track but one shouldn’t rely upon it!

Networking is important because many jobs are found and filled that way. I got my position at HRL partially because I visited there, at my own expense, two years before I even started my job hunt. That meant that when I circulated my résumé, I was more than just a piece of paper to them. You’ll look for job announcements in major journals, at conferences, online, and through your contacts.

In most companies, the hiring authority resides with the manager who owns the job position, not with the Human Resources department. HR can reject a candidate, but they cannot hire a candidate. As a hiring manager, my job is to only talk directly to candidates who are best qualified for the position. As a candidate, your job is to *find the individual with the ability to hire* and deal with that person directly, rather than solely with the HR department.

When do you start asking for interviews? You can start when you are able to give a talk about your dissertation work. Don’t be too early or too late, because you only get one chance per site. Academic positions generally have a particular “season” (much like getting admitted to school) that starts in the Fall and ends around April; industrial positions generally don’t follow that. The job hunt and interviewing process can take months; factor that into your time allocation.

The job supply and demand situation can vary dramatically in a few years, and anything I say here about the job market today will likely be out of date by the time you read this. For example, during the time I was initially job hunting (end of 1994 to early 1995), good positions were not easy to find. If I had a dollar for every site that told me “We don’t have a permanent position, but would you take a postdoc?” I could buy a lot of lunches. However, around 1997 the graphics job market became very strong, with many individuals getting multiple offers with high salaries. 1998 was an excellent year for people looking for tenure-track graphics faculty positions. I know many friends who found good tenure-track positions that year. So when I revised this guide in 2000, I said the job market was strong with high demand. Of course, the tech industry went downhill at that point. So I no longer say anything about how strong or weak the job market appears to be.

Instead, I will describe two consistent but unfortunate trends I have observed since graduating:

- *Tenure-track positions are increasingly requiring candidates to do one or more postdocs:* This trend has been documented by Anita Jones in the article The Explosive Growth of Postdocs in Computer Science (ACM Digital Library subscription required). Since 2007, hiring of Ph.D.’s in academia is increasingly dominated by postdoc positions rather than tenure-track positions. The requirements for a tenure-track position appear to have been redefined to make one or more postdocs nearly mandatory. This has been the case in other disciplines for a long time, but it is relatively new for Computer Science. This delays a Ph.D.’s career and forces people who want to become professors to endure several more years of low pay and status.
- *Industrial research positions have become difficult to find:* Overall, most businesses focus on the short term. Therefore, the trend has been to cut back or close industrial research labs. Big companies increasingly rely on letting startups attempt certain kinds of innovation and then partnering with or acquiring those. Companies also pursue innovation through advanced development groups that are different than traditional research labs.

Before starting the job hunt, determine your goals and parameters in advance and the “angle” you will take to sell yourself. For example, my strength was in systems, so I chose to emphasize that in my cover letters. Customize your approach to each site, if time permits. What you do for your thesis determines who will and who won’t take a look at you. Try to get at least one reference from outside your university.

This guide is not going to cover the basics of interviewing; you can get that from many books (e.g. the Martin Yate and Bob Weinstein books listed in the references). However, I will mention some tips. Don’t interview on the day of arrival, and try to avoid Mondays and Fridays. Be prepared for hard or illegal questions, by finding polite ways of addressing the underlying concern. **Do your homework** on each site before interviewing! It continually amazes me that people show up for interviews without knowing anything about the institution they want to join. If the target is a research lab for a major company, you can easily look up Wall St. Journal articles, annual reports and stockbroker reports. If your goal is an academic position, check out the Tomorrow’s Professor site and The Professor Is In for guidance. If you interview at a university, get their course catalog and *use their numbering scheme to describe the courses you can teach*. Interview to find out more about them, not just to sell yourself. Your 45-60 minute research presentation is crucial; make sure you practice it thoroughly. *Interviews create interviews*. That is, if you’ve already gone on many interviews at other places, that makes you appear more desirable since others want you, and that makes it easier for you to get more interviews. Broadcast this fact by keeping your interview schedule on your web page. There is an anecdote about one student who received offers to interview at many different places, but only after Stanford interviewed him! Keep logs on who you talk to, what you talked about, and when. That makes it easier to keep things straight when juggling several contenders. The major conferences in your field are a good place to schedule preliminary interviews to get your foot in the door, because it is cheap for the company or university. The people you need to meet are already there, so that saves them the expense of having to fly you out and house you at their site.

Offers are a waiting game. Be prepared for lots of frustration. You need a *written* offer or nothing is official; you should also accept or reject in writing. Negotiate, but be aware of the strength or weakness of your position. I also recommend doing only one round of negotiating (i.e. you counterpropose terms, and the organization responds to that, and then you make a decision). As a hiring manager, I can tell you that it is very frustrating when a candidate attempts to negotiate for a long time, and that can make an employer upset and possibly even rescind the offer. Look at the entire package. Starting salary may not be as important as the type of work, the environment, benefits, growth potential, and work-life balance. Drug tests and other factors are becoming more common; you will have to decide how you want to respond to those.

Ah yes, salaries. Everybody wants to know about those. For academic (tenure track) salaries, you can get typical numbers from the annual Taulbee surveys, printed in the Computing Research News newsletter and the Communications of the ACM. For example, the median salary listed in the 2015 Taulbee survey for associate professors was almost $114k. Realize that these are 9-month salaries. Whether or not you can procure funding to cover 2 or 3 months of summer salary makes a big difference to your bottom line. Also, professors can make money by consulting, although this is more common among established professors. Rates can be up to $4000 per day or more, depending on the type of consulting and the client. Figures for industrial salaries are harder to come by. The Maisel and Gaddy references are the only ones I have found that specifically survey young Ph.D.’s in industry, and those figures are now very old. Salaries depend heavily on geography. For example, salaries in the Silicon Valley and San Francisco are high. But before you decide to move to Palo Alto, remember that the cost of living there is also in the stratosphere. When I first wrote this guide (in 1997), nice houses in the Silicon Valley in good areas cost more than half a million dollars. In 2017, those same houses

probably cost $1.25M to $1.5M or more. More general computer science salary surveys are run by the IEEE and EE Times.

As a hiring manager, I will caution you against believing self-reported figures from sites such as Glassdoor. My experience is that those are not accurate and generally exaggerate salary figures. They also often confuse base salaries with total compensation that includes bonuses, stock and other benefits.

Acquire salary information on your own by making use of your network. Don't ask for someone's salary directly, unless it's someone you know very well and even then be very careful. Instead, bounce figures off people and see how they respond. Do they think the figure you mention is high, low, or about right? By seeing how people respond you can get an idea of what the market range is.

Factor in benefits and the expected workload into your compensation evaluation. An offer with high compensation may seem less attractive if you have to work 80 hour weeks in that position. You may have to do some detective work to determine the truth. A company might say they value work-life balance, while the established culture tells you a different story: where people have to work 80 hour weeks to get promoted or to even keep up with expectations and deadlines. For many positions, particularly in Silicon Valley, variable compensation (cash bonuses, restricted stock units and stock options) make up a significant part of the total compensation, along with benefits.

For Computer Science Ph.D.'s, there are four major categories of employers:

- Startups (including starting your own business or consulting)
- Commercial businesses
- Industrial or government research labs
- Academia

Startups: Joining a startup, or starting your own company, is potentially the most lucrative route. It is also the riskiest. Most startups pay below market compensation and cannot offer the benefits that Google can, but may offer equity that provides the chance of a "home run" that you won't get at a big company. Most startups fail. Overall, the home runs are few, but they do occur. For example, I know some people who joined Oculus prior to it being acquired by Facebook. Startups are a very different work environment than established big companies. They are typically small, informal, agile, and lacking in resources. They may be more flexible in work environment than most Fortune 500 companies. But they are also less likely to have knowledgable HR personnel who ensure that laws are followed. A paycheck from a Fortune 500 company is not likely to bounce. Startups tend to fire quickly and are more likely to shut down.

A startup has a limited amount of time and resources to establish itself so that it can become self sustaining or an acquisition target. That means it is not a place to pursue long-term research, no matter what the founders may say. The best analogy I heard: Joining a startup is like deciding to jump off a tall cliff with a bunch of other people, believing that you will successfully build working sets of wings and will soar away prior to hitting the ground. If you do this, you don't want to spend time and energy on things that aren't directly related to building wings! You might also check the base of the cliff beforehand to see how many bodies you find there.

Startups are not generally compatible with work-life balance. Due to the limited resources, startups have to demand more sacrifices than a more established company.

By working in a startup, you will likely fall out of touch with the research community in your field and lose the state-of-the-art knowledge that you worked so hard to acquire by getting a Ph.D. It is easier to

go from a research background to a startup or commercial position than it is to go the other direction.

Although old, the Kawasaki and Bell references listed at the end of this document may be useful if you want to work at a startup.

Matt Cutts was a graduate student at UNC Chapel Hill. We both had the same advisor. Unlike me, Matt did not finish his Ph.D. Instead, he left early to join a startup that had less than 100 people at that time. You might have heard of this startup. It was called Google.

If you win the startup lottery, like Matt, he offers some advice here and here. I also like how Google prepared its employees prior to its IPO.

For two different perspectives of startups, read Disrupted: My Misadventure in the Start-Up Bubble for a perspective of an older worker and how he didn't fit into one startup, and The Founder's Dilemmas, which explains challenges and key decisions that founders face in starting their own company.

Commercial businesses: Normal development or production jobs that focus on supporting or developing new products represent the vast majority of employment opportunities. However, getting a Ph.D. makes you overqualified for most of these. Ph.D. training prepares students for academic careers, rather than business careers. Most people who seek a Ph.D. are looking for different types of work than normal commercial jobs. However, if your interests lie in business rather than research, this can be the best way to go. There are Ph.D's who have become VP's and CEO's. Advanced development jobs can be interesting and challenging, and they provide the satisfaction of seeing your work impact product or a company.

Industrial or government research labs: These sit somewhere in between normal commercial jobs and academia. Typically they enable you to look somewhat longer term than a normal job, publish papers, go to conferences, etc. However, these are managed environments, so your research work must tie into the business of the company or the mission of the lab. Reorganizations and changes in priorities can commonly occur, and you have to surf those changes to stay employed and viable. The compensation in industrial research can be good, generally much better than government positions or academia. But like commercial jobs or startups, your job can get cut at any time. I worked at a lab where one day, without any warning, managers appeared and informed us that the company was shutting down our lab and that almost everyone would be laid off, including me. You also will not have the "home run" potential of a startup.

If you work in industrial research, you should really be motivated to make an impact on your company, by transitioning research into product or processes that directly contribute to your company's future. If your primary goals are to publish papers, advance the field and make a name for yourself, and you don't really care about the commercial and business aspects, then academia is a better choice. However, even if you focus on doing research that is important to your company, it is possible to achieve external recognition. For example, I recently was elected an IEEE Fellow, despite spending my entire career in industrial research. In this role, you should be ambitious to accomplish something rather than being ambitious to make yourself famous.

Labs that are completely owned by commercial companies or ones that have mandated government funding generally have a consistent stream of funding (until executives or politicians decide to change things). Other labs must rely on winning contracts, from other companies or from the government. That can be a volatile, frustrating way to work. It can be stressful knowing that your team's continued employment depends on winning the next contract. In a previous job, I sometimes felt we spent 100% of our time trying to secure funding, so we could spend the other 100% getting some research done.

Academia: Working in universities is the traditional career path for Ph.D.'s. A tenured professor is the most secure and stable research position that exists, and the one that grants the most freedom. Professors can choose what they want to work on. If you are focused on publishing and want to ensure that nobody can tell you what to do, then become a tenured professor. If your main motivation is to become a very famous researcher, then become a tenured professor.

However, tenure is not easy to achieve. Getting a tenure-track position is difficult. You have to be good and possibly lucky to get one. As I previously mentioned, postdoc experience is becoming an almost mandatory prerequisite. Read the Feibelman and Ralston references for tips on surviving a postdoc. Furthermore, getting tenure is a race against the clock to publish enough impressive research results that your department decides to grant tenure rather than sending you out the door. As Randy Pausch put it, tenure is a competitive process where you get compared with the other assistant professors and the already-tenured professors. If they worked 70 hour weeks for six years to get tenure, don't expect to get away with working 40 hour weeks.

The tenure track is not kind to those who want to start a family. Even if you start graduate school directly after finishing your Bachelor's degree, you will probably be in your late 20's when finishing the Ph.D. and in your mid to late 30's when achieving tenure. The realities of the biological clock tend to conflict with the demands required to achieve tenure.

Professor jobs tend to be focused either on research or teaching. Smaller colleges and universities tend to focus mostly on teaching, and professors are evaluated that way. Teaching positions generally pay less than the research positions at big universities, where professors are primarily evaluated by their research and how many trees they kill by publishing papers, and if their teaching is good enough to keep the dean from hearing complaints.

There are also "soft money" positions in academia, which are professors and staff who are paid from contracts and grants rather than tenured positions. These lack the security of tenure and it can be difficult to stay alive on such funding. Most contracts and grants are aimed at funding graduate students and covering one or two months of a professor's salary, but not toward paying for full-time staff.

The comments I made about fundraising in industrial or government research labs also apply to academic positions. Most of my friends who are professors in the US have to spend far too much time writing proposals, and the percentage of those that are awarded seems to keep going down. If you are tenured, then your job does not rely upon winning proposals, but without external money, you will not be able to support graduate students or pay for extra staff, and your impact will therefore be limited.

I saw a Computing Research News article estimating that total compensation for assistant and associate professors lags that of industrial counterparts by 25%. Compared against Silicon Valley compensation, I estimate the difference to be around 50%.

If you want to get a tenure-track position, read The Professor Is In, a book that goes into great detail about how to land a tenure-track job. The author also runs a blog and service to help students seeking to become professors. Keep in mind that the author has a background in the humanities, so if you are a CS Ph.D. student you have to factor in the differences between a CS Ph.D. program vs. one in the humanities. For example, CS Ph.D. students typically receive financial support, so accumulating large debts is less of a problem. In CS, publications at certain conferences are valuable, whereas in the humanities, conference publications may not count for much.

Other tips: When I had to look for a job in 2012, the single thing I did that was most helpful to my job hunt was creating my own website. A C.V. is a very dry, hard to read document. My website serves as a visual version of a C.V. where I provide images, videos, and detailed descriptions of the projects I

worked on. This is a much more compelling way of communicating who I am and what I can offer. As a hiring manager, I found it very helpful when candidates had good websites about themselves. LinkedIn is sufficient for many job hunters, but for people with a Ph.D., I highly recommend creating and maintaining your own website. It doesn't cost that much and is well worth the effort.

The article The Secret Formula for Choosing the Right Next Role (ACM digital library access required) suggests that when choosing jobs, focus more on what skills you will acquire, what you can accomplish there and who you will work with, rather than focusing on your job title, paycheck and initial project.

No matter where you go after you graduate, maintain your contacts with your alma mater. You may change jobs and move from place to place, but you will always have your degree from your university. If you keep good relations with your university and your fellow former students, that will serve as an excellent base for your personal network.

Conclusion

"Dissertations are not finished; they are abandoned."
- Frederick P. Brooks, Jr.

The following story, called "The Parable of the Black Belt," is excerpted from *Built to Last: Successful Habits of Visionary Companies*, by James C. Collins and Jerry I. Porras.

> Picture a martial artist kneeling before the master sensei in a ceremony to receive a hard-earned black belt. After years of relentless training, the student has finally reached a pinnacle of achievement in the discipline.
>
> "Before granting the belt, you must pass one more test," says the sensei.
>
> "I am ready," responds the student, expecting perhaps one final round of sparring.
>
> "You must answer the essential question: What is the true meaning of the black belt?"
>
> "The end of my journey," says the student. "A well-deserved reward for all my hard work."
>
> The sensei waits for more. Clearly, he is not satisfied. Finally, the sensei speaks. "You are not yet ready for the black belt. Return in one year."
>
> A year later, the student kneels again in front of the sensei.
>
> "What is the true meaning of the black belt?" asks the sensei.
>
> "A symbol of distinction and the highest achievement in our art," says the student.
>
> The sensei says nothing for many minutes, waiting. Clearly, he is not satisfied. Finally, he speaks. "You are still not ready for the black belt. Return in one year."
>
> A year later, the student kneels once again in front of the sensei. And again the sensei asks: "What is the true meaning of the black belt?"
>
> "The black belt represents the beginning -- the start of a never-ending journey of discipline, work, and the pursuit of an ever-higher standard," says the student.
>
> "Yes. You are now ready to receive the black belt and *begin* your work."

To me, there are two lessons in this story.

First, the Ph.D. is the beginning, not the culmination, of your career. Don't worry about making it your magnum opus. Get out sooner, rather than later.

Second, if you bother to talk to and learn from the people who have already gone through this process, you might graduate two years earlier.

Good luck.

Other Related Guides and Links

- Prof. HT Kung from Harvard provides advice about the Ph.D., particularly a Ph.D in systems.
- Matt Might is a professor who offers a large number of articles about graduate school and other topics. Scroll down to the section on Graduate School to find his articles.
- Ph.D. Comics. Dilbert meets graduate school. It is hilarious because too much of this is true. However, if you want to finish your Ph.D., read this only in small doses at a time or you will get too depressed to finish.
- Tomorrow's Professor, a collection of interesting articles for current graduate students and those seeking academic positions after graduation.
- The superb Graduate Student Resources on the Web! at U. Michigan
- Jeff Hollingsworth's guides on job hunting
- Improving the Graduate School Environment for Women in Computer Science
- Advice on Research and Writing
- Marie des Jardin's "How to be a Good Graduate Student"
- Wanda Pratt's Graduate Student Survival Guide
- (Humor) A Day in the Life of a Grad Student
- (Humor) The Ph.D. vs. the Lotto
- The National Association of Graduate-Professional Students
- RPI's Grad Student Survival Guide in Math Sciences
- Douglas Comer's essays on computer science and the Ph.D.
- (Humor) Lord of the Rings as an allegory for getting the Ph.D.
- Buffalo page of information about graduate school
- How to do research at the MIT AI Lab

Recommended Reading

Adams, Scott. *How to Fail at Almost Everything and Still Win Big: Kind of the Story of My Life.* Portfolio Hardcover, 2013.
`An interesting description of systems and skills that correlate with success in life.`

Allen, David. *Getting Things Done: The Art of Stress-Free Productivity.* Penguin Books, 2002.
`David Allen describes his methods to stay organized and productive.`

Bell, C. Gordon and John McNamara. *High-Tech Ventures: The Guide for Entrepreneurial Success.* Addison-Wesley, 1991. ISBN 0-201-56321-5.

Dated, but still recommended reading if you want to work for a startup.

Bronson, Po. *The Nudist on the Late Shift.* Random House, 1999. ISBN 0375502777.
A fun read, giving the flavor of what working in the Silicon Valley is like. Many of the chapters previously appeared as articles in *Wired*. A snapshot of the culture before the tech bubble burst in 2000.

Covey, Stephen R. *The 7 Habits of Highly Effective People.* Fireside Simon and Schuster, 1989. ISBN 0-671-70863-5.
Excellent overall, with sections on time management, guiding principles and interpersonal skills.

EE Times Salary Survey Issue.
EE Times produces an annual survey and commentary about industrial salaries.

Feibelman, Peter J. *A Ph.D. is Not Enough! A Guide to Survival in Science.* Addison-Wesley, 1993. ISBN 0-201-62663-2.
Good discussion of research career paths. A must read if you choose to take a postdoc.

Heath, Chip and Dan Heath. *Made to Stick: Why Some Ideas Survive and Others Die.* Random House, 2007.
A good reference on how to craft a message so that it is remembered.

Hong, Jason. Ph.D. Students Must Break Away From Undergraduate Mentality. *Communications of the ACM 56*, 7 (July 2013), 10-11.
Jason's article provides more evidence of how graduate school is a different ballgame than undergraduate education.

Jones, Anita. The Explosive Growth of Postdocs in Computer Science. *Communications of the ACM 56*, 2 (February 2013), 37-39.
Postdocs are becoming almost mandatory prior to getting a tenure track position in computer science. This is not good.

Kawasaki, Guy. *The Macintosh Way: The Art of Guerrilla Management.* Harper Perennial, 1990. ISBN 0-06-097338-2.
Describing the situation in the early days of Apple, this book shows the energy and chutzpah required to survive in a startup.

Kelley, Robert E. How to be a star engineer. *IEEE Spectrum* (October 1999), 51-58.
Good description of the skills that are needed to excel at work, which go beyond sheer technical skills.

Kelsky, Karen. *The Professor Is In.* Three Rivers Press, 2015. ISBN 978-0-553-41942-9.
Read this if you want a tenure-track position at a university.

Kroeger, Otto and Janet M. Thuesen. *Type Talk: The 16 Personality Types that Determine How We Live, Love and Work.* Tilden Press, 1988. ISBN 0-385-29828-5.
Introduction to the Myers-Briggs type indicators, useful for understanding different personality traits.

Lyons, Dan. *Disrupted: My Misadventures in the Start-Up Bubble.* Hachette Books, 2016.

One person’s negative experiences working at a startup company, particularly coming in as an older employee.

Maisel, Herbert and Catherine Gaddy. Employment and Salaries of Recent Doctorates in Computer Science. *Communications of the ACM 40*, 9 (September 1997), 90-93.
Maisel, Herbert and Catherine Gaddy. Employment and Salaries of Recent Doctorates. *Communications of the ACM 41*, 11 (November 1998), 99-101.
Two surveys about new C.S. Ph.D. graduates that include both industry and academic numbers. The low sample size is a problem, however. This is also old data.

Matsudaira, Kate. The Secret Formula for Choosing the Right Next Role. *Communications of the ACM 61*, 10 (October 2018), 44-46.
When choosing jobs, focus more on the team and the skills you can acquire and what you can accomplish, rather than the project, your job title and your paycheck.

Pascarelli, Emil and Deborah Quilter. *Repetitive Strain Injury: A Complete User's Guide.* John Wiley and Sons, 1994. ISBN 0-471-59532-2.
A good introduction to RSI injuries and avoiding them.

Pastore, Robert R. *Stock Options: An Authoritative Guide to Incentive and Nonqualified Stock Options, 2nd edition.* (printed Dec. 1999). ISBN 0966889924. PCM Capital Publishing.
This is an excellent reference for those of you fortunate enough to have a bundle of stock options. Give me a few options as a tip for finding this book, ok? :-) The book covers tax and legal issues and gives advice on when to keep or exercise your options.

Ralston, Anthony. The Demographics of Candidates for Faculty Positions in Computer Science. *Communications of the ACM 39*, 3 (March 1996), 78-84.
A must read if you are looking for tenure track positions. The author is a former CS professor who led a faculty search, so if you don’t believe what I say, then listen to him.

Wasserman, Noah. *The Founder’s Dilemmas.* Princeton University Press, 2012.
This book details key decisions and pitfalls in starting your own company.

Weinstein, Bob. *Résumés Don't Get Jobs: The Realities and Myths of Job Hunting.* McGraw-Hill, 1993. ISBN 0-07-069144-4.
Gritty, realistic job hunting guide for today’s market.

White, Pepper. *The Idea Factory: Learning to Think at MIT.* Plume (Penguin Books), 1992. ISBN 0-452-26841-9.
While this is not about C.S., it does dispel the notion of graduate school as an ivory tower environment.

Yate, Martin. *Knock 'Em Dead: The Ultimate Job Seeker's Handbook.* Bob Adams, Inc.
Good generic guide to job hunting and interviews, including a long section on interview questions.

Last updated: Friday. Feb. 1, 2019

Questions? Send email to `ronald.azuma at gmail.com`

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