GRADUATE STUDY IN THE COMPUTER AND MATHEMATICAL SCIENCES:
A SURVIVAL MANUAL

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1 Introduction

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This document grew out of a 1990 set of notes ("Graduate School in Your Future?") that I wrote as director of undergraduate studies in the Computer Science Department at the University of Maryland, College Park. The goal was to offer advice to students on entering, surviving, and thriving during graduate study and beyond.

In writing the notes, I kept in mind the mind-boggling customs and taboos faced by a person who might be the first in the family to attend graduate school. Although it often seems that everyone but you knows "the (unwritten) rules," it became clear to me that the majority of graduate students could benefit from more street smarts, so these notes try to smooth the transition from undergraduate to professional.

Since I deal with both mathematics and computer science majors, much of the advice is addressed to these two groups, but scientists, engineers and others might find some of it useful. It is also rather U.S.-specific, but students elsewhere may find a useful idea or two.

This is a work-in-progress. In particular, the resource section could use some work. The HTML is not fancy, but I hope it is readable.

Your additions to the resource section, comments on these notes, or corrections will be appreciated!

A Note on Reproduction

Acknowledgements

This work was inspired by conversations with Juan Meza and written at the University of Maryland. The resources section drew upon many sources,

especially links found by Tamara Gibson Kolda.

In some sense it is a small repayment of my debt to past and current mentors (Gene Golub, in particular), to friends (particularly my husband Tim), and to agencies (such as the National Science Foundation and the Hertz Foundation) and people who helped me along the way. I'm especially grateful to my parents, Raymond and Anne Prost, for support and guidance.

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2 Graduate School in Your Future?

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This section has been written for undergraduates who might want to consider advanced study in the mathematical and computer sciences. It may raise more questions than it answers. Please contact an advisor or a faculty member if you need further information or advice.

2.1 Why Go to Graduate School?

An undergraduate degree in computer science prepares you for many good jobs: applications programmers, systems analysts, etc. An undergraduate degree in mathematics might have fewer clear career paths (e.g., actuary, teacher). But there are many jobs that require advanced degrees: university professor, head of an industrial research division, etc. And there are many others that are difficult to attain without an advanced degree. Many graduate students report that they returned to school because they quickly reached a ceiling in industry above which they could not climb; project managers were almost always people with M.S. or Ph.D. degrees.

Research teams in the top industry think-tanks (IBM research centers, Google, Microsoft, Xerox PARC, etc.) and government labs (USA: Argonne, Los Alamos, NASA, NSA, Sandia, etc.) consist primarily of people holding masters or doctorate degrees. For better or for worse, the people who have the most flexibility in their choice of projects and methods, whether in industry or academics, are usually those with the highest degrees.

One of the goals of education is to make people aware of how little they know. An undergraduate major acquires a great deal of knowledge, but there are many (fun!) things that you do not have time to explore. The excitement of exploring the cutting edge of knowledge, and the thrill of your first research result, something *you* have discovered that no one else in the world knows, are worth savoring.

2.2 Can You Afford It?

Very few graduate students in the mathematical and computer sciences pay tuition. Because of this, even the most expensive private schools are accessible to most students who meet admission requirements.

Some students are supported by fellowships (i.e., scholarships). These fellowships are based on scholastic aptitude rather than on need. Some are awarded in nationwide competition by government (USA: DOE, NSF) or private foundations. Some are awarded by the individual schools.

Some students are supported by their employers and given full or part release time to complete their degree requirements. Often the student is required to stay with the company for a minimum time after completion of the degree.

The majority of graduate students work their way through school on assistantships, serving as teaching or research assistants. The typical work load is 20 hours per week, and the experience can be a valuable preparation for a career.

Teaching assistants may grade papers, teach laboratory or recitation sections, or be responsible for lecturing to a small section of a course. These assistants work under more or less close supervision by a faculty member, and usually attend training sessions before their first semester as a teaching assistant.

The jobs of research assistants may be less structured. They are responsible for learning about the general orientation of their professor's research and may assist that professor by developing or maintaining software or hardware, writing reports, supervising other students, and presenting research results at meetings.

Students on assistantships have these extra duties, but they also have office space and tend to feel more at home in the department. Students with fellowships or outside support need to make extra efforts to interact with faculty members and network with fellow students.

Typical stipends for fellowships and assistantships include tuition, benefits such as health insurance, and a modest salary. Graduate students generally don't get rich, but they don't starve.

2.3 What Is Graduate School Like?

Think back to the transition you made from high school to college. Your first semester may have been a time of great upheaval as you adjusted to additional freedom and additional responsibilities. Most students find college much less structured than high school, and they need greater discipline to budget their time and complete long-range projects.

Graduate students have much the same reaction as they make the transition from undergraduate life. A typical full-time course load is 9 hours. This means less time spent in class, but the demands of a graduate course are much greater than those of an undergraduate one, and students might spend three or four hours of preparation for every hour in class. Standards are higher: a "C" is often not a passing grade for a graduate student, even in an undergraduate-level course. There are fewer "checkpoints" (exams and due dates), and it is easier to yield to an urge to procrastinate.

A masters student typically completes a specified set of courses in the first year or so, and then spends time working on a research project with an individual faculty member. The completed project is written up as a thesis, and then the candidate gives a talk to a group of three or four faculty members and "defends" the work. The entire process may take two years, perhaps three. Some schools allow a written exam plus a scholarly paper to substitute for the research project.

The Ph.D. student follows a similar track, perhaps taking some required courses and a written exam. Before research is begun, however, there is usually an oral "candidacy" exam during which the candidate presents the research idea and is questioned on the necessary background knowledge. The student then completes the thesis research, writes it up, and has an oral defense. The entire process may take five years of graduate study (three beyond the masters degree), possibly as few as three years or as many as seven years.

The matchmaking of students to thesis advisors is a rather informal process. The student needs some initiative in order to seek out an advisor with compatible ideas and working style.

The thesis writing period is a particularly unstructured one with no exam or homework deadlines to meet. Again, extra discipline is required to keep the work progressing.

2.4 Could You Succeed in Graduate School?

If you are a mathematical or computer sciences major in a top-20 department, typically get A's and B's, have a good deal of self discipline, and are MOTIVATED, then you are a competitive applicant for the best graduate schools in the country. If your department is not top-20, then in addition to the top schools, you might want to apply to some lower-ranked departments as well. If your ultimate aim is a top-ranked school, then a masters degree from a mid-range school, coupled with supportive letters from your professors, can be a stepping stone toward this goal.

2.5 How Should You Prepare for Graduate School?

There are several things you can do (beginning in your freshman year!) that will make admission to graduate school and future success easier. Luckily, they are also good preparation for the business world, so you do not need to sacrifice any of your options.

1. Work hard in your courses, especially computer science and mathematics.

2. Take senior-level core courses in your major as early as you can. If you postpone most of them to your last semester, graduate schools will not have as much information about you.

3. Get to know a handful of faculty members well enough that they can give you advice and write knowledgeable letters about your talent, performance, and motivation. Don't try to go through school anonymously. If possible, choose teachers who are well known in their fields; their opinions mean a lot to graduate admissions committees.

4. Join a departmental honors program. Working on a project is an excellent way to get to know a faculty member, to receive individualized instruction, and to get an introduction to research.

5. Participate in other outside career-related activities. In computer science, look for organizations such as student ACM, the Minority Computer Science Society, programming or robotics contests, etc. In mathematics, learn about AMS, AWM, MAA, etc. See 15 Don't get over-committed, but one or two activities are worthwhile.

6. Apply for a summer internship with a company or government lab (e.g., NIST, any DOE lab) and/or a summer research experience for undergraduates (REU) at your own college or university or another one. This gives you extra experience and perspective as well as more potential people to recommend you for graduate school.

7. Start learning about various graduate schools early, preferably in your junior year. Visit the websites of schools of interest to you and of possible advisors at those schools.

Start working on the application process early in Fall for admission the following Fall.

- Watch for deadlines to take the GRE Exam, the "SAT" of graduate school. See 15. Plan to take the exam by early fall.

- Explore fellowship opportunities. Contact the NSF and other agencies. Talk to your advisor and ask for pointers. See 15.

- Plan to apply early: deadlines may be in December or January, particularly if you are seeking financial aid.

- Choose as references faculty members who know your work well. Talk to them about your goals.

Some students go on to graduate school directly after completing their undergraduate degrees; others gain some work experience before returning to school. There are arguments for and against each choice, but if your motivation is high, generally sooner is better, especially if your goal is a Ph.D.

Don't sell yourself short: if you are a high-achieving undergraduate, then you have the potential to be a very successful graduate student. Be prepared to work hard, but don't be afraid to accept the challenge.

3 Applying to Graduate School

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3.1 Where to Apply

It is usually wise to go to a different school from your undergraduate institution in order to gain an alternate perspective. Personal reasons might limit your flexibility, though, and staying at your strong undergraduate institute is not a disaster.

If you are not restricted to the immediate area, apply to your undergraduate institution as a backup, but consider a variety of top departments. For example, computer science students might consider Stanford, MIT, University of California Berkeley, Carnegie Mellon, Cornell, Princeton, University of Texas Austin, University of Illinois Urbana-Champaign, University of Washington, University of Wisconsin, Harvard, California Institute of Technology, Brown, UCLA, Yale, University of Maryland, University of Massachusetts Amherst, and Georgia Tech. Even better, talk to a faculty member who does research in an area that interests you and ask for advice about the best schools in that particular subject. The list is often quite different from the list of strong departments overall.

Departments are ranked in a (quirky) yearly survey by *U.S. News* and other surveys, and by old publications of the National Academy of Sciences.

Apply to several departments: there is an element of luck in the admissions process, and for each research interest, there are a number of strong schools that are good choices.

See Section **??** for some helpful links.

3.2 How Do Schools Choose Their Students?

The application process provides a tremendous amount of data to a department admission's committee, but people who have served on such committees can tell you that there is still a large element of uncertainty in sorting out the strongest applicants.

Different departments put different weights on the various components of the application, but here is what an "ideal" application might look like:

- A strong undergraduate record, with a substantial number of advanced courses in the mathematical and computer sciences, and a good number of A's in these courses.

- Letters of recommendation by trusted colleagues. (It is only human for an admissions committee member to say, "Prof. X wrote a strong letter for Z last year, and Z is doing well here. I can trust what X says about students this year," or "Prof. X is a leader in the field, so I can trust X's assessment of whether this student can succeed in our graduate program.")

- GRE scores that indicate past achievement.

- At least a modest number of outside activities and interests that indicate a well-balanced individual.

- An essay that is well-written, discusses previous accomplishments, shows motivation, and specifies some goals, even if they are somewhat vague.

- Some research experience, perhaps in a summer program labeled "Research Experience for Undergraduates (REU)" or in a summer internship at a corporation.

If you come from a small college that doesn't have a strong program, the admissions committee will be asking questions such as these: Did the student make the most of the opportunities provided at the college? (Evidence might include taking the hardest courses, doing a senior thesis, or doing an internship.) Do the letters say that this student is a self-starter, has gone beyond the course material, or is among the best students at the college? Is the student ready for our graduate level classes? Does the research statement indicate a focus and a motivation strong enough to sustain the transition to a "bigger pond"?

If you are not admitted to the department you want, you might work your way up the ladder by obtaining a master's degree at the best institution that admitted you and then reapplying to PhD programs.

3.3 Making a Decision

Suppose you are in the lucky position of being accepted to more than one graduate program. How can you decide which offer to accept?

- Think about what factors are important to you. The strength of the department should be high on your list, but you also need a place where you can feel comfortable enough to function well. Make a list of what is important, and then try to find out how the candidate departments measure up.

- Gather as much information as you can—graduation requirements, lists of courses currently offered (as opposed to those officially in the catalog but never taught), lists of faculty and their research interests, staff benefits (insurance, etc.), syllabi for courses and exams, etc. Much of this information should be available on the Web.

- It is becoming quite common for admittees to visit various schools before making a decision. Some departments even pay for part of the expenses of the visit for their top candidates.

Let the department know when you plan to arrive. Arrange to tour the facilities and talk to one or two professors and a few graduate students.

Wander around on your own, too. Visit the computer labs, the library, the bookstores, etc. Get a feel for how well the department and the school function.

Ask lots of questions—about the program requirements, the research strengths, the climate for graduate students, housing—about whatever is important to you. Trust your instincts: if the department feels wrong for you, it may well be!

- If you cannot visit in person, ask the department to arrange a phone interview or chat with some faculty members and graduate students. E-mail can also be used for this purpose.

- Talk to the people who wrote letters of recommendation for you. It is a chance to thank them, to let them know that their letters had good effect, and to ask advice.

4 The Life of a Graduate Student

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The life of a graduate student is much less structured than that of an undergraduate. Hours in the classroom are fewer, although hours of course-related work are greatly increased. The structure that might have been imposed on your undergraduate life by the routine of a dormitory, sorority, or fraternity is gone. You may find yourself far from home for the first time, or you may find that your family responsibilities are increased by marriage or parenthood. In any case, there will be more responsibilities to juggle and fewer fixed points to rely upon.

The next sections consider the major elements in the life of a beginning graduate student, some tools to help manage the workload, and sanity preservation. See Sections 15.2 and 15.5 for relevant links.

4.1 Courses

Graduate school gives you new freedom and flexibility in your choice of courses, although it might be a year or two before you experience this.

While the typical undergraduate carries 15 or more credit hours, the typical graduate students carries 9 or fewer. Expectations from the instructors are higher, however: you *really will* need to allow one or more study hours for every class hour. Different professors have different styles. Sometimes the instructor will lecture to supplement the text, and you will be required to master the textbook material on your own. Sometimes there is no text, so outside hours are spent in doing the suggested reading or in filling in the gaps in the course notes. Sometimes the students do the bulk of the presentations, with the instructor acting as resource person.

Choosing courses for your first semester must be done with care. Make use of your official academic advisor, the instructors for the courses that interest you, and fellow students. If you have any doubt about whether you are over- or under-prepared for a course, talk to the instructor about your background and get advice.

If you enter graduate school unprepared in some aspect of your major, remedying that deficiency should be your first priority. Try to take the elementary courses you are missing within your first year of study, but make sure that you also include some graduate courses if possible so that you can hasten your adjustment to graduate life.

Most departments have a set of course requirements or a set of exams that students are expected to pass within a given amount of time. Your second priority is to take the courses that will lead you to fulfilling these requirements. It is tempting to sign up during your first semester for several advanced seminars in a specialized area, but you cannot afford much time for this unless they fit into your plan of fulfilling the basic requirements. There will be time later to take advanced courses in the areas that interest you, and you may get a lot more out of those courses if you master the basics first.

On the other hand, it is a good idea to develop a good working relationship with a person whom you consider to be a good candidate for a thesis advisor—someone actively working in an interesting field who is willing to make time for you. It might be useful to take one advanced course during your first year or so with this person. Ph.D. students will also want to get a small start on research if at all possible.

Once you have completed the basic course requirements, you have additional flexibility. Strive for breadth in your knowledge even if not required for graduation. Often careers take unexpected twists, and an area that is now peripheral to your interests may be central later on. Strive for depth in your research area: make sure that you understand the full range of research problems.

Once you are past all the hurdles and are working on your thesis, your course work should be very selective. Don't dilute your energy by taking too many courses, but don't miss special opportunities such as seminar courses by top researchers.

If more than one section of a course is offered, get advice on which instructor to choose. In general, regular faculty are to be preferred to visitors teaching basic courses, so that you get to know the people with whom you will be working. Try to choose faculty who are possible advisors. If that is not possible, choose the ones with the best teaching reputations, but try for a healthy mix of junior and senior faculty. Remember that eventually you will need a set of letters of recommendation in order to find a job, so it is a good idea to become known to the faculty early.

Don't make your course decisions in a vacuum. Talk to your advisor about what background would be helpful for work in a particular area. Talk to fellow students about what courses are most useful and what professors are best teachers. Talk to the instructors of courses you are considering if you have any doubts about the course syllabus or your preparation for the course.

4.2 Life as a Teaching Assistant

The job of teaching assistant is a crucial one. The success of the course you are assigned rests in great part on your performance. The instructor sets the tone and the standards for the course, but you have several critical jobs:

- You are the student's best hope of understanding concepts that the book and the instructor fail to communicate. Whether you meet the students in office hours or in a recitation or lab session, or just answer questions online, you need to be well-prepared: read the relevant part of the textbook, know what the instructor has covered in class (in particular, the special notation used and supplementary information introduced), and solve the homework problems.

- You are eyes and ears for the instructor. A good instructor will appreciate regular reports from you on any errors you find in the handouts or homework assignments, what is confusing the students, and what concepts need more motivation. What the students tell you is important!

- You set standards of integrity and fairness. Your grading must be careful and objective and prompt, so that students are evaluated fairly and get quick feedback on their mistakes. You must put aside any prejudices in your interaction with students, treating each one with respect and an expectation that each can master the material. You must be alert to any attempts at cheating, and you must discuss any suspicious actions with the instructor.

- You can use the job as an apprenticeship, learning how (and how not) to teach from close observation of the instructor and from trying various techniques in your own interactions with students. Make use of your fellow teaching assistants, your instructor, and any campus teaching excellence offices to learn to communicate knowledge!

Some useful teaching advice can be found in Section 15.7.

4.3 Life as a Research Assistant

The job of a research assistant is amorphous, ranging from clerical help in finding references, to performing calculations or writing computer code to match precise specifications, to participation as an equal research partner with your supervisor. Usually the responsibilities increase with your experience, and if you find your duties to be too routine, make sure that your supervisor knows that you are ready for more responsibility.

You will probably be working on a very small part of a rather large project, but your role is crucial:

- Try to keep the big picture in mind. Ask your supervisor if you may read the research proposal under which you are funded, so that you can see how your project fits into the larger scheme of things.

- Try to keep your task clearly in your mind. Make notes immediately after talking to your supervisor so that you don't forget anything.

- If you have questions or are stuck, get help! Ask other students who are working on the project, or contact your supervisor as quickly as possible. Don't drift! Each project has a deadline, and it is important that you stay on track.

- Stay in close contact with other graduate students on the project to see how they are progressing and to provide sounding boards for each other's ideas. On the other hand, don't hinder their work by constantly distracting them.

Sometimes a major source of contention between a research assistant and a supervisor is how much credit should be given to the assistant when joint work is published. In general, a research assistant should be listed as a co-author if the work could not have been completed without the creative intellectual input of the assistant. If the assistant carried out the instructions of the supervisor in performing some computations or writing computer code to accomplish a task, then the supervisor is the author, but an acknowledgement could be made of the assistant's contributions. "Helpful discussions" between the supervisor and the student should be acknowledged as such. If a calculation required special expertise that only the assistant had, or if the work succeeded only because of a special set of new ideas designed by the assistant, or if the assistant found and fixed a major flaw in the supervisor's idea, or if the assistant made major suggestions for improving or extending the idea, then co-author status would be merited. Sometimes it is difficult to agree on the definition of "major" contribution. If the supervisor and the assistant disagree on whether the assistant should be a coauthor, the assistant should ask advice from another faculty member or student. In most cases, contesting a gray-area decision on co-authorship is not worth the resulting ill-will, but serious injustices should be resisted.

4.4 Life on a Fellowship

Some students are supported by a fellowship, a grant from their university or some outside agency. The funds may cover tuition and also provide a living allowance.

Unfettered by the responsibilities of being an assistant, graduate life can seem rather uncomplicated. This is largely an illusion, though, since the toughest part of graduate school is study and research!

There are a few pitfalls to avoid if you find yourself fortunate enough to have fellowship support:

- It can be more difficult to settle down to research, mainly because your fellowship support can make it tempting to just drift rather than actively seek the right advisor. You will need to make the effort to meet faculty members and get involved in seminars and independent study until you find your place.

- Try to get office space, at least once you have a research advisor. Without a desk, it can be difficult to make contact with fellow students or your advisor, and a place to work away from home is quite important.

- If you think you might want to become a professor, you might want to volunteer to TA for a semester in order to get some experience. This can be helpful in deciding whether the academic life is right for you, and it is a definite asset during a search for an academic job. Some graduate programs require teaching as part of the Ph.D. requirements.

4.5 Life with an Outside Job

If you have a full or part-time job outside the university, you may feel that you are between two worlds, without belonging to either one. Neither the university nor the workplace is well adapted to dealing with the other, and each may place demands that are incompatible with those of the other.

Your biggest problems may be the double commute, scheduling difficulties, and isolation.

While you are taking courses, each semester will bring challenges of how to arrange to be on campus at the necessary times without unduly hampering your work. Don't make the mistake of believing that you need time off only for going to class; a graduate student may need time for access to resources (e.g., labs or libraries) that have limited hours, for meeting with instructors or teaching assistants in their office hours, and for meeting with other students for group projects. Email, remote computer access, and other electronic communication will alleviate some of these problems but not all of them.

Many departments put time limits on progress toward degree that are incompatible with part-time status. Know and understand the rules, and have a plan to deal with them, either by taking a leave of absence from your job or by working as if you had two jobs.

Later, when you are involved in research, you will need to carve out time to meet with your advisor, as well as time for your thesis research.

Since you do not spend as much time on campus as a typical student, you may find it harder to get to know your colleagues, find study groups, and generally learn the ropes. Consider some of the advice given above for fellowship students.

4.6 Social Life

In some departments, the graduate students form relatively cohesive groups, organizing lunches, social hours, and excursions. In others, there is little interaction. Even if a department is relatively "cold" when you arrive, it only takes a few people to "warm it up." Try to get a core of interested students, and aim for establishing a graduate student lounge, a student chapter of MAA, ACM, SIAM, or IEEE, a weekly brown bag lunch (perhaps inviting a faculty member or a finishing student to give an informal presentation), or a monthly excursion.

If interactions within the department look hopeless, try making contacts in another science or engineering department, or through the graduate school of your university. The gym or a special interest club could lead to good friendships.

4.7 Becoming a Professional

You are on your way to becoming a professional, and you should act the part! If you haven't already, it is past time to join the important professional societies in your field:

- Computer Science: ACM: The Association for Computing Machinery.

- Computer Science / Engineering: IEEE Computer Society.
- Mathematics: AMS: The American Mathematical Society.
- Mathematics Education: MAA: The Mathematical Association of America.
- Applied Mathematics: SIAM: The Society for Industrial and Applied Mathematics.
- Statistics: ASA: The American Statistical Association.
- Women: Association for Women in Mathematics, Association for Women in Computing, SWE: Society of Women Engineers.

See Section 15.1 for links to these and other professional societies.

Watch the meeting schedules for your societies, and if any meeting in your research area is taking place close to home, find your way to it! If you are well along in your research, ask your advisor and your department to give you partial support to attend the right meeting, close or far!

There are also important contacts to be made by email. Several research areas (e.g., numerical analysis, approximation theory, and most computer science areas) have mailing lists or websites devoted to announcements of meetings, research results, open problems, and queries. Read them, and respond if appropriate, but keep in mind that you are becoming a professional, and your messages should not be frivolous or "flaming".

There are also resources for women and minorities in math and computer science. See 15

4.8 Maintaining Sanity

No student gets through graduate school without experiencing a significant amount of stress. There is always too much to do, and not enough time to do it. Sometimes it is not even clear what should be done—only that it should be completed now. It may seem that everyone except you is competent (the "imposter syndrome") You may doubt your intelligence, your creativity, your motivation, and perhaps even your sanity.

This is normal, and probably unavoidable. But there are certain factors that will make your life smoother.

To prevent Failure in graduate school, rely upon as many of these F's as possible:

- Friends. Use them as sounding boards, as shoulders to cry on, and as non job-related companions. And make sure that they can rely on you for the same things.
- Faculty. Try to find a supportive faculty member other than your advisor: perhaps someone in a closely related field, a former teacher, or someone

(perhaps a woman or minority member) you feel some kinship with. Make it a point to stop by once a month or once a semester just to report progress (or lack of it) and problems, and to get another perspective. If you can't find such a mentor locally, try one of the mentoring programs listed in Section 15.3.

- Family. The support of your family is a great resource. A healthy adult relationship with your parents can provide a great sense of security. The time you spend with spouse or children or other loved ones is a good way to recharge your batteries and remind you that career is not everything.

- Faith. A belief in God or a theory of why you are where you are can be a source of strength in keeping your perspective and knowing that hard times will pass.

- Fitness. The healthier your lifestyle, the more energy—especially creative energy—you may draw upon.

- Fun. Make time in your life for the other things you enjoy, whether music, theater, reading, art, or sunset watching. You are a scholar, and you need some balance in your life. You will be more efficient during your working hours if you allow yourself to shift gears and relax in your off-hours.

If, despite your efforts at balance, you find yourself depressed or having thoughts of suicide, don't hesitate to seek help. Also seek help if you find yourself regulating your mood with alcohol or illegal drugs. Most campuses have a health center through which you can easily find professional care. Seeking help when you need it is a virtue, not a weakness; failing to seek it when you need it is a mistake. See Section 15.5 for some resources.

5 Surviving Written Exams

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Many departments use a written exam as a major component of the graduate degree requirements. Typically, the exam covers three areas of your major in depth equivalent to one or two graduate level courses plus their prerequisites. Sometimes, though, the purpose is to ensure breadth at an undergraduate level, and the exam might cover the content of perhaps 5 undergraduate courses. Less commonly, there may be a "practical" component to the exam, requiring you to write a program or solve an applied problem within a specified time limit.

Whatever the level of the exam, there are some features that distinguish it from exams within courses:

- It is a one-time event. Thus, there is no chance to adapt to the style of your examiners' questions and grading idiosyncrasies.
- Ideally, the exam tests whether you have assimilated the material in a way that draws connections among courses. Thus, reasonable questions include all those that might be asked in a course exam, plus "metaquestions" that draw on the knowledge of several courses at once.

5.1 Preparing for a Written Exam

Here are some suggestions on preparation:

- Make a study plan. Know when and how you are are going to master each component.
- Most students find a study group to be helpful. It keeps studying a top priority, since you are responsible to the group to present certain material or discuss your answers to certain study questions. It gives you access to other people's problem solving skills, and a lot can be learned from that! Group members have a sense of working toward a common goal, and can support each other to combat the isolation and panic that single studiers can experience. Beware of groups that spend more time in socializing than in work, and groups in which the members come unprepared, but in general, the group is a useful tool.
- Even if you belong to a group, realize that preparation for the exam will require a significant investment of your solitary time. You need to prepare for the group session, and do extra work in the areas you find hardest.
- Don't just read the textbooks passively. Take notes! Try to explain the material to an imaginary audience! Look at the examples in the text but

then close the book and try to work through them before you check how the author did them. Work problems in the backs of the chapters. Work problems from old exams. If you cannot work a problem, seek help from more advanced students or a professor. If you find a problem hard but doable, go back and rework it in a couple of weeks to make sure you have mastered it. Finally, have a set of notes of facts and formulas that require memorization, and spend the last few days mastering them.

- Some schools have open book exams. Don't mistake this for a chance not to study. Many students spend 90% of their time in an open book exam leafing through the textbooks, not a good recipe for success. Have your material organized so that you can find any fact you might need. If possible, have 6–8 pages of notes with all of the facts and formulas you think you might need. Study just as hard as for a closed book exam; the only step that you can skip is the final memorizing of facts and formulas.

- Pace your study so that you have adequate time for the other demands in your life. Start early enough so that your job, family, course work, recreation, etc. still fit. Don't let yourself get exhausted from worry or work. An exam can change the course of your life, but it can't ruin it.

5.2 In the Exam

Follow the common sense rules that have gotten you through other exams:

- Come well prepared, with a good night's sleep, writing implements and scratch paper, a watch, and, if permitted, notes and books and a snack.

- Read all of the questions before you begin, and try to allocate your time.

- Do the easy problems first, trying to pick up fast points.

- Don't be discouraged by what you don't know; concentrate on what you do know and what you can derive.

- Make your answers well organized and legible; this will make your grader much more relaxed in reading your work.

- If time permits, check your work.

- If you believe that a question covers material not on the syllabus, note this on your answer sheet, but still try to answer the question.

5.3 After the Exam

If you fail the exam, make an honest assessment of your weak areas and prepare to try again!

Most departments have procedures for appealing the results of an exam. If you believe that your exam has been graded incorrectly, compose a thoughtful, concise, and non-belligerent summary of what you believe the error to be. Don't "nickel and dime" the graders, disputing every point. Concentrate on errors that you can document in textbooks or by other objective means.

6 Surviving Oral Exams

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To do well on an oral exam requires a rather different set of skills than those called for on a written exam. You still need mastery of the material, of course, but you need to access and articulate the material in a different way.

Most people find oral exams harder than written, but some really enjoy them!

In a well-designed written exam, the examiner has decided in advance what set of knowledge and skills is to be tested. Problems are designed to be completed within the given time limit, but some false starts and backtracking are expected. Each problem has a known correct answer.

The oral exam differs in each of these characteristics. Although the scope of the exam is given in advance, the examiner usually chooses questions dynamically, based on how the student answers the previous questions. Problems are designed to test the limits of the student's knowledge: often, an examiner will continue to ask questions in a particular area until a student no longer responds correctly. Examiners design problems (or give hints) that elicit the correct approach on the first try, without backtracking. And often the questions are open ended, asking for opinions or ideas for future work or aspects of the research area that the student has not yet considered.

Because of these factors, preparation for an oral exam requires a new approach, even for seasoned veterans of written exams.

You need to think on your feet. This is great if you have the skill. Otherwise, you can only compensate by great preparation.

Some previous experience is helpful: teaching, debating, oral presentations, tutoring, class participation, recitals, science fairs, etc.

6.1 Preparing for the Exam

The exam is usually tailored to the interests of the particular student. In this case, it is important to have a clear meeting of the minds between student and examiners on what material it included in the exam. Usually this is done by preparation of a written syllabus by the student, with the advice and consent of the examiners.

- Read and understand the department's rules for the exam. If you have procedural questions, ask them well before the exam.

- If exams are open to other students, sit in on one to get a feeling for the scope and format. Ask more advanced students for their experiences and advice. Ask your advisor.

- Choose your syllabus carefully, if you set it yourself. Make sure that it is limited enough to be a coherent body of information that you are able to master and that your committee is comfortable with it. If the syllabus is set by others, make sure you understand its scope clearly and are prepared for all of it.

- If you can choose your examiners, consider your options carefully. Choose people you are comfortable with, and avoid putting two people on the committee if they cannot get along with each other.

- Set up a study plan—when you will study, and in what order you will work through the material.

- Read and understand each item on the reading list, but also understand the relations among the items. Was x influenced by y? What does x think about the work of y? What common tools do x and y use? What is the contribution of x?

- Be prepared to lecture on the material—present the ideas clearly, give examples, work examples provided to you, prove theorems, compare different approaches, say what's 'new' about results in a given paper, discuss the strengths and weaknesses of an approach.

- Practice in front of a board. Even better, practice with other students who are taking the exam at roughly the same time. Get more advanced students to ask you questions. Check that your voice is loud enough. Aim for a logical presentation of ideas. Make sure that your English is understandable, even if it is not your native language.

- Ask your advisor to give you a few practice questions and critique your performance.

- If you provide any written material for the committee (proposal, thesis, etc.), check in with each member during the week before the exam, asking for any questions or suggestions. Some examiners don't read the package in advance, but others may appreciate the chance to clear up some issues, and this can prevent unpleasant surprises at the oral exam.

6.2 In the Exam

Sometimes the exam begins with a presentation by the student of initial research results or background material for a given research area. This talk should be carefully prepared, usually using slides. The presentation should be clear, well-rehearsed, and succinct. Your visual aids should be carefully organized and easy for you to navigate. Give some indication of what the problem is, why it is important, what you have accomplished, and what you hope to accomplish in the future. Sympathetic colleagues or your advisor can give very helpful advice if given a chance to listen to a rehearsal.

The rest of the exam is less structured. The examiners rotate, asking questions in turn. Sometimes one examiner will ask an entire set of questions in a row; other times the examiners interleave their questions with others.

Listen carefully to questions and make sure you understand exactly what is being asked. Follow instructions exactly – if a short answer is requested, keep it short. If more detail is desired, give a longer response.

Don't interrupt a questioner. Wait until he/she finishes the question before you start to answer.

Good examiners will ask you questions on a given topic until they tire of it or until you answer incorrectly. It is all right to be wrong—the purpose of the exam is to discover the limits of your knowledge, and it is all right to have finite limits! Students pass even if they don't know everything asked!

An important rule is to pause briefly after each question is asked. Take just a moment to compose your thoughts, decide what notation is necessary and appropriate, and organize your answer. If you do not understand the question, ask the questioner to rephrase it, or give your interpretation and ask if that is what is meant.

If you are sure you cannot answer the question, it is best to admit that and go on, rather than wasting time and focusing the examiner's attention on what you don't know rather than what you do.

If you are confident about a question, answer as directly as you can, but feel free to make comments about the relevance of this result to your work, etc.

Remember that each new question is a fresh start. Let the old one go. Don't get flustered—remember that the examiners expect you to be unable to answer some questions—that's how they explore the limits of your knowledge.

If you do find yourself losing your composure, ask the examiners for a brief break to get a drink of water or to sit down for a minute. You may be reluctant to delay them this way, but it saves time in the long run to get an accurate assessment of your abilities the first time.

Remember that an oral exam is an exhausting experience—comparable to running a marathon. Pass or fail, try to give yourself a break on other activities immediately before and after the exam.

6.3 If Things Go Wrong...

If you believe that the question covers an area not on the syllabus, it is best to state that directly and non-belligerently, but then answer the question if you can. If it does make the difference between a pass and fail, then you are on record as objecting to the question before failing the exam, and this lends credibility to the objection.

Occasionally, you may find committee members more intent on impressing or belittling each other than they are on exploring the extent of your knowledge. There is not much you can do about this other than staying strictly neutral and trying to avoid assembling the same group for any subsequent exam.

Bias can also be a factor in your exam performance. If you believe that an examiner was predisposed to fail you, try to document how that person's examination of you differed from his/her examination of some other student. Consider trying to get the person excluded from your next exam.

If you fail the exam, make an honest assessment of your weak areas and any weaknesses in your presentation style. Practice. Study. Ask advice from your advisor. Try again.

7 Finding and Dealing with an Advisor

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The choice of advisor is probably the most important one that a graduate student faces, yet it is often done haphazardly.

7.1 What to Look for in a Potential Advisor

The ideal advisor might have the following traits:

- **Has research interests in common with you.**

  Work is easier when both you and your advisor find the research area fun.

- **Has a national or international reputation among researchers.**

  Someday you will finish your degree work and be looking for a job. Your advisor's reputation and professional colleagues could be key in opening opportunities for you.

  More immediately, your advisor will be leading your research, at least at the beginning, and it is important that the advisor knows how do do quality research.

- **Has grant support for research.**

  If you are working your way through school as a teaching or research assistant, you may well want to be supported as a research assistant by your advisor. Even if you have fellowship support or an outside job, grant support is a sign of your advisor's skill as a researcher, although in a few areas of mathematics and computer science, research assistantships may be rare.

- **Has successfully directed students in the past.**

  You are new at research; it helps if your advisor has some experience in dealing with graduate students.

- **Has a reputation as a fair and reasonable advisor.**

  You don't want to work with an advisor who never shares credit for ideas, who expects every student to spend 7 years as a research assistant, or who doesn't know how to motivate and encourage students.

- **Has a high probability of staying at the university.**

  If your advisor moves to another university before you finish your degree, while you are trying to finish your work, you will have a severe handicap.

You may need to consider moving with your advisor or changing advisors—a difficult situation at best. Even if the advisor goes travelling for a year on sabbatical, communication can be temporarily difficult.

- **Is someone you like and admire.**

  You will be working closely with this person until your graduation, and the relationship will not end even then. The more comfortable the two of you are with the relationship, the fewer distractions from the research at hand.

- **Has an active research group.**

  You can learn a tremendous amount from more advanced students, and the opportunity to work in a group of motivated researchers working on similar topics is quite stimulating. Be aware, though, that if the group is too big, you will have little time with your advisor; you may be directed by a post-doctoral student or a more advanced graduate student.

7.2 How to Find an Advisor

Before you came to your university, you might have made sure that some faculty members were active researchers in areas of interest to you. Now is the time to consider each of those candidates as a potential advisor, measuring them up against the criteria in the previous section.

Use homepages, GoogleScholar, *Science Citation Index*, *Math Reviews*, or other electronic resources to find recent publications by each candidate. Read a few of these publications, and try to understand them enough to be able to ask intelligent questions and to see directions for further work.

Get to know potential advisors by taking courses from them, attending seminar talks given by them, and seeing them in their offices (by appointment or during office hours) to talk about their research interests. Ask for relevant papers to read.

Talk to other students about various candidate advisors.

Get advice from faculty members that you respect or from the graduate office of your department.

If your potential advisor is untenured, try to find out the prospects for promotion and tenure. Perhaps some other graduate students can help. Otherwise, good indicators are strong publications in major journals, some grant support, and a good teaching record.

Once you have a good candidate advisor, ask that person to be your advisor. Don't be discouraged by a "no"—try a different advisor. Good advisors are much in demand, and they don't remain good if they stretch themselves too thin.

7.3 The Advisor-Advisee Relationship

The best analogy for the relationship between an advisor and a student is probably that between a parent and a child.

> *At the beginning, the child has little independence, and almost every action is directed by the parent.* Initially, most students need close supervision, being told what papers to read and what tasks to accomplish.
>
> *As the child grows, independence develops.* A student begins to ask interesting research questions with minimal prompting and can set the direction of the next week's work. The advisor still plays a crucial role as catalyst and evaluator of ideas.
>
> *As adolescence sets in, conflicts arise.* The student realizes that all too soon, school days will end, and it will be essential to be able to function on one's own. A student eventually may feel that research would be more easily finished without the advisor's "interference," even though the student may lack the detachment necessary to evaluate the work. Independence is frightening, but dependence is resented, and frustration can run high.
>
> *In adulthood, parent and child redefine the relationship.* The process of graduate school should transform the advisor's student into the advisor's colleague. The two may or may not continue to collaborate after the student graduates, but future contact is ideally built on mutual respect, gratitude from the student to the advisor for the professional formation, and pride of the advisor in the student's accomplishments.

It is important that the advisor and advisee develop a compatible working style. Some people thrive on regular weekly meetings between the two that force the student to synthesize the week's accomplishments (or to explain the reasons for the lack of progress). Others rely on chance encounters in the hall. Some advisors have weekly group meetings at which each student discusses progress and everyone can comment. Some advisors expect students to attend seminars or journal clubs in order to keep up with recent research results.

If you feel that you are floundering (as every student sometimes does), ask your advisor for extra meetings, send frequent email messages asking for pointers, or discuss your work with another trusted faculty member or student.

As in any relationship, conflicts should be faced and discussed. Cultural and generational differences can lead to misunderstandings that are easily resolved once they are recognized. Sometimes a fellow faculty member or graduate student can lend some insight.

In rare cases, the relationship just does not work. In such cases, the student should seek another advisor, leaving the first with as little ill-will as possible.

8 Finding a Topic and Beginning Research

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There are some aspects of graduate school that are more daunting than others, and finding a research topic is perhaps the biggest obstacle for most students. The characteristics of an ideal topic are to some extent incompatible:

- The subject should be timely. Previous groundwork should leave your research problem ripe for completion, and it should be in an active area with potential for future work and employment.

  On the other hand, if a field is too crowded, and the subject too prominent, then you risk being "scooped" by a more experienced researcher who is able to work faster than you. In this case, you may be forced to start over again (rather disastrous) or at least publish jointly (possibly a blessing, but surely an inconvenience).

- Your work should lead to a well defined set of results to which you can lay claim. In particular, employment prospects will be lessened if you merely complete a small piece of a very large project or piece of software which is closely identified with your advisor, or is published with a long list of collaborators.

  On the other hand, it is impossible to work in a vacuum, and your task can be significantly harder if you don't have a group of people working on closely related problems with whom you can interact and share code.

- The best theses show a high level of creativity - and are often somewhat speculative. It is often unclear at first how the ideas will develop.

  On the other hand, a multiyear plan of research is a very valuable asset.

- You should really enjoy the subject, and want to spend the next several years with it!

  On the other hand, an ideal subject is of no use without a thesis advisor who is willing to direct you in it.

Clearly some compromise is necessary here!

8.1 Getting Research Ideas

8.1.1 Becoming an Active Reader and Listener

It is very important to make the transition from the passive mode of learning that traditional lecture courses encourage to an active and critical learning style. Whenever you read technical material, evaluate a piece of software, or listen to a research talk, ask yourself these *canonical questions*:

- From where did the author seem to draw the ideas?
- What exactly was accomplished by this piece of work?
- How does it seem to relate to other work in the field?
- What would be the reasonable next step to build upon this work?
- What ideas from related fields might be brought to bear upon this subject?

One technique that some find helpful is to keep a written log of technical reading and listening. Review it periodically to see if some of the ideas begin to fit together.

8.1.2 Exposing Yourself to Research

Set aside some time every week for trying to generate research ideas. Some possible catalysts are:

- Make a weekly effort to read at least the abstracts from the premier conferences or journals in your field. Choose an article or two to read in depth and then critique it.
- Make a weekly search to find preprints in your field. Read selectively and critique.
- Attend a research seminar or colloquium series. Listen and critique.

Add these to your log, and ask the canonical questions. As you review the log 6 months from now, you may find something that has become important to you but was beyond you when you first encountered it.

8.1.3 Directed Study

Which comes first: the thesis advisor or the thesis topic? The answer is, both ways work. If you have identified a compatible advisor, you could ask for an independent study course. Both of you together set the focus for the course, with you having more or less input depending upon your progress in identifying a subfield of research.

8.1.4 Developing the Germ of an Idea

Once you have identified a topic that looks feasible, make sure you are aware of all of the literature in the area. Keep reading and listening, and keep distinct in your mind what is different between your work and others. If you do not frequently review the literature you read months ago, you may find yourself unconsciously claiming credit for other people's ideas. On the other hand, don't let other people's frame of mind limit your creativity.

8.2 A Pitfall to Avoid

It is possible to spend almost all of your time in literature review and seminars. It is easy to convince yourself that by doing this you are working hard and accomplishing something. The truth of the matter is that nothing will come of it unless you are an **active** reader and listener and unless you assign yourself time to develop your own ideas, too. It is impossible to "finish a literature review and then start research." New literature is always appearing, and as your depth and breadth increases, you will continually see new connections and related areas that must be studied. Active listening and reading must be viewed as "continuing education" that will involve you for the rest of your career. Don't fool yourself into thinking it must be finished before you can begin research.

8.3 Choosing an Idea

From reading, interacting with your advisor during independent study, or working on a research assistantship, some possible projects will emerge. Make a list of open problems and possible projects that are of interest to you, and discuss them with potential advisors.

8.4 Remain Active

Even after you have decided on your initial focus, it is important to continue a routine of reading new material and attending seminars. All of these sources can contribute to the development of your idea.

At this stage you can add one question to the canonical list: How can these ideas help me solve my research problem?

Remember that often the initial idea is quite far from the final thesis topic. If you remain active in reading and listening, it will be much easier to generate alternative topics if the time comes.

9 The Thesis Writing Process

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Most students find that doing the research for the thesis is the most challenging part of graduate school. They often budget their time to allow a very short period for the actual writing of the thesis.

This plan invariably leads to an unpleasant surprise: writing results in a form that other people can understand is a **very** slow process! Here are some of the often unanticipated reasons:

- In order to get a well-written paper, the first 2 or 3 drafts must often be completely discarded!

- In the course of your several years of research, you have probably changed notation several times, developed new points of view on your work, and developed many results that looked significant at the time but now seem to contribute nothing toward your final product. Sorting through all of your work and reorganizing it is a lengthy process.

- Even if you have several technical reports, conference papers, or journal articles discussing partial results, the audience for your thesis is different, and thus the style of exposition must be significantly changed. A research paper is addressed to a group of experts in the field, who presumably know the literature and the background issues quite well. A thesis is written more for the generalist. A thorough literature review must be included, as well as an evaluation of where your work fits into the scheme of things.

- All the small details that were put off and forgotten must now be filled in. Citations must be checked, the historical progression of various results must be carefully documented, the "trivial cases" must be worked through, the documentation of your methods must be complete.

- Your thesis advisor will probably have strong opinions on how the work should be presented. Adapting your style to these requirements will take some flexibility and thought.

- Your committee members, your first detached readers, will often find undefined jargon or symbols, holes in your arguments (or at least in your presentation of them), and other deficiencies.

Even after you are on track, you will probably find that a "good" day of writing produces about 5 pages, leading to an overall average of perhaps a quarter page per day.

9.1 How Can You Minimize the Pain of Writing?

Some habits begun early in your research will help:

- Keep careful notes about your work. You might choose to keep bound logbooks (square ruled paper is helpful) or on-line notes. Write your notes regularly: write up every new result, but make an entry at least weekly even if you believe that nothing of significance has been accomplished. Even noting what you are thinking about can be helpful.

- If possible, write up each piece of the work for publication as it is completed. This makes the final writing easier because each piece is documented at its completion time rather than months or years later, and the early write-ups give a basis for organizing the thesis. In addition, it establishes your reputation early and makes the job search much easier.

- As you read other theses and published works, be a student of technical writing styles. Find out what works and what doesn't. Study a good writing manual; see 15.

A student who has developed skill at writing non-technical term papers as an undergraduate will have an easier time of learning to be a good technical writer, but there is one additional skill that must be added: you must also be a good teacher!

When you write a term project, you are explaining the work of others. You have a good idea of what is immediately obvious and what is more difficult to grasp, since you recently went through the exercise of grasping the material yourself.

It is easy to be fooled into thinking that since something is now obvious to you after several years of study, it is also obvious to your reader. The most difficult part of thesis writing is organizing and presenting your material in an understandable way.

An important early step is to develop a tentative outline. The outline will probably change several times, but it is important always to have a current one foremost in your mind so that you can make the pieces fit together smoothly.

A typical outline will be of the form:

Chapter 1: Introduction

What is the problem?
Why is it important?
What have other people done?
What are the central ideas and contributions of your approach?
How is the rest of the thesis organized?

Chapter 2: The problem

Define the problem.
Introduce the jargon.
Discuss the basic properties.

Chapter 3: Big idea 1

...

Chapter $k + 2$: Big idea k

Chapter $k + 3$: Conclusion

Recapitulate what you have accomplished and why it is important.
Discuss ideas for future work.

Don't think that the thesis must be written starting at page 1 and continuing until the end. Most often, the presentation of the "big ideas" shapes the presentation of "the problem." The introduction is often written (or at least rewritten) last. The important thing is to jump in and begin writing something, and make notes along the way of how other sections need to be adapted so that they all work together.

One way to organize each chapter is to present the material to a group of fellow students. (If you cannot find an audience, then present to an imaginary one.) If you can organize your ideas into a coherent hour lecture, on a level understandable by your fellow students, you are probably ready to write a chapter.

Remember that the style of thesis writing is expository: you are trying to communicate your ideas, their significance, and their limitations. It is not the compressed style of a page-limited conference paper or journal article. Don't make your reader work too hard! At the same time, don't talk down to the reader, wasting time with repetition or adding unnecessary filler. Committee members and later readers will resent such tactics.

9.2 Writing Tools

See 15.6 for suggestions on writing manuals.

A major decision to make is the choice of document processing system in which to write your text. Knowledge of a good text processing system is almost as basic a tool to a professional in the mathematical and computational sciences as calculus or a good programming language. Although technical typists used to be common, they are an increasingly rare breed, and professionals are expected to be able to produce their own manuscripts.

Currently, the most popular typesetting and formatting systems are Tex, AMS-Tex, and Latex. Less elaborate systems (e.g., Microsoft Word) might get you through your thesis, but eventually you may be forced to use one of these systems in order to communicate with colleagues and to transmit manuscripts to journals. The Tex-based systems can be used on workstations, personal computers, etc., and most journals can accept files in these formats, thus saving you the enormous job of proof-reading a manuscript that has been typeset after conversion.

Each university has a set of style requirements for the thesis. These requirements often give rules for the use of different fonts, the format for bibliographies, the width of the margins, etc. Check around and see if your department or university has a style file compatible with with your typesetting system, so that you can satisfy these rules easily. If not, be prepared to iterate a few times to make the style-checkers happy.

9.3 Dealing with Your Thesis Committee

Ideally, you have chosen your committee members because of their interest in your research area and in you. Ideally, the members have followed your research over the course of a year or more, and understand your problem and your approach. Ideally, they all get along well, and egos are not a factor. And ideally, they are willing to take the time to read your thesis in detail and give you valuable feedback.

But the world is not always ideal. You might be very lucky to find one professor other than your advisor who is willing to listen and read and comment meaningfully. Other committee members may prefer a less active role, at one extreme, simply showing up for your oral exam and questioning you. Rules or reality may have dictated that some committee members have little interest in your research area, or little time to devote to mentoring.

Whatever the situation, draw your committee members as much into the process as they wish to be. If the committee is established early, then stop by or send a brief update to them two or three times a year so that they can follow your progress. If it is established after the thesis is written, give them plenty of time to read the thesis, and then contact each one, asking whether it would be helpful if you stopped by to answer questions or discuss your work. You don't want to be surprised at the oral exam by a very unhappy committee member.

After the oral exam, it is courteous to give a bound or electronic copy of the final version of the thesis to each committee member, and to express gratitude for the time they spent on your committee. Their participation should be noted in your thesis acknowledgements.

10 Career Options

The two most common career paths for mathematical and computer science PhDs are the tenure-track academic path discussed in Section 11 and the industrial/government lab path, discussed in Section 12.

There are other options that might be a better fit, though, either at the beginning of your career or as your circumstances change later.

- You could begin your career with a post-doc experience. This is becoming increasingly common in the mathematical and computer sciences. A post-doc might allow you to concentrate on research without the distractions of teaching and without having responsibility for a product. To successfully transition out of a post-doc, keep up your publication rate and be visible at key conferences in your area.

- You could start your own company, either product-based or consulting. This can provide flexibility in working hours and worksite, ideal for those who have childcare or eldercare responsibilities. It also can provide good income potential (if you ignore the maxim,[1] "How do you make a small fortune in computer science? Start with a large fortune and put out a hardware/software product.") The main drawbacks are a possibly very large investment of time for a proportionally small payback, lack of job security, the probable need to raise venture capital, and the discipline required to concentrate if you work from home.

- Even if you start in a traditional research or teaching position, you may eventually want to transition to academic administration (department chairperson, dean, provost, president) or a management position in a laboratory or corporation.

- Many "non-traditional" careers are open to PhD scientists and mathematicians. Some can be full time, while others might be better as a part-time or after-hours job. Whatever your interests outside mathematics and science, with enough imagination you can probably find a way to make your technical expertise an asset.

  – There are science policy positions on the staff of the US congress and also in the US executive branch of the government.
  – Computer science and mathematical science consultants are needed in a variety of surprising places; for example, in the television and movie industry to vet plots and props.
  – Some PhDs take positions in journalism, writing for technical news services or the general press. Many mystery or science fiction writers have technical backgrounds, as do researchers and writers on the history of science.

[1] This is a variant on one quoted by Dan Reed regarding high-performance computing.

- Organizations such as the National Science Foundation and the Department of Energy hire PhDs to oversee their grant programs.
- Mathematical and computer modeling is used in a variety of non-traditional areas. As an example, a sports team might use such techniques to advise a player on how to improve performance.
- Some people with research PhDs become interested in K-12 education and serve as teachers, textbook writers, or as teachers-of-teachers.
- PhDs serve as consultants on patent applications and as expert witnesses in court trials.
- PhDs also bring an important perspective as elected officials, and a great deal of good can be done by advocating for science, mathematics, and education from a position of knowledge as well as power.
- There are many ways to combine technical expertise with the arts. This has been done by sculptors (e.g., George Hart, Bathsheba Grossman), painters, musicians, photographers, graphic artists (with a Society of Digital Artists), animation artists, and even needlework artists (Some patterns can be found in a book entitled *Making Mathematics with Needlework.*),

See Sections 15.8 and **??** for a few helpful links.

"The production of work is cumulative; nothing is produced in isolation and everything contributes something to the next piece." (Henryk Ptasiewicz) Your mathematical and computer science education may contribute in rather surprising ways to your life's work.

11 A Professorship in Your Future?

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This material has been written for graduate students who are considering an academic career. It may raise more questions than it answers. Please consult a sympathetic faculty member for further information or advice.

11.1 Why Choose an Academic Career?

You've been in school for most of the years of your life, and you've been around universities for more years than you may care to count. Why would anyone choose to stay in a university environment?

- Teaching can be a very satisfying, rewarding experience. It offers opportunities to influence your profession, to experience the energy and new ideas of students, to share your ideas with a receptive (though captive) audience, and to see your research have impact on the teaching of mathematical or computer sciences.
- Tenure has its privileges. A tenured professor has the opportunity to embark on risky research without needing to produce short-term results.
- Interdisciplinary research with university colleagues can be stimulating and fun.
- Flexible hours can be a great asset in juggling family commitments.
- No censorship rules apply: generally work is unclassified and there are no corporate restrictions on publication.

11.2 What Is a Professor's Life Like?

A professor's career is marked by two major transitions: from assistant professor to associate professor with tenure, and from associate professor to full professor. The period before tenure is essentially a probationary time during which the candidate has a chance to establish a reputation as a good researcher and teacher. The job can be terminated at the end of each contract period (generally 2-3 years). Generally, this would be done only if the candidate's performance was unsatisfactory or if the institution is redirecting its mission. After a professor has tenure, then job termination can generally occur only due to serious misconduct or if the institution eliminates the entire department, and then only after a prescribed appeals procedure.

Some educational institutions avoid giving job security by labeling positions as part-time or as "visiting". Unless this fits with your career goals, these are generally bad deals.

11.2.1 The Beginning

The first year teaching as an assistant professor can be quite a shock. Suddenly the "soft" deadlines of graduate study become "hard" deadlines, as teaching responsibilities claim a large proportion of time while the "tenure clock" ticks in the background. There are compensations, though: the feeling of liberation is comparable to that of leaving your parents' home.

Almost all beginning teachers devote a tremendous amount of time to class preparation. This eases with experience, but initially it can be overwhelming.

At the same time, there are other important goals for your first year: writing journal papers from your thesis and submitting them for publication (if you have not already done so), introducing yourself to people at granting agencies, applying for research grants, undertaking a mild amount of committee work for your department, getting to know the other faculty members, watching and learning how the department functions, and continuing your research. The first year out is quite taxing!

As in graduate school, it is a tremendous advantage to have a mentor, a colleague (or colleagues) who can review your research proposals, teach you about the workings of the department, give advice on teaching, and help you achieve visibility in the professional community. Luckily, if your new school can't provide all of this, you can rely on your advisor and other faculty from your graduate institution as well as on remote mentoring programs in your field.

In a good department, senior faculty members treat junior faculty as full colleagues. That doesn't mean that assistant professors will never feel intimidated by the senior faculty, but if the department functions well, they should be able to trust that disagreements with senior faculty members will not affect their career.

11.2.2 Preparing for the Tenure Decision

Each university is different, but in general, there are four criteria for promotion and tenure: teaching and mentoring, service, research, and reputation. A deficiency in one area can sometimes be overlooked if there is excellence in another. Here is one variant, perhaps relevant at a university with a Ph.D. program, but the weights of each criterion and the method of evaluation vary, and it is important to learn the local criteria early.

1. A "satisfactory" record for departmental and professional service. Conscientious performance on one committee assignment per year, plus serving as a referee, etc. is average.

2. A "good" record as a teacher and mentor. This is gauged by peer and student evaluations (numerical as well as personal comments), teaching awards, lecture skill, course material, and supervision of graduate and undergraduate students.

3. A "very good" record as a researcher, with potential for future achievement. This is gauged by impact of the work, number of publications,

quality of journals and conferences, and research grant support.

4. "Strong" letters from outside referees concerning research reputation. The candidate is asked for a list of 3-5 referees. The evaluation committee adds others. They should generally be full professors at "peer" institutions, or occasionally senior industrial researchers at a top company. The letters that carry the most weight specifically cite important research results and compare the candidate with contemporary stars, rather than making vague complimentary statements.

An undergraduate institution would put much more weight on teaching and service, and a state university might have higher standards for teaching than a private one.

Choose your referees carefully. Contact them, making sure to tell them of all of your important accomplishments. Don't just ask if you can use their name as a referee; ask if they can provide a strong recommendation. Try to guess the names the department will choose, and make sure that these people are also aware of your accomplishments.

11.2.3 The Tenured Life

No, tenure is not equivalent to retirement. In fact, many faculty members are shocked at the sudden imposition of departmental responsibility into their previously free time. Making tenure decisions about colleagues is a serious burden. There are also additional meetings and duties. But the major change is that there is the expectation that to maintain the respect of colleagues, each faculty member will take a leadership role in, substantial research initiatives, in development of the educational program, or in departmental administration.

Duties to the professional community also increase. Senior faculty are expected to serve on editorial boards, conference organizing committees, and as officers of professional societies. These commitments must be carefully chosen: worthwhile tasks well suited to the individual, providing some professional recognition, and not crowding out other responsibilities.

11.3 How Should You Prepare for an Academic Career?

There are several things you can do (beginning in your first year of graduate study!) that will make the prospects of success as an academic more likely. Luckily, they are also good preparation for the business world, so you do not need to sacrifice any of your options.

- Take "core" mathematical science courses or a broad selection of computer science courses as early and as often as you can. A broad background is an asset in teaching as well as in research.
- Get to know a handful of faculty members well enough that they can give you advice and write knowledgeable letters about your talent, performance, and motivation. Don't try to go through school anonymously.

If the faculty are well known in their fields, their opinions mean a lot to hiring committees.

- Choose your advisor and thesis topic carefully. Seek an advisor with whom you can work comfortably on an exciting topic, and remember that your initial reputation in the field will be tied to your advisor's reputation.
- Join the professional societies; see Section 15.1. Fees for students are low, and the credibility is important.
- Publish! Try to get involved in projects that will lead to written results, suitable for a technical report or even a conference or journal paper. Whether the project stems from a research assistantship, a term project, or a master's thesis, write it up! (If this fails, don't give up. Some professors come out of graduate school with no publications.)
- Pay attention to teaching. Do a good job as a teaching assistant. Observe good teachers and try to analyze what makes them good. Get feedback on your own teaching or lecturing.
- Start learning about other universities early. Whenever you read a research article relevant to your work, note the address of the author as a possible contact in your job search.
- Look for a good summer internship at a leading company or government laboratory (NIST, DOE labs, Army labs, etc.). This will give you the chance to see how research impacts applications, and the resulting perspective will inform your research and your teaching.
- Attend conferences and workshops, especially during your last two years. If possible, present a paper at several. Introduce yourself to other participants; ask questions; give a compliment on a talk when appropriate.

Don't sell yourself short: if you are a successful graduate student at a strong institution and if you enjoy teaching and research, then you have the potential to be a very successful assistant professor. Be prepared to work hard, but don't be afraid to accept the challenge.

11.4 How Do You Find a Job?

Start working on the application process early in summer or fall for an appointment the following fall. Ask your advisor and other helpful faculty members for advice on where and how to apply.

11.4.1 Applying

- Choose as references faculty members who know your work well. One of them should be able to evaluate your teaching or lecturing ability. Talk to them about your goals and provide them with a transcript, dissertation summary, and resume. Ask for advice on universities and faculty members to contact.

- Your resume (curriculum vitae) should give your educational background, awards (including scholarships and fellowships), publications, conference presentations, teaching experience, a list of courses you would be comfortable teaching, and a list of 3–5 references with addresses. If you are applying for industrial as well as academic positions, you probably want more than one resume, since achievement, skills, and goal-oriented resumes can be more effective in the industrial setting.

- Your cover letter can be brief, but express some enthusiasm, make a clear statement of your research accomplishments and research goals, and mention your advisor's name. Provide a one page dissertation summary along with your curriculum vitae. Many schools also require a brief teaching statement and research statement.

- Either you or your advisor could follow up applications by contacting a faculty member in your research area. Most departments filter the applications through the relevant field committee members, and an extra contact can prevent an early rejection.

- Apply to every department you are particularly interested in, even if it is not currently advertising. Sometimes positions become available unexpectedly, and an interesting application can trigger an appeal to the dean for a position.

- Consider a postdoctoral position. Occasionally such a position can provide an entry into a tenure track position at that institution, but in any case it is a chance to broaden your research experience and to strengthen your curriculum vitae (c.v.) without the tenure clock ticking.

11.4.2 Interviewing

Interviewing can be exhausting. Often appointments and talks span a 13 hour period each day. The first few interviews are fun, but it is difficult to keep up enthusiasm over a long series. Choose carefully if you are lucky enough to have many invitations.

- Practice your interview talk before your friends and advisor and, if possible, a video camera. Try to make sure that everyone from the specialist to the average department member gets some information from your talk: in particular, what problem you solved, how important it is, how it relates to other work, what originality you contributed, and future research directions. Everyone there will be making a judgment about your skill as an expositor as well as a researcher. Prepare more information than you need, and be prepared to insert more tutorial information or more detailed information to suit the needs of the audience. (Attending talks of candidates for positions at your institution can be helpful.)

- Do your homework. Find out about the people on the faculty. Read some of their papers. When you meet them, ask them what they are working on and try to establish a dialogue. Emphasize areas of common ground. Remember that these are going to be your colleagues.
- Try to avoid talk of quality-of-life issues if there are more technical things to discuss. There will be time for such things later.
- In some departments, the chairperson alone makes hiring decisions. In others, a vote of the whole faculty or a subcommittee decides the case. Find out how it works, and adjust your strategy.
- Be prepared to answer questions about your research plans, what equipment you would need to get started, with whom you would interact, what you would like to teach, etc. Don't get involved in salary negotiations; beginning salaries are relatively standard, and if asked, it is probably enough to say that you expect that their salary offer will be competitive with other institutions.
- If a faculty member served as your host, write a brief thank you. (Making the arrangements for a visitor can be a lot of work!) Also send a note to the powers-that-be thanking them for the opportunity to visit and commenting on particular discussions or events you enjoyed.

11.5 Some Fallacies about the Academic Life

Tenure, of course, was instituted solely to protect faculty from the political consequences of scholarly research. As a consequence, there is tremendous pressure on non-tenured faculty to prove their competence during a short (6–7 year) probationary period. This system is far from perfect, but for better or worse, that is how most U.S. universities operate.

Here are some common misconceptions about university life.

There is a good reason for my lack of productivity: if only I had a *better laptop, grader, secretarial help, travel support, software, books, etc.* I could do so much more.

> Be aware that most department chairs will do all that they can to accommodate reasonable requests from junior faculty, and you have little to lose by asking.
>
> You should also actively seek outside funding from government agencies (such as USA NSF, DOE, DOD) and from industry.
>
> If you still need resources, write your own research grant. Not a *proposal* but a grant! Academic salaries are not opulent, but they are certainly adequate for supporting most people. Allocate some of the surplus (maybe $10,000 per year) as your own "research grant" that you can spend guilt free to make your life easier. It is an investment in your future, as well as in your sanity.

In order to get tenure, I must work 70–90 hours per week.

> If you want to work such hours, by all means do so. But it is neither necessary nor sufficient.
>
> Slavery in the Unites States was officially abolished well over 100 years ago. That doesn't mean that slavery ceased to exist – only that no one can be legally enslaved without consent. Many untenured faculty members seem to give that consent.
>
> If your professional responsibilities are overwhelming you, consider your options: asking that the tenure clock be stopped, learning to say "no" to unreasonable demands, moving to another university in order to restart the clock, taking leave, converting to part time employment, or taking a position in industry or government.

University life would be so nice without the students.

> It is rare to find a good teacher who does not enjoy teaching, so if you feel burdened, consider a career change.

11.6 Some Notes (Not for Women Only)

See Section **??** for some links on women and minority career issues and Section 15.4 for pointers to some useful meetings.

The role model issue. Yes, women (and minorities) are underrepresented in the sciences and engineering, and it is especially important to demonstrate to students that diversity is useful and expected among computer scientists. A good woman can make a tremendous difference to students and to the academic environment but must avoid the pitfall of being stretched too thin. Each stands on the shoulders of her predecessors who faced somewhat different but quite daunting challenges.

Family issues. Yes, the academic life does have time pressures, and family responsibilities can be difficult to juggle. Some people believe that it is foolhardy to seek tenure if your family duties have a high priority in your life, but many people have been successful at both. Compared to industry, academic hours are more flexible and the deadlines somewhat softer. Tenure clocks can be restarted if necessary by a move to another university after three years or so, and such an upheaval can be stimulating to research.

Personal information on the c.v. Personal information (birth date, gender, minority status, marital status) is optional, but it is sometimes useful to mention if you are a woman or minority. It is also especially appreciated if your name does not reveal your gender, since it is awkward to acknowledge applications without knowing whether "Mr." or "Ms." is appropriate.

The uncomfortable interview. If a question seems out of line (too personal, etc.), dodge it as gracefully as you can, trying not to take or give offense. Usually the questioner means no harm but is lacking in social skills. If the issue is serious, follow up later, either directly to the individual, to the chairperson, or to a sympathetic faculty member at that institution, but don't let it distract you from the goals of your interview.

Negotiating. Negotiate for what is important to you: salary, teaching load, workstation in your office, access to teaching assistants, support for a graduate student, summer support, etc. Make sure that your requests are in line with the support given to other faculty members at that university, though.

The decision. Don't agonize. If you have a choice, there is usually no "wrong" choice, just different ones. Consult your advisor. Ask questions. Assess how each offer helps you toward your long term goals. Then prepare for your first encounter with undergraduates, who will suddenly consider you over the hill.

12 Careers in Government and Industry

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There are many exciting career opportunities in government and industry. Even if you firmly believe that you will spend your life as an academic, you may find yourself making a career change later, or doing some part-time consulting. Since the average person makes several job changes over the course of a career, it is important to keep your options open. In this section we focus on the attractions of non-academic jobs and on the job search process.

12.1 Types of Careers

There are some major differences between the university environment and the industrial/laboratory one:

- Industrial jobs give you access to state-of-the-art equipment and give you influence over the next generation of equipment.
- Unless you really enjoy teaching, you are doing yourself and the students a disservice if you take an academic job.
- Industry gives you opportunities for profit sharing and entrepreneurship.

There are many varieties of nonacademic jobs:

- A **consulting job** can provide flexible hours, a variety of work experience, and a chance to be your own boss. A consultant sells his/her services on a short or long term basis to an organization that needs a particular set of skills. The successful consultant must be flexible, work well under tight deadlines, be a good salesperson for his/her expertise, and tolerate risk well.
- An entrepreneur establishes a **new business** and markets a product or service.
- A **government lab** usually focusses on a particular set of research problems, related to the agency's mission – defense, energy, etc. Laboratories can provide good interdisciplinary opportunities, job security, and a healthy research environment.
- An **established company** may have needs for research and development or for support services for their products or customers.

Some organizations engage in classified research – particularly, some Department of Defense labs, National Security Agency, and Department of Energy labs. At installations such as this, some percentage of your time might be spent in research that cannot be made public. This work is important and interesting, but will do nothing to enhance your prospects for a move to a non-classified installation. If job mobility is important to you, then it is vital that you keep a high public profile as well, continuing to do research that can be published openly, and continuing to attend conferences in your research area.

Private industry hires people who can contribute in some way to the company's "bottom line" of profits. Different companies evaluate the contribution in different ways. At one end of the spectrum are companies who operate labs like Google, Xerox Parc, or IBM, where management has believed that a relatively unfettered research environment will lead to unexpected advances, some of which will generate new commercial products. Although people are encouraged to become involved in some less speculative work, a major part of their time can be spent in work much like that of universities. At the other end of the spectrum are companies that focus on short-term, product-specific tasks that lead to research questions whose answers will have immediate impact.

Again, an important consideration is how openly you will be allowed to talk about your work. Some companies do classified research, and others protect their research and their products as trade secrets or by copyright or patent.

Success in a research job may ultimately lead to a job in management of research. Many corporations make the mistake of making the management track the only path to high salaries, although more enlightened companies recognize the importance of rewarding senior researchers who do not choose (or have no aptitude for) management. A good manager understands the concerns of the researchers he/she manages and acts as buffer and advocate. A good manager is a filter, suppressing the "noise" from higher level management while keeping the unit informed of important news. At the same time, a good manager presents the unit's case for resources and keeps higher management aware of the unit's accomplishments and value.

12.2 What Are Industrial Jobs Like?

In an medium or large size organization, your first tasks will probably involve close team work with a more experienced colleague with similar background. You may participate in a project that is well underway, making a specific contribution to software, mathematical formulation, or modeling. Or you may be brought into a beginning project that you will help to shape and then make a fairly well-defined contribution. Evaluation of your work will include the quality of your contribution, your attention to deadlines, your ability to work harmoniously with others, and your oral and written communication skills.

After you have some experience, you may be asked to work more independently, perhaps serving as the sole person on a project with your particular specialty. For instance, Margaret Wright of Bell Labs speaks of a project that involved studying radio signal propagation in a building. The team involved one engineer, expert in radio signal modeling, two mathematicians, expert in numerical optimization, and one computer scientist, expert in graph algorithms. An important ingredient in such projects is mutual respect among the team members so that they can trust that the pieces of the project that they only vaguely understand are being handled well. Team members must contribute responsibly and be wise enough to ask help from people outside the team when they are unsure of themselves.

Further on, you may be asked to lead a team or perhaps direct a research division. This requires a whole new set of skills and you should be prepared for some retraining to meet a new set of challenges.

12.3 How Should You Prepare for an Industrial Career?

There are several things you can do (beginning in your first year of graduate study!) that will make the prospects of success in an industrial environment more likely. Check the list in the academic career section (Section 11) – all of that advice applies here. Work experience is invaluable. Look for opportunities to work in industry for a summer or a semester. Look for industrial workshops that will give you a chance to work on applied problems for an intensive session, preferably in a multi-disciplinary environment.

Obtain some breadth of background. In interacting with engineers or biologists or physical scientists, it is invaluable to know the vocabulary and to be able to understand the underlying principles. Broaden your areas of expertise through course work or seminar attendance.

12.4 How Do You Find a Job?

Industrial and government positions tend to work on a shorter time scale than academic ones. It might take several months to have the paperwork progress through the system and be called for an interview, but (at least for unclassified work) the time between interview, offer, and starting data is often quite short.

As in finding an academic job, consult your advisor and other faculty members, and use any contacts you have to inquire about positions.

12.4.1 Applying

- Choose as references faculty members who know your work well. Also try to include people who have supervised your work or industrial contacts who find your research useful. Talk to them about your goals and provide them with a transcript, dissertation summary, and resume. Ask for advice on whom to contact.

- Your resume should give your educational background, awards, publications, conference presentations, and a list of 3–5 references with addresses. You should list an objective; e.g., "a research position that applies skills in x, y, and z to w." If you have practical experience of any kind, highlight it on the resume.

- Your cover letter can be brief, but express some enthusiasm for the organization and position you are applying for. Make a clear statement of your research accomplishments and research goals, and mention your advisor's name. Also provide a one page research summary.

- Apply to every company you are particularly interested in, even if it is not currently advertising. Sometimes positions become available unexpectedly, and an interesting application can trigger a position.

- Watch technical publications (*SIAM News*, *Communications of the ACM*, *IEEE Computer*, etc.) for ads. Contact your university's career center. Attend job fairs. Use Internet resources of job listings, maintained by the professional societies and others. Consider contacting a "head hunter," an employment agency that circulates your resume to interested companies, charging the company a fee if you are hired.

12.4.2 Interviewing

Interviewing can be exhausting. Often appointments and talks span a 13 hour period each day. The first few interviews are fun, but it is difficult to keep up enthusiasm over a long series. Choose carefully if you have many invitations.

Check the advice in the academic career section (Section 11) for information on interviews and the aftermath.

13 Professional Ethics

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In this section we consider some of the "rules of the game." Some of these are obvious to most of us, but some might be surprising due to cultural differences or lack of consideration. Further resources can be found in Section **??**.

The purpose of ethical standards is to provide an implicit foundation upon which human interactions can proceed smoothly. They answer questions such as

- "How much credit do I need to give previous authors whose words or ideas I have used?"
- "How much help can I get on a homework assignment without cheating?"
- "Can I use the computers at school or work to earn extra money?"
- "Should I ask my student for a date?"
- "Should I warn a hospital that my company has delivered a shoddy piece of software to them?"

The next five subsections address each of these questions, and related issues, in turn.

13.1 Intellectual Property

In some cultures it has been acceptable to take another person's work and present it as your own. For instance, many Baroque music masterpieces are built upon musical themes "borrowed" without explicitly giving credit.

In current Western culture, this is unacceptable, whether it involves music, ideas, or words, and we define the taking of someone's words or ideas as *plagiarism*. (It was particularly disheartening to discover that someone had plagiarized this discussion of ethics!) Since ideas and words represent creative effort and have intellectual value, there is a well-defined system of property rights. Stealing words or ideas is theft, just as surely as stealing automobiles, and sanctions can be quite serious.

- Thus, if you take a paragraph from someone else's written work and include it in your own work, you must enclose it in quotation marks and give a citation. Even if you change some of the words but leave the writing essentially unchanged, you must put the unchanged pieces in quotation marks and list your source.

- If a substantial part of your paper (say, a page or more) consists of a summary of someone else's work using a condensation of their words, or following the same outline as their work, then you must say so: "This section is taken directly from [...]," or "This summary closely follows [...]," etc.

- You cannot publish a work that is substantially taken from another; you must have "added some value" by new ideas or new derivations or new implementations and you must clearly distinguish between your work and that of others.

The consequences of plagiarism might include an F in a course, expulsion from a graduate program, or banning from having any of your works published in a journal.

Patent rights must also be respected. If a device or idea is patented, it should not be used in your work unless you obtain the necessary permission.

People with a reputation for not giving due credit to other researchers generally find it hard to find collaborators and people who will write letters of recommendation for them.

13.2 Academic Integrity

The university system of education is built upon a high level of trust that students and faculty will be honest in their dealings with each other. It breaks down quickly if this honesty is lacking.

Here are some actions that violate the trust, along with the definitions given in the University of Maryland *Code of Academic Integrity.* Some of the examples are taken from an old University of Maryland *Student Guide to Academic Integrity.*

- **cheating:** "fraud, deceit, or dishonesty in any academic course or exercise in an attempt to gain an unfair adgantage and/or intentionally using or attempting to use unauthorized materials, information, or study aids in any academic exercise." It is cheating to use a solution set obtained by breaking into a professor's computer files, to use an unauthorized "crib sheet" on an exam, to have a friend do your homework, to look at another student's paper during an exam, etc.

- **fabrication:** "intentional and unauthorized falsification or invention of any information or citation in an academic exercise." You fabricate if you enter false data in a log book, add unused references to a bibliography, change your answers before submitting a paper for regrade, etc.

- **plagiarism:** "intentionally or knowingly representing the words or ideas of another as one's own in any academic exercise." Examples of plagiarism include copying homework from another studen andt claiming another person's idea as your own in a thesis.

It is also a violation of integrity to help someone else in such actions for example, by lending your homework paper to someone else, letting someone copy your answers in an exam, revealing exam questions to people preparing for an exam, helping someone to break into a colleague's computer files, etc.

Such violations of trust are taken quite seriously at universities and the consequences can include an F in a course or expulsion from the university.

You should make yourself familiar with the code of academic integrity at your university.

13.3 Use of Computer Facilities

Each university has had to think very carefully about the ethics involved in the use of computer facilities, and most now have a formal document defining acceptable and unacceptable use. The issues to balance include free speech, communication of research without unnecessary obstacles, and responsible attention to law.

Here are a few examples of activities that are universally prohibited:

- trying to access private files or unauthorized computers.
- trying to alter computer hardware or software without authorization.
- trying to disrupt other's use of the computer, for example, by sending email in another user's name, by locking other user out of a machine, etc.
- violating copyright or software agreements on software packages.
- running a money-making operation using university computers without permission.
- spamming. This means sending large volumes of email, thereby disrupting communications for an entire set of users. The usual purpose is either harassment of an individual or widespread dissemination of a "get rich quick" pyramid-scheme mailing.
- using computers for illegal activities, including pyramid schemes, making threats, theft, child pornography, etc.

Again, these are serious matters and are usually dealt with either by suspension of computer privileges, expulsion from the university, or legal charges.

You should make yourself familiar with the code of computer use at your university.

13.4 Human Relations

The United States is not alone in its history of discrimination toward large groups of people based on race, religion, or other factors, but the legacy of these actions continues to be divisive. In an attempt to redress past wrongs and prevent future ones, the United States has built perhaps the most complicated system of laws and regulations in existence, many of them contradictory to some extent.

Rather than try to understand every fine point (e.g., when are distinctions based on mental ability discriminatory?), it is perhaps easier to be guided by two basic principles that motivated the laws:

- It is wrong to use authority to coerce favors. You also cannot appear to be using your authority this way.
  - Thus you cannot ask students or employees to do personal errands for you as a part of their duties. This includes babysitting, shopping, etc.
  - What requests are permissible? You can ask students to do work assigned to the class. You can ask teaching assistants to do those duties associated with their assigned class: grading, office hours, recitation sections, etc. You can ask research assistants to do those duties associated with the research project: library work, programming, running experiments, writing reports, minor clerical work, etc.
  - Any requests outside of these boundaries must have the offer of compensation. For example, a babysitting request or a request to work at a professor's party must be accompanied by market-rate payment and must have the understanding of no penalty for saying "no." If you are asked to work at a conference that a professor is organizing, the compensation is usually a waiver of registration fee and a chance to network with experts in the field. If you are asked to help a professor referee a paper, then your help should be acknowledged in the professor's letter to the editor.
  - Supervisors cannot ask to be listed as an author of a paper to which they made minimal contribution. The American Mathematical Society statement on authorship is typical of professional standards:

    > All the authors listed for a paper, however, must have made a significant contribution to its content, and all who have made such a contribution must be offered the opportunity to be listed as an author. mklinkAMS Policy Statement on Ethical Guidelines http://www.ams.org/about-us/governance/policy-statements/sec-ethics

    See the section on "The Life of a Graduate Student" §4 for some additional discussion.
  - Inappropriate use of authority is particularly difficult to sort through if the relationship is defined on multiple levels. If you want to have a dating relationship with your student or employee, it is dangerous to do it while you still have authority over that person. It poisons the atmosphere for the class or research group by giving the impression

of favoritism. It opens you to charges of sexual harassment if the relationship sours.

- You must treat colleagues, supervisors, and students with respect. Even if you find it difficult to deal with their ethnic background, religion, etc., your actions or attitudes in response to these issues must not interfere with their work. You cannot use such personal issues as a basis for grading or promotion. You cannot harass anyone.

Again, these issues are tied up in a tangle of laws. If you run into trouble, talk to a trusted colleague and check the human relations policy at your university.

13.5 Professional Integrity

Professional integrity encompasses a wide variety of responsibilities. Here are a few of them.

- We must be honest in our professional dealings, giving due credit for other peoples' ideas and not claiming credit for work that we have not done.
- We must treat professional colleagues and students with respect.
- An old labor rallying cry says, "A full day's work for a full day's pay." Every job has its pleasant and unpleasant aspects. (For me, the worst part of professional life is dealing with academic dishonesty.) But in accepting a job, we agree to perform all of its duties, not just the pleasant ones.
- We cannot use the institution's resources (computers, copying machines, postage, etc.) for nonbusiness purposes without permission.
- The confidentiality of knowledge obtained through professional activities must be respected. For instance, we must safeguard students' grades, the contents of private databases and papers we referee, and trade secrets.
- The physician's motto is, "First, do no harm." This means that we must assure that any product or idea that we deliver is as correct as we can make it and has no unannounced defects. Our mathematical model may be used to determine load limits on a building or safeguards on a nuclear stockpile. Our computer program may be used as a module in a drug delivery system in a hospital or in a guidance system in a passenger aircraft. We must be sure that if our work is used as we say it can be, that it will perform as intended.

See Section **??** for pointers to the ACM Code of Ethics, the AMS Code of Ethics, and others.

13.6 Values

"Some people live to work; others work to live." Whether your job is your greatest joy in life or just a duty, it is worth reflecting on whether what you do at work contributes to making the world better. Maybe your work won't win a Nobel Prize, a Turing Award, or a Fields Medal, but you can use some of your creative energy to see that your efforts have some positive value. When all is said and done, your non-scholarly contributions might far outweigh your scholarly ones if you encouraged an at-risk student, wrote a clear textbook, helped a more junior colleague, organized a conference that catalyzed new research, or made a staff member's life a little easier. Whatever your values, bring them to work.

14 Some Gender Pitfalls and How to Minimize Their Effects

On the one hand, it is still a bit unrealistic to expect that every faculty member in the department is enlightened on the subject of appropriate ways to deal with faculty members of the opposite sex, or with those whose sexual orientation is different. On the other hand, it is doubly uncomfortable when the boors are in power positions.

If you do have uncomfortable encounters with faculty members or other colleagues, be prepared to set very precise rules about future interactions. Here are some samples that may or may not fit your style:

- Be polite but reserved until the relationship feels safe.
- Don't complain shrilly about every minor issue; reserve your credibility and your energy for big troubles.
- Hold discussions at a desk or conference table, not at a sofa, and in an office, not a residence.
- Don't become emotionally involved with one of your students or with one of your professors or supervisors. You will inevitably pay a high price professionally, whether the relationship goes well or ill. Consider the relationship (or, better, the *potential* relationship) on "hold" until after the professional obligation has ended.
- Refuse to discuss marital problems (or problems with a relationship) with a person who is attracted to members of your gender. Be sympathetic, but refer the person to a colleague for whom there is no potential attraction or to a professional.
- Refuse to tell or listen to sexual or sexist jokes in the office, even if you are comfortable with them at a social gathering.
- If you are being subjected to sexual harrassment, document it as carefully as you can: talk to a trusted colleague, keep a log, try to get witnesses or written evidence. If legal in your locale, record your interactions with the troublesome person; if not, consider maintaining a cellphone connection to someone who can listen and act as a credible witness. Once you have built a case, don't be afraid to pursue it, but don't underestimate the pain that it will cause you. (See the Resource section.)

15 Resources

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15.1 Professional Societies

- American Mathematical Society (AMS)
  http://www.ams.org/
- American Statistical Association (ASA)
  http://www.amstat.org
- Association for Computing Machinery (ACM)
  http://www.acm.org/
- IEEE Computer Society
  http://www.computer.org/
- Mathematical Association of America (MAA)
  http://www.maa.org/
- Society for Industrial and Applied Mathematics (SIAM)
  http://www.siam.org/
- American Indian Science and Engineering Society
  http://www.aises.org
- Association for Women in Computing (AWC)
  http://www.awc-hq.org/
- Association for Women in Mathematics (AWM)
  http://www.awm-math.org/
- Association for Women in Science (AWIS)
  http://www.awis.org
- Center for the Advancement of Hispanics in Science and Engineering Education
  http://www.cahsee.org/
- Graduate Women in Science
  http://www.gwis.org
- Mexican-American Engineers/Scientists
  http://www.maes-natl.org

- National Society of Black Engineers
  http://www.nsbe.org
- SACNAS: Advancing Hispanics/Chicanos and Native Americans in Science
  http://www.sacnas.org
- Society of Hispanic Professional Engineers
  http://www.shpe.org/
- Young Mathematicians Network (YMN)
  http://www.youngmath.net

15.2 Further information on Graduate Life

- How to Be a Good Graduate Student / Advisor
  http://www.cs.indiana.edu/how.2b/how.2b.html by Marie desJardins. Advice to both students and advisors.
- The TAP project of ADA
  http://women.cs.cmu.edu/ada gives many resources on professional life for women in computer science.
- A Letter to Research Students
  http://www.cs.williams.edu/~bailey/p/research.pdf by Duane A. Bailey
- The 1993 IUCS Graduate Student Survival Guide
  http://web.archive.org/web/20030424100909/http://www.cs.indiana.edu/docproject/handbook/part1.9.html
- Survival Skills for Graduate Women (1993)
  http://web.archive.org/web/20030207215328/www.cs.indiana.edu/docproject/handbook/section1.9.0.3.html by Jennifer Myers.
- How to do Research in the MIT AI Lab
  http://www.cs.indiana.edu/mit.research.how.to.html ed. David Chapman

15.3 Electronic Mentoring Networks

- AWM Mentoring Network
  http://www.awm-math.org/mentornetwork.html
- MentorNet for Diversity in Engineering and Science
  http://www.mentornet.net

15.4 Useful Meetings for Women and Minorities

- AWM Workshops for Graduate Women and Recent PhDs
  http://www.awm-math.org/workshops.html
- CRA-W Workshops for Graduate and Early-Career Women
  http://cra.org/cra-w/
- Grace Murray Hopper Celebration of Women in Computing
  http://gracehopper.org
- Richard Tapia Celebration of Diversity in Computing
  http://tapiaconference.org

15.5 Mental Health

- Depression
  http://www.nimh.nih.gov/health/topics/depression/index.shtml
- Depression, Anxiety, and Substance Abuse Screening
  http://www.mentalhealthamerica.net/mental-health-screening-tools
- Adult Attention Deficit Screening
  http://counsellingresource.com/quizzes/adhd/index.html (ADHD)
- Bipolar Disorder
  http://www.nimh.nih.gov/health/publications/bipolar-disorder/complete-index.shtml
- Drug Abuse and Addiction
  http://www.narconon.org/drug-abuse/signs-symptoms-of-drug-abuse.html
- Alcohol Dependence
  http://www.nlm.nih.gov/medlineplus/alcoholism.html
- National Suicide Prevention Hotline
  http://www.suicidepreventionlifeline.org/ 1-800-273-TALK

15.6 Literature on Technical Writing and Speaking

- Mark Leone's collection of pointers.
  http://www.cs.cmu.edu/afs/cs.cmu.edu/user/mleone/web/how-to.html
- *How to Write Mathematics* by P. Halmos.
- *How to Solve It* by George Polya, 2 ed. Princeton University Press, 1957.
- *A Manual for Writers of Term Papers, Theses, and Dissertations* by K.L. Turabian, 4 ed.University of Chicago Press, Chicago, 1973.

- *How to Read and Do Proofs* by D. Solow, John Wiley and Sons, New York, 1982.
- *Latex User's Guide and Reference Manual* by Leslie Lamport, Addison-Wesley Pub. Co, Reading, Massachusetts.
- *Mathematical Writing* by Donald E. Knuth, Tracy Larrabee, and Paul M. Roberts, MAA Notes No. 14, 1989.
- *Handbook of Writing for the Mathematical Sciences* by Nicholas J. Higham, SIAM Press, 1993.
- An Evaluation of the Ninth SOSP Submissions, or, How (and How Not) to Write a Good Systems Paper `https://www.usenix.org/legacy/publications/library/proceedings/dsl97/good_paper.html` by Roy Levin and David D. Redell

15.7 Teaching Advice

- Mathematics Archives `http://archives.math.utk.edu/materials.html` gives pointers on the teaching of mathematics.
- Educational Issues for Girls and Women in Mathematics `http://www.camel.math.ca/Women/EDU/Education.html`, Canadian Mathematical Society
- Mentoring Grad Students `http://www.vanderbilt.edu/cft/resources/teaching_resources/interactions/mentoring_grad.htm` by Jeff Johnston

15.8 Career Advice

- PhdsOrg: Science, Math, and Engineering Links `http://www.phds.org` Index of on-line resources, including other survival guides like this one.
- How to Have a Bad Career in Research/Academia `http://www.cs.berkeley.edu/~pattrsn/talks/BadCareer.pdf` by David Patterson
- Networking on the Network `http://vlsicad.ucsd.edu/Research/Advice/network.html` by Phil Agre
- On Being A Scientist: Responsible Conduct In Research `http://www.nap.edu/catalog.php?record_id=12192` from the National Academy of Sciences

- The Assistant Professor's Guide to the Galaxy
http://www.cs.iastate.edu/~honavar/assistantprofgalaxy.pdf by George A. Bekey
- A Guide for New Referees in Theoretical Computer Science
https://larc.unt.edu/ian/pubs/referee.pdf by Ian Parberry.
- Alan Jay Smith, "The task of the referee,"
http://www.cs.utexas.edu/users/mckinley/notes/reviewing-smith.pdf *IEEE Computer*, April 1990, pp. 65-71.
- Careers in Science and Engineering: A Student Guide to Grad School and Beyond.
http://www.nap.edu/catalog.php?record_id=5129
- Writing Research Proposals to the National Science Foundation
http://www.cs.cmu.edu/~sfinger/advice/advice.html Susan Finger, Carnegie Mellon University.
- The Impostor Syndrome
http://en.wikipedia.org/wiki/Impostor_syndrome

15.9 Resources for Job Searching

- Check the homepages for the professional societies listed above.
- Computing Research Association ad list
http://cra.org/jobs/
- How To Handle Illegal Interview Questions
http://www.collegegrad.com/ezine/23illega.html from Job Hunter E-Zine.
- Resources from ACM Crossroads
http://xrds.acm.org/resources.cfm

15.10 Resources for Applying to a U.S. Graduate School

- Graduate Record Exam (GRE)
http://www.ets.org/gre
- National Science Foundation Fellowships (NSF)
http://www.nsf.gov
- Department of Energy Fellowships (DOE)
https://www.krellinst.org/csgf/
- Hertz Foundation Fellowships
http://www.hertzfoundation.org/
- National Physical Science Consortium Fellowships
http://www.npsc.org/.

15.11 Literature on Women and Minorities in Science

- Computing Research News
  `http://www.cra.org/CRN/` has a large set of tables each year of computer science facts and figures, including data on percentages of minorities/females granted Ph.D's, average salaries in computer science departments, etc.

- AAAS Diversity Issues
  `http://www.sciencemag.org/tags/diversity`

- Journal of Women and Minorities in Science and Engineering
  `http://www.begellhouse.com/journals/00551c876cc2f027.html` by Donna J. Dean,

- CRA Committee on the Status of Women in Research
  `http://cra.org/Activities/craw/`

- Why Are There So Few Female Computer Scientists?
  `http://people.mills.edu/spertus/Gender/why.html` by Ellen Spertus.

- National Center for Women & Information Technology
  `https://www.ncwit.org/`

- Is There Bias for or Against Women in Academia?
  `http://homepages.inf.ed.ac.uk/perdita/GenderBias/` by Perdita Stevens

15.12 Professional Ethics

- Most professions have a code of professional conduct. Many of these can be found at the Online Ethics Center for Engineering and Science
  `http://www.onlineethics.org`

- Two specific codes are

  - ACM Code of Ethics and Professional Responsibility
    `http://www.acm.org/about/acm-policies-procedures`
  - Software Engineering Code of Ethics and Professional Practice
    `http://www.acm.org/about/se-code`

  Further information is available from

  - the American Association for the Advancement of Science AAAS Scientific Freedom, Responsibility, and Law
    `https://www.aaas.org/program/scientific-responsibility-human-rights-law`
  - American Physical Society statements on ethics
    `http://www.aps.org/policy/statements`
  - EthicsWeb Applied Ethics Resources on Science and Technology
    `http://www.ethicsweb.ca/resources/sci-tech/index.html`

- Most universities have a guide to academic integrity. Here is one for the University of Maryland
  `http://www.president.umd.edu/policies/docs/III-100A.pdf`
- Professional Ethics: Taking the High Road, Dianne P. O'Leary, SIAM News, October 18, 2011
  `https://www.siam.org/news/news.php?id=1921`
- Guidelines for determining authorship of papers are somewhat different in each field. Here are some references (thanks to Timothy O'Leary):

  Science, January 12, 1996 vol 271 pp 129-30 (letter to editor)

  Science, December 8, 1995 vol 270 p 1557 (letter)

  Science, November 10, 1995 vol 270 pp 927-928

  Science, June 23, 1995 vol 268p 1712-5

  **Science, May 12, 1995 vol 268 pp 785-6 (letter by author who appears from name to be the editor of New England Journal of Medicine)

  Science, April 7, 1995 vol 268 p 25 (news and comments on multiauthor papers)

  JAMA 1996 July 3 vol 276 p 75 (editorial)

  Nature 1995 July 13 vol 376 p 113

  Nature 1995 June 15 vol 375 p 522 (editorial on honorary authorship)

  Nature 1994 December 1 vol 372 p 390 (editorial on pitfalls of coauthorship)

  New England Journal of Medicine 1991 November 21 vol 325 pp 1510-12 JAMA 1990 October 10 vol 264 p 1857 (editorial on order of authorship)