CRA Workshops on Academic Careers for Women in Computer Science and Engineering

"Building Your Research Career"

Francine Berman, UCSD

Panel participants:

- Jeanne Ferrante, UCSD
- Barbara Simons, IBM
- Anne Condon, University of British Columbia
- Nancy Leveson, M.I.T.
- Mary Vernon, University of Wisconsin
- Vijaya Ramachandran, University of Texas at Austin

1. INTRODUCTION

"The joy of research must be found in doing because every other harvest is uncertain." [T. Smith]

"If you want to make important discoveries, work on important problems." [P.B. Medawar]

This chapter is a compendium of two excellent CRA-W panels and my own experience doing research. There is a wide variation in the level of the advice given here, from guidelines for pre-tenure researchers developing their first professional research programs to tips that will be relevant throughout your career. As the quotes above indicate, conducting the research is at least as much a part of the experience as your research results. The research experience can stretch you intellectually, professionally, and emotionally, and a satisfying research career can be well worth the effort and commitment it takes to succeed.

Why Go Into Research?

Computer Science and Computer Engineering are very exciting fields. There are many opportunities for innovation, creating new technology and designing and developing new research prototypes and products, in areas ranging from the most mathematical and theoretical to the most experimental. Researchers are members in a community of

scholars and innovators. The computing research community contributes much that is important and valuable to society and a career as a computer science researcher can be enormously and personally satisfying.

Researchers are as different as the research they do but certain attributes seem to help promote research success. It helps to be:

- curious about the whys and hows of things
- persevering in your approach
- an independent thinker and worker
- creative,
- disciplined and focused when you need to be.

In this chapter, we discuss practical strategies for building a research career as well as the art of doing research.

2. DOING RESEARCH

Your goal as a researcher is to investigate a problem with the goal of developing a solution which advances the state of knowledge about that problem. The choice of the research problem, the way you attack it, the way you communicate your results to your community, and the way you leverage individual research efforts to build a body of work all contribute to your success as a researcher. The following subsections describe different aspects of doing research in more detail.

2.1 CHOOSING A RESEARCH PROBLEM

The choice of a research area and research problems is fundamentally your own. *You should choose an area and problems about which you feel the most excited, interested and creative.* You will spend a lot of time thinking about your research and you want to engage the very best of your creative abilities over a long enough period to thoroughly understand the problem, and come up with innovative and successful solution strategies.

Work on important problems. The more important the problem, the more important your results will be. Good work which is considered too "incremental" or focuses on a problem that few people care about may not provide you the leverage in your research community you'll need at career transitions (first job, tenure, promotion to Full Professor, etc.).

The first problems you work on will probably be a collaboration between you and your thesis advisor or other faculty or students at your graduate institution. As you mature professionally, it will be important for you to develop a sense of what problems to work on and where the next problem will come from. Although some researchers have a natural feel for this, everyone else has learned this along the way so don't feel that you are not cut out for research if you do not know what to do next.

New problems can come from anywhere. A theoretician in the research community began to think about geometric algorithms when he had to move a piano into an upper level apartment. A high-performance computing researcher developed strategies for implementing distributed applications based on her observations of how drivers deal with freeway traffic. Your first problems on your own may come out of the "future directions" of your thesis or out of research papers you have read doing your thesis research. You can pick up new problems reading the literature, going to conferences and noting the areas of interest to your community, talking to colleagues, preparing for the courses you teach, working with students, etc. Many times you'll start addressing one problem and become interested in an offshoot of that problem which leads you to still another problem. Solving problems which somehow hang together or attack a particular theme can help in establishing you as a researcher with an identifiable body of work.

One possible approach to choosing problems is to look for the "hot areas" in your field. This approach has both plusses and minuses. Most research communities have hot areas that change reasonably frequently. Hot areas are often motivated by current issues of practical importance. Making a contribution in such areas is not only worthwhile but can provide you with additional research visibility. If the area is new, you may be able to come up with a significant result fairly quickly if many of the fundamental questions have not been widely researched. However such areas can also be high risk. The more popular an area is, the more people may be working in the area and the same result may be discovered independently by several groups of people. If you are not tied into your research community, you may not know that other people have come up with the same result until you see it published at a conference or in a journal. If you work in a hot area, make sure you know the other people working in the area and are in touch with them so that you are aware of new results.

Finally, *know the literature*. Read widely on your problem and in your area so that you can recognize what is new and what has been done previously. Read widely outside your area if you can because often the same problem may be addressed in different research communities. The more techniques you have in your research arsenal, the more techniques you will be able to apply to any given problem and the more you will improve your chances for success.

2.2 THE "MECHANICS" OF DOING RESEARCH

Professional researchers know a lot about the "mechanics" of doing research. The following is a partial list of research skills that experienced researchers have found helpful in developing an effective research program.

- **Set aside big blocks of uninterrupted time to think creatively on a regular basis.** Your brain is a muscle and it must be exercised to stay in top shape. Many researchers find it critically important to have uninterrupted time to work out research ideas. Although for many researchers, good ideas come at a variety of times (on the drive home, in the shower, at the office), the time to work through such ideas is critical to the development of research results. It is easy to get distracted by small

jobs, unimportant problems, or email during your research time. You must make this time a priority if you want to develop your research program.

- **Know when to work more deeply, when to work more broadly, and when to put things aside.**
  You'll need to develop a feel for when to push through on a problem, when to step back and consider your work in a broader context, and when to give things a rest. This is true both "locally" in terms of the time you spend considering different solution strategies for a particular problem, as well as for the time you give to the problem or the area itself. If things are not panning out for an excessive amount of time, it may be time to move on. It may be that your skills and your problem-solving approach is much better suited to a different problem or even a different area. It's often good to talk to a trusted mentor or colleague if you're at this point so you can get some perspective.

  Note that research is an uncertain profession. You will regularly work on things that don't pan out at the time but which turn out to be useful in completely different venues. Probably the only guarantee is that your work will almost never be "linear" – progressing from problem to result in a direct and straightforward fashion.

- **Start with problems rather than solutions.**
  The idea is to study the problem and understand it thoroughly without restricting your solution approach. Some researchers have had considerable success with particular solution techniques, but the assumption that the techniques you know best will fit all the problems that you are interested in can limit you unnecessarily.

- **Question assumptions.**
  One approach to investigating new solutions is to question the underlying assumptions of your problem. Do you need to assume that k is even or that messages are queued in FIFO order? You may find an innovative way of looking at the problem if you don't take the same path as everyone else.

- **Break the problem into manageable pieces that will fit into a whole.**
  One way to attack a problem is to break it into "pieces" and to try to solve each of the pieces. This approach has the benefit of building a successful solution from smaller solutions. Sometimes you may have a sense of what the next step is but not the step after that. Having a sense of what the pieces are can help provide a context in which to determine your strategy farther down the line.

  Note also that decomposing your research problem is an iterative process and that it may be necessary to re-evaluate the big picture frequently with collaborators, grad students, colleagues, etc. Things that appear to be show-stoppers initially might not be so bad as you get into the problem and things that you thought might be simple may turn out not to be. Keep an up-to-date perspective on the big picture of your research.

- **Know what it means to solve your problem and be able to demonstrate this to other researchers.**
  Have a clear idea about what it means to demonstrate that you have solved your problem. Theoreticians may use theorems and proofs, experimentalists may show comparative studies or simulations. Know what it means to your community to demonstrate that you have done something and make sure that that is part of your solution approach.

- **Have long-term and short-term research goals.**
  Have a sense of the big picture and where the problem you're working on fits within it. Your ultimate research goal is to develop a body of work that represents your talents and skills as a researcher and contributes to the body of knowledge in Computer Science and/or Computer Engineering . In the near term, you are probably working to solve pieces of one or more problems. Develop a strategy which leverages your immediate research goals into a long-term approach to research. Keep your goals in mind when you prioritize your time and effort at the day-to-day, week-to-week, month-to-month and year-to-year levels.

- **Promote your work.**
  No matter how important your results are, no-one will know about them if you don't publish them and present them to your colleagues. Professional research consists of the investigation of problems *and the communication of results*. In the next subsection, we will talk about several strategies for publishing your work but whatever strategy you choose to take, your success as a researcher depends on your ability to communicate your work.

  When you talk about your work, be realistically upbeat about it. Excessive modesty ("This isn't very important.") or excessive arrogance gives the wrong message about you as a researcher and distracts your audience from your results. Put your results into context but allow yourself to feel good about them – this is new work and as such is a real contribution to computer science.

2.3 PUBLICIZING YOUR WORK

Your main means of communicating your work to others, as well as building your research community, is to publish. Researchers often form a strategy for what and when to publish, taking into account how much should go into each paper, where it should be sent, when the work might be mature enough to publish, and how a publication will fit into their career plan. The following subsections synthesize some of the common issues around publishing for researchers.

2.3.1 Where to publish

Most people will tell you to publish in the best professional journals and conferences in your area. There are many good reasons for this – your work will reach the most relevant audience, the quality of your publishing venues will be noted at career transitions or if

you apply for a job elsewhere, and you do your good work justice by publishing it in good places. If you don't know where the good places to publish are in your research community, ask someone who would know and whose advice you trust.

Conversely, avoid publication venues that may be discounted by your professional community – these may include private journals with low readership, poorly refereed conferences, etc. Although workshops are not considered as good a place to publish than top quality conferences or journals, they are often attended by the best people in your field so you may want to publish in selected workshops, but possibly not your very best or most mature work. (In fact, people often use workshops to get feedback for new ideas and/or immature work.). Note that technical magazines are typically not considered as prestigious as good archival research journals (although they often have much broader audiences). IEEE Computer and ACM Communications are widely read and highly competitive and may be considered an exception to this rule.

The importance of journals, workshops and conferences will vary from area to area. In some areas, conferences are considered much more competitive and prestigious than journals; in other areas, journals are considered more prestigious. Some workshops are considered to be as important as good conferences. Make sure you know what venues are considered the best quality by your research community when you are considering where to send your papers.

By the way, in almost all areas concurrent submissions (sending the same paper to two conferences and/or workshops simultaneously or to two journals simultaneously) is considered unethical. Program committees, reviewers, and editors will generally automatically reject any work which they believe is being submitted elsewhere or is very close to work that has already been published. It is reasonable, however, to expand one or more conference papers into a journal submission. There should be more results in such papers than in their constituent parts.

2.3.2 What to publish

What constitutes a publication varies a lot from field to field and even from problem to problem. Your thesis advisor or other faculty can help you in determining what should go in your first publications which will most likely be the ideas in your thesis. For most students, there are 2-3 separable and publishable pieces of work within their thesis.

You can also study the conference proceedings and journals in your area to get a good idea of what constitutes a publishable result. In general, you want to publish one or more good new ideas that you have worked out or substantiated and put into context. Seek to publish the most innovative of your ideas but also the ideas most in need of feedback. Submit these to workshop or a rigorously refereed conference and use the feedback to improve your work. Over time you will develop a feel for what is publishable and what is not.

By the way, your colleagues and reviewers will always appreciate more in each paper rather than less. Although the quantity of publications in your resume does count at

career transitions, the quality counts more. Always publishing immature work or the "least publishable unit" will get you more publications but not earn the respect of your colleagues who will be asked to write letters evaluating your work at tenure time. Just as you will actively seek to investigate important problems, you should seek to write important papers which introduce good new ideas and do a comprehensive treatment of them. Strive to get a "best paper" award with your papers rather than just to be accepted. It will help you to be a better researcher and earn you respect in the eyes of your colleagues.

2.3.3 What do referees look for?

Most referees like papers that are written well, articulately describe one or more interesting ideas, and provide credible substantiation for the importance of the ideas. The quality of your writing is important. Your paper needs to describe to the referees why both the problem and your solution are important. At the same time, don't oversell your work. Many referees are likely to rank a paper higher which describes a solution and its limitations than a paper which purports to have fully solved a problem and hasn't. Beware of using too many buzzwords. Your goal should be to articulately, carefully and thoughtfully describe your problem and solution in a way that communicates to the referees the importance and quality of your work. Write a paper that you as a reviewer would consider excellent. Use classic papers in your area and "best papers" in conferences as a guide for what is good writing. Here are a few tips on style:

- *Make your paper both readable and interesting*. Reviewers are more likely to put unreadable, difficult papers aside to be picked up "later" and are less likely to review them well.

- *Don't try to snow people*. Take time and care to make your ideas understandable. The people who have really significant contributions to make do their very best to explain them in the simplest way possible.

- *Don't make up terminology or use non-standard notation* if conventional notation will do. Don't make up new terms for old ideas. Use conventional terminology.

- *Use both math notation and English to describe your ideas*. This helps your reviewers understand what you are doing. Use examples liberally as well.

- *Make sure your paper is well-organized*. Start with an introduction which sets the context, and describes the problem and solution. Follow with a more detailed description of the solution and your results. Provide some kind of summary or conclusion. Use examples to give readers a feel for what you're talking about.

- *Include a related work section in your paper*. Referees always look to see if the authors have read/surveyed the literature sufficiently. It is important that you do a good job of identifying references relevant to your paper and describing their

relation to your results. Although you want to strive for conciseness, too much related work is better than too little.

- *Use critical reviews to your advantage*. If you send a paper to a conference and several reviewers point out the same thing, listen to them. They are giving you real insight on your writing and your results. Although it may not feel that way at the time, it's often much more helpful to you in the long run to get and use real criticism for your work than it is for people to just say "Good work!". Note that from time to time, you may get reviews that seem overly nasty or personal. Ignore the nasty part, get what you can from the review, and move on – try not to take such reviews too much to heart.

- *Be generous in determining co-authors.* Many researchers err on the side of inclusion rather than exclusion when determining who should be a co-author. There is very little downside to including people who have participated in some way in the work as co-authors. In contrast, there is considerable downside to having people think that they participated in the research and are not being given proper credit. If someone helped but did not participate enough to be a co-author, put acknowledgements in your paper and include their name. Everyone appreciates thanks.

2.3.4 Ordering of authors

Ordering of authors varies widely between areas and between researchers and even for particular papers. Many researchers use a default alphabetical ordering. Other researchers try to determine who is largely responsible for the work and order authors accordingly. Many senior researchers generally put students or junior people's names first and their own name last. Use the ordering policy that seems reasonable to you and will be understood by people in your area. Note that at tenure time, University committees sometimes want an explanation on how much you contributed to a paper and may care about who is first author in non-alphabetical papers. Check with your department so that you're sure that you understand what is expected.

2.3.5 Other ways of publicizing your work

You can communicate your results in other ways than publications. Develop a habit of giving talks on your work at institutions other than your own. This is a great way to get exposure and feedback for your work, and to develop relationships with colleagues in your field. If you're going to be in the area anyway, it doesn't cost much for an institution to invite you to give a talk, so you can use your travel to conferences, meetings, etc. as leverage for building your research reputation. Researchers often do a "tenure tour" (giving talks at institutions where prominent people in your research area work) the year before they are up for tenure so that potential letter writers will be "fresh" and knowledgeable about their work.

You may also want to keep a mailing list of colleagues who are interested in your work. Send them your publications as you produce them, and generally keep in contact with

them on research topics. Note that they may not always read these papers but it doesn't hurt to have your work pass their desk. (Note that in this case, sending the paper rather than just a URL may help in getting them to read it.)

Finally, don't neglect publicizing your work within your own department and at your own university. The more your colleagues know about what you do, the better they can represent you to other researchers, potential students, etc. Knowing about your successes and your research will help your Chair, the Dean, and other administrators when it comes to promotion, support issues, etc.

2.4 DEVELOPING A COHERENT RESEARCH PLAN

Research is not just about individual papers or results, it is about developing a track record. Your work should build into a body which makes a significant contribution to one or more areas and identifies your research skills and interests.

Most researchers start in the area of their thesis work. This is a good starting point as it is an area where you have real expertise, have made real contributions, and have initial research strength. Build from this strength. Take the opportunity after your thesis to address problems you encountered doing your thesis research. You can also take the opportunity to apply the techniques you used to move into related fields. This initial work will provide you a good base from which to build your research.

Why does building a track record in a timely fashion matter? Academics are evaluated by senior people in their area at tenure time who compare them to the best people in their area at their career level. Having a solid record of accomplishments in a well-defined research area will allow you to gain visibility and make a favorable impression. Concentrating on a main area before tenure and having a solid record of accomplishments will help you build a successful tenure case. The following sections focus primarily on building a research career before tenure.

2.4.1 Developing a research area

It is initially a good idea to work in the area of your thesis but most researchers do not spend their entire career in their thesis area. At some point, you will want to branch into related or different areas. The good reason for this is that it keeps you interested, it keeps your skills as a researcher sharp and it's hard to make a very broad impact on research if you are always working on the same set of problems. That being said, the issue for pre-tenure researchers is *when* to shift into other areas. *Your focus pre-tenure is to establish yourself in an area for which there are identifiable senior people and for which you have made clear contributions.* This does not have to be your thesis area, but if it's not, you will need time to establish yourself.

Many researchers shift or expand into new areas either early in their tenure process or late, when they have established themselves in an area already. One strategy for branching out early is to work in your thesis area as well as related or other areas that are

interesting to you post-thesis. Make sure that at least one of the areas in which you work can be considered your "main" research area by your colleagues at tenure time. Note that it is *not* the same to have one good publication in each of *k* areas vs. having *k* good publications in one area. In the former case, senior people in the various areas may feel that they have insufficient data to evaluate you so that none of the communities you work in may consider you tenurable. In the latter case, you have built a body of work that is more visible and identifiable to the senior people in an area and they may feel more comfortable evaluating you for tenure.

2.4.2 Working in controversial areas before tenure

You may consider whether to work in a controversial area before tenure. In such areas, you may generate work that is both very much appreciated (and/or thought to be very important) by some researchers and very much condemned (and/or thought to be inconsequential) by others. If you choose to do this pre-tenure, you may run the risk of negative letters from researchers which may be difficult for your case (see the tenure chapter for more discussion of this process). On the other hand, your department may have other researchers in this area and an understanding that the work is valuable but controversial. Get good advice from your mentors on working in a controversial area. You may choose to work in such areas as a secondary or tertiary area and move into the area more fully post-tenure. However if you are absolutely confident that what you are doing is really terrific, and the problems engage you above all else, go for it. Research is all about risks and sometimes the best choice for your may also be the riskiest.

2.4.3 Collaborating before tenure

For many of us, one of the joys of research is collaboration. Research is often a social process where the synthesis of individual research perspectives can become more than a sum of its parts. Your collaborators will know you well and will understand and appreciate your results. The process of collaboration can be fun and immensely satisfying.

Throughout their careers, most researchers collaborate with a variety of people senior to them, at their level, and people junior to them, including students. In any given collaboration, the role of each person, and the amount contributed to the research by each of them varies. Your role in collaborative research is one of the things your tenure committee will be very interested in. Note that other researchers in the community will sometimes identify the most senior collaborator most with joint work. This can work against more junior collaborators who may actually have performed a considerable part or provided the fundamental vision for the joint work. (This can be especially true with your thesis advisor so you may want to avoid having a substantive part of your research be joint work with your advisor). When collaborating with colleagues, be clear about who will develop the software, who will write the paper, who will be first author, who will present the results, etc. *You can ensure that your work is given proper credit by having some singly authored papers, a variety of research collaborations, and collaborations in which you are the senior collaborator.*

2.5 GOOD RESEARCH PRACTICES

The process of doing research involves not just you but students, collaborators, colleagues, and others in your community. Since you are in it for the long haul, it makes sense to develop good research practices which not only contribute to your experience as a researcher but make you a researcher that is respected by others. Here are some things to keep in mind.

- **Be a good colleague**
  For most of us, research is a fun and social activity as well as an intellectually challenging activity. Be a good colleague. Value your colleagues' time and ideas as you would your own. Seek out good people to work with and nurture your relationship with them. Help others to succeed as people will no doubt be helping you. Give of your time and your expertise to your students, your department and your research community when you can. Don't focus on the trivial, the petty, or fads. As a researcher, you'll be a role model for a great many people. Be a good one.

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- **Use other activities as an opportunity to enhance your research**
  Rather than a distraction from research, teaching and other activities can often be used to enhance your research. Oftentimes, researchers will weave their teaching commitments and research together. If you have the opportunity to teach a grad course or a topics course, you can use it to stay current with the research in your area, and also to interest grad students in your research. Teachers often note that you never quite know a topic as well as when you have to teach it. Teaching even classic material can give you ideas about techniques or relevant work for the problems you are working on as well as interest students in working with you.

  Also, use any opportunity you can to think creatively. You may get good ideas from describing your work to a colleague on a university committee, or even your family. You can get good ideas from reading all kinds of literature and thinking about connections between what you're reading and your research. Lots of researchers get good ideas from looking at solutions to real-life problems, connecting freeway traffic to network problems, waiting in line to queuing theory, etc.

- **Celebrate your accomplishments**
  Academics generally don't get immediate rewards for doing good work. Recognition typically comes as a result of a long track record. Even for specific stellar results, it may be a substantial delay between the time you write up the solution and the time that you present your work or are recognized by your colleagues for it. Impart to your students and yourself a sense of accomplishment when you've completed a project. By the time you get recognition from the community, you will probably have moved on. Don't wait until a paper has been accepted or rejected. Celebrate the fact that you finished the paper and submitted it. If you and your students have worked hard on a project and it's finished, celebrate. You deserve it.

- **Find/create a supportive environment**
  Infrastructure is critical to many research activities. Experimentalists may need adequate numbers of personnel, large-scale computational platforms, and complex software environments in which to conduct their work. Inter-disciplinary researchers may need sophisticated collaboration environments in which to make progress. In order to work well, you will need to find or create enough resources to conduct your research. Often this means attracting sufficient grant money, but you may need resources that you may only be able to get from your department or university – space, furniture, network connectivity, administrative support, etc. Think carefully about your infrastructure strategy. Your success is in your university's best interest and it may be possible to partner with your university in building and maintaining your research program, depending on how tight resources are. In some cases for example, it is possible for the researcher to receive some of the university overheads or other kinds of support to help build the infrastructure they need.

2.6 WORKING WITH STUDENTS

For most academic researchers, much of your research career will be spent mentoring and advising students at all levels. It is extremely rewarding to see a graduate student evolve from a novice to a professional researcher and to see them take their place within the research community. After you have been a researcher for a while, you may even have "grand-students" (students of your graduated students)! Your relationship with your students is an important component of their present and future success as researchers. Good research advisors find a way to help their students mature as researchers, find and solve their own problems, and learn the mechanics of doing research and participating in a professional research community. You will need to consider how to support your students during the period in which they are working with you – intellectually, emotionally and financially. The following are some tips in mentoring and working with graduate students.

- **Find good students**
  If you teach grad classes and/or seminars, you have a terrific opportunity to find and assess students who may work with you on research problems. Many faculty pick the best and most interested students and ask them if they would like to follow up and do an independent study on a research problem of mutual interest. This allows both the faculty member and the student to "try out" a research relationship before they make a more formal commitment to be advisor and advisee.

  You can also give general talks in seminars in your department and see who comes. One approach is to send out a general note to grad students advertising your talk and letting them know that you have research slots in your group or research funding available. Interested students may come to the talk and approach you afterwards about working together.

Another approach is to offer to fund new students in the program or prospective students who have applied to your program. If someone has expressed an interest in a research area you work in, you can offer them an RA for one or more years even before the student has arrived on campus. This is a high risk/high benefit approach which can work out very well or not so well. Some of the risk may be mitigated by offering a promising new student one year RA with an option for further work, should both of you agree that you enjoy working with each other, however this is also higher risk for the student.

- **Develop good students**

  Working with students is not just a lot of work for the students, it is also a lot of work for you because you are essentially training them in the art of doing research. Initially, you will spend a lot of time introducing an area or investigating a new area with a student, getting a feel for their skills and their abilities, and developing a working relationship with them. At some point, you will have a publishable result and you will work with them to show them how to write a technical paper and to edit their work. You will also probably work with them preparing and giving talks and evaluating what's going on in your shared research community. Working with students is rewarding all along the way but especially as the student becomes more senior and interacts more as a colleague and a collaborator than as an advisee.

  Most students come to graduate school without a clear idea of what it takes to do research or be a researcher. One of the ways you can help them learn more about the mechanics of research is to give clear guidance and good feedback to your advisees. Teach them how to analyze a problem and where to look for answers. Teach them how to communicate with other researchers – good writing and speaking will be critical skills for your students no matter what they end up doing. It is very gratifying to see students who started not knowing much about research get jobs and be successful as professional computer scientists

  Note that as with any relationship, your research relationship with your advisees will ebb and flow. Many students find the process of finding a thesis topic difficult as that is their first real "hands-on" experience with the uncertainty of research. Some advisors provide the research problem and the student is tasked with developing a successful solution strategy; some advisors encourage the student to think through the process of finding the problem as well as the solution. Whatever your approach, or the approach taken by most researchers in your community, many students have a particularly difficult time during this period and need additional support. Meeting with the student regularly, finding a small concrete goal to focus on, and letting the student know that all researchers have periods of uncertainty can help a lot.

  When students are ready to graduate, you need to help them think beyond their thesis. What areas are they interested in branching out in and what problems do they want to work on? What problems that come out of their thesis do they plan to work on and what problems are you free to work on with other students? What are their career

goals? You can help them greatly during this period by assisting them to get a good start in their professional career.

- **Support your students**
  It is much easier for students to focus on research if they do not have an outside job. If it is possible for you to support your students, or help them find fellowships of their own, do so. Providing your student focused time and space within your research group gives them a context in which to do good work and can be extremely important in the creative process. If you don't have funding, you might be able to help your student get a fellowship or a TA – all of those help the student stay in the department while doing their research. Know that if a student works at a job outside of the university, it will probably take longer and they may not be as well-connected to their research community as students who are working doing research within the department.

  You can support your students in other ways. Nominate your students for fellowships and awards if you think they are good candidates. There are several national fellowships and internship programs sponsored by funding agencies (e.g. NASA and NSF) or industry (e.g. IBM and ATT) that distinguish good students while they are in graduate school. Being awarded one of these fellowships or internships can help your students both financially as well as providing important professional contacts that will help them after grad school. Your support is critical in order for them to be nominated for such fellowships. Finally, support your students in your department. They will appreciate your efforts and it will help them have confidence in their abilities as well.

- **Encourage your students to publish**
  When your students graduate and enter the job market, the number and quality of their research publications will be more or less of an issue for most jobs. For academic jobs, it will be critical that your student has some record of research productivity. Encourage them to publish throughout their graduate career and not just during their last year.

  The great majority of student publications are co-authored with their advisors. Most advisors feel that they have contributed substantively to the work through their guidance, support, collaboration, writing and editing, etc. to be a co-author on a student paper. There may also be cases in which advisors feel that it is more appropriate for students to publish certain results as a singly-authored paper or with other researchers. You will have your own ideas on what is appropriate on this. It is also useful to talk to other researchers you trust or to look around and see what other researchers in your community are doing in cases where it is not clear what to do.

- **Promote your students**
  The best thing you can do for your students is to give them a good start in their professional life. Help your students develop professional contacts and establish a professional network. Tell your colleagues about their good work. Credit them in

your talks and your papers for their ideas and their research. Nominate them for awards, program committees, etc. Tell funding agency managers about their work. Be a resource to them in finding a job, and in succeeding at their jobs. It is immensely rewarding to see successful researchers in the field who have been former students and who are now mentoring and developing new researchers themselves.

2.7 RESEARCH FUNDING

For many researchers, achieving an adequate level of research funding is critical to their success. Research funding is used to support students and staff, to travel to professional meetings and conferences, to obtain equipment necessary for research, etc. For some researchers in some areas, part of the process of doing collaborative research includes writing or being included in proposals with their colleagues. If obtaining funding is important to support your research or important for interacting in your research community, you will need to become good at it.

There is a whole chapter on obtaining funding in this booklet. In this section, we will briefly focus on the more "cultural" aspects of obtaining funding.

- **Recognize that different funding agencies have different cultures and different means of assessing your work.**

The process of applying for, attaining and reporting on the results of funding varies widely between different agencies. In computer science, researchers typically apply to DARPA/DoD, NSF, DOE, NIH, and NASA for funding. Each of these agencies have very different organizational structures which have a real impact in how proposals are solicited and evaluated, and how funding is allocated. For example, NSF currently uses peer panels to initially evaluate proposals whereas DARPA evaluation is focused around the Program Manager. There may also be very different expectations about what happens after funding is awarded and even what funding can be awarded for. NSF requires annual reports but does not generally focus on "deliverables" whereas these are an important part of DARPA contracts. Have a good feel for the culture and organization before you apply to a specific agency. The best way to do this is to ask people who are funded by that agency what the experience is like.

- **Know the difference between an contract and a grant**

Although you conduct the same kind of research for both, the constraints imposed by contracts and grants are very different. A grant provides you funding to investigate a problem or a promising solution with generally no expectation for concrete deliverables. Grants allow some freedom to follow the direction of the research during the granting period, but the funding itself may be very restricted to particular categories (e.g. salaries for technical participants, travel, equipment). Contracts are much more focused on the "products" of the research and allow less variance. In addition, the reporting requirements may be more stringent, however funds can often be spent on "infrastructure" – administrative staff, meals with visiting colleagues, etc --. which are not generally allowed with grants.

- **Read the RFP or BAA closely.**

The RFP ("Request for Proposals") or BAA ("Broad Area Announcement") contains the description of the program and what the evaluators of the proposals will be looking for. Read this carefully. Don't just read the title of the program and write what you want. Your proposal will be evaluated on the criteria provided in the RFP or BAA and it is critical that you provide enough information to be able to evaluate the work based on those criteria.

- **Be clear about your goals.**

In some areas, it is easy to get caught up in the acquisition of funding. Be clear about your goals – what is the right size group and funding for your research? If you are just starting out, you might focus on winning an NSF Career grant or building a relationship with program managers in the funding agencies who focus on your area. Build your funding program as you build your research and let your research drive your funding rather than the other way around initially.

Note that many very prominent experimental and systems researchers have large research programs which require huge amounts of support. Obtaining research funding can become a full-time job for such programs but the size of a large group also affords a researcher the opportunity to put forward a big vision. The overhead of a big research program is large – multiple grants and contracts are required with considerable management responsibilities, expectations for reporting and interaction with the funding agencies, and large-scale responsibilities for direction, promotion of the research results, and publishing. The responsibilities and scale of the research is large but the potential impact is also large.

3 INDUSTRIAL RESEARCH

Many industrial research activities are the same as academic research activities. Industrial researchers write papers and publish them in their area's technical conferences and journals, serve on program committees and panels, make professional contacts, review papers, etc. Many companies have summer or other programs with universities in which researchers supervise and mentor students. Some companies have sabbatical programs in which industrial researchers can visit universities or other institutions for a prolonged visit and take a long-term view of what they are doing. There are also differences between academic and industrial research. The following subsections briefly focuses on some of them.

3.1 Research Relationships

Researchers who have had both positions in industry and in academia advise that you have a fundamentally different relationship with your colleagues in academia than you do in industry. In academia, most researchers primarily work with their students where they are "project lead" and perhaps with a small number of departmental colleagues. In industry, many researchers work as part of a team where everyone is on the same footing.

Most people who join a company initially join as part of a group. The expectation is that the researcher will be a good team member of a project which may or may not be directly in the area you've been working. Researchers are expected to initially "pay their dues" doing research on the project they were hired on. After establishing their credibility, project members develop more independence within the company and can go on and propose research projects to the company. Successful project members may be tapped as research managers. In contrast, as soon as you join an academic department, you are assumed to be an independent researcher. You set your own direction, goals and agenda and you are responsible for your own research program. You enter as a research manager.

Note also, that the "infrastructure" of your research program varies as well. In industry, it is important to develop company contacts and support within the company. In effect, the company is your "funding agency" and needs to understand and appreciate what you do. Researchers in academia can rely on some infrastructure from the department but most of their research funding must come from outside contracts and granting agencies.
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3.2 Changing Fields

Many industrial researchers feel that it is easier to change fields within a company than in an academic department. The company allows the researcher the time to start up a new field and an environment of project colleagues which affords the researcher the opportunity to learn a new field and contribute. There may be hundreds or thousands of employees at the company and many projects so it may be easy to move within the company. In an academic department, the "startup" for a new area counts towards your next career transition (tenure, promotion to Full Professor). You must time moving into a new area and in particular, develop a strategy so that you have enough time to mature in a new area and so that letters reviewing you as a researcher at career transitions are positive.

3.3 Which is Harder?

Some researchers who have worked in both industry and academia claim that academia is harder. They say that there is more to do as an academic researcher and that it is easier to strike a balance between research and other activities as an industrial researcher. Other industrial researchers claim that the influence of management and the ultimate product orientation of industry make their jobs less stable than for tenured academic researchers.

Note that it may be easier for industrial researchers to move between companies than it is for academic researchers to move between academic departments. Companies may also have an advantage in dealing with "two body" problems as they may have hundreds or thousands of employees rather than tens.

3.4 Industrial Project Management

In most venues, success provides the ability to rise in the hierarchy of the institution. Many successful industrial researchers are given opportunities to lead and manage projects of their own. The experience of these managers varies widely. Some managers say that for some projects, they conducted essentially no research themselves. Some managers feel like they do a considerable amount of research on their projects. The advice of these researchers is to look at a management opportunity very carefully to get a clear idea of how much research is required and to consider who will be working for you, how well defined the tasks are, and how much scope there will be for research.

3.5 Switching from Industry to Academia

It's generally considered to be more difficult to switch from industry to academia than from academia to industry. Researchers who have made the switch stress the importance of keeping an academic profile and maintaining an academic resume. The idea is to do all of the same things the professors at your career level are doing in your research community: publishing papers, serving on program committees and leadership positions in your community, etc. All of this is much easier if your company rewards it. For some companies, having prominent researchers is important and they will give you a lot of latitude with respect to building your academic credentials. For other companies, such activities are considered secondary to activities which support the product development of the company. As with academia, it is probably easiest to move very early in the game, i.e. within a few years of attaining your Ph.D. or if you are a very prominent senior person within your community. In between those two extremes, it is more difficult.

4 "INTERRUPTIONS" AND LIFE AFTER RESEARCH

Your research career is just that, your career. It is not your life, although at times it feels that way, seems that way, or even is that way. Most researchers go through standard creative cycles which are interrupted from time to time by a variety of professional and personal events. The good news is that the research skills you are developing can be used at any time. Getting back into research from an absence is a bit more difficult if your research requires a considerable amount of infrastructure (such as experimental research for example) or if your absence from it is prolonged. *Be realistic*. Life happens, and most of it is much more important than research! Here are a few research "interruptions" and a brief discussion of their potential impact with respect on your research career.

4.1 Sabbaticals

Sabbaticals can be a great boost to a research career. The opportunity to go to a different place without the usual responsibilities and to be exposed to new people and new ideas is often rejuvenating for researchers. Many researchers take the opportunity to learn a new field or do a longer-term writing project on sabbatical. Sabbaticals also give researchers the breathing room to "empty their stacks" of work that has been piling up. If you have a

large research program or considerable infrastructure at your home institution, you will have to make arrangements for supervision and maintenance of your group. Sometimes students may travel with you on sabbatical, but this is less practical for administrative or technical staff. However most researchers consider the opportunity to take a sabbatical well worth the extra effort in arranging it.

Researchers say that the return from a sabbatical is like a "professional Monday morning" after a "research vacation" so plan in advance to make this transition as smooth as possible. While you were away, some things in the department will have changed and you may have missed getting to know some potential students. If you plan ahead, it is possible to minimize the down sides and enjoy the positive experience that getting away can be.

4.2 Moving/Changing Positions

Moving to a new place and a new position can be an exciting change. New colleagues, new students and a new department will influence your work and can provide a good source of new ideas. However, moving often has a real (immediate) cost on your research productivity. You will have to deal with issues around dismantling or leaving infrastructure (equipment and people) from your old institution and how best to set up a good environment at your new institution. At the same time you will be putting together a new life with your family in the new place as well and that takes time and energy. Both personal and professional startup can be time-consuming and will no doubt slow your immediate research productivity. It will take some time to get back up to speed and settle into/create your new environment so keep your expectations reasonable.

4.3 Having Children

For many of us, having children is a peak life event. It's one of the very most important experiences you will ever have so give it your full attention. Some pregnant researchers work until they're on their way to the hospital; some stop some time before that. Many new parents find that it is difficult both physically and psychologically to get back into a very creative research mode for the first few months or even the first year after the birth of their baby. *Be realistic about your priorities during this period*. You may decide to go into "maintenance mode" with respect to your research around the time your baby is born and until your family can re-integrate around its new member and stabilize. If you are pre-tenure, some universities acknowledge that this is a special time and allow the primary caregiver to stop their tenure clock for a period. You may also want to arrange for a lighter teaching load with you chair during this time, or perhaps take a leave to keep your stresses at a realistic level.

4.4 Life Events

Everyone has both expected and unexpected life events that interrupt our everyday lives. Divorce, marriage, serious illness, death, issues with aging parents or children, etc. can change your focus for a considerable amount of time. Be realistic about your priorities. Give yourself the time and space in your professional career to deal with difficult issues When it's time to get back to your research, it will be there for you.

4.5 Life After Research

Unlike ballet or baseball, researchers can do productive hands-on research for many, many years. For more senior researchers, it may be the case that it becomes time to take on new challenges at some point. Senior researchers sometimes evolve out of a direct research mode to take on administrative positions (Chair, Dean, etc.), policy positions in government, industry positions, etc. A productive research career is an important prerequisite for these positions, but the new challenges of these positions also allow the researcher to grow as a professional.

5 EPILOGUE

Research can be an extremely rewarding and satisfying career. Facing, managing and eventually overcoming uncertainty is a powerful experience, as knowing that you have contributed something to the body of knowledge in your discipline that no one has ever known before. Research is both an art and a science: It requires you to know your subject and to know yourself, to have knowledge of the mechanics of solving a problem, as well as a feel for what is promising and what is not. For many people, the experience of conducting research provides an opportunity to grow not only as a researcher, but as a person, in a deep and substantive way, and is well worth the commitment and effort.