1 Introduction to Research

One of the problems that you encounter immediately when you decide you wish to conduct "research" or you want to start a "research program" or you discuss the word "research" is that the term is used in many different ways that will not help you as a Computer Science graduate student.

1.1 What is research?

Perhaps not surprisingly, a very good source for a definition of the word in a context that is, at least, related to our discipline is the free online encyclopedia Wikipedia[**1**].

> *Research is a human activity based on intellectual investigation and aimed at discovering, interpreting, and revising human knowledge on different aspects of the world. Research can use the scientific method, but need not do so.*

The salient features of this definition might be summarized as:

> *Investigate to discover, interpret or revise*

But, investigate what?

1.2 What is Computer Science Research?

Unfortunately at the time of writing no one had attempted to create a "Wiki" for "Computer Science Research". The general definition of research is a good place to start as it introduces a number of different ideas and can be melded with and into our own discipline of Computer Science—which has many aspects to be discovered, interpreted or revised.

Perhaps a useful working definition of Computer Science Research might be:

> *A human activity based on the intellectual investigation of aspects of the world related to the discipline of Computer Science for the purpose of discovering new knowledge, interpreting existing knowledge or revising erroneous or incomplete knowledge.*

As soon as I wrote this definition I became uncomfortable with it. In order to become comfortable I tried to eliminate what is good from what makes me antsy.

1.3 What is Computer Science?

The concepts of:

Discovering new Knowledge
Interpreting Existing Knowledge, and
Revising erroneous or incomplete knowledge.

Seem fine to me. The problem lies in the phrase "related to Computer Science". It behooves us to determine what we mean by Computer Science. I find it helps to be inclusive when determining a definition and to reject definitions that rely on other terms that are generally poorly defined or defined so rigorously that the definition becomes useless through stagnation.

I found a useful working definition at the National Coordination Office for Networking and Information technology Research and Development[1] (NITRD). It reads:

> The systematic study of computing systems and computation. The body of knowledge resulting from this discipline contains theories for understanding
> - computing systems and methods;
> - design methodology,
> - algorithms, and tools;
> - methods for the testing of concepts;
> - methods of analysis and verification; and
> - knowledge representation and implementation.

I argue that this is a useful definition for graduate students because it provides enough meaning to allow a useful discourse about what broad area your research might fall into and who might be interested in it and the results you achieve.

1.4 The processes of research

Research is not an "exact science" and, in practice, can be very messy in the sense that many important discoveries are made in very unscientific, even improbable ways. The rational behind treating research in a formal way is that the process will prepare you for a result when and if it appears. Having said this, the following list is provided as a guideline to help you start a research project. The caveat box at the end of the section is to warn you about over expectation:

1.4.1 Start with a question

What is the problem you are attempting to address? What is the unsolved problem that your research will attempt to resolve?

> *"How can we encrypt a piece of information so that it can be easily decrypted by its intended recipient but cannot be decrypted by unauthorized recipients?"*

1.4.2 State a goal

This is the prize! It essentially answers the "nature" of the answer to your research question but does not actually answer the question. This statement will let you know when you are done.

> *The algorithm we devise will encode a message. The cipher will be impossible to decode for unintended recipients and easily decoded by intended recipients.*

[1] http://www.nitrd.gov/

1.4.3 Form a plan

The process of research is, by its nature, an uncertain task. This does not mean that you cannot plan the research even if the plan changes while you are actually conducting it. Essentially, the plan is a way of connecting your research question with your stated goal. It is a roadmap for getting from where you are to the goal. It does not mean that you cannot change the plan but it does remind you of what your intent was when you started.

The plan normally contains:

- Analysis of the question and how others have addressed it. This is sometimes called a literature review.
- Reasoning as to why the question is significant.
- The methods you intend to apply to the problem.
- The resources you will need.
- The Timetable you intend to follow.
- The Milestones you will reach.

1.4.4 Formulate experiments and hypotheses

> "The shrewd guess, the fertile hypothesis, the courageous leap to a tentative conclusion - these are the most valuable coins of the thinker at work. But in most schools guessing is heavily penalized and is associated somehow with laziness."
>
> Jerome Bruner
>
> "All life is an experiment. The more experiments you make the better."
>
> Ralph Waldo Emerson

An experiment is a set of actions and observations, performed to verify a hypothesis.

A hypothesis is really a guess at explaining the cause(s) of a(n) effect(s). It is not necessarily the right answer but it is a place to start and something to test. It may not always be necessary or even possible to form a hypothesis based on many factors including the unpredictability of whatever it is you happen to be experimenting with but it is often quite helpful to do so.

A simple example might be in order.

The question:

Why does my screen saver not go away when I press one of the computer keys?

Hypotheses:

1. The keyboard does not work.
2. The operating system is not sending the appropriate interrupt.
3. I am looking at a fish tank.

1.4.5 Make and state important assumptions

Assumptions are self-evident truths about your experimental world. The assumptions provide you with certainty so that your experiments can deal with the uncertainty. The assumptions also provide a detailed list of items that must be followed to test any hypothesis that you may prove true and can now be verified by others given that they follow your assumptions.

1.4.6 Collect and interpret data

> "Let's try it and note the results"
> Alexander Graham Bell

Data is collected so that interpretation can occur with respect to the hypotheses you have established. Data that remains uninterpreted is not research but simply a recording of selected events. Unfortunately it is not always easy to interpret data objectively nor is it always clear what data should be collected. This can be particularly true when dealing with any data generated by test subjects.

1.4.7 Research doesn't happen in straight lines

> "I have not failed. I've just found 10,000 ways that won't work."
> Thomas Alva Edison

Rarely does a result occur that is significant on the first try—sometimes not even after many tries at following this process. This should not be discouraging but instead it is an indication of what does not work and what hypotheses can be ruled out. Iteration through a series of experiments and the modification of plans is the norm and should be expected.

Sometimes the more interesting result is obtained by following a plan and proving a hypothesis wrong and being spry enough to catch an important result even when it

1.5 Never have your dog stuffed

> "Never Have Your Dog Stuffed" is really advice to myself, a reminder to myself not to avoid change or uncertainty, but to go with it, to surf into change.
> Alan Alda

What you are attempting to do in research is by its very nature uncertain. This is sometimes difficult to deal with. This is especially true when "uncertainty" looks like "failure".

In his book Perelandra *[2]*, C.S. Lewis describes an aquatic planet where one did not walk so much as hop between floating islands formed from clumps of vegetation. Currents under the islands kept them in a constant state of motion and therefore all footing was, at best, "uncertain". In some sense, this is the normal world of research. It is normal not to "know". It is important to keep this in mind when dealing with the realities of hopping between islands.

The problems with uncertainty are fairly obvious but the benefits are less so. One can look at this in many ways. It is possible to gather great satisfaction creating the certain from what was uncertain based on research. However one deals with uncertainty, it has a

certain beauty of its own--similar to an unfolding rose. But similar to a rose one must be careful how one deals with it.

1.6 Anecdote Section

I was once involved in a very large security enhancement project at a large telecommunication provider. The project's aim was to determine what the cost to a support desk would be of adding a security card to the process of logging onto network servers inside the company's central offices. The assumptions were that the security cards could be issued to authorized technicians who would carry them around in their ID tags and therefore not need to remember a set of passwords. In addition there was assumed to be a cost of the added security card in terms of creating more calls to a central help desk as people lost their cards or did not know how to use them properly.

We duly measured the calls to the support desk before the cards were implemented and again after the card readers had been installed. We found that the number of calls to the support desk actually diminished after the security cards were added. Everyone was happy with the result and the project—now shown to be successful by the data—was declared complete. A few months later one of the project team members was touring a central office and noticed one of the network access terminals had a security card chained to the card reader with a big sign taped to the chair reading "*to log in swipe card in reader*"—in fact, every single card reader had been modified with a chain in each of the COs. Human users had reduced the support desk's utilization but had actually increased the system's vulnerability as anyone could now walk up to the critical terminals, swipe the cards and gain access to the whole network.

1.7 Caveat Section

Neil Bartlett is an emeritus professor of chemistry at the University of California in Berkeley and his comments below are often too true.

Real discoveries in science are unanticipated[2]
I should teach the world that real discoveries in science are unanticipated. A discovery in science depends upon experimental observations, interpreted by an open mind capable of the conceptual demands made by those observations. Real discoveries cannot be ordered up. Nor will real discoveries be likely, if scientists are not allowed freedom to follow up unexpected findings, since the unexpected observation is usually the key to a real discovery.

Scientific research is often costly to carry out. Scientists usually have to compete for the financial support that is necessary for their research. Both the providers of funding, and the scientists receiving the funds, are eager to have research results that justify their expenditures. These pressures act against the spirit of free inquiry.

This is mainly a consequence of research funding being awarded on the basis of research proposals. These research proposals usually describe the research to be undertaken. Since

[2] Quoted from http://www.spiked-online.com/Articles/0000000CA9DB.htm

real discoveries cannot be reliably foreseen, it is highly improbable that a research proposal will detail such a finding. Ordinarily, the provider of funds expects that the research will adhere to the research proposal. More significantly, the scientist is constrained to follow that path, thus diminishing the freedom essential for truly new discoveries.

1.8 Assignments

- On no more than half a page please summarize your life, your academic training and your aspirations. Write in complete sentences.
    - It is not necessary to use a computer but it is important to be clear, concise and legible.
    - Ensure that you check your spelling and grammar.
    - Ensure you include your name and student number.