SYLLABUS FOR IT 944/SYST944/OR944
THE PROCESS OF DISCOVERY AND ITS ENHANCEMENT
IN ENGINEERING APPLICATIONS
[D. Schum]
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SYNOPSIS

By what means do we discover or generate new ideas? Since antiquity, many learned persons have tried to answer this question; it remains one of the most important, interesting, and difficult of all questions we might ask about our intellectual capabilities. At the simplest level we might say that new ideas are discovered as a result of imaginative reasoning. But what such reasoning involves is anything but obvious. In every context including science and engineering we draw conclusions about phenomena, events, and situations based upon observations we make. Over the centuries philosophers and others have come to recognize that it is one thing to justify or defend a possible conclusion based on evidence but quite another to determine how this possible conclusion and the evidence arose in the first place. There are few if any situations in which possible conclusions and all relevant evidential tests of them are provided for us. Hypotheses, evidence, and arguments connecting them, must be discovered by someone.

Rules, canons, or logics for justifying deductive reasoning have been with us since the time of Aristotle's *Prior Analytics*. Rules for justifying inductive (or probabilistic) reasoning have been more difficult to determine. If the philosopher Hume is correct, we may never have any set of inductive rules that can be defended as being uniquely ideal. On many accounts, imaginative reasoning involves something other than deductive or inductive reasoning. If imaginative reasoning does in fact differ from deduction or induction, does it nevertheless conform to any logic? On most views, the process of discovery, and the imagination it involves, is a distinctly psychological experience and one that cannot be expected to obey any rules, canons, or logics. But there are a few persons who argue that there is at least some hope for a logic of discovery. One thing quite apparent is that study of the process of discovery is a compelling enterprise in many different disciplines. Consequently, we have scholarship and recorded experiences concerning discovery and imaginative reasoning that come from many different disciplines. As expected, different views of the process of discovery are provided by different disciplines; this is providential. In studying intellectual processes of the highest order, such as those involved in the discovery of new ideas, we need all the help we can obtain from whatever source it may come. Different perspectives of imaginative reasoning and discovery each supply uniquely valuable insights. As we will see, help comes from some disciplines whose very existence is not widely recognized.

Not all new ideas deserve to be taken seriously. In grading the adequacy of a new idea, novelty alone is not nearly enough. Many truly novel ideas fail to explain anything, generate no new phenomena, or solve no problems. So we also have to be concerned about the extent to which the process of discovery is also efficient and productive. It is one thing to be able to characterize imaginative thought but quite another to be able to demonstrate how we might exercise our imaginations in more productive ways. In recent years, and in several different disciplines, there has emerged a strong interest in developing methods for providing computer assistance to persons performing discovery-related tasks. Considerable research on this matter is now in progress here at GMU.

As the title of this seminar announces, we will become absorbed not only in studying the process of discovery but also in studying ways in which this process might be enhanced or assisted in engineering and in other contexts. There is no single discipline from which we can obtain a necessary, much less a

sufficient, background for study of the process of discovery and the imaginative reasoning it requires. The only major requisite for taking this course is a willingness to consider scholarship and recorded experience from many different disciplines. In our work we will examine discovery-related thoughts of persons whose interests involve philosophy and logic, mathematics, neurophysiology, artificial intelligence, probability, history, psychology, the science of complexity, the study of chaotic processes, the writing of fiction, and semiotics (the study of the signs of nature and their possible meanings). It will be my essential role in this seminar to present discovery-related ideas from this mélange of disciplines in what I hope you will agree is an orderly way. A bit later in this syllabus I will mention what I believe your role should be.

AN ANNOTATED OUTLINE OF TOPICS

I have found it no easy task to decide how best to organize ideas from the vast literature concerning discovery and imaginative reasoning. Here is a selection of topics I believe congenial to the interests of persons who have different theoretical and/or practical objectives in mind as far as study of discovery-related processes are concerned. I have put no time-line on this outline since I cannot now predict how long we will wish to dwell on each of the following topics.

PART I. HISTORICAL COMMENTS ON THE PROCESS OF DISCOVERY

It is said that necessity is the mother of invention; but curiosity is the mother of science. I will have more to say about this idea as we proceed. As we all know, evidence of human inventiveness and curiosity goes back many thousands of years. No study of discovery and imaginative reasoning would be adequate without at least some consideration of human progress in discovery and invention from the earliest ages. The trouble is that this history is now as vast as it is absorbing; we could easily spend several semesters just examining the history of human scientific and technological accomplishments. However, what will absorb us the most, as we proceed through the ages, is what people seem to have thought about the process of discovery in which we are able to generate new ideas that offer potential explanations of phenomena of interest. It happens that developments in mathematics are of particular interest to us. It was believed in earlier times that all new ideas arise from processes similar to those involved in the proof of theorems in mathematics. Many noted mathematicians have been especially interested in the processes of discovery and invention. One very interesting question that we will consider concerns whether new mathematics is discovered or invented. On some views we will consider, the development of mathematics involves both discovery and invention.

A. The Earliest Discoveries in Middle Eastern, Eastern, and Hellenistic Cultures

We begin our historical tour of progress in discovery by considering a variety of accomplishments made in early Egypt, Mesopotamia, India, China, and Greece. Though there is ample evidence of imaginative thought, and certainly inventiveness, in many early cultures, it appears that it was the Greeks who first began to give serious attention to the intellectual processes involved in the act of discovery. The Greeks were deeply impressed by advancements made in mathematics and believed that discovery in other areas could follow similar lines. This idea persisted for many centuries. Though Aristotle distinguished between deductive and inductive reasoning, progress in the study of inductive methods was retarded for many centuries. As we will see, one explanation for this languishing interest in inductive reasoning concerns a lack of understanding of evidence, its properties, uses, and its discovery.

With the demise of Greece, and later of Rome, civilization entered what is usually described as the "dark ages". They may have been dark in western civilization, but not necessarily so elsewhere. Accomplishments were being made in Islamic, Asian, Hebrew and other cultures whose importance has

not always been recognized in the West. It is certainly true that scholars in the Middle East kept the wick turned up as far as progress in science is concerned.

C. The Rise of Experimental Science in the Early European Universities

With the rise of the universities in Europe, and even earlier among various Islamic scholars, came acknowledgment of the importance of putting questions to nature and conducting experiments. Interest in the study of inductive methods in science, which had been rather dormant since the time of Aristotle, began to arise. As far as inductive methods in science are concerned, it is said that Francis Bacon rang a bell that called all the wits together. Though he drew attention to the importance of induction in science, the methods he advocated are not quite adequate to the task.

D. The Beginnings of Modern Science: The Arch of Knowledge

By the time of Copernicus, Kepler, and Galileo, there were some definite ideas about the process of discovery. Using the metaphor of an "arch of knowledge", we will be able to trace, quite informatively, how the process of discovery was viewed by the likes of Bacon, Galileo, Newton, Hooke, and many others. As we will observe, for all of these individuals there was an inductive and a deductive arm on their arches of knowledge.

PART II. THEORIES OF DISCOVERY AND IMAGINATIVE REASONING

With one or two earlier exceptions, it was not until the 1800s that some persons began to suspect that, during the process of discovery, there may be forms of reasoning that are neither deductive or inductive. As we know, in deductive reasoning there is no content in a conclusion that is not already contained in premises. Induction involves justification, based on evidence, of hypotheses already generated or discovered by other means.

A. Discovery vs. Justification: More on the "Arch of Knowledge"

Using the "arch of knowledge" metaphor, we will consider views about the process of discovery as expressed in the very important works of John Herschel, William Whewell, and John Stuart Mill. Both Herschel and Whewell began to think that the generation or discovery of a new idea involves something other than deduction or induction. In the works of these three persons we will encounter a controversy that is still with us today. It is one thing to study how some hypothesis might be justified or defended on the basis of evidence but quite another, or so it seems, to say how this hypothesis and our evidence were generated or discovered in the first place. Some persons argue that discovery and justification are made of the same cloth; others disagree.

B. Discovery: A Matter for Philosophers or Psychologists?

For many years, even quite recently, philosophers seem to have been quite content to relegate the study of discovery to psychologists. The essential ground for such a view is that discovery seems to involve apparently unsystematic processes that cannot be captured by any form of logic we know about. As we will note in a later section, many philosophers now seem to be repenting their earlier disinterest in the process of discovery. Indeed, several contemporary philosophers have recently "migrated" into the field of artificial intelligence and are actively involved in research on computer-based means for the analysis of discovery-related processes.

C. Charles S. Peirce on Abductive Reasoning and the Efficiency of Discovery

It appears that the first person to state specifically that the discovery of new ideas requires reasoning other than deduction or induction was the American philosopher Charles Sanders Peirce (1839 -1914). Peirce coined the term *abduction* (he also used the terms *retroduction* or simply *hypothesis*) to refer to the process by which a new idea is generated. But Peirce was not only concerned about how new ideas are generated or discovered. He was also very much concerned about how we might make the process of discovery efficient. As I noted earlier, not all new ideas lead in productive directions. We will examine Peirce's thoughts on abduction rather carefully since they form perhaps the first attempt to study the process of discovery in a systematic way. In any case, his work has been very influential and has given some persons hope of discovering a logic of discovery. Peirce's thoughts on abductive reasoning and discovery were indeed seminal. But they can also be rather confusing since Peirce was not always precise or consistent in his discussions of abduction or retroduction. There are now some very valuable analyses of Peirce's works that we will examine carefully. From these works we gain additional insight into abductive reasoning and its connection with other forms of reasoning. There are some surprises here. For example, on one account we have the discovery of a new idea described in terms of the modern concept of an *inference network*.

D. Sherlock Holmes and Abductive Reasoning

A very interesting coincidence is that, at the same time Peirce was writing on abductive reasoning, Sir Arthur Conan Doyle was providing his fictional character Sherlock Holmes with reasoning skills that sound very much like Peirce's abduction. Conan Doyle seems to have been inspired by one of his medical school professors, Dr. Joseph Bell. Bell's abductive and diagnostic feats are truly astonishing. We will dwell upon Sherlock Holmes and Joe Bell not just for entertainment value. On several matters it seems that Conan Doyle rather than Peirce got things right as far as the role of abductive reasoning in discovery is concerned.

E. Semiotics and Abduction: Reading the Signs of Nature

A well-established discipline many of us never hear about is *semiotics*, the science of signs. The word *semiotics* stems from the Greek *semeiotikos*, a word referring to a person, such as a physician, who divines or interprets the meaning of signs. Although interest in the interpretation of signs goes back at least to Aristotle, contemporary semiotics has its roots in the work of Peirce. A sign is traditionally defined by the Latin phrase *aliquid stat pro aliqou* (something that stands for something else). Observing the signs of nature, we attempt to discover their meaning; here is the connection between semiotics and abduction. One contemporary semiotician, Umberto Eco, has attracted world-wide attention through his novels *The Name of the Rose*, *Foucault's Pendulum*, *The Island of the Day Before*, and recently, *Baudelino*. One of the required readings in this course is his work with Sebeok: *The Sign of Three: Dupin, Holmes, Peirce*. I regard this work as a feast for anyone interested in imaginative reasoning and discovery.

PART III. WHERE IS FANCY BRED?

Peirce frequently associated abduction with the sudden "flashes of insight" we all experience from time to time while we are attempting to draw conclusions from evidence or are working on problems of various sorts. But Peirce was not very informative about how such insights arise, whether or not they occur to us suddenly. You have certainly had the experience of deliberating on evidence, or working on some problem, when possible hypotheses or possible answers are elusive. So, you set the task aside for a while and later, often while occupied by other matters, a hypothesis or answer suddenly occurs to you.

Where did this new hypothesis or possible answer come from? One natural possibility, of course, is that your brain/mind was at work on this problem all the while you were doing other things. When it had an answer of some kind to report, it did so regardless of what else you were doing. In the process, you might reflect upon the fact that you were not at all aware of any mental processes that were taking place regarding the task whose possible hypotheses or answers were so elusive. In this section we come face to face with some very difficult matters concerning the mental activities and processes by which new ideas and possible evidential tests of them are generated or discovered. Be assured that all of the matters we discuss in this section have been of concern to persons in all of the sciences, especially in mathematics, physics, and in many other disciplines as well.

A. Insights: Where do They Come From ?

Shakespeare wrote: "Where is fancy bred? Or, in the heart or in the head"? We all expect that fancies, in the form of new ideas, somehow come from our heads. Once we start examining processes that may be going on inside our heads, we immediately encounter a very old issue that is certainly alive today. This issue concerns the distinction, if any, between our minds and our brains. This is sometimes called the *mind-body problem*. One important element of this issue involves distinctions between conscious and subconscious mental activities. It may come as a surprise to you to learn how many eminent scientists and mathematicians have been and are now vitally concerned about such matters. We might believe that such matters are of interest only to philosophers and psychologists. On several accounts that I will tell you about, explaining how our consciousness arises is reckoned to be the most difficult research problem that can be addressed. In addition, as noted above, many learned persons emphasize the role of our subconscious mental processes during the process of discovery.

B. Methods of Study of Mental Processes

Supposing that discovery and imaginative reasoning are mental activities of some sort: How are they to be investigated? We will examine several different methods that have been employed or are now being employed in various disciplines. Different methods will, of course, be informative in different ways. I will tell you about a recent experience I have had with two very recent forms of study of mental processes in the form of CAT scans and MRI examinations.

C. Mind vs. Brain: Arguments About the Distinction

In discussing intellectual processes such as discovery and imaginative reasoning, arguments about the distinction between mind and brain seem unavoidable. There have been no final answers in these arguments in the last 2500 years. I doubt seriously whether we will be able to supply any during this semester. But there are certainly some very strong advocates of various views that have been taken. Again, be assured that study of this distinction is not an idle distraction. We can easily observe the crucial role of our subconscious in work on problems in which we have a strong vested interest. Probably the most prevalent view today is that discovery and the imaginative generation of new ideas is the result of a very sophisticated interplay between our conscious and subconscious mental activities.

D. The "Enchanted Loom": A Bit of Neurophysiology

Persons in various disciplines in which there is interest in the process of discovery do not always talk to each other. When they do talk, sometimes they do not listen very carefully. On some views, we can easily discuss discovery, invention, and other "intelligent" activities without any reference to the work of persons who have made careful studies of the structures and functions of the human brain. I do not happen to be among those persons who argue that neurophysiologists have nothing to tell us about the

process of discovery and the origins of insight. In this section we will have a look at what nature has provided that seems to allow us to perform various discovery-related activities. In current jargon, this involves study of the "wetware" of our brains. A recent work I will tell you about berates the developers of "intelligent" systems for their innocence of the neurophysiological systems with which we have been so richly endowed by nature.

E. Neurophysiological Correlates of Discovery

The human brain has been referred to as the very "cathedral of complexity" in the known universe. It seems that the highest level of the "services" or activities in this "cathedral" involves creative, imaginative, or inventive reasoning. Here we have a look at very current research on activities in the brain that might plausibly be associated with the emergence of new insights. The views of several different research activities come together on this matter. In the process, I will provide you with what I regard as very informative work in an emerging area called the *science of complexity*.

PART IV. SOME MODERN SPINS ON ABDUCTION AND DISCOVERY

In this section we will examine various current views about discovery, abduction, and imaginative reasoning. In particular, we will observe how the term "abduction" has acquired a variety of different meanings in the field of artificial intelligence.

A. Abduction as Inference to the Best Explanation

The word *abduction* has many meanings; Peirce himself was none too consistent in his use of this term. As some of you may already know, this term has found current employment in various works in artificial intelligence. On some interpretations in AI, abduction is said to be *inference to the best explanation*. This interpretation goes back at least to John Stuart Mill. There is meaning here which is not reflected in any of Peirce's works on the topic. The word *best* is troublesome since it mixes justification with discovery. If this interpretation read: *inference to a possible explanation*, there would be a better correspondence. However, we are all entitled to use words any way we please. In fact, Peirce used the term *abductory induction* with reference to instances in which discovery and induction seem to be mixed together. As we discuss in a later section, we commonly experience various mixtures of abduction, deduction, and induction.

B. Koestler, Bisociation, and Chaos in Discovery

Another valuable work on on discovery is Arthur Koestler's *The Act of Creation*. Like Eco, Koestler wrote novels and thought very deeply about imaginative reasoning and discovery. He describes a process he called *bisociation*, wherein the mind makes leaps from one frame of reference to another. Quite recently, in their work *Turbulent Mirror*, Briggs and Peat have given an account of bisociation in terms of the theory of *chaotic processes*. This is fascinating stuff and leads to some very current research on complex phenomena. Unfortuately, Koestler's work is out of print. For years I assigned this book as required reading in this course.

C. Any Hope for a Normative Theory of Discovery ?

The work *Scientific Discovery: Computational Explorations of the Creative Processes* (Langley, Simon, Bradshaw, & Zytkow) attracted attention since it suggested that there might be a logic for discovery, at least within the context of science, that could be implemented by a computer. This work and other computationally-oriented works to be mentioned are held in reverence by Margaret Boden, whose

book *The Creative Mind: Myths and Mechanisms* has also been influential. Other persons in AI and elsewhere argue that there was actually no discovery but only hindsight revealed in the work of Langley et al. Whether a computer can be truly imaginative is a controversial issue at present.

D. Imagination, Creativity, and Invention

These three words are often used synonymously but they may refer to different activities. After an attempt to sort out possible differences among these activities, we will have a look at various studies of the characteristics of persons whose works allow us to label them as being especially imaginative, creative, or inventive. As expected, psychologists have been interested in characteristics of imaginative or creative people. There are several works on behavioral analyses of human imagination and creativity that are especially valuable.

PART V. DISCOVERY IN TIME: INQUIRY, SEARCH, AND HEURISTICS

Most of the previous topics concern the characterization of imaginative reasoning and discovery. It is one thing to characterize these important activities but quite another to discover ways of enhancing the process of discovery. We begin in this section by examining how episodes of discovery are played-out over time and how they all seem to involve the processes of inquiry and search. In some current works, focus is directed more on search than upon inquiry. I believe this to be unfortunate. My own view is that sophisticated search strategies are necessary but not sufficient for productive and efficient discovery. Asking the "right" questions is at least as important as having sophisticated search strategies. Since discovery occurs over time, perhaps we do not yet have on hand (in a searchable data base) information that will eventually lead us to further productive discoveries. Such information we can only be obtained by inquiry, a necessary topic of interest in its own right.

A. Temporal Patterns of Discovery, Justification, and Choice

The word *discovery* means different things to persons in different contexts. One reason is that they experience different temporal mixtures or cycles of three intellectual activities: discovery, justification, and choice. Stated another way, in different contexts we experience different mixtures or cycles of abductive, deductive, and inductive reasoning together with value assessments if our discovery and justification is a prelude to some eventual decision. Many attempts to provide computer-based assistance to persons facing difficult judgmental and decisional tasks have faltered because it has not been acknowledged that the processes of discovery, justification, and choice are frequently bound together in complex and interesting ways. As we will see, we have evidence in search of hypotheses, hypotheses in search of evidence, and the testing of hypotheses, all going on at the same time. In short, discovery involves mixtures of abductive, deductive, and inductive reasoning.

B. Time and the Interrogation of Nature

We get lots of information without asking for it. The trouble is that we frequently do not get the information we need. Every day my mailbox is full of information about products in which I have no interest. But it rarely contains information I need in the research I perform. In many cases, of course, we do not even know what information we ought to have in some problem we face. In science, engineering, and in other disciplines we get very little information unless we put questions to nature. Indeed, the process of inquiry is crucial in any episode of discovery. How do we know which questions to ask? Some questions we ask will be foolish or at least unproductive. Some questions will supply useful answers that

lead us to ask other questions. The process of inquiry feeds on itself over time; we cannot ask all pertinent questions at once. During discovery we have observations or data in search of hypotheses (explanations) at the same time we have hypotheses in search of data. In short, the process of discovery is bound together with the process of inquiry. We will examine several theories of inquiry, the most notable being that of the logician Jaakko Hintikka and his colleagues. In the work *The Sign of Three* (Chapters 7 and 8) you will discover that Hintikka believes the allegedly abductive talents of Sherlock Holmes can be better explained by saying that Holmes was simply adept at asking strategically important questions of nature.

C. Search and the Necessity of Heuristics

On some current accounts, the process of discovery amounts to having sophisticated methods for search (of records, files, data bases, etc). But this assumes that all the information we need to have is already at hand. But discovery is usually played-out over time and it will rarely be the case that we have all useful or relevant data at hand. In many situations we only begin to fill up a database through the process of inquiry. But it is certainly true that study of search is a necessary element of discovery (I just don't happen to believe it is also sufficient). Sherlock Holmes tells Watson: "You know my method, it is based on the observance of trifles". During discovery, trifles (or details) accumulate at an often-astonishing rate. In some lucky cases, a single trifle can suggest a hypothesis (or possibility), such as the finding of a fingerprint. In most cases, however, hypotheses are generated (or abduced) from *combinations* of trifles. The trouble is that the number of trifle combinations increases exponentially with the number of trifles we have. With even a relatively small number of trifles we can readily exceed the capacity of any known or possible computer to select all of their possible combinations. So, we find it absolutely necessary to have some guides or *heuristics* for deciding what trifle combinations to examine. Peirce made the use of the term "heuristic" central in his thinking.

D. Peirce, Polya, Lakatos, Lenat, and Others on Heuristics.

The word *heuristic* can be defined as any aid to learning, inquiry, or discovery. There are some very valuable works on heuristics by the persons just mentioned. It will pay us to examine these works rather carefully.

E. Discovery and Theories of Probabilistic Reasoning

We might ordinarily think of probability theories as being concerned only with inductive justification and not discovery. However, I believe there to be discovery-related heuristic merit in each of the current views of probabilistic reasoning we routinely examine in IT 842; here is the basis for this claim. We ask questions about our evidence in the process of establishing its relevance, credibility, and inferential force. But we also ask questions of our evidence in generating (abducing) new hypotheses and further evidence. Careful examination of the Bayesian, Baconian, and Shafer-Dempster systems of probabilistic reasoning each suggest various kinds of questions we should be asking about and of the evidence we gather.

VI. DISCOVERY AND ITS ENHANCEMENT IN VARIOUS APPLIED CONTEXTS

Having looked at what discovery is and the mental activities it seems to involve, we now ask an important question: can we design various methods for enhancing our ability to perform discovery-related tasks? I believe the answer to this question is: yes. Here are some examples of discovery-related research now underway at GMU. You may easily be able to mention work that is going on elsewhere about which I may have no present awareness.

A. Discovery and the Marshalling of Evidence

Several years ago my colleague Peter Tillers (Cardozo School of Law) and I enjoyed the support of the National Science Foundation in studying ways of enhancing the discovery-related activities of criminal investigators, auditors, historians, and many others whose work involves the tasks of generating hypotheses, evidence, and arguments linking them. Our work rests on a very simple premise that some may regard as too obvious to be stated. The premise is: How well we marshall or organize our existing thoughts and evidence determines how well we will be able to generate new hypotheses and further evidence. Though apparently obvious, it does not seem that this premise has formed the basis for the design of many existing databases. Many databases and other means of storing information are quite adequate for various archival purposes. Where they fail is that they are not also designed for heuristic purposes in the enhancement of the inquiry process so vital in discovery. The trouble is that discovery, and the imaginative reasoning it involves, is a very rich intellectual process. There are many requirements imposed on us during the process of discovery. It appears that there is no single way we can marshal or organize our thoughts and our evidence that will satisfy all of these requirements. What I will describe is an entire network of evidence marshalling operations, each of which is designed to be heuristically-valuable in generating further inquiry at various temporal stages of the process of discovery. We have constructed a computer-based prototype of the evidence-marshaling network that I will show you. Our present works draws upon nearly every topic mentioned during this seminar. In describing this research I will relate it to current work in knowledge discovery in data bases and the related process called data mining.

A former graduate student in our IT doctoral program, Carl Hunt, has generated some truly imaginative ideas for enhancing the important process of marshaling thoughts and evidence. For his doctoral dissertation he designed a system called ABEM [Agent Based Evidence Marshaling] in which evidence items can marshal themselves in the act of suggesting new hypotheses and new lines of inquiry. I will tell you about his research and how it employs many concepts from the emerging science of complexity that I mentioned above. I will also tell you about how we are applying our work on evidence marshaling strategies to current concerns regarding homeland security matters. With any kind of luck, Carl Hunt [retired Colonel, U. S. Army] will come to class to tell us about his work and how it has generated enormous interest in agent-based systems to assist in evidence-based reasoning.

B. Discovering Software Requirements

As many of you know, we have in IT&E a vibrant research program on the design and development of software systems. One of the most difficult tasks in this area is discovering what a client does or should want a software system to perform. This involves what has become known as Software Requirements Engineering. Several recent doctoral dissertations at GMU have addressed discovery-related issues in software requirements and others are in progress.

C. Knowledge Discovery in Data Bases

My esteemed colleagues Dan Barbara and Arun Sood in Computer Science are involved in yet another vibrant research effort at GMU. This project involves the process of discovering knowledge in databases using various forms of data mining. I have been very pleased to collaborate with Dan and Arun on some of these projects. As I noted above, "trifles" accumulate very rapidly and we must have better strategies for extracting useful knowledge from massive databases. This project concerns development of strategies for discovering patterns, relationships, and regularities or anomalies in large databases. This is

very interesting since it is argued that a major element in scientific discovery involves finding explanations for anomalies.

D. Engineering Design and Creative Problem Solving

Professor Tomasz Arciszewski is actively involved in the study of ways to enhance design processes in engineering. He considers a wide assortment of techniques, some of which he has developed himself, for solving engineering design problems in imaginative ways. He offers a seminar on these topics in the Department of Urban Systems Engineering [Engineering Design and Creative Problem Solving]. I hope Professor Arciszewski will be able to join us, as he has done in the past, to give us his perspectives on imaginative or creative reasoning as they influence engineering design processes. Tom and I have worked together on applications of a very sophisticated evolutionary computation system called *Inventor* by means of which new and more adequate designs for wind-bracing systems for tall buildings are generated. I was fortunate to be asked to collaborate with Tom and Ken De Jong on this project. I do hope Tom can join us as often as he can. As you will observe, he has some remarkable insights into the processes of discovery and invention.

E. The Learning Agents Center [LAC]: Professor Gheorghe Tecuci

For the past several years I have been privileged to work with Professor Tecuci, the director of LAC at GMU. Gheorghe and I, together with Professor Mihai Boicu, have worked on applications of a system Gheorghe has spent nearly 25 years developing, it is called *Disciple-LTA*, where LTA stands for: Learning, Teaching, and Assisting. We have obtained the support of several intelligence services regarding further development of Disciple-LTA to assist intelligence analysts in their very difficult tasks of making sense out of masses of different foms of evidence from many different sources. Much of these tasks involve discovery-related tasks that Disciple-LTA can assist analysts to perform. I have invited Professor Tecuci to be with us whenever he can. He is one of the world's authorities on the design of systems that can assist persons in performing some truly complex reasoning tasks.

ASSIGNED READING

There is no textbook written for a course such as this one. But there are some very excellent books available to get you started in thinking about discovery and its possible enhancement. My only difficulty has been in making a choice of works I regard as "required". The price of books is larcenous, as we all know. Happily, three of the four books I will list below are in paperback. Here are four books that I will ask you to read. Each of these books provides a different perspective from which to view discovery and imaginative reasoning. In class I will tell you why I have selected these four books in preference to others I might have chosen.

1) Root-Bernstein, R. S. *Discovering: Inventing and Solving Problems at the Frontiers of Scientific Knowledge*. Bridgewater, NJ, Replica Books, A Division of Baker & Taylor, 1991. If you have trouble obtaining this work at our bookstore, you can order it through Amazon.com. Its ISBN Number is: 0735100071. If you have trouble obtaining this work, please let me know.
2) Eco, U., Sebeok, T., *The Sign of Three: Dupin, Holmes, Peirce*, Bloomington, Indiana, University of Indiana Press, 1988 Midland Book (paperback) edition.
3) Polya, G., *How to Solve It: A New Aspect of Mathematical Method*, Princeton University Press, 1973
4) Hadamard, J. *The Psychology of Invention in the Mathematical Field*, New York, Dover, 1954 [paperback]

I addition to these books, I will have extensive notes for you on every topic we discuss in class. By means of these notes I hope to bring together, in some semblance of coherent form, the truly diverse literature on discovery and imaginative reasoning. In addition, these notes will contain a large assortment of matters not covered in the books I have asked you to read.

HOW SHALL WE PROCEED ?

Some of you already know of my fondness for what Francis Bacon said about the requisites of scholarship: reading makes us full, discourse makes us ready, and writing makes us accurate. This seminar will contain all three of these ingredients. You will certainly have lots to read. I will provide you with notes on each of the topics listed above. I will have these notes for you before the time at which they are to be discussed in the seminar. My intention is to maximize the time we spend in discourse about these topics. Be prepared to raise questions about matters we will discuss and to bring in your own thoughts about these matters as a result of your experience and/or other reading. My major objective in this seminar is to draw ideas and questions out of you. Your dissertation research rests on original ideas you generate. I will have more to say about this process as we proceedand how it relates to the New seminar SEOR/IT 763.

METHOD OF EVALUATION

This being a seminar on imaginative reasoning and discovery, my fondest hope is that your own imagination will be sufficiently stimulated so that you will make a discovery in your own area of research that brings you fame, if not fortune. Failing this, I at least hope your curiosity is sufficiently aroused by a discovery-related topic so that you will be driven to find out more about it from existing literature. The choice of topic is entirely yours provided that it involves the process of discovery and/or imaginative reasoning. If it is possible, depending upon the enrollment, we will allow time in the seminar for you to present your ideas to the class. In any case, at the end of the seminar I will expect to have written evidence of your thoughts on the topic you have chosen. As far as this paper is concerned, here is what you can expect as far as my grading standard is concerned. By the way, these standards are virtually the same as those you will face as far as your doctoral dissertation is concerned.

C = A paper that simply lists what others have found regarding the topic of interest to you. It is not enough to write that A says this and B says that. Such uncritical and unintegrated efforts more closely resemble a high school book report than they do an acceptable graduate paper.

B = A paper that provides a critical and a well-integrated assessment of existing work in the topic you have chosen.

A = A paper that is critical and well-integrated assessment of existing work and, in addition, gives evidence of your having applied your own imagination in extending thought on the topic you have chosen. So, you can look upon an A as representing the same criteria you can expect to be in force as far as your doctoral dissertation is concerned.

A final point is that I wll ask that you submit your paper in hard copy form so that I can make comments on it. I would much prefer to spend my time reading what you have written than to wait for your work to download and printed.

WHERE TO FIND YOUR INSTRUCTOR

I usually lurk in the vicinity of Room 2226, Engineering Bldg. (703-993-1694). I keep no office hours because you are always welcome at any time. I also teach in the Law School and expect to be at the Arlington Campus on Tuesdays. If I am not at school I will be working at home. Never hesitate to call me at home; the number is: 703-698-9515. My e-mail addresses are: <dschum@gmu.edu> and <dschum398@earthlink.net>. I will do all I can to make this seminar a stimulating and profitable experience for you.

FURTHER REFERENCES ON DISCOVERY, INVENTION, AND IMAGINATIVE REASONING

Here is a list of references relevant to various works on discovery. You can find other valuable references in the bibliography of each of the four works mentioned above. I have sorted the following references out in terms of the topics listed above. As you see, I have added a few comments to the various references I have listed. I will have additional references for you as we proceed.

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