Psychology Applied: A Fusion of Abduction and Ergonomics

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The world has an increasing number of problems, many of which involve a human-technological component, the solution of which requires strong methods. To explore problem solving methods, I proposed the development of an abductive-ergonomics framework. This framework must support the generation of theories that will support design. To achieve this, I discussed psychology's current method, the hypothetico-deductive method, suggesting that it is not a general method. As an alternative I discussed abduction, which provides a strong general method. I also explored the aims, perspectives, and unit of analysis offered by ergonomics. In the last chapter I proposed that abduction provides the control task structure to the real world domain described by ergonomics. The fusion between abduction and ergonomics provides the basis for the real world problem solving framework proposed in this thesis.

Introduction

The world grows increasingly sophisticated. In the current era we are experiencing deepening intra-global communications, mounting technology, and an growing wealth of information in the natural and social sciences (Ludwig, Potter, & Snidvongs, 1998). Despite the world's developing potential, we still face a wealth of social, technological and environmental dilemmas (Ludwig et al., 1998). How can we enhance our problem-solving methods in order to cope with the ever-increasing range of real world problems? We need methods to guide our approach to solving real world problems (Moray, 1995). We need to encourage sharing between research and application, and to tie research to the solution of real world problems (Rouse, Kober, & Mavor, 1997). In particular, I ask three questions: firstly, what are psychology's current methods and how do they affect real world problem solving? Secondly, are there any alternative methods that might influence real world problem solving? Lastly, what does ergonomics offer real world problem solving? I propose to use the results from these three target questions to develop a systematic real world problem solving framework, a framework designed to support both the research and design of solutions for real world problems, drawing from abduction and ergonomics. This framework will support both the scientific and innovative aspects of research and design in real world problem solving by applying psychological knowledge to the exploration and solution of real world problems. To achieve my objective I will explore four topics. These topics are: hypothetico-deduction, abduction, ergonomics, and real world problems.

The first of four topics will be an exploration of the inadequacies of psychology's current method - the hypothetico-deductive method. Hypothetico-deduction fails both as a general scientific method and as a conceptual framework supporting real world problem solving. The second topic will consider a previously unknown aspect of methodology known as abduction. I propose that abduction offers a better conceptual replacement for the hypothetico-deductive method. The third topic, ergonomics, contributes an interesting unit of analysis, aims, and perspectives in real world problem solving. The final topic will draw the threads together into an integrated conceptual framework, while providing a miniature exemplar test case of problem solving in action. This miniature test case will be a simplified real world problem that will help to explore the ways that the previous chapters integrate into a systematic real world problem solving framed. In summary, the overall aim of this thesis is to explore the negative influences of hypothetico-deduction, the positive influences of abduction and ergonomics in the context of applying psychological knowledge to real world problem solving. Despite its methodological character the contexts of this thesis are the real world problems of a human-technical nature. To place this work in context, let us consider the current state of the world.

The Problems of the World

From a positive viewpoint, in the last two years alone, since the events of September 11, the CSA Psyc-info database lists approximately 400 studies that related in some way to the social, psychological, and causal issue of terrorism (CSA, 2003). In Europe, recycling technologies have accelerated their recycling capability so that Germany can recycle nearly 80% of its consumer waste products (Hawken, 1993). This recycling involves items such as glass, metals, and packaging (Duales-System-Deutschland-AG, 2001). New trends in building design may see buildings of the future built with decreased energy consumption, increased used of recycled materials, and an increased resistance to sick building syndrome (Griffith, 1997). Refocused environmental education groups have intelligently targeted high school students, the up and coming policy makers of the next generation (Mogensen & Nielsen, 2001).

Information regarding the state of the world that originates from industry tends to support an optimistic view; with new technology and research solving problems created by 'old technology.' However, in a sickening contradiction, technology simultaneously helps victims of the chemical disaster in Bhopal India (3,800 dead due to leaking gas fumes[1]) while continuing to produce toxic waste in an effort to provide the first world with a civilized and comfortable mode of life. The current CEO of Dow Chemicals[2] made a statement in 2002 affirming this optimistic view, "...the tragedy [in Bhopal] changed our industry forever as companies across the globe collectively took on the moral responsibility to prevent anything like it from ever happening again... The products we produce benefit people around the world, improving their lives each and every day...." (Parker, 2002). Contrary to this

[1] This event was attributed to Union Carbide India (Parker, 2002)

[2] Dow Chemicals bought Union Carbide India (Parker, 2002)

optimistic picture, commercial pressure continues to weed out the solutions of the future in favour of the more cost effective fixes for today (Papanek, 1984).

First world nations give third world nations billions of dollars of aid, yet the third world continues to bear witness to an ever-increasing cycle of terrorism, corruption, and hatred (Kaplan, 1994). In the First World, a growth economy consumes an ever-increasing amount of non-renewable resources (Hawken, 1993). Each week every American consumes approximately 16 kg of resources, and 900 kg of waste are created as a result of the production of that 16 kg of consumable resource (Hawken, 1993). These waste products are placed in landfills and dump-sites, which are very short-term solutions. Furthermore, social and technological intercessions are often withdrawn before their effects can truly be felt. For example, despite owner protests, the EV1 (the General Motors production electric car) is currently being withdrawn from the market (Duffy, 2002).

There is always a range of viewpoints surrounding the issues of the world. From a pessimistic biological perspective, a neo-Malthusian viewpoint might suggest that the world faces a bleak future. Several hundred years ago, Thomas Malthus, predicted that a growing world population would eventually consume more resources then the earth could provide (Brown, Gardner, & Halweil, 1999). However Malthus's forecasts were clearly wrong. Brown, Gardner & Halweil (1999) note that those critical of Malthus's predictions are quick to note that few of his predictions occurred. Opponents to Malthusian theory (such as the Economic Optimists) use Malthus's temporal inaccuracy as support for their own perspectives, suggesting that a free-market economy will constantly adjust levels of technology to adapt and fix problems as they arise (Newbold, 2002). Rising crop yields and the increased food-production capabilities of the last 20 years suggest that we are indeed adapting to handle a growing population (Newbold, 2002). Meanwhile people die from starvation in Russia, Africa, and Korea.

Apart from dire predictions and rosy futures, what is important is what lies behind these divergent positions. Independent of predictions about when the world is or is not going to end, and independent of how this might or might not occur, can we gain an idea of why these problems occur? Can we explain any of the causal mechanisms at work in real world problems? Think about plastics for a moment.

Plastics are a long-lived commercial product, requiring petrochemical products in their production, affording durability, and a host of other action properties (Columbia-Encyclopaedia, 2003). Yet, non-degrading plastics should be used sparingly, if at all, as they accumulate in the environment. Humans, however, tend to avoid expending effort (Dishman, 2003). Instead, humanity favours increasingly hazardous behaviours rather than move toward alternate strategies (Newbold, 2002), like using non-degrading plastics despite the fact that UV degrading, biodegrading vegetable-based plastics are currently available (Columbia-Encyclopaedia, 2003).

At the very least, 100 % plastics recycling should be a global standard. Instead, environmental problems continue to emerge, based on the breakdown in the human-environment system, i.e. the relationship between the nature of plastics on the environment and human characteristics (Nickerson, 1999b). In another example, Lawrence (2002) suggests that urban crime may not be solely caused by social systems alone, but by an embedded human - environment system, specifically the human-architecture relationship. Thus, part of any urban crime solution must rest in a better understanding of the relationship between architecture and anti-social tendencies. It is to the augmented relation of human-artefact system relationship that we must look in order to see the roots of many emerging environmental and social problems (Bonnes & Bonaiuto, 2002). This human-artefact system relationship is mutually referential to both humans and technology. It is this relationship that is a strong causal factor in emerging real world problems.

Modern Psychology

Keeping these thoughts in mind about some of the possible causal factors in emergent real world problems, a former APA president suggests that the general populace was mistrustful of psychology and its motives (Miller, 1969). Miller (1969) proposed that psychologists should focus on using, applying, and making psychological knowledge available to the general public. Conversely, Hillman (1995) notes, "The traditional argument of psychology says: 'maintain the closed vessel of the consulting room, of the behavioural lab, of the field itself'..." (p. xxii). Positively, in many areas of traditional psychological research, there is a research trend towards the investigation of real world problems, such as research in applied memory, witness memory, and applied decision-making, all of which are real world domains (Durso &

Nickerson, 1999). Negatively, Norman (2002) laments that behavioural scientists are an important, but under-represented and badly trained part of product design. Unlike other scientific disciplines, psychology actually has relatively low rates of transference from research to application (Durso & Nickerson, 1999, ; Maxwell, 1984). At the very least, psychological information is a strong component in understanding and solving real world problems (Nickerson, 1999b).

If this is the case, what methods lie within psychology which would be useful for real world problem solving? Are there hosts of useful methods ready to aid in the definition, research, explanation, and solution of real world problems? Does psychology possess robust methodological frameworks which guide the sort of research that is useful in real world problem solving? These are important methodological questions, as we are never free from our methodological backgrounds, they conform us (Cattell, 1966). Proctor & Capaldi (2003) encapsulate this by noting that, "By ignoring the general context in which specific scientific methodologies were…initiated… [We]…fail to provide students with a sufficient methodological background to understand science…" (p. 17). Methods tell us how to go about gaining knowledge, how we organize the pursuit of knowledge, and what we consider to be high-quality knowledge.

So what types of methodologies lie beneath the practice of psychology? Philosophically, psychology has made clear commitments to an empiricist philosophy of science (Fletcher, 1996). Empiricism has known commitments to a context-free acquisition of truth (Maxwell, 1984). Success or failure in such a context free paradigm is only measured by how much knowledge is achieved, independent of its usefulness or applicability (Maxwell, 1984). These empiricist philosophies dovetail with what Rorer (1991) suggests is psychology's predominant method, the hypothetico-deductive method (HD). In turn hypothetic-deductive method emerges in everyday NHST statistical practices (Rorer, 1991). Granted, we might utilize another member of the range of logical inferences as our organizing method; HD is merely an example of one of them. Deduction is another inference, made popular by the Sherlock Holmsian characterization. Deduction makes the step from a premise (or set of premises) to a conclusion based on the premise(s) (Feibleman, 1960). When using deduction we cannot assume anything else beyond the information contained in the premises (Feibleman, 1960). Induction is another inference, which occurs when we make an inference from a small sample of observations to general laws.

Induction merely provides us with general laws about regularities in nature; it does not provide us with explanations. To predict and/or understand the laws governing the nature of an event is useful, but it is not the same as explaining the event. To predict an event is to say when it will happen. To explain an event is to ask 'why', and 'how'. To explain an event or understand it is to gain the information required to apply to a solution (IEA, 2001). Other works have questioned the suitability of HD methods for scientific discovery (Curd, 1980). I take this one step further and suggest that psychology's current methodological structures (HD method) do not provide an appropriate method of viewing and solving real world problems. However, the hypothetico-deductive method is not the focus of this thesis; there are four sections that we will examine: hypothetico-deduction, abduction, ergonomics, and real world problems. I will briefly discuss the content of each of these chapters.

Thesis Components

Hypothetico Deduction

As noted, psychology utilizes the hypothetico-deductive method (HD) as its methodological basis (Rorer, 1991).The HD trend of hypothesis confirmation runs throughout psychology. The APA publication manual mentions the testing of hypothesis as central to experimental method (APA, 2001). Granted, a report by Wilkinson and a statistical task force (1999) mandated by the APA, critically examines psychology's use of NHST procedures (implicitly critiquing HD). The Wilkinson report critiqued how NHST procedures were used, not necessarily their overuse. Furthermore, even popular ergonomists, such as Christopher Wickens, also perpetuate a hypothetico-deductive based approach as part of his exposition on research methods (Wickens, Gordon, & Liu, 1998). The theory of hypothetico-deductive method begins with the methodological formation of a hypothesis (Hempel, 1966). This leaves out two important prior steps: 1) choosing an approach, and 2) generating a theory. Instead, after gaining a hypothesis from whatever creative source possible, HD theory derives and tests a prediction (the deduction), presumably verifying the hypothesis. There are a range of issues with exclusively using an HD method-framework, issues which we will explore in the first chapter.

Abduction

In brief, abduction is an inference that moves from phenomena (isolated from data) to an explanatory hypothesis about the phenomena (Josephson, 1994). One of the many results of a lifetime of work on the part of Charles Sanders Peirce, abduction is the only generative method from the set of logical inferences, thus the only inference capable of generating explanatory theories (Brent, 1993). Granted abduction only provides tenable explanatory theory, which may or may not be true. Conversely, logic like deduction provides truth, assuming that the premises are true. Thus, the power of abduction lies not in its value as a procurer of ultimate truth, but as a method of transitioning from phenomena to explanatory theory. During abduction we look to form a problem, extract empirical regularities from a set of curious real world events, or based on experimental results. These regularities (states, processes, constructs) are phenomena, and from phenomena we infer towards explanatory theory (Woodward, 1989). Our chosen explanation is one of many possible explanations, but chosen as it best describes the data. Once a theory is generated, there are many ways of confirming it, perhaps using one of the previously discussed logical steps like HD or deduction.

The progression from phenomena to explanatory theory is the core of an abductive inference, and is central to the process of scientific discovery. An abductive inference can be the result of a range of motives: a real-world question, a research problem, or an interesting situation observed in the world. Abduction might seem like an overly simplistic logical inference, but it is in fact quite powerful. Abductive method follows the form of this inference, and is powerful because it is free to utilize all of the previous logical inferences in any part of the step from phenomena to explanatory theory. Thus, abductive method can be linked with other inferences to form complex research endeavours.

Ergonomics

Ergonomics is the science, design and art-form of increasing the fit between humans and their systems (Chignell, Hancock, & Takeshita, 1999). More importantly, I propose that ergonomics offers the aims, perspectives, and unit of analysis most suitable to our real world problem solving framework. Ergonomics perspectives and unit of analysis differ from much of mainstream psychology by viewing the human-environment relation as a unified system. This suits the causal influences discussed above. Real world problems arise from the interaction of humans and artefacts/environments. I will explore the aims, perspectives, and unit of analysis offered by ergonomics. I suggest that abduction provides the conceptual organization for problem solving but does not replace actual research practices; rather it re-organizes them. There are a range of human factors, ergonomics, engineering psychology, cognitive ergonomics, and applied cognitive research techniques used as specific research and design practices. A short list of the practices would include several types of experimental settings, like those in Figure 1, below. I will discuss some of these techniques in the last chapter.

Figure 1: Ergonomics Analysis

Usability studies (questionnaire data) Usage studies (performance data) Task analysis (questionnaire, observational, performance) User analysis (questionnaire) Environment analysis (observational, questionnaire) Mathematical analysis Simulation

Real world Problems

The last topic of this thesis will draw together the work from the first three sections in the context of a real world problem: Human-Paper Interaction. The basis of human-paper interaction is the relationship between humans and written language. Of all the aspects of psychology that add to our adaptive nature and distinctiveness, language is special in its ability to be placed on paper in a way that extends across time. When in print, words are a graphic instantiation of the information we gain from being embedded in an information rich world.

We have many reasons for writing, speaking, reading and listening. These reasons include self-entertainment, academic reward, and informative communication. Informative communication, both vocally or on paper, communicates our certainty and reduces uncertainty in others, or reduces our uncertainty by reading the ideas of others. Our interaction with paper in the modern age is perceptually similar to the first cave drawings thousands of years ago. Writing is still the process of altering the reflectance of the surface in a meaningful way (Gibson, 1966). Granted, since the days of ancient cave painting we have developed an alphabet, invented a method of mass producing the written word, and are close to developing electronic paper. For a while, technology appeared to offer us freedom from ever-increasing paper consumption. Unfortunately this has yet to eventuate. Mackay (1998) notes,

> The 'paper-less' office has proven to be a myth. Not only are office workers still inundated with paper, but they must now handle increasing quantities of electronic information. Worse, office workers are poorly equipped to bridge the gap between these two overlapping but separate, worlds. Perhaps it is not surprising that computers have had little or no impact (p. 1).

The advent of the computer has drastically affected paper consumption, in fact it has increased it (Mackay, 2000a). By spreading paper into electronic form, we have not dispensed with real paper but have created a disparity between instantiated paper and online files (Mackay, 2000a). Even more interesting, it is not the Luddites, and the techno-phobic masses that have refused moving on from paper. Rather it is often the most technologically savvy users who avoid the change to a paperless world (Mackay & Fayard, 1999). Modern computerized paper-management systems either cannot perform or perform badly the many tasks that 'old-fashioned' instantiated paper preformed well (Mackay & Fayard, 1999). I will make use the problem of human-paper interaction as the real world context in which to base the last chapter.

Summary

To review, the aim of this thesis is to develop a systematic real world problem-solving framework designed to support the research, design, and solution of real world problems. To achieve this aim I ask three questions. Firstly, what methods does psychology currently use and how do these methods affect real world problem solving? Secondly, what alternate methods can we use and how might these influence real world problem solving? Lastly, what aims, unit of analysis, and perspectives does ergonomics offer real world problem solving? These questions and the overall thesis aim will be answered via four chapters: hypothetico-deduction, abduction, ergonomics, and real world problems.

Chapter 1: Hypothetico-Deduction

In the introduction to this thesis, I proposed a methodological exploration of current methods and alternative methods, and an exploration of the unit of analysis, aims, and perspectives offered by ergonomics. Recall that the goal of this thesis is to develop a systematic real world problem-solving framework, drawing from both abduction and ergonomics. This chapter represents the first step towards this goal by exploring current methods: Null hypothesis significance testing (NHST), and Hypothetico-deductive method (HD). This chapter will begin with a brief review of NHST and some of its issues, followed by a deeper exploration of issues with hypothetico-deductive method. I will discuss four problems with HD method: lack of hypothesis generation, affirming the consequent, weak theory corroboration, and data obsession.

Statistical Obsessions: Null Hypothesis Significance Testing

Critiques of psychological method usually begin and end with the examination of null hypothesis significance testing (NHST). NHST is the most influential addition to the body of statistical methods that make up modern psychology (Nickerson, 2000). The NHST statistical paradigm is surprisingly entrenched in common psychological practices. Before 1935, less than five percent of the articles posted in several psychology journals[3] used statistical inference testing (Rucci & Tweney, 1980). After 1950, nearly thirty percent of the same journals discussed statistical inference testing of some sort (Rucci & Tweney, 1980). By 1972, ninety-one percent of the articles reviewed in several major journals[4] involved tests of statistical inference; this equated to nearly 1,195 tests (Edgington, 1974). These results suggest that statistical inference testing has not always possessed a strong position in psychology. The common link between many early foundational psychologists (e.g. Skinner, Piaget, Binet), is a lack of NHST testing (Gigerenzer, 2000). Many early psychologists followed the practices of scientific paradigms in disciplines such as biology and physics, avoiding a reliance on significance tests (Meehl, 1978). Binet was not familiar with t-tests, and instead

[3] The Journals reviewed in this study included the American Journal of Psychology, Journal of Applied Psychology, and Journal of Experimental Psychology.
[4] The Journals reviewed in this study included the Journal of Applied Psychology, Journal of Experimental Psychology, Journal of Personality and Social Psychology, Journal of Educational Psychology.

used graphical methods to explore developmental change (Meehl, 1978). Prominent psychologists, such as Skinner (1972) responded harshly to the rising tide of NHST work,

> For more than a generation…our graduate schools have been building psychologists on a different pattern of Man thinking. They have taught statistics in lieu of scientific method. As now taught, statistics plays down the direct manipulation of variables and emphasises the treatment of variation after the fact. If the graduate student's first result is not significant statistics tells him to increase the size of his sample, it does not tell him…how to achieve the same result by improving his instruments and his methods of observation" (p. 319)

Skinner's approach to method focused on experiments with limited numbers of subjects (Gigerenzer, 2000). This approach explored the patterns within the data generated by individual subjects, using strong experimental control as a method of controlling the variance generated by sample error (Gigerenzer, 2000). This contrasts current statistical methods, which often use weaker controls across large sample sizes, using the sample size to correct for error variance (Gigerenzer, 2000). Despite its relatively recent inception, there has been an exponential increase in the usage of NHST. This increase stemmed from psychology's special interpretation of the larger probabilistic revolution that swept indeterminism into the sciences. Indeterminism altered the deterministic scientific model of nature to accommodate uncertainty, drawing ideas from Schrödinger and Heisenberg (Hawking, 1998). However, psychology chose a different path from the rest of the sciences. Instead of utilizing the ideas from the probabilistic revolution to change psychology's scientific model of human behaviour and perception, psychology created its own version of the probabilistic revolution; the inference revolution. Rather than altering the model of nature, the inference revolution in psychology focused on automating the data to hypothesis inferences of the researcher (Gigerenzer & Murray, 1987). Meehl (1978) expressed his dissatisfaction with the creator of the inference revolution:

> Sir Ronald has befuddled us, mesmerized us, and led us down the primrose path. I believe that the almost universal reliance on merely refuting the null hypothesis is one the worst things that has ever happened in the history of psychology (p. 817).

However, the situation is more complex than this. What has been institutionalized and propagated via textbooks and editorial practices is a hybrid statistic based on a convoluted combination of Fisher, Pearson, and Neyman (Mulaik, Nambury, & Harshman, 1997). The NHST procedures are actually the amalgamated work of several people; NHST has no single history. To offer more confusion the un-witting originators of psychology's NHST techniques were in fundamental disagreement with each other, disagreement which leads many contemporary psychologists into confusion (Mulaik et al., 1997)

In sum, null hypothesis significance testing (NHST) has a controversial and complex history. This is not necessarily a judgment on the technique itself, but an admittance of its complex origins. Despite a controversial history, NHST is alive and well in the research literature. I note an experiment by Hsee, Abelson, and Salovey (1991) entitled, "The relative weighting of position and velocity in satisfaction." Following the best of NHST tradition, Hsee et al. (1991) begins by discussing substantive issues, "An important topic in social psychology…is the relation between desired outcomes and satisfaction…" (p. 263). Secondly, Hsee et al. (1991) discuss a possible research hypothesis (specific to their current research paradigm), "We believe that the relative weighting [of a specific factor] is not fixed, it varies from situation to situation..." (p. 263). Lastly, they pose a statistical hypothesis, "…we propose that, if an outcome is framed such that its position appears more salient, then the position effect would weigh more heavily [on previously mentioned factor]" (Hsee et al., 1991, p. 263).

The experimental/statistical hypothesis is familiar to most. Ideally, delineating between the various types of statements (substantive, research, and experimental and statistical) provides the most defensible form of NHST reasoning. However, due to NHST's nested presentation, errors arise due to the conflation of the various types of hypotheses. Nested hypothesis have a tendency to lead into each other and tend to imply that meaning can be transferred across levels (e.g. from statistical to substantive) (Schmidt & Hunter, 1997). Later, we will see that this is not the case. Even in its most defensible state, I question the strength of support offered by common NHST testing when moving from statistical hypothesis back onto substantive theory.

If there is confusion on what NHST offers researchers, there is some agreement on the structure of NHST. Chow (1996), Howell (2002), and Rozeboom (1960) all agree: after reaching the research hypothesis, the NHST procedure differentiates between the research hypothesis and the null hypothesis, with the null hypothesis being the logical opposite of the research hypothesis. Suppose that a research hypothesis is, "[presume]...an outcome is framed such that its position appears more salient, then the position effect would weigh more heavily [on previously mentioned factor]" (Hsee et al., 1991, p. 263). My null hypothesis would be the logical opposite of this, '[presume]...an outcome is framed such that its position appears more salient, then the position effect would [not] weigh more heavily [on previously mentioned factor].' Typical conceptions of the null hypothesis see the null hypothesis as a hypothesis of no effect, no correlation, and no effect (Cohen, 1994).

The statistical inference from sample distribution to presumed population is the core of the NHST technique. The data-sample provides the variance from which we derive our distributions of means and comparison distributions. Our comparison distribution, in conjunction with the means from our sample, provides the t-test by which we hypothetically compare our two samples as members of a larger population. This hypothetical population comparison leads us to describe our statistical procedure as the comparison of population means ($\mu 1$ versus $\mu 2$). In a sense, the null hypothesis distribution is the absence of expectation. NHST does not lead to any predicted values. At most, when using two tailed tests, we gain an indication of direction, but predict no effect, no post-hoc power level, nor a shape; merely that the null hypothesis represents a population of no effect (Cohen, 1994). A comparison of the research distribution and the null hypothesis distribution is a comparison of $\mu 1$ and $\mu 2$. At its core, a NHST procedure tests whether $\mu 1 = \mu 2$ or $\mu 1 \neq \mu 2$. This amounts to a decision, given the truth of the null hypothesis, how likely is it that the results are due to chance, i.e. is it likely (assuming that the null hypothesis is true) that our research distribution would be obtained via chance.

NHST's 70 year history has been controversial, journal articles discuss issues with NHST back through to its inception (Nickerson, 2000). It would seem that many academics have tired of this controversy, "...the debate keeps repeating itself but never leads to any definitive conclusions or changes in practices" (Anon, cited in

Schmidt & Hunter, 1997, p. 58). In 1999, the APA responded to the long controversy, assembling a task force dedicated to clarifying the issues surrounding significance testing and its alternatives (Wilkinson, 1999). The presence of such a task force, which included input from Paul Meehl, John Tukey, and Lee Cronbach, leads me to suggest that there is again a renewed interest in NHST. However, despite renewed interest, I will only mention one issue with NHST, as I am sensitive to the repetitive nature of the controversy.[5]

The error of conflating statistical and theoretical hypothesis

This is one of the most multifaceted errors of the NHST procedure. This error draws from the lack of practical significance from NHST, increase in sample size providing significance, arbitrariness of the alpha value, and a lack of effect size from p-values. To outline these issues: firstly, NHST has limited potential for providing practical significance. The NHST procedure provides statistical significance. Furthermore, NHST does not provide positive confirmation, only the conditional probability of gaining the data, given the truth of the hypothesis. Contrary to some mistaken opinion, the p-value is not the probability that the null hypothesis is true (i.e. low probabilities - $p < 0.000001$, which makes the null hypothesis very untrue). Instead, we construct a hypothetical situation where the null hypothesis is already true, where there is no difference, and then test our data to ascertain how likely the data given the truth of the null hypothesis. After gaining statistical significance, we are in a position to know the probability that the data were likely to have occurred due to chance variation (assuming the hypothesis is true) (Nickerson, 2000). On any reasonable interpretation, the NHST technique cannot provide the probability of the hypothesis given the data (P [H/D]). Despite this, it is a common and subtle mistake that Abelson (1997) suggests everyone has been guilty of at least once. Only a combination of Bayes Theorem and access to prior probabilities can provide P (H/D) (Mulaik et al., 1997).

Secondly, a mere increase in sample size can provide significance. In an un-published study Meehl and Lykken (1968) sampled 57,000 Minnesota students across 15 scales, and of the 105 chi-squares forming this study, 105 were significant. More importantly, these effects were significant at a high level. This suggests that as we

[5] Mulaik, Nambury, & Harshman (1997), Nickerson (2000) are some of the excellent coverage of the NHST controversy.

approach sample infinity, the difference needed to provide significance approach zero (Swoyer & Monson, 1975). Furthermore, given that issues of control may lay the blame of non-significance at the door-step of experimental technique, there is no pressure to confer greater confidence on a substantive theory, based on statistical results (Meehl, 1978). Consequently, a host of small p-values do not convey a greater confidence on theories, as this confidence might be due to sample size rather than effect.

Thirdly, the p-values are set using a dynamic criterion (alpha level) (Chow, 1996). This provides an arbitrary reason for deciding significance. Alpha levels are usually set on either 0.05, 0.01. Suppose for a moment that we gain significance with an alpha level of 0.05 but not with an alpha level of 0.01. Have we gained a substantively significant result with one finding and not the other, knowing that there is no specific substantive reason for setting the alpha level at 0.01 or 0.05? If statistical significance relies on something as arbitrary as the researcher's bravery, there is no way that we can propose a strong link between statistical hypothesis and substantive theories.

Fourthly, p-values do not convey any information about effect size. Significance cannot measure the importance or substantively significant of a result, a null hypothesis is literally a hypothesis of zero effect. The only information we gain from rejecting a null hypothesis is literally that our data significantly differs from zero (assuming H is true). By contrast, substantive hypothesis are a linked group of causal statements, which are always greater than a mere assertion about a particular population parameter (Meehl, 1997). Granted, there is a strong compulsion to reason from a small p-value to high confidence that the theory is true or has high verisimilitude (Abelson, 1997). The trouble with this is that a nonzero confidence interval can be derived from other theories, and given that soft areas of psychology have a sizable number of relations these competing theories have some plausibility (Meehl, 1997). The null hypothesis has a tendency to support any theory, rather than pointing to a specific theory (Cohen, 1994). This is a grave weakness in choosing a null hypothesis of zero effect.

In short, there is a tenuous supporting link between the statistical hypothesis and the substantive hypothesis/theory responsible for generating the statistics (Meehl, 1997). It is an error to assume that a lack of statistical significance, failing to reject Ho poses a strong threat against our belief in the theory (Nickerson, 2000). Chow (1996) defends NHST by proposing a clear differentiation between testing statistical hypothesis versus testing substantive theories. Yet, despite Chow's endorsement of separating substantive and statistical issues, NHST is the only widely publicized procedure offered for testing substantive theory and thus is constantly used to in-appropriately confer some measure of belief upon a substantive theory, based on the statistical results it provides (Dar, 1998).

Hypothetico-deductive Method

Most analysis of method in psychology stop with the statistics; few authors discuss or mention the scientific method behind the NHST. However, method is a central part of the scientific endeavour, and it is impossible to ignore the logical methods that give rise to our statistics (Cattell, 1966). NHST statistical procedures are the extension of a methodological current running deep within psychology (Rozeboom, 1997). This methodological obsession is best characterized as a fascination with the hypothetico-deductive method (Rorer, 1991, ; Rozeboom, 1997). In psychology, it is difficult to clearly delineate where hypothetico-deductive method stops and NHST begins, and thus some of the issues mentioned here are, a) openly visible in the NHST procedure, b) implicitly and directly linked to an issue with NHST, c) or specific to HD, but affecting NHST by proxy. The linkage between statistical testing and HD method is not as strong in other sciences. Physics, for example, never experienced an inference revolution (Gigerenzer & Murray, 1987). After all, there is no requirement to link HD method to the NHST statistical procedure. However, when considering psychology, Rozeboom (1997) suggests that NHST represents the "statistical excrescence of a deeper malaise that has pervaded our discipline...namely, the hypothetico-deductive (HD) method..." (p. 335).

The hypothetico-deductive method (HD) has its origin in the deductive method. Deductive method was an inference designed to draw further truth from non-problematic obvious observable truths (Tarski, 1994). Non-problematic truths are self-evident truths of an empirical nature, obvious via observation. For example, based on the existence of a category known as 'man' and the non-problematic existence of 'legs' (both empirical facts), we can form a deduction about 'John,' see Figure 2, below.

Figure 2: Deduction from non-problematic truth

Premise - John is a man Premise - Men have legs Conclusion - John has legs

The origin of the deductive method lies in the classical categorical syllogism, formalized by Aristotle (Copi, 1961). Conceptions of the deductive inference formalize deduction as obtaining a result from a rule and a specific case (Peirce, 1931), see Figure 3, below.

Figure 3: The deductive inference

(Rule) All the beans from this bag are white (Case) These beans are from this bag (Result) These beans are white (Extracted from Peirce, 1931, 2.623) John is a man = Case Men have legs = Rule John has legs = Result

Further along through history, in an effort to provide science with a method of certain truths, Newton used and supported a variation of deductive reasoning (Gower, 1997). Popper (1959) also choose a basis in deduction, emphasizing the deductive testing of theories in his book, "The Logic of Discovery" (1959). Later, Hempel (1966) continued with ideas from Popper to formalize the hypothetico-deductive inference, which is also known as the deductive-nomological inference. Despite ancient origins in deduction, the hypothetico-deductive method is a pervasive part of modern methodology. According to Lawson (2002), "...scientific discovery can be seen basically a [sic] hypothetico-deductive enterprise..." (p. 15). Thus, HD method is the foundation of method upon which other psychology-specific procedures rest. There are mixed opinions on the consequences of this dependency.

On one extreme, Lawson (2002) makes a bold claim of suggesting that HD inference is the central logical method in all of the scientific endeavour, "Regardless of the number of scientific methods that may ultimately be identified, the present analysis suggests that many, if not all, scientific discoveries are hypothetico-deductive in nature" (p. 21). On the other extreme, Rozeboom (1982) suggests that the hypothetico-deductive inference has been a harmful and useless research endeavour, "[the]...thesis that hypothetico-deductivism is hopeless is one with which I cannot agree more strongly..." (p. 637). To explore these extremes, I want to lay out a brief description of the strongest form of hypothetico deductive method. At a macro level, Rozeboom (1997) critically construes HD method as, "empirical tests of theoretical speculations" (p. 336). Un-packing this somewhat cryptic statement, Rorer (1991) describes HD method as an If → then relation between Theory (T) and Data (D) in the form of 'If T then D.' This hypothetico-deductive inferential relation between theory and data can take on several forms, see Figure 4, below.

Figure 4: Various aspects of HD inference

Destroying mode (Falsificationist Mode)
-If T then D
-Not D
-Therefore, not T

Affirming the consequent (Affirming Mode)
-If T then D
-D is found
-Therefore, T

Denying the antecedent
-If T then D
-Not D
-Therefore, not Q
(Meehl, 1997, p. 399)

Following a strict Popperian inclination, the HD inference only preserves certain truth when used in its falsificationist mode (Copi, 1961). Yet, many use the 'Affirming mode' and 'Falsificationist modes' interchangeably, producing logical truth in one case, and uncertain truth in the other. Lawson (2002) presents the hypothetico-deductive argument in a slightly different form; blurring the specific logical syllogistic relations of the hypothetico-deductive structure, and including a definitive point of origin for the HD cycle (the puzzling observation), see Figure 5, below.

Figure 5: Lawson's HD method

1. Identify a puzzling observation. 2. Identify and state the central causal question raised. 3. Search the literature and your own knowledge base for as many possible answers as possible. 4. Arrange the possible answers (the alternative hypotheses) more or less in order from most to least plausible. 5. Try to figure out how to test the alternatives more or less in the above order. 6. State as clearly as possible the predicted results of your planned tests. 7. Conduct the planned tests and record results. 8. Compare predicted and actual results. 9. Draw conclusions (Lawson, 2002, p. 17)

Are we lost between several variations of the hypothetico-deductive method? Not really; this difference is a matter of what aspects of the formal, syllogistic structure that each description of HD method chooses to reveal. Meehl (1997) clearly outlines the four logical manoeuvres that make up alternative data-theory relations within the hypothetico-deductive inference; whereas Lawson (2002) chooses not to reveal the logical inferences the represent the relation between theory and data, instead relying on a description of the HD method from a non-inferential point of view. However, in a common thread across these variations, using HD method involves an 'If...Then...Therefore' logical pattern (Lawson, 2000). Rozeboom (1997) presents the best amalgamation of Lawson's cyclic phasic approach and Meehl's logical syllogisms, see Figure 6, below.[6]

Figure 6: Rozeboom's Hypothetico-deductive

We determine that uncertain proposition C logically follows from uncertain hypothesis H. We ascertain that C is (a) true, or (b) false We conclude that H has been respectively (a) confirmed or (b) disconfirmed (Extracted from, Rozeboom, 1997, p. 337) Rozeboom's HD inference re-construed via Lawson's (2002) Theory/Data terminology… 1) If …Theory then Data (Proposition) 2) Then…Data or not Data (Test) 3) Therefore…Theory or Not-Theory (Conclusion)

[6] This differentiation between specific formal logic and more heuristically rational patterns will be an ongoing theme in this work.

Just previously, I noted that Lawson (2002) places HD method as central to science. Pushing this claim further, Lawson (2000) makes the bold claim that human acquisition of knowledge, utilizes at its core, an HD If...then...therefore pattern. As Lawson (2000) puts it, "The conclusion drawn is that knowledge acquisition involves a pattern of idea (representation) generation and test that, when cast in the form of a verbal argument, follows an If/Then/Therefore pattern" (p. 1). Considering the first claim, and beginning with statistics, NHST is a statistical procedure, a set of rules for manipulating data. NHST is not a global method, nor is it a logical inference. NHST suits HD method and it was developed under subtle pressure from the HD inference. Furthermore, in psychology, NHST is usually employed inside an HD framework (Rozeboom, 1997).

Beyond statistics, logic is the logical relation between premises and conclusions (Carney & Scheer, 1980). The assessment of logic involves the exploration of the correctness of given arguments (Carney & Scheer, 1980). Beyond logic, method is, "a sequence of actions which constitute the most efficient strategy to achieve a given goal" (Hooker, 1987, p. 139). Thus, HD method is the macro organizing structure upon which logics are placed, and logic is the guiding structure via which we implement statistics. In psychology, there is a blurred linkage between method, inference, and statistics. Lawson's first claim proposes that HD method offers the best conceptual framework for organizing and portraying the scientific endeavour. I challenge this claim, suggesting instead that HD is unable to act as a general methodological framework (Haig, 1995). I also suggest that suitable methods and inferences bring their own host of interesting statistical possibilities. It is important to note that none of my claims exclude or forbid the possibility of using other methods, inferences, and statistics.

I will not directly respond to Lawson's second claim, as I will not directly discuss whether hypothetico-deduction and abduction are cognitive/neurophysiological processes. In the next two chapters, I am most concerned with method. When considering these methodological questions, I will step away from a discussion about cognition. To take a psychological approach to understanding method disregards the abilities of each method/inference paring to cope with moderating and structuring the flow of information. It is easier to discuss the capabilities of method-logic-statistics as a question independent of cognition. However, in the last chapter of this thesis, I will consider the impact of hypothetico-deduction and abduction impact on real-world problem solving from an ecological point of view, which still steps away from Lawson' strong claim on the neurophysiological truth of hypothetico-deduction.

The exploration of HD and abduction from an ecological point of view will cut across subjective/objective, cognitive/environmental boundaries by adopting a mutual ecological perspective. I will use this last chapter to propose that abduction makes a better framework for real world problem solving in both a logical and an ecological sense. However, in this and the next chapter, I will challenge Lawson's claim that HD is central to science. I suggest that there are other methods more suitable to providing the general conceptual framework for an applied science. Specifically, I propose that abduction provides a better conceptual structure to support our inferences and statistics. This does not make the claim that method is science in its complete form, in the third chapter (ergonomics) we will be discussing other issues that arise in considering an applied science.

Issues with HD Method

Issue One: Lack of provision for hypothesis generation

HD method is the logic involved in testing hypotheses (Popper, 1959). In this sense, HD method and the HD inference are hypothesis-testing, theory corroboration devices. NHST dovetails with this mentality, focusing nearly exclusively upon hypothesis testing, and theory confirmation (Fisher, 1951). An obvious question that stems from this focus on hypothesis testing is, 'Where do hypothesis come from?' or alternatively put, 'How are hypothesis generated?' Hypothesis generation is the act of creating the theories, which in turn are tested, yet HD method (see Figure 7, below) fails to account for hypothesis generation.

Figure 7: HD method

1) If …Theory then Data (Proposition) 2) Then…Data or not Data (Test) 3) Therefore…Theory or Not-Theory (Conclusion)

There is no provision anywhere in HD method for the creation of theory. One of HD's formulators notes, "There are...no generally applicable... [ways]...by which hypothesis or theories could be...derived or inferred from empirical data" (Hempel, 1966, p. 15). In essence, there is no way to generate theories inferentially, methodologically, rationally, systematically, or even ecologically. Hempel (1966) goes further, "The transition from data to theory requires creative imagination. Scientific hypothesis and theories are not derived from observed facts, but invented [sic] in order to account for them"(p. 15). Therefore, classical HD method assumes the existence of the theories that it tests, without offering an explanation or method by which to generate them (Hanson, 1958b).

By siding with HD, NHST fails to account for theory generation, adopting the same stringent view on hypothesis generation offered by Hempel. According to Chow (1996), "...empirical research in psychology is seldom carried out to discover or build the theory." (p. 63). This statement is practically identical to Hempel's previous comments. Failing to provide for hypothesis generation may not be an important problem when considering rarefied and abstract research. However, applied psychology and ergonomics often co-opt methods from classical psychology (See, Wickens et al., 1998). Using HD as a general method of inquiry in applied psychology and ergonomics weakens our chances to solve real world problems, as real world problem solving requires strong theories. Such strong theories may end up guiding governmental policy or systems design (Rouse et al., 1997). Rouse et. Al. notes, (1997) "...experts...translate new knowledge about human...learning, and behaviour to bear on concrete products and processes (p. 24).

This transfer between theory and application requires a fine balance of methodology and application (Wilson, 2000). Wilson (2000) notes "its [ergonomics] goal is the well-being of individuals, organisations and national economies. This requires theory as well as practice, models, as well as methods" (p. 558). Failure to understand that strong theories are crucial to real world problem solving contributes to dire consequences. For example, the crucial factor involved in the mid-air collision between two 747's over the Canary Islands was a misunderstood radio communication between the pilot and tower control (Rouse et al., 1997). Failure to support the generation of strong real world theories contributes to these accidents by failing to provide the robust theories that will support eventual system design. Real world problems are legion and there are not enough pre-existing robust theories to feed a hypothetico-deductive theory-testing obsession. In a more scientific example of the importance of theory generation, Kepler's work on planetary orbits is a classic astronomical example of hypothesis generation. Confirmation comes after the real work of hypothesis generation, "HD accounts…agree that…laws explain data. However, they obscure the initial connexion [sic] between data and laws…" (Hanson, 1958b, p. 71).

Lawson's formation of HD theory (see Figure 5: Lawson's HD method) initially appears to offer logic of hypothesis generation. Step six of Lawson's construal of HD method notes, "Generating an initial possible cause (a hypothesis)," (p. 581). Lawson (2000) continues, "The process of hypothesis generation is seen as one involving analogies, analogical transfer, analogical reasoning, i.e., borrowing ideas that have been found to "work" in one or more past related contexts and using them as possible solutions/hypotheses in the present context…" (p. 581). Based on his support of some sort of inference towards discovery, it seems odd that Lawson later includes comments by Popper against inductive inference (Lawson, 2000). In a comment unrelated to this discussion, Lawson's view is odd because HD thinking includes some aspects of induction. Hempel wanted to avoid induction, but couldn't resist the what it offered (Gigerenzer, 2000). In a comment relevant to this discussion, Lawson's critique of induction is risky because induction is the process of inferring laws from several data examples, a process related to hypothesis generation.

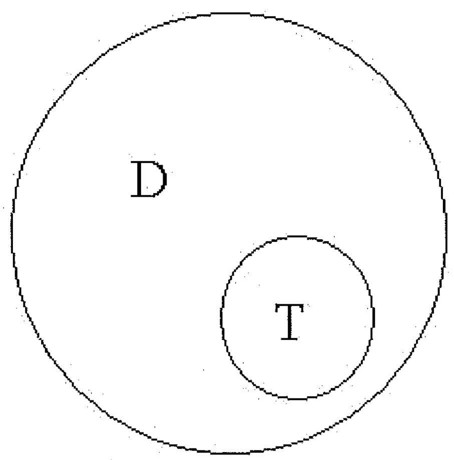
The solution to the contradiction between Lawson's comments comes when Lawson (2002) makes at another point, "It should be pointed out that the processes of assimilation and hypothesis formation take place largely at the subconscious level" (p. 2). At this point, it becomes obvious that Lawson believes that there is no logical or ecological sense behind discovery, ironic because we will later see that the process of analogy is one the important heuristics used in effortful, rational, and logical discovery.

Lawson continues to place the burden of discovery on psychological process, instead of upon method, logic, or ecology. This does not deny discovery, however it does suggest that it is out of reach of any form of logical or rational description. This distinction between rational and irrational psychological discovery is important and will be a continuing idea especially when considering abduction. It is enough to say for the moment that HD clearly avoids responsibility of outlining a rational method of hypothesis generation. HD might be an adequate method if we specifically focused on hypothesis confirmation, but it fails as a comprehensive account of method. Haig (1995) notes, "Despite its hegemonic status, hypothetico-deductivism is seriously deficient as a theory of scientific method" (paragraph 12)

Issue Two: Affirming the consequent

Suppose that we are using the HD inference, independently of any statistical procedure. We would form a hypothesis, experiment, manipulate or observe data, and confirm or disconfirm our hypothesis based on the data. The core of this manoeuvre lies in two logical steps. Firstly, we can compare our observed data to our predicted data. If we have gained the data patterns that we predicted, we can reject the not-data proposition. To reject the not-data condition is to use the destroying mode logical structure of HD method, 'If T then D, Not D, Therefore, not T.' However, HD method is an amalgamation of two HD inferences. The second inference used in HD method is the logical step from gaining the observational data as predicted and using this data to offer inferential support for the theory, If T then D, D, Therefore T. These two logical inferences are not compatible. How can we grasp this error? Rorer (1991) offers the diagrammatic usage of Venn diagrams to outline the nature of this error, see Figure 8, below.

Figure 8: The interrelation between Theory and Data



(Key: T = Theory, D = Data)

Supposing that 'If T then D' is identical to proposing, 'T is a subset of D.' However, if we obtain data (D), it does not necessarily follow that it is a part of our theory. Why does this occur? Recall Rozeboom's (1997) description of the HD method, see Figure 9, below.

Figure 9: Rozeboom's HD method

We determine that uncertain proposition C logically follows from uncertain hypothesis H. We ascertain that C is (a) true, or (b) false We conclude that H has been respectively (a) confirmed or (b) disconfirmed (Rozeboom, 1997, p. 337)

Despite Chow's (1996) endorsement of a mechanized NHST procedure used to produce a yes/no decision, testing hypothesis is a matter of adjusting our levels of belief, "...a scientist's data supply evidence [sic] for the conclusions he draws from them" (Rozeboom, 1960, p. 412). Furthermore, when using a hypothetico-deductive structure, our belief in our hypothesis, based on the data, must expand to include all other possible implications, auxiliaries, and any other propositions specifically connected to the theory. Rozeboom (1997) notes, "Some theories do...mediate confirmation from some of their verifiable consequences to other... [not yet verified, by known consequences]..." (p. 338). In Rorer's (1991) words, "...any evidence that confirms T also confirms any conjunction of the theory with another statement, such as 'Rorer is a genius.' Therefore, every time you obtain a positive outcome and interpret it as confirming your theory you are simultaneously confirming that I am a genius" (p. 76)

Think about the erroneous HD inference this way: suppose that I have a theory, 'Opening the refrigerator causes pain.' Obviously, I can deduce an empirical data prediction from such a concrete theory, 'If I open the refrigerator, it will hurt.' Suppose that I open the fridge and feel nothing, I could say that I had moved towards refuting my theory. However, if I open the fridge and do feel pain in my head, can I produce a yes/no decision as to whether I have confirmed my theory? Suppose that I had a headache beforehand and the headache is the causal factor in my pain, not the fridge. Although this is only one example, it indicates the weakness in the HD logical inference, "Verifying consequence (C) of hypothesis or theory (H) tells us that something in H beyond C may well be more belief-worthy than we thought previously" (Rozeboom, 1997, p. 338). However, we have no way to separate the evidence supporting our hypothesis from error in the data, or evidence supporting other alternate theories/hypothesis. In essence, there are numerous theories that might possibly predict a data-outcome. By their nature, theories are undetermined by data (Rosenberg, 2000). When using HD with its lack of formal criterion for choosing hypothesis, we have very weak theory conformation.

As Rozeboom (1997) notes, "The HD programs failure to advise on which hypothesis are worth testing becomes an evasion of educational responsibilities..." (p. 336). The concept of falsification is based on this very problem, the problem of using empirical observations to positively confirm theory (Popper, 1959). Despite everything I have mentioned so far, there is more to this situation than predicate logic. Meehl (1997) notes an amusing quote from Morris R. Cohen dealing with the nature of abstract logic versus practical work, "All logic texts are divided into two parts. In the first half...the fallacies are explained...in the second half...they are committed" (Attributed to Morris R. Cohen and cited in, Meehl, 1997, p. 399). Rigid adherence to the rules of logic creates the same type of mechanized, artificial scientific endeavour that the critics of excess NHST so decry. Despite this, reasoning from theory to data-prediction to obtained data and back to theory, or reasoning from the falsity of a null hypothesis to the truth of a theory involves the logical error of affirming the consequent (Nickerson, 2000). It is possible to accuse most sciences and most scientific paradigms of some form of affirming the consequent (Nickerson, 2000). Verifying a theories observational consequences is one of the more common methods science continually employs, thus continually risking affirming the consequent by doing so (Meehl, 1997).

It is not specifically affirming the consequent that it is issue; rather, it is the exclusive use of the HD method, HD inference and the NHST statistical procedure in the hope of strong theory corroboration. Yet, this does not relieve HD method of all responsibility for its consequences. The challenge to method is to cope and control the danger of affirming the consequent, something that HD fails to do. Suppose that we accept the risk of affirming the consequent. Upon doing so, it is important to realize that this does not leave us helpless to protect ourselves from the risks entailed by committing a logical error. There must be some conferral of belief transferred from empirical observations to theory (Hempel, 1966). Thus, the question is 'what can be done to increase the feasibility of this confirmation?' Rather than any one issue alone, it is the combination of issues presented by HD method that make HD method dangerous by being ignorant of its dubious theory confirmation.

<u>Issues Three: HD as weak theory corroboration</u>

It would be easy to reject HD in its entirety. However, most of science utilizes some form of observational verification as part of its theory examination procedures (Meehl, 1997). The key to accepting the risk of affirming the consequent is to make theory testing as strong as possible. Why is it so hard to test theories? Possibly, because of the extra information we connect to our theories. It is impossible to test theories in isolation. Rather, theory testing is a conjunction of Theory (T), Auxiliary Knowledge (A), and Experimental controls and conditions (E) (Rorer, 1991). This idea was first noted by Duhem and cited in Meehl (1978). The combined weakness of theory confirmation and our impulse to defend our theories leads to a weakness in our use of hypothetico-deductive method.

HD method compounds this weakness by providing the weakest possible theory corroboration (Meehl, 1967). What do I mean by theory corroboration? The use of the word 'corroboration', rather than 'confirmation', is due to Karl Popper and his theories of Falsificationism. According to Popper's (1959) ideas, it is impossible to confirm theories; it is only possible to falsify them. Theories that survive successive falsifications have some validity to them. It is a presumption to say that we have 'confirmed' theories, instead Popper chose the word, 'corroborate,' meaning that we had offered some provisional support (Popper, 1959). Taking this idea further, Meehl (1978, 1997) offers insight into the variation of corroborative strength offered by weak versus strong significance tests. These insights are not related to power, alpha size, confidence levels, probabilities, or confirmation. Meehl's ongoing dialogue on the strength or weakness of a significance tests focuses on the hypothesis's ability to offer corroborative support for our substantive theory (Meehl, 1997). This is an epistemic examination rather that a statistical comparison.

As early as 1967, Meehl was exploring our use of weak hypothesis during hypothesis testing. Hypothetico-deductive method is weak hypothesis testing because it fails to specify what hypotheses are worth testing, leaving psychology to adopt the zero value null hypothesis as the standard comparison hypothesis (Rozeboom, 1997). Exploring the strength of the comparison hypothesis rises above the choice of statistical test. We can test the statistical hypothesis derived from our substantive theory with a range of statistical procedures including confidence intervals, NHST, and Chi-squares. However, exploring statistical hypothesis with statistical tests encounters the problems discussed earlier, particularly the improper convergence between substantive theories and statistical hypothesis. I discussed this convergence earlier and suggested that the link between substantive theories and statistical hypothesis is tenuous. Statistical confirmation is all too often confused as strong theory corroboration, and NHST is too often erroneously used as strong theory confirmation (Dar, 1998). Granted, in their strongest use, statistical hypothesis offer some corroboration towards substantive theory. The question remains, how do different hypothesis offer different levels of corroboration at an epistemic level? Now that we have an appreciation of the method (HD) behind the statistical procedure (NHST), we can look deeper into the variation in strength offered by different types of hypothesis.

If different hypothesis offer different levels of epistemic theory corroboration, then the first step is to isolate what types of hypothesis are available. The first type of hypothesis is the point-null hypothesis (Meehl, 1967). Point null hypothesis are hypothesis of no-difference and no-correlation. In abstract terms, independent of statistical procedures, point-null hypotheses are the weakest choice of hypothesis. A favourable view of psychology suggests that the point-null hypothesis appears early on in a new research paradigm. Unfortunately, the point nil null hypothesis appears throughout psychology, "as almost universally used the null in Ho is taken to mean nil, zero" (Cohen, 1994, p. 1000). Psychology's original adoption of the NHST/HD amalgamation involved a miss-interpretation of the nature of the hypothesis to be tested. Granted, one of NHST's early supporters mentions that, "there are many ways of stating a null hypothesis," but continues with a description of the point null hypothesis as a hypothesis that assumes that, "...nothing but the laws of chance are operating in a free and unrestricted manner..." (Guilford, 1956, p. 204). This is akin to describing the null hypothesis as an effect that is no different than chance. The null hypothesis is quite literally the hypothesis to be nullified rather than the hypothesis of no effect (Cohen, 1994, ; Gigerenzer, 2000). We leave room for hypotheses beyond nil hypotheses when we describe the null hypothesis as the object of nullification, rather than the hypothesis of zero effect.

The directional null hypothesis is another type of hypothesis available, if there is enough work already carried out in an experimental paradigm. Directional null hypothesis presumes some pre-specified directional difference between experimental conditions. In the case of NHST statistics, this translates into a directional relation between the means of our populations (U1 > U2 or U1<U2), rather than a non-specified difference from zero (U1 ≠U2). Beyond hypotheses of null effects and hypothesis of directional null effects are the hypotheses predicting function forms and the hypothesis predicting a narrow range of values (Meehl, 1967). For a moment, remember that we are not dealing with alpha beta, or probability. Instead, the strength of significance tests involves an epistemic relation between the hypotheses and the corroboration of the substantive theory (Meehl, 1997). Other hypotheses include specific-form hypotheses and range predictive hypotheses, which offer stringent tests of theory. Specific-form hypotheses predict a function form (Meehl, 1967). Predictive range hypotheses predict a specific range of tolerated variables (Meehl, 1967). The progressively stronger forms of derived hypotheses offer stronger refutation of the theory (Meehl, 1997). Even for those who wish to avoid strong Popperian falsificationism the predictive range and specific-form hypothesis offer stronger corroboration of substantive theory.

The strongest form of a statistical hypothesis derived from substantive theory is the predictive point hypothesis. Predictive point hypotheses correspond to the type of theory corroboration found in physics (Meehl, 1967). In physics, the null hypothesis is a precise value, not literally a null hypothesis of no effect (Meehl, 1967). We can use confidence intervals to compare the substantive theory's predicted value, with the mean observed via experimentation. As experimental techniques, sample size, and control increase, values predicted lie within a smaller range, creating a more stringent test (Meehl, 1967). Strong and weak tests both have their own risks and requirements. Weak tests are easier to pass, but they provide less theory corroboration (Meehl, 1997). In contrast, strong tests are harder to pass, but may provide a real possibility of falsification (Meehl, 1997). The most fundamental weakness of the strong usage of significance tests is that strong tests require strong theories. Many areas in psychology may not have the grounding required to generate strong theories (Meehl, 1967).

Views on psychology's weak theory corroboration extend beyond the rarefied boundaries of methodology and philosophy. Renown for his work in ergonomics, humans factors, and complex systems design, Vicente (1998) notes on the continuum of theories, "Areas on this continuum include: categorical, ordinal, interval, and point predictions" (p. 224). Specifically commenting on Chow's (1996) well known defence of NHST, and its obsession with uni-dimensional theory corroboration, Vicente (1998) notes, "Chow is settling for 'low-hanging fruit' rather than striving to develop more sophisticated and powerful theories" (p. 224). Granted, as noted above, many of psychology's theoretical constructs may not have the development required to produce interval or point predictive hypothesis. Instead of encouraging strong theory development, psychology's use of HD method promotes nothing stronger than directional theory testing, even for those theoretical constructs that do have the sophistication to produce strong predictions. Strong theory corroboration becomes crucial when dealing with real world problems as theories directly affect human lives when they become instantiated in procedures, devices, artifacts and educational systems.

Issue Four: Data and testing obsession

HD's most complex issue centres on its dual data-centric and hypothesis-testing obsessions. This twofold, data and hypothesis testing obsession is apparent in Lawson's (2000) version of the hypothetico-deductive method. Bellow are several steps from Lawson's (2000) construal of HD method, see Figure 10, below.

Figure 10: Steps to knowledge acquisition

3). Generating initial possible hypothesis (and derive prediction)
5). Carry out test and match prediction to observed result of actual test
6). Compare expected and observed results, drawing a conclusion, hypothesis is supported or un-supported
(Extracted from Lawson, 2000, p. 581)

Lawson's (2002) description of HD begins, "Identify a puzzling observation…" (p. 17), the focus of this view is on singular data results. An HD framework promotes the testing of theories using comparisons of empirical data because data are what Popper would see as an acceptable basis for comparison with predicted values (Popper, 1945). Lawson (2000) summarizes the HD view as follows, "…try to use a process in which hypotheses leads to predictions, which then are compared with subsequent observations so that conclusions can be drawn…" The language used to formalize HD method simultaneously places its focus on data and hypothesis testing. However, science deals with regularities isolated from a range of instruments and settings rather than transitory registers upon one set of equipment (Bogen & Woodward, 1988). Using language from Woodward (Bogen & Woodward, 1988, ; Woodward, 1989, ,2000), these regularities are known as phenomenon.

Phenomenon are concepts separate from the empirical data that derive them (Woodward, 2000). What are phenomena? Phenomena are processes, states, forces, and objects: the causal forces that generate data (Woodward, 1989). For instance, the fundamental attribution bias is a classic cognitive psychology phenomenon, reproducible on different psychometric tests via different experiments and isolated from different data sets. If the fundamental attribution bias exists, then it is a mediated cognitive process and is unobservable. We presume that the fundamental attribution bias (FAB) is the causal factor influencing observable behaviour and the data recorded in attribution experiments. The FAB is the object that attribution theories discuss. In turn, attribution theories are separate from the phenomenon; theories are explanations, not states, or forces. Attribution theories explain why the empirical regularity known as the FAB occurs, its nature and character, but theories are not the phenomenon itself. We presume that there is an independent reality, in which the phenomena under focus exist independently of us (Hooker, 1987).

Phenomena exist in other forms besides representational and mediational constructs. Gravity is a physical phenomenon, reproducible on different instruments, isolated via different experiments, and obtained from different data sets. Granted, we cannot see gravity in a literal sense, but we can isolate the effects the gravity causes upon the world via different empirical data. In another more visible example, the boiling point of water is a phenomenon, and is indeed visible. However, our experience of boiling water is variable across occasions. At low altitudes, water boils at a higher temperature than it does at high altitude, where water boils at low temperatures. We could operationally define the boiling water as the conjunction of 1) a rolling bubble on the surface of the water, and 2) 100 degrees Celsius on a thermometer. However, this definition would not hold true for water boiled at altitude. Thus, when we consider the scientific concept of 'boiling point,' we are actually thinking of a very specific experiment, conducted at sea level, with pure water and laboratory apparatus.

More importantly, when specifying temperature we usually conduct the experiments identifying the boiling water phenomenon on several occasions and average the results. After all, with increasingly sensitive thermometers we would continue to see a variation in boiling point during a controlled experiment as we gradually increased our measuring capabilities or the experiment varied due to other conditions. This is part of the universal calibration error involved with our nature as a physical creature. No measurement or measuring technique is perfect, there will always be some aspect of error involved in our measurements. Assuming that our intention is to use our observations as support for our theories, and also assuming that our observations of data are variable across occasion, which boiling water event is to be the construct around which we base a theory of thermodynamics? Rather than focusing on a single event, the important phenomenon is the regularity across the range of empirical data events. After all, given strong laboratory controls, water usually boils on or near one-hundred degrees Celsius. This regularity is inherent to water.

The phenomena/data distinction is not without controversy. Glymour (2000) considers the distinction between phenomena and data un-necessary or superfluous. Glymour's (2000) notes, "Suppose the scientific inferences of interest are statistical inferences…We can…take the distinction between data and phenomena to correspond exactly to the distinction between sample and population structure" (p. 33). If the differentiation between data and phenomena corresponds to the distinction between sample and population than we are just renaming an already concrete description (Glymour, 2000). Conversely, if the data/phenomena distinction does not correspond to the differentiation between sample phenomena, then the statistical inference procedures occur independently of these distinctions and we do not need them. The crux of Glymour's argument rests on the nature of scientific inference, which according to Glymour (2000), is a statistical inference. If this premise is faulty, then the rest of Glymour's argument does not stand. I suggest, in response to Glymour's critique of the data/phenomena division, that there is more to inference than statistics. Granted, statistics are an important part of both hypothesis generation and hypothesis confirmation in science.

However, when considering theory confirmation, the meaningful relation between data and theory, is epistemic. Statistics are a method of control exerted on the noise inherent to measurement in an empirical world. After all, there are two aspects of error possible when considering the generation – confirmation relation. Firstly, there is error when isolating a phenomenon, we may not have correctly isolated the phenomena in question (Woodward, 2000). Secondly, there the error that occurs when testing the theory, we may not have generated the correct theory (Woodward, 2000). We use statistics in both phenomenon isolation and theory generation to aid use in avoiding error, but statistics are not the only techniques available. Our choice of nil, predictive, form, or directional hypotheses is a technique unto itself for producing stronger theory corroboration. Furthermore, Thagard (1992) offers the system of explanatory coherence as an alternative to statistical theory confirmation. Thagard's (1992) theories of explanatory coherence offer theory confirmation via explanatory adequacy and coherence. Thus, Glymour's initial premise is faulty, statistical inference is not the sum total of scientific inference. In turn, this suggests that Glymour's critique of the data/phenomena divide is flawed.

Why is this distinction between data and phenomenon important? It is important because the distinction between data and phenomenon is part of the distinction between dynamic data and casual forces. The most obvious aspect of this influence on psychology is psychology's past obsession with operational definitions. By defining every scientific term as an operational procedure that will provide an example of its existence, psychological theory becomes inexorably tied to dynamic data events. However, data objects have limited explanatory power, limited causal power, and are often variable across situation. On the other hand realist science occupies itself with understanding the causal mechanisms (Hooker, 1987). Good explanatory theories capture the regularity expressed by causal mechanisms. Drawing again from Vicente's (1998) ergonomics perspective, "Before one can meaningfully formalize, quantify, or experiment, one should identify a natural phenomena that is worthwhile investigating in more detail…" (p. 224). Although Vicente's use of the world 'phenomena' may not be a formal corroboration of the data/phenomenon distinction advocated by Woodward and Bogen (1988), at the very least it is a clear indication that science and ergonomics are concerned with more than data.

Strictly speaking, Bogen and Woodward (1988) appear to take the view that phenomena are un-viewable causal variables. In a way, this is true. Phenomena are a scientific label for a regularity spread across different informational events. To view a phenomenon would be akin to viewing all of its various constituent data events simultaneously. Yet, depending on viewpoint, phenomena are conceptually viewable. For example, Galileo looked at a pendulum saw data; Aristotle looked at a pendulum and saw constrained motion, which is a concept stable across a range of different oscillating pendulums (Woodward, 2000). For Aristotle, the pendulum's motion provided a perception that closely specified a motion event. Aristotle conceptually extended his perception of this event to apply to the causal forces in operation on all pendulums. Expanding this idea further into an observation about the nature of phenomena I suggest that we can conceptually see phenomenon if the phenomena and the data are tightly linked.

To push this idea further, the difficulty in isolating a psychological phenomenon depends on how tightly linked the phenomena and data are, and what perspective we hold. For example, when adopting a representational perspective on perception and action, the important causal phenomena are usually the representational mechanisms that drive behaviour (i.e. attitudes, emotions). These mental phenomena are constructs presumed to be located inside the head, located via psychometric testing (Barrett, 2002). Phenomenon with their referent inside the head will be difficult to isolate, how do we know that our test has measured the mental variable that we think it has measured? The information that specifies the existence of representational and mental constructs requires an inference from viewable data to un-viewable mental process. In comparison, consider the data that specifies a phenomenon with its referent in the world (e.g. boiling water). To extend these thoughts further, our perspective (referent of analysis) will govern how easy it will be to isolate a phenomenon and how confident we may be of our efforts. For example, many aspects of physics focus on observable phenomena. Observable phenomena are accessible. Most of psychology focuses on mental phenomenon. Mental phenomena are inaccessible.

Consider the proposition above that our referent of analysis will lead to different problems in isolating our phenomenon. To extend this proposition, let me link the concept of phenomenon with an ecological perspective. Data patterns that lead to ecological phenomenon place the referent of study in the shared relationship between a perceiver and their environment, rather than a specifically representational construct. This makes three controversial suggestions. Firstly, it suggests that we do not need to focus purely on the representational variables made popular by cognitive psychology, as they may be more trouble than they are worth at this stage of psychological inquiry (Paul Barrett, 2004, University of Canterbury Conference on Psychological Measurement). Secondly, it challenges the restrictive notion that we need to construe behaviour as entirely driven by these mental constructs (Gibson, 1979).

Instead, an ecological conception of cognitive phenomenon suggests that observable variables offer an emergent understanding of cognition in the wild (Hutchins, 1995). Cognition in the wild "refers to human cognition in its natural habitat" (Hutchins, 1995, p. xiii). This makes "the distinction between the laboratory where cognition is studies in captivity, and the everyday surroundings of the world, where human cognition adapts to its natural surroundings" (Hutchins, 1995, p. xiv). Emergent cognition does not deny that events occur within the central nervous system and higher nervous system. Rather, it relocates the shared unit of analysis (where possible) from purely representational constructs in the brain, to the shared relationship between the perceiver and their environment[7].

Thirdly, when we must examine intervening mental processes of the central nervous system, an ecological-phenomenon view suggests that we need to find more ecologically relevant ways of obtaining evidence for these processes. Modelling, simulation, and naturalistic observation may be preferable to some of the classical

[7] I will discuss this idea in greater depth, in Chapter 3

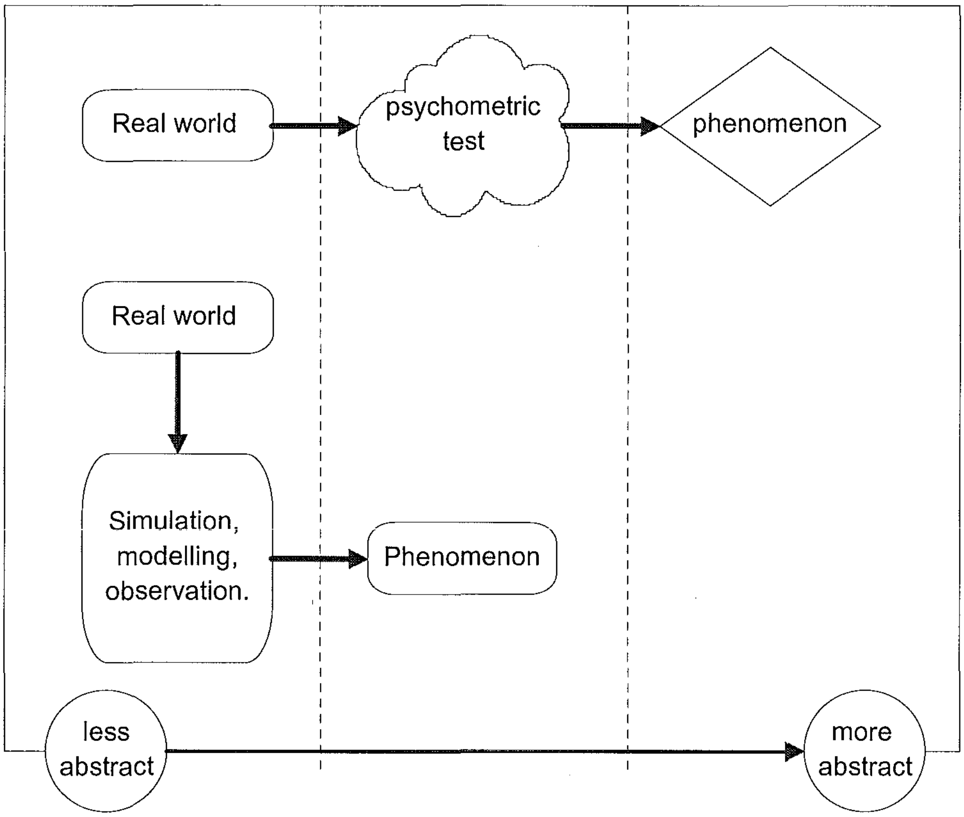
techniques, e.g. psychometric testing and questionnaires. Simulations and observation preserves the real world relationships that occur in an actor's natural interaction with their world (Hutchins, 1995). Many self-report methods, questionnaires, and laboratory studies are abstractions that preserve little of the real world reference situation because they have mediated the reference situation with paper, words, diagrams, and verbal communication. However, laboratory mediation does not preserve the information relevant to the reference situation (Vicente & Burns, 1996). Simulations and observations offer fewer levels of experimental mediation; psychometric tests offer more levels of experimental mediation.

For example, when exploring an intervening phenomenon like racial attitudes, simulations or observations of real world encounters between perceivers and peoples of different races are preferable because they observe the real world situation, or replicate it in high fidelity. Conversely, with psychometric testing we ask a perceiver about their actions and attitudes during an imagined event. Barrett (1998) notes,

> What is driving this process [of issues with psychometrics] is the gradual recognition that it is becoming harder and harder to conceive of generating tests and assessments that will dramatically improve our accuracy of prediction of individuals. As a spur to this process, several substantive professionals (noted above) have begun to question whether psychology's approaches to its problems are in fact the best approaches. This has required a fundamental rethink on current strategies of research, and on the measurement processes involved in psychometric tests in general. (p. 9).

I suggest the questions that professionals are asking orientate around the real world validity of our work, as the added layer of psychometric testing and laboratory abstraction often makes it difficult to investigate human psychology in complex real world settings, see Figure 11, below.

Figure 11: Un-necessary abstraction between phenomenon and test



Issues with psychology's data and data testing obsessions extend beyond psychologists. The noted physicist Feynman was very critical of psychology's scientific methods. In an amusing comparison with certain social habits of the pacific islanders Feynman (1989) notes,

> I think the educational and psychological studies I mentioned are examples of what I would like to call cargo cult science. In the South Seas there is a cargo cult of people. During the war they saw airplanes land with lots of good materials, and they want the same thing to happen now. So they've arranged to make things like runways, to put fires along the sides of the runways, to make a wooden hut for a man to sit in, with two wooden pieces on his head like headphones...They're doing everything right...It looks exactly the way it looked before. But it doesn't work...So I call these things cargo cult science, because they follow all the apparent percepts and forms of scientific investigation, but they're missing something essential because the planes don't land... (p. 310-311)

This missing factor is absolute scientific integrity (Feynman et al., 1989). A willingness to report everything that could explain or bias your results, things you've eliminated and how you eliminated them, and any doubts you have (Feynman et al., 1989). Scientific integrity includes publishing your results in whatever form they appear, thus publishing both positive and negative results. In reference to a set of rat experiments in the 1930's, and specifically relevant to this discussion, scientific integrity involves isolating the regularities that are the casual force behind transitory data, "isolating the clues that the rat is really using – not the clues that you think it's is using" (Feynman et al., 1989, p. 316).

Summary of Chapter One

Specifically speaking against Chow's (1996) rigorous approach to NHST, Vicente (1998) notes, "...the science of psychology is in trouble..." (p. 224). I suggest that the science of psychology is in trouble because of a deep source of theoretical influence from the hypothetico-deductive method. I have provided three reasons why hypothetico-deductive method (HD) fails to provide a general account of scientific method. Firstly, HD fails to provide an account of hypothesis generation. However, strong theories are required to provide the basis for design and failing to support the overt generation of theory is a deep flaw. Secondly, HD pretends to provide strong theory corroboration. In reality HD, usually in conjunction with NHST nil hypothesis, provides weak nil or directional theory corroboration. Lastly, HD method focuses obsessively on data events and hypothesis testing. This ignores the crucial step of isolating the regularities known as phenomenon. Based on the work in this chapter I suggest that HD method is not suitable as a conceptual basis for a real-world problem-solving framework. However, in the next chapter I will explore alternate method known as abduction, which may provide a better conceptual basis for our problem-solving framework.

Chapter 2: Abduction

In the first chapter I briefly discussed a statistical procedure known a Null Hypothesis Significance Testing (NHST), and closely examined a method known as the hypothetico-deductive method (HD). I suggested that most of psychology utilizes NHST in a statistical sense, and hypothetico-deduction as its central method framework. Psychology uses these procedures as a pair, while elsewhere in science they are often used separately. Lawson (2002, 2000) makes the strong claim that the hypothetico method is central to scientific endeavour. In response to Lawson, I discussed the flaws and limited capabilities with HD method and how it lacked suitability to provide the conceptual basis for our real world problem solving framework. Recall that the aim of this thesis is to develop a systematic real-world problem-solving framework drawing from both abduction and ergonomics.

This chapter continues with that aim by exploring alternative methods and conceptual frameworks, specifically a method known as abduction. The structure of this chapter is as follows: Firstly, I will introduce the history of abduction. Secondly, I will discuss my treatment of the relationship between abductive inference and abductive method. Thirdly, I will discuss four major issues with abduction: no such thing as the logic of discovery, abduction generating hypothesis, control over discovery, and abduction - logic of discovery or confirmation. Alongside each issue, I will discuss appropriate responses and amendments and in between issues and their amendments, I will discuss other techniques and components that are complimentary to an abductive method of scientific research. This chapter will specifically defend the proposal that abduction offers a logical account of discovery, whereas the last chapter of this thesis will extend abduction further by suggesting that abduction offers a strong ecological account of phenomenon isolation and theory generation.

Introduction to abduction

I have previously reviewed how the hypothetico-deductive method and its inferences owe their origin to the deductive syllogism (Hempel, 1966). However, there is an alternative history to the development of hypothetico-deduction. This alternate history includes the rebellion away from truth preserving syllogisms, like deduction, towards knowledge-producing syllogisms like induction (Schurz, 2002).

Early works on induction by Francis Bacon placed induction in opposition to a deductive science (Gower, 1997). By paying attention to experimental results, Bacon's induction ushered in a new trend of experimentalism (Gower, 1997). More specifically, paying attention to experimental results required attending to phenomena (Gower, 1997). Unlike deduction, induction does not preserve truth, "Induction or synthetic reasoning, being something more than the mere application of a general rule…can never be reduced to this [deductive] rule…" (Peirce, 1878, p. 187). Instead, induction is an inversion of the deductive inference, producing a rule (law) from a case and a result as seen in Figure 12, below.

Figure 12: Induction as an inversion of deduction

From Deduction…
A – (Rule) All the beans in the bad were white
B – (Case) These beans were in the bag
C – (Result) These beans are white

...To Induction
B – (Case) These beans are from this bag
C – (Result) These beans are white
A – (Rule) All the beans from this bag are white

(Extracted from Peirce, 1878, p. 188)

Induction was not well received by early supporters of deductive science (like Newton) nor by later creators of the hypothetico-deductive method. Kleiner (1993) notes, "Popper…Hempel…and other defenders of the hypothetico-deductive method argued at length that no such routines [inductive routines]…could have generated…powerful theoretical concepts…" (p. 3). Despite a cold reception, induction gained a large following of scientists and philosophers as it appeared to offer a method of discovering hypothesis (Langley, Simon, Bradshaw, & Zytkow, 1987). In contrast, the hypothetico-deductive method does not explicate how hypothesis arise, before they are tested (Hanson, 1958b). Based on this support, inductive reasoning has permeated deeply into all aspects of scientific inquiry (Shank, 1998).

Despite popular backing, induction has several drawbacks. Firstly, inductive reasoning does not provide truth, only a sense or probability that the conclusion follows the premises (Carney & Scheer, 1980). This may seem like a small price to pay for discovery, but great minds, like Newton, felt that an uncertain science was not worth contemplation (Gower, 1997). For many, the certainty offered by deduction seemed to outweigh deduction's inability to generate knowledge. Secondly, inductive reasoning makes an inference from a specific sample to a generalization, only when the phenomena upon which the inference is based have already been clarified, identified, and understood (Shank, 1998). Thus, induction still fails to explain how we generate explanatory theory from the isolation of phenomena. Despite these problems, many continue to believe that induction fulfils this goal, of providing scientific laws (Langley et al., 1987).

Induction may be part of the process of discovering generalizations, but it is important to note that generalizations and theories are not the same. Generally, science moves towards explanatory theories, based on stable regularities (Haig, 2000). Induction, whether simple or complex, makes the move from observations to generalizations (Hanson, 1958b). To generate a law or generalization is not the same as devising an explanation (Hanson, 1958b). Thus, despite its apparent ability to provide scientific hypotheses, induction is limited to generalization. This limitation makes induction unsuitable for generating explanatory theories and in turn unsuitable as the methodological backbone of scientific practice. If both deduction (hypothetico-deduction) and induction are not suitable as a general scientific method, and using standard portrayal of logic, we would be unable to progress further. Typical conceptions of logic are dualistic, logic is either deductive or non-deductive, "We will call any argument that is not deductive, a non-deductive or inductive argument (Carney & Scheer, 1980, p. 11). Rather than follow this dualistic portrayal of logic, I turn to abduction, an inference little known in psychology, but popular in computer science.

Peirce and Abduction

Consider the world of logical inferences. Inferences have traditionally separated into deductive inference and non-deductive/fallacious inferences. With the emergence of induction, this division became deduction versus induction. However, a lesser-known American philosopher, Charles Sanders Peirce, introduced one further differentiation in the common schools of logic. Peirce is one of America's most profound, versatile, and original philosophers (Brent, 1993). Both a philosopher and a scientist, Peirce's work was badly obscured in his lifetime and still suffers from the effects of anonymity (Brent, 1993). Having spent his life studying the major schools of logic Peirce was well familiar with variations in deduction and induction and the history of logic (Brent, 1993). In one of many of his works from 1864-1865, Peirce began the outline of a differentiation between deduction, induction, and a new type of logic, what was originally termed 'hypothesis' (Feibleman, 1960). The words ''retroduction,' 'reverse deduction' and eventually, 'abduction' appeared in later works by Peirce. This last term is the most popular, and is the term used in this thesis.

In its briefest form, and according to Peirce's original thinking, the abductive inference is another inversion of the deductive inference. See Figure 13 (below) for a deeper exposition on the abduction inversion, and Figure 14 (below) for the Peircian abductive inference.

Figure 13: The Abductive Inversion

From Deduction…

A – (Rule) All the beans in the bad were white
B – (Case) These beans were in the bag
C – (Result) These beans are white

…To abduction
A- (Rule) All the beans from this bag are white
C- (Result) These beans are white
B- (Case) These beans were in the bag

(Peirce, 1878, p. 188)

Figure 14: The Abductive Inference

The surprising fact, C, is observed
But if A were true, C would be matter of course,
Hence, there is a reason to suspect that A is true.

(Vol. 5.189, Peirce, 1931, p. 117)

Despite the differences between abduction and induction, many have made a fatal error of confusing these two inferences. In his early thinking, even Peirce blurred induction and abduction. In each case, we are making a generative claim, firstly towards an explanation (abduction), secondly towards a rule/generalization (induction). Peirce (1931) was aware of his possible confusion between these generative inferences and was eager to clarify their differences: "The analogy of hypothesis [abduction] with induction is so strong that some logicians have confounded them" (Vol. 2.630, p. 378). Imagine an example of abduction: We are looking at a torn jacket, and we suspect we know who the wearer is. We search her closet and find a sleeve that matches the jacket. The abductive inference occurs when we infer that the jacket belongs to the women. Given the right portrayal the inductive and abductive inferences might be inappropriately confused. Peirce (1931) noted that abduction has often been called an induction of characters, "A number of characters belonging to a certain class are found in a certain object; whence it is inferred that all the characters of that class belong to the object in question…" (Vol. 2.633, p. 379).

From the example, it is obvious that induction and abduction clearly share the same principles. However, during an induction we are justified in saying that we matched the jacked and sleeve on some coarse irregularities and this led us to match the two on finer lawful irregularities. On the other hand, abduction moves from matching the jacket and sleeve towards a claim about ownership, a claim that is both brave and risky at the same time. Josephson (1998) takes an interesting position in this argument, suggesting that, "inductive generalizations can be insightfully analyzed as special cases of abductions…" (p. 18). As mentioned, generating a generalized law is not the same as explaining something. Knowing that all A's are B's does not explain why there is a casual link between them (Josephson, 1998). However, Josephson (1998) suggests that inductive enumerations explain by offering a causal story. This causal story explains a portion of the event under examination, but not the reasons behind the event. In a sense, induction does appear to explain its own premises, much the same as abduction. I find this characterization interesting, but not necessary or even convincing. Thus, for my purposes abduction and induction are the same genus but not the same species.

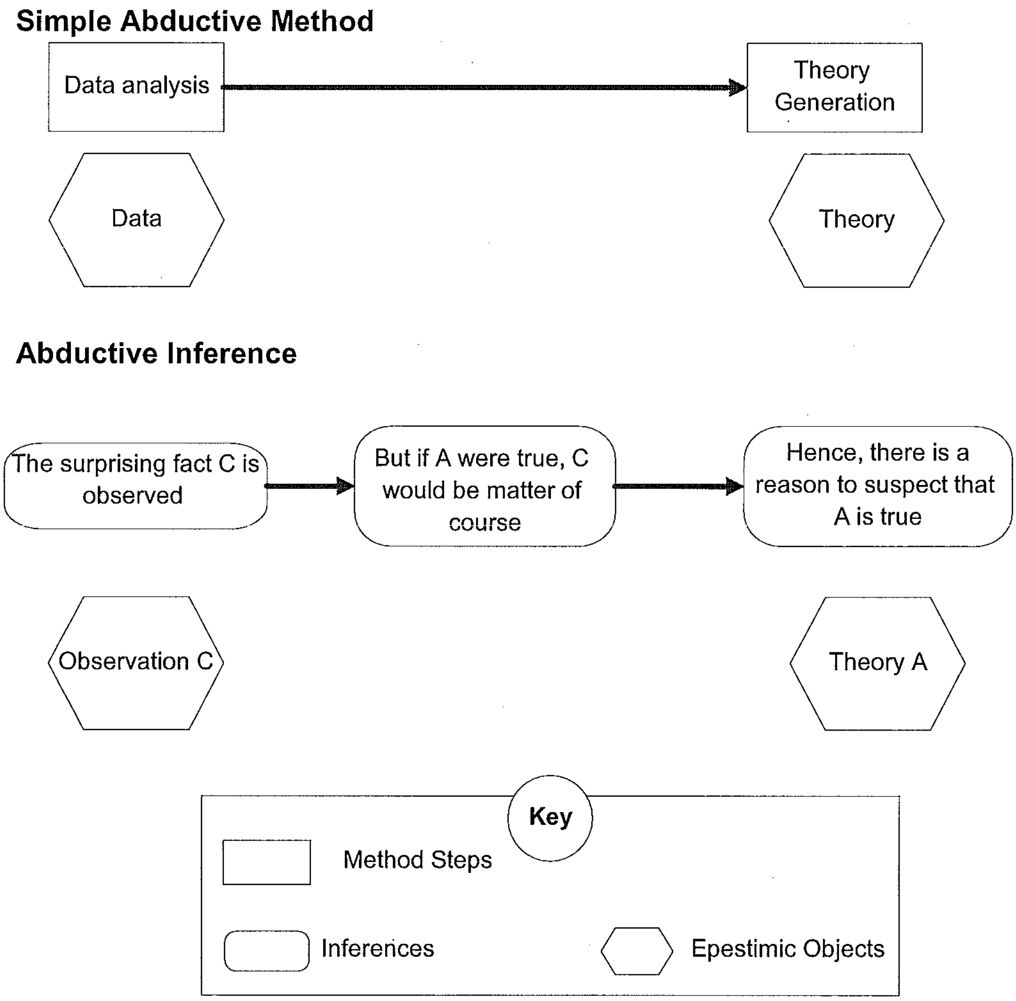
It is clear that an abductive inference is not a truth preserving inference. Furthermore, abduction is possibly weaker than induction (Peirce, 1878). Despite its weakness, abduction's advantage rests within its ampliative nature, and the nature of what it produces. In being ampliative, abduction provides us with more information than we originally had, the production of new knowledge (Yu & Behrens, 2003). Granted, induction is also an ampliative inference. However, even Peirce's brief conception of abduction suggests that abduction offers a method of producing explanatory theories, Peirce (1931) notes "This sort of inference [abduction] is called making a hypothesis" (p. 188). As mentioned previously, induction provides generalizations, not explanations. Thus, abduction is explanatorily ampliative. The explanation generated by abduction is uncertain, abduction opposes logical positivism, by offering an uncertain place for research to begin (Yu & Behrens, 2003). However, an abductive inference is not random guessing, rather, it is informed conjecture. Abduction provides the creation of new concepts, and in turn new language to describe them, via the rational creation of hypothesis (Yu & Behrens, 2003). It is clear that Peirce's underdeveloped conception of abduction leaves us with some issues to discuss. Starting with Peirce's original concepts, I intend to move towards a more sophisticated and modern portrayal of abduction.

Abductive method versus abductive inference

Before exploring abduction, I want to clarify an important differentiation between two types of abduction. To revise from the last chapter, statistics and data-manipulation techniques are local procedures for working on the information in a given domain. Inferences are the logical premise conclusion relationships, which act as the functional intermediaries between data, phenomena, and conclusions. Methods are global conceptual frameworks that encourage the global trends realized in inferences. I see data-manipulation techniques and inferences as method made real. Global methods impose their influences on the way we use local inferences, but it is through using inferences that we follow the influence of a global method. In essence, inferences are method realized. To put this in the context of abduction, the abductive inference is the inferential relationship described previously (See, Figure 14: The Abductive Inference, pg 42). Conversely, the abductive method is the global framework that supports and encourages scientific practice to progress from real world data to scientific explanations.

The abductive method encompasses, but is different to the abductive inference, a difference expressed by a change in modelling language. The abductive inference is a logical relation, utilizing local premise-conclusion relationships. On the other hand, the abductive method is a conceptual framework utilizing global task-goal relationships. I have illustrated this difference in Figure 15, below.

Figure 15: Abductive method versus abductive inference



As Figure 15 indicates, the methodological steps of abductive method support the goal of generating an explanatory theory and the abductive inference describes exactly how this occurs. Peirce usually focused on abduction as an inferential logic (Haig, 2003). However, I intend to establish a more sophisticated conception of abductive method by exploring relevant aspects of abductive inference as I believe that the best way to understand the impact and use of abductive method is by exploring the local abductive inferences, conditions, and components that make up the building blocks of a revised conception of abductive method. In the last chapter I intend to use the overall abductive method structure as the structural basis of the real-world problem-solving framework that is the goal of this thesis.

Issues with abduction

Issue one: No such thing as a logic of discovery

Discussions in the previous chapter highlighted a weakness in HD method, specifically that HD method supports an account of hypothesis confirmation, but fails to provide a methodological account of hypothesis generation (Hanson, 1958b). Hypothesis generation is located under the heading of, 'logic of discovery'. In order to unpack the concept of 'the logic of discovery,' compare hypothesis generation with theory confirmation. The logic of confirmation examines previously generated theories by deriving testable hypothesis (Simon, 1977). Conversely, the logic of discovery is a systematized inferential relation between data and theory that describes and maps how hypothesis and theories are generated from data (Hanson, 1958a). Initially then, it would seem that these two logics represent a reciprocal relationship, one creating hypothesis, and the other testing them. However, HD clearly abandons the logics of hypothesis generation and innovation (Simon, 1977). Why is this important in terms of abduction? Understanding whether there can be a rational logic of discovery is important because abduction is often identified as 'a logic of discovery' (Kleiner, 1993). Given the hypothetico-deductive abandonment of rational discovery, it is unclear whether we can actually use abduction as the basis for an innovative real world problem-solving framework.

To reconfirm the character of Peircian abduction, Peirce (1931) notes, "Abduction is the process of forming explanatory hypothesis…It is the only logical operation which introduces any new idea" (Vol. 5.172,). Indeed, Peirce (1931) goes so far to suggest that, "All the ideas of science come to it by way of abduction…Abduction consists in studying the facts and devising a theory to explain them" (Vol. 5.145). Previous sections indicated how HD avoids granting any rationality to the process of hypothesis generation and innovation, by placing the burden of discovery into unconscious psychology (Lawson, 2000). I want to expand on this topic further by exploring various arguments against the rationalization of discovery, and submitting arguments in favour of an abductive logic of discovery. I want to focus on three sub-critiques levelled at the logic of discovery. Firstly that discovery is a psychologically creative process and thus uncontrollable, secondly that discovery is mystic serendipity and thus not rational and thirdly that the reasons for suggesting theories, and the reasons for supporting them are the same and thus, that there is no logic of discovery.

Discovery as psychology

Although Popper might disagree in principle with the usage of HD thinking in its confirmatory form, his ideas are a strong influence on HD's inception (Popper, 1945). Consider Popper's (1959) thoughts on the logic of discovery, "The initial stage, the act of...inventing a theory, seems to me neither to call for logical analysis nor to be susceptible of it..." (p. 31). This does not suggest that hypothesis are not generated, but rather that the process by which they are generated are psychological, and unsusceptible to any type of rationally (Popper, 1959). Granted, a deeper study of the psychology of hypothesis generation might be both interesting and fruitful, but this does not answer our methodological questions, which are, in a certain sense independent from psychological questions. HD fails to provide support for a logic of hypothesis generation because philosophers thought that such a logic was impossible (Hempel, 1966).

The key to this first critique rests in the difference between an uncontrollable psychological explanation and a logical explanation. Popper's conception of scientific method places the burden of hypothesis generation squarely in unconscious psychology. Popper (1945) notes, "Essence of Scientific Method: One puts up a hypothesis, a guess, a leap into the unknown, and from this one deduces consequences and tests these" (p. 3). Thus, the core of Popper's conception of hypothesis generation rests in the 'guess' and the 'leap into unknown thoughts;' these sorts of activities are psychological, and in many cases apparently unconscious. Granted, although all reasoning is a psychological activity not all psychological activities are logical inferences, i.e., not all cognitive activities are susceptible to logical description and systemization.

Rational systems are concerned with the progression of evidence from premises to conclusions, something that is fundamental to the nature of science (Irvine, 1996). Conversely, psychology, particularly cognitive psychology explores the cognitions of a perceiver undergoing rational thought. Placing hypothesis generation inside the head and out of reach of method (and logic) places discovery in a cognitive domain, a place to which we may never have access. This is not an acceptable outcome. Having the ability, to test our theories (knowledge claims), but no methodological way to describe how we generated these knowledge claims places a severe limitation on science (Hanson, 1958b). Thus, if it is the case that discovery is purely "psychologism" then the logic of discovery cannot be defined in logical form (Popper, 1959). Of course, this begs the question, 'what is logic?'

The study of logic is, in itself, a labyrinth of a question if investigated to deeply. A simple clarification from Copi (1961) is informative enough: "...the logician is not...concerned with the dark ways in which the mind arrives at its conclusions during the actual process of reasoning. He is concerned...with the correctness of the completed process..." (p. 6). Recall, logical systemization is concerning with clarifying the logical relation between propositions in a way that conclusions follow premises, or premises give good evidence for their conclusions (Irvine, 1996). Granted, logical systemizations are not completely true conceptions of the world; our world influences the nature of our perception, which is in turn subject to social influences. This does not detract from the requirement that, if discovery is to have logic, then there must be some form of structured relation between data and theory, which we can quantify, discuss, and utilize.

Granted, the logic of discovery is not likely to be explicated in deductivist terms; it may be construed as a systemized relation rather than a pure deductive logic (Langley et al., 1987). Irvine (1996) notes, "logic of the twentieth century has come to include, not only theories of formal entailment, but informal logic" (p. 9). We do not want to obscure the question of whether hypothesis generation can be a rational and systemized by arguing whether the logic of discovery will be deductively correct. A modern portrayal of logic leaves ample room for the systemization of non-deductive logics. This suggests that abduction can assume the mantel of 'logic' and in turn provide the logic of discovery and innovation.

To understand this first objection to irrational discovery, we need to extend these ideas into the real world. For our purposes, discovery is analogous to creativity. The question then becomes, what is the nature of the creative endeavour. Is there a structured relation between the world and the generated explanation? For a real world example, consider a poet composing poetry. Poetry is clearly a creative process, calling for inspiration, and perhaps even genius (Langley et al., 1987). Yet, to decompose poetry for a moment, what are the basic components required in generating poetry? Accepting that an informal logic will allow for some creativity, we must also accept that behind creativity the circumstances required include a understanding of grammar, form, spelling, linguistics, and the auxiliary knowledge of a vocabulary; these are the components required to generate poetry (Langley et al., 1987).

Poetry generated by such a mechanical approach might not reach a laureate standard, as the individual ability to perceive and assimilate the information supporting innovation is a factor in the discovery process. However, to align discovery totally with unconscious processing is to ignore the systematic, pattern-searching nature of hypothesis generation. At its core, discovery is a reasoned process. Hanson (1958b) notes, "...the original suggestion of a hypothesis is a reasonable affair" (p. 1083). Perhaps it takes genius to provide the intense effort and focus required for creative hypothesis generation, but it does not follow that there is no logic to the act (Hanson, 1958a). To agree with the deductivists, the conclusion that there is no logic of discovery mistakenly accepts the false premises that discovery is fully psychological in nature.

Discovery as mystic serendipity

The second critique of the logic of innovation asserts the mystical, serendipitous nature of discovery. This critique is related to the suggestion that discovery is a completely psychological endeavour. However it goes further and implies that it is impossible to rationally construct a method of discovery because there is something mystical (spiritual, dreamlike, and magical) about the way that discoveries occur and the process that support them. A classic example of this type of discovery comes from the history of chemistry. This example concerns the discovery of the shape of the benzene molecule by the chemist Kekulé. The following is a translated portion of a speech given by Kekulés[8] (Original German text extracted from Rothenberg, 1993, p. 289-281, Translated by Anna Collins).

> During my stay in London I lived for a long time in Clapham Road near the common. In the evenings, however, I often was with my friend Hugo Miller in Islington, which was at the opposite end of the town. We spoke of a great number of things, but mostly about our

[8] This quote comes from a speech given by Kekulé in 1890, to the German Chemical Society.

> beloved chemistry. On a beautiful summer day I travelled on the last omnibus "Outside" on the roof of the bus, like always through the empty streets, which were otherwise a busy world city. I sank into my dreams. There before my eyes were atoms. I had always seen them in motion, these tiny beings, however I was never able to work out the nature of their motion. Today I saw how often two small atoms made a small pair, how a large atom fixed to two small one, how three or four of the large ones fixed to the small ones and how they all moved giddily. I saw how the large atoms of the row joined and the end of the chain still dragged the little ones. I saw what the old Master Kopp, my highly respected teacher and friend showed in his book "Molecular World" had shown us, but I saw it long before him. The cry of the conductor, "Clapham Road" awoke me from my dreams, but I used part of the night, at least, to sketch the dreams on papers. This is how the theory of structure came about.
>
> Similarly, this is how the benzene theory occurred. During my stay in Gent, in Belgium, I occupied an elegant room in the main street. However, my workroom was on a narrow side alley and had, during the day, no light. For a chemist who did hours during the day in the laboratory this was not a disadvantage. There I sat and wrote out my textbook, but it was not right, my thoughts were elsewhere. I pulled the chair to the heating and fell into a half sleep. Again the atoms appeared before my eyes. Small groups put themselves in the background. My mental eye, which through repeated hours of a similar nature had been sharpened, differentiated now to larger pictures of manifold constructions. Long rows which were perhaps thickly, strongly stuck together. Everything in motion, like a snake they moved around in a winding motion. And look, what was that? One of the snakes bit its own tail and then the image disappeared before my eyes. Like a lightening bolt I awoke. I needed the rest of the night to work out the consequences of the new hypothesis....

In response to Kekulé's achievements, Hempel (1966) notes,

> In his [Kekulé's] endeavour to find a solution to his problem, the scientist may give free reign to his imagination...scientific objectivity is safeguarded by the principle that...hypothesis...may be freely invented...they can be accepted into...scientific knowledge only if they pass critical scrutiny... (p. 16).

It is doubtful whether this story (although fascinating) supports the argument that a logic of discovery is impossible. Assuming that others were at times working on the same problems as Kekulé, why did they not make the same scientific breakthroughs? It might be that the background knowledge gathered by Kekulé was more important to the discovery of benzene's structure, than the nap in front of the fireplace (Yu & Behrens, 2003). Granted, a fire of whirling snakes is an analogistic medium, but without a long professional career in chemistry, such analogy would not have occurred, or would not have meant anything to Kekulé (Yu & Behrens, 2003). In this way, progress in science requires the minds at the edge of the discovery to possess the correct facts at hand (Tursman, 1987). The Oxford Dictionary (Waite, 1995) defines mystic as, "truths beyond understanding." Thus, an argument appealing to mystical things devolves because it makes an appeal to something that is a) apparently intrinsically true or b) un-provable and un-testable. The combination of these factors makes mystical things beyond the reach of science. Conversely, I suggest that hypothesis generation is not necessarily mystical, but depends on the prepared mind (Yu & Behrens, 2003). This suggests that we can structure discovery in a rational manner.

Reasons supporting discovery identical to reasons for discovery

The third critique of abduction as a method of hypothesis generation, suggests that that the very reasons offered as reasons for generation of a hypothesis are the same reasons offered for support of the confirmation of hypothesis. That is, if the logical reasons for generation and logical reasons for confirmation are the same then there is no specific logic of discovery other than an extension of confirmation theory. Hanson (1958a) disagrees with this stance, suggesting that reasons for acceptance are different to reasons of generation, "...it still seems that ones reasons for entertaining a hypothesis are different to reasons of accepting it..." (p. 1077). Hanson's (1958b) examination of Kepler, provides a good example of the patterns and logic behind creative astronomical proposals. I will use Hanson's work on Kepler to explore this third objection.

In about 1600, Kepler responded to work by Tycho Brahe concerning the orbit of Mars (Hanson, 1958b). Kepler begin his investigations with both the auxiliary beliefs held by astronomers for nearly 2000 years (namely that planets had circular orbits), as well as observational data from Brahe (Hanson, 1958b). Kepler discovered continuing errors in prediction when calculating orbits based on Brahe's data and standard circular orbital models. Over time, based on these errors in the data, Kepler came to wonder whether the circular orbital model was wrong. Up to this point, Kepler's work was mostly hypothetico-deductive testing, comparing previously held theories with real world data. When Kepler went beyond ancient orbital theory, he made, what Peirce (1931) termed the, "most impressive retroduction of our time"(Vol.

1, p. 31). Making a break from the previously held circular orbital hypothesis, and based on patterns in his calculations on the relevant data Kepler generated a new orbital theory (Hanson, 1958b). In terms of HD theory, this move would have been creative in an amethodological way. Hanson (1958a) notes, "If the HD account were construed as a description of scientific practice, it would be misleading…natural scientists do not 'start from' hypothesis. They start from data…" (p. 1081). HD theory has a way of obscuring the rationality behind the truly impressive feat of creating a theory, while focusing on the more pedestrian act of theory refinement and testing (Hanson, 1958b).

Following the abductive progression from data to theory, Kepler's progression towards theory begin with data: Mars's velocities (time taken to travel at 90, and 270 degrees), and observed distances from earth (focusing on 10, 104, and 37 degrees of arc from aphelion) (Hanson, 1958b). From these constraints, Kepler reasoned towards a new orbital model, the ellipse (Hanson, 1958a). Granted, this was not an instantaneous process; before settling on an ellipse Kepler considered the possibility of an ovoid orbit (Hanson, 1958b). However, an ovoid orbit could not account for the data and eventually Kepler abandoned the idea. Proposing that there is 'logic to discovery' does not suggest that all discoveries happen with a mechanical ease. Rather it suggests that there is a rational inferential pattern in progressing from data to theory. More importantly, "By the time a law gets fixed into the HD system, the original scientific thinking is over…" (Hanson, 1958a, p. 1081).

Kepler did not wait to empirically verify his results, which would be a time intensive process that any competent astronomer could complete (Hanson, 1958b). Hempel (1966) suggests that the creative imagination behind scientific discovery is safeguarded by a constant careful theory confirmation procedure, in which predictions are confirmed by empirical data. This would seem to jar with Kepler's confidence in his results. Rather, beyond a model describing the orbit of Mars, Kepler went on to analogically and rationally abduce from one planetary orbit (knowing that Mars is typical of planets in the Sol system) to all of the orbits in our solar system. It is hard to grasp the enormity of this step. Even Galilee Galileo, who risked the wrath of the Christian Church by suggesting a heliocentric model of the solar system, kept perfectly circular orbits as a part of his solar system model.

To understand the difference between generating theories and supporting them, note that there were two abductions present in Kepler's thinking. The first abduction proposed a theory concerning the orbit of Mars, the second proposed a theory concerning the orbit of all the planets in the solar system. In the first abduction, the reasons for suggesting an elliptical orbit stemmed from a rational exploration of the patterns and regularities in the data. In essence, the nature of the phenomena both prompts and constrains its own hypothesis. These patterns and regularities are what constrain and direct the generation of a hypothesis, but they do not constitute sufficient test (Hanson, 1958a). In the second abduction, a phenomenon concerning the orbit of Mars and an analogical link between Mars (as a planet) and the rest of the planets was sufficient reason for Kepler to offer an orbital model for the entire solar system. Again, Kepler's reasons for proposing the system-wide orbital model (an analogy to Mars's orbit) were not enough to establish the theory as confirmed. There is a clear logical difference between the reasons behind the generation of a hypothesis, and the reasons offered to support a hypothesis. The distinction between reasons for acceptance and reasons for generation supports the idea that there is a logic to discovery, distinct from psychology.

Issue two: Abduction generating hypothesis

Having accepted that the idea of logic behind discovery is plausible, let us look more closely at the abduction inference. Peirce's thoughts remained protean throughout his development of abduction, he separated abduction from deduction and induction, but the nature of this separation is weak. Frankfurt (1958) pinpoints a possible flaw in abduction, specifically a lack of clarity about where the hypothesis originates from. Frankfurt (1958) suggests that abduction does not actually generate hypothesis, but is responsible for admitting hypothesis to consideration, "...establish the admissibility of hypothesis to rank among the set of hypothesis" (p. 597). Reconsider the Peircian abductive inference depicted in Figure 16, below.

Figure 16: Pure Abductive Inference

1. The surprising fact, C, is observed
2 But if A were true, C would be matter of course,
3. Hence, there is a reason to suspect that A is true.
(Vol. 5.188, Peirce, 1931, p. 117)

Frankfurt (1958) observes, "…it is very easy to show that abductive inference cannot be the method by which we arrive at new ideas" (p. 594). Logically, a new idea must then appear somewhere in the premises of the abductive inference for abduction to produce a hypothesis as its conclusion (Frankfurt, 1958). Furthermore, Peirce (1931) suggests that we cannot abduce a hypothesis until the entirety of the hypothesis is already inside the premises. Based on this confusion, I suggest that the original inference offered by Peirce requires adaptation.

To revise Peirce's original conception of abduction, we must take into account several factors that support hypothesis generation. Hypothesis generation does not occur in a vacuum, and a revised conception of abduction must take into account a modern conception of the constraints surrounding discovery. These constraints are auxiliary knowledge constraints, phenomena constraints, and problem constraints. Recall that a more tolerant, modern portrayal of logic will allow for considerations outside the bounds of traditional formal logic (Irvine, 1996). Firstly, hypothesis generation occurs in a rich field of auxiliary knowledge (Yu & Behrens, 2003). We need to invoke certain aspects of auxiliary knowledge when generating hypothesis and these aspects would be included as additional premises.

In a critique of methods of discovery, Hempel (1966) suggests that the logic of discovery is faulty because,

> …scientific theories are usually couched in terms that do not occur…in the description of the empirical findings on which they rest…For example, theories about the atomic and subatomic structure of matter contain terms such as 'atom', 'electron'…yet they are based on laboratory findings about the spectra of gases…all of which can be described without the use of these 'theoretical terms' (p. 14).

Continuing further, Hempel (1966) notes, "rules of the kind envisaged here [logic of discovery rules] would…have to provide...a routine for constructing, on the basis of given data, a hypothesis or theory stated in…novel concepts" (p. 14). Hempel's critique is heavily reliant on an operational conception of science, in which concepts contain operational definitions that describe how they can be produced empirically. In contrast, a rational conception of hypothesis generation suggests that the new terms associated with new theories arise from auxiliary knowledge. Auxiliary knowledge is the consciously gained knowledge of the world that supports an analogistic search for alternative conceptions and descriptions of the patterns encountered in data. This process is not the unconscious analogistic process proposed by Lawson (2002, 2000). Rather, it is the conscious and effortful search for an analogistic description of 'something that is like the pattern we are looking at'. In this way, abduction breaks from the bonds of a permanent language, forming new hypothesis alongside the formation of new language to accommodate them (Thagard & Shelley, 1997).

Re-considering the issues raised by Hempel about the linguistic concepts surrounding atomic theory, the original atomic theory, proposed nearly 3000 years ago by Leucippus, defined the atom as the elementary, indivisible, and immutable elements of reality (Pullman, 1998). The word 'atom' was composed from the Greek word 'Atomos', which means indivisible (Merriam-Webster, 2003). Thus the generation of the word 'atom' is a logical amalgamation of linguistic concepts used to model what Leucippus's was trying to conceive. Roughly 2000 years later, in the 1800's, the well-known New Zealand scientist, by the name of Ernest Rutherford, begin experiments with the patterns generated when alpha particles are deflected through atoms (Pullman, 1998). One of the first atomic models of the 1800s, proposed by J.J. Thomson, suggested that atoms were uniform clouds of electrons and protons arranged much like a 'plum pudding'(Pullman, 1998). Rutherford's experimental results contradicted this model, for atoms deflected particles in an uneven pattern, not in the even pattern dictated by a plum-pudding atomic model (Pullman, 1998).

Patterns from Rutherford's results indicated that the mass of the atom was highly concentrated, with most of the mass concentrated in a space smaller than the diameter of the atom itself (Pullman, 1998). Using auxiliary knowledge of the way in which solar bodies behaved, Rutherford developed the solar system model of atomic structure (Pullman, 1998). In this model, the atom is a small central core of mass orbited by electrons. Although this model has required adaptation over the years due to new findings, in principle it remains a relatively good (non-quantum) description of atomic structure. This step from data through analogy to theory is a classic example of the systematic reasoning behind discovery, highlighting the necessity of auxiliary knowledge. In the case of atomic theory, the auxiliary knowledge was the Greek language (the analogistic adoption of the word 'atomos'), and Rutherford's analogistic auxiliary knowledge of solar motions.

Second on the list of revisions of Peirce's notion of abduction is the ignorance displayed by science on the importance of specifying the research problem (Haig, 1987). Typical descriptions of the scientific process begin with pre-specified theories. Research problems are a feature often ignored in the hypothetico deductive progression. However, the research problem is a highly useful device for organizing research and realizing our research goals (Haig, 1987). It is impossible to avoid a research problem because avoidance buys into the naive perception that data gathering is atheoretical. More importantly, problem avoidance buys into the perception that research and innovation are valueless. Some conceptions of the research problem suggest that we do not need to propose a research problem in advance, as problems will arrive during inquiry (Schatzman and Strauss 1973, cited in Haig, 1987). However, this ignores how we often start investigations, albeit with badly formed problems. Despite the rudimentary nature of early research problems, investigation constantly aids the refinement of a strong research problem. The research problem provides the constant intentional guide that drives research.

Adopting an applied perspective for a moment, theories of Natural Decision Making (NDM) indirectly support the proposition that problems are often ill structured (Orasanu & Connolly, 1993). Natural decision-making examines decisions in dynamic real world settings, rather than constrained laboratory surroundings. Although NDM theories have yet to focus on the decision making efforts of scientists undertaking research I suggest that many of the theoretical principles surrounding NDM apply to the nature of dynamic research problems. NDM theories emphasize decision making is part of a dynamic system, which suggests that the research problem is part of a conception of a cyclic and dynamic scientific exploration.

A strong research problem does not detract from the main source of system feedback when solving real world problems, namely achievement of a better world. Moray (1995) notes that the goals of real world problem solving are to offer a "technology for changing behaviour to that which offsets the problems" (p. 1699). Given that research problems provides the constant intentional reinforcement it would be applicable to note that any real world problem solving framework must have some drive to offset the issues of the world. This need affects the nature of our revision of abduction by purposing the type of problems applicable and our reasons for answering these problems. Purely abstract scientific problem solving may be free from these over-riding real world goals, but for a real world framework problem solving framework, world-changing goals are the ultimate purpose of creating such a framework.

Thus, in my conception of abduction, the research problem provides constraint on the phenomenon. For example, based on my basic understanding of the state of the world, I propose a problem, 'I sense that people are using too many plastic bags and they need to use less.' The proposed problem constrains what phenomenon I initially look to isolate and explain (e.g. plastic bag addiction). Given the cyclic nature of the system, a changing problem will affect where I look for phenomenon and in turn what phenomenon I isolate, perhaps I start to examine why we prefer plastic to paper. In essence, changing the problem alters what aspects of the world come into focus, which directly affects what phenomenon will be available for isolation.

The last revision of Peirce's abduction deals specifically with the phenomena. Last of the set of constraints, phenomena constrain development of the theories used to explain them. Peirce's portrayal of abduction begins with a 'surprising observation.' From the wrong perspective, Peirce's formulation of abduction links too closely to transitory data (Haig, 2003). If abduction is the key to generating theories, and remembering the distinction between phenomena and data posed last chapter, then the abductivly inferred theory must be based on something less transitory than observed data (Haig, 2003). Singular observations may signal the beginning of an investigation, but they are not a good basis for a theory. A deeper examination of Peirce indicates that Peirce's surprising observation may actually be an indication of a deeper sense of regularity.

Peirce (1931) notes, "What, then, is that element of a phenomenon that renders it surprising, in the sense that an explanation for it is demanded? Par excellence, it is irregularity, says Dr. Paul Carus...I cannot but think that there is a faulty analysis here" (Vol. 7.198, p. 112). Peirce (1931) continues, "Nobody is surprised that the trees in a forest do not form a regular pattern, or asks for any explanation" (Vol. 7.189, p. 112). Continuing further, Peirce (1931) notes, "...whereas if it were an equally un-expected regularity that we had met with, we certainly should have asked for an explanation…" (Vol. 7.189, p. 112). This reading of Peirce suggests that he was aware of the necessity of regularity providing the basis of explanation (abduction). This coincides with the work by Woodward and Bogen (1988), indicating that phenomena are the basis for explanation. Re-formulating the abductive inference along with these revisions would create an inference something like Figure 17, below.

Figure 17: Revised Abduction

1. Phenomenon (P) is detected.
2. Via Auxiliary knowledge (A), Problem constraint (Ps), Phenomena constraint (Pc): Possible hypothesis (H) is obtained *
4. Assuming H is possibly true, H explains P
5. Therefore, based on H is worth further consideration.

*Premise 2 is where hypothesis are generated based on the constraints

(My revision is similar to a revision proposed by Haig, 2003)

These adaptations to the abductive inference preserve the nature of Peirce's thoughts, but include a better understanding of the requirements surrounding hypothesis generation. To return to Frankfurt's critique, a revised conception of abduction indicates that the abductive inference is responsible for the generation of hypothesis. Granted, abduction does not have the same certainty as deduction, or perhaps even as induction (Peirce, 1878). Yet, deduction is a static logic, seeking to preserve truth and complete unto itself, whereas induction and abduction are more dynamic, in that, they require extended heuristics and principles to support their inferences. Does this mean that there is no logic to discovery? Not really, merely that to understand discovery we must assume a more modern approach to logic. More importantly, the specific adaptations to the abductive inference reflect on the overall character of the abductive method. Assuming for a moment that abduction does generate hypothesis, how is this process controlled?

Issue three: What about the control of discovery?

For abduction to be controllable, it has to be a rational and systematic process. Peirce (1931) notes,"…abductive inference shades into perceptual judgment without any sharp line of demarcation between them…" (Vol. 5.181). Is Peirce suggesting that discovery is both logical and non-logical? It seems, that Peirce is pre-empting (by a number of years) the move that Lawson (2000, 2002) makes with HD theory, suggesting that abduction is also a cognitive process. If abduction is utterly cognitive than we cannot logically control the abductive inference and there is no rationality to discovery.

Burton (2000) offers a way into this problem: "The problem of control in abduction arises…[on]…the occasion of the initial thought of an explanatory hypothesis often characterized as a conjecture…" (p. 149). If there is no conscious control during abduction then there seems little point in defending abduction as distinct from psychology. If there is rational control over hypothesis generation then the control is a sustained confirmation of abduction as the logic of discovery. There seem to be two ways of looking at the problem of control over the abductive inference, firstly from the point of view of the person doing the generation, and secondly from the point of view of the environment surrounding the generation.

The first way of looking at the problem of control comes from Burton (2000) and focuses on the knowledge contained by the perceiver. In a previous section, I noted that Peirce's simplistic conception of abduction must include the constraints offered by auxiliary knowledge, the constraints imposed by the phenomena, and constraints imposed by the scientific problem. The focused effort required to gain a deeper understanding of the nature of these constraints relates to the amount of control we can apply on generation of the initial explanatory hypothesis. Burton (2000) notes, "…we certainly exercise significant conscious control as we dedicate time and effort to acquire theoretical knowledge in more specialized domains…" (p. 152).

This suggests that the hypothesis search and hypothesis generation is a search through space that is both planned and organized affair, based on the effortful acquiring of knowledge (Hanson, 1958b). The revisions made to Peirce's original formulation of abduction aid this search and organization. Hanson notes (1958b), "Perceiving the pattern in phenomena is central to their being 'explicable as a matter of course'" (p. 87). In this way, we realize that a person making the same exploration may not make the same discoveries, because they did not prepare adequately to perceive the patterns available (Yu & Behrens, 2003). The time and effort we dedicate to gaining knowledge provides fertile ground for hypothesis generation. This type of control may seem indirect, but it represents an important aspect of crucial control.

The second way of looking at the problem is still from the point of view of the perceiver. Burton's comments suggest that abduction does in fact exist, and that there are several ways to conceive the indirect control exercised over the abductive inference during the initial suggesting of the hypothesis. These methods of indirect control are similar to the types of indirect control we exert over perception. As perceivers, we have a variable freedom to dictate where we guide our attention. This is selective attention (Schiffman, 1990). From a cognitive perspective, selective attention is the process of choosing to focus on some of the information flooding our sensory receptors while ignoring other pieces of information (Schiffman, 1990). This type of effortful choice of attention does appear to exhibit some control over what we perceive, and thus over what we abduce.

In some cases effortful control over attention may change a focused hypothesis generation into a 'self-conscious' and cramped hypothesis generation (Burton, 2000). How does this relate to the concept of control? Burton (2000) suggests that hypothesis generators must relax their focus (attention) and let the information enter in from 'subliminal' sources. It seems to me that the selective attention approach defeats the whole purpose of formulating abduction as the rational logic of discovery. There are two ways to consider these claims. Firstly, we might suggest that the sort of systemization and logic that occurs when expressing abduction will never be on par with other more stringent systemizations. I do not like this option; after all, abduction provides all the requirements for understanding the slow reduction of the hypothesis search space, to the point where patterns in the data suggest the appropriate hypothesis.

The second way to understand this claim of 'subliminal sources' is to suggest that in his efforts to understand the nature of abductive control, perhaps he makes the mistake of blurring the lines between the abductive inference and abduction involved in psychological processes. Like Burton, I have discussed psychological issues (selective attention); however, I have done so unwillingly, more to reveal Burton's arguments than to fully invest in them. In principle, I disagree with Burton's offering of perceptual control (selective attention). I suggest that we can understand control over the initial creation of hypothesis based on factors other than selective attention. The most appropriate understanding of control, especially the control of a logical inference requires an examination of external factors. The external factors encompass the following: the ecological factors, the nature of abduction its surroundings, the nature of any additional systems and heuristics we might pair with abduction, and the nature of the patterns in the data, which are assumed to have a reality independent of the perceiver. Although Burton offers an interesting viewpoint on issues of control over hypothesis generation, I think that his claims are weakened by an ignorance of ecological issues.

To take these external factors that exert control over hypothesis generation, we come to the second way of approaching the problem of control, which views the control problem from the point of view of the factors surrounding the hypothesis generation, specifically the problem search space. The search space, from a realist perspective, is literally the space of all available hypotheses explaining patterns isolated from a set of data. Looking at the issue of control via the problem-space model, trouble is quickly apparent, "It is well within bounds to reckon that there are a billion…hypothesis that a fantastic being might guess would account for any given phenomena…" (Vol. 7.38, Peirce, 1931). This is equivalent to saying that possible hypotheses are infinite in nature. A hypothesis search through an infinite number of hypotheses would require an infinite number of inferences from phenomena to hypothesis, assuming that we have correctly isolated the phenomena in the first place (Simon, 1977). A scientist would have to check each and every accounted hypothesis against the data (Simon, 1977). This explosion of possible hypothesis is known as the combinatorial explosion.

The combinatorial explosion is, indirectly, another reason why there must be some rational logic behind the inferential procedures of discovery. Peirce (1931) notes, "…it suffices to show that according to the doctrines of chance it would be practically impossible for any being, by pure chance, to guess the cause of any phenomena…" (Vol. 7.38,). In this way, Popper and Hempel are both wrong in assuming the good hypothesis thus arises via chance. Lawson's (2002, 2000) construal of hypothesis generation as an unconscious analogical process is closer to the truth, but still not a rational portrayal of discovery. A rational process is what makes choosing the right hypothesis out of an infinite set seem at all possible.

Ironically, the issues mentioned earlier in critique of hypothetico-deductive theory, are relevant here, specifically the problem of affirming the consequent. The concept of combinatorial explosion suggests that a large number of alternate hypotheses can be generated to explain any phenomena. Furthermore, theories are almost always underdetermined by observational data (Rosenberg, 2000). Thus, it is hard to understand how a theory is supposed to match the phenomena it was abduced to explain. This is the danger of affirming the consequent, theories affirming a hypothesis that is not only unsupportable by the data but a confirmation of any other statement we choose to link to it (Rorer, 1991). When considering either hypothesis generation or hypothesis confirmation, we are not attaining truth. Our attempts to understand reality are analogous to making maps, not creating mirrors. In this sense, science attempts for approximate truth (Hooker, 1987). It is not rational to expect abduction to produce truth. Thus, a further revision of Peirce might include the annotation that the hypothesis generated by abduction is not 'true' in any literal sense, but rather deserving of further attention (Haig, 2003).

Returning to the problem at hand, how do we control the explosion of alternate hypothesis? The answer re-affirms three things. Firstly, Peirce's conception of abduction is a step in the right direction, but is too limited to control the enormous number of alternative hypothesis. Thus, our previous adaptation of the abductive inference is again useful, this time to control the combinatorial explosion. The second thing confirmed by control of the hypothesis explosion is that abduction needs to be linked with further heuristic principles independent of its revised structure. Peirce suggested several principles governing the initial discovery of hypothesis (see Figure 18 below). The last thing suggested by this issue, re-affirms our differentiation between abductive method and abductive inference. Inference is not enough, as a greater conceptual framework is required to organize the various heuristics and adaptations that enrich inference. This greater conceptual framework is abductive method.

Figure 18: Heuristics governing hypothesis generation

Economical Considerations
Cheapness
Intrinsic Value (Naturalness and Likelihood)

Relation of Hypothesis
Caution
Breadth
Incomplexity (Simplicity)

(Extracted from Vol. 7.224, Peirce, 1931, p. 146)

To explore some of the extra heuristics relevant to controlling the hypothesis explosion, consider explanatory breadth. Peirce (1931) notes, "For when we break the hypothesis into elementary parts, we may, and should inquire how far the same explanation accounts for the same phenomenon when it appears in other subjects" (Vol. 7.221, p. 142). Put another way, a hypothesis that explains more than its rival hypothesis has a better chance of being the abduced explanation. Usually, this applies to a hypothesis within a discipline that can explain a range of facts. In another location Peirce discusses the concept of simplicity. Simplicity is personified in the concept of Occam's razor; a simple explanation has more power than a complex explanation (Peirce, 1931). This does not dogmatically imply that explanations have to be simplistic. In some cases, a more complex explanation is suited to the situation (Peirce, 1931). In some cases it is easy to disconfirm simple generalizations or simple explanations, it is difficult to make objects such as feathers obey Galileo's law of falling bodies, as this law applies only in an ideal sense (a perfect vacuum)(Simon, 1977).

Rather, we must add additional stipulations to our original theory to understand the behaviour of a feather in less than ideal conditions. Kepler's move from the simplistic circle to the complex ellipse involves an increase in complexity and would seem to defeat the whole concept of simplicity (Kleiner, 1993). In this sense, the concept of simplicity is rather vague and undefined (Kleiner, 1993). However, consider the relation between planetary orbits and a circular hypothesis. A circular hypothesis requires a number of ad-hoc adaptations, in order to explain the motion of planets. Conversely, an elliptical hypothesis although initially more complex in nature, explains the motion of planets in a more complete and simple manner. In a sense, the heuristic of simplicity suggests that explanations should not be unnecessarily complex in the context of their explanation. These heuristics are just one of the ways to actively and rationally control the combinatorial explosion. Other methods of control include experimental controls, experimental planning, and statistical techniques, especially exploratory statistics.

Exploratory Data Analysis

Possibly the most obvious aspect of control over abduction comes from the methods used to explore the data. Certain quantitative statistical approaches to data analysis fit perfectly into the larger abductive methodological framework, specific among them, exploratory data analysis. At its core, "Exploratory data analysis is detective work – numerical detective work – or counting detective work – or graphical detective work" (Tukey, 1977, p. 1). However, this does not give free reign to idle speculation. "It is true that EDA does not require a pre-determined hypothesis to be tested, but it doesn't justify the absence of research questions or ill-defined variables" (Yu, 2003b). This is where the previously outlined research problem comes into use. EDA also has its own purpose in an abductive framework. EDA is "…quantitative analysis [that] allows parsimonious descriptions of the structure of the world in precise numerical terms that can provide rich descriptions of the phenomena of interest" (Behrens & Smith, 1996, p. 950). At its core, EDA is diametrically opposed to hypothesis testing; EDA seeks hypothesis generation and model construction (Behrens & Smith, 1996).

Velleman and Hoaglin (1981, Cited in Yu, 2003b) pinpoint four aspects of data analysis that best encompass exploratory data analytic methods: data visualization, residual analysis, data transformation, and resistance procedures. These statistical techniques are not just number crunching but an approach to scrutinizing the patterns in data that characterize phenomena (Yu, 2003a). EDA is the inevitable first step in data analysis, "Exploratory data analysis can never be the whole story, but nothing else can serve as the foundation stone – as the first step" (Tukey, 1977). . Based on this conception of EDA, it is clear that the abductive inference and EDA fit together brilliantly. Yu (2003a) goes so far as to suggest that, "Abduction, the logic suggested by Peirce, can be viewed as a logic of exploratory data analysis" On the contrary, Haig (2004, Personal communication) suggests that EDA describes patterns in data, whereas abduction explains them. I take the middle ground and suggest that

EDA offers statistics that control the extraction of patterns from data, which grants indirect control over the explanations used to explain the data patterns. Thus, EDA provides the object of explanation. However, I agree with Haig that EDA is not abductivly logical, as its influence on the explanation is only circuitous, yet this indirect influence is part of the global effort to control the end-result: the explanation.

Issue four: Abduction: logic of discovery or confirmation?

So far, we have discussed abductions ability to systematize hypothesis generation and discovery, and clarified aspects of control relating to this generation. Up to this point abduction has been characterised specifically as a logic of discovery, while hypothetico-deductive method has been characterized as hypothesis corroboration. From Peirce's writings, it is not clear how far abduction was to extend. In one passage Peirce (1931) comments, "Hypothesis [abduction] is where we find some very curious circumstance, which would be explained by the supposition that it was a case of a certain general rule and thereupon adopt that supposition" (Vol. 2.624, p. 375).

This implies that abduction not only generates hypotheses but also confirms them. In another passage, Peirce (1931) notes, "abduction…furnishes the reasoner with the problematic theory which induction verifies…" (Vol. 2.776, p. 497). This second passage suggests that abduction is specific to hypothesis generation and that induction is what verifies hypothesis once generated. There are a range of views on this apparent inconsistency in Peirce's writings. One side of this argument suggests that abduction is specific to hypothesis generation (Yu & Behrens, 2003). In this view, abduction is responsible for generating the hypothesis that induction verifies (Peirce, 1931, ; Yu & Behrens, 2003). This type of generative abduction has been the focus of previous discussion.

<u>Abduction as hypothesis evaluation</u>

At the other extreme, abduction is an inference designed to confirm or infer which of the generated hypothesis is best. This is a radical departure from discussions of generative abduction. Construing abduction as hypothesis confirmation is synonymous with the concept known as inference to the best explanation (IBE), "The inference to the best explanation' corresponds approximately to what others have called 'abduction'" (Harman, 1965, p. 88). Inference to the best explanation (IBE) is a method of assigning plausibility to generated hypothesis. It is a type of confirmation, "one infers, from the premise that a given hypothesis would provide a 'better' explanation for the evidence than would any other hypothesis"(Harman, 1965, p. 89). This variant on generative abduction has its own form of inference, See Figure 20.

Figure 19: Inference to the best explanation

P is detected,
H1 explains P,
Out of H1, H2, H3...H∞, H1 explains P better than the rest,
Therefore, approximately H1

<u>Abduction as a generative-evaluative inference</u>

The intermediate position between abduction as a confirmatory procedure (IBE) and abduction as hypothesis generation is a third alternative. The middle position between generation and confirmation interprets abduction as a generative-confirmatory inference (See, Figure 20, below). Abduction is clearly a method of hypothesis generation, "Abduction seeks a theory..." (Vol. 7.217, Peirce, 1931, p. 136). Yet, it is obvious that many of the criteria used to control the generation of hypothesis (simplicity and consilience) are also used as a method to corroborate abduced theory (Burton, 2000). Maintaining a sharp break between hypothesis generation, evaluation, and confirmation may lead to, "uninteresting and useless hypothesis" (Magnani, 2001, p. 26). Remember that hypothesis generation can lead to a combinatorial explosion of possible hypothesis. This is a problem that we have already considered, noting that a pure Peircian abductive inference needs to be paired with additional heuristics to combat the endless permutations of possible explanations.

Figure 20: IBE incorporated with Revised Abduction

1. Phenomenon (P) is detected
2. Via Auxiliary knowledge (A), Problem constraint (Ps), Phenomena constraint (Pc):
3. Possible hypothesis (H) is obtained *
4. Assuming H is possibly true, H explains P
4.1 (IBE). Out of H1, H2, H3...H∞, H1 explains P better than the rest,
5. Therefore, based on H is worth further consideration.

Josephson (1994) takes this a step further, suggesting that abduction needs to encompass the entire process generation and acceptance, "We take abduction to include the whole process of generation, criticism, and possible acceptance of explanatory hypotheses" (p. 8). In this way, abduction is capable of developing hypothesis by weeding out the many alternate hypotheses available to explain a phenomenon. Furthermore, mixing generation and criticism, and having a rational account of both, would also seem to follow a balanced account of problem solving in science (Magnani, 2001). Thus, the middle ground may be the strongest: abduction has a generative-evaluative inference.

Peirce's few cryptic comments on hypothesis confirmation are not enough to offer a theory of abductive theory confirmation. However, recall Peirce's examples of initial heuristics governing theory generation (See, Figure 18: Heuristics governing hypothesis generation, pg 63). This time, in the context of theory confirmation, Thagard takes the concept of explanatory breadth further using the term 'consilience' (Thagard, 1978). "Consilience is intended to serve as a measure of how much a theory explains…"(Thagard, 1978, p. 79). Specifically, theories with high consilience (or explanatory breadth) explain several classes of facts within a discipline. Consilience is not explaining a thousand unnecessary and pointless facts, but explaining a variety different classes of facts (Thagard, 1978).

Beyond consilience, Thagard (1978, ; 1992) forms the protean ideas present in IBE into a well-developed Theory of Explanatory Coherence, including simplicity and analogy along with explanatory breadth. Furthermore, TEC contains seven principles that govern the parameters used to guide decisions of explanatory coherence, symmetry, explanation, analogy, data priority, contradiction, competition, and acceptability (Thagard, 1992).These principles instantiate the macro criteria of explanatory coherence. This type of hypothesis confirmation is markedly different to the statistical-predictive hypothesis confirmation offered by NHST/HD. In common terms, explanatory coherence is an evaluation of the explanatory relations between a set of propositions that comprise a theory (Thagard, 1992).

Explanation and the other principles are brought to life in a connectionist program known as ECHO (Thagard, 1992). ECHO is a parallel processing program designed to generate an overall measure of coherence between the hypotheses of competing theories. The hypotheses generated by theories are tested against data propositions that each theory seeks to explain. Via a connectionist excitory/inhibitory activation network and across the seven principles of coherence, the program decides which theories cohere. Obviously, the hypothesis that best explains the data is simpler, has greater explanatory breadth and is activated based on analogy, whereas hypothesis that fail to cohere are inhibited. The theory with the most hypotheses activated is construed as the 'best' theory. I have tested an example of ECHO instantiated in Java, and despite being an evaluative version; I could see that aspects of ECHO have the potential to be embedded in a more user friendly and adaptable software system.

Luckily, such a system already exists, developed by Patricia Schank. Schank offers a more user friendly, alternative conception of TEC and ECHO in the form of a program known as ConvinceME. ConvinceME is a structured replication of ECHO that allows participants to organize hypothesis via their excitory and inhibitory links, making their own assessments of belief and then having ECHO assess coherence, "Convince Me functions as a "reasoner's workbench" (Ranney, in press cited in, Ranney & Schank, 1995). "Our empirical findings reinforce the utility of Convince Me as a research tool with which people can progressively represent and evaluate more globally coherent bodies of information" (Ranney & Schank, 1995).

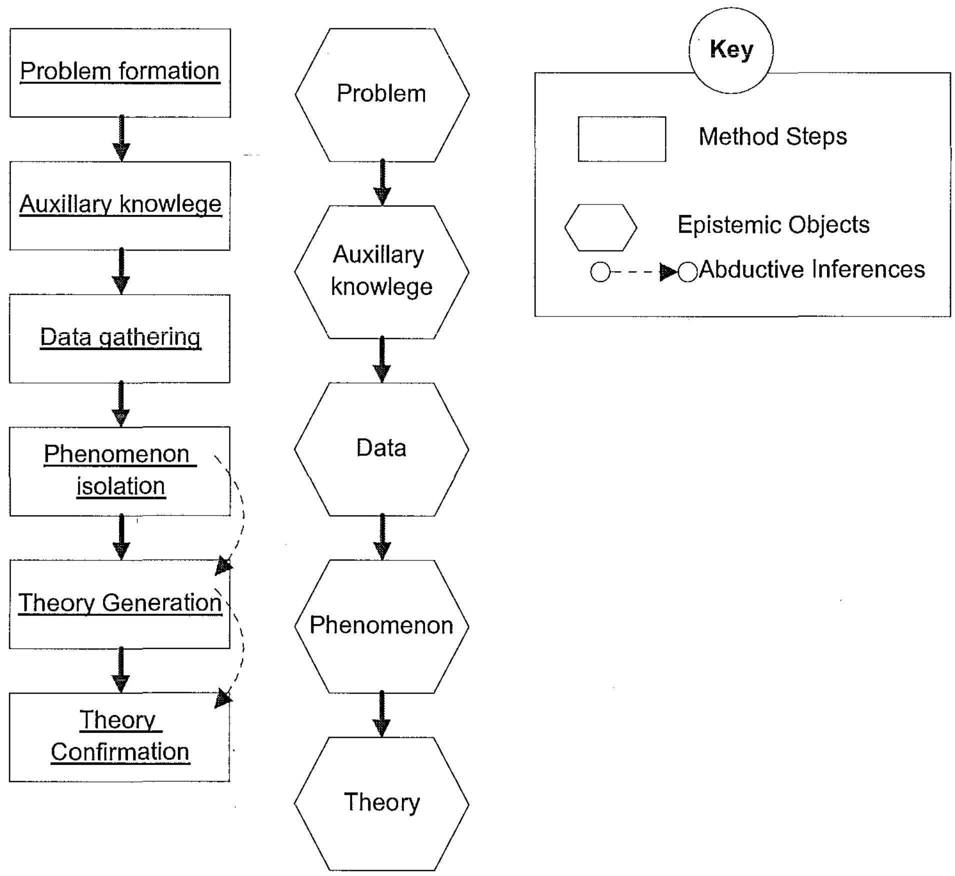
Abductive method

The issues discussed so far have outlined several observations about abduction. Firstly, the abductive inference is flexible in its application, indicating a strong adaptive ability (Meheus, 1999). This does not imply that there is no rationality to discovery, rather that the abductive inference supports discovery and is not deductive (Meheus, 1999). Secondly, the issues explored so far have outlined the very real necessity of something beyond local inferences. In essence, no inference stands on its own. Inferences are not isolated structures, but are parts of greater methodological practice, which includes an overall method structure; heuristics, and statistics.

The discussions throughout this chapter have covered all these important components. We have discussed the important constraints on generating hypothesis, auxiliary knowledge, problem formation, and phenomenon isolation. These constraints will be a clear part of an expanded conception of abductive method. The heuristics for control will be part of an extended part of abductive theory generation.

Exploratory statistics will be part of phenomenon isolation. Taken together, these techniques for an expanded, revised, and sophisticated conception of abductive method, like Figure 21, below

Figure 21: Revised abductive method



Summary of Chapter two

In summary, we have introduced the concept of abduction, and its separate history from deductive logics. We have adopted a modern conception of logic, which allows for the inclusion of non-deductive inferences, heuristics, and problem solving models. We have discussed several issues with the pure Peircian form of abduction, and have made several alterations and changes. Firstly, we have differentiated psychological explanations of discovery from logical and systemized characterizations of discovery, and have suggested that abduction is a systematic and rational account of discovery if not classically logical. Secondly, we have refuted the claim that discovery is mystical, suggesting that it is a rational process. Thirdly, we have differentiated the reasons for generating a hypothesis from reasons for supporting it. Fourthly, we have discussed issues surrounding the actual generation of the hypothesis by the abductive inference and have adapted Peirce's original conception of abduction to include; the research problem, phenomena constraints, and auxiliary knowledge. This is a move from a simple inference to a complex constraint based generative inference.

Fifthly, we have discussed the lack of control over initial hypothesis generation and have offered control heuristics and exploratory data analysis as additions to abduction. We have also enhanced control by blurring the strict definitions between hypothesis generation and hypothesis evaluation, construing the abductive inference as a generative-evaluative cycle. Lastly, I have come full circle by describing how each of our revisions fits into a better conception of abductive method. I propose that the revised conception of abductive method will provide a crucial component of our proposed real world problem solving framework.

Chapter 3: Ergonomics

In the first chapter of this thesis, I explored the hypothetico-deductive method, a methodological framework currently active in psychology. In the second chapter, I explored a replacement framework known as abduction. I explained how abduction encourages and supports the transition from data to and phenomena to theory, making it an excellent conceptual framework for both science and innovation. Recall that the intention of this thesis is to develop a systematic real world problem solving framework drawing from both abduction and ergonomics. Thus, in light of my aim, this chapter is the final basis for my proposed real-world problem-solving framework. This chapter focuses on the second half of our intended problem solving components by exploring the aims, perspectives, and unit of analysis offered by ergonomics. The structure of this chapter is as follows: I will review the history and aims of ergonomics, the relation between basic research and design, the perspectives behind modern ergonomics, and finally the integrated ergonomics unit of analysis.

Ergonomics

History and aims

From the outset, a historical exploration of ergonomics is hampered by an over-abundance of terminology. A brief selection of related terms would include Ergonomics, Cognitive Ergonomics, Human Performance Engineering, Human Factors Engineering, Applied Experimental Psychology, and Engineering Psychology. To offer a brief review of these various terms in historical context, Bailey (1989) suggests that the deliberate improvement of human performance extends back as far as Greece (3,500 BC), with runners and athletes deliberately planning and initiating an effortful program to improve their performance with running, javelin, and discuss. These ancient traditions are the beginning of a long history concentrating on altering the individual to suit the machine (Bailey, 1989).

First credit for the term 'ergonomy' goes to Professor Wojciech Jastrzebowski, who published a short series of articles on the science of labour in the late 1800s (Cornell, 2003, ; Marshall, 2003). Later, in 1949, Hywel Murrell coined the term 'ergonomics', during the formation of the Ergonomics Research Society in Britain (Marshall, 2003). The term ergonomics is a fusion of Greek roots, ergon =

'work', and nomos = 'natural law' which combine as the 'natural laws of work' (Cornell, 2003). The increased interest in human-machine interaction included a strong shift toward the redesign of equipment to suit the person, opposite to the ancient goals of human performance engineering. Alongside the official definition of the word 'ergonomics,' ergonomics work was boosted by World War II which spawned an intense focus on the interaction of humans and machines, specifically the use of aircraft, tanks and other military hardware (Meister, 1989).

Work before World War II (and even before World War I) was characterized by a strong trend of human performance engineering, a trend known as 'Taylorism', based on research by F.W. Taylor (Taylor, 1919). For example, via the alteration of miner performance (selection, training, and shift scheduling) Taylor was able to increase miner tonnage output from twelve tonnes to forty tonnes (Meister, 1989). Later, the famous Frank Gilbreth, made Tayloristic methods famous in his 'Cheaper by the Dozen' time and motion studies (Meister, 1989). Classic human performance engineering concentrates on the adaptation of human behaviour to increase performance. If performance constitutes the actions we carry out to satisfy a goal, and behaviour is the set of actions that make up performance, adapting human performance involves adapting goal directed human behaviour (Bailey, 1989). For example, a task-orientated view of writing my name involves Searching (my pocket), Finding (my pen), Removing (cap), Replacing (cap on base), Moving (to paper), Positioning (on paper), Using (to write name) (Bailey, 1989). How many of these actions are necessary, what actions can be adapted, and what parts of the sequence can be reorganized to decrease the behaviours required and increase performance times? These are the questions asked by an human performance engineer (Bailey, 1989).

Work carried out during World War II helped encourage the shift away from strictly physical ergonomics to psychological ergonomics, as well as the shift away from altering human performance towards altering the machine to suit human abilities and limitations (Meister, 1989). Physical ergonomics is the familiar side to ergonomics work, concerned with the fit between human physiology and device. For most people the word ergonomics implies the redesign of office chairs and mouse-pads. Conversely, psychological ergonomics concerns the fit between human psychology and the machine. Work during WWII tended towards psychological ergonomics, focused on studies of sensation-perception, signal detection, and the impact of social psychology on the use of complex technology (Nickerson, 1999a).The new machine-centric and psychological-centric trends of WWII did not ignore human performance, but placed the adaptation of the machine in primacy to offloading the work requirements onto the human.

Great ergonomists like Fitts and Chapanis owed their origin to WWII, as army research grants placed an ever increasing focus on how the design of military machinery affected human performance (Nickerson, 1999a). The Tayloristic principles made famous by Taylor and Gilbreth could not explain why military personal with the appropriate skills (selected via psychometric selection) were still producing erroneous performance, and having accidents when using complex machinery (Nickerson, 1999a). Tayloristic methods, although they are effective in many cases, have the downside of increasing routine-fatigue and decreasing worker satisfaction (Nickerson, 1999a). Offloading the work requirements onto the human component of the system may extend human performance beyond safe and healthy human capacities.

In the first human factors text book, Chapanis, Garner and Morgan (1949) describe experiments by Fitts and Jenkins during WWII. Their work was one of the first efforts to systematically focus on how the design of the machine affected human performance. Instead of automatically blaming mistakes on pilot error, researchers found that the largest source of error stemmed from control confusion, "mistakenly operating one control when another was the correct one" (Chapanis et al., 1949, p. 299). The introduction of shaped textured and coloured controls made it possible for pilots to differentiate between controls placed near each other spatially, but controlling different and often contradictory components of the aircraft (e.g. throttle and wheels). Fitts and Jenkins found that the regular use of shape, texture and colour lessens errors across aircraft when the same controls are placed in different locations (Chapanis et al., 1949).

Later work by Franklin N. Taylor (Taylor, 1957) created a distinction between engineering psychology and mainstream psychology, differentiating real world problem solving further. Although psychology was responsible for spawning engineering psychology, Taylor (1957) felt that good psychology did not necessarily equate to good engineering psychology. This urge to separate engineering psychology from psychology did not presume that the two disciplines had nothing to offer each other, rather that each discipline required its own language and way of approaching problems (Taylor, 1957). Based on this shared origin with psychology, engineering psychology takes its definition as, "bringing psychological knowledge…to bear on the design of devices…" (Nickerson, 1999a, p. 3). Taylor's work was crucial in continuing to explore how psychological knowledge would aid the design of equipment and the enhancement of human performance, health and safety, "Because of…'human errors'…psychologists were asked to help the engineers produce machines which required less of the man and which, at the same time, exploited his special abilities" (Taylor, 1957, p. 249).

Developed alongside engineering psychology, the field of human factors focuses on the application of the scientific results gained by engineering psychology (Sanders & McCormick, 1993). Expressed another way, human factors seeks to apply psychological knowledge to the redesign of equipment with the aim of solving real world problems. Meister (1989) defines human factors as, "the study of how humans accomplish work-related tasks in the context of human-machine system operation, and how behavioural and non-behavioural variables affect that accomplishment" (p. 2). On the other hand, engineering psychology seeks to scientifically understand and explore psychological knowledge in relation to the use of equipment. The contrast between human factors and engineering psychology is similar to the differentiation between science and design with engineering psychology as the bridge between problem-focused human factors and explanation-discovering scientific psychology (Wickens et al., 1998).

To add another layer to this multitude of definitions, applied experimental psychology is another independently defined discipline, defined separately from engineering psychology, human factors, and ergonomics. Applied experimental psychology seeks to, "…begin with a practical problem, and design experimentation for the express purpose of addressing that problem…" (Nickerson, 1998, p. 2). Nickerson (1998) suggests that human factors and applied experimental psychology overlap, but neither subsumes the other. In yet another layer, the term ergonomics makes its resurgence in the form of cognitive ergonomics. Cognitive ergonomics focuses on the information flows in or around human-machine interaction. More importantly, cognitive ergonomics shifts focus from work domains towards human-artefact interaction in general. Like the trends away from physical ergonomics, cognitive ergonomics are part of the ever increasing focus with cognition (Nickerson, 1999a). Human-artefact interaction is a diverse area, whether piloting an aircraft, driving a car, playing golf, studying in a classroom, or reading a book.

It is possible that the various paradigms mentioned so far defy a unified description in a way that both their relation to each other and their own responsibilities are clear (Nickerson, 2000). However, Vitalis, Walker, and Legg (2001) note that there is a stability to the definitions offered over 30 years by the International Ergonomics Association; with a continued emphasis on the safety, efficiency and health of humans in their environments. Unfortunately, these trends look set to change as potentially dangerous currents bring up a resurgence of human performance engineering. Rather than changing the job or machine to lessen the stress of the worker, a new current in ergonomics and human factors concentrates on job training, with the intention of training workers to handle larger stress loads (Vitalis et al., 2001). Granted, no matter how artifact-centric we construe ergonomics to be, there is some necessity for training when bettering the fit between human and artifact. However, this training does not extend to increasing human workload beyond the region of safety and health.

The current definition of ergonomics by the International Ergonomics Association (IEA) highlights a global focus. The IEA (2000) defines ergonomics as "…the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance…" In Europe, the terms ergonomics is both popular and broad in its use, the term has been expanded to include engineering psychology and human factors (Nickerson, 1999a). Based on this and the definition posed above, I suggest that a blanket construal of human-factors, ergonomics, engineering psychology etc, is possible, and will use the term 'ergonomics' to encompass the range of possible terms associated with real world problem solving.

Using the term ergonomics, I propose that the IEA offers an apt viewpoint on what modern ergonomics/human factors/engineering psychology aims to achieve. Quite literally ergonomics is the discipline aimed at improving the fit between people and technology, designing systems and artifacts to appropriately match human limits (Nickerson, 1999a). This definition implicitly commits to supporting human abilities by altering the machine. The human is the reason that that system exists, and human health, safety and happiness is what motivates system efficiency (Nickerson, 1999a). My brief review of the history of ergonomics indicated how it is not acceptable to offload work requirements onto the human when it is possible to alter the machine to suit the human worker. Humans and machines accomplish less than what they accomplish as a system. When there is a breakdown in the interaction between humans and technology the result is either catastrophe on a grand scale, or a long list of more minor frustrations, stressors, and inefficiencies.

Basic, applied and applicable research

Ergonomics is a hybrid discipline that subsumes psychological work. However, ergonomics is different to psychology via its social commitment to increasing the fit between humans and their systems. Granted, modern ergonomics shares a strong history with research psychology, so much so that the field of human factors is often parsed into research and practitioner domains (Meister, 1989). This division accompanies a deep and ongoing negative assumption that curiosity based research and basic theoretical work are somehow more superior and fundamental than applied work and practice (Meister, 1989). There are actually three varieties of research: basic, applicable, and applied (Owen, 2001, Personal Communication). Current psychological research is often curiosity driven, knowledge for knowledge's sake. This sort of scientific research links to the philosophies of standard empiricism. The ideas behind empiricism reach back into Platonic philosophy and the idealistic search form pure truth devoid of values (Maxwell, 1984). These philosophies intertwine with requirements of experimental isolation, abandonment of values, feelings, desires, and needs (Maxwell, 1984). This pervading approach is known as the philosophy of knowledge, the philosophy of gathering knowledge independent of its impact (Maxwell, 1984). Applicable and applied research stems from an underlying need to apply research to real world problems (Friedman, 2003).

It is difficult to clearly define a distinction between basic, applicable and applied research. In some cases, basic research can occur in the field and applied research can occur in the lab. In other situations, basic research is general and applied research is specific. On the other hand, applied research can sometimes be general. The previous chapter indicated that basic research focuses on gaining a general understanding of a paradigm via the isolation, prediction, and explanation of phenomenon. Usually, applied work involves, "dealing with 'natural' situations with the aim of acting upon them" (Hoc, 2001, p. 282). The validity relevant to applied work and in many cases, the validity that should be relevant to basic research, is ecological validity. Ecological validity is defined as the relation of research findings to the context or natural situation from which the research originated (Hoc, 2001).

It can be easier to understand ecological validity from the obligation of solving real world problems versus the requirements of basic research. On one hand, basic research, is concerned with the relation of experimental conclusions relative to the available experimental data, this is also known as internal validity (Hoc, 2001). In some cases basic research may also extend into aspects of external validity, but this is confined to provide covering laws and generalized theories. Finding a general theory to a paradigm is often an ideal goal (Hoc, 2001). In contrast, applied and applicable work is more interested in context, how much fidelity a research paradigm, phenomenon, and theory has with its target real world problem. In this way applied work sometimes limits generalization to the problem at hand or class of problems.

This difference in validity requirements between basic and applied research can lead to a differentiation between the levels of basic understanding and applied operation. For example, the theories explaining the interior thermodynamics of a blast furnace are still vague and incomplete, despite a 2000 year history of blast furnace use (Hoc, 2001). This might suggest that many of our basic theories will always fare badly in real world settings. This is not the case, as utilizing an interdisciplinary approach to real world problems suggests that can work from both a top-down (from technology and real world application towards science) and bottom-up approach (from basic science explanation to technology) depending on the cost and availability of understanding and applicability from each perspective. In many cases, complex field studies can be replicated in the lab with good ecological validity, and excellent fieldwork can appear difficult to apply. Negatively, lab work can strip all the meaning out of situation and make it impossible to use any of the research in terms of real world intervention, it all depends on how ecologically valid the research.

Gibson (1967/1982) once observed, "...when a science does not usefully apply to practical problems there is something seriously wrong with the theory of the science" (p. 18). In this way the validities and controls relevant to basic research exist in tension with ecological validity. Moving research out into the real world lessens the amount of control over the experimental paradigm and in turn lessens the linkage between data and theory. Sacrificing internal validity and control will increase ecological validity (Hoc, 2001). However, to increase the control by moving an experiment back into the lab will sacrifice the all-important ecological validity. The key to ecologically valid work is involves employing methods that support the simulation, modelling, or replication of the reference situation (the real world situation) while preserving control. To achieve this, we must make basic research applicable. This means that basic research can no longer be ecologically insensitive. It means that there is a responsibility to make the research paradigm and research findings applicable. Many psychological constructs and experiments exist only in the laboratory, with little relationship to the reference situation. To combat this problem, we must ask the crucial question, "how might lab research become more ecologically valid" (Dean Owen, 2003, Personal Communication).

Fusing Science and design

Ultimately, beyond research, the act of solving a real world problem must at some point intervene with the real world, whether in the form of training, technology, laws or social structures. However, many believe that science and design can be qualitatively differentiated (Eekels & Roozenburg, 1991). In science, the problem is the relation between knowledge and reality. Reality exists, and it is up to science to manipulate our knowledge claims until they appropriately map the facts (Eekels & Roozenburg, 1991). On the other hand, design seeks to alter the facts to match values and needs (Eekels & Roozenburg, 1991). Science is focused on the 'real' world, whereas design focuses on alternate worlds.

Eekels and Roozenberg (1991) construe scientific logic as induction, with science as the process of moving from observations to a general law about a specific instance of reality. Conversely, they conceive design as moving from a general law to an instance of reality as shown in Figure 22 below.

Figure 22: Eekels and Roozenberg on Science and Design

Science (Induction)
If...P1 & Q1....P2 and Q2....P3 & Q3
Then....If P then Q

Design
Q
P
If P then Q.
(Extracted from, Eekels & Roozenburg, 1991, p. 201)

Put another way, science moves from reality back into knowledge generation, whereas design stems from mind back into reality in the form of technical action. Essentially, science attempts to, "bring about a change in the realm of the mind, by including new and improved knowledge." Engineering on the other hand, "attempts to bring about a change in the physical material world" (Eekels & Roozenburg, 1991, p. 198). Wilhelm (1990) supports the conception that science and design have two different aims. He suggests that science is an understanding of the natural world whereas, design is action imposed on one's environment with the aim of achieving a goal. "Science knowledge is part of the fabric with which the designer's design" and "Design begins with...perceiving a need and...concludes with the development of an effective means of meeting that need..." (Willem, 1990, p. 44).

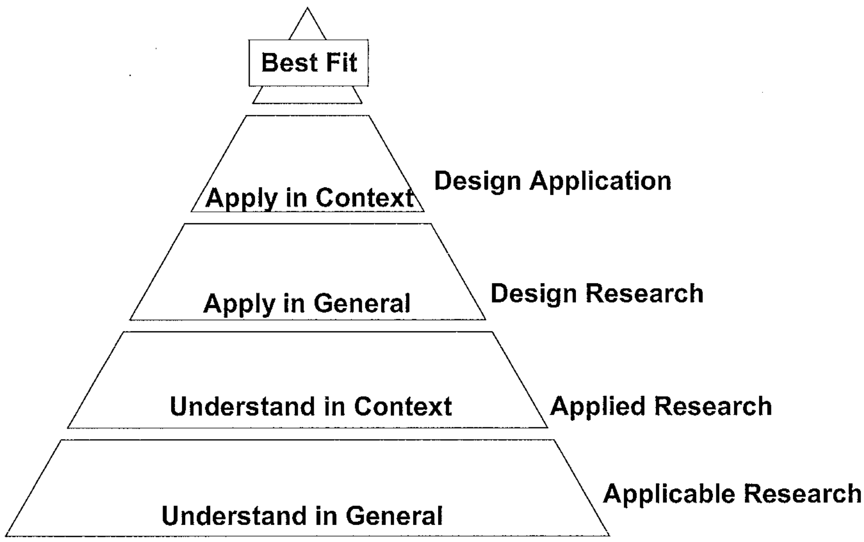
However, despite their differences, science and design also appear quite dependent. Science is the basis for design and design is the act of making science visible (Willem, 1990). Design is determined by the amount of science present, for example, increased scientific understanding about the nature of organic compounds led to better tires (Willem, 1990). Alternatively, design can move away from the science that supports it, by discovering a new field of inquiry, but this in turn opens a new field of science, which will in time lead to alternative designs (Willem, 1990). In sum, Wilhelm, Simon, Eekels, and Roozenberg all agree that science and design are dependent in some way. I propose that it is a mistake to ask, 'Are science and design related?' Instead, we will adopt a functional approach, accepting that real world problem solving will encompass both scientific and design aspects.

The differentiation between science and design may be based on a faulty premise, that there is some hard and fast difference between them (Meister, 1989). Instead, real world problem solving must encompass both the mechanistic and humanistic worldviews (Vicente, 2003). Engineering adopts a mechanistic worldview, which focuses on technological achievement, whereas the social sciences adopt a humanistic, human-science worldview, which focuses on human capabilities and human nature (Vicente, 2003). In essence, engineers defend the machine aspects, and psychologists defend the human aspects (Sanders & McCormick, 1993). However, to effectivity support real world problem solving a framework must extend from science back into design by incorporating both the mechanistic and humanistic world-views (Vicente, 2003).

Thus, despite Eekels and Roozenberg's six degrees of separation between science and design I am not totally convinced, and agree more with Meister (1989). Our approach to design differs depending on the questions we ask, we can approach design from a scientific or applied viewpoint, as the key to merging science and design is seeking to fix real world problems. The level at which the disciplines merge will depend on the limitations of knowledge constraints specific to the problem at hand as well as constraints imposed by commerce and urgency. Wilson (2000) offers an alternative definition of ergonomics, "...ergonomics is the theoretical and fundamental understanding of human behaviour and performance in purposeful interacting socio-technical systems, and the application of that understanding to design of interactions in the context of real settings" (p. 560).

Although the IEA definition is more inclusive, Wilson's definition highlights the nature of the relation between research science and practical design. Science and design are two sides of the same coin. When trying to reach for the best fit between human and their systems, science and design are best construed as a mutually supporting relationship (Rouse et al., 1997). This supporting relationship indicates that science (applied and applicable research) and design fit tightly into the larger picture of real world problem solving as shown in Figure 23 below.

Figure 23: The Fit Pyramid - fusing science and design



The work so far indicates that we should adopt a shared relationship between science/design and use the term ergonomics as an overall term to describe the ultimate aim of increasing the fit between humans and their systems. To push these ideas further I want to examine the perspectives of modern ergonomics in an effort to clarify how an incorporated view of ergonomics is possible via an integrated unit of analysis. It is an integrated unit of analysis that offers the best frame of reference for encouraging real world investigation and intervention.

The structure behind modern ergonomics

The information supporting perception

Affordances and effectivities

A language of mutuality classifies the human-environment relationship in relative terms, with the 'affordance' being one of the principal units of this structured relationship. Affordance terminology is heavily realist; affordances are not mental constructs, nor are they perceptions of the mind. They are properties of the world (a world of surfaces, objects, and mediums) taken with reference to the properties of the animal. In his most famous quote about affordances, Gibson (1979) notes, "The affordances of the environment are what it offers animals, what it provides or furnishes, either for good or ill" (p. 127). For example, relative to a human, physical objects such as chairs have certain affordances. Chairs afford sitting on, throwing, breaking, standing on, and avoiding falling from. Relative to a hedgehog, chairs afford crawling under; hedgehogs are not capable of exerting the leverage required to break a chair and thus the chair breaking affordance does not exist for the hedgehog.

Affordances are the set of act-on-able properties offered by items in the environment, in reference to the human (Gibson, 1979). This is a functional description of the human-environment relation, parsing the actor-environment system in terms of possible actions. Quite literally, the root of "affordance" is the transitive verb 'afford', which is defined as, "to make available" (Merriam-Webster, 2003). Unfortunately, Gibson's use of the term 'affordance' seems to imply that affordances are nouns, suggesting that affordances are physical objects rather than opportunities for action (Flach & Smith, 2000). Gibson created the word 'affordance' from the verb 'afford,' which would have been an excellent word to emphasise the dynamic relation between objects and actors (Flach & Smith, 2000). Flach and Smith (2000) note, "[when] reifying this abstract relation with the noun affordance...It is not long before researchers begin searching to localize this concrete substance..." (p. 44). Correctly speaking, affordances are both the possible opportunities for action and action's possible consequences. We see how we can act, but also what will happen when we act.

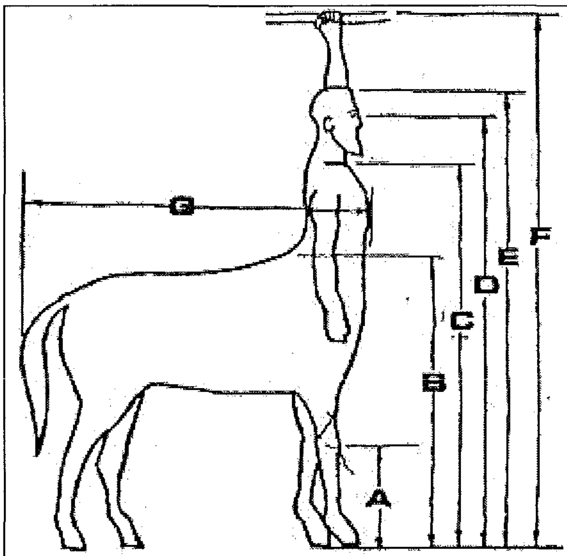
Affordances arise from more than the perceiver's interaction with inanimate objects. People offer us, "the richest and most elaborate affordances of the environment..."(Gibson, 1979, p. 135). People are detached objects with reflecting surfaces, people release and admit substances, and people emit sounds (Gibson, 1979). Locomotive activities, specified via optical patterns in the light medium offer perceivers information concerning other humans. Slow leaden movements of the limbs may indicate depression or weakness (Koffka, 1936). To a perceiver, this information directly indicates whether the target affords attacking or cuddling, depending on the intention of the perceiver and the properties of their target. Conversely, fast, turbulent motions may indicate avoidance or excited participation, depending on the perceiver's intentions.

Human-based affordances are especially complex because deceitful humans may broadcast false information, leading us to perceive affordances that do not lead to the consequences we anticipated. After all, affordances are opportunities to act, but they do not force action, nor do affordances force perception (Gibson, 1977). Affordances exist whether we perceive them or not. An external observer can provide us with a list of affordances relevant to us, even if we do not perceive them. Furthermore, all affordances, including those offered by both animate and inanimate objects can be misperceived. We can fail to perceive both the affordance and the consequence, or perceive the affordance but misperceive the consequence. In each case, our actions can result in different errors. For example, if I perceive an affordance but misperceive its consequence, depending on the object, I might offend someone with an inappropriate action, or fail to use an object properly and hurt myself.

The key to understanding affordances comes when we realize that affordances are inseparable from the organism to which they apply; they are a referential term. Objects in the environment support actions in conjunction with the nature of the perceiver. The set of affordances available to us is our ecological niche (Gibson, 1979). More importantly, affordances offer both positive and negative consequences. For example, a cliff is simultaneously climb-on-able or fall-off-able (Gibson, 1977). Two of these activities are within 'safe boundaries of action' whereas the third action (falling from a cliff) is a consequence afforded by the cliff that results in harm to the actor. Gibson called affordances leading to undesirable consequences 'negative affordances.' Part of the subtlety of perception involves correctly perceiving an affordance as a positive or negative affordance by correctly perceiving its consequence.

Affordances are not the only units quantifying the human-environment relation. The perceiver has his or her own perspective on the shared person-environment relation since people have effectivities. Effectivities are our abilities, our ways of being effective (Shaw, 2001). I have long arms, forward facing vision, and a low hip structure; these are some of my effectivity properties. My effectivities combine to give me the ability to run in a bipedal manner. My effectivities allow me to make use of the affordances of flat ground and chase something while looking at it, whether it is on a comparable level spatially, or in the air. Our effectivities determine what affordances we can make use of, but not necessarily whether we will be aware of an item's possible use. Wise and Fey (1981) introduce an amusing example of how changing effectivities radically changes the affordances available. In their scenario, the imaginary creature is centaur, a mythical human-equine combination, see Figure 24, below.

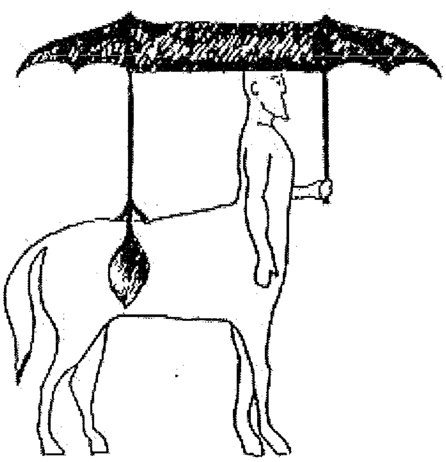
Figure 24: A Centaur



(Extracted from, Wise & Fey, 1981, p. 247)

The altered effectivity properties of a Centaur generate a different set of action possibilities from objects (e.g. from umbrellas). See Figure 25, below.

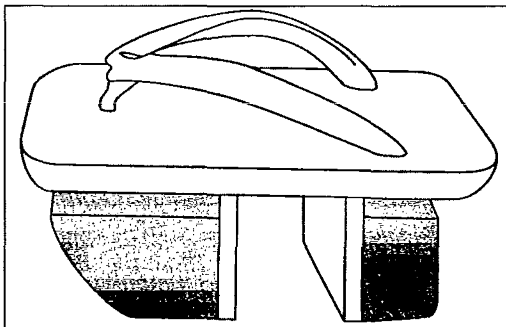
Figure 25: Using a centaur umbrella



(Extracted from, Wise & Fey, 1981, p. 249)

The interaction between human effectivity properties and the structure of a Centaur umbrella will not result in the same affordances. In pairs, humans might be able to lift and use a Centaur umbrella, but to a single human it would be too large and too awkward for use as an umbrella. Experimental evidence indicates that we are intrinsically aware of the relation between the properties of the world and our own properties, and we adapt to our various effectivities depending on our goals. Participants wearing geta (a traditional Japanese shoe show in Figure 26, below) were able to retune their performance across different locomotive tasks despite the large alteration of their effectivities (Hirose & Nishio, 2001). This reaffirms that affordances are relative to the perceiver: body-scaled and perceptually detectable.

Figure 26: A traditional Japanese shoe known as a geta



(Extracted from Hirose & Nishio, 2001, p. 54)

Adapting our effectivities with the use of artefacts or training also alters the affordances available to us. Blignaut (1979) presents a classic example where appropriate human-performance engineering increases benefit in the domain of mining. Human-performance engineering is useful, only when it is: a) possible to avoid the risk of placing undue workload on the subject, or b) fiscally or practically impossible to use a machine device to increase fit, or c) a technological artifact will not be adaptable enough to cope with the dynamics of the situation. During mining operations, nearly 50% of the mining fatalities occur due to rock-falls. Explosive rock-fall events are less avoidable as they are due to chaotic variables. However, rock-falls are avoidable because avoidance is entailed by the appropriate perception of hazard and the appropriate reaction. After isolating the appropriate environmental variables (patterns of rock-fall events and the characteristics of a dangerous rock face), Blignaut constructed an ingenious rock-face simulator. Built with real rock sections mounted on hinged plates, the simulator represented a highly realistic snapshot of the affordances present in two-thirds of a mine tunnel. Four between-experiment groups were tested: three groups of novices (warned, trained, and control) and one group of experts.

Trained novices were given specialized search pattern training, with the intention of teaching them better methods for visual hazard identification. Their search training was based on an analysis of the characteristic perceivable qualities of pre-rock fall environments. Results indicated that trained novices exhibited expert-level behaviour, performing significantly better than the other two groups of novices. This experiment pinpoints several important themes. Firstly, "Hazard perception was viewed as the obtaining...of visual information" (Blignaut, 1979, p. 998). The perception of affordances is crucial to human activity and safety and Blignaut's experiment sought to ascertain the relevant negative affordances and train perceivers to avoid them. Thus, real-world research requires the simulation of the affordances relevant to the situation. Secondly, whether we design artefacts or employ training we can enhance the fit between humans and their environments by altering our effectivity properties.

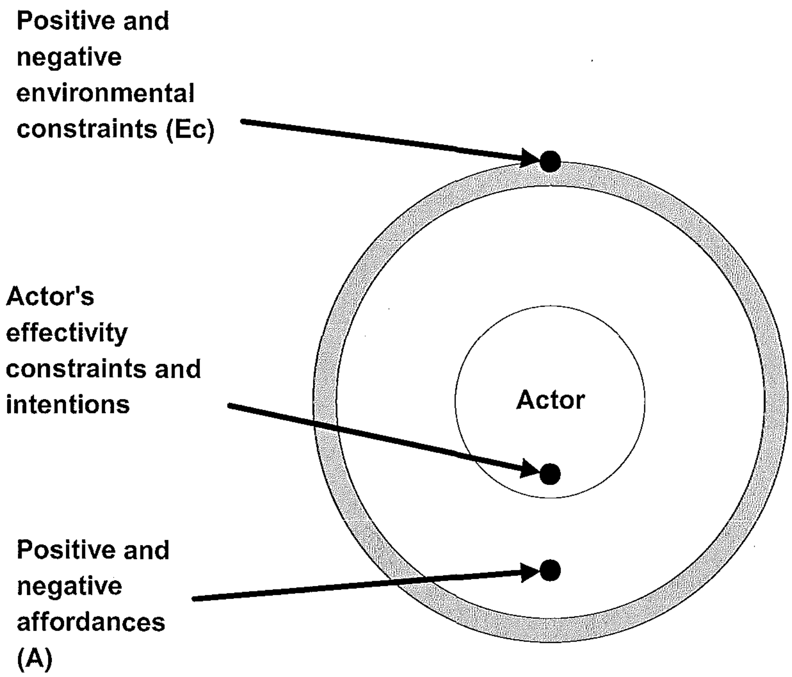
Constraints

Constraints are another layer of understanding in the mutual relationship between actors and objects. A descriptive way to understand the concept of constraints is to consider a related approach known as field theory. Simon (1996) offers an interesting field-theory parable: imagine an ant, making its way along a beach surface, towards a particle of food. The ant's behaviour (path chosen across the beach) is modelled in two ways. Firstly, we can describe the behaviour from the perspective of the cognitive activities occurring in the ant's brain and our scientific constructs used to describe ant cognition. Secondly, we can describe the ant's behaviour as a function of a relationship between the ant's properties and the properties of the terrain on the beach.

Attempting to understand the ant's path from the point of view of ant cognition is a complex endeavour. However, field-theory proposes that we can describe the complexities of behaviour via the environment that constrains the actor (Simon, 1996, ; Vicente, 1999). In this example, the troughs and dunes in the sand are environmental constraints on the ant's locomotion. The ant is likely to follow the path of least resistance, making its way across planes and beside dunes, while making directly for the food. Thus, a complex pattern of behaviour can be resolved by understanding the boundary conditions or constraints imposed on safe or efficient action (Vicente, 1999).

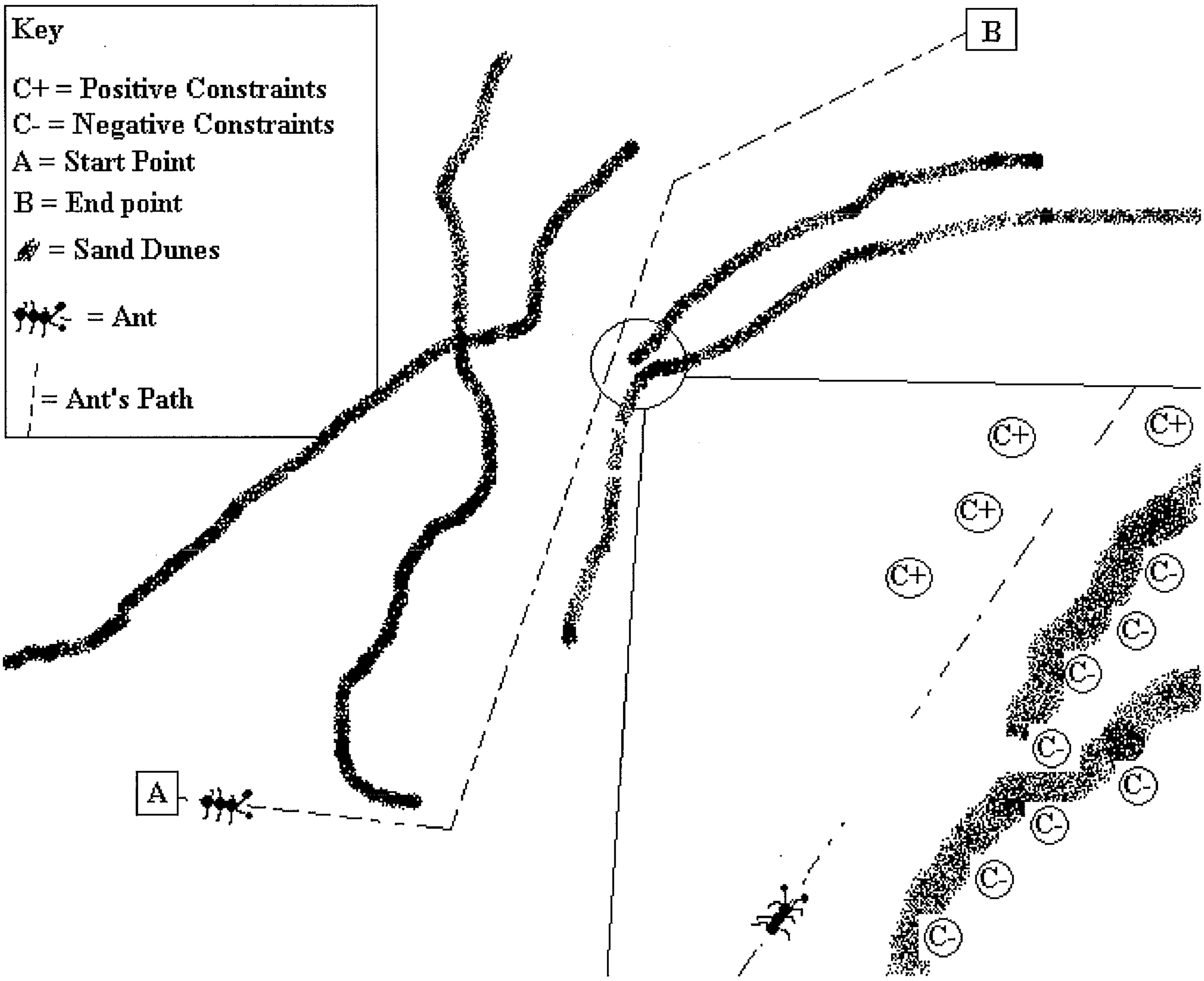
Constraints are not a one-dimensional property of objects. There are several aspects of constraints. Firstly, the environment offers constraints. Environmental constraints include all aspects of the environment surrounding the perceiver; this definition including any surrounding technology. Environmental constraints are in reference to the actor. Environmental constraints that affect an ant are not likely to affect a human. Environmental constraints are both positive and negative, relative to intentions. As intentions change, a negative constraint can become a positive constraint. For example, gravity is a negative constraint with regard to high-jumping, but a positive constraint to containing. Without gravity we could not use open ended containers. Due to gravity, liquids placed in upright containers are constrained from departing the container. Thus, positive environmental constraints are beneficial. Secondly, actors possess their own constraints: effectivity constraints. Effectivity constraints are the constraints on an individual's effectivities (ways of being effective), with reference to the realization of an affordance. For example, when interacting with a menu on a computer interface, our memory is an effectivity constraint on our realization of the menu-component-affordances offered by the interface. The concept of constraints and the concept of affordances are closely related. Put briefly, constraints set the envelope of affordances, as seen in Figure 27 below.

Figure 27: Affordances and Constraints



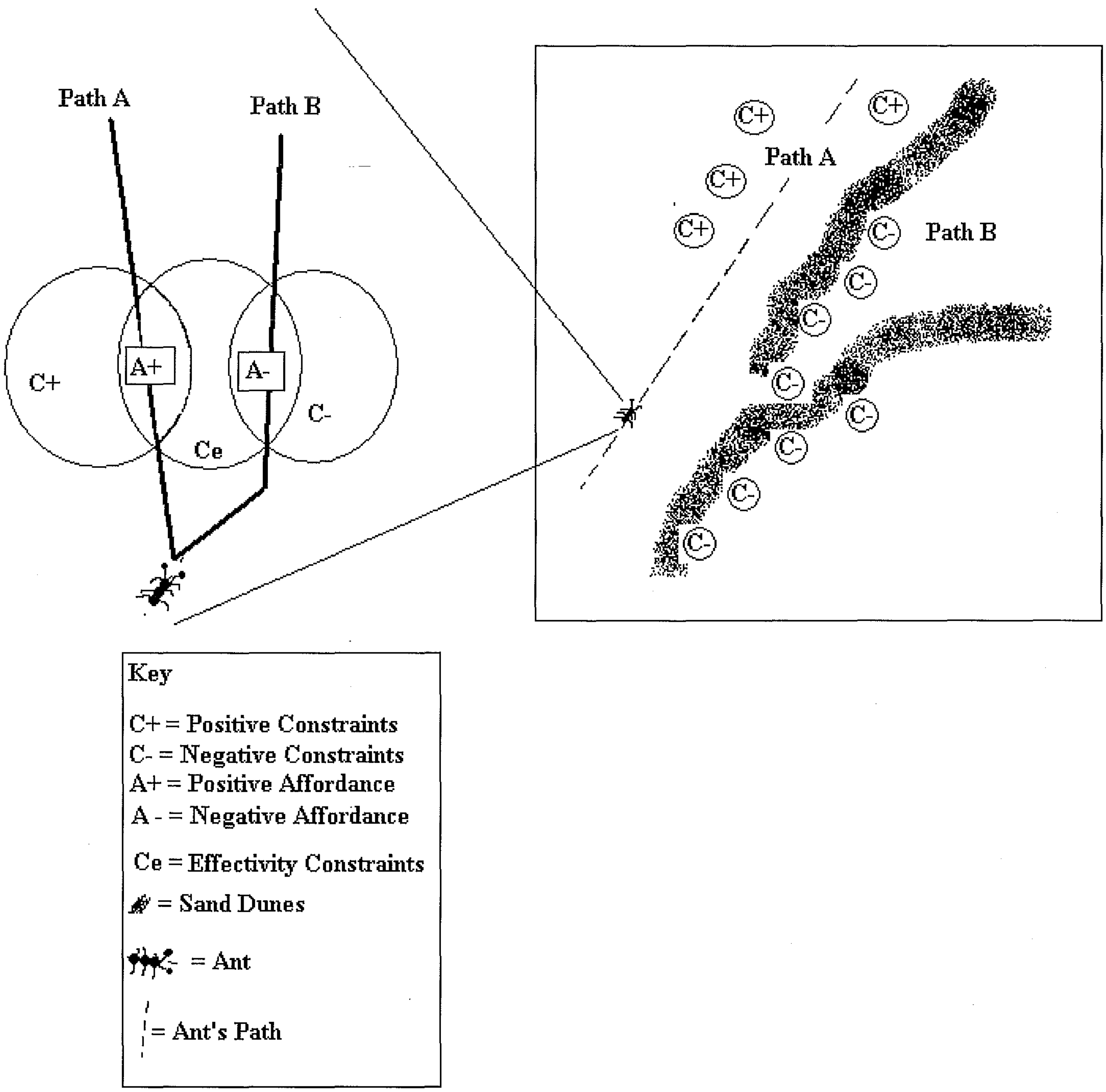
To place these new terms in context, recall the example of the ant and its path through the small dunes and troughs in the sand. This example is shown graphically in Figure 28 below.

Figure 28: The Ant and the Beach



As the key in the figure above indicates, the action domain is composed of an ant, its path across a plane, and sand dunes. In the expanded section of the diagram (lower right) I have indicated, in reference to the ant the aspects of the environment that are either positive or negative constraints. The sand dunes are negative constraints because they hamper the ant's progress. In some cases, unstable sand dunes might collapse, burying the ant. Thus, the clear path along the sand plain (indicated by dotted line) is a positive constraint. A flat plain constrains the ant to moving in two dimensions, restricting motion into the third dimension (either under the sand or into the air). In contrast, water allows for three dimensional motions and is thus dangerous for an ant that cannot hold swim. To add another layer to our analysis, let's include our previous concepts of affordances and effectivities. Consider Figure 29, below.

Figure 29: The Ant and the Beach, with affordances and Effectivities



Recall the concepts involved in this relationship. Affordances are the positive and negative opportunities for action and actions' consequences relative to the actor. Effectivity properties are our ways of being effective. Effectivity constraints are the ways in which our effectivities constrain our actions. Environmental constraints are the properties of the environment that constrain action which is relative to the actor's effectivities and intentions. The conjunction of the environmental and effectivity constraints decides what actions are supported. In essence, constraints set the envelope of affordances, this was described above. Consider the ant's situation. Although the ant used path A (the path along the sand plain to the left) it could have used path B (the path through the pass of sane dunes to the right).

These alternative paths serve as a good focal point to describe the relationships between constraints, effectivities and affordances (these alternative paths are depicted by the Venn diagrams in the upper left-hand corner of Figure 29). Suppose for a moment that the ant had utilized path B. Path B would require that the ant move through a pass between two neighbouring sand dunes. Assume that the ant's intentions are to make it to its goal safely and efficiently. Its effectivities mean that the ant (in our example) will find it time-consuming to burrow out from under a collapsed sand dune. Therefore, the ant's effectivity constraints, in reference to the unstable nature of sand, and the close proximity of two sand dunes make the affordances of path B negative affordances. It is only via a mutual relationship between the ant's effectivity constraints, and the environmental constraints that we see the emergence of the affordances of path B.

That is why the Venn diagram in Figure 29 indicates that the conjunction of the ant's effectivity constraints (Ce) and the environmental constraints of path B (C-) support negative affordances (A-). Conversely, path A has an even distribution of sand and no narrow passes between unstable sand dunes. These constraints, in reference to the ant's intentions, and the ant's effectivity constraints support positive affordances. That is why the Venn diagram of Figure 29 indicates that the conjunction of the ant's effectivity constraints (Ce) and the environmental constraints of path A (C+) result in the support of positive affordances (A+). In each case, the affordances (both positive and negative) are in reference to the mutual conjunction of the ant and its environment. More importantly, this relationship is dependent on the actor's intention. Suppose that the ant's intentions change from progressing towards its goal to hiding. In this case, the labels applied to the diagram above would reverse. Negative constraints would become positive constraints and vice-versa. A flat plain affords high ant-visibility for any creature that eats ants, and a shadowed pass between sand dunes affords hiding behind. In this situation, Path A would offer the negative affordances and path B would afford positive affordances.

In a more human example, consider the interaction between a sailor's effectivities, the ocean, and a sailboat. From one viewpoint, we consider the sailor's effectivities to be extended by the sailboat (the sailboat increases his displacement). Thus, a conjunction of the altered effectivities, and the environmental constraints of the ocean affords the sailor floatation. At another level of analysis the boat itself poses environmental constraints on the sailor. In conjunction with the sailor's effectivities (land-attuned balance systems) the boat affords the negative affordance of being injured against the rigid, oscillating deck. This is the utility of the affordance, effectivity, constraint approach to human-technological analysis: it adjusts to the relevant situational level of analysis (e.g. Boat + Sailor versus Ocean or Sailor + Deck Shoes versus Boat etc).[9] The only independent aspect of these nested interactions is unsafe action, which occurs when the actor misperceives the negative constraints that form the boundaries of safe action in reference to their own effectivities and intentions, or misbehaves. Unsafe action is failing to avoid negative affordances, affordances supported because of the conjunction of effectivities with negative environmental constraints.

Many ergonomists analyse human-artifact relationship from a task-analysis perspective. Task analysis perspectives are concerned with the tasks we carry out to complete a goal. This is akin to the previous human-performance analysis example of writing our name (Obtain pen, Remove cap, Position over paper etc). The weakness to this method of analysis is that the analyst has restricted the freedom of the actor to cope with unexpected situations. Task completion essentially becomes a rigid and robotic response. Designing equipment by way of task analysis produces equipment that is specific to the designer's conceptions of the task, but not necessarily in tune with the dynamic nature of the work domain. On the other hand, constraints are the ultimate boundaries on safe or efficient action. Within their boundaries, they do not force any specific behaviour. Thus, analysis and design with a constraints perspective leaves the actor the freedom to adapt their action to best suit the conditions of the

[9] The level of analysis in this example depends on whether I am examining the interaction between the sailor and boats or the sailor and the ocean.

dynamic task environment, while leaving them the freedom to cope with the unexpected. Put another way, we parse human-artifact interaction via constraints because constraints are the boundary conditions to safe behaviour (negative constraints) or efficient behaviour (positive constraints). Any system designed based upon boundary conditions leaves the actor freedom of choice within the boundaries of safe action. Constraints analysis supports design and optimization according to what the environment supports or does not support. In summary, constraints, affordances, and effectivities are concepts that help to understand an actor's relation to complex systems across complex and dynamic tasks. These concepts provide a stable referent for understanding actor behaviour in the context of his/her socio-technical-natural environment.

The process of perception

Direct perception

The interaction of environmental and effectivity constraints form the envelope of affordances relevant to the actor. The information for these mutual relations is delivered via the structured nature of the environment relative to the perceiver. However, this leaves deep questions as to how the information is acquired. The ecological approach to perception is perhaps the most contentious aspect of ecological theory (Flach, 2000). Ecological theory stipulates that affordances are directly perceivable (Flach, 2000). This entails that the mapping between the structure in the optic array and the affordance is a non-mediated relation (Flach, 1995, p. 9). Put another way, "If one accepts…that affordances are properties that have functional meaning for an actor, and if one accepts….that there is structure in the medium that is specific to these properties, then it seems possible that these [functional] properties can also be 'seen'"(Flach & Warren, 1995, p. 199). Direct perception is about directly acquiring the information for affordances.

Given the historical dominance of representational theory, direct theory can be a difficult idea to understand. To understand direct perception we have to recall the information-processing model, which proposes that flows of arbitrary information are assigned meaning through the interaction between perception and memory. In the information processing model, neural impulses are the currency of perception, and memory is the medium in which neural impulses are matched to symbolic representations (Carlson, 2001). On the other hand, direct perception theory makes the bold claim that, "meaning is the raw material; it exists independent of any processing. It is available to be discovered and acted upon by an agent" (Flach, 2000, p. 88). Direct perception is perception as an act of discovery, via never ending cycles of cybernetic feedback. Direct perception theory proposes that our manipulation of, action on, and locomotion through the environment aids us in the direct, non-mediated perception of possible actions relevant to us, via the juxtaposition of environmental and effectivity constraints. This places the referent of analysis in the world, rather than in the head. This is important because real world analysis and understanding are made easier when the referent of study is in the world rather than in the black box of interior cognition.

It is crucial to understand the environment in which the actor is embedded to avoid placing all the emphasis on cognitive process as an answer to understanding complex behaviour, while ignoring the world in which the cognitive agent belongs (Shaw, 2002). Due to its non-mediated automation, direct perception is akin to skilled/expert behaviour. Programming computer interfaces to support the direct-perception characteristics of affordances encourages skilled behaviour on behalf of the operator. Conversely, programming computer interfaces to include abstract representational structure requires an experienced operator, and even with an experienced operator, the odds are enhanced that mistakes will be made. Because direct perception occurs without mediation and with high automation, perception action mappings occur with little cognitive effort. Thus, designing for clear perception-action mappings offload the work of using an interface onto the system, lessening the load on the human.

Ecological theory speaks strongly against a representational theory of perception. Gibson (1979) notes that direct perception is "the extracting of invariants from the stimulus flux. The old idea that sensory inputs are converted into perception by operations of the mind is rejected" (p. 2). In its briefest form, Gibsonian direct perception theory represents a rebellion away from a classic aspect of representational perception: privatized cognition. Placing the referent of study 'in the head' forces research and application to conform to a system that they have no direct access to. Granted, neurophysiological evidence might be the link between observable behaviour and conjectures about cognition. However, there is a risk of exploring a complex emergent system from its individual neural components. The individual parts of the system can in no way be said to understand their activities, but the overall system in a way does understand (Copeland, 1993). A biological account of perception occurs at the level of energy affecting the rods and cones and undergoing transduction into nerve impulses, which are referred back to the occipital cortex, and then onto the temporal and parietal areas (Carlson, 2001). A representational answer to the 'problem of knowledge' (how to we know what we know) can be a complex answer involving representations that exist propositionally or spatially somewhere in the biological areas of the brain; propositions that respond to incoming perceptions.

Instead, rather than investigating the perceptual system from information processing constructs and representations, direct theory explores the system at a level relevant to mutual activity, the human-environment mutuality[10]. On the surface Gibsonian thought draws a strong parallel with behaviourism. However, the difference remains that Gibson never denies the existence of phenomenal activities, "[direct perception] is not to deny that imagination and fantasy actually occur, it is only to deny that they have an essential role to play in perceiving" (Gibson, 1979, p. 254). Nor does ecological theory deny cognition; direct perception theory rejects the representational theory of perception but agrees that perception itself is cognitive.

An ecological rebellion is, at its core, a rebellion away from the homunculus. The representational conception of perception embraces the camera-picture metaphor with the "eye as a camera at the end of a nerve cable that transmits the image to the brain" (Gibson, 1979, p. 60). However, proposing that information is a representation in the head begs the question of, 'what looks at the representation' and then 'what looks at the representation in the head of the thing looking at the representation' and so on and so forth. Direct perception cuts across this mediated account of perception, suggesting that the perceptual system (with the brain as a component of this system) operates on information, not representation. Specifically, the perceptual system functions on the information about affordances. This ties perception into survival, as the actor's survival depends on the adequate perception of action relevant, meaningful properties of the human-system mutuality.

[10] "Environment" includes and does not distinguish between natural environments and technological environments.

Perception at second hand

Recall that the direct perception of affordances occurs in an information rich medium. What happens to direct perception theory when we consider the impact of instrumentation, language, and pictures? Many of these circumstances do not involve direct perception in its pure form because the meaning (meaning of the word dog) associated to the event (language event of 'dog') is not directly specified in the medium. These circumstances appear to offer challenges to direct perception theory. To consider these examples, starting with instrumental mediation, information in modern systems is highly variable because modern systems involve complex instrumental mediation. In the context of instrumental mediation, Gibson (1979) notes, "...voltmeters, accelerometers, and photometers, are hard to understand. The child can see the pointer and the scale well enough but has to learn to 'read' the instrument...Indirect knowledge...is a far extreme from direct perception of the affordance dimensions in the environment" (p. 260). At another location he notes, "Some instruments...demand a complex chain of inferences" (Gibson, 1979, p. 260). Gibson (1979) also proposes that, "some measuring instruments are closer to perception than others" (p. 260). To understand instrument perception, we have to understand alternate types of perception, specifically a differentiation between direct perception of the instrument and perception of an event at second hand.

In essence, the instrument acts as a mediator for second-hand perception. Consider the related context of picture perception Gibson (1979) notes,

> I conclude that a picture always requires two kinds of apprehension that go on at the same time, one direct and the other indirect. There is a direct perceiving of the picture surface along with an indirect awareness of virtual surface – a perceiving, knowing, or imagining, as the case may be" (p. 283).

In the case of a photo, we are directly aware of the two-dimensional optical array presented by the picture's surface, and indirectly aware of the affordances of the object that the picture displays. A well-designed instrument will use the same perception action mappings provided by a picture. A digital thermometer is a bad example of a perception-action mapping, using numerical coding. The digital readout is abstractly connected to the temperature, and only through knowledge of numerical codes can we act upon information provided by a digital thermometer. Conversely, an analogue thermometer (mercury thermometer) directly provides optical flow, specifying a close relationship between rising mercury and rising temperatures. In another instrument example, a gauge specifying fluid flow should utilize a pictographic two-dimensional particle display that closely represents the fluid flow in the actual pipe. The more linguistic the relation between perception and action the more abstract the relation between the perception of an instrument and action relating to the instrument's target environment. Some instruments do away with most of the abstraction. Binoculars and microscopes are both mediating instruments that extend our perception into the very small and the very large but they do so in a way that seamlessly extends our effectivities without resorting to abstraction.

Consider the problem of language. Language is a constant component of complex socio-technical systems, which include numerous aspects of written, spoken, and displayed language. Words are linked to an object or idea by arbitrary associations so that language is a coded event. Spoken language offers several types of information. Language offers direct perception of the articulatory event, which is informative two ways. Firstly, we gain information about the articulatory event itself, and secondly we gain information about something beyond the speech event, i.e. whatever the speech is referring to. Again, language is a mediator of perception at second hand. Suppose that instruments, language and pictures are information at second hand. What is this information at second hand? Consider this, "Perceiving, knowing, recalling, expecting, and imagining can all be induced by pictures, perhaps even more readily than by words. The image makers can arouse in us an awareness of what they have seen, of what they have noticed, of what they recall, expect, or imagine, and they do so without converting the information into a different mode" (pg 262, Gibson). In the case of both pictures and language, the information at second hand is information about affordances.

Representational theories often parse perception and knowing, as if they are two separate acts. Conversely, ecological theory suggests that "The theory of information pickup...closes the supposed gap between perception and knowledge...Knowing is an extension of perceiving" (Gibson, 1979, p. 258). Language, pictures, and instruments mediate perception by mediating the flow of information. Gibson (1979) notes,

> Perceiving is the simplest and best kind of knowing. But there are other kinds, of which three were suggested. Knowing by means of instruments extends perceiving into the realm of the very distant and the very small; it also allows of metric knowledge. Knowing by means of language makes knowing explicit instead of tacit. Language permits descriptions and pools the accumulated observations of our ancestors. Knowing by means of pictures also extends perceiving and consolidates the gains of perceiving" (p. 263).

Related to the concept of perceptual mediation by instruments, pictures and language is the problem of non-specific, multi-specific or unavailable information. In response, Vicente (1995) suggests, "a stronger emphasis on problem solving may be required if experts are faced with unfamiliar or unanticipated situations, or the perceptual information they receive is impoverished" (p. 57).

These problems highlight an important point, that an account of ecological perception requires a new theory of learning and a new theory of memory, things that are beyond reach of this thesis. However, to clarify a few ideas: direct theory suggests that perceivers undergo perceptual attunement or learning to adapt to the variable, mediated or impoverished flows of information, "The state of a system is altered when it is attuned to information of a certain sort. The system has become sensitized" (Gibson, 1979, p. 254). Direct theory does not destroy the concept of learning rather it embraces it, "The process of pickup is postulated to be very susceptible to development and learning. The opportunities for educating attention, for exploring and adjusting, for extracting and abstracting are unlimited" (Gibson, 1979, p. 250). Perception is continually refined as the actor continues to act and perceive. An important part of Gibson's perspective on perception is that, where possible, the unit of analysis is no longer privatized cognition.

<u>Disconnected perception</u>

Recalling that ecological theory is a rebellion away from the homunculus, one of the most prevalent challenges levelled at direct perception theory is that human cognition continues to occur in silent contemplation. Challenges to ecological theory suggest that ecological theory does not support or account for the intervening process that occur during 'consciousness', 'imagery', or 'perception with our eye's closed.' However, ecological theory does approach these problems, specifically with the same restructuring that direct perception theory and perception at second hand applied to perception, "The redefinition of perception implies a redefinition of the so-called higher mental processes" (Gibson, 1979, p. 225). The denial of the homunculus is not a denial of self-awareness, or even consciousness, but a restructuring of these concepts and their importance to system interaction. When considering aspects of extended awareness, it is important to note that Gibson's theory of direct perception is a more localized theory of direct perception-action cycles, not a total theory of cognition.

Challenges levelled at direct perception concerning its failure to support constructs such as imagery do not apply to direct perception theory, in that, "The ecological theory of direct perception cannot stand by itself. It implies a new theory of cognition in general" (Gibson, 1979, p. 263). Gibson never achieved a complete theory of non-perceptual awareness, thus ecological ideas concerning this area are less then substantial. Gibson (1979) notes of phenomenological processes, "No list of them was ever agreed upon, but remembering, thinking, conceiving, inferring, judging…I am convinced that none of them can ever be understood as an operation of the mind. They will never be understood as reactions of the body, either" (p. 255). This statement is ecological theories' rejection of dualism; what replaces it is a tentative theory of continuous perception, combined with theories of embodied cognition based on invariant structure.

Take visualization as an example of a process usually conceived as representational. Gibson (1979) notes, "To expect, anticipate, plan, or imagine creatively is to be aware of surfaces that do not exist or events that do not occur but that could arise or be fabricated within what we call the limits of possibility. To…imagine wishfully…is to be aware of surfaces or events that do not exist or occur and that are outside the limits of possibility" (p. 255). We clearly have an awareness of surfaces, events or objects that exist but are not in our visual field, or of events and objects that have never existed. These truthful or fictional visualised surfaces aid in the planning and implementation of action and it is clear that these visualizations are not derived from the direct perception of surfaces in the world (Gibson, 1966). Representational theories propose that these activities are based on manipulations of construct representations in the brain.

To illustrate an alternative perspective, reconsider perception. Gibson's (1979) refutation of dualism proposes that "...a perceptual system that has become sensitized to certain invariants and can extract them from the stimulus flux can also operate without the constraints of the stimulus flux" (p. 256). Through the application of ecological theory, what is a representational theory of imagery is better construed as disconnected perception. Gibson (1979) notes, "The awareness of imaginary entities and events might be ascribed to the operation of the perceptual system with a suspension of reality-testing" (p. 263). Disconnected perception redefines awareness as the inevitable part of a perceptual system that will not shut down.

In the absence of external stimulation the system continues to perceive information in an isolated manner, "Information becomes further detached from stimulation. The adjustment loops for looking around, looking at, scanning, and focusing are then inoperative" (Gibson, 1979, p. 256). Disconnected perception does not deny ideas, "The having of ideas is a fact, but it is not a prerequisite of perceiving. Perhaps it is a kind of extended perceiving" (Gibson, 1979, p. 250). Rather, ideas, visualizations, and other activities becomes part of the effects of a complex perceptual system. This does not in any way deny their current adaptive value in plan making and problem solving, or our feelings of self-fulfilment in having these abilities.

The abolishment of pictures in the brain does not deny the existence of fictional visualization, "Fictions...do not automatically lead one astray...They can promote creative plans. They can permit vicarious learning when the child identifies with a fictional character who solves problems and makes errors" (Gibson, 1979, p. 261). If an individual is driving a car, the affordances available are for the most part direct and specified by the optical array. If an individual is playing Dungeons and Dragons with playing cards, there is both information directly specified by the surfaces and reflectance of the playing cards, but the visualization derived from the non-stimulus perception of dragons via the words printed on the cards, is not specified in the optical flux.

The visualisation involved is disconnected perception and intervening non-representational cognition. If the perceiver is playing Dungeons and Dragons with electronic playing cards, over an internet website on the computer then the situation grows more complex. The actor does not directly perceive dragons but visualization of the dragons is linked to direct perception by a set of nested perceptual-action relations. The player directly perceives the optical information specified by the light emitting from the monitor, and gains second-hand information about the dragon from the language on the playing card. The second-hand information cannot directly specify dragons perceptually, but it can informationally specify disconnected perception of the dragon based on the detached activity of the perceptual system. Ecological theory specifies that there are never any pictures in the brain (Gibson, 1966).

With ecological theory speaking against representations we immediately beg several questions, 'what mechanisms carry out direct, second-hand, and disconnected perception and how do they work', and, 'what form is the information in?' If there are not pictures in the brain, what are there? The answer to these questions is beyond the scope of this thesis, but I will offer a few thoughts. Gibson (1966) proposed the idea that system-wide resonance as a replacement of traditional representational concepts of memory and learning. Current research suggests that neural synchrony "is thought to implement the 'dynamic binding'...in the brain. It has also been suggested that neural synchrony is part of the process by which consciousness emerges from distributed brain activity" (Pozega & Thagard, 2001, p. 780). To strip away the representational language, neural synchrony (or system resonance) may be a way to explain the obvious learning effects exhibited by the system during direct, second hand and disconnected perception.

Granted, this does not answer what form the information takes. Whatever the form of information, the crucial move is to alter our conceptions of cognition from representational to perceptual, meaningful, and informational. To take a classic representational example, consider internalized speech, "The child who has learned to talk about things and events can, metaphorically, talk to himself silently about things and events, so it is supposed" (Gibson, 1979, p. 262). Recall that direct perception is about the detection of invariants. In a sense then, the child has internalized perception of the invariants in their own vocalizations. To talk to oneself is to disconnectedly re-perceive vocal invariants, just as perceptions of dragons is to creatively and disconnectedly perceive novel combinations of invariants originally specified by our environment. From an alternate perspective, Barsalou (1999a) notes,

> During perception of the external world, proprioceptive events, and introspective states, selective attention focuses attention on components of experience...As a result, associative areas in the brain capture patterns of activation in sensory-motor systems and in systems that represent introspection....Later these associative areas partially reactivate these perceptual representations in the absence of perceptual input, thereby simulating the experience of what an external or internal event was like…(p.69)

This quote reads closely with my previous description of disconnected perception. Although there are differences between Barsalou's ideas and ecological theory, there is a strong shared push towards a perceptual theory of knowledge, in which the information in our brain is composed of invariant forms, not representational pictures (Barsalou, 1999b).

To summarise this section, representational theories of perception and cognition focus extensively on post-perceptual processing, as if perception stops. Ecological theory extends aspect of perception (direct, second-hand, or disconnected) indefinitely. Due to information scarcity, and mediation (by informational variability, instruments, and language) aspects of disconnected perception and cognition clearly occur, and they must be both understood and supported (Flach & Warren, 1995). Disconnected perception may be part of what makes us highly adaptive, by constantly supplementing the flow of information through the disconnected function of the perception-action system. Our understanding of second-hand and disconnected perception/cognition requires a new theory of cognition. A meaningful theory of perception and action includes the usage of affordances, constraints, and effectivities. Affordances are directly perceived in accordance with direct perception theory, situating the referent of direct-perceptual action in the human-environment shared relation. However, under conditions of instrumental, pictorial, and linguistic mediation, direct perception cannot account for all activity. Second hand perception, disconnected perception, and cognition account for these activities.

Richardson, Spivey, and Cheung (2001) note, "In general, proponents of an embodied perspective reject the idea of cognition as wholly the processing of abstract, or amodal, symbolic representations. They emphasise the ways in which the…processing burden of cognition can be offloaded on the external world and the motor and perceptual systems that interact with it…" (p. 1). Granted, much of the work in this area continues to employ internal representations and propositions that eye fixations serve as cognitive connections between internal and external events. Trends towards ecological and embodied theories of cognition support the work done in the previous chapter, which suggest that the difficulty in isolating a phenomenon comes from the linkage between phenomenon and data and the experimental perspective. Ecological theories offer an embodied perspective on the cognition that occurs during human-artifact interaction and a tight linkage between the empirical data and any intervening process. After all, ecological theories do not debate the existence of cognition; rather they debate cognitions representational nature. Furthermore, ecological theories support direct perception theory. Direct perception is based on meaningful information not symbols thus it is more reliable than indirect perception (Vicente & Burns, 1996). In essence, direct perception provides more information about the reference situation. Vicente and Burns (1996) discuss research dealing with actor perception of the information stemming from control rooms versus the information in the field. The information gained from a dial coded to specify temperature and pressure is nothing like the information gained from watching the rails of a pipe vibrate when under load (Vicente & Burns, 1996). Designing to support direct perception taps into the most enriched type of information; information from direct perception is always richer than other types of information (Vicente & Burns, 1996).

Systems thinking

A system is defined as, "…the arrangement of human and machine elements organized into a whole by the need to accomplish a specific goal" (Meister, 1989, p. 92). Modern ergonomics adopts a strong systems perspective. With regard to systems thinking, Gibson (1979) notes, "What psychology needs is the kind of thinking that is beginning to be attempted in what is loosely called systems theory" (p. 2). There are several ways to conceive the relationship between people and their environments. We can study people and environments separately, people affecting environments, or environments affecting people. Finally, we can study the mutual interaction between people and their environments. The last conception of human-environment relations is classic systems thinking.

Meister's (1989) systems definition does not exclude complex social-social systems: schools, governments, church-groups. These systems, contrary to their stereotypical image, utilize both technological and artifactual augmentation. Simon (1996) notes that, "The world we live in today is much more a man-made, or artificial, world than it is a natural world" (p. 2). To extend this idea, the world today is predominately technological, and whether we have efficient interaction with technology depends on how natural the technology is. I suggest that we are unlikely to find any human-human system independent of supporting artefacts and technology. Even the most primitive people on Earth utilize spears, grinding stones, loin-cloths, and architecture. Even the most basic first-world human-human systems use chairs, tables, and telephones. The simplest social networks communicate with mediating technology, supplement their effectivities with clothes and other objects, and make use of the affordances offered by augmented effectivities

Systems exists to fulfil goals or tasks, this is a key component of any systems definition. Task related activities are considered to be performance, whereas activities that are not task-related are merely behaviour (Meister, 1989). The focus of systems analysis is the human-machine system fit in relation to performance, "It [human factors systems thinking] emphasizes work or task performance – only behaviour that is relevant to task performance is of interest" (Meister, 1989, p. 3). Idiosyncratic behaviour does not move a systems towards its goals, and Meister suggests that such behaviours (like daydreaming) are not important in systems analysis, unless such behaviours conflict with system performance (Meister, 1989).

This is both true and false. In some systems, daydreaming (defined as contemplation and musing) may be part the task requirement, thus enhancing the system would require an enhancement of daydreaming behaviour. Systems exist to complete tasks, but it is important that a systems analysis matches the requirements of the system at hand, and not the pre-arranged opinions of the systems analyst. In some cases, the task may not be meaningful in a sense of commercial work output, but it may be meaningful for the sake of stress-relief, enjoyment, or relaxation. Systems that fulfil relaxation tasks are just as important candidates for study as the system formed by an ocean going cruise liner. A system is any collection of human(s) and artefact(s) distributed across the environment in which they are embedded, and reaching towards task/goal requirements. Components of systems can include any number or type of human and artefact elements including books, computers, laws, and social conventions.

Systems thinking extends beyond a simplistic human-machine model. Stimulus – Operation – Response (SOR) models may be adequate to understand singular human-machine interactions, but fail to help understand larger and more complex systems (Meister, 1989). Furthermore, when humans interact with computer equipment, architecture, planes, etc. the combination forms an entity that has properties of both elements, as well as its own emergent properties (Meister, 1989). SOR models do not recognize the augmented aspects of cognition formed by human-machine systems as they are based on the concept of a 'standard single experimental subject', a concept that does not exist now and may have never existed (Chignell et al., 1999).

Instead, we are rarely outside the confines of some artificial aspect of our world. As mentioned previously, (See, Affordances and Effectivities on page 81) technology alters human effectivities, either positively increasing, or negatively decreasing the affordances available relative to the perceiver. However, "...where does the person end and the technology begin? What is our definition of human when there is an increasingly synergistic and symbiotic relationship between humans and information technologies?" (Chignell et al., 1999, p. 298). Although a post-modern world of totally immersive cyberspace (e.g. William Gibson's[11] "Neuromancer") may be some years away, it is clear that we exhibit a fused relationship with our technology. In order to cope with this augmented relationship, real world research and intervention must adopt a strong systems perspective, with the system as the unit of analysis in order to understand the way the world is changing (Chignell et al., 1999, ; Meister, 1989).

Systems' thinking is especially powerful because, in conjunction with an ecological perspective, it challenges the 'divide-and-conquer' approach derived from

[11] In William Gibson's post-modern technological future, human beings are able to cybernetically link to the world-wide information matrix (a.k.a. the Internet) and see the data with a neuro-optical link. Hacking thus becomes a visual-perceptual experience.

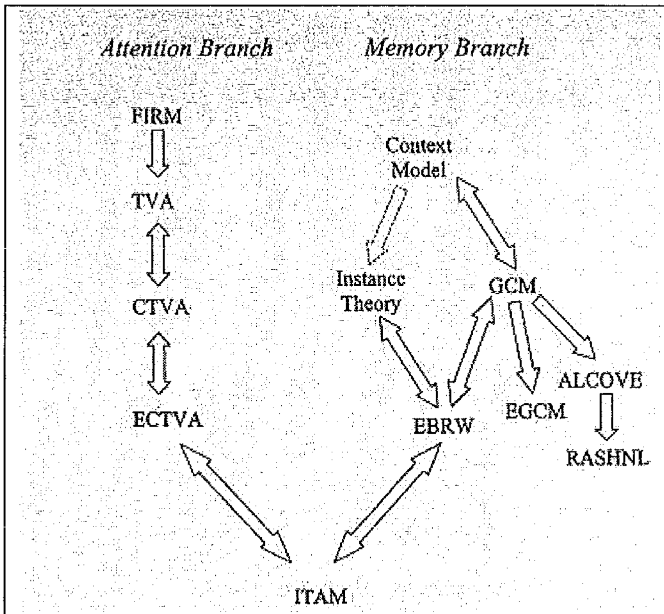
traditional cognitive psychology. Consider Logan's (2002) conception of the divide and conquer approach in cognitive psychology,

> You walk into the parking lot and look for your car...Imagine your colleagues analyzing the simple act of cognition underlying that look. A student of attention would be interested in how your gaze went to other cars, rather than structural features. A student of categorization would be interested in how you knew those were cars in the parking lot. And a student of memory would be interested in how you did...pick your own car out of the group. These differences in perspective reflect the divide-and-conquer approach prevalent among researchers for the last 20 years or so... (p. 376).

Cognitive approaches divide the smooth and continuous functioning of an individual into abstract and disconnected phenomena. Logan (2002) makes the brave move towards creating a unified concept of attention, memory, categorization and other phenomena involved in perceiving and acting on the world by unifying previously disparate but related theories as seen in Figure 30, below. Logan's approach is highly cognitive and not very ecologically sensitive, but is a key aspect to systems theory and ergonomics. The unified approach suggested by Logan re-affirms placing the unit of analysis at the level of the human-environment/artifact system. In indirect support of Logan, Barrett (1998) notes,

> Our developing knowledge of the spatial and temporal events associated with brain functioning (from positron emission tomography and functional magnetic resonance imaging) is beginning to show that personality, temperament, and cognitive abilities may well be indivisible from one another (p. 8).

Figure 30: A Unified Theory of Cognition



A family tree expressing the relations between ancestors on the attention branch and the memory branch. Theories connected by bidirectional arrows can be made equivalent to each other, through ITAM.
(Extracted from, Logan, 2002)

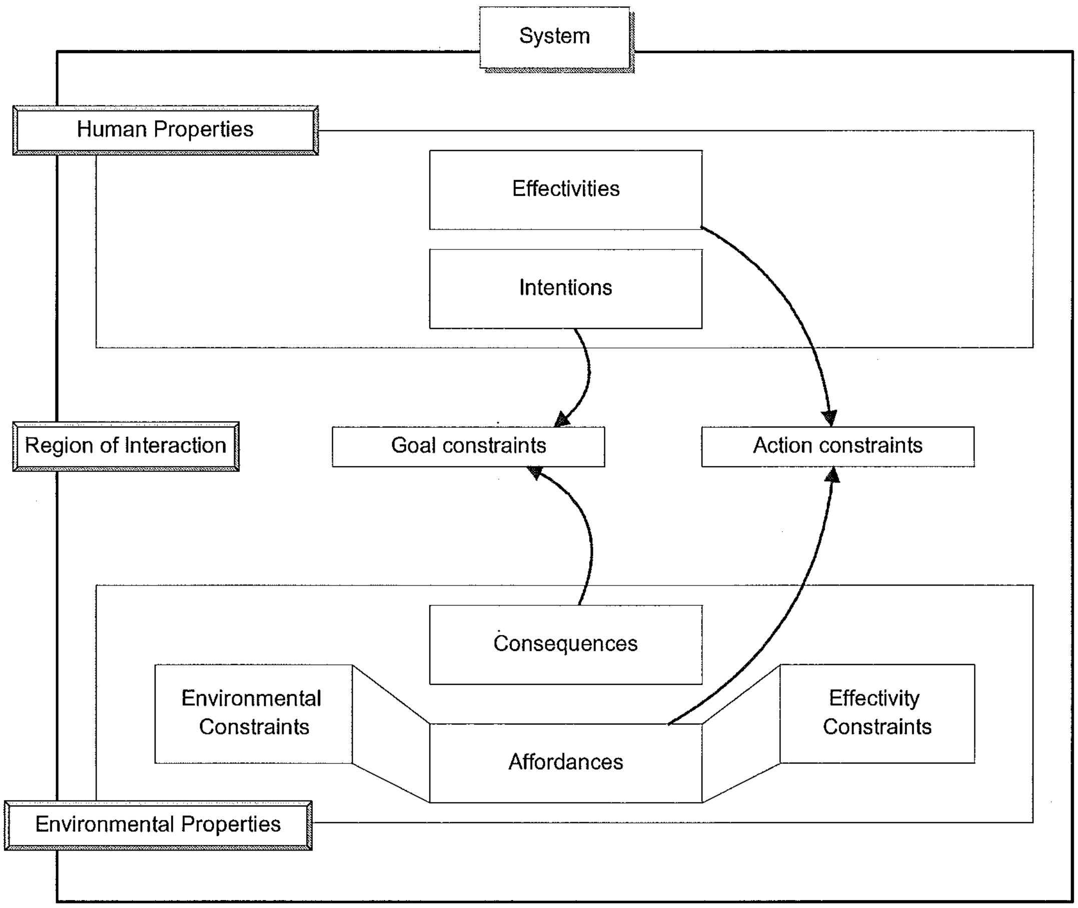
Key to Figure 30: A Unified Theory of Cognition

FIRM = Fixed-capacity independent race model
TVA = Theory of visual attention
CTVA = COntour DEtector (CODE) theory of visual attention
ECTVA = Executive control of TVA
GCM = Generalized context model
EBRW = Exemplar-based random walk model
EGCM = Extended generalized context model
ALCOVE = Attention learning COVEring theory
RASHNL = Rapid attention SHifts 'N' Learning theory
ITAM = Instance theory of attention and memory.

The integrated ergonomics unit of analysis

Although Bailey (1989) accepts the importance of human-machine interactions, in a departure away from the strong mutuality proposed by an ecological systems unit of analysis he suggests, “The human is the most complex of the three elements” (p. 12). This proposal may or may not be correct, but its implication is certainly incorrect. The human may or may not be the most complex, active, or motivating factor in a system, but this does not mean that they are the only aspect of a system. Cognitive research has long placed the human in a position of primacy, and it is this anthropocentric perspective that makes cognitive research blind to the interaction with, and augmentation of our modern world. Adopting an ecological/systems perspective does not place either the human or the machine in primacy to each other; their mutual relation is the minimal unit of analysis. This is the core of modern ergonomics, a commitment to studying the complex, augmented, technical world at the level of the ecosystem. Furthermore, a systems perspective tends to view the human aspect of the system as a unified organism. In essence, we are unified systems that exhibit a tight embedded, interlinking relationship with the marco-systems that surround us. This position, known as the ergonomics unit of analysis and is portrayed in Figure 31, below.

Figure 31: The Real world unit of analysis



The above diagram indicates how affordances, effectivities, effectivity constraints, environmental constraints, intentions, and goals unify in a human-system mutual unit of analysis. The actor offers intentions and effectivities, and effectivity constraints relative to the environment. The environment offers affordances and consequences relative to the perceiver. Together these concepts map the interactive embedded relationship between humans and their systems.

Summary of Chapter 3

Human factors, engineering psychology, applied experimental psychology, and cognitive ergonomics, are best encapsulated by the global term 'ergonomics.' Modern ergonomics aims to better fit the human and their technology to suit that task, while improving health, efficiency, and productivity. Ergonomics adopts a strong ecological perspective, using affordances (what objects afford), constraints (properties that bound action), and effectivities (ways of being effective) to classify the human-environment mutuality. Direct perception theory dictates that the information for affordances and constraints is present in the medium and does not require representational processing.

The ergonomics perspective is compared to the cognitive-representational perspective, which construes perception as analogous to the extraction of meaning from meaningless noise. Granted, at the every edge of the information envelope, information is too much or too little, mediated by instruments, technology, language, and pictures. In these situations some aspect of intervening mental activity clearly occurs. However, these processes are better construed as perception at second hand and disconnected perception. Furthermore, many complex activities, such as language, can be construed as embodied cognition rather than purely mental activities.

The ergonomics mutual unit of analysis explores the relationship between people and their technology rather than concentrating specifically on either technology or people independently of each other. Exploring humans and technology in a mutual context helps to blend the mechanistic (engineering-centric) and humanistic (anthropocentric) worldviews. The mutual unit of analysis is composed of affordances (opportunities for action) effectivities properties (ways in which we are effective), consequences, and intentions arranged in a system. Exploring complex socio-technological systems with the ergonomics aims, perspectives, and mutual unit of analysis helps to support design. This human-technology relationship is best analysed via a systems analysis perspective. Designing to support the ecological principles of direct perception produces equipment that offloads some of the work from the human by understanding human limitations, makes the safe boundary conditions of behaviour apparent, and encourages expert performances.

Chapter 4: Real World Problems

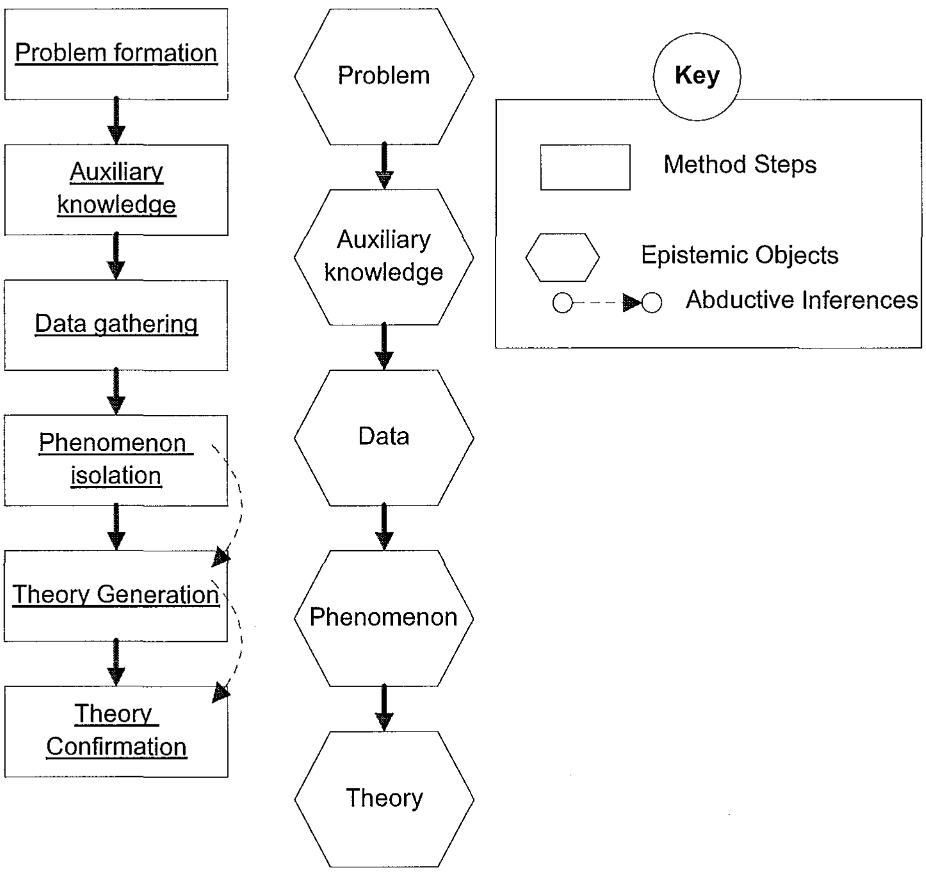
In chapter one, I discussed psychology's current methodological framework, a framework known as the hypothetico-deductive method. I outlined several weaknesses with the HD method, among them a failure to support the isolation of empirical regularities and the subsequent generation of explanatory theories. In chapter two, I discussed a complimentary framework known as abduction, which supports the generation of explanatory theories. I discussed how abductive method supports the progression from data to phenomenon and from phenomenon to theory, defending abduction's right to exist as the logic of discovery. In contrast with HD method, I proposed that the abductive method supports the isolation of phenomenon and the generation of scientific explanations, with the abductive inference providing the structure behind theory generation. In chapter three, I explored the aims, perspectives, and unit of analysis offered by ergonomics. Recall that the intention of this thesis was to develop a systematic real-world problem-solving framework drawing from both abduction and ergonomics. This chapter is the final step in formulating this framework. In this last chapter, I plan to show that there is a close interlocking relationship between ergonomics and abduction, in the context of real-world problem solving.

I intend to achieve this aim by showing that abduction can be a systems orientated, ecological approach to scientific discovery and design. To support this intention, I plan to extend my logic-based arguments of Chapter 2 (Chapter 2: Abduction) and offer further ecological support of abduction as a means phenomenon isolation and theory discovery. In Chapter 3 (Chapter 3: Ergonomics), I suggested that ergonomics offers the ecologically relevant unit of analysis, perspective, and aims relevant to applied and applicable real world research. Given the nature of ergonomics and abduction, I propose that abduction and ergonomics can combine to provide the applied and applicable explanatory theories that support regularity based scientific design. The structure of this chapter is as follows. Firstly, I will provide a brief diagram-based prelude of the aspects of abduction and ergonomics relevant to this chapter's discussion. Secondly, I will explore the proposed links between abduction and ergonomics, in the context of a real world problem, namely human-paper interaction. Using this real world problem as an example, I will cover six aspects of positive convergence between abduction and ergonomics: forming the research problem, gathering auxiliary knowledge, data gathering, isolating phenomenon, theory generation, and design.

Linking Ergonomics and Abduction - Prelude

To review the concepts involved in the formation of a real world problem-solving framework, recall the abductive methodological framework offered in Chapter 2 (See Figure 32, below).

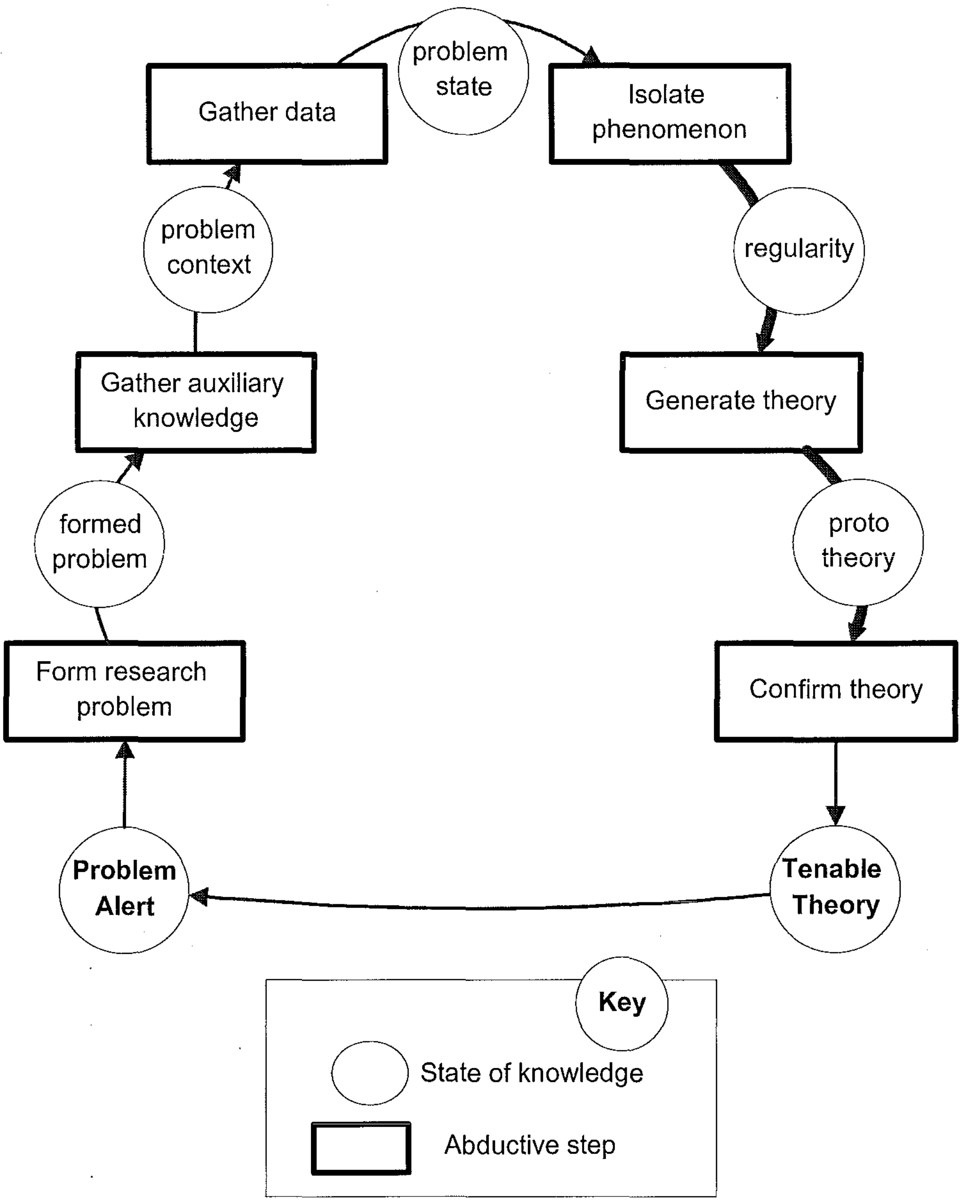
Figure 32: The abductive framework from Chapter 2



Although the framework diagrammed in Figure 32 is a step in the right direction, there are some final graphical and conceptual changes needed to provide the basis for a fusion of abduction and ergonomics. For a moment, consider what the abductive methodological steps are. Construed from a systems perspective, abductive method is a set of general tasks set in a global framework that describe how a scientist moves towards explanatory theories. In the previous chapter, I mapped the steps involved in moving towards explanatory theories as linear flow sequences. However, the progression from problem to solution is not a linear flow even when abductive logic is a systematic framework. To provide for the tangential and cyclical nature of research, I have drawn inspiration from an ergonomics modelling technique known as the decision ladder. The decision ladder is a modelling tool found in Vicente (1999). Although the decision ladder is not meant to model human-information processing, it does help to map what control tasks need to be carried out, and what information requirements need to be met in order to complete a system goal in a reliable manner (Vicente, 1999).

More importantly, a decision ladder maps these requirements independently of who will do them and how they will be carried out (Vicente, 1999). Furthermore, the decision ladder exhibits a reciprocal relationship with the work domain. The work domain provides information to the control tasks and the control tasks act upon the work domain (Vicente, 1999). I initially raised the idea of the decision ladder because I believe that abductive method will benefit from a non-linear perspective. Expert performance often includes the use of shortcuts and dynamic real world problem solving often involves unexpected tangents, thus, any construal of abductive method must be adapted to include this flexibility. Therefore, I propose that the methodological steps making up the abductive method can be construed as control tasks, as this change emphasises their relevance to the actor. I will also replace the epistemic objects with states of information. Although in most cases this will not change the names, nor will it change their epistemic status. Using the term 'states of information' reminds us of the relevance of the abductive control task to actors and also suits the pre-requisite structure of a decision ladder. Control tasks result in states of information (Vicente, 1999). Figure 33 below displays a revised conception of abduction based on these alterations.

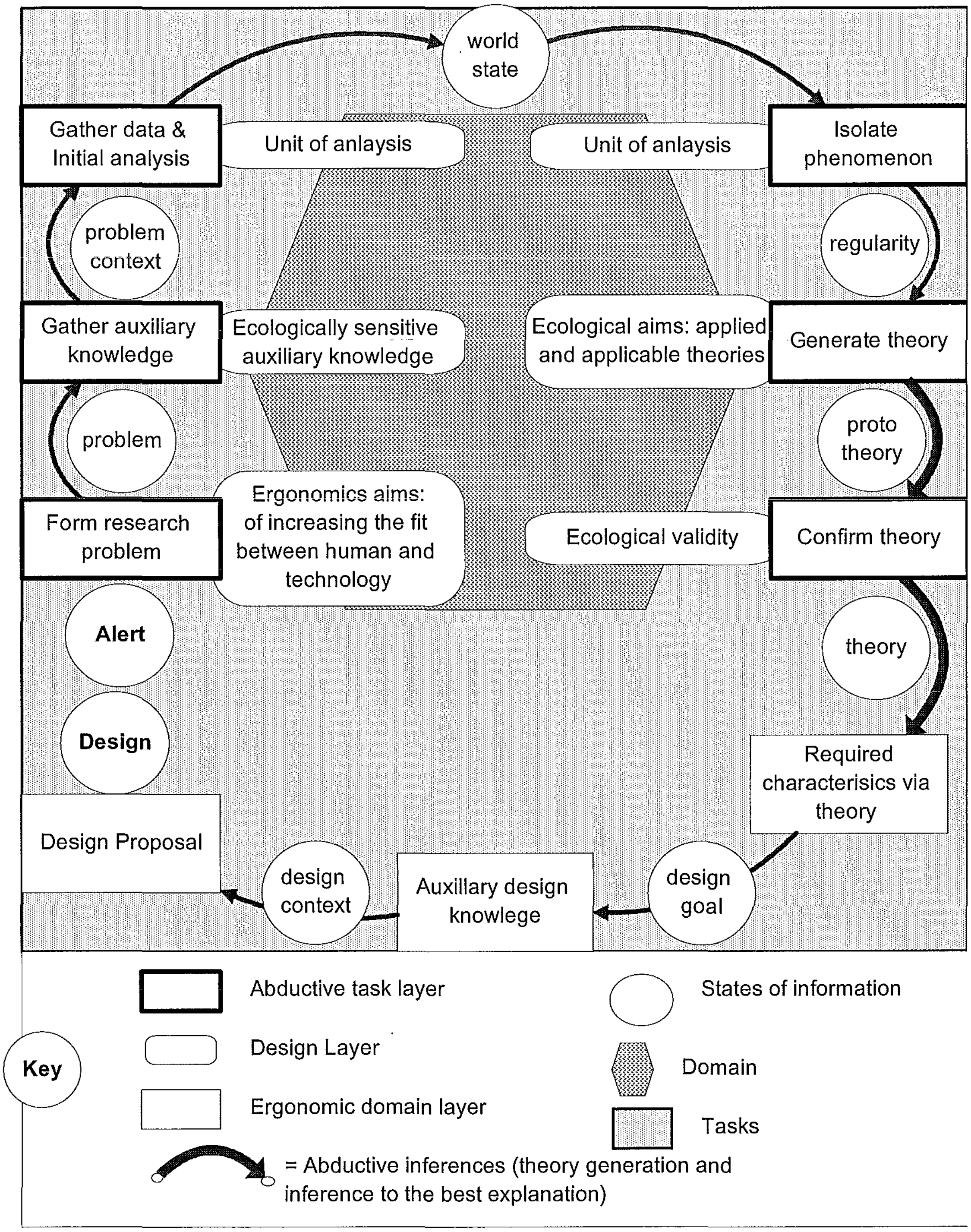
Figure 33: Revised abductive method



Chapter 2 of this thesis introduced the concept of abduction, including all the ideas that formed the abductive method displayed above (See Figure 33). Chapter 3 introduced ideas from ergonomics, which included the ergonomics unit of analysis, ecological perspectives, and real world aims. The ideas in these two chapters will provide the basis for the convergence of abduction and ergonomics in this chapter. The rational behind this convergence rests on the corresponding nature of abduction and ergonomics in the context of real world problem solving.

To outline my proposals, I argue that abduction provides the general control task structure relevant to scientific innovation and design. In addition, I suggest that ergonomics provides the unit of analysis, ecological perspectives, and overall aims relevant to real world problem solving. In essence, I propose that ergonomics supplies a good analysis of the important components in the real-world problem-solving domain. Furthermore, based on the relationship between control tasks and domain analysis expressed by Vicente (1999), I propose that abductive method and ergonomics fit together in a control task – domain description relationship. I suggest that abduction maps the control tasks, which act upon the work domain described by ergonomics. Equally, ergonomics describes the work domain, which provides the information for the control tasks mapped by abduction. In short, the real world problem-solving framework that is the goal of this thesis is based on a complimentary relationship between abduction and ergonomics. The abductive methodology acts on the domain and ergonomics provides the real world domain context for abductive method. This relationship is expressed in Figure 34, below.

Figure 34: The Abductive (control task) / Ergonomic (domain) framework



To explore the relationships described above, in real world context, I turn to the problem of human-paper interaction.

Linking Ergonomics and Abduction – The Problem of Paper

Sensing a dilemma

A science fiction conception of the future, along with spaceships and autonomous robotics, often depicts a world free of paper. Thirteen years ago, Xerox PARC introduced one of the potential changes behind a paperless world, Mackay (2000a) describes this moment.

> In 1991, I saw a then top-secret talk by N. Sheridon at Xerox PARC on an extraordinary new technology called 'electronic paper'. Instead of a bulky computer monitor, displays of the future would be the thickness and flexibility of a sheet of paper. The technology is clever: tiny pixel-sized drops of ink, half white and half black, are spread into a thin layer, each surrounded by a miniature pocket of oil. The pixels are bi-stable: under ordinary conditions they do not change direction and act like ordinary ink. Yet when connected to a tiny device, each individual pixel can be rotated at will, making is possible to display text and images with the same control as any computer monitor.... (p. 1).

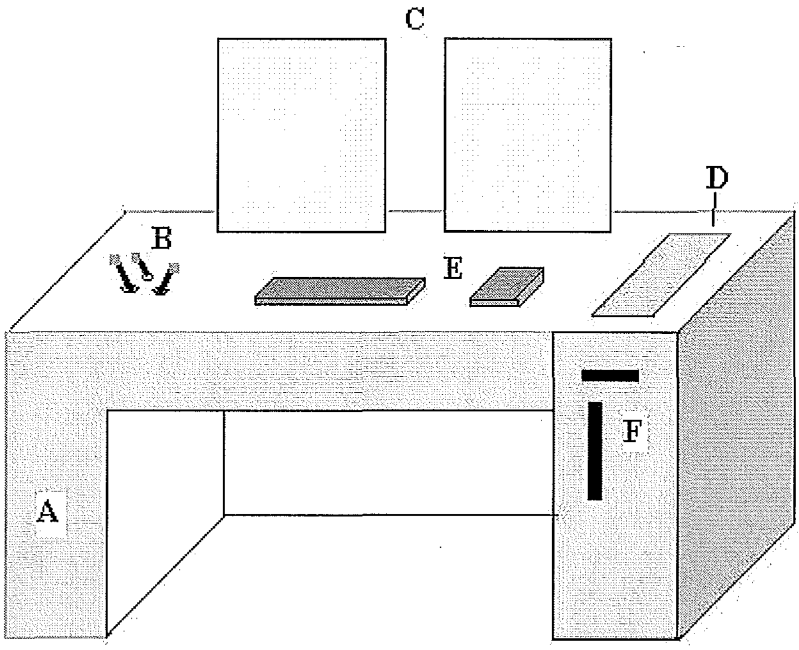
Thirteen years later the technological potential exhibited by electronic paper is only now coming into commercial use. Whether it will affect the populace of paper users is still an open question, as there are still unresolved issues surrounding the human-paper interaction. Much earlier than the Xerox PARC demonstration of electronic paper, a visionary by the name of Vannevar Bush noted that our interaction with paper was a growing concern. Nearly 50 years ago Bush (1945) noted, "There is a growing mountain of research. But there is increased evidence that we are being bogged down today as specialization extends. The investigator is staggered by the findings and conclusions of thousands of other workers - conclusions which he cannot find time to grasp, much less to remember, as they appear" (Section 1, para. 3). Bush predicted how difficult it would be to moderate and control the flood of information, especially instantiated paper-based information and he offered his view on a solution:

> Consider a future device for individual use, which is a sort of mechanized private file and library. It needs a name, and, to coin one at random, 'memex' will do. A memex is a device in which an individual stores all his books, records, and communications, and which is

mechanized so that it may be consulted with exceeding speed and flexibility. It is an enlarged intimate supplement to his memory (Section 6, para. 4)

For my depiction of the Memex, see Figure 35, below.

Figure 35: My depiction of the Memex, from Vannevar Writings



Key A-The Memex desk B-Control levers C-Display screens D- Document input scanner E-Keyboard and buttons F-Microfilm input

Sellen and Harper (2002) note, "Bush…[was] foreseeing the explosion of information to come, recognizing that paper-based systems were simply no longer going to provide adequate solutions for dealing with it [information]…" (p. 5). The internet feeds this information frenzy by providing us with the abilities to simultaneously access/print old archived information, while continuing to create new information (Sellen & Harper, 2002). Furthermore, home printing technologies are nearing print-lab quality. Printing high-quality photos, drafts, and digital-documents is constantly becoming cheaper and more available. Thus, despite intervening paper-replacement technologies, many of which are more impressive than microfilm, paper consumption has only increased (Peters, 2002, ; Sellen & Harper, 2002). This consumption has subsequent costs, such as paper, management time, and environmental effects. Sellen and Harper (2002) note, "To store 2 million paper documents, an organization can expect to spend between $40,000 and $60,000 on filing cabinets alone" (p. 28).

I introduced the concept of electronic paper as a 'potential change' because that is all that technological advancement is: latent potential. Mackey (2000a) notes,

> In each case, the naive assumption is that the introduction of the computer will replace existing paper artifacts. Yet more often than not, the result is more complex: Users come to rely on the new features offered by the computer, but also maintain the paper artifact. They must thus manage two kinds of documents: those embodied as physical paper and those entirely on-line, with a new problem of how to manage the link between the two (p. 1).

The tenuous link between electronic and instantiated paper costs the user in management time. We are entering a world where misfiling electronic and real files costs companies hours of wasted time; time which is directly proportional to money. On average, managers in the United States spend nearly 3 hours or more a week looking for misfiled documents (Sellen & Harper, 2002). It seems that despite the range of current display technologies, people continue to prefer reading from paper (Schilit, Price, Golovchinsky, Tanaka, & Marshall, 1999). Mackay (2000a) notes about the problem of paper, "What is it about the physical characteristics of the users' interaction with paper that makes it so powerful? How can we design systems that take advantage of both the physical and virtual characteristics of paper?" (p. 1).

Ergonomics and Abduction: Formulating the research problem

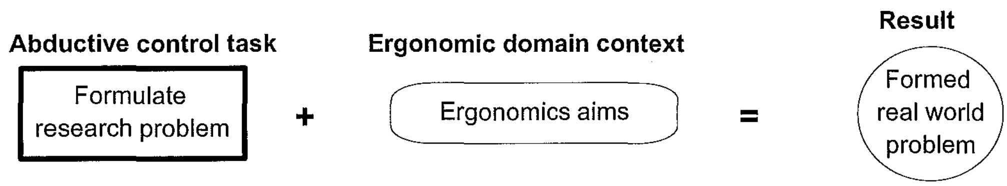
In the prelude to this chapter, I proposed that abduction provides the control tasks relevant to creating exploratory theories and ergonomics provides the domain context applicable to real world problem solving. Nowhere is this more apparent than the formulation of a research problem. In formulating the research problem, abduction provides the structure/intention to form a research problem and ergonomics provides the real world aims. On one side, the abductive method is committed to the provision of scientific explanations based on stable regularities in data. On the other side, ergonomics is committed to bettering the fit between people and their systems. A good fit between people and their technology represents natural interaction.

This fit between people and technology presumes an ultimate aim of altering the technology to enhance the task in accordance with our natural ways of being effective. It is this commitment that guides the explication of local ergonomics problems. By adopting the aims and goals of ergonomics, abduction is guided towards applied and applicable explanatory theories. The abductive method relies on ergonomics to provide the context, in which abduction can provide the problem-orientated conceptual impetus towards defining a real world problem. The formulation of a research problem, however ill-formed, provides important constraint on both the isolation of phenomena and the eventual abductive inference of a theory to explain the phenomenon.

In essence, abduction provides the conceptual emphasis on beginning with a problem, and ergonomics provides the responsibility to commit to problems that increase the fit between people and their systems. Granted, science is never simple. For many research endeavours, there will be pre-existing problem formulations and auxiliary knowledge to include in the initial formulation of a research problem. The real world problem discussed above (See 'Sensing a dilemma', p. 117) is an example of the general auxiliary information that is part of sensing a problem. How we come upon this type of early-warning information in the first place is outside the scope of this thesis.

In contrast with the relationship between abduction and ergonomics, consider the relationship between hypothetico-deductive method and real world problem solving. The hypothetico deductive method does not have nearly the same relationship with problem formulation and real world problem solving. Hypothetico-deductive (HD) theory does not support the development of explanatory theories. Rather, HD theory presupposes the existence of a theory for the sake of theory testing. Thus, HD problem formulation is laden with a strong bias towards theory testing rather than domain exploration and explanation. This commitment does not suit the requirements of real world problem solving, which requires applicable and applied explanations, upon which to base designs (Rouse et al., 1997). Conversely, abduction provides the control task requirement of formulating a research problem, and ergonomics helps abduction to converge on a meaningful research problem, this forms the first stage of a real world problem-solving framework.

Stage 1: Real world problem solving framework



Human-paper example: The problem of paper

Assume that we are aware that a problem exists. Also assume that our real world problem solving is under pressure from the fused abductive-task/ergonomic-domain requirements. However, we must confine the problem. The more confined the problem, the more constrained the elements involved in generating explanations and designs (data, phenomenon, and theory). The brief preface to this problem (see 'Sensing a dilemma', p. 117) and the introduction to this thesis are enough to indicate the complexity and scope of human-paper interaction. In order to cope with this extensive problem we must limit the system to its smallest, but still meaningful aspect. Thus, I choose to limit this problem to the visual aspects of paper, excluding anything auditory.

More specifically, I want to focus on the authoring aspects of human-paper interaction. I define authoring as the ultimate system goal of uniting the information from notes, books, and papers into a single informative document (Sellen & Harper, 2002). Authoring includes the process of drafting, reviewing, and revising ongoing drafts. In a sense, authoring is active reading, critical thinking, and writing across multiple texts (Schilit et al., 1999). While editing online knowledge workers read and refer to other documents 89 percent of the time (O'Hara & Sellen, 1997). I have further constrained my exploration of authoring by presuming that actors have already read the materials applicable, have taken notes, and have prepared bookmarked chapters. This restriction on the problem excludes note-taking for the sake of note-taking (i.e., notes taken during meetings), but does not exclude notes and sketches created in the process of authoring a paper, e.g. notes created on the fly to aid the fusion of various reference sources.

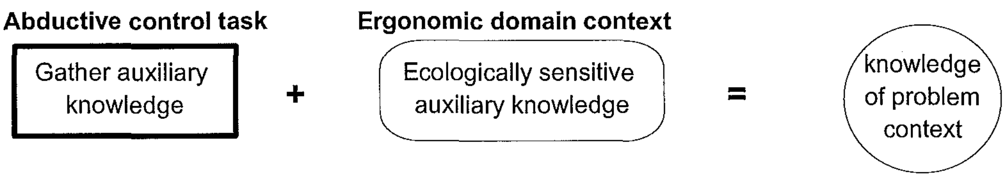
This restriction of this exploration to the task of authoring is a justified restriction, as Sellen and Harper (2002) note that knowledge workers spend a lot of time reading and writing. In a study at the International Monetary Fund, knowledge workers spend an approximate 3,700 minutes writing their own documents (1,700 minutes) and collaboratively authoring (2,000 minutes) (O'Hara & Sellen, 1997). In comparison, no other activity exceeds 1,200 minutes of time, and most activities (note taking, responding to mail etc.) average at 500 minutes or less (Sellen & Harper, 2002). I am especially interested in examining our interaction with instantiated and virtual paper. Instantiated paper is the paper that exists outside the computer interface. Instantiated paper is the paper-based printed documents, mail, newspapers, and books that fill our libraries, homes, and offices.

Conversely, virtual paper is the paper that exists within a computer interface. Virtual paper takes the form of Word documents, Adobe PDF files, text documents, e-books and other virtual paper formats. Virtual paper is the replication of written language in an electronic format. Terms such as e-paper and e-text are also used to describe virtual paper. Based on these restrictions, I can phrase an initial draft of the research problem as: 'what form of paper best achieves the aim of increasing the fit between human and paper during the task of authoring, and why?' This fit must accomplish the goal of supporting effective authoring by making use of positive affordances and avoiding any negative affordances relevant to this interaction. We need to know if there would be any effects due to a reduction in our usage of instantiated paper. Changing the work domain for the sake of eradicating paper may be foolhardy; in some situations paper may be safer to use (Mackay, 2000b).

Ergonomics and Abduction: Gather Problem-Relevant Auxiliary Knowledge

The second control task in the abductive framework calls for the collection of auxiliary knowledge relevant to the specific problem paradigm. The abductive framework proposed in this paper makes this stage an explicit step of the abductive method rather than an implicit aspect of scientific exploration. General auxiliary knowledge provides the pool of metaphoric patterns from which we draw analogies and correspondences between the data patterns and phenomena and from regularities to theories. Examples of this were given in Chapter 3. Leucippus and his general auxiliary knowledge gave rise to a theory about the existence of the atom. The relationship between Rutherford's experimental data and his general auxiliary knowledge gave rise to an analogistic solar system model of the atom. Paradigm specific auxiliary knowledge encompasses specific work carried out beforehand and its impact on the current exploration. As the relevant control task is 'gathering auxiliary knowledge', then ergonomics supplies the relevant context prompting the collection of ecologically sensitive auxiliary knowledge. The combined influence of abduction and ergonomics suggests that we require the collection of ecologically appropriate auxiliary knowledge.

Stage 2: Real world problem solving framework



Human-paper example: Ecological theories of language

Considering the auxiliary knowledge relevant to human-paper interaction, Hutchins (1995) notes, "Many of the foundational problems in cognitive science are consequences of our ignorance of the nature of cognition in the wild" (p. 370). Language is possibly one of the most imperative components of a shared and cross-generational human existence. Hutchins (1995) maintains that, "Humans more than any other species, spend their time producing symbolic structure for one another. We are very good at coordinating with the regularities in the patterns of symbolic structure that we present to one another..." (p. 370). However, language is about the world, not about pictorial representations: "Ontogenetically speaking, it seems that the symbols are in the world first" (Hutchins, 1995, p. 370). He notes, "Originally, the model cognitive system was a person actually doing the manipulation of the symbols with his or her hands and eyes" (p. 361). The current symbol-representational manipulation model of cognition places a large barrier between the world we inhabit and cognition (Hutchins, 1995). To adopt a functional perspective on language, we must move away from traditional concepts of stage-based representation theory and consider the shared relationship between humans and paper.

Physically, paper is nothing but a surface; an area that affords application, deformation, and manipulation. Since ancient times, writing and drawing have been the act of altering the reflectance of a surface and leaving a trace that provides a structured optic array (Gibson, 1966). Drawing is still the same in the modern world, although our structuring of the optic array applies to both real and virtual surfaces. Nearly 24,000 years after the first known drawings, humankind developed the alphabet (Gibson, 1969a). Perception of the alphabet requires perception of something beyond the optical invariants specifying letters (Gibson, 1969a). It is via the culture that surrounds us that we learn to associate certain letter invariants with semantic meanings.

At a practical level, writing words on paper is the act of instantiating information by means of symbols. In greater depth "...the fundamental graphic act...is defined as any kind of manipulation which leaves traces on a surface..." (Gibson, 1969a, para. 1). "The skill of writing also develops out of the graphic act, but at a later age. This skill depends on the learning of the grapheme-phoneme correspondences of the alphabet…and learning their vocal equivalents" (Gibson, 1969a, para. 5). In our case, the relevant human-paper system is the system of intentionally informative language. The act of inscribing coded symbols onto an instantiated or virtual surface allows for the transmission of information about affordances between members of our species. In essence, authoring conveys action-relevant meaning. Although we often write for pleasure, language has the evolutionary advantage of conveying and structuring action relevant meaning to ourselves and to others in our own time or in the future (Barsalou, 1999a). To put it another way, assuming that our relationship with the world can be parsed in terms of affordances, effectivities, and constraints; we can consider language to be externalized information about affordances.

Granted, fantasy and fictional language play complicated and important roles in refining human interaction with our environments. From a purely recreational perspective, perception is an intrinsically enjoyable experience. From a more practical perspective, fictions are methods of re-perceiving the affordance information gained from direct perception of formless invariants, or the information about affordances from language in fictional/fantastical contexts (Gibson, 1979). In this way human knowledge is ampliative. However, beyond communication, language is important because it supports the self-management of our own information. Written language makes system information instantiated and spatial. Written language converts the disconnected re-perception of linguistic invariants that occurs with the intervening personal monologue, into a real world perceptual-action manipulation. In essence, writing is a form of externalized and embodied cognition. Gibson (1979) notes, "Knowing is an extension of perceiving. The child becomes aware of the world by looking around and looking at, by listening, feeling, smelling, and tasting, but then she begins to be made aware of the world as well [by language]" (p. 258). We make ourselves aware of our surroundings by writing about them.

How might language actually work? Taking another tack on language with a related concept, consider Gibson's (1969b) views on visualization: "visualizing seems to be a knowing of invariants under perspective transformations over time; an awareness of formless invariants. To remember is not to search through the file of snapshots stored in the brain. To 'imagine' is not to have an eidetic image, an after image, or a pictorial image, nor is it to represent something to oneself' (para. 1). Later Gibson (1979) suggests, "The awareness of imaginary entities and events might be ascribed to the operation of the perceptual system with a suspension of reality-testing. Imagination, as well as knowledge and perception, can be aroused by another person who uses language or makes pictures" (p. 263). In essence, the visualizations inspired by language may be the continual functioning of a perceptual system. Via language, "Information becomes further detached from stimulation. The adjustment loops for looking around, looking at, scanning, and focusing are then inoperative. The visual system visualizes. But this is still an activity of the system, not an appearance in the theatre of consciousness" (Gibson, 1979, p. 256).

To perceive language is to perceive both the structured optical information on the page and the information specified by the coded relation between the alphabet and its associated informational meaning. However, this does not suggest that language is associated with meaning by connecting the words to mental pictures. Rather, language is paired with the formless invariants relevant to its meaning. For example, words referring to dogs resonate to the formless invariants relevant to dogs: including the visual, auditory, and tactile invariants. There is growing support for this rather controversial idea. Barsalou (1999b) proposes an idea of what is captured by the total eye-body-brain perceptual system,

> Perceptual symbols are not like physical pictures; nor are they mental images or any other form of conscious subjective experience. As natural and traditional as it is to think of perceptual symbols in these ways, this is not the form they take here. Instead, they are records of the neural states that underlie perception. During perception, systems of neurons underlie perception. During perception, systems of neurons capture information about perceived events in the environment and in the body (p. 582)

Ecological theories of language support tight sensory-motor links between language, cognition, and action. Thus, the phenomena important to the supporting authoring are the phenomena that tightly link knowledge, perception, language and action. There is support for these views from a range of alternative, but related perspectives. Some suggest that language and the world are dynamically related and perceived (Barsalou, 1999a). Griffen (2004, in press) suggests that eye movements reflect the allocation of system resources. Richardson and Spivey (2000) present research that suggests that the perceptual system uses spatial indices to link memories to spatial locations in the world relying on, "an embodied cognitive system that employs a spatial indexing procedure and relies on the stability and availability of external information" (p. 24). The term 'embodied-cognition' is popular in theories that propose a tight linkage between language and the world.

Barsalou (1999a) supports ecological theories of language, advancing the proposal that language comprehension has the purpose of preparing the agent or actor for situated real world action. In general, people often find a way to apply comprehended information. In an evolutionary sense, language provides a gain in information that is relevant to situated action. The situation-action pairing may not exist yet, may have existed previously, or may never exist, but the perceiver still continues gains wisdom, knowledge, and judgement by using language. Thus, even fiction provides information that is meant to be relevant to situated action. Even abstract concepts are part of preparation for situated action (Barsalou, 1999b). Abstract concepts should be viewed as complex and temporally extended, rather than abstract and un-situated (Barsalou, 1999a). Given the various aspects of auxiliary knowledge gathered so far, I need to refine my research problem. Firstly, does real paper actually enhance authoring activities? Secondly, does virtual paper contain the same invariants as real paper? Thirdly, if instantiated paper enhances authoring, what is it about the nature of real paper that makes authoring more efficient? Last, what does virtual paper offer the authoring activity?

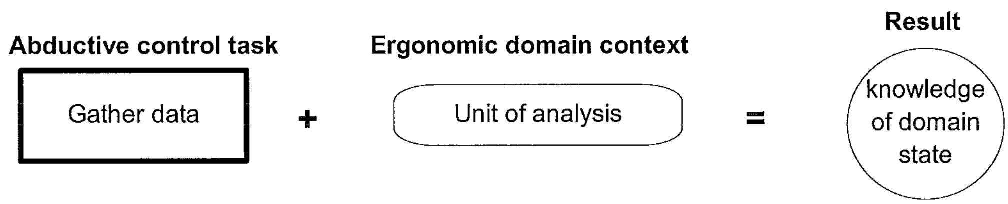
Ergonomics and Abduction: Data gathering

Hypothetico-deductive techniques focus on gathering and testing alternative hypothesis (Hanson, 1958b). This ignores and avoids the exploratory approach that occurs before hypothesis testing; the approach advocated by abductive method. Good explanatory theories rely on stable empirical regularities isolated from our exploration of experimental data (Woodward, 2000). This places the burden of science on the formation of strong experiments, the collection of good data, and the exploration and explanation of data patterns. Recall Feynman's (1989) critique of psychology, that too often it tests for the patterns we believe exist rather than trying to explore what actually exists. To rectify this problem, the abductive control task relevant to this step is data gathering, which incorporates experimental planning. Experimental planning is subsumed under the greater heading of data gathering because it complicates a methodological framework to have each sub-category of control task expanded to its full extent.

In turn, ergonomics provides the abductive control tasks with its relevant domain context by focusing experimentation and data gathering on applicable and applied research techniques. Applied research techniques utilise the ergonomics mutual unit of analysis which captures shared relationships between humans and the systems of which they are an embedded part. An example of ergonomics research techniques are experiments that seek to isolate pi-numbers. Pi-numbers are dimensionless measurement ratios produced using a human-environment mutual unit of analysis. For example, the ability to step over objects on the floor of the room is specific to a dimensionless relationship between stride and clearance (both governed by leg height) and object size (X, Y dimensions). This is a ratio known as a pi number. Experiments by Warren (1995) indicate that stair-climbers are limited to a dimensionless relationship of, riser height / leg length = π number. This relationship is expressed via a maximum ratio of 0.88 (Warren, 1995). For example, the maximum riser height is 0.88 meters for a stair climber with a leg height of a meter.

If the step is any higher, the stair climbers must resort to non-bipedal stair climbing behaviour. A heads-up-display device might aid stair climbing by illuminating objects in green than can be surmounted with a stride and illuminate objects in red that are insurmountable. Simulation is another example of an excellent applied research technique. Human-airplane interaction is a real world area that benefits from the use of simulation for both research and training. For the sake of research or training, simulation can replicate dangerous system events, i.e. events that are improbable and rare but dangerous to the aircraft's safety (O'Hare & Roscoe, 1990). Ideally, money and time would not be constraints on research. However, in reality this is not the case. The number and nature of experiments that can be conducted are directly related to the amount of finance, time, and work force available, as well as the severity of the problem (Norman, 2002). Thus, even low-cost simulation can also be a cost-effective solution to reproducing the task relevant real world domain in a controlled environment for the sake of training and experiment (O'Hare & Roscoe, 1990).

Stage 3: Real world problem solving framework



Human-paper example: Human meets word

The types of data relevant to the current problem are: biometric information, virtual paper Virtual Reality Modelling Language (VRML) prototype simulations, and case studies. The biometric information is displayed in Figure 36 and Figure 37, below. The VRML simulations and the case studies are beyond the biometric information.

Biometrics of reading

Figure 36: Human Effectivity information

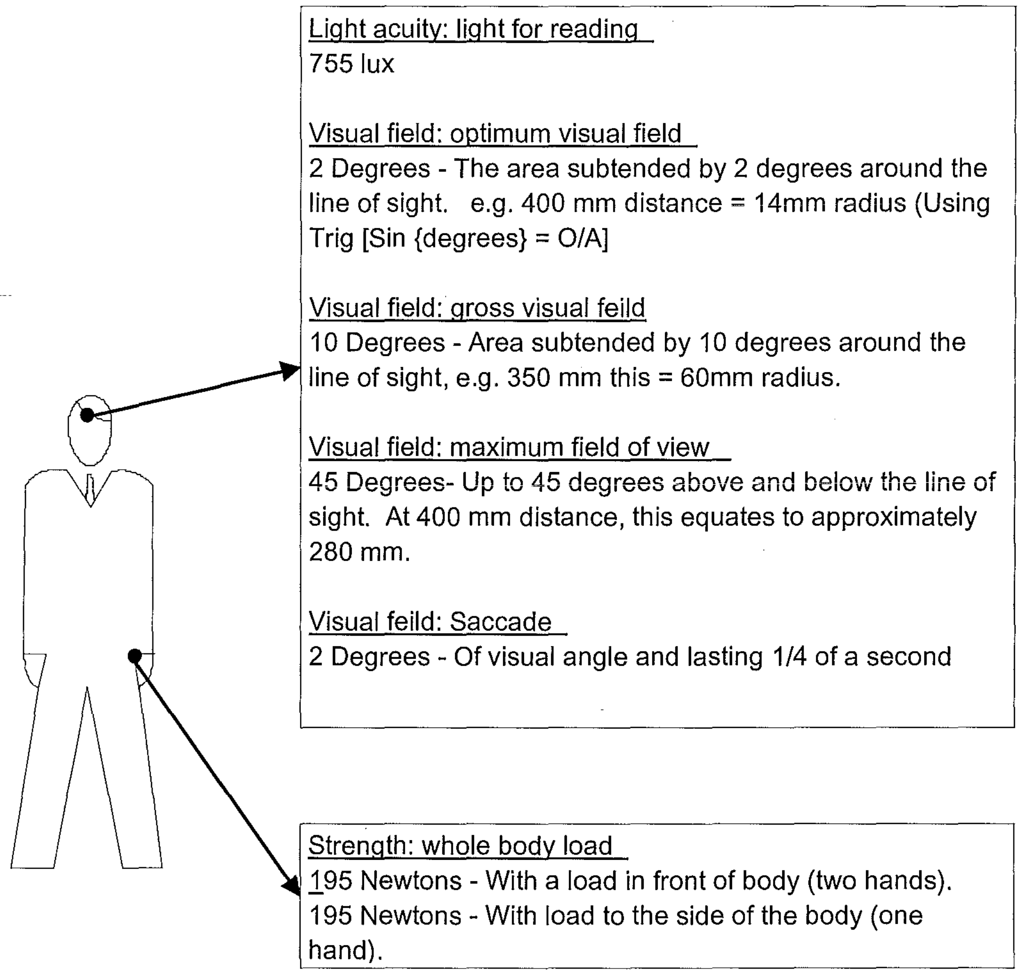
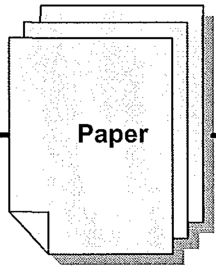


Figure 37: Paper properties



Real paper properties

Ink/Paper contrast
Low reflectance symbols on high reflectance backround (except over 10 lux, and then it is opposite)

Weight
0.6 grams Single sheet of paper (500 per ream)
3 kg Ream of A4 paper (All Purpose, Copy Paper, A4, Impact corporation)

Size
21 cm wide
29.7 cm long

Authoring and modification
Writing involves the variable surface alteration via an implement and the application of a reflectance altering material. This results in a semi-permanent (pencil) to relatively permanent mark (pen, marker). Paper can also be deformed, creased, cut, glued, stapled etc.

Reviewing and searching
Paper can be re-altered in fixed layers (post it notes, or notes applied to the surface). Paper can be searched directly by exploring, semantically by heading and chapter titles, or by using contents and title pages.

Virtual paper properties

Ink/Paper contrast
Low reflectance symbols on high reflectance backround (except over 10 lux, and then it is opposite)

Size and Wieght
Variable -- micro-grams per sheet (when stored on DVD)

Authoring and modification
Writing on virtual paper involves the variable surface alteration via an implement resulting in the initiation of a reflectance alteration. This results in a semi-permanent/variable mark. Virtual paper cannot be directly altered, only the content can be changed across documents.

Reviewing and searching
Virtual paper can be altered in fixed layers or in in one seamless layer. Virtual paper can be re-altered in fixed layers (post it notes, or notes applied to the surface). Virtual paper can be searched directly by exploring visually, semantically by heading and chapter titles, by using contents and title pages, or by using the search function.

Simulation prototypes

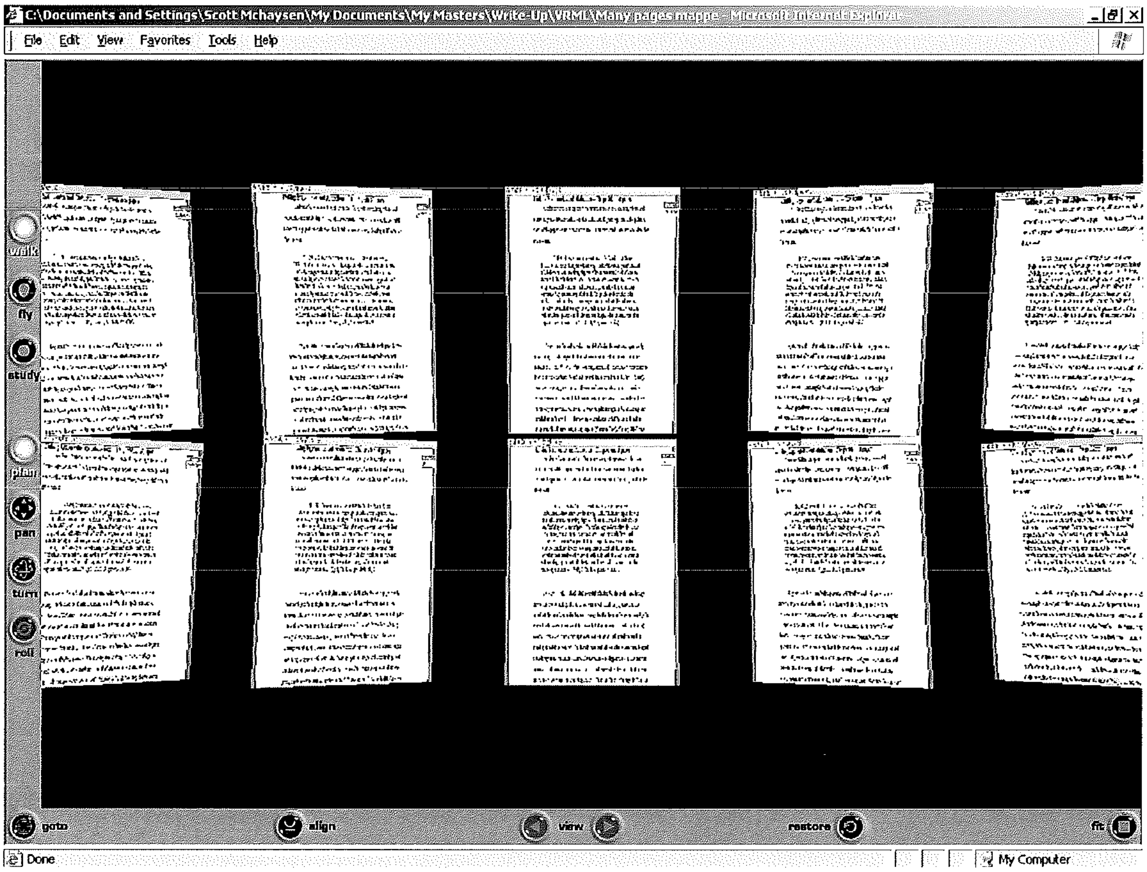
The Virtual Reality Modelling Language (VRML) is a programming language used to create virtual environments, objects, and dynamic events. VRML objects and environments are portable, small, and can be viewed through any VRML capable web-browser. VRML objects are also the basis for many applications of augmented reality, mixed reality, and virtual reality. I have created a range of virtual paper VRML objects for the sake of simulating and exploring human-virtual paper interaction. I used VRML to simulate virtual paper because it allowed me to control the distance that the virtual paper was placed away from the user. Using page view with Microsoft Word allows an actor to place multiple pages on the screen at the same time but it does not specify how far away the pages are placed in virtual space. I created virtual paper simulations in billboard mode (the always orient towards the actor) or non billboard mode (the pages stay static relative to the actor's motion in the virtual world. I used two methods of placing text on the virtual pages. Firstly, I wrote the text on the object using the geometry text node. Secondly, I used the 'ImageTexture' node to paste a screenshot picture of an essay on the surface of the page.

VRML virtual paper simulations (See Appendix 1 for a VRML code example)

- 2 pages, with plain text typed on their surfaces
- 2 pages in billboard mode, with plain text typed on their surfaces
- 2 pages in billboard mode, with two different text sizes on their surfaces
- 2 pages in billboard mode, with a zoomed screen shot (119% zoom) mapped on their surfaces
- 4 pages in billboard mode, with a screen shot mapped on their surface
- 10 pages in billboard mode, with a screen shot mapped on their surface
- 1 page with a screen shot mapped onto its surface

See Figure 38 below for an example of a VRML virtual paper simulation page.

Figure 38: Ten virtual paper pages with a screen shot mapped onto their surfaces



Case Study: DanTech

Sellen and Harper (2002) present a case study of office paper-reduction by a Danish company known as DanTech. DanTech is an example of an established technology company with a shrinking market share. In order to curb shrinking profits, DanTech resorted to a radical program of organisational restructuring. To gain a new foothold in a dynamic market, DanTech sought new process, systems, and an organization that emphasized flexibility, mobility, and dynamic work patterns. Typical work patterns were structured around anchored work process. Desks, offices, cubicles, and filing cabinets are all anchored workstations; items that tie workers to a specific spatial location. In opposition to this anchored organisation, DanTech built an entirely new office and created technology that would free people from their desks. This was not specifically an attempt to create a paper-free environment, but an attempt to enhance mobility. DanTech carried out new projects by assembling knowledge workers on demand in a centralized location. Besides a flexible open plan work environment, with side office meeting rooms creating privacy space, DanTech utilized a unique roving virtual paper file system.

Very much like the roaming computer log-in associated with many tertiary institutions, DanTech's portable electronic desktops/filing systems followed employees anywhere in the facility. Roving log-in allows workers to let go of the permanency associated with desks. A roving electronic desktop provides the bare requirements of work: a filing system, e-mail, spreadsheet, calendar, and a word editor. Assembled project teams at DanTech are allowed one rolling paper file-system per project and paper mail is scanned and shredded. Shredded paper is routed through the cafeteria via a translucent pipe giving employees a positive perceptual action cue relevant to reducing paper.

DanTech has not abandoned the paper medium entirely. Instead, paper is the medium for immediate 'work in progress.' Interestingly, most of the paper mail at DanTech is rarely referred to, once acted upon. Documents (both instantiated and virtual) often have a temporal window, but once this window is past, the document is no longer useful in supporting work (Roosen, 2002). Scanned project papers also passed out of the temporal boundaries once projects at DanTech were completed. Scanned project documents did not provide the instantiated company memory that the systems designers planned. Instead, the knowledge became a part of the wider company-worker system. DanTech's most pervasive lesson is that alterations to the medium supporting paper work must occur via a change in the underlying work practices. Furthermore, change costs the company enacting the change, but pays for itself. DanTech has regained its market share, due to a combined improvement of work performance and company image.

Case Study: UKcom

Sellen and Harper (2002) present a case study of a British company forcing the introduction of a paperless office for the sake of reducing paper, rather than enhancing work practices. UKcom is an example of a company seeking change for the sake of change. Like DanTech, UKcom also found itself with a shrinking market share and sought change to rectify its position. To initiate this change, UKcom formed a 'paperless task force' focused on changing the paper usage for one of its major components: Bids and Sales. Bids and sales were the department specifically focused on customer account management and costing. Bids and sales staff, the account managers, were the company interface with customers; they were experts that elicited the requirements and needs from the company's customer base. Traditionally, customer information was documented and shared via meetings. However, the task force believed that to increase efficiency, account managers really needed to interface in real time with the greater Bids and Sales department. This was both to inform the company and to better inform the customer of new advances and developments.

Despite high hopes, the introduction of the dynamic information network for account managers produced a negative employee reaction. Account managers usually possessed sizeable amounts of personalized and private information on good clients, family details, names, and relationship with the company. Account managers also possessed details on clients they would not choose to deal with. Instead of creating a two-way street, account managers drew from the information network, but kept their own databases private. Thus, the UKCom system did not gain the approval and performance anticipated or desired. Sellen and Harper (2002) note, "If the task force wanted to change the way that account managers shared, it would need to change the underlying work process, not the technology." (p. 47)

Case Study: Real world reading patterns

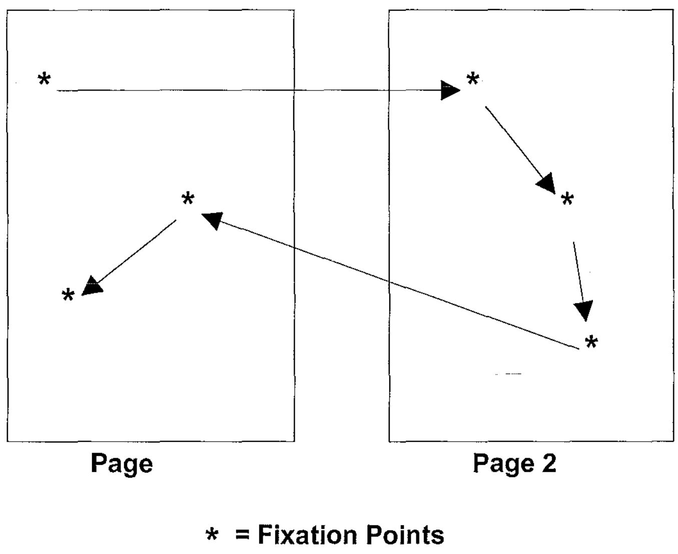
An observational experiment conducted by O'Hara and Sellen (1997) explored the real world writing and reading patterns of several subjects undertaking an authoring task. Subjects were placed in two groups: virtual paper users and real paper users. Both groups of participants completed the same task, with the virtual group completing the task on a computer, and the paper group completing the task on paper. O'Hara and Sellen (1997) confirmed that people perform better using paper, both for note taking and the final authoring task. Moreover, reading and writing often occur together (especially when authoring), across multiple documents (O'Hara & Sellen, 1997, ; Schilit et al., 1999). Authoring activities are often corroborative and spread across several people or groups of people. The case study found that paper supports authoring activities three ways: flexible navigation, spatial information, and annotation-interweaving. These will each be reviewed briefly.

Firstly, flexible navigation serves several goals: planning and on-demand note taking, checking facts, and checking understanding. However, real-world paper and online paper afford vastly differing navigational abilities. When using paper, there is an overlap between the perception-action mappings for page turning. Put another way, there is an overlap between the intention to turn the page and the action resulting in the page turning. To encourage users to link intentions and actions in a smooth and natural manner is to encourage behaviour that is analogous to expert performance. In the case of paper navigation, this smooth perceptual-action linkage occurs because the affordances controlling the physical manipulation of paper and the affordances providing for informational navigation are the same. Both are located at the surface of the interface. Participants could utilize both hands to simultaneously position and navigate several pieces of paper, indicating that navigation via real paper was resource efficient (Sellen & Harper, 2002).

Navigating paper in an online condition is time-consuming and wearisome. The affordances responsible for the perception-action mappings between intention and result are mediated and artificial. Manipulation is specifically one-handed. The computer requires a sort of serialization not found in the real world. We cannot select and navigate two different active windows at the same time. More importantly, the computer imposes severe spatial constraints on navigation, especially across documents. Where real paper allows for direct manipulation, virtual paper requires complex actions to carry out goals, drawing concentration from the formation of words. For example, resizing windows and catching hold of active windows via the title bar requires complex actions. Re-positioning paper in the world is a direct and natural action.

The second aspect of freedom is the liberty of spatial position. When dealing with paper, participants in the experiment unclipped pages to allow free placement of pages in space. Multiple pages were placed in a position where information could be passed back and forth, or notation documents were placed next to active documents to support composition. Fixations occurring during this activity varied across the page in an idiosyncratic manner (see Figure 39 below). Pages were in constant dynamic motion, moving towards the centre of the visual field when they were relevant and moving outwards towards the periphery of vision when they were no longer relevant. Essentially, having more than one page in the field of view at a time was crucial to performance.

Figure 39: Fixations across page



In order to replicate real paper interaction, several participants used 'page layout mode' in Microsoft Word. However, with page layout mode, the loss of resolution is so severe that reading becomes impossible and participants loose the ability to "lay out information in space" (Sellen & Harper, 2002, p. 94). Alternate methods included resizing, cascading, and tiling windows. All of these options restrict resolution and field of view. Participants reported a sense that information was being lost. Even two separate documents clutter the desktop severely. Participants in the online condition spent more time selecting, positioning, and exploring, than they did writing.

The third aspect of freedom from O'Hara and Sellen's study was the choice to annotate while reading and fusing ideas into a single paper. Annotations include asterisk, margin notes, underlines, and circles. The choice of annotations was entirely idiosyncratic. The freedom to act upon the text and impose our own structure links directly to the perceptual-action linkages by which we comprehend language and instantiate ideas. More importantly, annotation of real paper is a layered but transparent affair. Participants can see the results of their note taking, as the invariant structure of notes differs perceptually from the structure of the original paper. However with virtual paper note taking and reading may overlie each other due to a shared spatiality of surfaces. We do not need to interrupt reading to take notes, saccades and variable fixations allows simultaneous reading and note taking across multiple documents. These separate notes instantiate the planning required in the construction of new documents. On-line work is a very different situation. Granted, virtual paper is powerful because it affords recoverability and adaptability; computers can easily modify the linguistic information.

Ergonomics and Abduction: Isolating Phenomena

One of the previous critiques of the HD method stemmed from its obsession with comparative data for hypothesis testing. Data are not suitable as the basis of explanatory theory as they are intrinsically transitory, whereas empirical regularities are stable across data. Recall the pi-number experiments mentioned in the previous section. It is the regular relationship between leg length and riser height that forms the basis of good designs. The height of the stairs may change across situations, but the pi-number phenomena of leg length to riser height will be the same. In this way, phenomena isolation is highly compatible with ecological thinking and ecological design. Abduction provides for this phenomena isolation with the phenomena isolation control-task. While data gathering suits initial data analysis and experimental planning, exploratory data analysis is a group of statistical techniques that suits the isolation of phenomena. Given that abduction provides the control tasks, ergonomics offers the real world domain context to phenomena isolation. The convergence of abduction and ergonomics offers ecologically relevant, applied phenomena, which are based on the shared human-system unit of analysis.

The isolation of phenomena is a crucial point of the abductive control task. Once completed, the abductive inference will have constrained the problem search space to the point where we can generate an explanatory theory. Although phenomena isolation is not specifically an abductive inference, it is still one of the crucial aspects to a general abductive method. I thus make the claim that during real world problem solving it may be more important to have applicable phenomena and an impoverished theory, than impoverished phenomena and a well developed theory. Having phenomena that are applicable to the real world domain (reference situation) is important even when we do not yet have theories to explain the phenomena's existence or causal relationships. There are many phenomena that we have isolated, but have not explained. Granted, in some situations we posit new phenomena, based on generative theory. However, my claim is not a denunciation of theory. I place emphasis on the isolated phenomena because the phenomena, along with auxiliary knowledge and the research problem have been proposed as constraints on the eventual abductive generation of an explanatory theory. The informational structure that makes up a theory can only be as good as the information that constrains its generation.

How do phenomenon constraints, auxiliary knowledge constraints, and research problem constraints actually constrain the search space? To clarify this relationship, let me use some of the ecological terminology employed in the previous chapter to further map and explore the relationship between abduction and ergonomics, during this phase of problem solving. In the previous chapter, I described several ecological terms used in classifying the human-system mutuality. The terms used to map the human-system mutuality were affordances, effectivity constraints, and environmental constraints. In Chapter 3, I discussed how the convergence of environmental and effectivity constraints forms the boundaries of what is affordable to the actor.

To retrace our steps for a moment, why is the pre-phenomenon paradigm-specific auxiliary knowledge important to the isolation of phenomena and the generation of theory? I have previously proposed that auxiliary knowledge is important to scientific explanation because the auxiliary knowledge constrains the eventual problem solution. I extend this idea by proposing that auxiliary knowledge constrains the eventual problem solution by attuning the scientist's effectivities. I make this proposal as an appeal to the strong element of ecological compatibility between abductive ideas and ergonomic ideas, when used together in the context of real world problem solving. Effectivities cut across the subjective/objective differentiation, for they have no existence apart from their shared relation between the properties of the actor and the properties of the environment (Flach, 1995). To restate, our effectivity properties are our ways of being effective and our means of acting. Shaw, Flascher and Kadar (1995) note, "effectivities determine whether a specific class of actors, for whom the information specifying the relevant affordance property is available, can use the information to realize that affordance property..." (p. 304).

I propose that the intentional acquisition of auxiliary knowledge attunes our effectivity properties. This proposal is based on Gibson's conception of perceptual refinement. Gibson (1979) notes, "The process of pickup is postulated to be very susceptible to development...The opportunities for educating attention, for exploring and adjusting, for extracting and abstracting are unlimited..." (p. 250). In essence, our effectivity properties are not necessarily always physical. Actors have cognitive effectivity properties that can be affected by information, "The state of a perceptual system is altered when it is attuned to information of a certain sort. The system has become sensitized. Differences are noticed that were previously not noticed. Features become distinctive that were formerly vague" (Gibson, 1979, p. 254).

For example, my physical effectivity properties include my ability to grasp objects. Using a steel glove, I can extend my effectivities so that I can grasp objects that would have previously harmed me. This relationship also applies to the refinement of cognitive effectivities. By reading about a scientific paradigm I extend my effectivities so that I am able to form theories that would have previously escaped me. Furthermore, our formation of the research problem also affects our effectivities. In fact, the research problem constrains what auxiliary knowledge we intend to explore. Changing the research problem changes where we look and what we look for, which will govern what we find. Together, the auxiliary knowledge and the research problem are two important pieces of information that form the major component of a scientist's effectivity constraints. In the case of complex socio-technical scientific systems, the combined auxiliary-knowledge/research-problem effectivity-constraints can be distributed across a range of actors and externalized informational systems.

If both auxiliary knowledge and the research problem are effectivity constraints then there may be strong ecological reasons for using an abductive framework to describe and map the control tasks relevant to the problem-solving domain described by ergonomics. In conjunction with my claims about the place of problem formation and auxiliary knowledge in the mutual unit of analysis, I also propose that the data gained from the data-gathering control task represents the environmental constraints. The data gathered from the control task represents both the positive and negative environmental constraints. The drive to solve the research problem is the intention that give the data gathered from experiments their value as positive and negative constraints. The effectivity constraints (research problem, auxiliary knowledge) combine with the positive environmental constraints (positive patterns in the experimental data). This combination affords organiseability or negatively affords disorganiseability. By offering regularity, phenomena afford organization, and organiseability is an informational affordance. The conjunction of these ideas suggests that abduction provides for a strong ecological understanding of problem solving. To consider this relationship diagrammatically, recall the search space metaphor offered in the last chapter. I propose that the phenomenon isolation domain can borrow the same metaphors used in the example from last chapter. Consider the diagram of phenomenon isolation (see Figure 40, below).

Figure 40: Phenomena Isolation via ecological theory

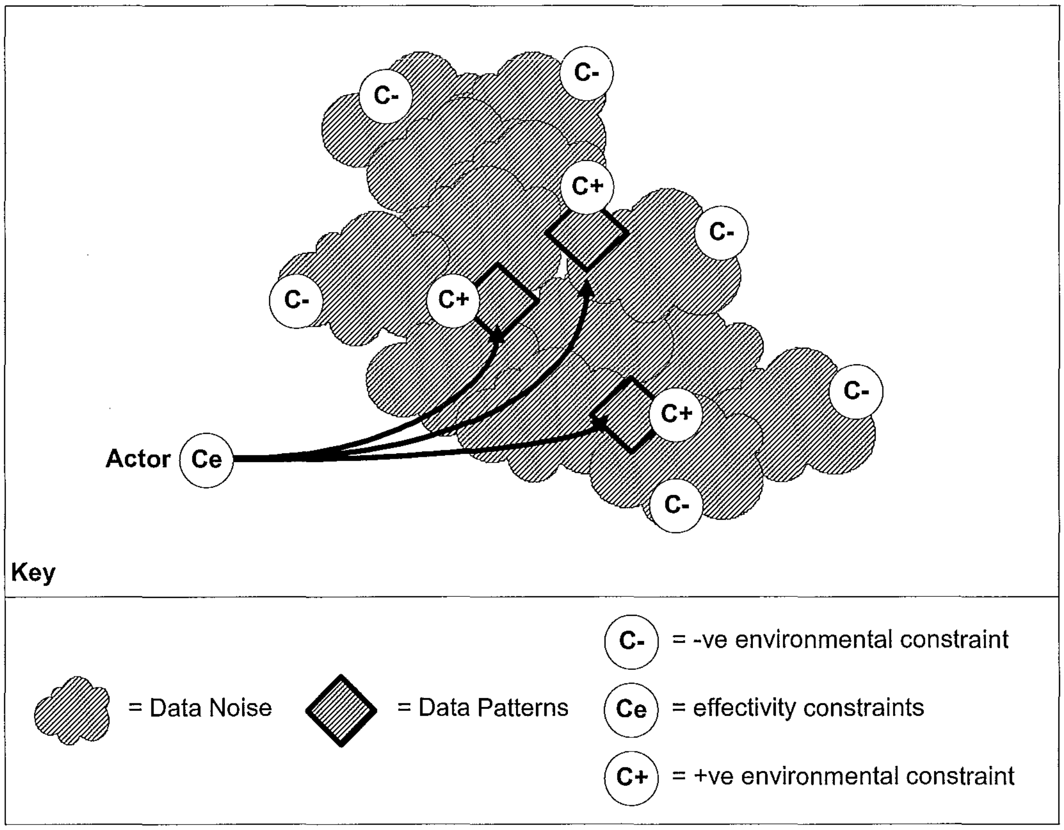
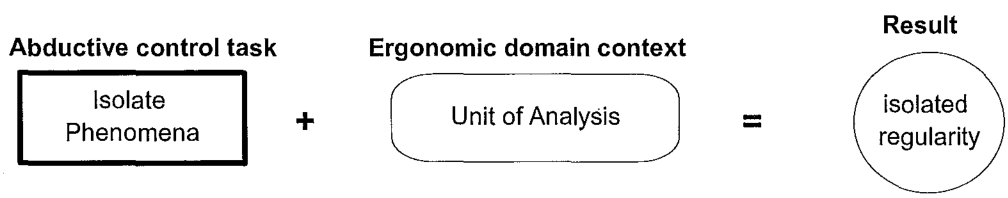


Figure 40 presents a visual metaphor of the phenomena search space. Again, the positive and negative environmental constraints are the data gathered during experimentation and research. Environmental constraints are positive depending on intention. In this example, our intention is to seek regularity. Thus, the data that falls into patterns provides positive constraints, whereas noisy or irregular data provides negative constraints. Despite our ecologically sensitive portrayal phenomena isolation is still an intricate concept to grasp. The key to understanding phenomena isolation comes when we realize that a claim about phenomena is a scientific abstraction from patterns in data. The distinction between data and phenomena is not a denunciation of ecological theories, ecological psychology, or the ecological unit of analysis. Ecological psychology commits to ideas such as 'direct perception' and 'affordances.' Thus a differentiation between real world data and phenomena might seem to be a critique of ecological psychology.

This is not the case. It is important to distinguish between the real world usage of concepts and the scientific exploration of hypothesis. In their most literal scientific sense, phenomena are rarely viewable, in that they are categorical abstract labels of real world empirical regularities. However, in practical use, a phenomenon is perceivable depending on its nature. I previously mentioned that, 'Not all phenomena are created equal.' However, ecological design makes an intelligent commitment to focus on isolating ecological phenomena in order understand the interaction of artefacts and people, rather than studying cognitively representational or mediational phenomena, which by their nature are more difficult to discuss and isolate. Affordances, constraints, and effectivities are all examples of sound ecological phenomena.

Stage 4: Real world problem solving framework



Human-paper example: Human-paper interaction phenomena

Case studies analysis

To summarize some of the patterns from the case studies discussed above:

- Reading is relevant in most everyday activities.
- Paper is the medium of choice when authoring.
- Reading and writing are intertwined.

- Reading and writing occur across multiple documents.
- Paper-based work still does make use of whatever technologies are at hand
- When authoring with real paper we look through text using both hands and eyes. Authoring with real paper becomes an exploration-based, perceptual, and externalized endeavour, using high quantities of direct perception.
- Authoring with virtual paper becomes a serialized, linear, cognitive endeavour, using high levels of disconnected perception.
- There is no way to specifically catalogue the control tasks relevant to authoring, as everyone authors documents differently, with different combinations of reading, writing, fusing, note-taking, sketching, diagramming, corrected, reviewing, re-reading, and finalizing.

Mathematical biometric analysis

The phenomena relevant to this brief real world examination are perceptual-action in nature. The isolation of the perceptual action phenomena applicable to authoring begins with visual fields. The maximum field of view for the human eye extends 45 degrees above and below the normal line of sight (which is 15 degrees below the horizontal) (Pheasant, 1987). The parafoveal , which is a region of general vision extends 10 degrees above and below the normal line of sight (Pheasant, 1987). The foveal visual field, which is the area of maximum visual acuity extends 2 degrees above and below the normal line of sight (Pheasant, 1987). Assume that an average desk is 120 cm long and 60 cm wide, and a sheet of A4 sheet of paper is 21 by 27 cm. Thus, an average desk can accommodate five sheets of paper lengthwise, and two sheets along its width. However, with a laptop on the desk, this equates to a practical arrangement of two sheets by two sheets per desk and laptop combination.

The average reading distance is 400 (mm). This means at 400 mm, the prime visual field extends into a radius of 13 mm and the gross visual field extends into a radius of 70 mm. Peripheral vision accounts for a far wider radius, but provides little detail definition. A visual saccade accounts for 2 degrees of the visual angle and lasts for two seconds (Pheasant, 1987). Assume that we have covered our desk with two by two sheets of paper (four sheets) and a laptop, and that we begin with our eyes at a normal visual angle (15 degrees below horizontal). With several saccades and a slight inclination of the head, we can read and manipulate anything within this visual perimeter. In fact, placing visual displays anywhere within 30 of horizontal (and fifteen degrees off the normal line of site) is the preferred display zone (Pheasant, 1987). The preferred display zone is the best place to locate displays, a field which also extends 15 degrees on either side of the head (Pheasant, 1987).

Regarding characters, a person with normal eyesight can resolve features, which subtend an angle of one minute of arc (Pheasant, 1987). One minute of arc is 1/60 degrees, which equals 0.0003 radians. However, the recommended character size suggests that characters should subtend 0.005 radians times distance (0.005 times Distance), all the way to 0.007 radians (Pheasant, 1987). In an average paperback book, the approximate character height is three mm. Three mm is also approximately the size of twelve-point font. Assume that S (size of a feature), D (distance), and optical angle (A). These are related by A = S/D (with A in radians)[12]. Given A = S/D, the optical angle of average paperback character at four hundred mm is 0.007 radians. This is clearly sufficient to read. Complications arise when considering a differentiation between virtual paper and real paper. Thus, for the sake of this brief real world exploration, real paper and virtual paper[13] differ in one respect, virtual distance.

To explain this factor, paper in the world occupies a large domain space. Given complete actor mobility, paper can occupy three hundred and sixty degrees of space around the actor. However, virtual paper is constrained by the computer monitor. Granted, with virtual reality, augmented virtual paper, or screen-projector technologies the virtual work domain can begin to imitate the large visual spectrum that paper occupies in the real world work domain. However, Schilit, Price, Golovchinsky, Tanaka, and Marshall (1999) note, " Readers often work with more than one page at a time. Reading appliances can support...[this]...by including additional digital displays, but since each display costs far more than a piece of paper, reading appliances do not suffice" (p. 68). Based on this cost increase, I will focus for

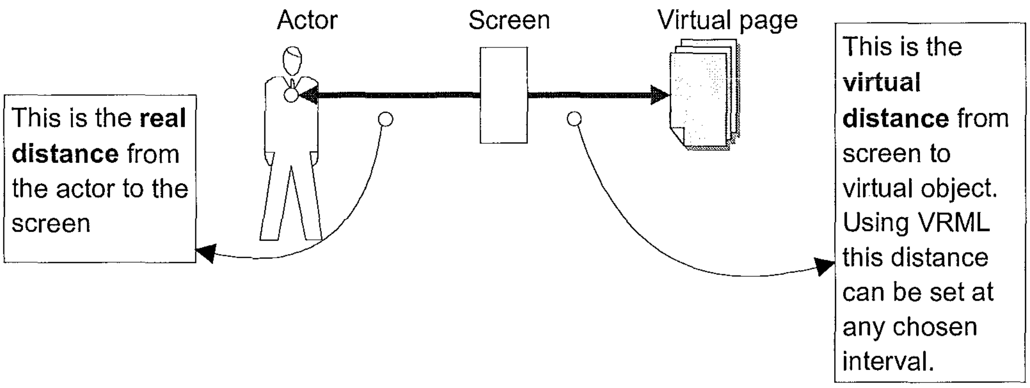
12 The relationship of Tan = O/A produces the same result in degrees.

13 This assumes that the virtual paper exists on a single display screen.

the moment on a user's interaction with single displays. At a later point I will discuss broadened virtual paper domains.

A block of two by two sheets of real paper can fill the visual field at around 400 to 500 mm. In a virtual world, in order to present a block of two by two sheets (four sheets total), and assuming that the actor is 400 to 500 mm from the computer screen, the virtual sheets need to be much further into the screen perspective (see Figure 41).

Figure 41: Real and virtual distances



The distance from screen surface to sheet surface into the screen is the virtual distance. Thus, the relative distance from actor to paper in a virtual situation is always the real distance (actor to screen) plus the virtual distance (screen surface to virtual paper). Reading virtual paper works best when a single page is presented on screen. After all, the average laptop is twenty-one cm high, and can almost accommodate an entire sheet of paper on screen. This limitation presents obvious problems when we consider the characteristics of multiple documents. This limitation presents further difficulties when considering the newest range of every growing personal digital assistant devices with their limited screen space.

Consider the optical angles present in real paper. Assuming a twelve-point font and an average reading distance of four hundred mm, each feature subsumes 0.007 radians. Assuming a paper height of two hundred and ninety seven mm and a reading distance of four hundred mm, paper subsumes 0.725 radians of optical angle. Feature height divided by paper height equates to a character/paper relationship ratio of 0.01. Virtual paper displays the same character/paper relationship ratio of 0.01, because the virtual paper posses the same relationship between paper size, and character height. However, consider a presentation grid of two by two sheets of paper. With real paper, every letter is readable. With virtual paper, presenting a two by two block of virtual paper on screen creates an unreadable blur. Suppose that we create a further ratio between the a) readable character/paper relationship ratio and b) reading distance. This produces a 'reading ratio' for real world paper of 2.50E-05, or 0.000025[14]. Recall that virtual paper displays a virtual + real distance relationship. The total distance to create the same two by two page display in a virtual setting requires a real distance of four hundred mm and a virtual distance of seven hundred and fifty mm (1150 mm total distance). A reading ratio for virtual paper is 8.70E-06, or 0.0000087. Suppose that we create an ascending series by calculating the reading ratio for a range of different distances, starting at 1150 m (see Table 1 below).

Table 1: Reading ratio versus distance

Real paper reading ratio	Running reading ratio	Total Distance	Virtual distance
2.50E-05	8.70E-06	1150	750
	9.09E-06	1100	700
	9.52E-06	1050	650
	1.00E-05	1000	600
	1.05E-05	950	550
	1.11E-05	900	500
	1.18E-05	850	450
	1.25E-05	800	400
	1.33E-05	750	350
	1.43E-05	700	300
	1.54E-05	650	250
	1.67E-05	600	200
	1.82E-05	550	150
	2.00E-05	500	100
	2.22E-05	450	50
	2.50E-05	**400**	**0**
	2.86E-05	**350**	
	3.33E-05	**300**	
	4.00E-05	**250**	
	5.00E-05	**200**	
	6.67E-05	**150**	
	1.00E-04	**100**	
	2.00E-04	**50**	

NB: All the values in bold are equal to or larger than the target value of the real paper reading ratio (2.50E-05, or 0.000025).

[14] Reading ratio = (character/paper ratio) / (reading distance of 400mm)

As Table 1 indicates, the reading ratio for real paper and virtual paper are the same when the virtual page is, in effect, pressed directly against the screen. Previous relationships indicated how font on screen and font off-screen carry the same optical angles, thus presenting the same approximate reading ease. However, as the virtual distance grows (increasing the total distance), the reading ratio drops due to a loss in optical angle. Suppose that we form an ascending series of Angle = Size/Distance based on an assumed the character size of three mm for virtual paper, see Table 2 below.

Table 2: Angle = Size/Distance

Total Distance (mm)	Angle (radians)	Character size (mm)
1150	0.002608696	3
1100	0.002727273	3
1050	0.002857143	3
1000	**0.003**	**3**
950	**0.003157895**	**3**
900	**0.003333333**	**3**
850	**0.003529412**	**3**
800	**0.00375**	**3**
750	**0.004**	**3**
700	**0.004285714**	**3**
650	**0.004615385**	**3**
600	**0.005**	**3**
550	**0.005454545**	**3**
500	**0.006**	**3**
450	**0.006666667**	**3**
400	**0.0075**	**3**
350	**0.008571429**	**3**
300	**0.01**	**3**
250	**0.012**	**3**
200	**0.015**	**3**
150	**0.02**	**3**
100	**0.03**	**3**
50	**0.06**	**3**

NB: The figures in bold are the distances at which the angle of a standard 3 mm character becomes smaller than the reading angle of 0.003 radians.

As Table 2 above indicates, with virtual VRML paper, a standard character which is three mm high produces an optical angle less than paperback reading at 450 mm total distance. A prediction suggests that the characters in a single page VRML simulation would subsume less than an optical angle of 0.003 at 1000 mm total distance, which is 600 mm virtual distance (this measurement is the smaller than the recommended size of letters labelling instruments and gauges). Further simulations with a single sheet of virtual paper (in VRML) indicate that reading actually becomes impossible around 750 mm total distance (400 mm virtual distance). Thus, the optical mathematics predicts the readability of virtual paper +/- 200 mm. This error is probably due to the inherent resolution problems of the VRML simulation technique. The pictures mapped on the virtual pages are merely screenshots of documents. However, the pattern that does emerge suggests that there is a bottleneck in the presentation of information provided by multiple virtual papers when they are presented on single screens.

The unit of analysis

The analysis carried out during the abductive stage of phenomena isolation is an attempt to isolate the phenomena, with ergonomics providing the relevant domain for the abductive phenomena-isolation control task. The phenomena relevant to the human-paper authoring system are affordances, constraints, and effectivities. These properties interact to make up the ergonomics unit of analysis. By the end of this section, we will have isolated several phenomena from the data gathered previously. These phenomena (affordances, constraints, and effectivities) will provide the basis for the regularity based theories that contribute to design. Figure 42 and Figure 43 below indicate the relevant affordances, constraints, and effectivities for both virtual and real paper.

Figure 42: Virtual paper unit of analysis

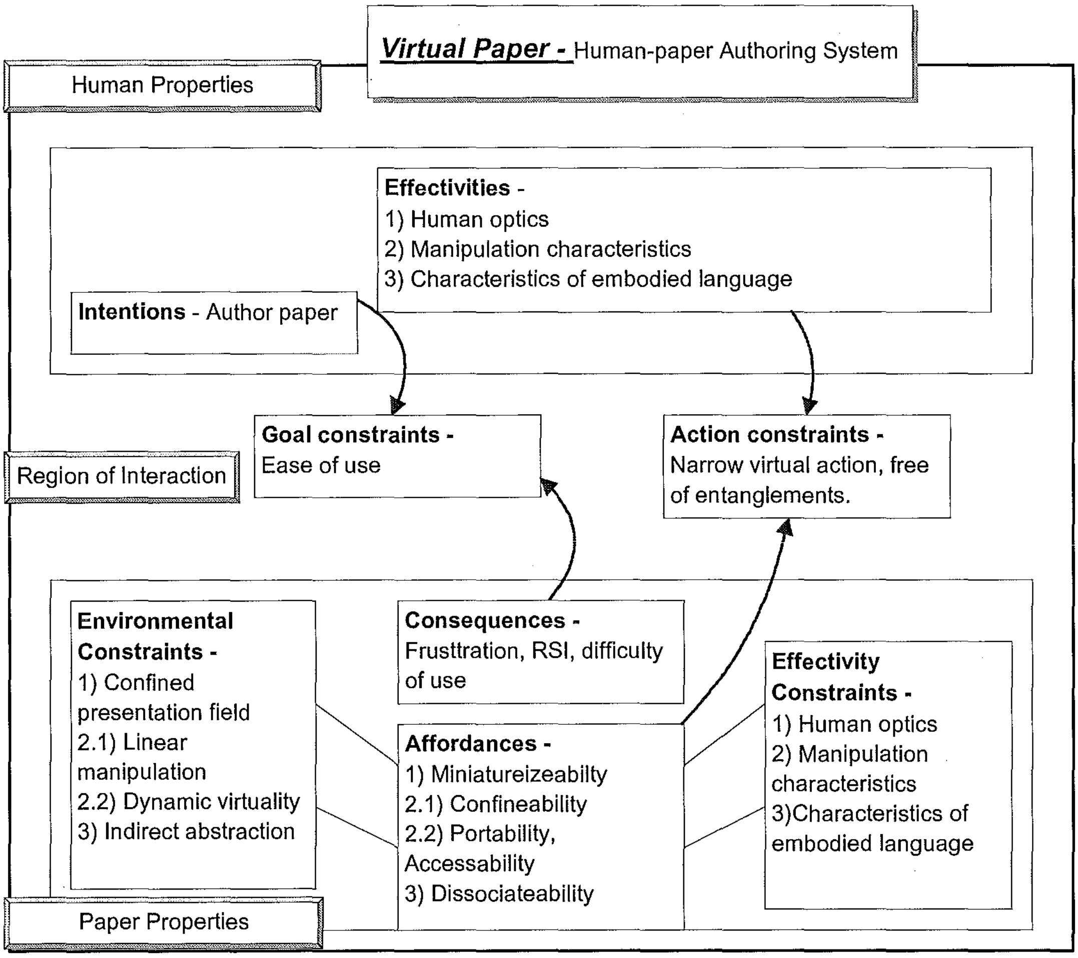
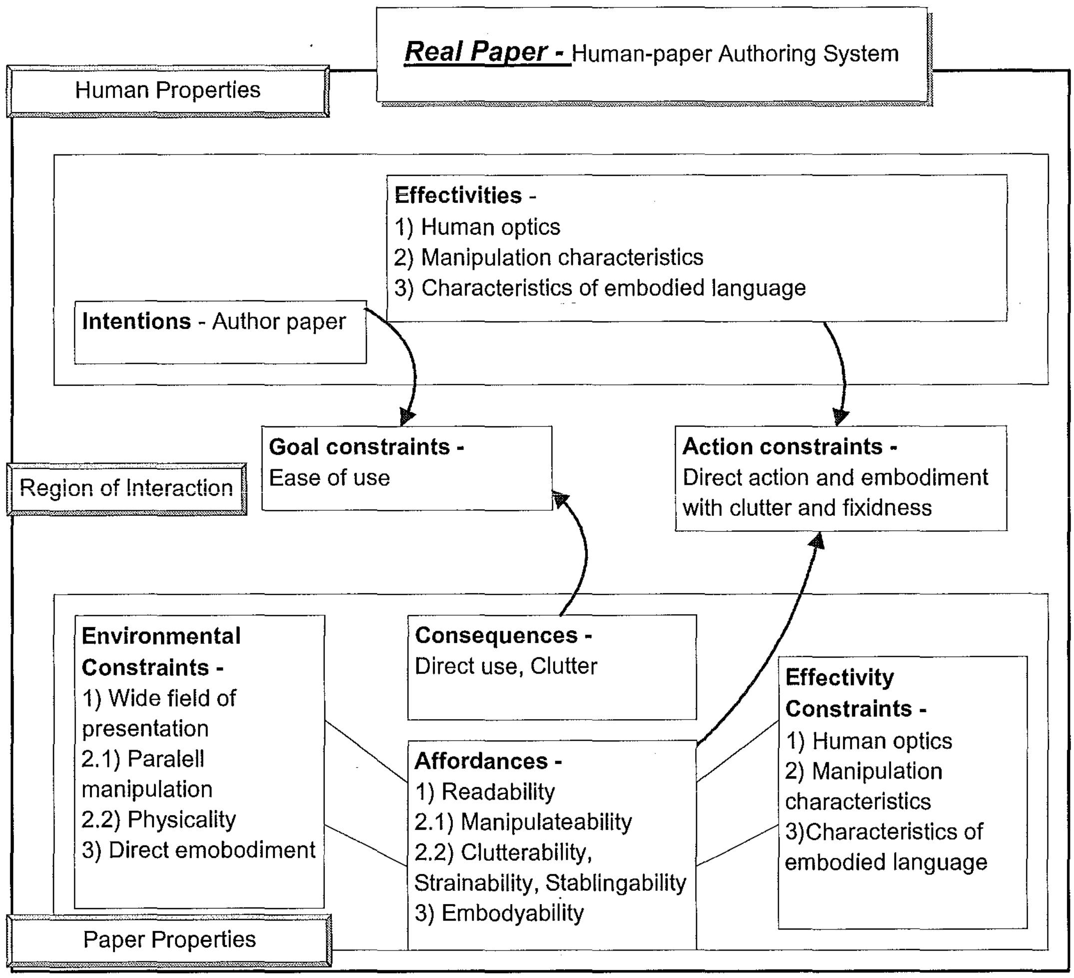


Figure 43: Real paper unit of analysis



Virtual paper

With virtual paper, there are three effectivity constraints that I have focused on[15]: optical constraints, manipulation constraints, and embodied language constraints. There are four environmental constraints: confined presentation field, linear manipulation, dynamic virtuality, and indirect abstraction. Each of the effectivity constraints are taken with reference to one of the environmental constraints, except for the second constraint pair. In this case, the effectivity constraints (manipulation characteristics) are taken with reference to two environmental constraints (linear manipulation and dynamic virtuality), resulting in four affordances (confineability, portability, and accessibility, and adaptability). I will

[15] This is not an exhaustive presentation; there are probably many more affordances than those that I mention in this chapter.

briefly move through each of these constraint pairs and discuss the affordances made available by each pair.

Constraint pair 1: Human optics and confined presentation field - The eye is essentially a structure-seeking device with a limited field of view. Yet, due to its coordinated head and eye motor activities, the perceptual system provides a wide field of structure acquisition. However, virtual paper, in its current form provides a limited window of presentation, or a confined visual presentation field. Granted, virtual paper has the same invariant structure as real paper. Despite its increased total distance from the eye, virtual paper employs the same page/character ratio as real paper, suggesting that the character/page invariants presented in the real world and the virtual world are much the same. Ecological theory supports this, suggesting that good pictures continue to preserve the same invariants of their real world counterpart objects. This is really what a computer screen is, a dynamic picture, creating false perspective and structure in three dimensions on a two dimensional surface.

The conjunction of optical effectivities and the confined visual field of presentation of the computer screen combine to provide the negative affordance of miniatureizeabilty. In essence, in order to view multiple pages at once, virtual paper must imitate real paper by tiling across the screen. However, the limited field of view provided by the computer screen, in conjunction with the eye's limitations, negatively affords miniatureizeabilty. Miniatureizeabilty is a factor of the number of pages specified by the screen at any one point in time. The negative affordance of miniatureizeabilty can be countered by adding screens, virtual reality, or augmented reality. Added screens or larger screens create more screen acreage, providing more space to arrange virtual documents.

Constraint pair 2, part 1: Linear manipulation and manipulation characteristics – The perceptual-action characteristics of the human body suggest a capability of dual manipulation; i.e. we have two hands to act with. Virtual paper exists within windows, whether it is a MS word, VRML, or txt document. Each interface window requires linear and sequential manipulation and only one window can be active at a time. For example, an actor cannot write in one window while scrolling in another. Human effectivity constraints and environmental constraints combine to form the negative affordance of confineability. In essence, we are confined to one active window of action. This cannot be changed easily because it is based on the linear nature of computer input. Adding extra screens would increase the field of view, but would not change the way in which we act on the computer interface.

Constraint pair 2, part 2: Dynamic virtuality and manipulation characteristics – The human body has a limited load capacity; i.e. limited manipulation characteristics. Given the average weight of a single ream of paper, we are usually limited to lifting a limited number of sheets paper at any one time. Yet, virtual paper, in effect has no weight. Thus, the two constraints combine to offer the positive affordance of portability; i.e. virtual paper is very portable. A paper project equivalent to a ream of paper (500 sheets) can be carried on a single floppy disk. However, there are two other affordances offered by the same constraint pairing.

The manipulation characteristics of the actor and the dynamic virtuality of virtual paper re-combine to offer the affordances of accessibility and adaptability. To clarify, extended perception and disconnected perception allows extended knowledge of interface characteristics beyond those features immediately visible on the surface of the interface. Furthermore, the computer maintains a constant record of every word in the virtual document. This environmental constraint, combined with our extended perception of extra interface characteristics affords accessibility, or direct text searching with a text-search engine. In essence, when dealing with virtual paper intra-document search engines offer a strong intra-text interaction. Real paper offers a contents page, but a contents page does not account for every word in the text.

The environmental constraints of dynamic virtuality combine again with human manipulation characteristics to afford adaptability. After all, virtual paper is more adaptable than real paper. The physical alteration of letters is easier on a computer than with a manual typewriter, pencil, pen or real document. Granted, we can mark directly on top of real documents, but over time the multiple layers tend to occlude each other. Virtual paper offers both dynamic and layered alteration. For example, I can directly alter the words on this page by deleting and retyping or I can add a MS Word reviewing note which exists on top of the text without altering previous text structure. Thus, both accessibility and adaptability are positive affordances.

Constraint pair 3: Indirect abstraction and characteristics of embodied language –Embodied and ecological theories view language as an embedded, contextual, perception-comprehension system. Language offers support for situated action, external memory storage, and transmission of information about affordances. More importantly, the process of producing and comprehending language is considered to be an active perceptual-action cycle rather than a passive, mediated, representational, linear-recording system (Barsalou, 1999b). This suggests that we use our spatial placement of written language on pages, books, and sketches in combination with previous effectivity constraints for an active language system. The embodied language that occurs during authoring depends on the spatiality of real paper.

Conversely, virtual paper is indirect and abstractly spatial; computer screens are pictures. They are not three-dimensional environments and they do not afford the strong perceptual-action-manipulation linkages that embodied language requires. Thus, virtual paper negatively affords dissociateability. As actors, are dissociated from their paper interaction, which forces them out of embodied linguistic processes. Granted, we can interact with our paper via search engines (see previous constraint pair). Search engine interaction is a different type of human-paper interaction; I suggest that search engine interaction is not embodied because it requires a dissociated perception of the entire structure of the essay. Conversely, embodied interaction requires spatial freedom of each page in the visual field, and the freedom of the actor to move and interact with the spatially arranged pages.

Real paper

Constraint pair 1: Human optics and wide presentation field – In opposition to single screen virtual paper, real paper offers a wide field of presentation. Depending on how active the perceiver is, we can literally cover our work environment with paper, in a 360-degree field of view. Saccades, head movements, and ambulatory motions can carry an actor through a totally papered-over environment. The constraints offered by real paper, in conjunction with the capabilities of the entire perceptual-action system (eye, nervous system, brain, body) combine to provide the positive affordance of readability.

Constraint pair 2, part 1: Parallel manipulation and manipulation characteristics – The perceptual-action characteristics of the human body are dualistic. When using real paper we can flip pages, write, and scan a book, all at the same time. Thus, our effectivity constraints and environmental constraints combine to form the positive affordance of manipulateability. Actors are free to act upon the entire world of paper with two hands.

Constraint pair 2, part 2: Physicality and manipulation characteristics – Real paper is heavy and we have a limited lifting capacity. In masse real paper is too heavy to move, and too arduous to shift in allotments. Furthermore, remembering that our interaction with real paper is not confined to one specific area, real paper also has the capability of clutter up our lives. The two constraints at this level combine to support the negative affordances of strainability, and clutterability. There is a third affordance offered at this level, which is either positive or negative depending on intention. Recall that virtual paper is adaptable and dynamic. Conversely, with real paper each word is un-accounted for, only the actor is aware of the location of words or phrases. There is no computer in the loop to help offload the memory requirements when searching through the text. Thus, the effectivity constraints and environmental constraints unite to offer the affordance of loadability. In essence, when using real paper it is up to the actor to maintain an index of the content of the whole paper, this places the load on memory rather than the machine.

Constraint pair 3: Direct embodiment and characteristics of embodied language – A picture is worth a thousand words, but words can pass the wisdom of the ages. We have already discussed the characteristics of embodied language. It is enough to say that real paper has both spatiality and embodiment. Interaction with real paper can be a full-body, perceptual-action cycle. Instead of relying on narrow interaction (as with computers), we can interact with real world paper across the full breadth of our environment (office, den, living room) using many of our physical effectivities. Thus, real paper positively affords embodyability. Real paper supports embodied language as we are embedded into the interaction. To review this entire section, the phenomena of interest are the affordances and constraints relevant to human paper interaction, across the task of authoring.

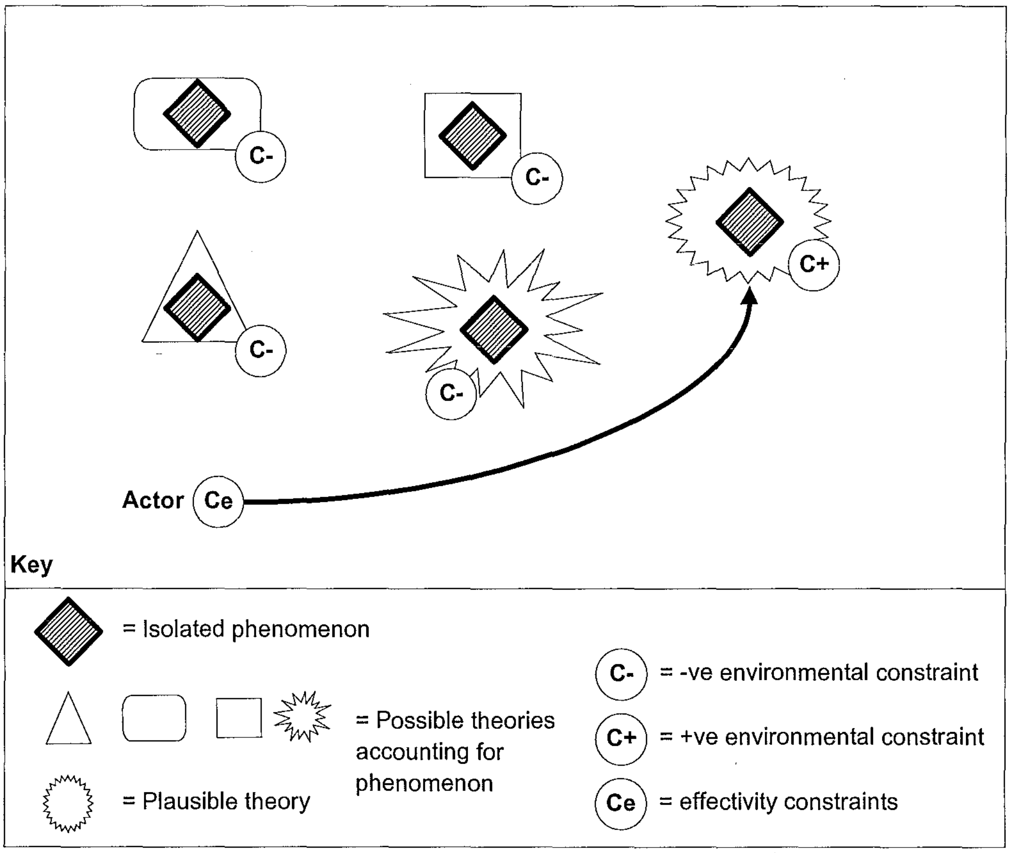
Ergonomics and Abduction: Theory Formation

The hypothetico-deductive method avoids the responsibility of providing a methodological structure for generating theories. Theories are generated amethodologically, without a methodological linkage between the data, patterns, and theories. This thesis has presented abduction as a feasible method of generating explanatory theories. I have proposed that abduction appropriately describes the control tasks and information states involved in the formation of a research problem, gathering of knowledge, formation of experiments, isolation of phenomena and the eventual theory generation. Meanwhile, ergonomics continues to offer the domain context relevant to real world problem solving. Together, abduction and ergonomics form an ecologically sensitive real world problem solving framework.

My portrayal of theory formation suggests that theories are the result of a linear progression. In practice, a cyclic abductive method is more realistic. Theory formation is part of the continuing abductive cycle towards strong explanatory theories. Certain phenomena may lead quickly to theory, whereas others may require long cycles of data-gathering, auxiliary knowledge, and phenomena isolation. Again, theories are often only as good as their phenomena. I want to use the ecological perspective adopted when considering phenomena isolation because I think it provides a concise summary of what has already occurred. In the previous section, I made a link between the stages of knowledge/information produced by the control task components (auxiliary knowledge, research problem etc.) and the ecological terminology used to describe the human-system mutuality.

I previously proposed that the auxiliary knowledge and problem formation represented effectivity constraints. Further I suggested that the data gathered represented positive and negative environmental constraints. This suggested that there are strong ecological reasons behind our ability to ascertain patterns in data. Together with our effectivities phenomena afford organiseability. To repeat, certain collections of experimental data explored during EDA act in conjunction with our effectivities and lead us to phenomenon. Phenomena afford organiseability. Organiseability is not a physical affordance; rather it is an informational affordance offering informational stability and regularity. To apply this metaphor to theory generation, consider the theory generation space pictorially. Consider a diagram of theory generation (see Figure 44, below).

Figure 44: Theory generation

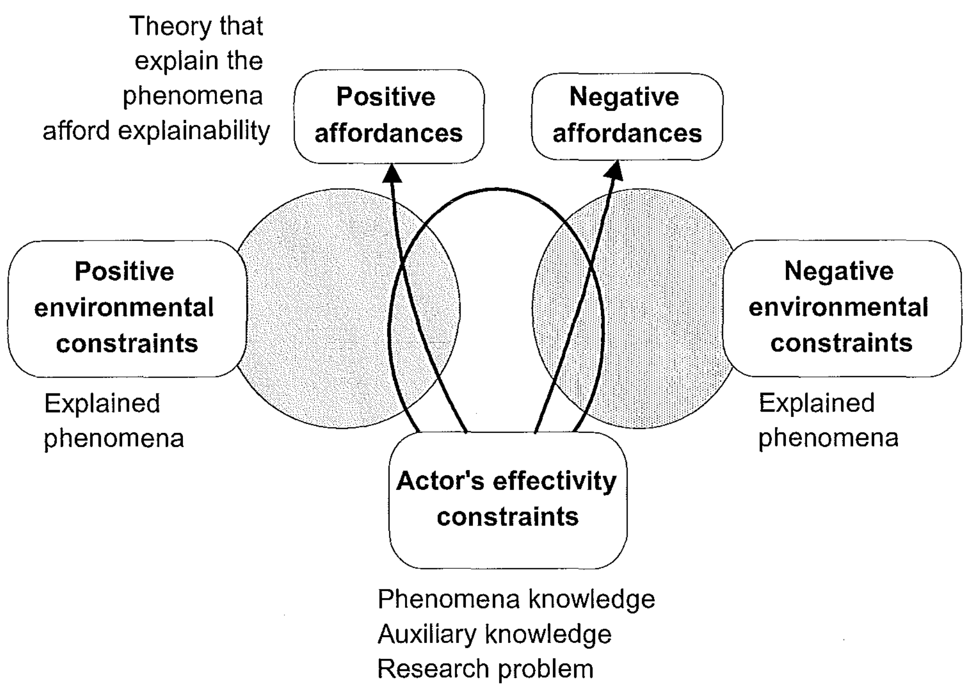


During theory generation, the intentions, environmental constraints, and effectivity constraints are different. During phenomena isolation, the environmental constraints are data. Conversely, during theory generation the environmental constraints are the theories. Recall, the theory generation abductive control tasks requires that we seek an explanation for the isolated regularities, usually in conjunction with the real world goal-directed questions posed in the research problem. Thus, given the task of explaining a phenomenon, the environmental constraints that fill the hypothesis search space are explained phenomena. In the diagram, the multiplicity of possible explanations is indicated by the different theory shapes.

However, each of the theories is focused on explaining the phenomena isolated in the previous stage of the abductive control task (phenomena isolation). Continuing with the ecological description of theory generation, I propose that the auxiliary knowledge and problem formulations continue to form the effectivity constraints relevant to theory generation. However, during this phase the effectivity constraints are affected by a change in intention. During theory generation, the goal is to explain phenomena, not to isolate data patterns. Thus, in addition to auxiliary knowledge and the problem, our effectivity constraints are moderated by our knowledge of the previously isolated phenomena, as phenomena are the object of our explanations.

Thus, our effectivities include knowledge of phenomena (empirical regularities) and our intentions include a desire to explain these regularities. Moving away from directly perceivable experimental information, the positive and negative environmental constraints during theory generation are represented by the various theories that might account for the phenomena. This is the space of all possible hypotheses. Given the interaction of our effectivity constraints (auxiliary knowledge, phenomena knowledge, problem formation), intentions (develop theory), and environmental constraints (theories explaining phenomena) theories that do not explain the phenomena negatively afford confuseability. Theories that do not explain the phenomenon, or explain it wrongly, will confuse or mislead the researcher (see Figure 45).

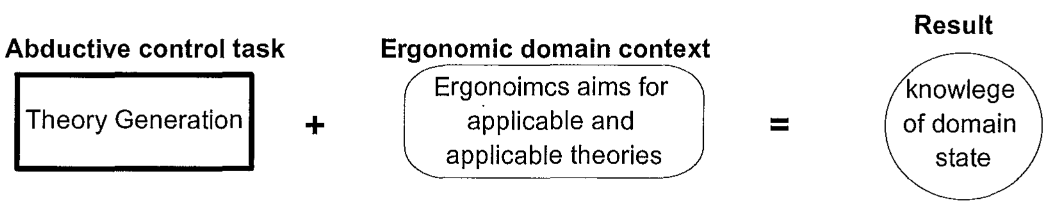
Figure 45: The ecological relationship between theories, phenomena and the scientist



Theories that explain the phenomena fit our auxiliary knowledge, problem formation, and knowledge of the phenomena afford explainability. Essentially, theories that explain the phenomena will lead us towards understanding. In true ecological style, the convergence of effectivities, intentions, and environmental constraints sets the envelope of affordances available. In brief, I have proposed that phenomena and theories are conceptual objects that offer informational affordances. Phenomena afford organiseability and disorganiseability, and theories afford confuseability and explainability. Based on the tight linkage between abduction and ecological theory, I suggest that abduction provides for the generation of explanatory theory in both a logical and ecological sense.

When abduction links to the correct real world domain by the ergonomics-context, abduction provides for relevant, real-world explanatory theories. At a practical level, if this were a complete real world investigation, HD theory testing might be applicable at this point. However, theory testing is a smaller part of science. This does not deny that experimentation is crucial. The experimentation used to produce data from which to generate theories involves different skills from hypothesis testing. Granted, provisional testing also occurs at the gathering data stage, and the phenomena isolation state, research is circular.

Stage 5: Real world problem solving framework



Human-paper example: Ecological paper interaction

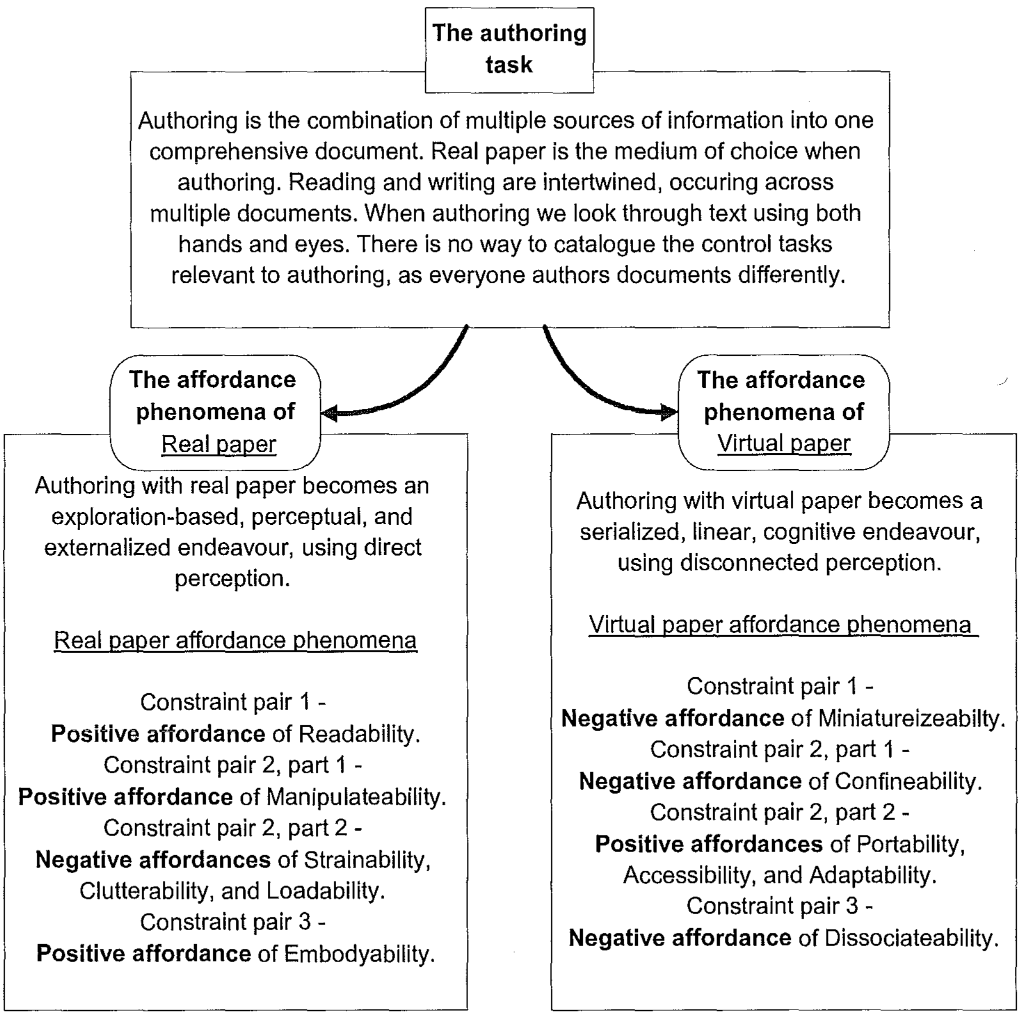
To place theory generation in context, reconsider the problem of human-paper interaction. More importantly, recollect our target problem questions....

- Firstly, does real paper actually enhance authoring activities?
- Secondly, if real paper enhances authoring, what is it about of real paper that makes authoring more efficient?

- Thirdly, does virtual paper contain the same invariants as real paper?
- Lastly, what does virtual paper offer the authoring activity?

To answer these questions and to provide some form of a human-paper interaction theory I reintroduce the affordance phenomena isolated in the previous abductive control task (see Figure 46, below).

Figure 46: Affordances



At first it appears that virtual paper does not support efficient work practices. However, this is not the case. Both real paper and virtual paper have three positive and three negative affordances each. Can these negative affordances be avoided? After all, affordances are relative opportunities for action. Altering the machine or training human effectivities may remove many of the negative affordances relevant to both real and virtual paper. As mentioned previously, the single window of interaction offered by the computer screen can be added to or expanded; this would work towards changing the negative affordance of miniatureizeabilty for virtual paper. However, these are issues we will discuss later. At the moment we need to focus on forming explanatory theories based on these affordance phenomena.

To consider our four target questions, the observational experiments indicate that real paper does appear to enhance authoring activities. Observational experiments indicate that real paper does enhance authoring activities (O'Hara & Sellen, 1997). Given that real paper enhances authoring, real paper's advantage is that it affords readability and manipulatability, and embodyability. In essence, real paper enhances embodiment and embodied language. However, virtual paper contains the same invariants as real paper. The difference between real and virtual paper lies in the limited and distanced presentation field offered by a single computer. Real paper places the page/letter invariants into a large three-dimensional environment. Conversely, computers under-specify the perceptual information, by failing to use the entire visual field. By being a constrained window of perception, single screens also limit action. A single computer screen does not utilize the full visual field and does not use the full range of perceptual action mapping that occurs with real embodied paper. However, virtual paper offers some power affordances to the authoring task. Recall that virtual paper affords accessibility (intra-text search engine) and adaptability (layered or non-layered annotation). I previously described accessibility as the ability to search and index every word in a virtual document. Virtual paper also affords adaptability; virtual paper can be adapted at the level of text or by adding further layers on top of the text. Most importantly, virtual paper offers a freedom from clutter, a lure that is hard to avoid.

To tie the analysis together, consider the human-paper authoring system. The ultimate intention is to author a paper. Authoring is the intention to imprint marks on a page in the form of an article, letter, prose, or poem for the sake of communication. The localized goals change, but the general intentions stay the same. The specific intentions of authoring behaviours involve the creation of a separate document that informs other actors and is based on a range of other informational sources. I have suggested that the fusion of these separate sources of information into one document is more efficient when using instantiated real world paper, then when using just computer-based materials on a single computer monitor.

So, in this situation, why is it that real paper makes the job easier? To propose a possible provisional theory we need to consider the intent of language. Language informs. In some way, even abstract concepts (like theories about methodology) prepare the actor for situated action (Barsalou, 1999a). Language is a one of a group of methods of informing at second hand; whereas gaining information by direct perception is information at first hand. Although we have conceptually parsed information at first hand and information at second hand, in practice, these ideas are inseparable. In the real world, perception, action, and interpretation all occur seamlessly. This is the essence behind embodied cognition and ecological theories of language. Although linguistic knowledge has been abstracted away from the items/object/state it refers to, it is still part of a perceptual-action interaction. Research shows that eye movements are used to index semantic information, in essence connecting mental events to visual scenes (Richardson & Spivey, 2000). These ideas support the concept that written language is tied to the world, in reference to the world, and produced/comprehended using perception-action linkages.

Based on these ideas, I will suggest two theories, one real-paper-centric theory and the other a virtual-paper-centric theory. From a real paper perspective, I propose that we find authoring easier when using real paper because real paper provides the affordances required for embodied authoring. Specifically, real paper provides direct-action embodiment via its spatiality. In contrast, virtual paper on a single computer screen provides a narrow window of perception and action, which limits embodied authoring. From a virtual paper perspective, I propose that electronic paper offloads memory onto the computer. The computer keeps account of everything in a virtual document; words, phrases, highlights, format styles etc. Using an intra-document search engine, the author of a virtual document can offload their memory of specific phrases, words, and locations onto the interface.

I suggest that we prefer real paper because placing paper in the world makes all the optical invariants available to direct perception. In essence, when using real paper references during authoring, we place the entire set of relevant references on a limited number of perceptual levels. This limits the amount of second-hand and disconnected perception required to re-perceive or disconnectedly perceive the various reference sources for fusion into a single document. After all, second-hand and disconnected perceptions are more effortful than direct perception. It is difficult to re-perceive an entire document, or to re-perceive a set of relevant passages from a set of varied reference sources. Instead, we prefer real paper because we can place the various reference sources around the work domain, in effect storing their information in the open, where the information can be quickly and easily accessed visually rather than via re-perception.

However, virtual paper affords an adaptability that far exceeds real paper. Assume that handwriting speed is roughly 18-20 words per minute (wpm). We can also approximate that the average typing speed is 30-60 wpm, voice dictation is 60-160 wpm, and machine shorthand is 100-225 wpm. When using a pen and paper, the speed at which we can author a document is limited by the pencil-letter bottle-neck. This is the speed at which we can form letters. However, keyboards or voice dictation allows authoring that occurs at higher speeds. In essence, I suggest that virtual paper better supports immediate sentence formation, assisting more efficient authoring behaviour. After all, language production is an activity heavily dependent on the working memory manipulation of current or former perceptions (Carlson, 2001). In ecological terms language production is about re-perceiving meaningful invariants with the intention of communicating meaning. Classical cognitive psychology clearly suggests that working memory is limited (Sanders & McCormick, 1993). Furthermore, human factors guidelines suggest that, "any technique that can offload more information in working memory will be of value" (Wickens et al., 1998, p. 159). Slower methods of authoring force the actor to utilize more working memory. In contrast, by allowing high-speed sentence production virtual paper supports authoring by allowing the actor to partially offload sentence production onto the interface. Furthermore, once sentences are complete, virtual paper allows for adaptation and alteration of the text (Sellen & Harper, 2002).

To summarize, real paper supports authoring because it spatially instantiates information into the world, enhancing embodied language activities. However, virtual paper offers high-speed dynamic control and accountability over the authoring task; virtual words are accounted for and search-able. A virtual interface allows for dynamic authoring that increases efficiency by offloading working memory onto the interface. These two proto-theories could easily form the core of a larger research endeavour. More importantly abductivly inferred theories are based on phenomena, specifically affordance phenomena. By explaining the interaction and causal force of the affordance phenomena, abduced theories offer explanatory power over the human-paper domain. Furthermore, the abductive framework is both cyclic and recuperative. If later testing indicates weaknesses in abduced theories, the abductive cycle can re-attempt the abduction of theories based on the previously isolated patterns in data. In order to provide an overview of the process so far, I have reconstructed this real world example using the logical inference format found in Chapter 2. This will provide an overview of the linkage between the methodologies and the real world results (see Figure 46 below).

Figure 47: A summary of the components of the abductive inferential process

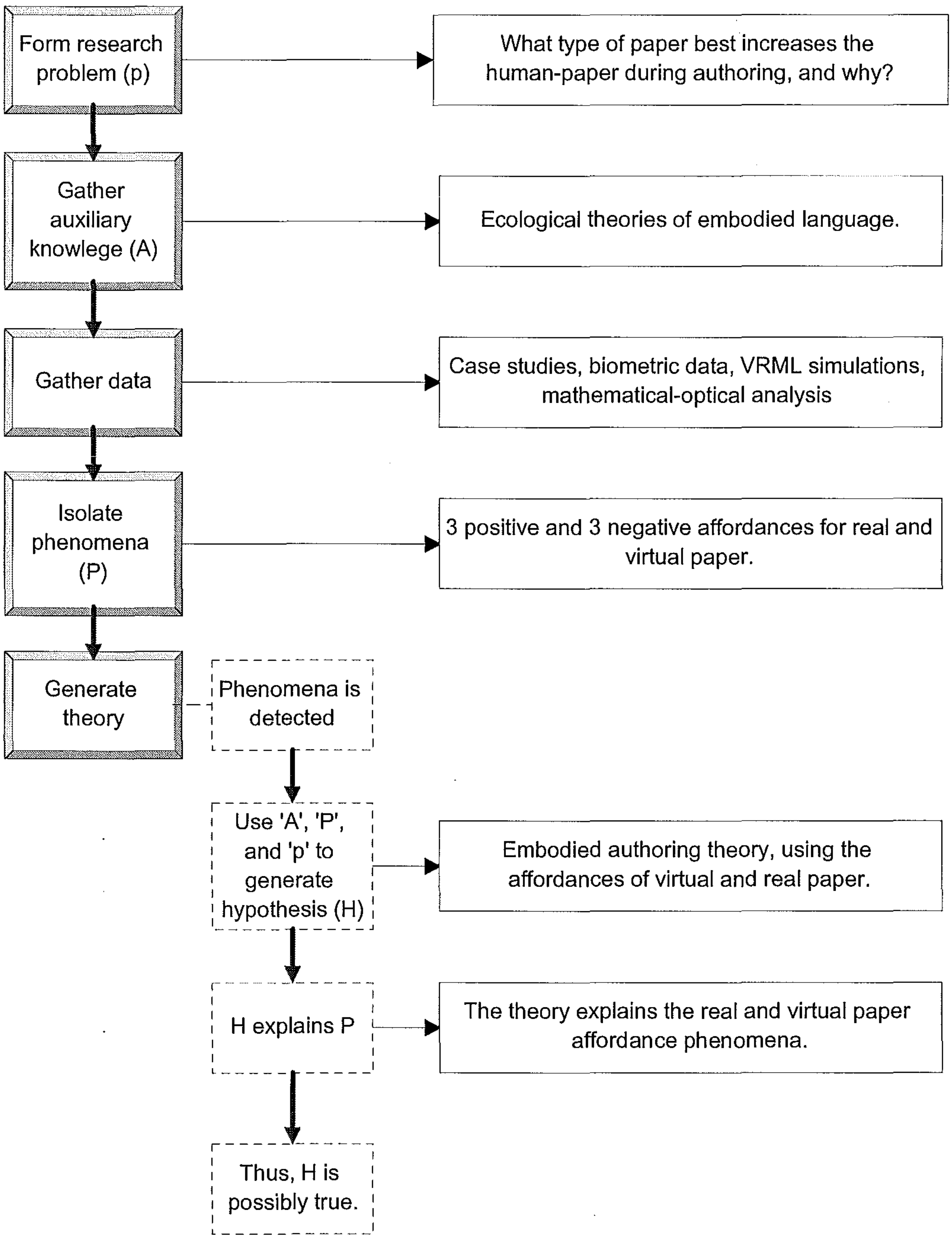


Figure 48: Summary of the abductive inference for the real world examples

1) Positive and negative affordances of real and virtual paper detected. 2) Using the research problem (what best supports authoring), auxiliary knowledge (ecological language theories), and phenomena (+/- affordances of virtual real paper) we abduce a theory...We theorize that real and virtual paper each offer a part of efficient embodied authoring. One offers spatiality and one offers adaptability. 3) This theory explains the real and virtual paper +/- affordances. 4) Therefore, this theory seems worth pursuing further.

Ergonomics and Abduction: Design

Real world problem solving must encompass both the mechanistic and humanistic worldviews (Vicente, 2003). Engineering adopts a mechanistic worldview, which focuses on technological achievement, whereas the social sciences adopt a humanistic worldview, which focuses on human capabilities and human nature (Vicente, 2003). The mutual unit of analysis discussed in the previous chapter provides the domain context for the abductive control tasks and is a step towards blending humanistic and mechanistic worldviews. A mutual unit of analysis explores the shared relationship between people and their technology rather than concentrating specifically on either artifacts or humans. However, to support real world problem solving, a framework must extend from science back into design. I believe that the abductive-ergonomic framework proposed in this thesis can also support design, thus completing the full system cycle of problem to theory and theory to design. I offer two types of support for this proposal: abductive method providing ecologically sensitive regularity based theories and the specific application of abductive inference (or a closely related inference) in design.

The conjunction of the abductive control tasks and the ergonomics domain context produces ecologically sensitive theories. These theories are based on regular patterns that specify the affordances, effectivity, and constraint phenomena relevant to the ecological unit of analysis. In this way, theories generated by this framework possess a standard of applicability essential for guiding design and artifactual application. A problem framework that focuses on the redesign of products improves gradually (Rouse et al., 1997). Knowledge research leads to paradigm changing innovative research proposals (Rouse et al., 1997). The abductive-ergonomic framework proposed throughout this chapter provides a powerful impetus behind innovative design. Conversely, by focusing on data, prediction, and hypothesis testing, the hypothetico-deductive method does not provide the appropriate guidelines for applied research or design.

The second aspect of support for abductive design comes from a side effect of using the abductive inference, specifically that the abductive inference offers an inferential integration between science and design. Fawcett (1987) suggests that there are three types of knowledge applicable to a design: the design itself, the laws which apply to the design context (Rules), and information about the design that comes from the first two components (Description). Deduction, induction, and abduction combine two of these aspects to produce a third, see, Figure 49, below.

Figure 49: Abductive inference and design

Design context	Deduction	Induction	Production/ Abduction
Known	Design	Design	Description
|	|	|	|
|	Rules	Description	Rules
|	|	|	|
Unknown	Description	Rules	Design

Although Fawcett (1987) suggests that design is a broad process, more akin to problem solving than specific inference, he is clear to note that at an inferential level only abduction ends in design. Thagard and Croft (1999) also note a connection between abduction and design (innovation). Recall that generative abduction is concerned with the generation of explanatory scientific theory (Thagard & Croft, 1999). Conversely, design is concerned with the production of a design to answer a need (Willem, 1990). Based on these differences, Thagard and Croft (1999) propose that abduction is not specific to innovation, yet the process behind science and innovation have a very similar structure (see Figure 50, below)

Figure 50: Abduction and Design

Abduction Why X? Y would explain X. So maybe Y. Design How to do X? Y might do X. So maybe try Y. (Extracted from, Thagard & Croft, 1999, p. 134)

In each case, the inference moves towards answering Y (a phenomenon or need), with X (either a scientific explanation or design). March (1976), agrees with previous differentiations made between science and design, "The major goal of scientific endeavour is to establish general laws or theory, the prime objective of designing is to realize a particular case or design" (p. 18). Continuing with the theme of abduction as a logic of design, in a rephrase of Peirce (1931), March (1976) notes, "We conceive of rational designing as having three tasks – (1) the creation of novel composition, which is accomplished by productive [abductive] reasoning…" (p. 18). Whether the abductive inference accurately describes a rational view of design is debateable. However, given Thagard and Croft's (1999) view of an abductive-like design inference, I suggests that it is up to abductive method (rather than inference) to support design. After all, the control tasks that make up abduction already support the progression from data to phenomena to theory. Theories are the most abstracted type of knowledge in this progression.

Data are directly perceivable, phenomena are sometimes directly perceivable. Theories are linguistic/conceptual structures that are abstracted away from their reference situation. Theories are information that has been abstracted away from the perceptual arrays that specified the data and phenomenon. Even applicable theories are somewhat abstracted away from their reference situation. I suggest that design is the process of moving back towards a specific reference situation based on our understanding of the situation from an explanatory theory or isolated phenomenon. Thus, the abductive control tasks that moved us towards theory generation can be reversed in a way that moves from theory back to design.

Human-paper example: two-tiered design proposal

I previously theorised that we find it easier to author papers when using instantiated paper because it provides the affordances required for embodied authoring, and virtual paper does not provide the appropriate affordances. Specifically, real paper provides direct action embodiment by being arrange-able spatially and manipulatable throughout the entire visual field. In contrast, virtual paper provides a narrow aperture of perception and action, thus limiting embodiment. However, real paper accumulates because of its instantiation. This accumulation affords both clutterability and strainability when trying to shift loads of books and papers. Thus, as part of our design proposal I suggest that we need an artifact that preserves the positive affordance relationships between humans and real paper, while taking advantage of virtual paper's portability, adaptability and accessibility. Why change virtual paper, why not change real paper to do away with its negative affordances?

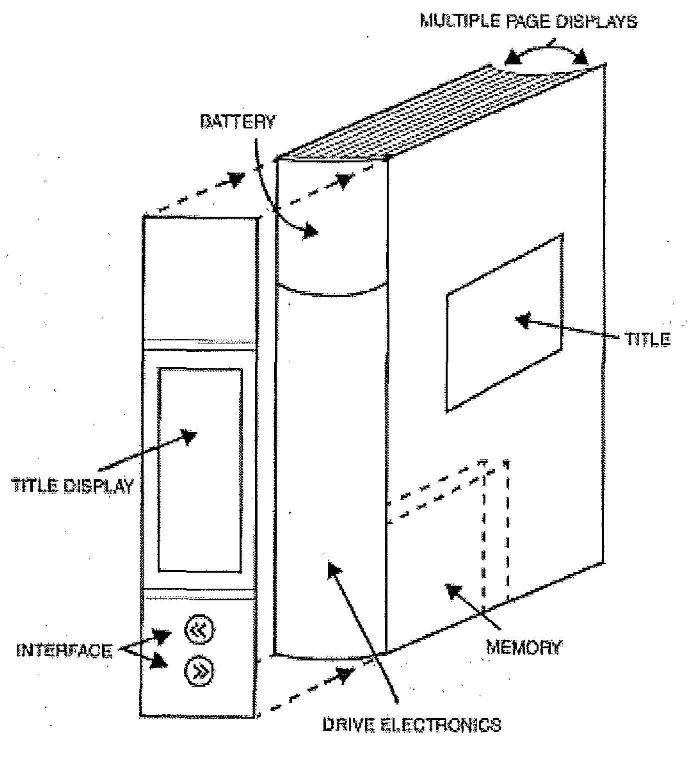
I propose changing virtual paper because the technological architecture that supports virtual paper is easily adapted. This adaptation alters the affordances relevant to the human-paper interaction, possibly eliminating the negative affordances. After all, if single screen virtual paper supports accessibility and adaptability, then multiple display devices might avoid virtual paper's negative affordances of confineability and miniaturizeability. Conversely, real paper does not offer the same adaptability. Thus, our total design requirement requires that we best suit virtual paper to real paper's strengths, while making use of virtual paper's positive affordances. There are two tiers of design proposal that affect this design requirement: instantiated solutions and augmented reality solutions.

Tier 1: Instantiated solutions

The flexible, electronic-ink displays discussed in the introduction to this chapter by Mackay (2000a) have finally reached technological fruition. eInk Corporation, one of several manufacturers currently working on electronic paper displays has demonstrated several working prototypes. The Eink electronic paper technology is a passive display technology with small power requirements. Instead of emitting light, like most current display technologies, e-paper displays rely on reflected light. Given that various e-paper technologies have been in the development process for a number of years, researchers and designers have had time to respond to e-paper's potential. In response to early e-paper prototypes, Jacobson, Comiskey, Turner, Albert and Tsao (1997) proposed an electronic replication of the book called the Last Book. The Last Book is a re-writable electronic artifact using e-paper micro particle display technology (see Figure 52). Most importantly, the Last Book imitates the physical and optical affordances of a real book. This is very different from the current e-book prototypes (like the Rocket e-book reader), which imitate personal digital assistants by not using any of the physical affordances of books and offering a single small screen of interaction.

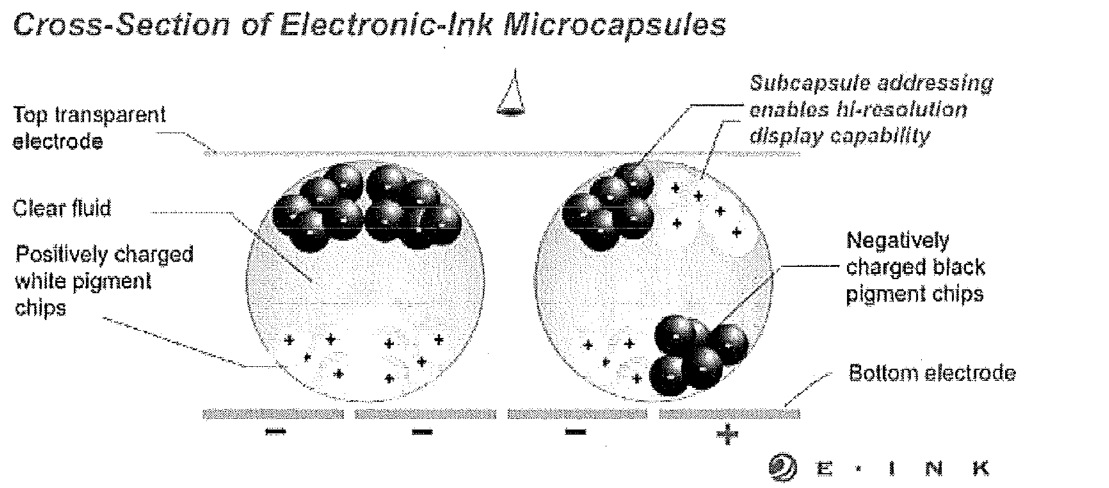
Jacobson et. al. (1997) propose that the Last Book is a replacement for our paper-based books, their conception of the electronic book provides the same embodiment and spatial support of a real book (see Figure 51 below).

Figure 51: The last book



(Extracted from Jacobson et al., 1997, p. 458)

Figure 52: eInk passive micro particle display



NB: The images on an eInk system are displayed using a passive-display technology.

(eInk, 2004)

Assume for a moment that I can rent or download a number of e-books to my Last Book reader. I suggest that the Last Book provides the same narrow window of perception on multiple documents offered by a computer monitor, which is not a problem when we are reading one book. However, authoring activities require the use of many different materials, including books, articles, sketches, and personal notes (Sellen & Harper, 2002). Our ability to place our materials in different locations in the authoring space provides the externalization and offloading required to support effective authoring activities. Granted, we might use several Last Book readers simultaneously, using each one to load a copy of a different reference material, but this would in effect reproduce the problem of carrying around multiple instantiated materials in order to support authoring.

As an alternative to physical instantiation, a lot of research has focused on Rapid Serial Visual Presentation (RSVP), which delivers text in rapid linear sequence, often in block sequences or in single words (Goldstein, Quist, Bayat-M., Bjrk, & Ljungberg, 2001). RSVP is useful for text comprehension when the display device has little screen space. RSVP can support high-reading speeds to the detriment of task loading (Goldstein et al., 2001). Further improvement to RSVP by Öquist (2001) have rectified the fixed interval presentation of standard RSVP with fixation based adaptive presentation. Fixation based presentation alters the presentation speed based on a word-size/sentence chunk algorithm (Öquist, 2001). However, this still does not support the theory of multiple document embodiment proposed in this thesis. Using RSVP for authoring purposes increases the load on system memory, rather than externalizing the load into the visual field. Thus, physical instantiation still seems the best way to support embodiment and the multiple reference source manipulation required in authoring.

As well as physically instantiating the visual aspects of real paper, designers have considered replicating real paper's direct manipulatability. Instigators of the Last book, Jacobson et. al. (1997) note: "Provisions are also made to allow the display address matrix to sense the presence of a stylus directly, thus acting as a pen input. Such a provision may be used, for instance, to resize text on a page, insert a larger margin space, or add hand-written annotations" (p. 461). For example, the Xlibris annotation system supports the direct manipulation and annotation of reference materials via tablet PC architecture (Price, Schilit, & Golovchinsky, 1998). The Xlibris system can highlight, underline, circle, and annotate text with freeform digital ink (Price et al., 1998).

Tier 2: Augmented and Virtual solutions

Tier 2 designs are more technologically demanding than the inert screen e-paper books proposed in Tier 1. I draw inspiration for my proposal from a paper called, "Tiles: a mixed reality authoring interface" by Poupyrev, Tan, Billinghurst and Kato. Poupyrev, Tan, Billinghurst, and Kato (2001) discuss augmented reality techniques currently being explored by Human Interface Technology Laboratories in both the United States and New Zealand. The Tiles interface is an ingenious use of visual computer pattern matching technologies, which is closer to an embodied interface than any flat screen technology. Tiles are literally, 'in the world,' using a conjunction of display spectacles, computer cameras, and computer based pattern-matching algorithms. In brief, the augmented reality software used in the Tiles interface interposes a virtual image on the real world. Kato, Billinghurst and Poupyrev (2000) note, "ARToolKit uses computer vision techniques to calculate the real camera position and orientation relative to marked cards, allowing the programmer to overlay virtual objects onto these cards" (p. 1). Given that I used VRML objects to simulate and explore virtual paper, and that the ARToolKit can display VRML objects, it is a short progression towards proposing that we can use augmented reality to display a range of virtual texts. This would have a several dramatic advantages.

- We could display multiple documents hovering over the augmented reality targets.
- We can interact with reality and augmented reality simultaneously, because augmented reality only presents a virtual layer, rather than replacing reality.
- We could interact with the virtual documents with a keyboard, as long as we had a method of activity updating the augmented objects.
- Augmented reality paper could have all the advantages of our interaction with real paper, without the disadvantage of carrying around kilograms of papers and books.

Augmented reality is an unfamiliar concept to a world familiar with virtual reality. In virtual reality, the information usually supplied by the world is totally replaced by information supplied by a head-mounted display. In contrast, when using augmented reality, the information supplied real world is not replaced. Rather, the computer system superimposes digitized imagery on top of the real world. Andrews (2003) of IBM's Business Consulting Services notes,

> Augmented reality overlays computer-mediated information on the real world. This ability enriches environments for action and learning and offers the potential for new kinds of shared experiences. Already used by the military to support action in the field, this technology is beginning to work its way into daily life in the form of everything from aircraft maintenance to providing drivers with better night vision (p. 1).

Augmented reality (AR) is a mixed reality system where users can simultaneously interact with all the components of reality while adding augmented visual and auditory functionality; the possibilities are endless. More importantly, when consider the interface between augmented reality techniques and virtual paper something thing become immediately apparent; the augmented reality interface replicates the 360 degree field of view offered by the real world, while continuing to offer access to virtual paper. To understand the mixed reality offered by AR, see Figure 53 below.

Figure 53: Augmented reality

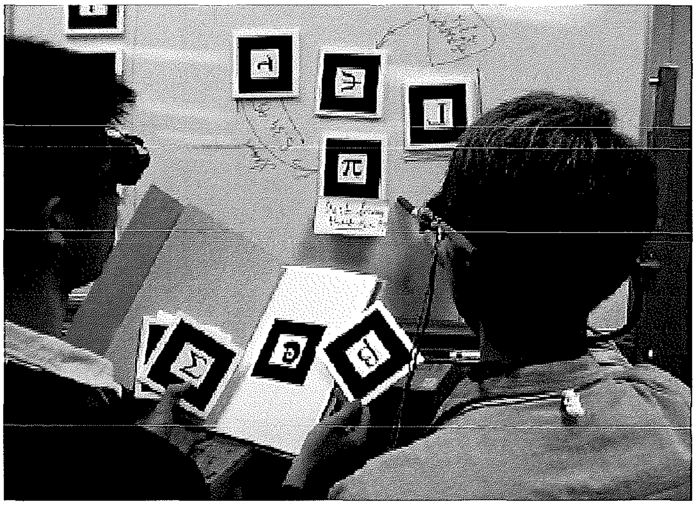


Figure 1: *Tiles* environment: users collaboratively arrange data on the whiteboard, using tangible data containers, *data tiles*, as well as adding notes and annotations using traditional tools: whiteboard pen and notes.

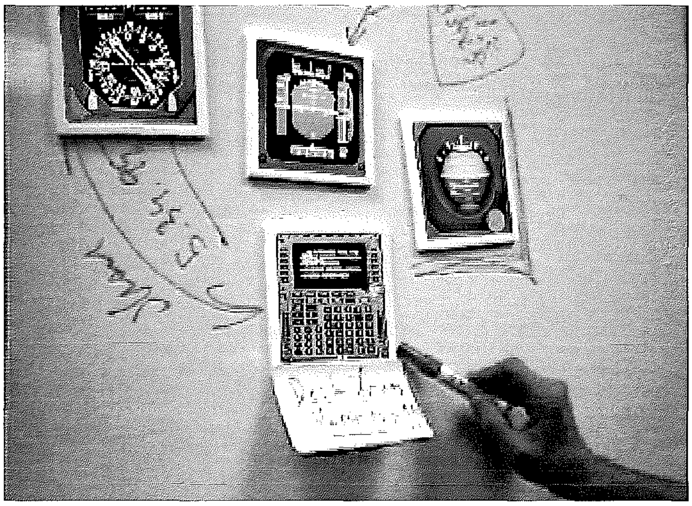


Figure 2: The user, wearing lightweight head-mounted display with mounted camera, can see both virtual images registered on tiles and real objects.

NB: As seen in the pictures, augmented reality does not replace the real world. Rather, the computer interposes digitized mediated onto cardboard tracking markers. This allows the actor to simultaneously view the real world and the digitized media.

(This image was extracted from Poupyrev et al., 2001, p. 4)

Independently, an e-paper reader or an augmented reality system will not support authoring without the appropriate organizational structure. The link between the previous two tiers of the design proposal is an informational rather than display-based technology. The problem with proposing a range of different virtual paper solutions (instantiated paper, augmented reality paper) is that we increase system complexity in a vertical, rather than horizontal sense. The key to interacting with real paper (books, notes, sketches) is that it requires little mediation for them to interact with each other. Ideas are transferred from paper to book and book to paper, by writing. Virtual architecture is vertical, as there are a number of virtual paper formats (Word Documents, PDF, txt). Moving across formats or across platforms requires step up, or step down conversion. The solution is to create a cross-platform virtual-paper format that supports virtual paper use by providing the affordances relevant to authoring.

The key to this concept of cross platform virtual paper requires that we package the affordance relevant to authoring with the document, rather than with the interface. A mark-up language would support this design intention by allowing embedding of the affordances relevant to authoring into the virtual document, rather than specifically to the device. A seamless, cross-platform mark-up language would allow use of both the augmented and instantiated design proposals in conjunction with each other. We already use a very popular type of cross-platform markup language, known as HTML (Hypertext mark-up language). At its core the HTML format is a way of enhancing the optical invariants of written language by specifying its presentation and by embedding other media information like pictures within the fabric of the virtual document. HTML is part of a family of mark-up languages that began with SGML (Standard General Markup Language). HTML has many weaknesses, among them an inability to describe the information within the HTML document and an inability to create its own markup tags.

The introduction of XML (eXtensible Markup Language) rectifies this problem. XML is not HTML's replacement. Rather, XML describes the data and HTML describes how to display it. HTML has been improved with the advent of XHTML (eXtensible hypertext markup language), an XML specific display language. Programmers are now able to create large-scale cross-platform documents, which can be searched, dynamically acted upon, and displayed in various ways. Creating cross-platform virtual paper is a popular idea, and one that is already partially in use. The OeB (Open E book) forum (2003) proposes that, "The goal of this [OeB] specification is to define a standard means of content description for use by purveyors of electronic books (publishers, agents, authors et al.) allowing such content to be provided to multiple Reading Systems" (OeB, 2003, p. 1). OeB documents are essentially books based on the XML markup language. For an example of this format, see Figure 54, below. The example shown below is an extract of an OeB format e-book, Wuthering Heights by Emily Bronte.

Figure 54: An OeB XML markup E-book

```
<?xml version="1.0"?>

<!DOCTYPE html
      PUBLIC "+//ISBN 0-9673008-1-9//DTD OEB 1.2 Document//EN"
      "http://openebook.org/dtds/oeb-1.2/oebdoc12.dtd">
<html xml:lang="en-US" xmlns="http://www.w3.org/1999/xhtml">
<head>
<title>Wuthering Heights</title>
<link rel="stylesheet" href="wuthering.css" type="text/x-oeb1-css" />
<meta content="text/x-oeb1-document" />
</head>
<body>
<!--=================================================================-->
<div class="titlepage">
<p class="booktitle">
Wuthering Heights
</p>
<p class="author">
by Emily Jane Bront&euml;
</p>
</div>
<!--=================================================================-->
<div class="chapter" id="chap01">
<p class="chaptitle">
<a class="invisible" href="toc.html">
Chapter 1
</a>
</p>
<p>
1801. - I have just returned from a visit to my landlord...
</p>
(OeB, 2003)
```

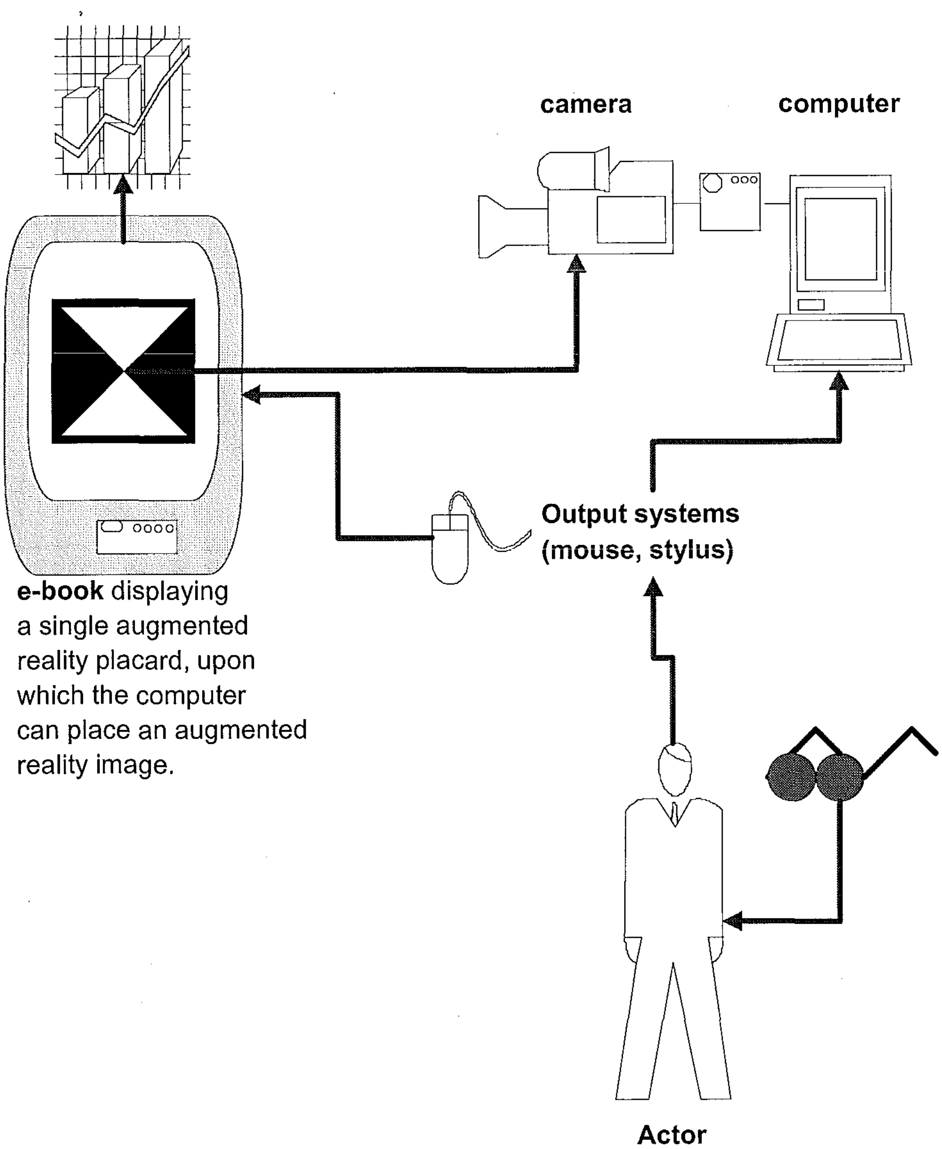
Bos (1999), on behalf of W3 (the internet's organizing body) notes, "XML is for structuring data…Structured data includes things like spreadsheets, address books, configuration parameters, financial transactions, and technical drawings. XML is a set of rules (you may also think of them as guidelines or conventions) for designing text formats that let you structure your data" (para. 1). I suggest that OeB's progress towards a standardized e-book format based on XML is a good idea. XML is not machine dependent code and it provides the basis for a cross platform e book system. However, in Figure 54, the OeB text markup mostly deals with text position, format, style, and hyperlink relationships between chapter headings and the table of contents. To date they have not considered the full flexibility required from virtual paper. Granted, the OeB e-book format (2003) contains elements such as 'spine', which "defines a primary linear reading order of the publication" (p. 21). These elements aside, it does not seem that the OeB forum is trying to create enhanced virtual books. Rather they appear to be creating a rigid reproduction of instantiated books. This fails to support the sketches, documents, and notes that we are free to create on instantiated paper.

File formats like Adobe PDF also add extended functionality to virtual paper documents, but again they do not preserve the annotative and positional freedoms associated with real paper. In essence, any augmented reality or e-book solution will always be only as good as the file formats that they display. After all, using augmented reality to display a single Microsoft Word text editor window would defeat the purpose of using Microsoft Office in augmented reality. It would waste the conjunction of e-paper and augmented reality if we were to use these items to display standardized word documents. Granted, both Microsoft Office and Adobe PDF have both attempted to capture the manipulateability of instantiated paper documents. Microsoft Office offers a 'Reviewing bar' that can track changes and allow other users to edit documents while preserving the original document structure. Adobe PDF allows users to leave comments on a separate layer from the text; in fact users cannot alter the original text of a PDF. The solution to a virtual paper format lies somewhere between Microsoft Office, Adobe PDF, and OeB's open e-book format, a format that offers annotate-ability but continues to offer the order-ability of virtual documents.

To bring all these design concepts together, recall the affordances offered by real paper: readability, manipulateability, and embodyability. Either instantiated e-paper or multiple augmented reality pages would allow for strong embodyability. E-paper or augmented reality paper (AR-paper) would make use of a larger visual field, restoring embodied human-paper interaction and supporting authoring. Both e-paper and AR-paper would allow for readability, as they could deliver the information specifying multiple documents through the entire visual field, rather than the small portion specified by the computer screen, this would allow the user to expand in on pages. Lastly, both e-paper and AR-paper might allow for direct manipulation of the paper's surface. With e-paper this would be accomplished by moving the paper. With AR-paper, this could be accomplished by moving the placard above which the AR image was hovering, or altering the text with a tablet style pen based input into a separate input device. Real paper allows actors to navigate, explore, embody, and offload information (O'Hara & Sellen, 1997). Virtual paper does not yet support these requirements. However, an augmented reality authoring system would allow actors to achieve all of the positive affordances associated with both real and virtual paper, while avoid the negative affordances offered by both real and virtual paper.

Using either of these versions of virtual paper does not preclude the importance of transferring the information from e-paper to augmented reality continually and dynamically. The benefit of augmented reality is that we can still see the normal world, so we could still read both e-paper and real paper documents. However, the real link between these systems and paper in the real world truly depends on the structure of virtual paper. In a speculative design proposal, I suggest that there are strong links between the instantiated eInk paper and augmented reality applications. It may be possible to use a high-resolution eInk page (or multiple pages) to display the augmented reality placard(s) (see Figure 53) necessary for the computer to identify the real world location for the virtually augmented image. This would dispense with the necessity of having to carry the augmented reality placards, as an e-book could store numerous placards for display and subsequent visual augmentation. On a practical level a wirelessly interconnected e-book + computer system could assign each page a new placard or, in the spirit of the virtual paper simulations in this chapter, each placard presented on the e-book screen could represent a new reference source (see Figure 55, below).

Figure 55: Augmented reality word processing concept system



Summary of Chapter 4

In summary, I have proposed that the collaborative fusion of abduction and ergonomics provides the basis for the real-world problem-solving framework proposed in this thesis. Firstly, I have proposed that abduction provides for the generation of explanatory theory in both a logical and ecological sense. Abduction makes ecological sense because it provides the effectivity constraints, environmental constraints, and affordances relevant to the isolation of phenomena and the generation of theories. Specifically, I have suggested that abduction is a good conception of the control tasks structures required in organizing real world problem solving. Conversely, ergonomics provides the domain perspective relevant to each control task. Abduction and ergonomics converge because control tasks and domains interact with each other in a deeply meaningful way.

This meaningful interaction occurs because the control tasks, specified by abduction, act upon the work domain specified by ergonomics. Alternatively, ergonomics specifies the work domain that provides the information for the control tasks previously specified by abduction. During this chapter I progressed through each of the control-tasks associated with abductive method using the real world example as a test of ergonomics domain perspective, and abduction's adequacy as a control task structure. Using the human-paper example I have moved through each step of the framework, exploring the reciprocal relationship between abduction and ergonomics. Conclusions from this exploration suggest that abduction provides excellent organization for real world problem solving, and ergonomics provides a strong characterisation of the mutual unit of analysis applicable to human-technology interaction.

Discussion

Review

To briefly review the steps we have taken in this thesis: In the introduction, I explored the state of the world, suggesting that we face an ever-growing list of social, environmental, human-technological inspired problems. I asked three target questions. Firstly, what are psychology's current methods, and how do they aid real world problem solving. Secondly, are there any alternative methods that might support problem solving. Thirdly, what does ergonomics offer real world problem solving? The aim behind these three questions was to develop an organized real world problem solving framework, drawing ideas from abduction and ergonomics. This framework would support the research and solution of real world problems. This goal and the three target questions provided the impetus behind the four chapters of this thesis: hypothetico-deduction, abduction, ergonomics, and real world problems.

In the first chapter I proposed that hypothetico-deduction and NHST form the fused set of techniques that best represent psychology's current set of methodologies. I moved briefly through NHST, discussing its inappropriate conflation of statistical and theoretical hypothesis. I focused on hypothetico-deductive method, exploring its inceptions, nature, and issues with its structure. When used appropriately, the hypothetico-deductive method (HD) is a theory testing device. However, HD fails on three counts. Firstly, HD fails to provide an account of hypothesis generation. This fails to provide the theories important to eventual system design. Secondly, HD is actually a very weak theory corroboration, when used as a system of null hypothesis testing. Point-predictions, ranged predictions, or form function predictions are stronger forms of theory corroboration. Thirdly, HD focuses excessively on hypothesis testing and single data events. However, strong theories are based on empirical regularities, patterns that extend across singular experiments. These patterns are known as phenomena. Strong theories must be based on phenomena. Furthermore, our choice of phenomena will dictate the ease of our research endeavour; mediational phenomena are difficult to explore, whereas environmental phenomena are readily apparent.

In Chapter 2, I explored an alternative methodology known as abduction. I explored abduction's alternate history to hypothetico-deduction, specifically abduction's non-deductive character. I discussed four issues with abduction as a way of exploring abduction's abilities. Firstly, I explored critiques with the logic of discovery, indicating how there is a logic behind discovery and that abduction is a strong characterisation of the logical process. Secondly, I investigated abductions ability to actually generate hypothesis, suggesting that revised aspects of the abductive inference provide a constraint conception of hypothesis generation. Thirdly, I examined abduction's ability to control the hypothesis generation, given issues of underdetermination and the combinatorial explosion of alternative hypothesis. Lastly I analysed abductions ability to provide for both hypothesis discovery and confirmation. Along with each issue I discussed amendments to the abductive method and extra techniques suitable for inclusion in a general abductive methodological framework. Finally, I explored abduction's general methodological structure, specifically how all the amendments and inclusions fit together in a systematic methodological framework.

In Chapter 3, I explored the aims, perspective, and unit of analysis offered by ergonomics. I moved through the history of human factors and ergonomics, settling on both a term (ergonomics) and an aim (better the fit between people and the systems which they are a part of, while not placing undue pressure on the human components of the system). I explored the relationship between basic, applied and applicable research, suggesting that ergonomics reaches towards applied and applicable theories and a fusion between science and design. When investigating the structure behind modern ergonomics, I introduced the terms: affordances, effectivities, and constraints. Affordances are opportunities for action, effectivity properties are our ways of being effective, and constraints are the boundaries on safe action. I explained how environmental constraints and effectivity constraints combine to decide what affordances will be supported by the interaction of the actor and their environment. I discussed the systems that support perception, suggesting that an embodied conception of human cognition will be based around direct perception, second-hand perception, and disconnected perception. I agreed that perception is cognitive, but disagreed that it is always mediational. I suggested that perception is not representational, rather it is informational. I explored a systems conception of human-technological interaction suggesting that the mutual unit of analysis offered by ergonomics is a system of actor and environment, which share affordances, constraints, and effectivities, actions and consequences.

In Chapter 4, I proposed that abduction and ergonomics are linked by a control task – domain structure; abduction provides the control tasks that act upon the work domain described by ergonomics. Put another way, ergonomics specifies the domain, a domain that provides the information for the control tasks that abduction specifies. I moved through each of the control tasks associated with abduction in the real world problem context of human-paper interaction. This exploration took us through: formulating the research problem, gathering auxiliary knowledge, data gathering, isolating phenomena, theory formation, and design. Conclusions for the real world exploration suggest that real world paper and virtual paper both offer positive and negative affordances to human-paper interaction during the task of authoring. Single screen virtual paper narrows the whole window of perception and action heavily limiting embodied authoring.

Conversely, real paper utilized the entire visual field allowing users to spatially arrange their references in a way that allows embodied authoring. However, virtual paper allows for accessibility and adaptability. I concluded that virtual paper can be adapted to avoid the negative affordances and make use of both real and virtual papers positive affordances. At a methodological level, the real world example was a test of both the ergonomics domain perspective and abduction's adequacy as a control task structure. I suggested that abduction provides excellent control task organization for real world problem solving and that ergonomics provides an outstanding domain portrayal relevant to real world problem solving. Together they form an applicable and efficient real world problem solving framework.

Evaluation and limitations

To answer our target questions: firstly, psychology uses HD method as is central methodological structure. There are many issues associated with using HD methods, and as a result it fails to support real world problem solving. Secondly, abduction offers alternative methods that provide high-quality support towards real world problem solving. Abduction aids real-world problem-solving by supporting the generation of regularity based theories. Thirdly, ergonomics provides the aims, perspectives and unit of analysis relevant to a human-technological mutual unit of analysis. Ergonomics aims towards bettering the fit between humans and the systems in which they are embedded using the ergonomics mutual unit of analysis. The strong collaboration between abduction and ergonomics occurs when abduction provides the control tasks that act upon the information provided by the domain specified by ergonomics. This fusion provides the real world problem solving framework proposed in this thesis. Speaking directly against psychology, if we continue on our current methodological path,

> we will continue to have a science of psychology that holds a narrow view of science, that only seeks weak qualitative theories, that has little to say about activities outside of the laboratory, and that strives so hard to look like "real science" that it puts itself into an intellectual straitjacket (Vicente, 1998, p. 225).

The work in this thesis provides the conceptual basis for an alternative path, which leads away from research without application and towards applied and applicable theories. Granted, the work in this thesis is the initiation, the appliance of these ideas has yet to come. Given the youthful nature of these ideas, there are several limitations associated with this research. Firstly, there are many deeper technical details to be explored, particularly in two areas: quantitative/qualitative statistical methods and experimental techniques. There are many quantitative and qualitative techniques relevant to problem solving that were not mentioned here, or mentioned here but not covered in depth.

There are also many applied and applicable experimental techniques beyond simulations that would greatly aid real world problem solving. Secondly, we need a deeper exploration of theory corroboration. I focused on theory generation because it is an under-defined component of modern psychology. However, this does not detract from the importance of theory corroboration. Thirdly, it would be interesting to explore the ecological aspects of abductive discovery in greater depth. Lastly, we need a deeper social-educational philosophy behind the framework. Methodological frameworks require a deeper educational and social impetus behind their use.

However, limitations aside, I believe that the framework offered here provides a fruitful basis for further application in the real world. I suggest that I have achieved the aim set out in the opening of this essay; specifically the formation of a real-world problem solving framework drawing from ergonomics and abduction designed to support the generation of regularity based theories that will guide design. The best way to extend the work done here would be to use the method discussed here to solve real world problems. Real world problems are the coalface; this is where solutions must work. That is precisely what I advocate; get out and solve problems. From my own perspective, the ideas discussed in this thesis have helped greatly to crystallize the methods behind my real-world problem-solving. If the ideas suggested here contribute to the efforts of others than I have achieved my aim.

Conclusions

We reach towards the lofty goals: "the coupling of wisdom to applied science for the solution of human problems, and the betterment of the world in which our children and our children's children will have to live" (Moray, 1995, p. 1706). What is wisdom? I believe that wisdom comes from a combination of two factors; one is controllable and the other is not. Firstly, the controllable component of wisdom are the methods we learn, which aid us to efficiently state, research, and solve problems. A gain in wisdom is directly proportional to new methods or an increase in efficiency of already existing methods. The uncontrollable component of wisdom is having the courage to use our real-world problem-solving methods in meaningful ways to change the world for the better. This thesis has focused on the first half of wisdom: the systematic methods that encourage the generation of domain-relevant, applicable and applied, regularity based theories; theories that provide the bedrock for eventual systems design. The second part of wisdom comes from you: the courage to apply methods to the solution of problems for the betterment of the Earth we serve stewardship to and the society that populates it.

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Appendices

Appendix 1: VRML code examples

Example 1- Text based VRML paper object

```
#VRML V2.0 utf8


DEF Page Billboard {
   axisOfRotation 0.0 0.0 0.0
   children [
               Shape {
                     appearance Appearance {
                   material Material { }
                                 }
                       geometry Box {
                          size 21.0 27.0 0.0
                                 }
                     },

Transform {
   translation -5.0 5.0 0.5
   children [
               Shape {
                     appearance Appearance {
                     material Material { diffuseColor  1.0 0.0 0.0
                            emissiveColor 1.0 0.0 0.0}
                                 }
                     geometry Text {
                          string ["To be or not to be", "", "That is the question"]
                          fontStyle
                                FontStyle   {
                                      family "Serif"
                                      size 2.0
                                      justify "BEGIN"
                                      }
                                      }
                     }
               ]
         }
   ]
},

Transform{
         translation 30.0 0.0 0.0
         children [USE Page]
         },


Transform{
```

```
        translation 0.0 30.0 0.0
        children [
Billboard {
   axisOfRotation 0.0 0.0 0.0
   children [
                  Shape {
                        appearance Appearance {
                     material Material { }
                                      }
                           geometry Box {
                              size 21.0 27.0 0.0
                                    }
                        },

Transform {
   translation -5.0 5.0 0.5
   children [
                  Shape {
                        appearance Appearance {
                        material Material { diffuseColor  1.0 0.0 0.0
                              emissiveColor 1.0 0.0 0.0}
                                          }
                        geometry Text {
                              string ["Twas brillig twig and slithy", "", "Did
Jabberwocky climb"]
                              fontStyle
                                    FontStyle   {
                                          family "Serif"
                                          size 2.0
                                          justify "BEGIN"
```

```
Example 2- Picture mapped VRML obejct
#VRML V2.0 utf8
Viewpoint {
    position 0 0 65
# *!* position    0 0 40
   description "Default"
},
DEF Page Billboard {
   axisOfRotation 0.0 0.0 0.0
   children [
                  Shape {
                        appearance Appearance {
               material Material { }
                  texture ImageTexture {url "Essay.JPG"}
                                    }
                     geometry Box {size 21.0 27.0 0.0}
                  }
 ]
```

```
},

#Top Row
Transform {
 translation 23.0 0.0 0.0
 children [ USE Page]
 },
Transform {
 translation 0.0 -30.0 0.0
 children [ USE Page]
 },
Transform {
 translation 23.0 -30.0 0.0
 children [ USE Page]
 },
```

!: Note the piece of code on line three is the piece of code where the programmer can control the initial virtual distance for the actor.

```
Example 3 – Single page snapshot
#VRML V2.0 utf8
# This page was a snapshot taken of a document at 100 % #zoom

NavigationInfo {
   headlight  TRUE
   speed      20.0
},

Viewpoint {
   position    0 0 35
   description "Default"
},


DEF Page Shape {appearance Appearance {
                 material Material { }
                    texture ImageTexture {url "Essay.JPG"}       }
   geometry Box {size 21.0 29.7 0.0}
                    }
 ]
},
Transform {
 translation 25.0 0.0 0.0
 children [USE Page]
 },
Transform {
 translation 0.0 -30.0 0.0
 children [USE Page]
 },
Transform {
```

```
translation 25.0 -30.0 0.0
children [USE Page]
},
```