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THE 1987 WHITE PAPER ON DEFENCE:

A THREE-DIMENSIONAL MODEL

OF THE DECISION-MAKING PROCESS

BY

ROGER M. H. TODD

A Thesis

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- General 0318
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- Clergy 0319
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Anthropology
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Geography 0366
Gerontology 0351
History
- General 0578
- Ancient 0579
- Medieval 0581
- Modern 0582
- Black 0328
- African 0331
- Asia, Australia and Oceania 0332
- Canadian 0334
- European 0335
- Latin American 0336
- Middle Eastern 0333
- United States 0337

History of Science 0585
Law 0398
Political Science
- General 0615
- International Law and Relations 0616
- Public Administration 0617

Recreation 0814
Social Work 0452
Sociology
- General 0626
- Criminology and Penology 0627
- Demography 0938
- Ethnic and Racial Studies 0631
- Individual and Family Studies 0628
- Industrial and Labor Relations 0629
- Public and Social Welfare 0630
- Social Structure and Development 0700
- Theory and Methods 0344

Transportation 0709
Urban and Regional Planning 0999
Women's Studies 0453

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BIOLOGICAL SCIENCES
Agriculture
- General 0473
- Agronomy 0285
- Animal Culture and Nutrition 0475
- Animal Pathology 0476
- Food Science and Technology 0359
- Forestry and Wildlife 0478
- Plant Culture 0479
- Plant Pathology 0480
- Plant Physiology 0817
- Range Management 0777
- Wood Technology 0746

Biology
- General 0306
- Anatomy 0287
- Biostatistics 0308
- Botany 0309
- Cell 0379
- Ecology 0329
- Entomology 0353
- Genetics 0369
- Limnology 0793
- Microbiology 0410
- Molecular 0307
- Neuroscience 0317
- Oceanography 0416
- Physiology 0433
- Radiation 0821
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- General 0786
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Geophysics 0373
Hydrology 0388
Mineralogy 0411
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Paleoecology 0426
Paleontology 0418
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- Physical Therapy 0382
- Public Health 0573
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- Elementary Particles and High Energy 0798
- Fluid and Plasma 0759
- Molecular 0609
- Nuclear 0610
- Optics 0752
- Radiation 0756
- Solid State 0611

Statistics 0463

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  - Asiatique 0305
  - Canadienne (Anglaise) 0352
  - Canadienne (Française) 0355
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  - Latino-américaine 0312
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  - Histoire générale 0578
  - Ancienne 0579
  - Médiévale 0581
  - Moderne 0582
  - Histoire des noirs 0328
  - Africaine 0331
  - Canadienne 0334
  - États-Unis 0337
  - Européenne 0335
  - Moyen-orientale 0333
  - Latino-américaine 0336
  - Asie, Australie et Océanie 0332
- Histoire des sciences 0585
- Loisirs 0814
- Planification urbaine et régionale 0999
- Science politique
  - Généralités 0615
  - Administration publique 0617
  - Droit et relations internationales 0616
- Sociologie
  - Généralités 0626
  - Aide et bien-àtre social 0630
  - Criminologie et établissements pénitentiaires 0627
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  - Études des relations interethniques et des relations raciales 0631
  - Structure et développement social 0700
  - Théorie et méthodes. 0344
  - Travail et relations industrielles 0629
- Transports 0709
- Travail social 0452

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  - Agronomie. 0285
  - Alimentation et technologie alimentaire 0359
  - Culture 0479
  - Élevage et alimentation 0475
  - Exploitation des péturages 0777
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  - Pathologie végétale 0480
  - Physiologie végétale 0817
  - Sylviculture et faune 0478
  - Technologie du bois 0746
- Biologie
  - Généralités 0306
  - Anatomie 0287
  - Biologie (Statistiques) 0308
  - Biologie moléculaire 0307
  - Botanique 0309
  - Cellule 0379
  - Écologie 0329
  - Entomologie 0353
  - Génétique 0369
  - Limnologie 0793
  - Microbiologie 0410
  - Neurologie 0317
  - Océanographie 0416
  - Physiologie 0433
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  - Zoologie 0472
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  - Généralités 0786
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- Géographie physique 0368
- Géologie 0372
- Géophysique 0373
- Hydrologie 0388
- Minéralogie 0411
- Océanographie physique 0415
- Paléobotanique 0345
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- Paléontologie 0418
- Paléozoologie 0985
- Palynologie 0427

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  - Administration des hipitaux 0769
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  - Dentisterie 0567
  - Développement humain 0758
  - Enseignement 0350
  - Immunologie 0982
  - Loisirs 0575
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  - Ophtalmologie 0381
  - Orthophonie 0460
  - Pathologie 0571
  - Pharmacie 0572
  - Pharmacologie 0419
  - Physiothérapie 0382
  - Radiologie 0574
  - Santé mentale 0347
  - Santé publique 0573
  - Soins infirmiers 0569
  - Toxicologie 0383

SCIENCES PHYSIQUES

Sciences Pures
- Chimie
  - Genéralités 0485
  - Biochimie 487
  - Chimie agricole 0749
  - Chimie analytique 0486
  - Chimie minérale 0488
  - Chimie nucléaire 0738
  - Chimie organique 0490
  - Chimie pharmaceutique 0491
  - Physique 0494
  - PolymÇres 0495
  - Radiation 0754
- Mathématiques 0405
- Physique
  - Généralités 0605
  - Acoustique 0986
  - Astronomie et astrophysique 0606
  - Electronique et électricité 0607
  - Fluides et plasma 0759
  - Météorologie 0608
  - Optique 0752
  - Particules (Physique nucléaire) 0798
  - Physique atomique 0748
  - Physique de l'état solide 0611
  - Physique moléculaire 0609
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- Statistiques 0463

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- Psychologie du comportement 0384
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- Psychologie industrielle 0624
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THE 1987 WHITE PAPER ON DEFENCE: A THREE-DIMENSIONAL MODEL OF THE DECISION-MAKING PROCESS

BY

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A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

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The 1987 White Paper on Defence:

A Three-Dimensional Model

of the Decision-Making Process

Abstract

The problem addressed in this thesis is how to create a model, capable of being mounted on a computer, which can represent how particular public policy decisions are arrived at. The specific example considered for application purposes is the 1987 Canadian White Paper on Defence. The procedure followed is to create an architecture, utilizing recent developments in cognitive science, to model the decision-making processes involved in the 1987 Canadian White Paper. The result of this modelling exercise is the demonstration that the model is consistent with the findings of cognitive science and research into neural networks. The conclusion is that the model is coherent and that decision-making processes, like those involved in the 1987 White Paper, can be simulated using the architecture of this model.

Acknowledgements

The author would like to acknowledge the support of the Department of National Defence in the preparation of this thesis, including Lieutenant General D. Huddleston, former Commander of Air Command, and Dr. K. J. Calder, Assistant Deputy Minister for Policy and Communications, who agreed to be interviewed. Thanks are also due to Ken McVicar and Waldron Fox-Decent of the University of Manitoba who provided advice and guidance.

TABLE OF CONTENTS

Page

LIST OF FIGURES

CHAPTER 1. - THE CANADIAN 1987 DEFENCE WHITE PAPER

INTRODUCTION

This thesis will formulate a model which can be useful in understanding how particular Canadian public policy decisions are arrived at. This thesis will address, in particular, the policy decisions which were embedded in the Canadian 1987 White Paper on Defence. Utilizing recent developments in the disciplines of cognitive science and artificial intelligence, this thesis will explore the relationships between the cognitive processes of the individual and public policy decision-making, arguing that public policy decisions are best understood by modelling the decision-making process according to the numerous constraints, including environmental factors, which impinge on the decision-making process.

A number of premises lie behind this thesis. One of them is that the human decision-making process is inherently "rational" according to most accepted definitions of rationality. Although it is beyond the scope of this thesis to resolve definitively the issue of human rationality versus irrationality, it should be noted that a good case has been made in the literature of cognitive psychology for taking a position in favour of rational human mental processes.

Margaret Boden, for example, has observed that roulette players who fall victim to the Monte Carlo fallacy, i.e. believe (wrongly) that a preceding run of blacks increases the probability of the next outcome's being red, are still acting rationally. In trying to win a fortune by playing red, their behaviour is still rational in the sense that it is determined by the semantic content of their beliefs and desires.[1] This approach to rationality is a more general perspective than those of some such as Manzer, for example, who takes the position that to choose rationally is to select courses of action and means for their attainment that maximize the probability of achieving certain ends at least cost.[2]

Another premise is that environmental factors, i. e. technology, existing social or political institutions, the economic environment, etc., are best treated as constraints in the analysis of decision-making processes rather than as driving forces for decisions.

It is also assumed that there is some validity to recent developments in the fields of cognitive theory and artificial intelligence, particularly in the field of neural computers, and that these applications have significance for the understanding of political decision-making processes.

---

[1] Boden, M. A. *Computer Models of Mind: Computational Approaches in Theoretical Psychology*. Cambridge: Cambridge University Press, 1988, 171.

[2] Brooks, S. *Public Policy in Canada: An Introduction*, Toronto: McClelland and Stewart Inc., 1989, 65.

The thesis will provide a three-dimensional model which can be used to represent decision-making processes. This model will be used to illustrate various aspects of the decision-making process employing an analysis of the 1987 White Paper as a case study. The application of the three-dimensional model is utilized, not only to make explicit the organizational and logical structure of the decision-making process, but also to provide a map of the decision-making constraints.

Throughout this thesis it will be argued that the value of this particular approach is that it permits the application of much that has been learned in a number of disciplines to the understanding of human political behaviour. This model, if successful in representing the actual human decision-making process, may be useful in diagnosing the reasons for policy decisions and thereby may be valuable in determining appropriate responses. The model may also facilitate the application of neural network or other computer technology to the analysis of foreign policy and other decision-making situations.

The Decision Process

There is much to be gained from looking at decisions from the point of view of what constraints must be met in a decision-making process, rather than approaching the question from the positive perspective of what ends are to be achieved by a decision. This thesis takes the position that phenomena such as "satisficing" behaviour occur because there are usually a number of constraints to be taken into account in any decision-making process, and that these constraints affect the actions of the decision-maker and the degree to which the decision-maker's goals are achieved.

A simple example would be in a troop of monkeys going after food, such as coconuts. Using the proposed model, one would say that the monkeys would be using "resources", (i.e. their time and energy), to achieve a goal or maximize a value, (i.e. getting coconuts), using the available climbing technology, (i.e. their feet and tails), which, at the same time, represents a technical constraint. There are also "environmental" constraints which are comprised of the situation under which the monkeys evolve their strategy. There would have to be, for instance, coconuts within reach, and no leopards around; the time of day would have to be right, etc.

Another kind of constraint which might be identified is a "resource" constraint. Closely tied to "technical" constraints, this would involve, for example, whether or not there are enough monkeys to employ the strategy of weighing down the tree trunk until the coconuts come within reach.

In the case of a troop of monkeys, there may be a group decision to go after the coconuts. This decision may be dependent on who is dominant within the troop, the relative status of each monkey having input into the decision, and what each is allowed to contribute to the troop decision. These relationships can be seen as "structural" constraints.

The application of the model can be depicted graphically using Figure 1.:

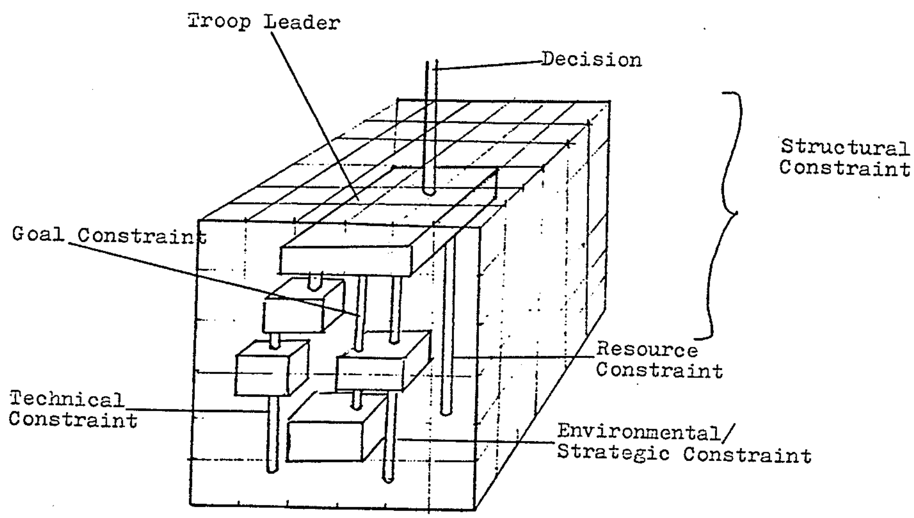

Figure 1. The Coconut Problem. A food-procurement decision process among a troop of monkeys can be illustrated using a three-dimensional matrix. The decision-making process as a whole is encompassed within the larger cube, while the individual participants are represented by the smaller cubes. The vertical columns depict the cognitive interactions of the participants.

Several aspects of the above model should be noted. First, the individual members of the troop are depicted in terms of their position within the decision-making process.

The representation of the troop leader is modified to suit the depiction of the connections with the other members of the troop. Their inputs to the troop leader's decision are represented by vertical columns. Vertical columns also represent the constraints as perceived by the participants in the process. There is a ubiquitous use of vertical columns, because what is important are the perceptions and mental processes of the actors. It can be argued that, with respect to the human brain, cognitive inputs need to be differentiated only once they are perceived. Thus, so far as the diagram is concerned, the categorization of the various constraints is merely an analytical convenience. In terms of processing the information, however, it is the logical structures in which the constraints are embedded which are critical.

Although human decision processes may be more elaborate than the monkey example, one can examine human decisions in a similar fashion and even use the same categories for the constraints in the decision-making process. This thesis uses the Canadian government's 1987 White Paper on Defence as an example of an explicit decision-making process. This is partly because the White Paper puts forth a series of policy decisions, with an accompanying rationale. As will be demonstrated, this rationale is fairly elaborate and specifies, in effect, many of the constraints that were considered in the decision-making process. For convenience, these constraints are categorized in a fashion similar to that in the foregoing example, i.e. in terms of goal/value, environmental/strategic, technical, resource and structural constraints.

One objection which might be raised at the outset, however, is whether there really is a "decision process" in connection with the 1987 White Paper on Defence to be modelled. At first glance, it seems difficult or impossible to fit decision processes to any structure. As Rear Admiral S. Mathwin Davis commented with respect to the decision processes which resulted in Canada acquiring conventional submarines in the 1970s:

> ...the decision process..."moves in a mysterious way", and ...it is not always easy to determine, from the record, that there was a systematic process of reaching the best possible decision.[3]

At least in the case of major Canadian procurement decisions, the process is remarked to be somewhat "erratic, not always discernible, subject to marked (and perhaps unexpected) changes of direction, and certainly not always guided by what are considered to be military necessities."[4] As will be noted in the following discussion of the 1987 White Paper, factors

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[3] Davis, Rear Admiral S. Mathwin (CF Ret'd). It Has All Happened Before: The RCN, Nuclear Propulsion and Submarines - 1958-68. In *Canadian Defence Quarterly*, Aug. 1987, 40.

[4] *Ibid. 40*. Lieutenant-General D. Huddleston, who was the Associate Assistant Deputy Minister for Policy in the Defence Department, and participated in the drafting of the 1987 White Paper, during an interview, also questioned the existence of a "process" with respect to decisions like those in the White Paper.

other than military effectiveness are considered in defence decisions.

The Duties of Defence Officials and Politicians

It has been pointed out by Douglas Bland that defence policy is influenced by social, economic and political factors.[5] It might be suggested that, to some degree, the actors in the policy formulation process have different roles to play. In a democratic society, defence policy decision-making is a political responsibility. While, on the one hand, there is a tendency among the military to over-ride political and bureaucratic needs for compromise, it is important, as Bland indicates, that the military do not accept compromises and risks to the national defence.[6] The military would not be fulfilling their role in the defence policy process if they did so. It is for the Cabinet to make the compromises and decide to take the risks, if necessary. It is important, however, that the decisions taken by the Cabinet are based upon adequate information. It is the responsibility of the military and the bureaucracy to provide that information. As Bland states, "managing the flow of information and developing

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[5] Bland, LCol D. L. The Armed Forces Council and the Defence Policy Process. In *Canadian Defence Quarterly*, Winter 1987, 27.

[6] *Ibid.*, 30.

policy positions...is at the heart of the policy process."[7]

Thus, one would assume that the recommended decision-making structure would be something like the one in Figure 2., with the final decisions emanating from the politicians, with the military personnel and bureaucrats making their policy recommendations and providing information to the political decision-makers.

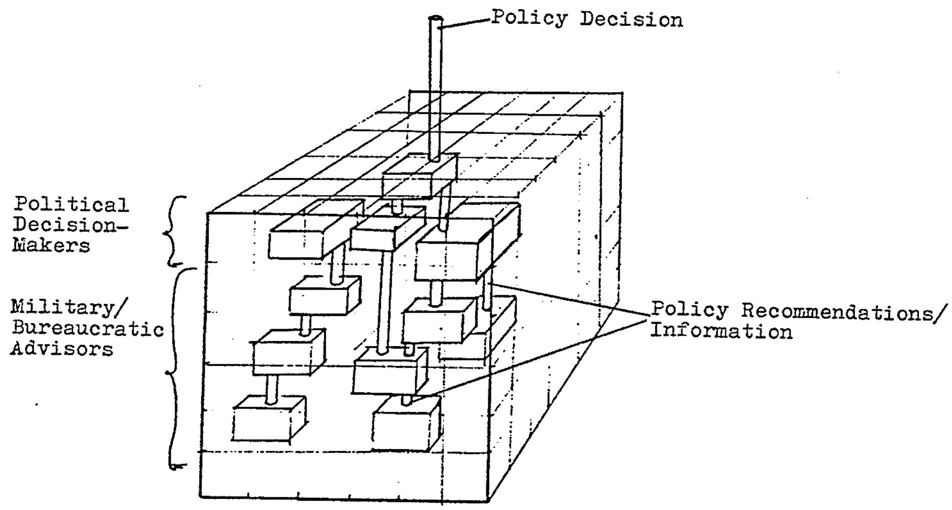

Figure 2. The Basic Decision-Making Structure. The basic defence policy decision-making structure is provided here. The military/bureaucratic advisors provide their recommendations to the political decision-makers, from whom policy decisions emanate.

[7] *Loc. Cit.*

Goals of the 1987 White Paper

Like the 1971 White Paper on Defence, the 1987 White Paper was a document produced by the government to make explicit the assumptions underlying government policy and to set the direction of government defence policy for the future.[8] In doing this, as R. B. Byers suggests, the 1987 White Paper had to satisfy several audiences. Because support for defence expenditures in Canada is generally "soft" and "fragmented", the White Paper had to convince the general public of the correctness of its defence policy.[9]

At the same time, particularly during the Cold War, it had to demonstrate the government's future intentions and its resolve in following that course to both Canada's allies and her potential adversaries. The production of a White Paper is therefore a complex and politically sensitive exercise. Byers identifies three main requirements that any Defence White Paper must fulfil: (1) outline security and defence policy; (2) serve as a general guidance and planning document for the Defence Department and the Canadian Forces; and (3) educate and inform the public.[10]

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[8] *Challenge and Commitment: A Defence Policy for Canada*, National Defence, June 1987, 1.

[9] Byers, R. B. The 1987 Defence White Paper: An Analysis, Autumn 1987, *Canadian Defence Quarterly*, 11.

[10] *Loc. Cit.*

The Impact of the 1971 White Paper and the Perceived Change in the Strategic Situation

The production of a White Paper is not normally without consequences for Canada's defence policy. In the case of the 1971 White Paper, for example, which followed a review of foreign and defence policy conducted in 1968-69, the consequence was major reductions in the Canadian Forces.[11] Canada's single aircraft carrier, the HMCS Bonaventure, was sold in 1970, the Canadian Forces in Europe were reduced by one-half; and the regular strength of the Canadian Forces was cut by 17,000. There was also a reduction in the portion of federal expenditures and Canadian GDP devoted to defence. From 1967-68 to 1971-72 the share of the federal budget spent on defence fell from approximately 18 per cent to 13 per cent. The percentage of Canadian GDP allocated to defence dropped from 2.5 per cent to 2 per cent.[12]

The decisions resulting in these cutbacks arose from a fundamentally different view of the world and set of priorities from those that underlay the 1987 White Paper. In the view of the Canadian government, as Brian Mulroney stated in the preface to the 1987 White Paper, there was a perceived change in the world situation since the previous review of

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[11] *Challenge and Commitment: A Defence Policy for Canada*, National Defence, June 1987, 1.

[12] *Loc. Cit.*

Canadian defence policy.[13]

If one were to depict a changed strategic viewpoint pictorially, in the context of the defence policy decision-making framework, especially when the perception of the environment changes from one of minimal threat to highly threatening, then something like the matrix in Figure 3. would be the result. It will be dealt with in more detail later.

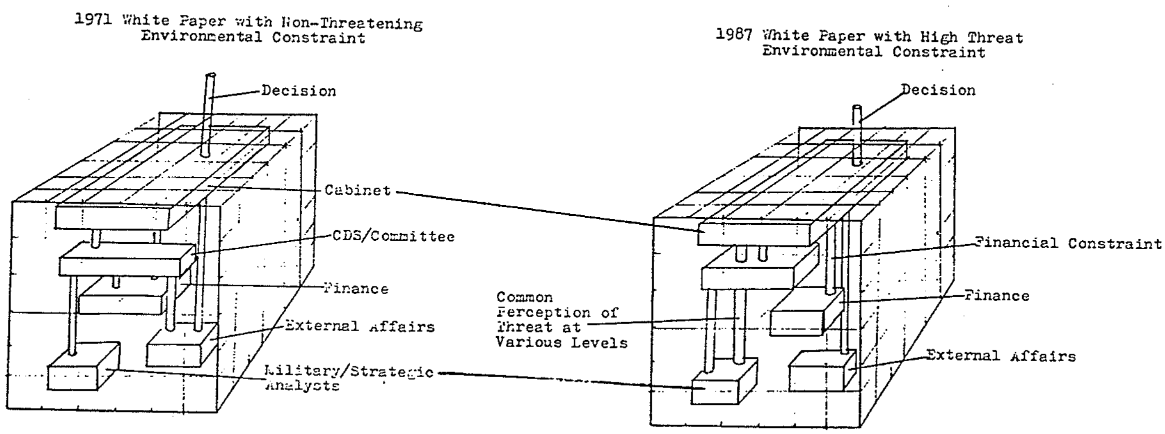

Figure 3. The Changed Strategic Perspective. In 1971, the strategic environment was not viewed as particularly threatening by the current government. In 1987, there was a commonly-held view of malevolent Soviet intentions, by both the Defence Minister and the military advisors.

The emphasis here is on **perception** rather than **reality,** however one defines that. Although technically both White Papers were released during the Cold War, there were some fundamental differences in the outlooks or *Weltanschauungen* of

[13] *Loc. Cit.*

the political decision-makers responsible for each of the White Papers. Given these differences, the strategic environment was indeed a different place in 1987 from what it was in 1971, and is displayed in the diagram as such.

POLICY DECISIONS

The major policy decisions in the 1987 White Paper, as R. B. Byers points out, can be classified into three general categories. In this classification, Byers identifies the policy priorities according to the following military clusters: (1) maritime forces; (2) surveillance and control capabilities; and (3) the Reserve Forces.[14] One might also add a fourth: the consolidation of European commitments, since the 1987 White Paper itself gives the following summary of the policy priorities:

> We will create a modern navy capable of operating in the Atlantic, the Pacific and the Arctic. We will bolster our capacity for surveillance and defence of Canadian territory. We will revitalize and enlarge the Reserves so that they can assume a greater role in the defence of Canada. We will consolidate our land and air commitments in Europe on the central front, thereby providing a more credible and sustainable contribution to collective security.[15]

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[14] Byers, R. B. *Op. Cit.*, 16.

[15] Challenge and Commitment: A Defence Policy for Canada, National Defence, June 1987, 89.

If one wanted to produce a diagram to illustrate all of these decision clusters together, one would produce something like the diagram in Figure 4.:

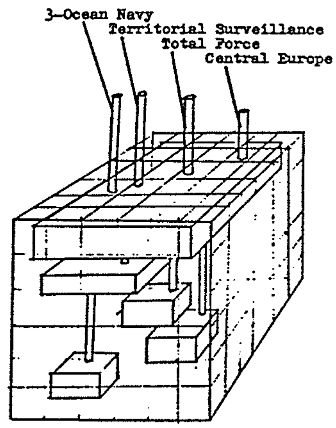

Figure 4. The Four Decision Clusters. There were four groups of decisions emanating from DND and therefore from the government, as expressed in the 1987 White Paper: the 3-ocean navy; the priority on territorial surveillance and sovereignty; the integration of the Reserves into Regular Force activities; and the concentration of Canadian military resources in Central Europe, as opposed to dispersing them through "penny-packaging".

This diagram concentrates on the outputs of the policy process, rather than the mechanism for generating the decisions. For simplicity, the details of the various constraints are omitted.

GOAL CONSTRAINTS

Objectives and Policy Principles

Any decision is generally intended to achieve one or more objectives. These objectives may take a number of forms. In some cases, they may be positive, i.e. altering the *status quo* towards achieving some more desirable state. Decision objectives may also take the form of avoiding or minimizing the effects of some negative influences, i.e. hindering the movement towards an undesirable state. As is apparent, questions of what can be considered a desirable or undesirable state are extremely subjective. In fact, underlying all statements of objectives are values. It is the commonality of these values within a community which usually enables a consensus on objectives to be achieved. It is because objectives can be agreed upon that decisions can be made which are acceptable to a group or community. In some cases, it is possible to make statements about how specific decisions should be framed, based on agreed-upon values and objectives. These statements are what is commonly referred to as "policy".

Values, objectives and policies have the effect of constraining what decisions are made. Although they are influenced by the environment, these values, objectives and policies operate somewhat internally and independently within the mind of the decision-maker. It appears that within the logical process, the achievement or satisfaction of this set of constraints is vital for any decision to be made. If one removes values or objectives, then one makes decisions impossible.

In the 1987 White Paper, this particular set of constraints was made quite explicit. Among the values or goals to be achieved through Canadian defence policy were:

1. the maintenance of strategic deterrence;
2. a credible conventional defence;
3. the protection of Canadian sovereignty;
4. the peaceful settlement of international disputes; and
5. effective arms control.[16]

At another point in the 1987 White Paper, the principles underlying Canadian defence policy are listed as:

1. defence and collective security;
2. arms control and disarmament; and
3. the peaceful resolution of disputes.[17]

However formulated, all of these goals or objectives are based on another more fundamental set of values and perceptions which, it can be argued, were held by the decision-makers responsible for the 1987 White Paper.

Goal Constraints and the Issue of Sovereignty in the 1971 White Paper

Canada's defence policy also was affected by the change in the government's policy goals from 1971 to 1987. Reflecting Canadian public opinion to some extent, the 1971

[16] *Ibid.* 49.

[17] *Ibid.*, 3.

White Paper emphasised the need to protect Canadian sovereignty and focused on Canada's part in the defence of the North American continent.[18] This represented a diminished concern with conventional forces in light of the dominance of nuclear weapons, as well as a lessened commitment to defending Western Europe because of its increased ability to defend itself. Also noted in the 1971 White Paper was the loosening of the bipolar international system and a lessening of the scope for useful and effective peacekeeping activities.[19]

In the 1971 White Paper, Canada's national aims were defined in the following way:

> (1) that Canada will continue secure as an independent political entity;
>
> (2) that Canada and all Canadians will enjoy enlarging prosperity in the widest possible sense; and
>
> (3) that all Canadians will see in the life they have and the contribution they make to humanity something worthwhile preserving in identity and purpose.[20]

These goal constraints were seen as framing government policy decisions, which were in turn viewed as maximizing the following set of objectives:

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[18] Rossignol, M. *Canadian Defence Policy*, Ottawa: Library of Parliament, Research Branch, Political and Social Affairs Division, Feb. 1988, 11-12.

[19] Macdonald, D. S. *White Paper on Defence*. Ottawa: Information Canada, 1971, 1-3.

[20] *Ibid*. 1.

(1) to foster economic growth,
(2) to safeguard sovereignty and independence,
(3) to work for peace and security,
(4) to promote social justice,
(5) to enhance the quality of life, and
(6) to ensure a harmonious natural environment.[21]

Given this set of national objectives and the premise that government policy should seek to maximize these values, it appeared to make sense to have defence policy also framed in these terms. Thus, the first concern of defence policy, as expressed in the 1971 White Paper, was seen to be the national aim of ensuring that Canada should continue secure as an independent political entity. This was viewed as a pre-condition to the achievement of the other goals. Thus arose the importance of maintaining sovereignty and independence.[22]

The concern expressed in the 1987 White Paper with protecting Canada's sovereignty within her territorial limits, particularly in the Arctic, thus goes back at least as far as the 1971 White Paper on Defence, and can be traced to the persistence of a set of value or goal constraints.

Non-Military Goal Constraints in the 1987 White Paper

Also acknowledged in the 1987 White Paper were certain non-military or strategic goals which were also constraints in

[21] *Loc. Cit.*

[22] *Loc. Cit.*

the decision-making process. It was pointed out that defence programs make a significant contribution to overcoming regional economic disparities.[23] Defence dollars can serve the dual purpose of strengthening local and regional economies and satisfying defence requirements. Among the economic benefits of defence spending was cited the fact that the $12 billion spent on defence in 1985-86 generated $1.6 billion in taxes and created approximately 294,000 jobs, 178,000 in the private sector.[24]

If one wanted to illustrate simultaneously the various "goal" constraints operative in the defence policy decision-making process, one would thus include the non-military objective of regional economic development, as in Figure 5.:

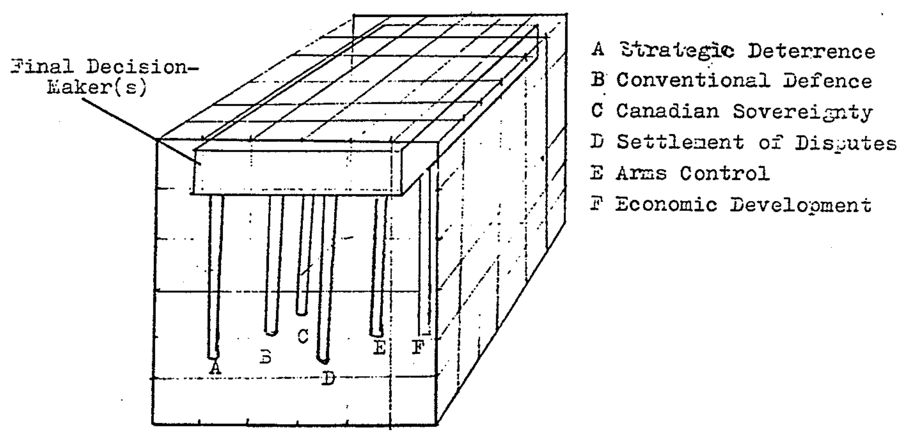

Figure 5. The Six Goal Constraints. According to the 1987 White Paper, there were 5 major values or objectives which the government sought to maximize in formulating defence policy. These are represented by vertical columns. A sixth unlisted objective was regional economic development.

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[23] *Challenge and Commitment: A Defence Policy for Canada.* National Defence, June 1987, 85.

[24] *Ibid.*, 83.

These "goal" constraints are linked in various ways, some of them having in common certain underlying values and principles, such as the avoidance of war and maintenance of peace.

In seeking to maximize the stated objectives, some compromises were recognized in the 1987 White Paper as being necessary because of numerous other constraints on the government. As will be discussed in more detail later, the technical constraint of equipment obsolescence was seen as forcing the government into making some critical decisions with respect to how the given goal constraints could continue to be met. In the view of the drafters of the 1987 White Paper, there were only three approaches which appeared to be open to the government. They were:

> (1) increase significantly the resources devoted to defence so that, over a period of 10 to 15 years, the Canadian Forces would become capable of meeting current commitments;
>
> (2) reduce commitments to the point where those remaining could be carried out by existing forces, within existing resources; or
>
> (3) seek some combination of these two alternatives.[25]

The option which the government chose was the third one. Thus, the government declared that it would:

> (1) alter some commitments to bring them more into line with resources;
>
> (2) improve the effectiveness with which the remaining

[25] *Ibid.*, 47.

commitments are carried out; and

(3) increase spending in a determined fashion to make the defence effort more responsive to the challenges of the 1990s and beyond.[26]

As subsequent events made evident, the third of the policy directions which the government proposed to follow was highly constrained by the resources available and could only be partially implemented.

The increase in defence program funding was to take place in the context of the implementation of a new funding program which would make up for what was termed "decades of neglect".[27] The consequences of not expanding funding, but rather reducing defence commitments to fit existing levels of resources, were seen by the government as being extremely negative, both for the armed forces and for the local economies where military bases were currently located.

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[26] *Loc. Cit.*

[27] *Loc. Cit.*

CHAPTER 2. - THE CONTEXT OF DEFENCE POLICY DECISION-MAKING

ENVIRONMENTAL/STRATEGIC CONSTRAINTS

The Implementation of the 1987 White Paper

The political environment within which the formulation of the White Paper takes place has a powerful influence on decisions which are taken. These decisions include not only what is to be recommended in the White Paper, but also whether what the government says it is going to do is actually done. Following the release of the 1987 White Paper, R. B. Byers raised the issue in the publication, *Canadian Defence Quarterly*, as to how far the White Paper was likely to be implemented.[1] As Byers pointed out, there were political, economic and military-strategic factors which could affect those decisions. In his view, there were three inter-related sets of factors which affected the prospects for implementation: (1) the response within DND; (2) political considerations; and (3) the economic implications for defence resources.

Among the political concerns was the prospect of a general election and the probability of a minority Conservative government. In this scenario, it appeared

[1] Byers, R. B. The 1987 Defence White Paper: An Analysis. In *Canadian Defence Quarterly*. Autumn 1987, 18.

possible that the government would have to modify its defence policy, particularly with respect to the proposed nuclear submarine fleet. Both the Liberals and New Democrats had expressed opposition to this proposal.[2] In the event of an election, it could also be expected that, during the election campaign, the more controversial aspects of the 1987 White Paper could come under scrutiny and would affect the decisions any subsequent government would take regarding implementation of the policies. Some organizations, such as Operation Dismantle, the Canadian Centre for Arms Control and Disarmament, and the Voice of Women had taken stands opposing certain aspects of the 1987 White Paper.[3]

There were thus environmental constraints which lay outside of the logic of the 1987 White Paper itself which ultimately affected its implementability and which had some long-term effects that had to be considered when formulating the White Paper. Because these factors were largely beyond the control of the government and were difficult to foresee, there was relatively little that could be done about them within the context of the 1987 White Paper.

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[2] *Ibid.*, 20.

[3] According to some reports, there was even opposition to some aspects of the 1987 White Paper from within Cabinet, including from the Minister of External Affairs, Joe Clark. See: Manthorpe, Jonathan. Military's Spirits Buoyed by Big, Fat Wish List. In *The Edmonton Journal*, June 6, 1987, 2.

Strategic Issues and the Policy Process

Because of issues such as the implementability of the White Paper and the pressures regarding the creation of regional employment opportunities, it is easy to see how a government, in the formulation of defence policy, can stray from meeting the goals which defence policy is theoretically meant to address. Confusion can also arise between ends and means, i.e. between how programs are to be put in place and what they are intended to achieve. In Bland's opinion, the focus on programs, and "the misapprehension that **the program** is **the problem**," has submerged the central concern of the defence policy process. This central concern, he argues, should be "strategic issues".[4]

Within the White Paper itself, however, heavy emphasis is placed on the strategic context. It is R. B. Byer's perception that the section dealing with the "military threat" is strongly influenced by information contained in *The Military Balance*, an annual publication of the International Institute for Strategic Studies (IISS). The data from the IISS are generally respected as reliable and objective.[5]

In theory, if not always in practice, as Byers acknowledges, the formulation and implementation of security

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[4] Bland, D. L. The Armed Forces Council and the Defence Policy Process. In *Canadian Defence Quarterly*, Winter 1987, 29.

[5] Byers, R. B. *Op. Cit.* 12.

and defence policy should be primarily determined by strategic constraints.[6] Because policy decisions are influenced by factors other than the strictly military-strategic, but also by the domestic political environment surrounding the decision-makers, this thesis chooses to treat both military-strategic and domestic political constraints as aspects of "environmental" constraints.

Soviet Aims and Views

The 1987 White Paper reiterates in a number of places its assumptions concerning the strategic environment. This constraint was formulated in terms of a Soviet leadership perceiving the world as being divided into two antagonistic camps.[7] The Soviet Union was seen as "an ideological, political and economic adversary whose explicit long-term aim" was "to mould the world in its own image."[8] This would encompass "the dissolution of NATO, the neutralization of non-communist Europe and the weakening of the West as a whole."[9] The Soviet leadership was seen as having demonstrated in the

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[6] *Ibid.*, 11.

[7] *Challenge and Commitment: A Defence Policy for Canada*, National Defence, June 1987, 15.

[8] *Ibid.*, 5.

[9] *Ibid.*, 15

past its willingness to use force, both at home and abroad, to achieve political objectives. The White Paper acknowledged that the Soviet leaders were aware of the dangers of overt military aggression against NATO. Nevertheless, the Soviet Union was perceived as continuing to seek to translate military power into political gain.[10]

The 1987 White Paper speculated that the Soviet obsession with security may have been somewhat understandable, given Russian history, but pointed out that the result of this for other nations was to make them feel decidedly insecure.[11] Despite this atmosphere of insecurity, war with the Soviet Union was not seen as inevitable, and mutually beneficial arrangements were viewed as worth pursuing.

The Canadian View of the World

In dealing with environmental constraints, the 1987 White Paper made some generalizations about how Canadians tend to view the world. According to the 1987 White Paper, Canadians are inclined to approach international relations

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[10] *Ibid.*, 15.

[11] *Ibid.*, 5.

optimistically, and assume the best from other nations.[12] One might remark that the previous White Paper, released in 1971, was consistent with this, displaying a typical Canadian optimism concerning international peace and security.[13]

The world situation in 1987, so argued the more recent White Paper, did not justify this optimism, but rather, called for a more sober approach to international relations and the needs of security policy. The position was that:

> the world is not always as benign or predictable as we would wish, that the spectre, if not the reality, of violence is ever-present and that those who do not look to their own military forces can become the victims of others.[14]

This view of the world runs counter to the Canadian tendency to believe that Canada would not have to resort to force of arms to resolve problems, even though Canadians generally accept the necessity of some kind of defence effort.[15]

The 1987 White Paper suggested that Canadians generally do not feel militarily threatened and have difficulty imagining another country as an enemy. The approach of the 1987 White Paper, however, was that a threat from the Soviet Union did exist and that this threat encompassed Canada. No other threats, unique to Canadian security, were envisioned.

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[12] *Ibid.*, 89.

[13] *Ibid.*, 2.

[14] *Ibid.*, 89.

[15] *Ibid.*, 89.

The 1987 White Paper put forth the premise that, to deal with the Soviet threat, Canada could not rely on its own resources alone.[16]

Arms Control

The optimism underlying the 1971 White Paper was criticised in the 1987 White Paper particularly within the framework of what had happened in the areas of détente and arms control. Developments in the late 1970s and early 1980s were taken to indicate that the early promises of détente had been exaggerated.[17] Negotiation was not seen as having been as useful a tool as once thought in resolving differences between East and West. Although force had not been used in dealings between East and West, the threat of its use had always remained in the background, and there had been little movement towards lessening the likelihood of its use. In the rest of the world, as well as within the Communist Bloc, a bias towards the use of force to achieve political objectives was seen as being quite persistent.

Although the 1987 White Paper acknowledged the greater diffusion of power foreseen in the earlier White Paper,

[16] *Ibid.*, 3.

[17] *Ibid.*, 2.

particularly in Europe and the Far East, it insisted that its extent was not so great as had been anticipated. The East-West confrontation still remained a critical aspect of the world strategic situation.

Progress in arms control had not met the expectations of some of the more optimistic, with the Mutual and Balanced Force Reductions (MBFR) talks, already envisioned in 1971, having made little progress by 1987.[18] Diagrammatically, if one wanted to compare some of the strategic paradigms in the 1987 White Paper with those in the 1971 version, one would define some of the environmental/strategic constraints somewhat differently. In simplified form, the diagrams would be as in Figure 6.:

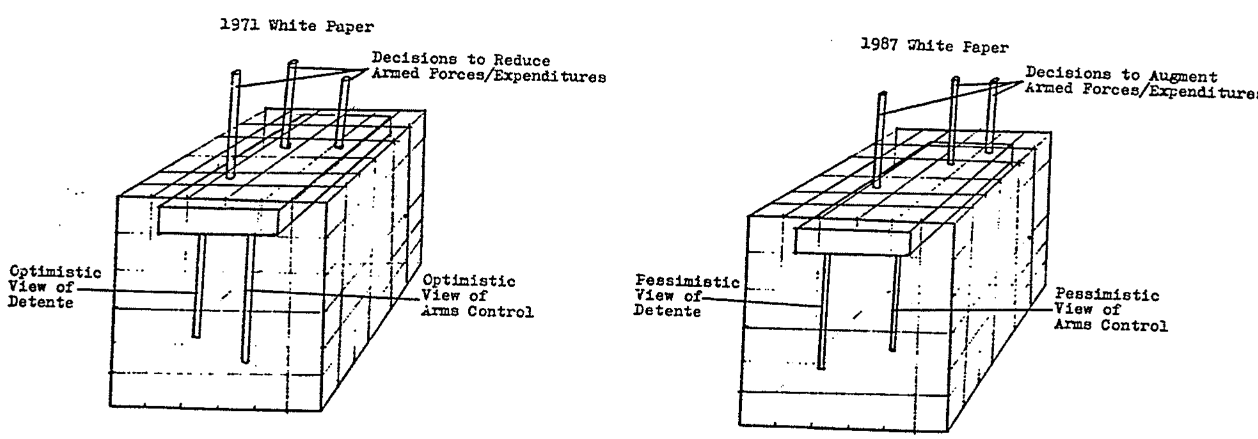

Figure 6. The Changed Environmental Constraints. The impacts of the optimistic views of détente and arms control prevalent in 1971 are contrasted with the outcome of the pessimistic views of these processes prevalent in 1987.

[18] *Ibid.*, 1.

There were a number of trends current in the world of the early 1980s that led the government to take a pessimistic view of arms control. These factors contributed to the government's proposing the augmentation of the Canadian armed forces and defence expenditures, in contrast to the cuts that took place as a result of the 1971 White Paper.

TECHNICAL CONSTRAINTS

Comparison with 1971

As mentioned before, this thesis treats as technical constraints those factors which physically limit the degree to which certain objectives can be attained. The 1987 White Paper went into some detail as to how there had been an increase since the 1971 White Paper in the technical constraints on the government's attempts to meet its defence commitments. This increase in technical constraints was largely attributed to the decisions resulting from the 1971 White Paper, as well as to the previous government's disinclination to devote resources to those projects which were proposed in the 1971 White Paper.

According to the 1987 White Paper, the equipment used by the Canadian forces had deteriorated due to underfunding, purchases having been deferred or spread over a longer period of time.[19] Equipment was often replaced on a less than one-for-one basis, and modernization programs were reduced, even when this ran counter to military logic.

In detailing the negative effects of the underfunding of military requirements, the 1987 White Paper enumerated deficiencies in each of the branches of the armed forces. In the navy in 1987, for example, all of the major vessels were in commission or under construction in 1971, the newest ship already being 14 years old and the oldest being 31. A reduction had taken place from 45 major warships and 10 minesweepers in 1963 to 26 warships and no minesweepers.[20]

In the air force, only 2 significantly new aircraft systems, the CF-18 fighter and the CP-140 Aurora long-range patrol aircraft, had been acquired since 1971. As with naval vessels, fewer aircraft were procured than those they replaced. Thus, the air force had, in 1987, approximately 75 per cent of the aircraft, fixed wing and helicopter, that it had in 1971.[21] The White Paper described similar reductions in equipment levels due to funding cuts for the army as well.

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[19] *Ibid.*, 44.

[20] *Loc. Cit.*

[21] *Loc. Cit.*

Equipment Shortcomings

The result of funding restrictions and consequent equipment shortages was, according to the 1987 White Paper, an increased inability to achieve policy objectives. Thus, the maritime forces were seen as having too few operational vessels for the missions assigned to them. In particular, the navy had a very limited capacity to operate in the Arctic and no capability to keep Canadian waterways and harbours clear of mines.[22] In the case of the land forces, equipment shortages were described as severe. The number of combat-ready soldiers was seen as too small, with the militia being too ill-equipped and trained and not numerous enough to make up the difference.

A serious shortage of air transport was viewed as preventing the air force from being able to move troops and equipment to Europe and sustain them there in times of tension or hostilities. The 1987 White Paper described the air force as having too few maritime patrol aircraft. There were also seen to be shortages of modern armaments for the CF-18 fighters. Any CF-18 aircraft lost in peacetime would lack replacement.[23]

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[22] *Challenge and Commitment: A Defence Policy for Canada.* National Defence, June 1987, 43.

[23] *Ibid.* 43.

The Non-Nuclear Option

All of the manpower and equipment shortcomings detailed above can be seen as constraining the armed forces' ability to meet certain defence policy commitments. The range of decisions which the government could take to ameliorate these technical constraints was further limited by the technical requirement that the Canadian government not acquire nuclear weapons. As the 1987 White Paper states:

> Canada does not have nuclear weapons. We have no intention of acquiring them. To deter a nuclear attack on Canada, we rely on the nuclear forces of our allies.[24]

This meant that whatever the arguments might have been in favour of the technical efficiency and effectiveness of nuclear warheads on anti-aircraft and anti-ship missiles or torpedoes, this option was not exercisable because of Canada's maintenance of the principle of abstention from the possession of nuclear weapons.

In summary, then, the major groups of technical constraints on the Canadian military can be pictured as in Figure 7.:

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[24] *Ibid.*, 17.

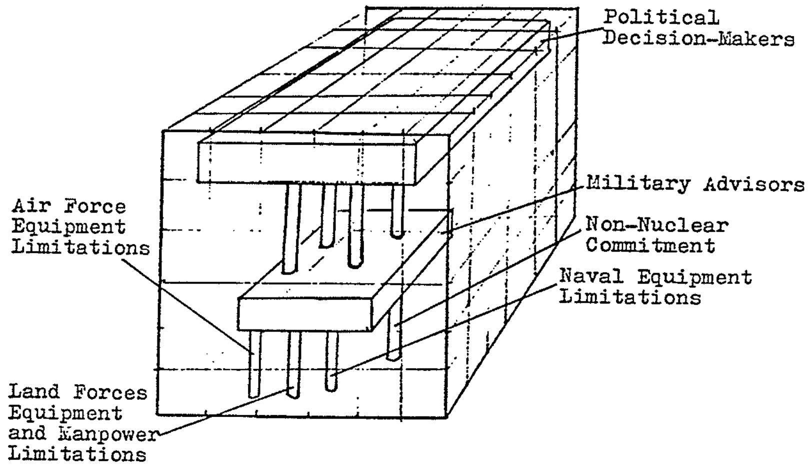

Figure 7. The Groups of Technical Constraints. The technical constraints are pictured as being the immediate concern of the military advisors. Their assessments and recommendations are passed on to the political decision makers.

The above constraints restricted in terms of physical capacity the degree to which Canadian policy objectives could be met, and therefore increased pressure to make decisions to change certain policy commitments. As the diagram shows, technical constraints were primarily of concern to military advisors who had to indicate to the political decision-makers a range of technically-feasible policy options.

RESOURCE CONSTRAINTS

The Proportion of the Defence Budget Used for Equipment

The extent and nature of technical constraints are largely dependent on resources. The 1987 White Paper pointed out, for example, that, in effect, some of the technical constraints on Canadian military policy had been eliminated through increased expenditures to purchase equipment.[25] Some of this new equipment included new frigates and low-level air defence batteries. The 1987 White Paper maintained, however, that the recent equipment acquisitions were inadequate to make up for the "bow wave" of deferred equipment acquisition built up since the 1960s.

Among the statistics which the 1987 White Paper used to demonstrate the resource constraints which equipment acquisition had been under, was the fact that the percentage of the defence budget spent on capital projects had declined from more than 20 per cent in 1962-63 to about 9 per cent in 1972-73. Thereafter, there had been a reversal of this trend until, by 1982-83, capital projects once again took up at least 20 per cent of the defence budget. In NATO countries, however, on average, in 1985, approximately 25 per cent of defence budgets was spent on equipment acquisition.[26]

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[25] *Ibid.*, 45.

[26] *Ibid.*, 43.

Changes in Defence Commitments

One of the more serious consequences of a lack of resources devoted to equipment acquisition is that military commitments can not be met. Among the alternative courses of action defined in the 1987 White Paper was the reduction of commitments to the point where those remaining could be carried out by existing forces within existing resources. This would have meant massive cuts in military commitments, which would, in turn, have had significant results for Canada's relations with the U.S. and the Western European allies.[27] In other words, there would have been environmental constraints on any Canadian decision to cut defence commitments. The 1987 White Paper argued that a reduction of defence commitments sufficient to close the gap between commitments and capabilities would result in Canada's not meeting her NATO responsibilities and would threaten the cohesion of the alliance.[28]

If Canada were to have gone in the other direction and honour all of her defence commitments, Canada's defence effort would have had to increase substantially. The 1987 White Paper maintained that defence expenditures would have had to rise so

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[27] *Ibid.*, 47.

[28] *Ibid.*, 47.

much in real terms as to be beyond Canada's ability to pay.[29] Thus, meeting Canada's current defence commitments was seen as being clearly impossible, given resource constraints; some re-negotiation of defence arrangements would be necessary. Nevertheless, the 1987 White Paper argued, defence commitments are more easily negotiated if a willingness to make the required effort to contribute to the alliance is seen to be there. Thus, as in Figure 8., the decision whether to shrink commitments to match existing defence expenditures or to increase expenditures to match commitments was subject to both environmental and resource constraints.

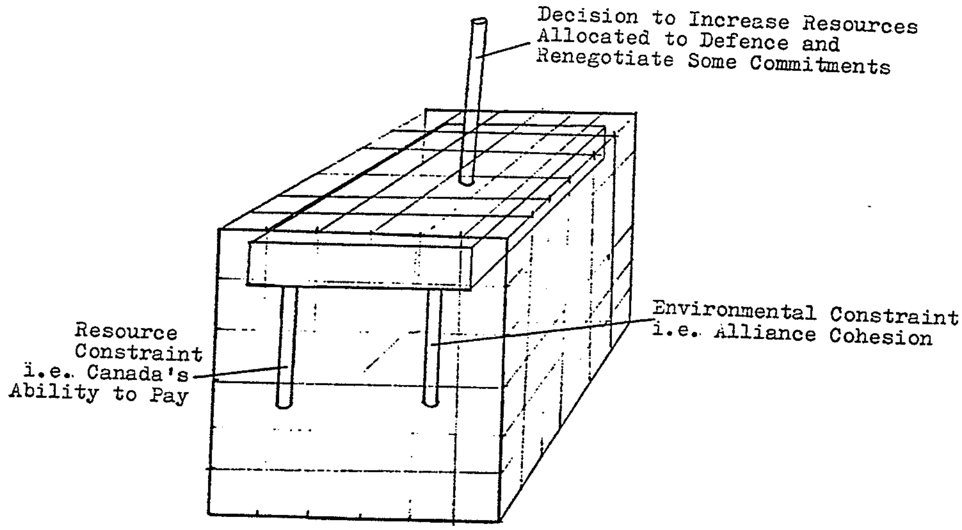

Figure 8. Changes in Defence Commitments. This diagram illustrates the two main constraints involved in the decision to increase the resources allocated to defence, while at the same time renegotiating some commitments.

[29] *Ibid.* 47.

The government decided to resolve this dilemma by doing a bit of both: (1) modify defence commitments to bring them into line with Canada's resource capabilities; and (2) increase Canada's defence expenditures to ensure that commitments, once made, would be met.

Future Large Defence Expenditures

The importance of the resource constraint was explicitly acknowledged in the 1987 White Paper, and certain budgetary impacts were defined. In the calculations used in the 1987 White Paper, the government would have been committed to a base rate of annual real growth in the defence budget of 2 per cent per year after inflation. This would have been carried over the 15 year planning period.[30] In addition to these increases, other allocations were anticipated to meet the needs of major projects, and their peak requirements.

Presumably, among these heavy users of defence resources would have been the nuclear submarine project. As R. B. Byers points out, the SSN fleet proposal attracted much criticism and this, together with the planned future level of defence

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[30] *Ibid.*, 67.

spending, created substantial opposition to the proposals of the 1987 White Paper.[31] The White Paper was not understating the situation when it acknowledged that the proposed programmes would be expensive and would pose a significant challenge to the current and future governments.[32]

The 1987 White Paper further acknowledged that it is difficult for democratic governments, in peacetime, to find the resources necessary for defence. This was attributed to the pressures to provide economic and social programmes to improve the quality of life of the society. By contrast, expenditures on defence seem to be an "unnatural use of national resources."[33]

Thus, one can depict decisions to allocate resources to defence as subject to certain environmental constraints, i.e. the pressures in the body politic to devote resources to economic and social programs. These environmental constraints would be pictured as in Figure 9.

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[31] Byers, R. B. *Op. Cit.*, 20.

[32] *Challenge and Commitment: A Defence Policy for Canada*, National Defence, June 1987, 67.

[33] *Loc. Cit.*

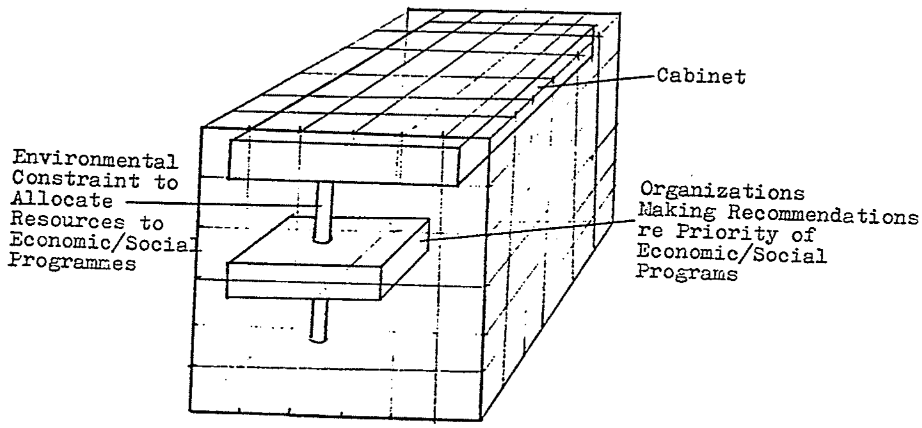

Figure 9. The Social Programs Constraint. This diagram illustrates the pressures on Cabinet to devote more resources to economic and social programmes, as opposed to defence. The organizations making these representations are grouped together for convenience.

Pressures to allocate more resources to social programmes would most likely be exerted through various moulders of public opinion, such as the media, the academic establishment, the trade unions and social action groups, as well as through the political establishment itself. The strength of these environmental constraints would also be manifested in Cabinet where the decisions are made and where some members will tend to give priority to economic and social programs.

Long Range Planning

Because technical constraints are heavily tied to resource constraints, it is necessary, when providing resources to alleviate technical constraints, to arrange the allocation of resources in such a way as to facilitate the meeting of technical requirements. As the 1987 White Paper pointed out, defence planning is long term, and most major projects take at least 10 years to produce results.[34] Therefore, the Defence Department announced the introduction of a 5-year funding plan within a 15-year planning framework. This would effectively have brought the supply of resources into line with the requirements of defence technology. To prevent resources from becoming a negative constraint on technical program requirements, an annual Cabinet review was to take place each autumn to establish firm budgets for the following 5-year period and planning guidance for the remaining 10 years.[35]

It was anticipated that through such measures as the new funding plan and the planning framework, the government would have been able to ensure the implementation of its blueprint for defence policy up until the end of the century. Setting in place a mechanism whereby technical goals could be realized was meant to ensure that equipment decisions would respond to, rather than lead policy. Policy would thus have led resource allocation, which, in turn, would have conditioned technical constraints, i.e. equipment, rather than equipment or

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[34] *Ibid.* 67.

[35] *Ibid.* 67.

technical constraints determining policy options. In terms of Figure 10., it would mean that technical constraints, although they would have to be considered, would not be critical in policy decisions. They would, of course, be of concern to military and other technical advisors, and these people would provide their input to the Cabinet decision-making process; the technical constraints, however, would not be of primary concern to the political decision-makers. In other words, there would be adequate technical resources to do the job.

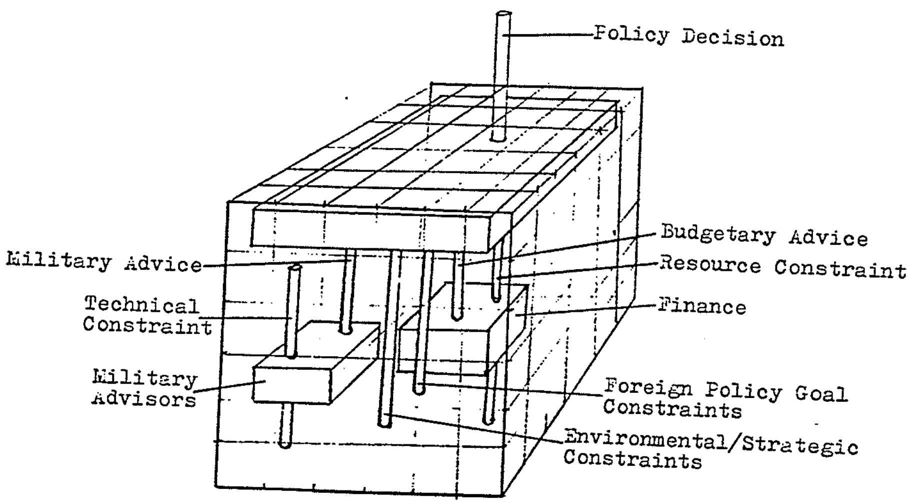

Figure 10. The Effect of Long-Range Planning. Cabinet decision-makers would set policy through a combination of military advice, coming from Defence Department advisors, together with budgetary advice coming from Finance and Treasury Board, and foreign policy advice coming from External Affairs and other entities. Long-range planning with adequate assured resources would remove the technical constraint from the Cabinet's consideration.

At the same time, given the improved funding picture for defence, the resource constraint would not be of primary concern to the political decision-makers either. The

Department of Finance, Treasury Board and other budgetary authorities would be concerned with the financial resources required for various decision options, and would provide advice in the decision-making process as well. But the resources would be there, according to the scheme envisioned in the 1987 White Paper, and the political decision-makers could concern themselves with what is properly their domain: the environmental or strategic constraints, as well as Canada's foreign policy goal constraints.

The Proportion of the Federal Budget Going to Defence

Where the political in-fighting gets particularly fierce at the Cabinet level is in resolving which department gets what share of the federal budget. The 1987 White Paper noted that many of the problems concerning the shortcomings of the Canadian armed forces had to do with the level of funding for defence over the previous 25 years. Other concerns took priority over defence, so that there was a long-term trend towards spending smaller percentages of the federal budget and Canada's GDP on defence.[36] In some of those years, Canada's defence expenditures fell in dollar terms, and sometimes even in "real" terms, i.e. not keeping up with inflation.

[36] *Ibid.*, 43.

For Canada to implement the kind of policy advocated in the 1987 White Paper, the share of the federal budget devoted to defence would have had to be increased, and implicitly the shares accounted for by each of the other departments correspondingly decreased. As Perrin Beatty acknowledged in *Canadian Defence Quarterly*, the defence program envisioned implied heavy costs, and these costs would have had to be sustained beyond the year 2,000.[37] The planners at DND would have had to work with a basic budget that would increase by 2 per cent per annum in real terms.

The diagram below illustrates the Cabinet-level decision-making that must have occurred to have produced an agreement to release a White Paper which would have resulted in such a shift of resources.

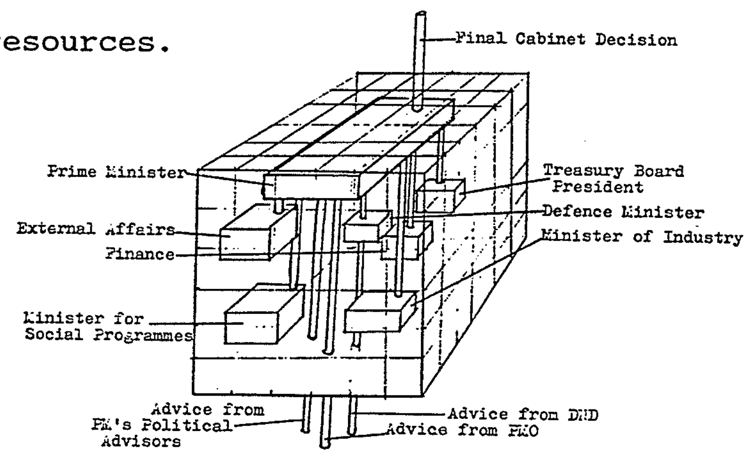

Figure 11. The Cabinet Structural Constraint. The Cabinet decision-making process on defence issues is depicted, including some of the key players. Inputs are also received from outside of Cabinet, including the DND bureaucracy itself, the Prime Minister's Office, and other Prime Ministerial political advisors.

[37] Beatty, P. A Defence Policy for Canada. In *Canadian Defence Quarterly*, June 1987, 12.

One would thus diagram the decision-making process within Cabinet by identifying the various players and the constraints they were operating under. Many of these constraints have already been mentioned in this thesis, such as budgetary and external/strategic constraints. Also considered to be constraints would be the political goals of Cabinet and the advice received from the other entities in the decision-making process.

In this thesis, "Cabinet" is treated as the final decision-making body. Traditionally in Canada the Prime Minister has more decision-making influence in Cabinet than the other ministers. Different decisions would involve a different constellation of players within Cabinet, and different constraints and different inputs from outside of Cabinet. Space does not allow for the definition of all of the relationships within Cabinet for all of the decisions involved in the 1987 White Paper.

The Consequences of Inadequate Defence Expenditures

There are, of course, issues relating to defence which are of concern to the Cabinet, other than how one divides up the federal budget between the departments. Also of importance, particularly to the Prime Minister and the Department of External Affairs, is whether Canada's defence effort is adequate to meet Canada's international commitments. The 1987 White Paper served warning that if deferred equipment acquisition were to continue unabated, then "rust out", or "the unplanned and pervasive deterioration in the military capabilities of the Canadian forces," would become a major problem.[38] The 1987 White Paper argued that only by increasing the amount of resources devoted to defence could Canada's defence commitments continue to be met.[39]

Failing to meet her international commitments would then entail major problems for Canada's Prime Minister and the Department of External Affairs. Thus, there was a certain community of interest in setting and resourcing defence commitments in Cabinet in a way which is mutually acceptable.

STRUCTURAL CONSTRAINTS

The way in which the various actors participate in the decision-making process can be considered a structural constraint. Within Cabinet, for example, there is a structural constraint in the degree to which the Prime Minister dominates, or does not dominate the decision-making process.

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[38] *Challenge and Commitment: A Defence Policy for Canada*, National Defence, June 1987, 45.

[39] *Ibid.*, 47.

The relationship between the various actors in the process has an effect on how decisions are made.

It is more difficult to represent structural constraints in the proposed model using vertical columns, than is the case with the other constraints. One can represent advice, decisions or recommendations passing from one actor to another using vertical columns, but the organizational juxtapositioning of the actors appears to be most effectively rendered in 3-dimensional spatial terms using blocks or cubes.

As well as the representation of departmental or organizational groupings, and the actors within Cabinet, it is also possible to represent the structural constraints within the Defence Department itself using the model. An essential element of the Defence Department's organization has been the three services. In the post-war years, as the 1987 White Paper pointed out, the services became increasingly integrated, and in 1964 the responsibility for command and control of the armed forces was assigned to the newly-created position of the Chief of Defence Staff.[40] The structure of the Defence Department changed further with the *Canadian Forces Reorganization Act* in 1967, which unified the services into a single Canadian Armed Forces. There still remained, however, the distinct service elements with their inter-service rivalries. One might even argue that these rivalries became

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[40] *Ibid.*, 69.

exaggerated in order to maintain the distinctiveness of the element group identities.

As well, there remained the split between the military and civilians in the department. In 1972, the Canadian Forces military headquarters and the departmental headquarters were combined as the result of a Management Review Group recommendation. It was felt that the new structure enabled military officers and civilian officials to provide advice to ministers more effectively.[41]

Another structure within the Defence Department which facilitates the flow of advice to the Minister from the military side is the Armed Forces Council. It is through this body that the commanders of the individual commands and senior staff officers develop and provide policy advice to the Chief of Defence Staff.

The Chief of Defence Staff, on the military side, and the Deputy Minister and his/her advisors, on the civilian side, then provide recommendations on policy to the Minister through the Defence Management Committee (DMC). Douglas Bland describes the DMC at the time of the White Paper as being of much the same composition as the earlier Chiefs of Staff Committee (COSC), but with some changes in leadership and agenda.[42]

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[41] *Loc. Cit.*

[42] Bland, D. L. *Op. Cit.*, 28.

The Defence Management Committee is jointly chaired by the Deputy Minister (DM) and Chief of Defence Staff (CDS), and is comprised of the Vice-Chief of the Defence Staff (VCDS), the senior staff officers of NDHQ, and (since 1981) the three service commanders (i.e. of Maritime Command, Forces Mobile Command and Air Command). The previous Chiefs of Staff Committee contained officials from outside DND. The current Defence Management Committee's focus, however, is on internal program management, and therefore only DND officials attend meetings.[43]

It appears that the recommendations for the 1987 White Paper emerged through the interaction of the membership of the DMC and the Minister, and then were further refined or fought out in the Cabinet environment. The structure of the process, in general terms, would be represented by Figure 12.:

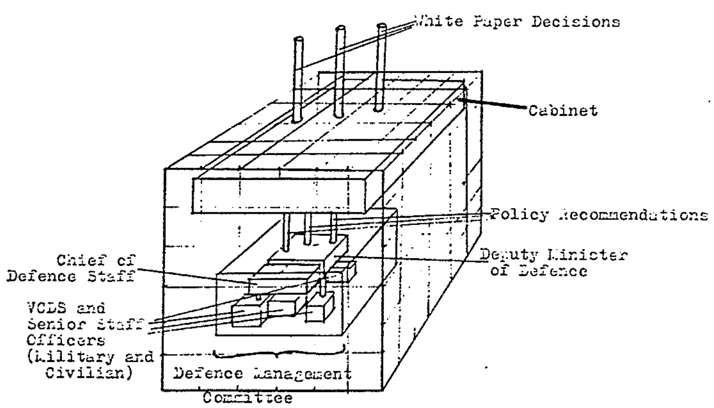

Figure 12. The DND Decision-Making Structure. The Defence Management Committee (DMC), including the Deputy Minister and the Chief of Defence Staff, is treated as the main advisor to the Cabinet on defence matters. Policy recommendations are pictured as moving from the DMC to Cabinet, from whence the final White Paper decisions have to emanate.

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[43] *Loc. Cit.*

The above diagram concentrates on the structural constraints and does not include the other types of constraints discussed in this thesis. Because of the complexity of any decision-making process, any diagram attempting to simultaneously represent all constraints would quickly become too cluttered to decipher.

It should be noted that the level of complexity of the defence policy decision-making process can, in general, be efficiently handled through computerization. As is emphasised in this thesis, one of the advantages of the proposed theoretical architecture is that it is amenable to computer application. Neural networks, because they are designed along the lines of cognitive processes, may be particularly suited to this application.

CHAPTER 3. - COMPUTER METAPHORS AND APPLICATIONS

THREE DIMENSIONAL REPRESENTATION

The purpose of this part of the thesis is to demonstrate how the proposed model is consistent with recent developments in cognitive science, including neural network computers and the findings of cognitive psychology. The model involves a pictorial representation of the relationships and interactions between the primary entities in a decision-making process, as well as of the cognitive processes within the mind of the individual decision-maker. This is achieved through both micro- and macro-representations as in Figure 13.:

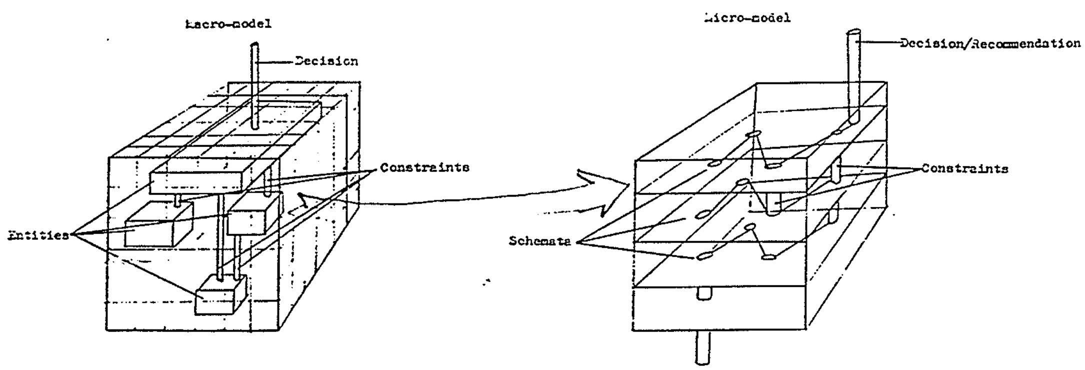

Figure 13. Macro- and Micro-Models. The macro-model on the left displays the decision-making process as a whole, concentrating on the depiction of the decision-making entities. The micro-model on the right illustrates how each of the entities goes about making a decision or recommendation, including how each of the constraints is dealt with.

The mental processes of the individual entities are tied together into a three-dimensional matrix using the constraints which they share. These constraints are the common perceptual inputs to mental processing. They can be defined or categorized in a number of ways. This thesis, for the purposes of reviewing the 1987 Canadian White Paper on Defence, classifies them as goal, environmental/strategic, technical and resource constraints. The relationship between the entities in the decision-making process can also be considered to be a constraint as well, because it is a major determinant of the outcome of the decision-making process.

In the model, the constraints in the macro- and micro-models, except for structure, are represented by vertical columns transpiercing the various organizational entities or participants. The decisions or recommendations coming from each entity are also represented by vertical columns. This is the case for both the macro- and micro- representations of the model.

There is some difference in the representation of processes within each box. The macro-model is concerned with representing the decision-making process from an organizational point of view and with defining the relationships between each of the entities in the process and what they have in common; it also illustrates where the inputs come from and where the outputs go to.

The micro-model is concerned with the mental processing itself. It is somewhat difficult to ascertain precisely how neurons exchange information and produce a coherent output. One hypothesis about how this occurs involves a form of pattern-matching which will be discussed later in connection with "schemata". The model at this point, however, can proceed far enough to represent how the process, whatever the sub-processes are, can be structured to produce a logically predictable output. To some extent, reverse engineering is applied in the model, as well as heuristics and other principles which are being utilized in cognitive science.

The micro-model displays internal mental processes by using parallel horizonal layers, each containing some pattern of nodes. These nodes are connected in various ways to one another using many of the vertical columns that appear in the macro-model. The output from the individual mental processes is also represented by a vertical column emanating from the top layer. As a general protocol, inputs occur at the bottom of a matrix, and outputs emerge at the top.

One of the more prominent aspects of the proposed model is that it represents a decision-making structure in three dimensions. At the same time, it is suggested that the model is amenable to computer application. There are certain advantages to a three-dimensional representation of a computerized model. In the example of SemNet, an exploratory research project to advance the understanding of problems facing developers and users of large knowledge bases, directed graphs in three-dimensional space are utilized.[1] SemNet

[1] Fairchild, K. M., Poltrock, S. E. and Furnes, G. W. SemNet: Three Dimensional Graphic Representations of Logic Knowledge Bases.

depicts knowledge bases graphically because knowledge bases represent information about symbolic entities, and graphics are seen as an effective way to communicate relationships among objects. Such a presentation exploits the skills that people already have developed for recognizing visual patterns and moving in three-dimensional space.

As with the proposed model applied to the decision-making processes involved in the 1987 White Paper, SemNet, in representing a knowledge base as a graphic network, concentrates on the organization or structure of a knowledge base.[2] Also like the proposed 3-D model, SemNet is concerned with providing a more understandable representation than is possible in two dimensions. One of the obstacles to comprehending the organization of a knowledge base is the large number of arc crossings in conventional representations of any large knowledge base. In a flat two-dimensional display, the multiple intersections impede the eye's efforts to trace interconnections. In the case of knowledge bases, crossing points may be visually confused with nodes.[3] In the case of the proposed model, the "constraints" act as connections between entities in the decision-making process.

In Guindon, R. *Cognitive Science and Its Applications for Human and Computer Interaction*, Hillsdale, N.J.: Lawrence Erlbaum Assoc., 1988, 202.

[2] *Ibid.*, 207.

[3] *Loc. Cit.*

The limitations of the two-dimensional approach will be evident later in the conventional two-dimensional representation of neural network processing.

As with the depiction of knowledge bases in SemNet, the proposed decision-making model is highly amenable to a spatial representation in which the involved entities are mapped to positions in three-dimensional space. This allows for a more effective hierarchical representation of the entities involved in the decision-making process.

THE MACRO-MODEL

Another respect in which the proposed model mirrors recent developments in cognitive science is in the emphasis on the structural relationships between the entities involved in the system being analyzed. During the past decade, there has emerged an off-shoot of specialists in artificial intelligence research called "connectionists". A "connectionist" is someone who is "interested in systems that are made up of many simple, interacting computers."[4] Many of these people consider their field unique enough to be considered a science of its own.[5]

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[4] Aleksander, I. and Burnett, P., *Thinking Machines: The Search for Artificial Intelligence*. New York: Alfred A. Knopf, 1987, 197.

[5] Crevier, D. *AI: The Tumultuous History of the Search for Artificial Intelligence*, New York: Basic Books, 1993, 215.

The connectionists represent a line of research, which was almost abandoned in the late 1960s, into emulating how the brain functions electronically. A theoretical construct called the "perceptron" had earlier been devised because the orthodox computer did not seem capable, to the minds of some researchers, of matching the performance of the brain. The brain is made up of millions of interconnected cells which, somehow through their interactions, generate an intelligence superior to that of commercial computers. For reasons which will be discussed later, the "perceptron", as it was first conceived, proved inadequate and research along "non-orthodox" lines was almost abandoned.

John Hopfield of the University of California at San Diego was one of those who continued to look for a mathematical explanation for the workings of the "neural nets" in the brain. It was largely because of his efforts in the early 1980s that interest began to revive in the computational properties of neural networks. This gave rise to the movement known as the "new connectionism".[6]

In 1986, a group of adherents to Hopfield's approach published a group of papers in a book, *Parallel Distributed Processing: Explorations in the Microstructure of Cognition*, which came to be considered to be the "Bible of

[6] Aleksander, I. and Burnett, P. *Op. Cit.* 198.

connectionists".[7] This book was such a success that many of the members of the PDP group made significant advances in their academic careers. Terrence Sejnowski moved from Johns Hopkins to his own laboratory at the Salk Institute in La Jolla, California. James McClelland and Geoffrey Hinton taught briefly at Carnegie-Mellon, Hinton eventually moving on to the University of Toronto.[8]

As is evident, there are some "connectionist" aspects to human organizations, if one draws a parallel between the thought processes of individuals acting together as a group entity and a network of computers linked together. This, to some extent, is what the macro-version of the proposed model represents. There are further parallels in the way in which the model is organized.

The "connection machine", as described by Igor Aleksander and Piers Burnett, consists of a sort of "warehouse" containing a mass of processors and a program controller.[9] The program controller sets up the appropriate pattern of interconnections between processors and provides each processor with a program that enables it to perform its allotted role.

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[7] Crevier, D. *Op. Cit.*, 215.

[8] Jubak, J. *In the Image of the Brain: Breaking the Barrier Between the Human Mind and Intelligent Machines*. Toronto: Little, Brown and Co., 1992, 49.

[9] Alexander, I. and Burnett, P. *Op. Cit.* 203.

As with human decision-making processes occurring within the context of an organization, the relationship between the entities involved and the role of each of the entities within the process in a connection machine are subject to change. In most human decision-making situations, the individual or body at the top of the hierarchy with the most formal or informal power plays the role of the "controller" and assigns the role that each of the individual entities within the decision-making process will play. At the same time, the "controller" is influenced by its environment. In the "connection machine", the controller reacts to the instructions defining the task, as well as to the potential and limitations of the processors to be formed into a network. The "controller" continually reacts to and adjusts the network to achieve the desired result according to feedback from the system. The connection machine is diagrammed as in Figure 14.:[10]

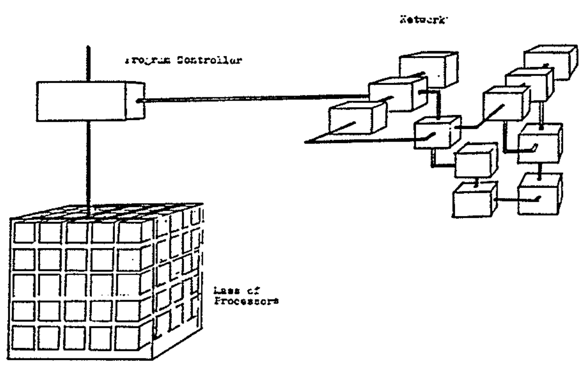

Figure 14. The Connection Machine. This diagram, adapted from I. Aleksander and P. Burnett, illustrates the fundamental elements of the connection machine concept.

[10] *Ibid.*, 203.

As mentioned, the mass of processors pictured above is arranged by the controller into a network appropriate to the demands of the processing task. This is intended to mimic the way in which the brain organizes its neurons into a structure to perform a given task. As has been pointed out in connection with neural networks, the most important property of unpredictable systems, such as those involved in thought processes, is "the ability to change spontaneously their structural behaviour as a result of parametrical periodic excitations."[11] In the context of a decision-making process, a "parametrical periodic excitation" would be the requirement that a certain decision be made, given a particular set of constraints. As well as resembling what the brain does, the "connection machine" is remarkably similar to the macro version of the proposed decision-making model.

Thus far, the main value of the "connection machine" is seen to lie in studying brain-like connectionist networks, since it allows such systems to be simulated more readily than with a conventional computer.[12] While neural networks attempt to simulate the "higher" mental functions, it is impossible to ignore the way in which the rest of the brain operates and the impact that it has on human consciousness and the way in which

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[11] Barhen, J., Zak, M. and Toomarian, N. Non-Lipschitzian Neural Dynamics. In Eckmiller, R. *Advanced Neural Computers*, New York: Elsevier Science Publishing Co. Inc., 1990, 110.

[12] Aleksander, I. and Burnett, P., *Op. Cit.*, 202.

we process information.[13]

It is possible to see the proposed model as largely structured along the lines of the brain, some of the constraints in the model emerging from the "lower" levels of the structure in much the same way as our "primitive" impulses emerge from the lower parts of the brain. Thus, utilizing the micro-model, one would mirror these particular constraints in the following way against the brain:

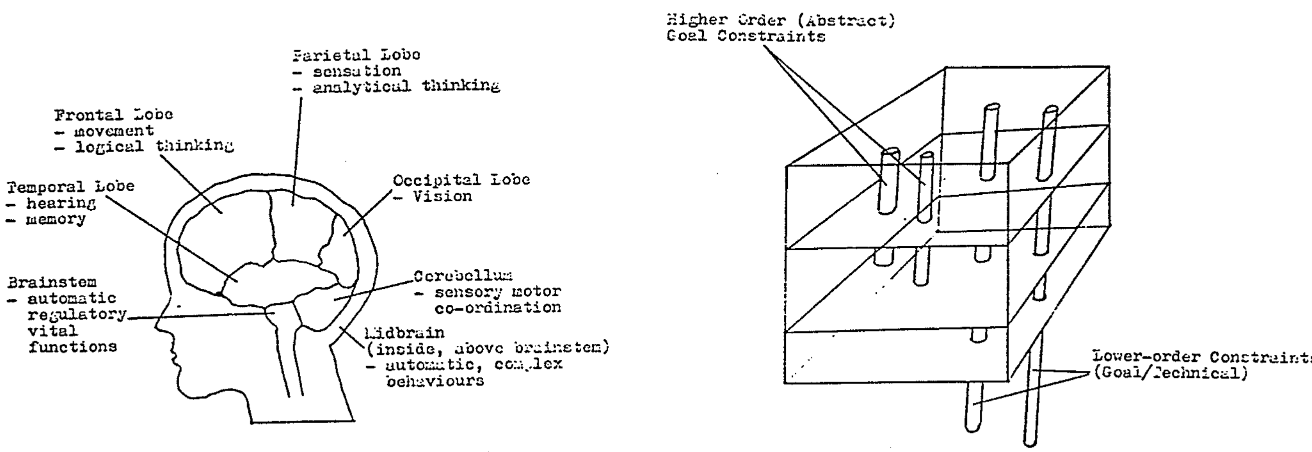

Figure 15. The Structure of the Brain. The micro-model presented in this thesis is structured to mirror, to some degree, what is known about the structure of the brain and neural processing.

As Figure 15. illustrates, the kernel of the brain is the "reticular formation" or brainstem. This is about the size of a lemon and grows out of the upper end of the spinal chord; this is the brain of our reptilian ancestors.[14] Some see the "reticular formation" as being "programmed" genetically to

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[13] Maloney, C. and Moc A. D., Forgotten, but Not Gone. In *The Winnipeg Free Press*, Nov. 15, 1993, B3.

[14] Crevier, D. *Op. Cit.*, 306.

stake out a territory and attack prey or enemies. One might argue that the presence of such a structure in our mental equipment explains so-called "primitive" tendencies in our cognitive processes. Some of our value or goal constraints, for example, may originate in the brain stem. This would explain the dominance of such considerations as maximizing breeding opportunities or the control of territory. One might argue as well that a tendency towards violence as a solution to problems is a "technical constraint" which we have inherited from more primitive life forms.

We also carry the legacy of our mammalian ancestors, the "limbic system" or "midbrain", which is wrapped around the reptilian brain. This area presumably developed among our warm-blooded ancestors approximately 100 million years ago to enable them to care for their young. The limbic system gives us most of our emotions; its programming often contradicts the reptilian brain and gives rise to our internal conflicts.[15] The "cerebral cortex", composed of the frontal, parietal, occipital and temporal lobes, contains our higher reasoning functions and forms the outer layers of the brain. It communicates with the inner parts of the brain through nerve fibres, which coordinate its action with theirs. The next section of this thesis will deal with how this communication takes place.

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[15] *Loc. Cit.*

THE MICRO-MODEL

Differences between Neural Nets and Conventional Computers

It should not be forgotten that for many of the pioneers in computer research, the aim was to understand how the human mind works. To some degree, the physical computer was a by-product of this effort: a means, rather than the end. When Norbert Weiner published his work *Cybernetics* in 1947, for example, he proposed a new science devoted to the study of information or "control" mechanisms in both men and machines.[16] The emergence of the "new connectionists" has resulted from some researchers following the reasoning that if computers are to behave like brains, they have to look more like brains than conventional computers do.[17]

It is not only the structure of conventional computers that has been thrown into question. Their processing mechanism is also being reviewed. Rather than viewing the thinking process in terms of symbols, the new connectionists argue that the focus should be on neuron-like connections. Thus, although neural nets are still within the realm of artificial intelligence, i.e. "the science of making machines do things that would require intelligence if done by people," in not

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[16] Aleksander, I. and Burnett, P. *Op. Cit.*, 32.

[17] *Understanding Computers: Artificial Intelligence*, Richmond, Virginia: Time-Life Books, 1987, 109.

relying on the manipulation of symbols they deviate from the fundamental paradigm of conventional artificial intelligence.[18]

"Intelligence" in connectionist systems is not entirely the product of programming. Rather, it derives at least in part from the way in which the elements are interconnected.[19] This approach can be defined as a "non-Euclidean" geometrical approach, versus the Euclidean/Cartesian approach of the early von Neumann computers. Figure 16. illustrates the various aspects of the evolution of computers:

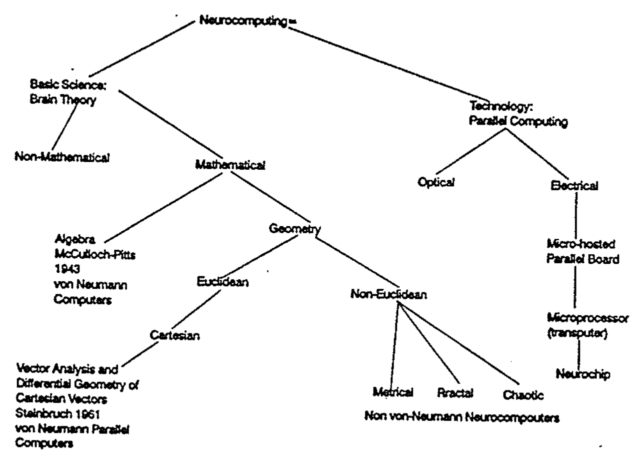

Figure 16. The Evolution of Neural Networks. Source: Pellionisz, A. J., Peterson, B. W. and Tomko, D. L. Vestibular Head-Eye Coordination: A Geometrical Sensori-Motor Neurocomputer Paradigm. In Eckmiller, R. *Advanced Neural Computers*, New York: Elsevier Science Publishing Co. Inc., 1990, 63.

As the diagram shows, there are two sides to accomplishing neurocomputing: (1) the theoretical side, i.e. brain theory;

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[18] Crevier, D. *Op. Cit.*, 215.

[19] Aleksander, I. and Burnett, P. *Op. Cit.*, 197.

and (2) the technological side, which involves parallel processing.[20]

In parallel processing, several instructions can be handled simultaneously by multiple central processing units. Thus, four or five instructions can be executed in the time that one instruction is executed using normal serial computers.[21] One type of parallel processing used by current supercomputers is array processing. This allows them to perform the same operation on a list of values. This means, for example, that instead of adding two lists of numbers together one pair at a time to arrive at a third list, one array processing instruction would cause all pairs on the two lists to be summed at the same time.

Generally speaking, massive parallel systems rely on thousands of processors instead of just a few.[22] Massively parallel architectures gain speed by ganging together large numbers of microprocessors, which put logic, memory and communications mechanisms onto one chip. One massively parallel design which has become emblematic of the massively

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[20] Pellionisz, A. J., Peterson, B. W. and Tomko, D. L. Vestibular Head-Eye Coordination: A Geometrical Sensori-Motor Neurocomputer Paradigm. In Eckmiller, R. *Advanced Neural Computers*. New York: Elsevier Science Publishing Co. Inc., 1990, 63.

[21] McKeown, P. G. *Living with Computers*, 2nd ed. New York: Harcourt, Brace, Jovanovich, 1988, 611.

[22] Corcoran, E. Calculating Reality. In *Scientific American*, January, 1991, 105.

parallel wave is Hillis' Connection Machine.[23] Hillis and other advocates of parallelism argue that many problems are naturally parallel, but that they have simply not been expressed that way in the past.[24]

On the theoretical side, it has been established that some kind of mathematical representation is necessary to model the brain's activity, but there is still some uncertainty as to exactly what it should be. In the micro-version of the proposed model, the specific computational process is represented as being somewhat of a "black box". For purposes of convenience, a binary logic tree is used to represent reasoning processes in the proposed model. This can take the form of a "schema" or pattern.

In neurocomputers, the massively parallel neural processors are built around arrays, i.e. vectors and matrices.[25] The utilization of such an approach leads to the representation of these "n-tuplets" in a mathematical space using non-euclidean geometry. As Figure 16. illustrates, while von Neumann parallel computers utilize Cartesian geometry, which is a slight variation from Euclidean geometry, non-von Neumann neurocomputers are being designed using alternate approaches, some of which include metrical, fractal and

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[23] *Ibid.*, 107.

[24] *Ibid.*, 108.

[25] Pellionisz, A. J. *et al. Op. Cit.* 63.

and chaotic geometries.[26] Although neural computers attempt to mimic the way in which neurons exchange information, this is not to say that the mathematics used in neurocomputers is necessarily the same as actually used in the brain.

The Visual System

There is a strong bias in this thesis towards visually-intelligible representations in three dimensions, as well as explanations of processes which are based on our visual system. As Christoph von der Malsburg points out, it seems that the basis for our mental processes is the architecture developed for visual perception. He identifies the data elements in our visual system with the neurons in our brain.[27] There are still some uncertainties, however, about the mechanics of the visual system. It is not precisely known, for example, where the decision is made as to which object in a visual field should be the primary focus of attention. Clinical research has suggested that parts of the parietal

[26] *Loc. Cit.* John von Neumann introduced the concept of the stored program in the EDVAC computer. An earlier computer, the ENIAC, had to be rewired for each job. (McKeown, P. G. *Living With Computers*. 2nd ed., New York: Harcourt, Brace, Jovanovich, 1988, 38).

[27] von der Malsburg, C. Considerations for a Visual Architecture. In Eckmiller, R. *Op. Cit.*, 308.

lobe play a vital role in making this decision.[28]

The decision process involves the control of the movement of the eyes during the visual scanning process. When reading, looking at a painting or steering a car, the eyes engage in short, jerky movements called "saccades" to input information to the visual system. The question is how or why the eyes move in a particular fashion to conduct this input.

It has been suggested that the mental process which was developed to perform this input, as well as the layout of neurons to process this input, is the basis for all or most of our cognitive functions. It seems that evolution took advantage of the retina's particular layout early in the development of vertebrates.[29] Eventually it became locked into place by building our cognitive systems around its architecture.

Some researchers see the visual system itself as being the key element in the way in which our brain works. It constitutes more than one-third of our brain, for example.[30] It is noteworthy that our intelligence seems to be related to things that can be formulated as scenes, which are largely visual. It can be argued that language only makes sense by

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[28] Ritter, H., Martinetz, T. and Schulten, K. *Neural Computation and Self-Organizing Maps: An Introduction*, Reading, Mass.: Addison-Wesley Publishing Co., 1992, 144.

[29] Crevier, D. *Op. Cit.*, 307.

[30] von der Malsburg, C. *Op. Cit.*, 303.

continuous reference to visual imaginations. Many cognitive theorists have argued that cognitive maps are stored in the form of images, although Michael Eysenck, for example, admits that the evidence for the accuracy of this hypothesis is inconclusive.[31]

Jan Droesler places the question of cognitive images within the larger context of how scientists formulate theories. He suggests that researchers strive to produce images of subsets of the world based on reproducible data. These images do not have to be visual, but rather can be formulated in a language suitable for syntactic control. One of these languages is often mathematics.[32] Droesler suggests that these images form a flexible sequence in which a new image replaces an older one if it is less complicated or if it describes more data.

When someone looks at another person, a series of neuron stimulations occurs in a random pattern in the brain. It has been observed that, if one looks at the same person repeatedly, the same neurons are stimulated and the pattern is amplified. This concept particularly has the advantage of being in accordance with what has been noted about human aes-

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[31] Eysenck, M. W. *A Handbook of Cognitive Psychology*. London: Lawrence Erlbaum Assoc., 1984, 323.

[32] Droesler, J. *Quantitative Psychology*. Goettingen: Hogrefe & Huber Publishers, 1989, 33.

thetics and our perceptions of physical attractiveness.[33] Another well-known application of image-processing theory is in Konrad Lorenz's ideas concerning "imprinting", whereby some animals, at an early age, identify their mother through a specific set of stimuli.[34]

Thus, there is a body of opinion that sees our mental processes as ultimately rooted in an apparatus designed for processing visual information. One might then further hypothesise how the contingencies of visually tracking a moving object could result in a process for creating engrams being developed which could have other applications. Neurological linkages used for processing visual stimuli may have eventually come to be adapted for other stimuli, including progressively: sound, music, language, and ultimately more abstract stimuli such as mathematical processing. Therefore, understanding vision may mean understanding how the brain works, and eventually the "mind".[35]

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[33] Gentry, C. Hey, Good Looking. In *Winnipeg Free Press*, Jan. 6, 1990.

[34] Dobzhansky, T. *Mankind Evolving: The Evolution of the Human Species*, New Haven, Conn.: Yale University Press, 1962, 62.

[35] von der Malsburg, C. *Op. Cit.* 303.

Schemata and Frames

As stated, there is a strong bias in cognitive science towards linking the patterns which are used in the visual system to interpret objects and their movement and the structures used in cognitive processes. One of the terms used to describe these patterns is "schema". Immanuel Kant first used the word "schema" in his *Critique of Pure Reason*, published in 1787.[36] Since then, it has been used in various ways in philosophy and psychology. In 1932, Frederick Bartlett, a British psychologist, used "schemata" in his studies on memory to describe how we recall the essential elements of a story.[37] One might use a fairy tale as a schema, for example: "Valiant prince frees princess from bewitchment." It can be argued that we remember a given story as the superposition of its schema and the particular traits that made it stand out.

Jean Piaget, a Swiss psychologist, used the concept of "schema" in his theory of mental development. The concept was also used by the German philosopher and psychologist Max Wertheimer in the *Gestalt* theory of perception. Its vagueness, however, prevented experimental psychologists from

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[36] Kant, I. *Kritik der reinen Vernunft*. Stuttgart: Phillip Reclam, 1966, 216-221.

[37] Crevier, D. *Op. Cit.* 245.

making concrete use of it.[38]

Finally, the schema concept found an application when Marvin Minsky introduced schemata into the field of artificial intelligence in his paper published in 1975, *A Framework for Representing Knowledge*. Minsky used the term "frames" rather than "schemata" to provide a new perspective. Minsky's frame has the appearance of an income tax form, its most noticeable feature being a set of slots to fill in. Some of these slots would normally be empty, while others would contain default values corresponding to usual or necessary characteristics of a concept.[39]

The *Gestalt* Approach

Another of the theoretical approaches which have been developed for defining how the brain interprets perceptual stimuli is the "*Gestalt*", or "form" approach, which focuses on cognitive structure.[40] There is a long history of using the concept of "form" or "*Gestalt*" to explain what underlies our perceptions. Idealistic philosophers such as Plato, Kant and

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38 *Ibid*. 246. See also: Piaget, J. *Biology and Knowledge*. Chicago: University of Chicago Press: 1971, 3-13.

39 *Loc. Cit*.

40 Furth, H. G. *Piaget and Knowledge: Theoretical Foundations,* 2nd ed., Chicago: University of Chicago Press, 1981, 73.

Hegel interpreted the common elements or base concepts of our cognitive processes as being reflective of the external structure of some ultimate reality. Today's cognitive psychologists, by contrast, treat such structures as being aspects of how the brain interprets stimuli.

According to Hans Furth, "the *Gestalt* is a totality inherent in the perceptually given data to which the organism responds."[41] "Totality", in this sense, can be interpreted to mean "structure". These perceptual *Gestalten* are not learned, but are, rather, already extent or preformed in the human brain.

Dyadic Reasoning: The Binary Logic Tree

It could be that the model proposed by Kleinmuntz and Kleinmuntz, which emerges when one "thinks aloud" about diagnostic searching, is as good a representation as any of how the brain works. This model involves a variant of the game of *20 Questions*, which has proven amenable to the systematic study of a number of decision-making variables.[42] The end product of the diagnostic neurology game can be displayed as

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[41] *Loc. Cit.*

[42] Kleinmuntz, B. and Kleinmuntz, D. N. Multivariate Diagnostic Information Processing By Computer. In Hirschberg, N. and Humphreys, L. G., eds. *Multivariate Applications in the Social Sciences*. Hillsdale, N. J.: Lawrence Erlbaum Assoc., 1982, 247.

a tree structure.

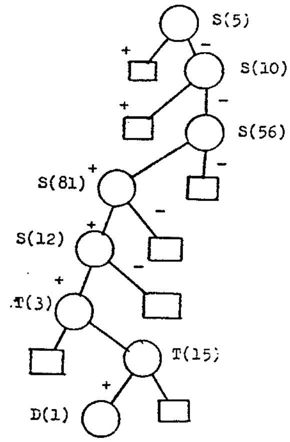

Figure 17. A Binary Logic Chain. The diagram illustrates a variant of such a logic chain, the pluses and minuses indicating positive and negative responses, respectively. At the end of the chain, a decision (D1) is taken. The "S" indicates an option chosen, while a "T" indicates the choice of a "True" over a "False" response.

One can see how just about any kind of chain of logic can be expressed in this fashion. It is possible that the patterns in the brain's laminae, or schemata, are structured something like this.[43]

Whether or not the schemata or *Gestalten* conform to the above diagram is not critical to the model proposed. As will be seen, however, the pattern proposed by Kleinmuntz and Kleinmuntz is amazingly convenient as a working structure when tied in with the other aspects of human cognitive processes.

One can, for example, apply Festinger's observations concerning cognitive dissonance using this model. In fact, one

[43] *Ibid.*, 248.

can even speculate how it was that Festinger, whose specialty was visual perception, would arrive at a concept such as cognitive dissonance. As discussed, it is quite likely that the schemata for visual perception are the antecedents for the schemata that we use for our logical processes. By focusing on visual perception in his research, Festinger developed a schema or system of schemata which he later applied to human rationality. It is not surprising that such schemata should be highly effective in explaining human rational processes.

Such an approach also makes understandable the empirical bias of B. F. Skinner. Apparently, Francis Bacon was an important early influence for Skinner. This would partly explain Skinner's materialism. One might say that Skinner's thought incorporates a number of the schemata provided by Francis Bacon's work.

Perceptrons

Another essential aspect of the development of artificial neural net theory was the discovery by Warren McCulloch and Walter Pitts of a way to represent mathematically how interconnected cells, by transmitting or failing to transmit impulses, could perform logical operations.[44] In other words, they managed to produce a binary model of how the brain might compute.

John Hopfield carried this research further when, in 1982, he showed how networks of neurons could acquire the ability to calculate; in doing this, he used a mathematical theory similar to thermodynamics.[45] In Hopfield's model every neuron was connected to every other neuron. There was no "internal structure" to his model. Whereas later neural networks are usually structured, Hopfield's was "homogeneous".[46]

The lack of structure in early neural nets proved to be a major shortcoming and was open to criticism for a long time. As early as 1969, when Marvin Minsky and Seymour Pappert of MIT published their book, *Perceptrons: The Principles of Computational Geometry*, the practicality of neural net computing was under assault. The first neural networks were conceived during the 1960's as single layers of McCulloch-Pitts neurons sandwiched between input and output units, and were termed "perceptrons".[47] Minsky and Pappert argued that the perceptron could never compute basic properties of an image,

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[44] Crevier, D. *Op. Cit.*, 30.

[45] *Ibid*. 215.

[46] Ritter,H. *et al*. *Op. Cit.*, 51.

[47] Crevier, D. *Op. Cit.*, 214.

such as whether or not two elements were connected.[48] They felt that many fundamental classification operations would permanently remain outside the capabilities of perceptrons.[49] Therefore a new approach was needed - one which overcame the limitations of the single-layer model.

MULTI-LAYERED NEURAL NETWORKS

Multi-Layered Perceptrons

As is evident, the evolution of neural net-type computer architectures has not been a straight-line kind of development. Minsky and Pappert's work on perceptrons in 1969, for example, almost resulted in the neural network approach being abandoned.[50] One of the breakthroughs which allowed further progress to be made in neural network research was the discovery by Paul J. Werba, a Harvard graduate student, that perceptrons, or artificial neurons, could acquire new abilities if additional perceptrons were inserted between

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[48] Aleksander, I., and Burnett, P. *Op. Cit.*, 157.

[49] Crevier, D. *Op. Cit.*, 214.

[50] Aleksander, I. and Burnett, P. *Op. Cit.*, 198.

input and output units. It was argued that Rosenblatt's "Perceptron Learning Rule", which had nearly caused the abandonment of neural network research, would not apply to such networks.[51]

While the perceptron concept, which corresponded to a single layer of neurons, allowed for limited "transformations" between input and output units, every additional layer increased the capability of the network. Each individual layer of neurons performs a "partial transformation" of the preceding layer.[52] Thus, the limitations of the perceptron are overcome by connecting several layers in series and concatenating their transformations. The following diagram of a 3-layer neural net illustrates the principle, each layer having connections to the layer just above it:

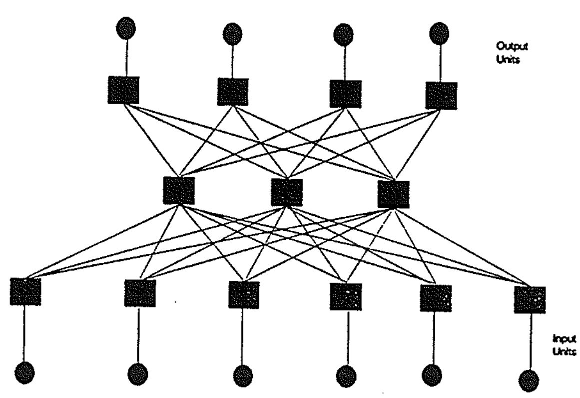

Figure 18. A Three-Layer Neural Net. Source: Ritter, H., T. Martinetz and K. Schulten. *Neural Computation and Self-Organizing Maps: An Introduction*. Reading, Mass.: Addison-Wesley Publishing Co., 1992.

[51] Crevier, D. *Op. Cit.*, 214-215.

[52] Ritter, H. *et al*. *Op. Cit.*, 51.

The usefulness of connectionist models, such as Multilayer Perceptrons (MLP), has been recognized for such applications as speech recognition because of their suitability for pattern classification problems.[53] The main advantages of Multilayer Perceptrons, as Hervé Bourlard points out, are "their discrimination-based learning, their flexible architecture (which permits easy use of contextual inputs), their weak hypotheses (about statistical distributions), and their highly parallel architecture." Many researchers in the field of neural networks are convinced that a layered approach is required if neural computing is to provide the engines that supply the cognitive capacity to represent scene and language understanding. The architecture of rule-based artificial intelligence systems has proven itself to be inadequate.[54] What the layered system allows is for different levels of abstraction to be represented.

Vertical Organization of Visual Processing

It has been noted that the brain has a layered aspect to it and that this layering plays a part in processing

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[53] Bourlard, H. A. How Connectionist Models Could Improve Markov Models for Speech Recognition. In Eckmiller, R. *Op. Cit.* 247.

[54] Aleksander, I. and Morton, H. The Logic of Neural Cognition. In Eckmiller, R. *Op. Cit.*, 102.

information. In the case of visual processing, for example, eye movements, or saccades, are triggered in the superior colliculus, a mounded, multilayered neuron sheet that is located in the upper region of the brainstem.[55] It appears likely that this layering of neurons has some functional significance.

The hierarchical layering of the brain is mirrored in the capacity of the proposed model to illustrate the hierarchical layering of a decision process. Vision involves decisions. One of the aspects of the process of visual tracking which has been noted by Sejnowski and Smith-Churchland is the extent to which it is under voluntary control and depends on expectation.[56] As they describe it, one pathway of the smooth pursuit system for tracking visual targets originates in the retina, leads to the lateral geniculate nucleus (LGN), to the cortex and through distinct visual topographic areas, down to the pons, and eventually to the oculomotor nuclei.

It has been suggested that a mapping process takes place, whereby visual input from adjacent areas on the eye's retina is relayed, or "mapped" onto adjacent areas of the visual cortex of the brain.[57] This is consistent with Sejnowski and

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[55] Ritter, H. *et al*. *Op. Cit.*, 144.

[56] Sejnowski, T. J. and Smith-Churchland, P. Brain and Cognition. In Posner, M. I. *Foundations of Cognitive Science*. Cambridge, Mass.: MIT Press, 1989, 307.

[57] Engineers of the Mind in *Macleans*, April 11, 1988, 46.

Smith-Churchland's description of how visual output is transmitted to different layers of the brain. They suggest that neurons in an intermediate layer of the superior colliculus of the cerebral cortex represent information about eye movements.[58] According to their assessment, sensory input from the thalamus typically projects to layer 4, the middle layer, while output to subcortical motor structures issues from layer 5. Intra-cortical projections originate mainly in the superficial layers, i.e. layers 2 and 3, while layer 6 mainly projects back to the thalamus.

This stratified system of sensory processing, with the initial activity taking place in the inner layers of the brain is adopted in the proposed decision-making model. The initial lower-level processing takes place at the base of the structure, with the more advanced decision-making, or resolution processes, taking place on the upper levels. It has been suggested that the arrangement and processing of visual information in vertical columns is reflective of the organization of the processing mechanisms in other parts of the brain. As David Hubel suggests, "it may be that other sensory systems in the brain are arranged in the same way."[59]

The design of architectures to recreate cognitive processes is increasingly taking place with reference to the

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[58] Sejnowski, T. J. and Smith-Churchland, P. *Op. Cit.*, 312-313.

[59] Engineers of the Mind. In *Macleans*, April 11, 1988, 46.

brain's structure. It is suggested in this thesis that such an approach is appropriate in attempting to model more complicated cognitive processes such as those involved in decision-making.

Parallel Processing

What the layering of neurons also suggests is that each layer of neurons, although linked, acts somewhat independently of the other. What is being proposed is that in each layer, some processing takes place. The result is then passed up to the next layer of neurons.

To some extent, this is modelled in computer parallel processing. In artificial intelligence research, newer theories have emphasised the need for extensive parallel computation and that, within the human mind, there are large numbers of cooperating "agents".[60] "Intelligence" would thus be the product of a network of interacting entities. This matches, to some degree, the modular aspect of the macro-version of the proposed model. Like parallel processing, intrinsic to the proposed model is the "simultaneous application to a single task of many processors, be they

[60] Crevier, D. *Op. Cit.*, 215.

neurons or computers."[61]

One of the main advantages of parallel processing is the speed at which computations can be executed. For computers, this means overcoming the "light-speed barrier". For the brain, some type of parallel processing would imply that a multitude of inputs could be processed simultaneously, rather than in a step by step fashion.

Computer neural networks are designed in accordance with what is believed to be the brain's pattern recognition mechanism, with a plethora of electronic signals being released simultaneously. We thus know, using a computer analogy, that the brain's "hardware" exchanges signals simultaneously in its pattern recognition process.[62]

One might suggest that some form of parallel processing might explain what we call "intuition". Although we can rationalize our decisions in a linear fashion, the way in which our decisions or discoveries are actually made appears to be quite different. One might also then propose that in an organization, the decision process is also not linear, although in our idealized schemes for rationality we often insist that it should be so. This would be another advantage to the proposed model: that it does not misrepresent "real world" decision processes in a linear fashion.

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[61] *Ibid*. 301.

[62] Stoll, M. Neural Networks Bring Pattern Recognition to PCs. In *PC Week*. March 23, 1987, 8.

In computers, parallel processing means that the rate at which computations can be executed is not regulated according to the drumbeat of a central clock. New technology has also allowed the semi-independent units to be miniaturized as well as made faster. Much of the development of fifth generation computers has to do with the extensive implementation of parallel processing.[63]

Feedback Loops

It has also been established that, not only are brain signals emitted simultaneously, but that they do not just travel in one direction. Rather, there are feedback loops. Information from the sense organs, for example, does not just flow in one direction up to a decision centre and then down to motor centres. Instead, interactions between sensory and motor pathways occur at many different levels. Dean has pointed out that simple reflexes allow direct modulation of motor output on a local level without passing information up and down the hierarchy.[64] It is hypothesised that these pathways form feedback loops acting to either stabilize specific parameters,

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[63] Crevier, D. *Op. Cit.*, 301.

[64] Dean, J. The Neuroethology of Perception and Action. In Neumann, O. and Prinz, W. *Relationships Between Perception and Action: Current Approaches*. Heidelberg: Springer Verlag, 1990, 119.

or to ensure that commands from higher centres are faithfully carried out.

The model presented in this thesis makes extensive use of feedback loops, the loops serving the purpose of ensuring that cognitive dysfunctions or inconsistencies are resolved. In the decision-making process presented, there is provision for a cyclical process whereby information is run through the 3-D matrix of schemata multiple times if necessary, to find the correct logical pathway. It is this feedback loop which would presumably be emulated by the pattern-matching processes utilized by neural network computers, including back-propagation algorithms, in the application of the proposed model.

INPUT AND OUTPUT

Neural Network Structure

Merely applying the principles of parallel processing in a computer does not solve all of the problems encountered in trying to achieve performance comparable to that of the human brain. The way in which parallel processing is implemented, and its architecture, are important as well. One of the new architectures being investigated is that of neural network computers. Neural networks are now usually structured in such a way that several layers of neurons are connected in series. The first, or bottom, layer is reserved for input patterns, every neuron of this layer sending out connections to every neuron in the next layer, as per Figure 17. This structure is continued until the last or top layer is reached; the activity pattern of this last layer constitutes the output.[65]

The development of a multi-layered structure for neural networks marks a departure from previous practices. Whereas earlier efforts tended to treat human cognitive processes as somewhat of a "black box", multi-layered neural nets or perceptrons attempt to understand and mimic how the brain is organized. Some researchers believe that this is the way to go and are quite critical of the earlier approaches to representing structures such as the vestibulo-occulomotor system with "black-box" diagrams.[66] To some degree, the representation of how the "mind" functions has been in the form of "black box" diagrams because of a lack of understanding of the processes taking place there.

Emotion

One of the biggest problems facing "rational" theories of

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[65] Ritter, H. *et al*. *Op. Cit.*, 51.

[66] Pellionisz, A. J. *et al*. *Op. Cit.* 63.

how the human mind works is what to do with all of the contrary evidence which tends to show that there is a large "irrational" component to human mental processes. Occurrences of "irrationality" reach an extreme in cases where the subjects are deemed to be "insane". If one is going to insist that all human mental processes are "rational" or "logical", then one must account for instances where the appearance of logic is lacking and there is a large emotional component to the decision-making process.

In attempting to deal with the emotional side of human mental processes, some psychologists have focused upon the origins of what appear to be non-rational mental processes. It has been suggested, for example, that many mental illnesses and even personality quirks may be the result of inherited characteristics.[67] Jerome Kagan, a Harvard University psychologist, notes that 10 per cent of healthy two- and three-year-old children whom he has studied are shy and withdrawn in unfamiliar surroundings. He hypothesises that these children were born with a low "threshold of excitability" in the limbic system, that part of the brain which is associated with the emotions.[68]

Just how emotional predispositions fit into decision-making processes has yet to be determined. Joseph LeDoux

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[67] Engineers of the Mind. *Macleans*, Apr. 11, 1988, 41.

[68] *Loc. Cit.*

maintains that a common position among cognitive scientists is that an adequate theory of mind, once it appears, will have to incorporate feeling, affect, emotion, or some other concept as a central construct.[69] LeDoux has some reservations about the current approaches of cognitive science towards the human mind, arguing that the mind being modelled thus far has no place for emotions.[70]

How feelings, affect or emotion should be plugged into or related to cognitive models has remained a mystery. It is clear to LeDoux, however, that cognition and emotion are closely-related, since they are both mental processes expressed through brain mechanisms.[71] The question is: how to express this relationship in a model. The model proposed in this thesis treats some aspects of the impact of emotions on the cognitive process as constraints in the logical process.

This thesis also stresses the importance of building any model to represent cognitive processes around neural mechanisms. Donald MacKay argues that the understanding of human cognitive experience cannot be divorced from the study of the neural processes that embody and shape our changing conditional readinesses. He does not believe that abstract

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[69] LeDoux, J. E. Cognition and Emotion: Processing Functions and Brain Systems. In Gazzaniga, M. S. *Handbook of Cognitive Neuroscience*. New York: Plenum Press, 1984, 357.

[70] *Loc. Cit.*

[71] *Loc. Cit.*

theories of "ideal" cognitive processes should be developed in ignorance of all neuroscience.

It might be argued that this is what those who posit "ideal" theories of rationality are guilty of when they label human behaviour "irrational" when it fails to match their ideal model. Theoretical models should not be constructed in isolation from reality.

A lack of evident logical structure in human mental processes has led to some decisions being labelled as "irrational". Herbert Simon, for example, in his political science doctoral research at the University of Chicago in 1943, analyzed how certain departments of Milwaukee's civic government made decisions. Simon concluded that "irrationality" plays as large a role in organizational behaviour as "logic".[72] The Nobel Prize that he was eventually awarded in 1978 in economics involved the extrapolation of his ideas on "bounded rationality" to the fields of commerce and industry.[73]

It might be argued that what we call "irrationality" involves logical processes taking place of which we are not aware. Even in fields such as science, in which logic

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[72] For a neural network application dealing with various decision strategies, including "non-optimal" strategies, see Usher, M. and Zakay, D. A Neural Network Model for Attribute-Based Decision Processes. In *Cognitive Science*, Vol. 17, 1993, 349-396.

[73] *Understanding Computers: Artificial Intelligence*, Richmond, Virginia: Time-Life Books, 1987, 32.

presumably "reigns supreme", there appear to be hidden mental processes which do not conform to linear logic. What is termed "intuition" or "flair" plays a role in discoveries. Many scientists, in recounting how they have made breakthroughs, have stressed that when they found the answer to the crucial problem, they intuitively recognized it to be right and only subsequently went back and worked out why it was right.[74]

"Intuition" or other "irrational" processes have their counter-parts in neural networks. Layered feed-forward networks, in contrast to single-layered perceptrons or nets of the Hopfield type, contain "hidden units" that are not directly connected to input or output lines.[75] The processes that go on within these hidden units are thus not directly affected by the outside world. They can only be affected indirectly through the internal circuitry of the network. This is analogous to brain processes, whereby the "privacy" of the individual's mental activity is preserved.

Among the types of hidden units are Hidden Markov Models (HMM), which are widely used for automatic speech recognition. The HMM is particularly valuable because it can be used to incorporate the sequential and statistical character of the speech signal.[76] In neural networks, the artificial neurons in

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[74] Aleksander, I. and Burnett, P. *Op. Cit.*, 196.

[75] Ritter, H. *et al*. *Op. Cit.*, 51.

[76] Boulard, H. A. *Op. Cit*. 247.

the hidden layers provide an internal representation of the input patterns. Through evolving appropriate connections with each other, these internal representations make problems solvable for the following layer of neurons.[77]

HEURISTICS

Brain-Computer Comparisons

When neural computers were first being designed, Warren McCulloch and Walter Pitts saw some parallels between the computing powers of artificial neural networks and digital "Turing" machines. Some researchers in the field of artificial intelligence seized upon these similarities and concluded that the brain must work like a digital computer. This false conception led to much wasted effort in research into artificial intelligence based on digital computers.[78]

One of the problems with the digital approach is that of logical structure. Most approaches to artificial intelligence (AI) require a computer to sort through a vast number of

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[77] Ritter, H. *et al. Op. Cit.*, 56.

[78] Crevier, D. *Op. Cit.*, 30.

possibilities to find a solution.[79] In exhaustive, or brute-force searches, a logic or decision-tree is explored systematically until a solution is found. If a tree is compact enough, this approach, although tedious and time-consuming, can be reliable and practical. But in the case of more numerous possibilities, the fastest digital computers can be defeated by the sheer number of calculations required. The number of possibilities is multiplied exponentially as the complexity of a problem increases, resulting in a "combinatorial explosion".

One way of preventing such a combinatorial explosion is to effectively "prune" the decision-tree so that the number of resulting possibilities is reduced. This reduction of options is accomplished through "heuristics" or rules of thumb, which are pre-existing rules which are programmed into the system to guide the search by choosing the most promising branch at any given point.[80] In AI systems, a combination of heuristics and brute force calculation is commonly used, heuristics first being used to prune a decision tree and then the remaining options being explored exhaustively.

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[79] *Understanding Computers: Artificial Intelligence*, 36.

[80] *Ibid.*, 37.

Case-Based Reasoning

There are alternatives, however, to labouriously distilling expert knowledge into rules which can then be programmed into artificial intelligence systems to prevent combinatorial explosions. One can, as Janet Kolodner discovered in 1980, record the cases that the rules are extracted from and let the computer discover the rules or patterns. This "case-based reasoning" approach was applied in Kolodner's doctoral project for Roger Schenk to model the mind of former U. S. Secretary of State Cyrus Vance.[81] In this approach, when the computer is confronted with a new case, such as a set of symptoms in a patient or the salient points in a logical argument, the computer's memory is searched for a similar case. The previous case existing in memory is then adapted to the new situation and a conclusion is drawn accordingly.

Neural networks use a similar case-based reasoning strategy, which is unlike the set rules used in "expert" systems. Instead, the neural network "learns" how to deal with problems through storing information from a series of similar cases. A model is thereby created which can be used to develop a solution for the project at hand.[82]

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[81] Crevier, D., *Op. Cit.*, 239.

[82] Noakes, S. Coming Up: Computers that Think Like Humans, *Financial Post*, Oct. 16, 1993, 52.

In order for rules to be derived from cases, some sort of backward reasoning has to occur. Allen Newell and Herbert Simon used this approach in their Logic Theorist program. Rather than explore all logical possibilities in trying to reach a solution and thereby risk a combinatorial explosion, Newell and Simon developed a program that began with the theorem to be proved and then worked out what the preconditions were for the theorem itself to be true.[83]

When it came later to finding a way to get multi-layered neural networks to perform complicated operations, a backward-reasoning approach was again employed. Paul Werbos had devised a procedure called the "back-propagation" algorithm in 1974, but it was not until the 1980s that its value became clear for neural networks. David Rummelhart at the University of California at San Diego and David Parker at Stanford University independently hit upon the back-propagation algorithm as the solution for getting multi-layered neural nets to function using case-based reasoning.[84] The back-propagation algorithm made it possible for the neural network to integrate hidden units or artificial neurons, something that the single layer perceptron could not do.[85]

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[83] *Understanding Computers: Artificial Intelligence*, 35.

[84] Crevier, D. *Op. Cit.*, 215.

[85] Ritter, H. *et al. Op. Cit.*, 56.

Genetic Algorithms and Auto-Organizing Systems

Another principle used in neural networks is that of auto- or self-regulation. It has been concluded by some researchers that, in order to understand the mind, one must think in terms of complex, non-linear and self-interacting systems, governed by relatively simple rules of interaction.[86] One of the ways of achieving auto-organization in computers is through genetic algorithms. Closely identified with John Holland, genetic algorithms represent an approach to computation whereby a system develops its own algorithms. Through a process of artificial evolution, efficient computer programs are allowed to "grow".[87] This is in place of the process whereby a human software engineer is asked to understand a problem and create a program to deal with it.

Genetic algorithms can be compared to stochastic searches, the difference being that instead of having just one system searching through an "energy landscape", many searches can be conducted simultaneously. A complex system like the brain can thus be "grown", without every single connection and how it relates to the final product having to be understood.[88] Genetic algorithms are being used by some researchers to

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[86] von der Malsburg, C. *Op. Cit.*, 310.

[87] Juback, J. *Op. Cit.* 264.

[88] *Ibid.*, 265.

configure the connections in neural networks. This is in place of designing a single algorithm, i.e. using the best insights available on how to perform a task and then hoping that the algorithm can find the most efficient path through the energy landscape. Instead, the researcher designs many suitable algorithms, allows them to search, and then has the best of those "reproduce" and "mutate" into new generations of algorithms. These then search the landscape and again reproduce.

This search and reproductive activity mimics certain aspects of living entities. Some scientists have gone so far as to ascribe life attributes to these creations, referring to them as "virtual life".[89] Chris Langdon, for example, has created a life form, despite the absence of carbon or DNA, which he refers to as "vants".[90] These "vants", or "virtual ants" were created, not to find a better algorithm or an improved neural network, but rather to aid in understanding how the organized structure which we refer to as "life", originated. Somewhat like real ants, Langdon's "vants" search their environment, meet other vants, and reproduce to create new vants. As of yet, there appear to be no limits as to how far these endeavours will take us in understanding life processes.

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[89] *Ibid.*, 268.

[90] *Ibid.*, 267.

REASONING AND COMPUTER APPLICATIONS

Problem Solving and Human Reasoning

It is noteworthy that much of the early motivation for computer development came from a desire to emulate human reasoning processes. This would also include understanding how people make decisions. One of the first attempts to devise a way of duplicating human reasoning on a computer was Alan Turing's concept of a "universal machine". In 1936 Turing demonstrated, in principle, how one could design a device which, using purely "mechanical" methods, could perform any and every mathematical or logical process that was "computable".[91]

Later, in 1947, Norbert Weiner, a mathematician, speculated about how devices, such as servo-mechanisms, could be used to regulate and control other machines and drew parallels between this and the biological machinery which allows the brain to regulate and control the body. Weiner predicted that it would eventually be possible to build "working models", or "neural networks", of at least some part of the brain.[92]

Herbert Simon was also working along the same lines. In

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[91] Aleksander, I. and Burnett, P. *Op. Cit.*, 35.

[92] *Ibid.*, 32.

1949 he founded the Graduate School of Industrial Administration and later taught courses in the computer science departments at Carnegie Tech. Simon was joined in 1952 by Newell and Shaw, and together they began to devise a computer program that would simulate human reasoning.[93] In 1956, the Logic Theorist program was presented, demonstrating that a machine could complete tasks which were thought to require human intelligence and imagination.[94]

Allen Newell and Herbert Simon continued their experiments concerning means-ends analysis during the 1960s, performing psychological tests to determine how people solve problems and trying to embody these processes in software.[95] Research into neural networks is a continuation of the work that they initiated.

The Connection Machine and the Parallel Distributed Processing Study Group

Some of the findings related to neural networks and the resulting hypotheses have had major implications for related

[93] *Understanding Computers: Artificial Intelligence*, 32.

[94] *Ibid.*, 33.

[95] Crevier, D. *Op. Cit.*, 259.

fields such as modern linguistics and cognitive psychology.[96] David Rumelhart's model of how the mind works, for example, has had a significant impact. Rumelhart is one of the group of scientists headquartered in San Diego calling itself the Parallel Distributed Processing (PDP) Group.

Among the founders of the group were psychologist James McClelland of Carnegie-Mellon and Francis Crick, the Nobel-laureate.[97] Before joining the group, McClelland had been pursuing neural network models in connection with his research into the psychology of perception. Applying the work of researchers such as James Anderson of Brown University, McClelland had started to build computer models that tried to explain perception and its psychology as the result of many neurons working together in a connected network.[98]

One of the products of the revived interest in neural networks during the 1980s was the "connection machine", largely engineered by Daniel Hillis. As discussed earlier, the connection machine consists of a pool of 64,000 processors that may be connected in any way the user chooses. A special version of LISP was developed to serve as a sort of "hardware compiler". This enabled the programmer's instructions to be translated so that specific functions would be allotted to

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[96] Jubak, J. *Op. Cit.*, 45.

[97] Crevier, D. *Op. Cit.*, 215.

[98] Jubak, J. *Op. Cit.*, 46.

each processor and necessary connections would be established between the processors. The connection machine proved to be particularly adept at increasing the speed at which conventional programs could be run, including David Marr's "vision" algorithms, as well as rapidly-changing high resolution graphics.[99]

Neural Network Research in the U.S. and Canada

The demand for computers to solve complicated problems has increased continuously. After the Gulf War in 1991, the U.S. military funded research into expert systems for supplying materiel and equipment for warfare and for managing military personnel.[100] The demands of this sort of planning are high with respect to making subjective judgments and handling changing variables, such as the number of casualties and conditions in the field. Neural networks are particularly suited to handling these kinds of problems.

Neural network systems have already successfully tackled such tasks as artificial speech generation, learning to play

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[99] Aleksander, I. and Burnett, P. *Op. Cit.*, 202.

[100] Noakes, S. *Op. Cit.* S21.

backgammon and driving vehicles.[101] In 1991, there were approximately 10,000 people in the U.S. involved in neural network research. This number can be expected to increase as more applications are found for the approach. It is expected that eventually neural networks will be capable of information processing comparable in sophistication to that carried out by biological systems.[102]

Prototypes of neural network chips have been created, and there is even one commercially available. This is the Dendros I designed by Carlos Tapang of Portland, Oregon. According to Jim Jubak, this chip is still quite crude and would be difficult to utilize in any working system.[103]

In Canada, some progress is being made in getting neural networks to solve problems in economics and business. Approximately $60 million is being devoted to artificial intelligence research by industry and academia in Canada, according to Jean-Claude Gavrel, the vice-president of Precarn Associates in Ottawa.[104] Precarn is a consortium made up of 35 Canadian companies dedicated to developing new technologies with practical uses in the private sector. Precarn's 5-year

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[101] Crevier, D. *Op. Cit.*, 215. Another application of neural networks is in investment management (See Barr, D. S. and Mani, G. Using Neural Nets to Manage Investments. In *AI Expert*, Feb 1994, 16-21).

[102] Barhen, J., Zak, M. and Toomarian, N. *Op. Cit.*, 103.

[103] Jubak, J. *Op. Cit.*, 20.

[104] Noakes, S. *Op. Cit.* S21.

research plan has budgeted expenditures of $35 million. The Institute for Robotics and Intelligence Systems with a $25 million budget is a federal centre of excellence and is also managed by Precarn.

One can see that, with the current developments in applications for neural networks, the proposed use of neural network technology to model decision-making processes is quite feasible. As has been demonstrated, one can represent the elements of decisions in such a way as to be amenable to neural network application. That the proposed structure mirrors both how the brain works and neural network architecture facilitates the application. Thus, one can foresee the day when highly-accurate simulations of events in government and private-sector decision-making will be possible.

CHAPTER 4. - CONCLUSIONS

AN INTERDISCIPLINARY APPROACH

Multi-Disciplinary Approaches

> Any search for THE cause of the industrial revolution is doomed. For there is no single or dominant cause. Technology, by itself, is not the driving force of history. Nor, by themselves, are ideas or values. Nor is the class struggle. Nor is history merely a record of ecological shifts, demographic trends or communication inventions. Economics alone cannot explain this or any other historical event. There is no "independent variable" upon which all other variables depend. There are only interrelated variables, boundless in complexity.[1]

The above statement is applicable, not only to the industrial revolution, but to the understanding of other social phenomena as well, including public policy decision-making. At various points in this thesis, it has been suggested that the nature of the subject of decision-making processes within particular organizational contexts demands a multi-disciplinary approach. This may be the time, as some cognitive scientists have suggested, for a convergence of research from hitherto isolated fields.[2]

The need for multidisciplinary approaches has been

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[1] Toffler, A. *The Third Wave*. New York: Bantam Books, 1981, 116.

[2] Sejnowski, T. J. and Smith-Churchland, P. Brain and Cognition. In Posner, M. I. *Foundations of Cognitive Science*. Cambridge, Mass.: MIT Press, 1989, 344.

formally recognized by some universities. McMaster University, for instance, has been redefining its programs to break down walls between disciplines. Students are thus learning how to synthesize theories, data and common sense, combining, for example, engineering skills with philosophy and ethics.[3]

In postulating a model for human cognitive systems, including decision-making, this thesis has followed the example of Kosslyn in borrowing material from Artificial Intelligence (AI), Cognitive Psychology and Neuropsychology.[4] This thesis has indicated, in applying a theoretical model, how it is possible to borrow from various specialties so that the model has some application in the real world, and can be tested. It has been noted that until recently, cognitive science has been dominated by learning, linguistic and artificial intelligence concerns.[5] It is now time to apply the findings of cognitive science to the understanding of public policy.

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[3] A Harsh New World: Cash-Strapped Universities are Struggling to Teach Students How to Adapt to an Ever-Changing World. In *Maclean's*, Nov. 9, 1992, No. 45, 35-36.

[4] Kosslyn, S. M. Toward a Computational Neuropsychology of High-Level Vision. In Knapp, T. J. and Robinson, L. C., eds. *Approaches to Cognition: Contrasts and Controversies*. Hillsdale, N. J., Lawrence Erlbaum Assoc., 1986, 223.

[5] LeDoux, J. E. Cognition and Emotion: Processing Functions and Brain Systems. In Gazzaniga, M. S., ed. *Handbook of Cognitive Neuroscience*. New York: Plenum Press, 1984, 357.

Public Policy and Non-Rational Factors

Some might object that public policy involves factors such as emotion and is governed by decisions which involve intuition as much as they do rational decision-making. This thesis has displayed in pages 85 to 90 of Chapter 3, however, that recent developments in cognitive science have encompassed and integrated these aspects of human mental processes into general concepts that allow for so-called "non-rational" mental activity. The model proposed in this thesis also takes these factors into account.

An Integrated Concept

What this thesis also has done is to amplify the findings of cognitive psychologists to arrive at an integrated concept which postulates a structure and utilizes it to explain decision-making processes in the real world, including both those of the individual and those of organizations. Thus, it is possible to represent decision-making processes, such as those made at the national level relating to defence, using a model which is structured similarly to the cognitive processes which occur in the individual human brain. The remainder of this thesis will now summarize what has been accomplished or demonstrated, first in relation to cognitive science, and second, regarding practical applications of the model.

COGNITIVE SCIENCE

Simplification - The Black Box

It is sometimes necessary to take measures to simplify a model so that the complexities of the actual process do not overwhelm the analyst. This is sometimes also necessary to allow the analyst to work with processes about which there is little specific information. Often, the only information which is possessed about a particular process concerns the relationship between that process and the rest of the system. Treating a mechanism as a "black box" allows the analyst to ignore certain details of the mechanism in order to find properties that play a prominent role in the function.[6]

There is, of course, the danger of dealing with processes on too superficial a level. Some descriptive models can provide too little information about underlying psychological processes.[7] The model proposed in this thesis, utilizing micro and macro versions, has hopefully succeeded in avoiding that problem through postulating a cognitive structure which can be tied into the decision-making process.

As has been stressed throughout this thesis, it is desir-

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[6] Sejnowski, T. J. and Smith-Churchland, P. *Op. Cit.*, 342.

[7] Huesmann, L. R. Process Models of Social Behaviour. In Hirschberg, N. and Humphreys, L. G. *Multi-variate Applications in the Social Sciences*. Hillsdale, N. J.: Lawrence Erlbaum Assoc., 1982, 261.

able to create a model for decision-making processes which is consistent with what is known about the basic human cognitive processes. It is argued that the multi-layered matrix of schemata which is offered does achieve this.

Cognitive Architecture

This thesis has also argued that what is needed is the adoption of new approaches to modelling human cognitive processes, i.e. a new cognitive architecture. Much of the research done in the area of mental information processing, such as that attempting to explain human arithmetic and other problem-solving activities, has been criticized as not identifying the basic tasks and the information-processing constraints.[8] This thesis has focussed on "constraints" and has tried to resolve "how" mental processing takes place, rather than just settling for the definition of an input.

As part of this cognitive architecture, the "layering" aspect of brain development has been borrowed and adapted for the model of the human decision-making process presented in this thesis. To some degree, this is because of the perception that structure, both physical and cognitive, has a lot to do

[8] Boden, M. A. *Computer Models of Mind: Computational Approaches in Theoretical Psychology*. Cambridge: Cambridge University Press, 1988, 170.

with how decisions are made and their outcomes.

Structural Parallels with the Brain

Another aspect of the composition of the brain is how the neurons within it are organized. The thesis has utilized the suggestion of cognitive scientists that many brain areas display not only topographic organization, but also a laminar organization.[9] Laminae are layers or sheets of neurons in register with one another. It has been found that a given lamina conforms to a highly regular pattern of where it projects to, and from where it receives input. The brain receives visual input in superficial layers, and tactile and auditory input in deeper layers.[10] The model proposed in this thesis is thus largely structured in accordance with this concept of how the brain is structured. This is done because the structure of the brain is significantly related to how information is processed.

The thesis thus utilizes the observations of some cognitive scientists who have discovered cortical structures which display vertical organization. A high degree of commonality has been identified between cells in vertical columns. These

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[9] Sejnowski, T. J. and Smith-Churchland, P. *Op. Cit.* 312-313.

[10] *Ibid.* 312-313.

vertical columns cross laminae. The commonality between cells is seen as reflected both anatomically, in terms of local connections between neurons, and physiologically in terms of similar response properties.[11]

The presence of vertical columns in the neural structure of the brain is mimicked in the proposed model. In the model, these vertical columns serve to transfer the output of particular processes to the next stage of processing. They also serve to embed logical constraints in decision-making processes where there is a certain commonality to these constraints.[12]

Hypertrophy

In the processing of visual information, our ability to mentally image complex objects depends on visual processing systems that likely evolved from other functions.[13] An important theme in this thesis has been that our reasoning processes are a hypertrophy of our sensual processing systems. This

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[11] *Ibid.* 313.

[12] It has been stressed in this thesis that to understand how the brain works, it is important to keep in mind that the human nervous system is the product of a long process of evolution. The model has the advantage of representing human mental processes in a way which is consistent with what is known about human evolution.

[13] Sejnowski, T. J. and Smith-Churchland, P. *Op. Cit.* 34.

underlies the position that our mental processes are "rational", in the sense that they conform to logical patterns. These logical patterns are seen to derive from the brain's constitution and the structured interaction of neurons.

Dyadic Reasoning

It has been suggested that the process of pattern recognition begins with the extraction of features from the presented stimulus. This set of features would then be combined and compared against information stored in permanent memory.[14] How is this set of features combined? The model allows for the possibility of using a form of pattern recognition combined with binary logic.

The model proposed has the advantage of presenting a reasonable approach to the problem of how to represent the mental processes of an individual. In this thesis, it has been hypothesised that the human reasoning process is based on patterns or schemata and that these patterns have a dyadic quality to them. This would be consistent with the parallelism which appears to exist in the yes/no or on/off tendencies in human cognitive processes. There is, for example, the normal

[14] Eysenck, M. W. *A Handbook of Cognitive Psychology*. London: Lawrence Erlbaum Assoc., 1984, 40.

decision-making process which appears to be predisposed to a friend/enemy dichotomy. Our individual schemata appear to possess logic gates which bifurcate the logic channel so that a decision, such as the decision to identify a detected aircraft or missile as a threat, can be passed on to the next schema.

One of the hypotheses presented in cognitive psychology is that the reasoning process is largely like a game of *20 Questions*, which means that the process is somewhat dyadic, i.e. composed of yes/no questions and framed by a set of constraints which determine the questions. The model proposed in this thesis opts for this approach, representing the constraints in the decision-making process by a system of vertical columns. In computerization, this binary logic could also be used to tie the schemata in the model together. This structure seems feasible, given what has been observed about human brain structure. What is proposed is not a radical departure from the conclusions drawn by researchers such as Newell and Simon concerning the "if-then" rules in human reasoning.[15]

The model also has implications for other fields of research. The use of the "schema" concept in the proposed architecture would help explain, for example, why we appear to design or model our inventions according to our own "tools"

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[15] Waldrop, M. M. *Man-Made Minds: The Promise of Artificial Intelligence*. Rexdale, Ont.: John Wiley & Sons, 1987, 35.

or faculties. One might surmise, for example, that our designing of computer chips using on/off electronic switches is a reflection of the dyadism in our logic processes. Thus it may be not merely "gods" which we design in our own image. This characteristic also makes it understandable why it took so long for us to invent the wheel: the wheel concept is dependent on abstract schemata and does not correspond to our physical attributes like our arms or legs. Levers, on the other hand, are based on schemata which have obvious physical counter-parts.[16]

Logical Structures

Although researchers have demonstrated that humans fail to follow rules or laws of logic in their reasoning processes,

[16] The proposed cognitive architecture also makes sense in terms of human evolution. The dyadic reasoning processes built into the model are consistent with what is known about our cellular development, whereby the relationship between our cells is based on electro-chemical receptors which operate on unambiguous messages. These messages are unambiguous because that is the way in which cells appear to be designed to handle information. The light receptors and other sensory apparatus of one-celled animals are likely restricted to the simplest form of interpretation of input, which is dyadic. This feature is possibly inherited from crystalline evolution which, as Richard Dawkins suggests, gave rise to the components of the first life forms. It is also possible that the proffered model could be used to represent the physical or electro-chemical processes within the brain itself. See: Dawkins, R. *The Blind Watchmaker: Why the Evidence of Evolution Reveals a Universe Without Design*, New York: W. W. Norton & Co., 1987, 148-157.

there is still a structure to human decision-making processes, and the proposed model attempts to represent this structure. The proffered model contains cognitive matrixes which are set up something like our rules of logic. The hypothesis is therefore arises that our so-called "rules of logic" could originate in the patterns in our brain, rather than in the external world. It is possible that the brain's neurons are formatted in such a fashion, through learning or through genetically-transmitted inheritance (as in the case of language), that a particular output is generated at each level for transmission to the next.

One might thus draw the conclusion that our "laws of logic" have no aspect of universality to them, other than that they seem to be cognitively comprehensible to Homo sapiens. It may be that they are the creation of our minds and that some of what we perceive to be structure in abstract relationships, such as scientific "laws", are merely the mirror image which our mind perceives as it analyses input data. Therefore, it is critically important to understand how our cognitive equipment is structured, for without knowing this, one cannot have confidence in the validity of the structure and reality of what we perceive.

Rational Decision-Making

This thesis has adopted the approach that human decision-making processes are fundamentally logical and therefore rational. Decision-making fits into the rational process through the making of choices as to how particular goals are to be met. It is the setting and following of specific goals which is crucial in deciding what our actions should be.[17]

In the context of public policy, one observes quite a bit of confusion between how decisions are actually taken and how they should be taken. Stephen Brooks, for example, outlines some of the issues in his discussion of the debate between the rationalist and incrementalist models.[18] Adie and Thomas outline the debate in a similar fashion.[19]

This thesis provides a tool to resolve the confusion between arguments concerning how decisions should be taken and how decisions actually are taken. The 3-dimensional model can be used to explicitly display how decisions are taken, as in the example of the 1987 White Paper, and a separate and distinct model can be constructed of how we think decisions should be taken.

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[17] Boden, M. A. *Op. Cit., 170.*

[18] Brooks, S. *Public Policy in Canada: An Introduction.* Toronto: McClelland & Stewart Inc., 1989, 65.

[19] Adie, R. F. and Thomas, P. G. *Canadian Public Administration: Problematical Perspectives.* Scarborough, Ont.: Prentice-Hall Canada, Inc., 87-103.

COMPUTER MODELLING

The Use of a Computer Model

This thesis has two tie-ins to computers. As well as the discussion as to whether the mind works like a computer, there is also the proposition that this model can facilitate the application of neural network or other computer technology to the analysis of foreign policy or other decision-making situations, provided the proper architecture is used. While this thesis does not provide and test a neural network computer application, it is possible to say something about the suitability of the proposed model for computer applications.

In order for the decision-making process associated with the 1987 White Paper on Defence to be modelled using a neural network computer system, what would be needed would be a multi-level structure which would allow for independent processing within particular modules. It is believed that this thesis provides such a structure. The independent modules within the proffered organizational model would represent the cognitive processes of the individual decision-makers. These independent modules could then be programmed for simulation by neural network computers using established techniques. As might be noted, for instance, the proposed model for representing decision-making processes mirrors much of the structure of multi-layered perceptrons and hopefully shares some of the advantages.

The proposed structure could also be used to create a computer model of the human decision-making process with the aid of various high-level software packages, such as *Lotus 123* or *Mathematica*. In addition, one might utilize computer graphics packages to illustrate cognitive structure and activity. Generally speaking, however, this thesis has expressed a preference for the use of neural network computers to handle the complexities of human decision-making processes.

One of the difficulties with trying to analyse the complexities of public policy is the limited capacity of the analyst to handle all of the variables. Human mental limitations are conceded by a wide range of specialists in various fields. Richard Dawkins, a biologist, for example, points out how our brains are built to cope with only narrow bands of sizes and times.[20] Leon Festinger, the psychologist credited with originating the concept of "cognitive dissonance", also acknowledges how limited human cognitive capacities are.[21] Alan Allport, a cognitive scientist, maintains that:

> The fundamental constraint that underlies all the operations of attention, imposing their essentially

[20] Dawkins, R. *Op. Cit.* 160.

[21] Festinger, L. *The Human Legacy*, New York: Columbia University Press, 1983, 167.

> selective character, is the limited information-processing capacity of the brain.[22]

Another cognitive scientist, D. E. Broadbent, argues that the constraints of limited brain capacity directly affect the processing of sensory information.[23]

To many investigators, this limited mental capacity explains the selectivity with which information is processed. They see the basic function of these selective or attentional mechanisms as being the protection of the brain's limited-capacity system (or systems) from informational overload.[24]

This perceived lack of capacity is seen by some to have major implications for the understanding of human mental processes. It has been suggested by Dr. Jerry Warsh, a neurochemist at the Clarke Institute of Psychology in Toronto, for instance, that the human mind may prove inadequate to the task of understanding itself.[25] The way to bypass human limitations, Warsh suggests, is through the use of computers to integrate the large amounts of data required.

This thesis takes a similar approach in postulating a model which can be applied to macro decision-making processes

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[22] Allport, A. Visual Attention. In Posner, M. I., *Foundations of Cognitive Science*, Cambridge, Mass.: MIT Press, 1989, 632-633.

[23] *Ibid*. 633.

[24] *Ibid*. 632-633.

[25] Engineers of the Mind, *Macleans*. Apr. 11, 1988, 46.

in such a way as to make them comprehensible. This model can also be computerized, utilizing case-based reasoning or some other modelling technique.

Reverse Engineering

The proffered model both utilizes "reverse engineering" techniques to display how decision-making processes take place, and is itself the product of "reverse engineering", for to some degree, there was some "reverse engineering" involved in the process of deriving the model. As this thesis has illustrated with the example of the 1987 White Paper, it is perhaps easier to describe an empirical situation where decisions are actually made, and then afterwards develop a decision-making model that will match it, than to develop a model and then design experiments with an adequate degree of control to validate the model, as in the physical sciences. Thus the "reverse engineering" approach utilized in cognitive science is applied here.[26]

Although this model was first arrived at independently through "reverse engineering", starting at the public policy analysis level, the concepts have also been suggested by researchers working in the field of cognitive psychology to

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[26] Sejnowski, T. J. and Smith-Churchland, P. *Op. Cit.*, 344.

explain the workings of the brain. One concept is the use of pattern-matching processes in multi-level networks to explain how mental arithmetic takes place.[27]

As might be noted, this thesis has included a discussion of how cognitive psychologists perceive the brain performing its higher functions, including the interpretation of sensory input. This material was included to establish the parameters which the reverse engineering process must meet, i.e. defining what the inputs are, how they are processed, by what entities, in what order and what the outputs are.

The Limitations of Artificial Intelligence

There is some question as to which computer architecture will prove most useful in the context of cognitive science. Under the umbrella of "artificial intelligence", computer systems have been designed to reproduce some of the characteristics of human cognitive processes. It has been found, however, that "expert systems", along with natural-language and other AI technological interfaces, although they are successful in some respects, are deficient in other areas,

[27] Boden, M. A. *Op. Cit.*, 170.

particularly with regards to pattern recognition.[28] It is hoped by some that neural networks will prove to be the solution to these weaknesses.[29]

One of the advantages of neural computers over other types of AI architectures is their heuristic reasoning capabilities, which enable them to apply "rules of thumb" and to refine and adapt these rules through experience.[30] Neural computers especially differ from conventional computers in that they "learn" through experience. Because of their heuristic capabilities, they thus can make decisions that rule-based expert systems are incapable of.[31]

Largely for this reason, there is a bias in this thesis towards utilizing neural computers in the automation of the proposed model, although Lotus 123 Release 3 has been used initially to present the structure and demonstrate the feasibility of building into the model certain data-processing features and their output (which then becomes input to the decision process). In the proposed model, "rules of thumb" would appear as the schemata or patterns formed by the

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[28] Stoll, M. Neural Networks Bring Pattern Recognition to PCs. In *PC Week*. March 23, 1987, 8.

[29] Madhavan, R. Goal-Based Reasoning for Securities Analysis. In *AI Expert*, Feb. 1994, 23-29. This article also makes reference to an interpersonal model of goal-based decision-making developed by Stephen Slade to simulate American Congressional voting.

[30] Waldrop, M. M. *Op. Cit*. 24.

[31] Stoll, M. *Op. Cit*. 8.

the vertical columns in the layers of the cognitive matrix.

Pattern Recognition

Another of the advantages of the proposed model is its compatibility with neural computers. If one accepts that human decision-making processes are a hypertrophy of the basic sensual input processing mechanism of the brain, then it seems reasonable that neural computers, which mimic human pattern recognition, should also be applicable to human decision-making. This would especially be true if, as is argued in this thesis, human decision-making is best understood in terms of pattern-matching through the mechanism of schemata.

What is particularly attractive about neural computers, from the point of view of the implementation of this model, is their pattern processing ability. One of the main strengths of neural computers is in the area of pattern recognition. They can, like the human brain, recognize patterns, whether based in text, graphics, procedure, sound, or any other form.[32]

[32] Stoll, M. *Op. Cit.*, 8.

PRACTICAL APPLICATIONS OF THE MODEL

The Model as a Tool

The applications developed to enable computers to perform human functions are seen by some researchers to be of epoch-making significance. To D. A. Allport, the advent of computational models grounded in artificial intelligence is the "single most important development in the history of psychology".[33] In Allport's eyes, the previously "chaotic" state of cognitive psychology was characterized by myriad experimental results jostling for attention without any kind of unifying theory.[34] There was also, as Allport put it, a "lack of adequate theoretical notation in which to formulate questions about mental processes." Allport made the prediction that "artificial intelligence will ultimately come to play the role vis â vis the psychological and social sciences that mathematics, from the Seventeenth Century on, has done for the physical sciences.[35]

There may be a substantial amount of truth in Allport's prediction, especially if one considers, from the perspective of schemata, the phenomenon of the creation of computing

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[33] Boden, M. *Op. Cit.* 259.

[34] *Loc. Cit.*

[35] *Loc. Cit.*

devices which mimic the brain's structure and processes. The development of mathematical notation and the embedding of it in a system of schemata has greatly facilitated human progress in the physical sciences. Because the social sciences, including psychology, are heavily oriented towards human mental processes, it is vital that appropriate tools be developed that adequately reflect human cognitive functions. It is hoped that these tools, such as the model proposed in this thesis, will advance our understanding of complex behavioural phenomena which have thus far defied effective modelling utilizing mathematical tools borrowed from the physical sciences. As far as can be determined, short of actually building a neural network system, the structure of the proposed model appears suitable for neural network application.

Another aspect of the proposed model is the attempt to represent human cognitive processes in geometric space. This is nothing new, since factor analysis and multi-dimensional scaling both attempt to represent data in geometric space in order to provide some reduced and presumably higher-level perspective of cognitive phenomena.[36] Rather than presenting a model in four or more dimensions, as some researchers do,[37]

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[36] Snyder, C. W. Jr., Law, H. G., Hattie, J. A. and McDonald, R. P. *Research Methods for Multimode Data Analysis*. New York: Praeger, 1984, 29.

[37] Harshman, R. A. & De Sarbo, W. S. An Application of PARAFAC to a Small Sample Problem, Demonstrating Preprocessing, Orthogonality, Constraints and Split-Half Diagnostic Techniques. In Law, H. G., *et al. Op. Cit.* 615.

this thesis utilizes a 3-D model which (unless a dynamic model utilizing time as a fourth dimension is used) can present a static visual representation, and hopefully conforms somewhat to the physical reality of the brain's structure. The conceptual difficulties of dealing with an entirely abstract model are thus avoided. The 3-D representation is visually easily comprehensible, while at the same time being structured similarly to how the brain is known to function. Ultimately, it is hoped, the model can serve as the architecture for computerized simulations of public policy decision-making processes.

As with the development of the back-propagation algorithm, a long period of time can pass between the inception of a concept and its application in a practical context. The ideas presented in this thesis are still in the conceptual stage. Like the wheel or the back-propagation algorithm, the value of a concept does not become obvious until it is embedded in a practical application. In the case of the wheel, for example, the early inhabitants of the Americas failed to apply the concept in their technology and therefore handicapped the advancement of their civilizations in certain respects. Although it is beyond the scope of this thesis to demonstrate the practical superiority of the proposed model, for instance, in terms of predictive capacity, certain potential applications can be pointed out.

Feedback

The model has the capacity to graphically and electronically portray the "feedback" process which occurs in the mind of an individual within an organization as an issue is debated or preconceptions are checked against reality. This is made possible by the model's capacity to display hierarchical structures, which would include both the mind of the individual and the structure of an organization.

In the model, feedback would be represented as the matching of patterns which are formed by the interaction of vertical columns in a cognitive matrix. The matching of patterns in the verification or feedback process enables the model to reflect the "real" world, rather than some idealized "rational" process.

Experts and Prediction

To be optimally rational, decision-processes should include the best sources of information available. This would suggest that decision-makers should rely heavily on the recommendations of experts.[38] The value of experts is measurable to some degree on the basis of their success as forecasters.

[38] Brooks, S. *Op. Cit.* 65.

Successful prediction is often regarded as the true hallmark for the success of any scientific theory.[39] The same criterion can be applied to "experts". It is also expected that the proposed model, once computerized, can function as a sort of "expert" and can be used to "predict" certain decisions.

Whatever model of cognitive processes might be generated from the analysis of policy areas, such as defence requirements, for example, this model has to be consistent with what is known about basic cognitive processes. Establishing how the human mind works within its own context is a major challenge since the complexity of the behavioural repertoire increases with increasing numbers of neurons.[40]

While the decision-making processes of the individual are admittedly complex, the complexity of the decision-making process increases when many individuals are involved. The process is again complicated by organizational structures and can become immense and unwieldy, unless one can develop a model that will logically structure these processes. The model presented in this thesis attempts to do that.

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[39] Palmer, S. E. and Kimchi, R. The Information Processing Approach to Cognition. In Knapp, T. J. and Robertson, L. C., eds. *Op. Cit.*, 63.

[40] Dean, J. The Neuroethology of Perception and Action. In Neumann, O. and Prinz, W. *Relationships Between Perception and Action: Current Approaches*. Heidelberg: Springer Verlag, 1990, 120.

Statistical Input

The model under discussion has the capacity to represent and integrate mathematical or statistical factual input as well, since these tools are sometimes used by "experts" or other participants in the decision-making process to provide advice. These statistical functions can be embedded in schemata within a cognitive matrix, in much the same way as Hidden Markov Models are utilized in neural network architecture. It is likely that, in applying this model to neural nets, one would treat statistical functions in a similar fashion.

The "Constraint" Concept

It should also be noted that in the literature concerning neural computers, there is constant reference to "constraints". In the example of the 1987 White Paper on Defence used in this thesis, the constraints upon the Canadian government's decision-making process were grouped into five categories: (1) goal/value constraints; (2) strategic/environmental constraints; (3) technical constraints; (4) resource constraints; and (5) structural constraints. The first four of these groups of constraints were represented by vertical columns, while the fifth constraint category was illustrated by a spatial distribution of cubes or blocks representing entities which had input into the decision-making process.

A complicating factor in modelling decision-making processes is the fact that the decision-making organization and its environment are subject to change. It must be acknowledged that many executive decisions are highly constrained by time.[41] This has multiple impacts on the decision-making model. For one thing, it limits the number of factors that can be considered in the model and thus has the effect of minimizing the number of constraints dealt with. On the other hand, it increases the importance of certain resource and technical constraints. Certain technical options which offer quick solutions and are easily implementable are often favoured. Resource constraints come into the picture because, since time is a resource, the amount of pressure to make a decision can vary. In some cases, a decision-maker is afforded the luxury of procrastinating making a precise commitment. This can result in a non-decision, i.e. a decision not to make a commitment.

This thesis has demonstrated how it is possible to model the rationale for the government's announced decisions provided in the 1987 White Paper in accordance with a three-

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[41] Snoyer, R. S. and Fischer, G. A. *Everyone's Support Systems: A Complete Guide to Effective Decision Making Using Microcomputers*. Homewood, Ill.: Richard D. Irwin, Inc., 1993, 104.

dimensional cognitive matrix of schemata, utilizing micro- and macro-models, tied together with a system of "constraints". As pointed out in the thesis, this configuration is markedly similar to the architecture of the connection machine developed by Daniel Hillis. Another of the aspects of the proposed model which is noteworthy is that the "constraint" concept offered in this thesis is not too dissimilar to the use of the term in neural network literature.[42]

The model presented in this thesis has the potential to be dynamic, although it is treated in this thesis for convenience as static. The illustration of the 1987 White Paper decision-making process is thus only a snap shot of a decision-process at a point in time, i. e. the publication of the White Paper. To represent what happened following publication of the 1987 White Paper, a dynamic model would have to be used, illustrating modifications to policy as the decision-making process later evolved. A dynamic version of the model would most likely be best represented by an animated graphics program.

The Model as an Agent of Change

It should also be observed that it is possible to perform

[42] Hedberg, S. New Knowledge Tools. In *Byte*, July 1993, 107.

organizational analysis and design within the context of the proposed model if one starts from the premise that the human decision-making process is logical and that it is performed according to a number of types of constraints, one of which is organizational. Another advantage of the proposed model, therefore, is that it can be used as a tool in effecting change in organizational structure.

As in the case of the example of the 1987 White Paper, the purpose of this thesis was not to recommend change. Rather, what this thesis hopefully has accomplished is to suggest what mechanisms are currently in place whereby humans make decisions, and in-so-doing, provide a tool for predicting and also for engineering change in a controlled and systematic fashion.

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