# Fruits of Enlightenment

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# Fruits of Enlightenment
## A Special Program for the Cognitive Sciences

## Preface

The cognitive sciences study how knowledge is acquired, processed and used. The recent accomplishments of these sciences, and the impact they are expected to have in the near future, fully justify the decision of the Netherlands Organization for Scientific Research (NWO) to launch a *Special Program for the Cognitive Sciences.* This document presents the outline for this program as proposed by the Program Preparation Committee (PPC).

It has long been accepted that cognition constitutes a fundamental characteristic of reality. As such it is a proper subject for scientific investigation, with its own theoretical and methodological framework. Compared with the natural sciences the coherent and cumulative study of cognition has been slow in coming. It may seem strange today that for centuries it has been doubted whether the brain would be at all necessary for cognition. One should take into account, however, that until modern times the only tools available to unravel this question were the power of reasoning and the intuition of guessing. Since the nineteenth century the development of experimental research and clinical observations have demonstrated the inadequacy of the traditional Cartesian view. Yet, it has been difficult enough to develop a precise understanding of the neurophysiology of the mind. Only in the course of the past fifty years, however, cognition has become accessible to systematic conceptual and experimental analysis. Important results leading to a fundamental understanding of the relations between knowledge, neural function, behavior and communication are now within reach.

An important factor in this development is that the scientific disciplines most directly involved – including the neurosciences, linguistics, psychology, artificial intelligence, and still others – are spontaneously converging towards a common conceptual and methodological frame of reference. Scientific disciplines that, in the past, had little to communicate to each other, now realize the fundamental importance of combining their different perspectives.

If this path is successfully traveled, cognitive research will soon be able to generate unprecedented, fundamental insights in the workings of the mind/brain. At the same time it will enable the cognitive sciences to trigger relevant innovations in all the major fields of human activity, work, education, communication and well being.

The proposed Special Program explicitly aims at (a) strengthening the theoretical and empirical foundations of the cognitive sciences; (b) strengthening the cross-disciplinary coherence between the cognitive sciences; and (c) establishing a solid level of public acceptance and support for the cognitive sciences. Evidently it should aim for research of the highest quality. This is why the PPC decided to propose a thematic framework and a flexible outline of administrative procedures, rather than prescribing a detailed

program for cognitive research. What is desirable in the eyes of one part of the research community may well be *anathema* for the other. Yet, in order to ascertain an adequate focus for the Special Program as a whole, the committee has defined four broad areas that invite cutting-edge, cross-disciplinary research, on the basis of the program's stated objectives. In particular the committee recommends that priority be given to research proposals with a thematic focus on the following areas:

- **Neuron to cognition.** At present the most noticeable trend in the cognitive sciences is the emergence of cognitive neuroscience. Recent advances in experimental techniques present unprecedented opportunities for studying the whole gamut of cognitive functioning, from individual signals at the neural level to the complex behaviors of the entire organism. Progress in this domain requires the development of formal models of cognitive functioning that are not only neuroscientifically grounded but also behaviorally relevant.
- **Unconscious and planned behavior.** Action control is a central issue in the cognitive sciences. While some cognitive activity takes place under deliberate control, many behaviors, simple and complex, appear to be 'automatic' or 'unconscious'. Understanding how smooth adaptive behavior comes about requires a thorough structural analysis of the (natural and social) context in which that behavior takes place. This raises the problem of formally describing such behavior in terms of computational theories.
- **Communication and socially situated cognition.** Human cognition evolved as a consequence of the social reality of human existence. In the process a number of communicative tools emerged, of which language is the most extraordinary example. These culturally determined tools serve to overcome the limitations of the individual brain by enabling the complex exchange of information between the individuals in a group. Research on the biological, psychological and social determinants of socially shared cognition, is of fundamental importance for understanding how a community can share a common view of reality.
- **Organization and accessibility of knowledge.** Two major achievements in the ways we can organize and handle knowledge have been the development of a theory of computation and complexity on the one hand, and that of the theories of learnability and proof on the other. Together these would seem to provide the mathematical vehicle for the cognitive sciences. The major challenge for the near future is to determine how the two hang together as steps on the way towards a general theory of learning and memory.

For each of these areas the committee has signaled a number of topics that lend themselves for innovative research. In addition, the committee recommends a systematic theoretical and methodological debate with explicit ramifications for the program as a whole.

Although the Special Program is intended primarily to support fundamental cognitive research, the committee stipulates the importance of carefully weighing the potential of such research for applications. For this reason the committee recommends the establishment of a national Platform for Cognition. This should provide a forum where scientists, external funding parties (industry), and the public sector, can discuss both scientific findings and common interests of an applied nature.

Another important issue is that cognitive research is increasingly a matter of international cooperation. Whilst Dutch researchers are already involved in many international collaborative efforts, the committee explicitly recommends that new initiatives be encouraged, especially those that would help to enlarge the scale of cognitive research. One commendable way would be to set up a project with an important, specific long-term goal. Such a project requires sustained international cooperation for a period of many years.

Finally the committee argues that the increasing impact of the cognitive sciences will eventually require a much larger dedicated funding, far beyond the scope of the proposed Special Program. The committee recommends that ways and means for future support be negotiated with NWO, in time to secure the continuity of cognitive research in the Netherlands beyond the term of the Special Program.

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> Aufklärung ist der Ausgang des Menschen aus
> seiner selbst verschuldeten Unmündigkeit.
> *Immanuel Kant, 1784*

# 1 Introduction

### 1.1 The study of cognition comes of age

The cognitive sciences constitute a natural federation of scientific disciplines with a shared research agenda. Their aim is to study how knowledge is acquired and processed. Knowledge, broadly understood, includes all types of perception, attention, learning, memory, thinking, language, motor functions, emotions and social interaction, as manifested in and by natural, artificial and formal systems. The disciplines most directly involved are psychology, cognitive neuroscience, linguistics, logic and artificial intelligence.[1]

Underlying the cognitive sciences is the conception of human beings as information processing systems – individually as well as collectively. This makes it possible for researchers to study natural and artificial intelligence, their similarities and differences, and the interfacing between the two, from a coherent theoretical perspective. The study of the ways in which cognition is embodied, naturally or artificially, may thus offer a lead towards resolving the mind-body problem that has haunted philosophical thinking through the ages.

The cognitive sciences reached a certain level of maturity in the course of the last fifty years. During that period progress has been accelerating. As a result we are witnessing the emergence of cognition as an independent, integral domain of scientific activity. Formal methods for analysis and model building have greatly facilitated theoretical progress in the various disciplines. Importantly too, methods and techniques have become available that have created entirely new inroads into the territory of intelligence and consciousness.

A failure to take a prominent part in this development would have tragic consequences for a country that aspires to be among the leaders in the 'knowledge revolution'. With the definitive map of the human genome in sight; with new imaging tools available to visualize the brain structures involved in cognitive processes; with the means for subtle behavioral analysis in place; and with the explosive developments in information and communication theory and technology, a breakthrough in the cognitive sciences is a fact and should not be missed.

[1] For the disciplines explicitly mentioned here cognition constitutes a principal object of study. In addition many of the natural and social sciences, as well as the humanities, study aspects of cognition.

In the Netherlands research in the cognitive domain meets, by and large, a high (international) standard. In the past it has shown a high degree of continuity and a remarkable potential for innovation. This conclusion follows from the periodic evaluations by VSNU and from the relevant state-of-the-art reviews produced by the OCV.[2] It is also witnessed by the relative contribution of Dutch researchers to the production of international 'high impact' publications and by the Dutch involvement in international scientific activities and organizations.
This state of affairs more than justifies a Special Program to support the cognitive sciences. Ultimately the question is not so much *whether* such a program is indicated but, rather, what efforts will have to be made in order not to miss this one-time opportunity to play a substantial role in the 'knowledge revolution'.

## 1.2 A Special Program to stimulate the cognitive sciences

In 1997 a national advisory committee, the OCV Verkenningscommissie Cognitiewetenschappen, reported to the Minister of Education, Culture and Science on the state of the cognitive sciences in The Netherlands.[3] The recommendations made by this committee included the following:

- the establishment of a national research facility for neurocognition;
- the stimulation of research, especially in the areas of knowledge transfer, education, work and organization, and the quality of life;
- the launching of a special program to support basic research in the cognitive sciences;
- the institution of an advisory council for the cognitive sciences within NWO.

This report effectively triggered several important initiatives. In the first place the decision was reached to establish the much-needed national neurocognitive research facility recommended by the OCV advisory committee.[4] Secondly, a project dealing with some features of knowledge transfer was launched under the name *ToKen2000.*[5] The follow-up on the third recommendation of the advisory committee eventually came about when NWO revealed its plans for the period 2000-2004. NWO assigned highest priorities to the cognitive sciences – and to biomolecular informatics.[6] Subsequently the NWO Board of Governors decided to launch a Special Program for the cognitive sciences. In May 2000 the Board instituted a Program Preparation

2 For a list of acronyms used in this report see Appendix E.
3 De kennisraffinaderij: *De cognitiewetenschappen in Nederland*. Eindrapport van de OCV Verkenningscommissie Cognitiewetenschappen. Amsterdam: KNAW, 1997.
4 The F. C. Donders Center in Nijmegen opened its doors in the fall of 2000.
5 Recently this program was described in a brochure with the title *Toegankelijkheid en Kennisontsluiting in Nederland 2000.* The Hague, NL: NWO.
6 *Inzet op vernieuwing: Ruimte voor talent.* Meerjarenplan NWO 2000-2004.

Committee – hereafter to be referred to as PPC – to draft a plan for such a program.[7] The PPC was charged with the following tasks:

- formulate a concrete and detailed program proposal within the conditions specified by NWO;
- consider possibilities for systematically obtaining extra funding, outside NWO;
- define research themes and indicate preferences with respect to implementation and project size;
- make recommendations regarding project management (including criteria and procedures for the selection of research proposals);
- secure support from the field with respect to the actual thematic choices made;
- delineate the program with respect to other initiatives, including *ToKen2000;*
- consider possibilities for linking the program with relevant international initiatives.

## 1.3 The proceedings of the PPC

Following a preliminary meeting in July 2000 the committee subsequently met on four occasions later in the year. Additional communication took place mostly on a bilateral basis between the chair and individual members, and largely by means of electronic mail. Following its meeting of 12 December 2000 the PPC agreed on a draft report that was circulated among the members early in January 2001. This draft was subsequently made public, for consideration by the cognitive research community on 23 January 2001.[8] Also a brief questionnaire was sent to the Research Schools that are active in the cognitive domain. Eight schools did reply in writing.[9] Finally, a public hearing was held on 9 February 2001, during which the proposal received overwhelming support. The event attracted an audience of approximately 130 active researchers. Three important points, raised during the discussion, also figure prominently in the written responses received from the Research Schools. They concern (a) the modest size of the anticipated funding; (b) the broad scope of the proposal; (c) the (near) impossibility to honor requests for matching. The PPC has given due attention to these concerns when preparing the definitive version of its report.

This report describes the PPC's considerations. The principal aim for the proposed Special Program is to boost the significance of cognitive research in the scientific sense. In addition the program offers opportunities to enhance the significance of the cognitive sciences in the context of the increasingly knowledge-intensive character of society.

7 The composition of the PPC is presented in Appendix A.

8 At the same time the text of the draft report was made available on the website of NWO (*www.nwo.nl*).

9 See Appendix B for a list of Research Schools active in the cognitive domain.

This entails the following specific objectives for the program:

- to achieve a significant increase in the understanding of the phenomenology of knowledge and its underlying mechanisms and processes (acquisition, retention and use);
- to support the research community in maintaining – and, where appropriate, establishing – a qualified position among the international top in the domain of the cognitive sciences;
- to establish venues for applying the insights gained and to achieve a significant improvement of methods, techniques and tools for the acquisition, management and use of knowledge in society (in all relevant domains, such as, e.g., communication, education and health care), both with respect to natural and artificial intelligence.

# 2 Why a Special Program for the Cognitive Sciences?

## 2.1 Introduction

In this chapter the PPC considers the question why a Special Program for the Cognitive Sciences is needed. Reviewing the remarkable evolution of the study of cognition during the past fifty years, the conclusion is that a Special Program is indeed urgently called for and should explicitly be directed at strengthening:

- the theoretical basis of the cognitive sciences;
- the empirical basis of the cognitive sciences;
- the cross-disciplinary coherence between the cognitive sciences;
- the use of the existing research infrastructure in academia and dedicated extra-mural research institutes;
- the position of the cognitive sciences with respect to field-oriented innovative and adaptive research.

## 2.2 The development of the cognitive sciences

Cognition has long been considered a defining characteristic of *homo sapiens.* This special status is reflected in the central role cognition plays in religion. Sacred, revealed knowledge was the most advanced form of systematic codification of human understanding of the world until it lost this exalted position to scientific insight. This sacral tradition postulated a fundamental duality between matter and soul (or mind) that persists until the present day. Yet, that position has weakened, as scientific insights leveling the walls between body and mind became more comprehensive and effective. Current views recognize cognition as a generic complex of functions. As such cognition is not restricted to humans or even to living systems in general, but appears to be a defining characteristic of artificial and virtual systems (organizations) as well. Moreover, it is now realistic to claim that we understand cognition to the extent that we can construct or model cognitive systems.

Cognitive systems can represent states of the world in ways that enable them to function adaptively – be it within certain constraints. In other words, cognition serves adaptive action. In this context we are not just talking about the 'mechanics' of acquisition, retention, elaboration and use of information, but also about the reflection upon *what* is acquired, retained, elaborated and used – in other words, reflection upon what knowledge is and where it comes from.

Cognition has been a subject for systematic study since the birth of philosophy. Epistemological questions – questions asking what knowledge is, how it is acquired and how it is used – have been at the center of the intellectual debate at least as long as the philosophical questions concerning physical reality. Yet, while the latter questions gave birth to the natural sciences in the 16th and 17th century, nothing similar happened with respect to epistemology. Very little was known about the nervous

system and there was no suitable paradigm to describe mental activity systematically, a situation that persisted until the beginning of the 20th century.
Around 1950 a number of related and more or less simultaneous developments gave a definitive impulse to what soon was to be called the 'cognitive revolution'. According to some this revolution began at an MIT- symposium, in September 1956. On that date George Miller on behalf of psychology, Herbert Simon and Allen Newell for artificial intelligence, and Noam Chomsky for linguistics, presented for the first time their revolutionary insights into the structure and function of human cognition that were to determine the course of events in the cognitive sciences for the next three decades. Others put the date even somewhat earlier, as neurocognition was already making rapid progress in directions such as neurocomputation (involving, e.g., John von Neumann, Ross Ashby, Warren McCulloch) and neurophysiology of perception (e.g., Karl Lashley, David Hubel and Torsten Wiesel). Therefore, whatever may have been the precise date, it is clear that it is by standing on the shoulders of these giants that we are now able to see so much farther.

## 2.3 Achievements

Although the world is quickly becoming replete with the spin-offs from research on cognition, the visibility of the cognitive sciences has remained surprisingly low; not only for the general public but also for the professionals in the technological domain who are constantly applying these results. This is surprising, because the achievements of the cognitive sciences during the past half-century are truly awe-inspiring.
In the formal sciences (mathematics, logic) the axiomatic treatment of such concepts as information, communication, feedback and dynamic control took off. These activities eventually resulted in a variety of theories of information, computation and complexity. Together with the availability of increasingly powerful computers this resulted in several new disciplines, such as computational linguistics, modal logic (e.g., temporal and action logic) and learnability theory, branching out in what is now most often subsumed under the heading artificial intelligence.
In psychology these developments led to the insight that human beings (and, at least, the higher animals) may, and perhaps should, be regarded as information processing systems. In this context the *rationality* of behavior (that is, the efficiency of a controlled action, given the complexity of conditions under which that action takes place) is a linking concept. In particular Herbert Simon's view that the rationality of real systems is *bounded* by the nature of their physical embodiment stands as a significant insight. It unites the study of natural and artificial intelligence and has also fundamentally influenced the ways in which we think about the behavior of organizations.
Linguistics too underwent a radical change. Originally rooted firmly in the philological tradition of the arts faculties, it has fundamentally changed its outlook over the past decades. At present it entertains close connections both with the formal sciences, giving rise to computational linguistics, and with psychology, resulting in the joint venture of psycholinguistics. The recent efforts to link psycholinguistics and cognitive

neuroscience hold considerable promise for the definitive understanding of language and language use, the most complex cognitive skill of all.
Finally, the neurosciences have made unprecedented progress in their understanding of the development and functioning of the brain, in terms of genetics (genomics), molecular processes (over the entire range from gene expression to signal transduction at the synaptic level), and complex behavioral mechanisms. This was greatly facilitated by huge advances in experimental and analytical techniques (neuro-imaging, artificial neural networks, non-linear dynamics, among others). Although it took some time before these results began to make a mark on the other cognitive disciplines mentioned, their impact is now spreading rapidly, fundamentally affecting the 'received views' of such fields as neuropsychology and psycholinguistics.
Indeed, the development, during the last twenty years, of tools that allow the visualization of brain activity in direct relation to cognitive processes has revolutionized research at the interface between brain and cognition. The importance of what the cognitive sciences have achieved in the past fifty years is immediately clear when one realizes that *all* of the following topics have blossomed only after 1950 or even (much) later:

- problem solving considered as a form of heuristic search;
- the bounded rationality of choice and decision making;
- artificial neural networks and autonomous agents;
- functional genomics of normal and abnormal behavior;
- the computational complexity of the brain;
- neuro-imaging in real time of the intact brain;
- the nature of short- and long-term memory;
- generative grammar and the development of language.

This inventory is by no means complete, but it should bring home the fact that, if some thoughtful person or institution of authority would establish a major prize for Cognitive Science – comparable in status to the Nobel Prize, or the Kyoto or Heineken Prizes – a jury would have a good number of ground breaking discoveries and inventions to choose from, all made during the past 25 years. Some recipients of existing awards *did* in fact receive them for their work as cognitive scientists, among them Herbert Simon, David Hubel, Torsten Wiesel, Konrad Lorenz and Nico Tinbergen (all Nobel laureates), Noam Chomsky and Anthony Hoare (Kyoto Prize), and recently Eric Kandel (Heineken and Nobel laureate of the year 2000).

## 2.4 Unification: How far and at what price?

In contrast to marked tendencies towards specialization in science, the spontaneous convergence of such traditionally disparate disciplines as neurobiology, psychology, linguistics, anthropology, computer science and philosophy stands out as a quite unique development in the dynamics of science. As a result of this spontaneous display

of synergy between these, and other, constituent disciplines, rapid progress has been made towards the paradigmatic independence of the cognitive domain. In the opinion of the PPC, this is a development that the Special Program must explicitly support. This remarkable convergence has tempted some to believe that in the not too distant future a monodisciplinary, unified Cognitive Science will emerge. This, however, is not the opinion of the PPC and it should not be a driving motive behind the proposed Special Program. In the natural sciences too, a considerable degree of conceptual and methodological convergence prevails, and yet they are not usefully conceived of as a unified Natural Science. The committee expects the cognitive sciences to reveal a similar convergence, without unnecessary and unproductive claims to unification. If we continue to speak of unification it should be on the understanding that scientific explanation requires several independent levels of discourse, each with its own *irreducible but complementary* 'language of mind'.[10] Unification on the basis of these levels, by defining in what ways they complement each other, is a realistic objective for the cognitive sciences. It allows the rational and computational aspects of knowledge and communication to be connected with the (neuro)biological architecture and the (neuro)psychological analysis of cognitive function.

## 2.5 The conceptual core of the cognitive sciences

In the course of the past 50 years a substantial methodological and technical agreement has been reached with respect to many of the conceptual bricks and boulders that, together, make up the building of the cognitive sciences. Figure 1 illustrates the special position occupied by four 'corner stones', each of which represents a fundamental quality of the object of study:

- neural function (neurocognition, functional genomics, molecular processes and brain-functional imaging);
- communication (linguistic and non-linguistic interfaces between agents);
- computation (complexity and representation);
- action control (goal-directed behavior in natural and social environments).

The first of these is primarily focused upon by the neurosciences and other branches of biology and biophysics. The second is the 'home territory' of communication theory and linguistics, but also involves parts of anthropology, the social sciences and the humanities). Complexity and representation are primarily dealt with in computational and dynamic systems theory, logic and artificial intelligence. Finally, action control ('unconscious' as well as 'deliberate'), is covered most extensively by cognitive and social psychology and, again, artificial intelligence.

[10] The philosopher Dennett has influentially proposed three such levels or 'stances', called the physical, design, and intentional stance respectively. See, e.g., D.C. Dennett (1978), *Brainstorms.* Hassocks, Sussex: Harvester Press.

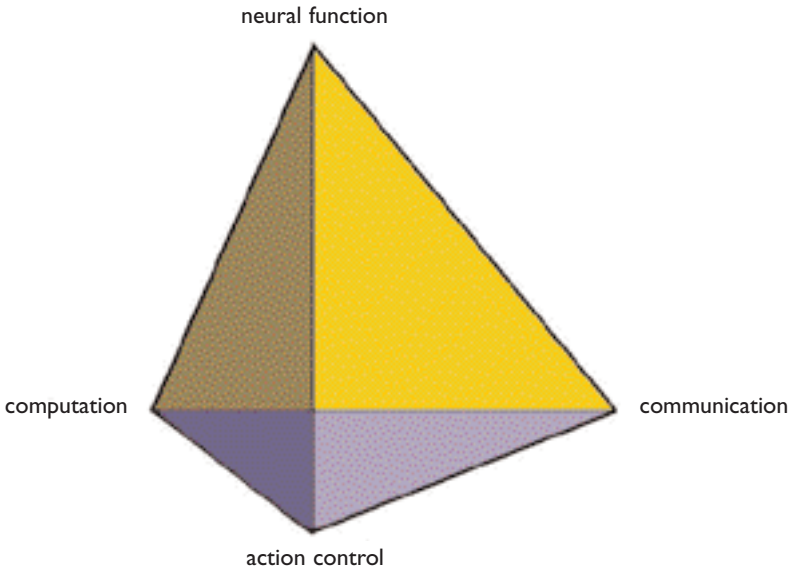


**Figure 1 – The conceptual core of the cognitive sciences**

Each corner of the tetrahedron in Figure 1 represents one of these central theoretical concepts. For each of its edges and sides cross-disciplinary concepts may be identified that are shared by two or more of the basic perspectives. It is in these intersecting areas that we expect the 'fruits of enlightenment' to ripen. The Special Program should preferentially stimulate thematic choices that invite cross-disciplinary collaboration. Relevant examples are not difficult to find: the extension of psycholinguistics – itself already a joint venture of linguistics and psychology – towards neuro-psycholinguistics comes readily to mind. And so does the computational treatment of neural functioning in relation to the control of complex behavior.

Altogether the volume of the tetrahedron in Figure 1 summarizes the interdisciplinary approach to the central questions about knowledge, intelligence and consciousness (self-awareness). Evidently this representation overlooks much detail. It overlooks, for instance, the fact that, in spite of all convergence, there is still abundant use of widely divergent terminology. The PPC is of the opinion that a serious attempt to settle at least some of these conceptual disputes, will greatly benefit the quality and cross-disciplinary coherence of the Special Program. For this reason theoretical and methodological issues should receive ample consideration within the program's context.

# 3 The Cognitive Sciences in the Public Arena

## 3.1 The cognitive revolution in society

Society is rapidly trading its traditional labor-driven production economy for a knowledge-driven service economy. In order to cope adequately with the ensuing demographic, environmental and economic challenges, the development of 'smart' systems that transfer knowledge reliably and independently and that learn from experience, has considerable urgency.[11] While this creates more opportunities to deploy knowledge effectively, the risk of errors, with potentially far-reaching consequences, increases correspondingly. This combination of potential and risk is evident in every social sector where new information and communication technologies are playing a role: in science, law and politics, health care, manufacturing, service industries, data management, transport, etc. Policies for managing such processes must be grounded in a detailed understanding of the relationship between human beings as natural information processing systems (individually as well as collectively in organizations) on the one hand, and artificial information processing systems on the other.

## 3.2 Why society needs the cognitive sciences

The cognitive sciences have already had a substantial impact, but for the general public this has gone largely unnoticed. To a considerable extent this is the result of the unchecked introduction – largely on the basis of their (expected) market appeal – of fragmented bits of information and communication technology. This has resulted in a very uneven distribution of resources for research and development. The PPC is of the opinion that the Special Program should raise awareness of the significance of the cognitive sciences among the general public and their representatives, politicians and public administrators. It should not be too difficult, for instance, to point out that basic research in the cognitive sciences will eventually pay off in terms of 'really smart' applications. One way to improve visibility is directly through the media. Another way is to place (parts of) the Special Program in the context of prominent social issues, such as robotics, knowledge management, education, public safety, or health. Required is, in any case, a thorough understanding of the needs and beliefs regarding such matters among the public at large.[12] By way of example, we briefly review three areas, mentioned by the OCV Verkenningscommissie Cognitiewetenschappen, in which such 'cognitive issues' are abundantly manifest.[13]

11 See P. Lyman & H. R. Varian (2000). *How much information?* The report is available at *www.sims.berkeley.edu/how-much-info/*.

12 See B. Reeves & C. Nass (1996). *The media equation.* Cambridge: Cambridge University Press.

13 A more detailed review can be found in the *De Kennisraffinaderij,* the final report of the OCV Verkenningscommissie Cognitiewetenschappen (1997).

### (a) Human-Computer Interfacing

In today's society the points of contact, the 'interfaces', between humans and machines are increasing rapidly in number, diversity and complexity. At present the most important direction in information and communication technology appears to be that of digital multimedia communication. This development will certainly create new professions and add new dimensions to existing professional skills. New interfaces are being created continuously for the storage and preservation of knowledge in artificial memories such as computers. Humans are not good at memorizing the type of material that can easily be stored digitally. Artificial memories, on the other hand, lack selectivity. In order to access artificial memories more intelligent navigation and mining tools need to be developed. In robotics issues of agent autonomy and human-robot interfacing urgently require innovative solutions. Such issues emerge at the crossroads of information technology and cognitive science, especially as they must be designed specifically with human cognitive abilities and limitations in mind. The convergence between knowledge systems and the context in which they are to operate, engages social and cognitive processes that have not been studied in any great detail.

### (b) Education and training

Today's educational systems, especially the earlier stages, do not adequately tap the didactic potential of the new communication and information technology. Involving cognitive scientific expertise in the development of educational programs would definitely increase their quality and effectiveness, and consequently help to avoid costly failures. There are very good reasons to shift attention from educational ideology to the establishment of an integrated long-term vision, one that concerns the desired cognitive outcomes of the educational process and how they can be taught. Altogether there is a considerable potential for a focused application of cognitive theories to issues of education and training. A particularly relevant line of research follows from the observation that communication and information technology is leading to a further individualization of the educational system. Replacing ready-made with tailor-made education requires a much better insight into cognitive capacities and limitations of children than is currently available. New communication and information technology is also of vital importance to the education of children and adults with mental, motor or sensory handicaps.

### (c) Quality of life

The cognitive sciences contribute substantially to the quality of life. In the near future two developments in particular will drive this contribution. The first is aging. In the absence of advances in treatment and rehabilitation methods, afflictions such as Alzheimer's or Parkinson's disease and stroke, threaten to put an ever-greater demand on the resources for health care. Effective screening and (early) therapeutic interventions that optimally use the tremendous plasticity of the brain, should therefore lead to significant cost reduction in the cost of health care. The second development is

society's increasingly knowledge-intensive nature. This makes it increasingly difficult for someone with a cognitive handicap such as aphasia or dyslexia to function in society. The treatment of such handicaps is as yet insufficiently informed by current cognitive neuroscientific insights, as is the development of 'smart' aids to support the disadvantaged. A third important line of research in the area of health care and well being is the study of the emotional, neurophysiological and developmental determinants of cognition. This includes, among other things, research on stress and stress management, and research into the etiology, prevalence and treatment of major neuro-psychiatric conditions characterized by disorders of cognitive function.

# 4 A Research Agenda

## 4.1 Challenges, priorities and justification

In this chapter the PPC considers the thematic content of the Special Program. Section 4.2 identifies the long-term challenges for the cognitive sciences that have guided the selection of what the committee considers to be relevant and promising research priorities. Presented in Section 4.3 are the short-term priorities; they should assist the research community to find a suitable balance between the general and the specific, the local and the international, and between the fundamental and the practical. Also, the committee has opted for topics that invite a cross-disciplinary approach, so as to stimulate the active participation of the various cognitive disciplines.

## 4.2 Challenges: The long-term perspective

The cognitive sciences are facing at least three major conceptual challenges. The first deals with the theoretical questions concerning the fundamental laws of knowledge and intelligence, both in the formal sense and as constrained by their physical or virtual modes of embodiment. The latter leads to the second challenge, the question namely, how knowledge is acquired, stored and used in individual, social and cultural contexts. The third challenge amounts to the application of what we are learning about knowledge and intelligence, especially where the design and use of intelligent artifacts is concerned. The two key issues – what knowledge is and what intelligence – are related to the even more fundamental question what information is. It may be argued that the central tenet of the cognitive sciences is captured simply by the relation *Knowledge* = *Information* + *Intelligence*, and that sorting out the details of this relation constitutes the principal challenge for these sciences.

At present there appear to be two inroads to this quest: natural cognition and artificial cognition. These have become accessible as the result of the advances in neurocognition and the computational approach over the last half-century. Over most of that period these developments took place in relative isolation. Only during the last decade or two there has been a substantial *rapprochement*. The Special Program anticipates a serious further step towards the integration of these lines of research.

### (a) Natural Cognition

For most of the 20th century it remained difficult to develop a precise understanding of the neurophysiology of the mind. As happens so often in science, it was necessary for new tools to become available to open wider perspectives in this field. Among the most important developments of recent decades are the non-invasive brain imaging techniques (e.g., PET and fMRI) and the artificial neural networks, that have opened new possibilities for modeling and empirical testing. Similarly, the significance of animal models for understanding human cognition has become increasingly important during this period.

The technical accomplishments in functional brain imaging of the last decades opened up new research possibilities up to the point that a new discipline, cognitive neuroscience, emerged. In this context it is relevant to emphasize that it is now possible to visualize which brain areas are active while a subject is engaged in cognitive tasks, using these modern brain-imaging methods. However we are still far from understanding what these patterns of activity really mean in terms of brain functions. To advance significantly in this field of cognitive neurosciences, it is necessary to integrate these studies of the living human brain with basic neurobiological research aimed at understanding the brain substrates of cognitive processes operating at the level of neuronal networks. In this respect novel possibilities are emerging in the field of functional neurogenomics that may permit a higher degree of specification of such brain mechanisms.

Outcomes from such molecular and functional research are foundational to the more complex issue how an intelligent, 'evolved' processing system can transform these 'raw data' into complex 'meaningful' objects and concepts. This leads to the further question how such a self-organizing system eventually becomes a conscious (self-aware) being. The answer to that question is based on the insight that cognition is embodied and that it did evolve for the control of adaptive action. Any adaptive action is 'situated', that is, closely tuned to its immediate environment or *Umwelt.* The long-term challenge this presents is to establish the precise conditions under which evolution, genetic transmission and expression, development and learning, of individual and social behavior take place.

### (b) Artificial Cognition

The developments in artificial intelligence have shown that it is possible to simulate aspects of cognitive functioning that seem to mimic human performance. This has progressed along several different lines (e.g., rule-based symbolic systems, connectionist networks and autonomous agents), each based on rather different assumptions. Among the theoretical issues that will occupy a prominent place for some time to come is the comparative study of the similarities and dissimilarities of these approaches, in the light of the specific cognitive contexts in which they are supposed to operate. As soon as the digital computer was recognized as a generic symbol-processing system, it became meaningful to think in terms of intelligent action. Over the years such systems have evolved from simple rule-based decision-support systems into adaptive 'agents' capable of analyzing fairly complex situations and of planning their actions. In this domain, the major challenge the cognitive sciences are facing is to gain more insight into the cognitive structures and functions that play a role in the advanced, so-called 'creative', manifestations of human intelligence. This will make it possible to study, for instance, how designers design, composers compose and surgeons surge. Consequently it will improve the methods for teaching these complicated cognitive skills and make their (partial) automation easier to accomplish. A socially relevant consequence of advanced research in computer-assisted cognition is that it is gradually

bridging the gap between individual welfare and collective policy or, more generally, between decisions made by individuals and those made by groups, such as choosing in favor of or against environmental measures or medical treatments.
Autonomous robots that can operate independently in a variety of dynamic environments constitute a major long-term challenge for the cognitive sciences. One of the key questions in this research is how to create robots that are oriented both to their task at hand and to the human-dominated context in which they must operate. As systems of our own design are becoming increasingly intelligent they may eventually develop in ways that are at cross-angles with natural intelligence. Computers not only facilitate or replace tasks, they also create new environments – not necessarily virtual – raising the question how humans can 'stay in touch' under such circumstances.

#### (c) Merging natural and artificial cognition

This breakthrough in the field of human-computer interaction is fundamental, demanding the development of task representations and environments that correspond effectively to the needs and intentions of users. The development of such tasks requires a profound understanding of the higher rational and emotional processes, since convergence problems with computers will be experienced particularly at that elevated level. This work has brought much closer one of the central aims of the cognitive sciences, namely the comparative study of natural and artificial intelligence and the interfacing of the two – not only rationally, one should add, but also emotionally.

### 4.3 Priorities: The short-term perspective

With these long-term considerations in mind, the PPC proposes, in this section, the research agenda for the Special Program. In accordance with the brief received from the NWO Board of Governors, the committee has outlined a number of active areas of cognitive research in which, in the course of the next decade, important and innovative outcomes are expected. This selection is representative of a number of thematic distinctions that do, in fact, cut through the traditional boundaries between the cognitive sciences:

- from neuron to cognition
- unconscious and planned behavior
- communication and situated social action
- organization and use of knowledge.

These are themes of great importance to all cognitive disciplines. They have immediate relevance for most, if not all, of the NWO research areas. They should, therefore, invite genuinely cross-disciplinary research proposals and stimulate a broad conceptual debate. The selected topics also represent actually or potentially strong points of cognitive research in the Netherlands. Finally, the committee has also considered their potential for application, an essential condition for a successful cooperation between

the laboratory and the field. It should be emphasized that this choice of the committee does not rule out alternative themes that show a high promise. Alternative topics should be admissible under the Special Program, when and if the research community can present a convincing case, showing that that their proposal fits the overall framework of the program.

### (a) Neuron to cognition

At present the most noticeable trend in the domain of the cognitive sciences is the emergence of cognitive neuroscience. The recent advances in non-invasive recording and imaging techniques now seem to give empirical access to the whole spectrum of cognitive functions. Eventually, however, this challenge will be met only to the extent that it will be possible to generate plausible formal models of cognitive functioning. Such models should be neuroscientifically grounded and behaviorally relevant. In addition, they should generate experimentally testable predictions. If that path is successfully traveled, we may expect neurocognitive research to generate substantive applications in several fields, first and foremost in health care and general well being. The field of clinical neuroscience is particularly likely to benefit from neurocognitive research, as cognitive deficits are apt to reveal the role of brain systems in, for instance, psychiatric disorders. Mental health researchers, who did play an important role in the development of neuro-imaging techniques such as PET, continue to press for development of novel techniques to address questions on normal and abnormal cognitive brain function.

- **Neural networks.** Among the most prominent achievements of the cognitive sciences is the much-increased understanding of the processes that explain how neurons and neural networks can store information. Artificial neural networks should provide answers to a host of questions concerning complex cognitive functioning as they provide a rigorous, formal means of modeling modularity, multilevel and distributed processing. They also make it possible to test formal assumptions about the meaning and purpose of cognitive functioning to guide the search for neural mechanisms and processes.
- **Behavioral genomics and individual variation.** The definitive map of the human genome will offer unprecedented possibilities for study of the genetic determinants of human behavior. The aim should be to make the findings from the Human Genome Project available for the general study of cognitive functions (intelligence, information processing), and for the study of individual and typological variations in normal and pathological behavior (e.g., substance dependency, aggression or compulsive behaviors).
- **Life span related issues.** It is now possible to obtain a detailed insight in the mechanisms of memory and selective attention, the organization of language and speech and the control of complex behavior, across the entire life

span. At the same time the pathology of such mechanisms is becoming accessible to close scrutiny and intervention. Such issues are definitely of great importance at every station of human life, almost from conception to old age. The developmental aspect of knowledge, how knowledge is acquired over time, currently constitutes a very active area of research. Also aging should be recognized as a towering public challenge that demands a contribution of all and any of the cognitive disciplines. A concerted effort to study aging from the cognitive point of view would satisfy, in the opinion of the committee, all relevant criteria, including that of social relevance.

- **Adaptation and plasticity.** Closely related to the previous topic is neural plasticity, currently one of the most important issues in neurocognitive research. New results clearly show that the plasticity of the adult human brain is much greater than was assumed until recently. Research in this area will increase the insight in the acquisition and retention of complex cognitive skills (e.g., sustained attention and coping strategies). The combination of knowledge about complex cognitive activity and knowledge about the underlying neural architecture will, among other things, facilitate the early diagnosis of degenerative diseases. It will also be important for the diagnosis and treatment of cognitive and behavioral disorders, such as aphasia and ADHD.
- **Neuropsycholinguistics.** When linguists and psychologists first got together in the early 1960s they quickly realized that they were going to have a lasting affair. Now, forty years later, it is evident that establishing the link between psycholinguistics and cognitive neuroscience holds considerable promise. In recent years much progress has been made in the functional analysis of linguistic abilities and the modular architecture of this faculty. The findings from this research should provide guidance to neurocognitive research, which has now reached a level of experimental precision that can now, importantly, follow the real-time course of linguistic phenomena.

### (b) Unconscious and planned behavior

Behavioral control is a central issue in the cognitive sciences. The scientific study of cognition emerged from the consideration of highly rational cognitive activity, such as logical theorem proving and mathematical intuition. On the other hand, more than a century of behavioral research has revealed the astonishing degree to which behavior appears to occur 'unconsciously' or 'automatically', that is, without deliberate control by the agent. Unconscious or automatic action may be purely reflexive, it may develop spontaneously at some stage, or it may be the end of a long and sometimes involved period of training. Each of these routes to smooth, adapted behavior requires a thorough structural analysis of the domain to which the behavior under concern applies. This raises the problem of formally describing that domain in terms of a 'computational theory'. The tools available for formulating computational theories are becom-

ing increasingly sophisticated which, in turn, will accelerate insight in the structural and functional aspects of behavioral control, unconscious as well as conscious. Research on neurological and psychiatric disorders will benefit from experimentally derived models of the mechanisms underlying behavioral control, as they can help to explain the various symptoms associated with mental illness in terms of abnormal handling of information. Conversely, clinical neurocognitive research provides valuable insight into the effects of brain damage on cognitive function, thus contributing to the development of theories on normal brain function much the way neuropsychology has done in recent decades.

- **From perception to action.** At different times in the history of experimental psychology and sensory physiology attempts have been made at the integral study of the sensori-motor loop, inclusive of the external (environmental) part of the loop. Examples are the early theories concerning neural networks (cell-assemblies and perceptrons) and, more relevant for our present concerns, the more recent developments in robotics and distributed processing. Sophisticated research programs are now underway that hold great promise for a coherent description of the information processing cycle in its entirety. Such studies should be guided and supported by detailed results from neurocognitive studies involving brain imaging, as well as from animal models, and even from recent accomplishments in the realm of autonomous robotic agents.
- **Executive control.** Cognitive systems adapt to situations in which they operate. Recently there has been a shift from rule-based (top-down) computational models to a perspective favoring more flexible models that rely only on low-level control functions. This has led to renewed interest for mechanisms that can bring about complex, autonomous behavior under such 'rudimentary' control conditions. This topic should profit considerably from joint ventures with cognitive neuroscience. The time seems to be near to expect the rather piecemeal approach traditionally followed in this area to evolve into a quest for a true 'grammar of action'.
- **Cognitive strategies in transition.** The rapid introduction of information technology is not just causing a change in communication patterns or in the replacement of one conventional skill over another. Radically new cognitive strategies are required for coping with the novel complexities of the environment. An example would be the problems one encounters while navigating a virtual world, especially if the 'laws of nature' in such a world have been manipulated. Here, the domain of information and communication technology on the one hand, and the cognitive sciences on the other, share basic interests. As a result of the push towards multimedia applications and the ongoing miniaturization, instantaneous 'mobile computing' is already in sight. Such new technologies demand fundamental cognitive research leading

to the development of 'smart agents' that can come up with appropriate solutions under unfamiliar circumstances. This includes affective computing that makes it possible to interpret and react appropriately to emotional and motivational aspects of a situation, as well as 'ubiquitous' and 'wearable' computing that will inconspicuously support the user at all times. It should be clear that such questions crucially depend on our insight in human cognition and not on a total technology-driven redesign of intelligence.

### (c) Communication and socially situated cognition

Cognition is not just an intra-individual phenomenon but an inter-individual one as well. This is a direct consequence of the adaptive nature of cognitive functioning; human cognition evolved as a consequence of the social reality of human existence. In the process a number of communicative tools emerged, of which language is the most extraordinary example.

These culturally determined tools serve to overcome the limitations of the individual brain. They are enabled by the complex exchange of information between the members of a team. Research on the biological, psychological and social determinants of socially shared cognition, is of fundamental importance for understanding how a common worldview can arise in a community. The core questions in this area focus on the development of and the individual variations in interpersonal cognition.

- **Social agents.** Socially shared cognition is based on assumptions about the interactions between individual, intelligent agents. The question is under what conditions we can speak of collective intelligence. In this context a social agent is seen as an embodied cognitive system, capable of representing (and acting on) complex socially structured task environments. Such a framework opens up the possibility of analyzing various forms of planned behavior in the joint context of (natural and artificial) embodiment and computation, thus allowing a precise definition of the level of structural complexity of the social environment in which the behavior of social agents is taking place.
- **Situated action.** In recent years the computational approach to cognition has been reproached for neglecting the fact that the behaving organism is 'situated in the real world'. This refers to the oversight, in the early computational models, of the cyclical relation between perception and action. Recent developments in robotics and autonomous systems are taking heed of this objection by treating cognition and action as equivalent.
- **Cultural transmission of ideas.** Increasingly attention is being paid to the processes involved in the transmission of ideas within a culture or even between cultures. Central to this topic is the study of knowledge acquisition in complex environments. Not only does this include education and training in school and professional contexts. It also covers the study of the process of scientific discovery. The acquisition of complex representations is first and

foremost a matter of situated cognitive functioning, but it also relies on a number of mechanisms and processes that have been uncovered under such names as 'naive physics', 'naive statistics', 'representational momentum' and 'perceptual kinematics.' This is a research area that in many respects is still *in statu nascendi*, but that, in principle, has great importance for teaching and education, as well as for disciplines such as cultural anthropology, history (of ideas), philosophy and even law.

- **Motivation and emotion.** The view that cognition is embodied implies that cognition, emotion and motivation are all part of an overall self-regulatory process. In other words, an emotionless cognitive agent would not be smart and rational, but almost totally non-functional. Thus, patients with brain damage affecting their emotional systems are drastically impaired in rational decision making, although their verbal abilities and tested intelligence remain relatively unaffected. Emotion and motivation, with their cognitive concomitants, norms, values and esthetic preferences, are all equally indispensable and inseparable functional parts of a unified self-regulatory system, subserving adaptive action.

### (d) Organizing and accessing knowledge

This theme concerns the most abstract level at which cognition is studied. At the same time, it is most directly related to the humanities (*geesteswetenschappen*) that have traditionally dealt with knowledge in a variety of systematic ways. The cognitive revolution has caused a genuine landslide in the ways of organizing, handling and accessing knowledge. The humanities, like most other scientific disciplines, have profited from these developments at least in the traditional sense that it has become easier to compile large amounts of data, factual and textual, to sort and query archives, and to perform many other conventional 'tricks of the trade' in much more sophisticated ways than they could in the past.

From a more fundamental point of view, the change has been much more dramatic. Linguistic theory and logic are among the disciplines of which theory and methodology have changed almost beyond recognition. The risk of a separation between disciplines that for centuries stayed together would not seem imaginary at all. In view of the unfathomable sediment of wisdom and knowledge deposited in the humanities, and their experience in organizing and accessing that information, makes the active participation of the humanities in the Special Program imperative in the opinion of the PPC.

- **Complexity and learnability.** In this area two major achievements have occurred in the past half-century: the development of a theory of computation and complexity on the one hand and that of the theories of learnability and proof on the other. Together these would seem to provide the mathematical vehicles for the cognitive sciences. A major challenge for the near future is to determine how the two hang together. This is one realistic

objective for unification in the cognitive sciences: not by way of combining separate cognitive disciplines, but by focusing on the common laws and constancies underlying each separate domain of investigation, as steps on the way towards a general theory of learning and memory.

- **(Robotic) models of situated cognition.** The trend to incorporate the 'situated' character of cognition in models of cognition is currently an important and growing field. The importance of this line of research is difficult to overestimate, as it introduces innovative hypotheses and experimental paradigms that may throw a new light on aspects of natural cognition. A variety of approaches have emerged and more is to be expected. Apart from the, by now already 'conventional', neural networks, there are models (and robots) that implement an integrated perception-action cycle. Other approaches are the embodied robots (mobots) developed by Brooks[14] and the various attempts at self-reproduction in relation to a search for complex forms of 'artificial life'.
- **Logical dynamics of cognitive processes.** 'Managing' knowledge is an interplay between the (static) representation and the (dynamic) processing of information. Despite the important theoretical achievements of the last 50 years, an integrative theoretical account that would give us a firm grip on the expressiveness and complexity of 'real' cognition still seems a far cry. It appears, however, that several important steps in the right direction are currently being made. The first concerns fundamental analyses of the exact information that is being transmitted between the actors in a variety of cognitive acts. These include the analysis of belief revision by humans and machines, and the game-theoretical description of action-oriented reasoning and language use. The second step to be mentioned concerns the logical discussion about the heterogeneous character of the various media that are commonly used as information carrier – e.g., alphanumerical or graphic – and their theoretical integration. A third development can be seen in the transition of the early ideas about cognition as a generic aptitude to a more modular, differential conception of cognitive functioning. Until recently most of the work in this trend was empirical for lack of an adequate mathematical foundation. Recently interest in the fundamentals of modular information systems has been growing. A final example is what is known as 'emergent behavior'. Emergent qualities are properties of systems that cannot be predicted on the basis of the properties of or the rules of interaction between the components of these systems. As such they are traditionally considered the 'scandal' of reductionistic theories. Explaining emergent behavior is one of the big challenges in this domain of cognitive research.

14 See, e.g., R. A. Brooks (1999). *Cambrian intelligence.* Cambridge, MA: Bradford Books/MIT Press.

## 4.4 Justification: Theory and method

There are many instances where insufficient concern for the epistemological foundations of a scientific paradigm has held up progress. One serious danger resulting from such negligence is an incoherent 'body of knowledge'. Occurring even in well-established scientific domains such as physics, matters are not different in the cognitive sciences. There is no lack of relevant concepts, perspectives, methods, paradigms and models. The PPC admits, however, that it is much too early for a systematic approach of the cognitive domain as a whole. Consequently the research agenda presented in this chapter must not be considered in the same light as, for instance, *Hilbert's Program* for mathematics.[15] The committee is convinced, however that the Special Program, as envisioned, does present a unique opportunity to initiate a penetrating theoretical and methodological debate. For this purpose the committee proposes to establish a project to analyze the conceptual core of the cognitive sciences (see Section 2.5 above). This project must consider the grounding of theories, models and methods with which to approach, from the different disciplinary perspectives, the fundamental questions about knowledge, intelligence, consciousness, self-organization and embodiment.

15 Since 1931 we know that even Hilbert failed after all.

# 5 Form and Function of the Special Program

## 5.1 Circumnavigating the seven C's

In this chapter the PPC presents an outline for the 'form and function' the Special Program should take. Starting from the objectives as specified in Section 1.3 above and from the thematic priorities as outlined in the preceding chapter, the committee's considerations are essentially a matter of creating a research environment that will make it possible to satisfy the following criteria

- **Conceptual consensus.** The Special Program will stimulate the debate concerning foundation and structure of the cognitive sciences;
- **Coverage.** The Special Program will deal with pertinent empirical questions concerning the long-term challenges defined in Section 4.2;
- **Consolidation.** The Special Program will support the tendency towards conceptual and methodological independence of the cognitive sciences;
- **Cross-disciplinarity.** The Special Program will facilitate relevant cross-disciplinary collaboration;
- **Coherence.** The success of the Special Program will depend on the overall coherence of the program;
- **Commitment.** Participating research entities should endorse the overall form and content of the Special Program as stated in this proposal.
- **Competitiveness.** The Special Program will help the research community to attain and maintain a prominent position at the international level.

## 5.2 Activities

### (a) Theoretical and methodological debate

It is imperative to institute a high-level integrative project to facilitate a proper theoretical and methodological grounding of the program activities through intensive communication between the leaders in the field. This will guarantee an ongoing theoretical debate and a critical *forum* for ideas that are pertinent to the objectives and the research of the Special Program. The project must be carried by a 'focus group' of experts, whose involvement is made possible by offering them part-time sabbaticals.[16] Apart from generating and developing new ideas, the forum will advise on matters concerning the content and the scientific merit of the various program activities.

16 It may be possible to coordinate this activity with the NIAS. Another possibility is to establish a (temporary) center where the participants in the project can meet. One of the universities participating in the Special Program may be interested in providing the required facility.

### (b) Empirical studies

The mainstream of activities will consist of research projects addressing important issues in the cognitive sciences. The principal funding instruments will be substantial collaborative program grants and smaller project grants. The collaborative program grants are intended to stimulate the cooperation of researchers of different disciplines and research schools. The smaller research projects will offer the possibility to researchers of choosing challenging and innovative approaches fitting within the general aims of the Special Program.

### (c) Infrastructural support

Technical and methodological facilities for cognitive research in the Netherlands vary considerably, ranging from reasonable to very good. A general problem is, however, that cutting-edge research in this domain relies on advanced instrumentation of which the running costs are exceedingly high. Moreover, the availability of the equipment for research purposes tends to be low. The Special Program must be so managed as to enable optimal use of the available facilities under reasonable conditions. Rather than providing means for new hardware provisions, however, the Special Program should only facilitate the use of what is already available. The F. C. Donders Institute in Nijmegen, for instance, will be stimulated in its role as a national research facility. This does not exhaust the infrastructural aspects of the support to be provided. The expansion of the cognitive sciences requires additional basic facilities. Illustrative examples of facilities that will have a substantial 'added value' include a *behavioral genomic database* as a means for efficiently linking genetic with behavioral and environmental data, or a standard *battery of cognitive* tests that can measure certain cognitive functions validly and reliably. Requests for such facilities as these may be submitted as integrated parts of proposals within the context of the Special Program, in which case their long term costs and benefits must be explained in detail. In this context the PPC recommends the establishment of a multidisciplinary network of researchers (CogNet), dedicated to the development and constant updating of technical facilities, computer algorithms and models for the acquisition, analysis and interpretation of functional brain images.

### (d) Education and professional training

In the view of the PPC there should be a coordinated graduate curriculum with well-defined entrance and end terms. An important problem is that presently it is far from clear how an appropriate level of coordination between the research schools can be established, given their very limited jurisdictions. It is evident that this is primarily a matter of concern for the research schools. Yet, by stimulating such activities as summer courses and advanced tutorials, the Special Program will contribute to the advancement of the education and professional training of cognitive scientists. In addition the program will encourage dissemination of results by creating opportunities for young researchers to present themselves nationally and internationally.

## 5.3 Selection criteria and procedures

Research proposals must indicate clearly how they will meet the objectives of the Special Program as specified in Section 1.3. That is, their contribution to the scientific understanding of cognition, to the international status of Dutch cognitive research, and to the applicability (not necessarily the application) of the proposed research will have to be explained. A certain latitude in the review process will be required to ascertain that highly innovative research proposals will receive due consideration even if they depart from the mainstream of the Special Program. With this *proviso* the PPC recommends that the criteria include at least scientific quality (including high theoretical and methodological standards and cross-disciplinarity), compliance with the overall stated objectives of the Special Program (clarity of aims and innovative potential), and presence of adequate qualitative and quantitative support for the successful completion of a project.

## 5.4 Funding

### (a) Direct funding

In the opinion of the committee up to about 65 per cent of the program budget may eventually be allocated to relatively comprehensive program-oriented grants and up to about 20 per cent to smaller scale program-related projects. The remaining 15 per cent will have to be retained for activities that specifically serve the purpose of increasing the depth and coherence of the program, including conferences, curricular activities and management overhead. The exact proportions should eventually be determined by criteria of quality and relevance to the objectives of the Special Program. The committee recommends the size of collaborative program grants be of the order of 0.5 – 1 M€. The smaller grants for specific projects and special awards should be of the order of 100 – 250 k€. This implies that in each of these two categories some 7 – 10 grants can be awarded (within the limits of the NWO resources). In principle this could mean that in each of the four main themes 2 or 3 programmatic and an equal number of more specific proposals may be accepted. The committee wishes to emphasize, however, that this is no plea for an egalitarian distribution of means; quality, innovative potential, and cross-disciplinary fertilization should gain the upper hand at all times. The PPC wishes to emphasize that funding projects through the Special Program should not reduce the opportunities for the possibility of submitting research proposals through the regular NWO channels. A diminished likelihood of cognitive projects being granted by the area councils, once the Special Program is underway, would transform the program into a mirage.

### (b) Second party funding

As the program should be developed in close harmony with the relevant academic research schools and a limited number of 'extra-mural' research entities, these should agree to the aims and intentions of the program. They should be invited to acknowledge their commitment explicitly in their plans and proposals. All the same, the

Special Program should remain receptive towards innovative research proposals. Matching, a popular instrument for stimulating research during the 1990's, has outlived its usefulness. Most research schools and comparable institutes have little or no programmatic freedom left. The PPC has considered this matter and has reached the conclusion that new ways need to be found to secure a fertile basis for the program's resources. The PPC recommends that funding by the Special Program should be based on research plans that specify in adequate detail the complementary nature of the resources requested. This should create a form of reciprocity or partnership between applicants and Special Program (viz. the program committee) that is *conceptually* rather than *administratively driven.* This form of support allows more flexibility in the research programs and at the same time, it will provide the program management with better control over the coherence of the program as a whole. In this way the PPC expects to stimulate a substantive participation of the universities and research organizations in the Special Program.

### (c) Third party funding

There are signs that business and industry are increasingly aware of the significance of fundamental research for their own long-term activities. Therefore the committee recommends the institution of a Trust for Cognition. Successful initiatives along these lines have already been taken elsewhere.[17] Private organizations may become members of such a trust by an annual contribution fee (e.g., 50 k€). Membership of the Trust entitles organizations to consult, on a payment basis, scientists working in the program. The Board of the Trust holds one seat in the Steering Committee, which gives it a certain influence in the Special Program. Members will be invited for an annual event in which state of the art presentations are given, and questions and answers from industry and the scientific world can be matched. The Trust can also play an active role in the suggested twinning-projects by bringing young entrepreneurs and scientists together in spin-off programs. The committee suggests that NWO initiate a discussion with VNO/NCW to sound the willingness to play a substantial role in founding such a Trust.[18]

Some European programs may also provide extra means. The committee recommends that the Special Program be tailored to these developments and actively make use of these possibilities. For this purpose the committee suggests that a review be prepared of relevant agencies in at least the European countries. The committee also recommends that serious efforts be made in cooperation with institutions and organizations elsewhere in Europe, to get the cognitive sciences higher on the agenda and the 'knowledge society' to the top of the agenda. Agencies that may be instrumental in

17 The German *Stifterverband,* for instance, is a channel through which large and small companies get involved in various ways in scientific research and in which DFG, the Max Planck Gesellschaft, the Fraunhofer Gesellschaft and other scientific organizations participate (*See www.stifterverband.de*).

18 In line with this proposal the PPC also recommends organizing such an event in June 2001, in order to introduce the Special Program to the Dutch industrial market.

this respect include the ESF (European Science Foundation), ALLEA[19] and the European Commission.
In particular the PPC recommends that NWO approach the Ministry of Economic Affairs for additional funding. This Ministry implements ICT policy. Cognition and applications involving cognition are a central topic for ICT-development as *knowledge processing* represents the ultimate level of information processing. A second source for co-financing from a government department may be found in the Ministry of Transport and Communications. A specific reason for approaching the central government at the ministerial level is discussed in Section 5.7 below.

## 5.5 International collaboration

It should be emphasized that internationally the cognitive sciences in The Netherlands occupy a prominent position. Many of the active research groups entertain close ties with research groups all over the world. There is explicit collaboration in joint projects. Yet, the cognitive sciences offer plenty of challenges and opportunities for extending and improving international ventures. Usually prominent research groups experience little difficulty in establishing and maintaining international contacts. Consequently the PPC is of the opinion that the means of the Special Program should not be allocated directly for communicative purposes. The quality of the Special Program should be such that regular sources of funding for exchange visits, workshops and the like, should be relatively accessible to the researchers involved in the program. Apart from establishing (and maintaining) direct collaborative contacts, it is also important to relate the objectives of the Special Program to those of cognitive research groups elsewhere in the world in order to obtain an appropriate demarcation for the research activities under the Special Program.[20] Much research is already taking place and, when setting up a detailed plan for the Special Program, the question what should be considered the program's 'niche' will have to be answered in at least some detail. In sum, however, the committee is of the opinion that international collaboration has a lower priority than the scientific relevance of a research program, as long as it does reflect an adequate division of labor in relation to the activities of the research community at large.
Not all international collaboration should necessarily be left to the discretion of individual researchers or individual institutes. One way of establishing a context for collaboration is to set up a project with an important, specific long-term goal. Such a project would justify the argument that the scale required for the further development of the cognitive sciences, making optimal use of the present momentum, makes international cooperation imperative. This implies an increase of scale size of at least a factor ten

19 ALLEA is a recent body established by *ALL E*uropean *A*cademies of Science.
20 A list of important programs in foreign countries is presented in Appendix C. This list makes no claim to any degree of completeness.

and it demands an approach that will subsequently force funding agencies to continue support (in order to avoid annihilating capital investments). On the European scale ESA and CERN are successful illustrations of this principle. Developing a reasoned plan for such a long-term effort in and by itself constitutes an argument in favor of concerted action. One of the next programs of the European Commission might suitably incorporate such an endeavor.

### 5.6 Visibility and impact

In a recent publication the director of the Bureau of Social and Cultural Planning (SCP) has signaled a serious lack of interest in science among the general public in the Netherlands. Although this is a depressing finding, the PPC has noticed that books and other media presenting information about consciousness, intelligence and mental activity in general currently attract relatively much attention.[21]

Yet, finding suitable ways of stimulating public interest in the cognitive sciences is not a simple matter. Earlier the OCV Advisory Committee recommended the establishment of an agency to serve as a mediator between the scientific community and the users of cognitive science. On balance the PPC is of the opinion that this task could well be taken on by a national Platform for Cognition. This platform will offer the research community and its principal customers opportunities to discuss their priorities and establish productive modes of collaboration. The platform may also play a central role in tapping external sources for funding. It will be necessary to address different target groups in different ways: politicians and administrators, multimedia specialists, ICT consultants, and the general public have different interests and all invite a different approach. The platform could assume the role of mediator in the communication between the research community and the media. It could take a lead in developing an Information and Cognition 'profile' for the highschool curriculum. Finally the Platform, supported perhaps by the Trust proposed in Section 5.4(d) above, would also seem to be the preferred place to consider more extravagant ways of communicating with the public at large. This might include finding a sponsor wanting to fund a substantial award, establishing a national lottery with substantial prizes, or developing an absolutely irresistible computer game offering a serious cognitive challenge.[22]

[21] Consolation was, for instance, drawn from the book review section of the *New Scientist* (11 november 2000, vol. 168, nr. 2264, p. 55) which observed that "(e)veryone seems to want to read about intelligence, be it artificial or evolved or even collective."

[22] To prevent misunderstandings: the first kind of prize (of let us say, 1 M€) is awarded to cognitive scientists; the second kind (first prize also 1 M€) is paid to the owner of a winning ticket.

## 5.7 The Netherlands as the Brainport of Europe

Recently the Dutch government announced that, in compliance with the European Union's Lisbon-agenda, it will be spending an extra 2.5 Gfl (approximately 1.1 G€) in the year 2001. On top of this sum the government will also provide a tax relief for industry and commerce. Of course the government has in mind its traditional goals – innovation and stimulation of business and industry – but this time it also promised to pay attention to the quality of human capital.[23]

Successful implementation of the Lisbon-agenda should turn Europe into the most innovative and competitive region in the world. Apparently these intentions fit the government's scenario for the 'knowledge society': It suggests a transformation of the Netherlands' traditional position as *Mainport of Europe* to that of *Brainport of Europe*. Unfortunately the technology-driven approach that is characteristic for the way such ideals are pursued is extremely costly. For fear of missing grand opportunities, society spends lots of money, public and private, on technology-driven developments of scientifically and practically doubtful caliber. Recent years have, for example, seen an inordinate amount of 'cash burning' by companies and agencies whose aspirations lost contact with reality. The Special Program should help to clarify this situation so that, in the future at least some of the available money may be used more prudently.

Part of the problem is the attitude among the responsible authorities concerning the adequate scientific foundation of this 'knowledge society'. This attitude reveals a serious disregard for the abilities and limitations of the intended subjects of such a society. Increasingly, negligence for the cognitive demands on operators (and users) is responsible for system failures. Given the complexity of present-day systems, even simple failures may easily turn into disasters on a grand scale. Guiding people safely out of a building on fire is, in the first and foremost place, a matter of understanding what is 'moving' people under such circumstances. Only when that is understood sensible rules and procedures can be developed.

Given the very substantial costs associated with the complexification of society that is inherent in the ever greater reliance on information and communication technology, cognitive scientific research is economically extremely advantageous, and from the point of view of human welfare it is even an ethical imperative.

The PPC recommends that in the proposed contacts with the government (*viz.* the Ministry of Economic Affairs and the Ministry of Transport and Communications) the desirability of substantial funding within the terms of the 'Lisbon-agenda' be strongly advocated.[24]

23 In this context the committee refers to the (applied) Innovative Research Program on Human Machine Interaction (IOP-MMI) initiated by the geovernment. More information is available at the IOP website *www.iop.nl.*

24 For the Special Program a very conservative estimate of such a contribution has been set at 5 million Euros (see Appendix D).

## 5.8 Beyond the Special Program

The Special Program will undoubtedly serve as an incentive for cognitive research in The Netherlands. It should be clear, however, that it constitutes only a modest initial effort at putting the cognitive sciences in The Netherlands more robustly on the map. NWO should therefore ascertain that the Special Program will indeed come *on top* of what is customarily spent on cognitive projects through the regular channels. Furthermore, basic funding over a longer period than the running time of the Special Program will be indispensable. The committee recommends that the option of continued funding be considered well before the termination of this program. The Steering Committee may negotiate such a sequel with the NWO Board of Governors as part of the mid-term evaluation of the Special Program. This also presents an excellent opportunity to determine the nature and extent of a long-term policy that could, for instance, lead to the institution of an NWO Advisory Council for Cognition, as proposed earlier by the OCV Advisory Committee for the Cognitive Sciences.

The need to establish a long-term perspective for the cognitive sciences was already stipulated in the initial memorandum on which the present proposal is based. This memorandum referred to relevant initiatives in Germany, France, Scotland, Japan and the USA. The Japanese Science and Technology Agency decided on a substantial budget increase 'to bring together the life sciences and information sciences. Several prominent universities (e.g., Edinburgh, Indiana, Saarbrücken) already restructured their faculty organization by establishing new faculties for 'Information and Cognition'. A variety of other examples could be added[25], such as the substantial investments that are currently being made in the USA to stimulate the cognitive sciences: California Institute of Technology 100 M$, Harvard University 200 M$, the University of Princeton 200 M$, Johns Hopkins University 213 M$, Massachusetts Institute of Technology 45 M$ for AI and 350 M$ for the McGovern Institute for Brain and Behavior Studies.[26]

25 See the list in Appendix C.

26 On the occasion of the official opening of the McGovern Institute the president of MIT described the mission of the institute as follows: "The new institute's mission is (...) exploration of human learning and communication through interdisciplinary research that encompasses neuroscience, molecular neurobiology, bioengineering, cognitive sciences, computation and genetics. Widely seen as the next new frontier of science, these areas of study have profound implications for human health and quality of life." Source: *http://web.mit.edu/newsoffice/nr/2000/neurorelease.html.*

# 6 Management structure for the Special Program

## 6.1 Overall structure

The domain covered by the cognitive sciences being broad, the program's management structure should reflect this latitude. Since the Special Program has its ramifications in most if not all NWO areas, it requires a coordination and management structure that supersedes the boundaries of the established area councils. The PPC recommends that for this purpose an suitable organization and management structure be set up with a relatively independent Steering Committee and a Program Committee at its core (Figure 2). In the following sections the envisioned structure is outlined. Although the size of the committees is numerically explicit, the PPC acknowledges that there may be good reasons to prefer a smaller number of members, especially for the steering committee.

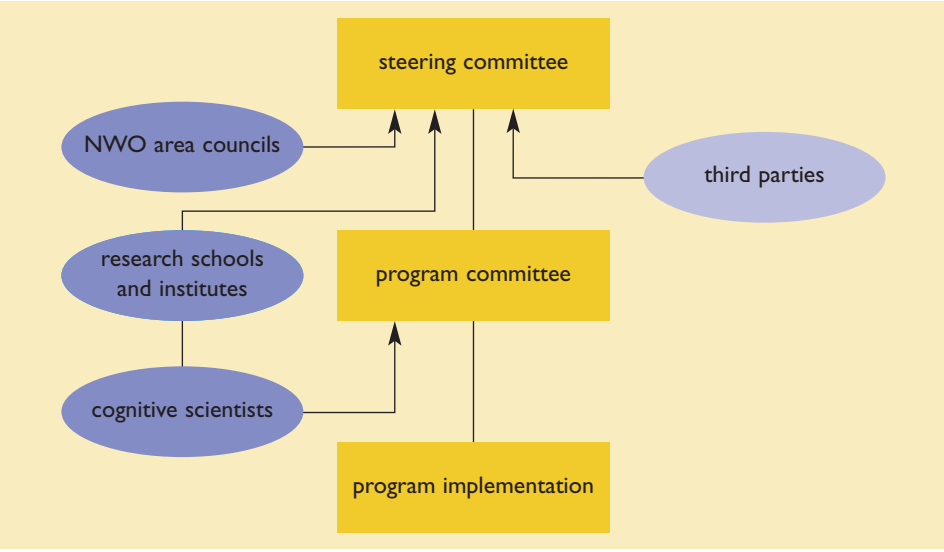


**Figure 2 – The management structure of the Special Program**

## 6.2 The Steering Committee

The Steering Committee is accountable to the NWO Board of Governors. It will consist of five members to be appointed by the Board of Governors of NWO after consultation with the research community, the participating NWO area councils and co-financing entities (third parties). All members must have a senior status in the cognitive domain; their professional backgrounds should reflect the latitude of the domain.

The responsibilities of the Steering Committee include:

- appointing the Program Committee;
- overseeing the proper execution of the Special Program with respect to progress and coherence;
- signaling relevant external developments and bringing the overall goals of the Special Program in line with these developments;
- authorizing funding;
- submitting an annual progress report and budget estimate to the NWO Board of Governors;
- overseeing the mid-term and final external evaluations of the program.

### 6.3 Program Committee

The Program Committee is responsible for the day-to-day coordination and management of the Special Program. The Program Committee consists of prominent cognitive scientists representing different disciplinary backgrounds and affiliations. Their number should be large enough for a satisfactory coverage of the cognitive domain. Two members are nominated by the Program Committee to serve as chair and co-chair. The members of the Program Committee are appointed by the Steering Committee.

The responsibilities of the Program Committee are:

- executing the program in agreement its objectives;
- launching calls for proposals;
- monitoring the judgment and ranking of research proposals on the basis of the agreed criteria by a review procedure that involves international experts;
- monitoring progress and organizing the mid-term and final external evaluation of the program;
- stimulating collaboration between relevant research schools;
- stimulating knowledge transfer to other researchers and potential users;
- prepare the documents for the annual progress report and budget estimate.

### 6.4 Administrative support

The Special Program will have a Secretary, serving both the Steering Committee and the Program Committee. The Secretary will have a background in one of the main cognitive disciplines. The budget for management activities and administrative support should not exceed 5 percent of the program funds.

## 6.5 Evaluation procedure

The Special Program will be evaluated towards the end of its third year and immediately upon completion. The conditions and criteria underlying these evaluations, including the ways of determining whether these conditions and criteria have been met, must be set by NWO at the start of the Special Program. Any revision during the running time of the Special Program must be agreeable to the Steering Committee.

# 7 Conclusions and recommendations

- With this report the PPC has answered the request to formulate a concrete and detailed program proposal meeting the conditions specified by NWO. Both the scientific and the applied perspectives reveal an accelerating growth of the cognitive domain. This justifies the envisioned Special Program. The committee is of the opinion that the program should serve primarily as a means of establishing a thematically focused and coherent range of fundamental research activities.
- The PPC was asked to consider possibilities for systematically obtaining extra funding outside NWO. The committee is convinced that the increasing impact of the cognitive sciences should eventually translate in much larger dedicated funding, beyond the modest scope of the envisioned Special Program. The committee recommends that the option of continued funding into the more remote future be explicitly negotiated with the NWO Board of Governors prior to the termination of this program. Meanwhile, extra funding may be obtained by soliciting applied research, provided that it has a demonstrable added value for the principal research objectives pursued by the program. Establishing a national platform where research community and users can meet to discuss common interests, may present opportunities for obtaining some additional means for basic research. In particular, a Trust in which industrial and other interested entities participate could become a source of additional financial 'backing up'. The PPC also recommends that concerted efforts be made, in close cooperation with research entities elsewhere in Europe, to bring the cognitive sciences higher on the international agenda for the establishment of the knowledge society.
- The PPC was asked to define research themes and to indicate preferences with respect to implementation and project size. The committee has outlined four areas that qualify in terms of the following criteria: (a) clear promise as cutting-edge research, both with respect to content and methodology; (b) appropriate latitude in order to stimulate convergent interactions between disciplines; (c) inter-relatedness in order to contribute to the overall coherence of the research with respect to the long-term objectives of the program; and (d) ramifications for the main fields of application as identified by the committee. Themes that, according to the committee, meet these requirements include the following:

  - from neuron to cognition;
  - 'unconscious' ('automatic') and planned behavior;
  - communication and socially situated behavior;
  - organizing and accessing knowledge.

In each of these major areas a number of relevant topics has been identified that may lead to substantive programs under the Special Program. It is up to the research community to turn these suggestions into proposals that satisfy the criteria of excellence to be set by the Program Committee.

- In addition the committee emphasizes the need for theoretical and methodological activities in order to secure as much as possible the depth and coherence of the program; this requirement may be met by instituting a permanent 'forum debate'.
- In the opinion of the committee a substantial part, perhaps up to 65 per cent of the program budget must be allocated to relatively comprehensive program-oriented grants. Of the remainder some 20 per cent may be allocated to smaller scale program-related projects. The remaining part of the budget should be retained for activities that specifically serve the purpose of increasing the depth and coherence of the program. The latter share would include the management of the Special Program.
- The PPC was asked to make recommendations regarding project management (including criteria and procedures for the selection of research proposals). Recommendations about these issues comprise a simple management structure with an independent Steering Committee with a predominantly supervising task and a Program Committee for actually administering the program. A highly qualified secretary should assist these two committees. Criteria for selecting research proposals include (i) high scientific quality and (ii) relevance for the objectives of the Special Program.
- The PPC has taken initiatives to gain support from the research community with respect to the present proposal. In response to this request the PPC has circulated its draft final report to the research community, specifically to the relevant research schools and to a selection of prominent researchers and science policy authorities. Subsequently a hearing was organized, which took place on 9 February 2001. Contacts with the organization VNO/ NCW and the Department of Economic Affairs and the Department of Education, Culture and Science were being established at the time this report was made public.
- The PPC was asked to delineate the program with respect to other initiatives (including *ToKen2000*). Researchers in the Netherlands are engaged in a good number of international activities. These should be maintained and if necessary stimulated. The growing impact of the cognitive sciences may require considerably increased funds that can only be raised on an international, or at least European, scale. NWO and other institutions and agencies, including the government, must take an active role in supporting initiatives of this nature.
- With respect to *ToKen2000*, the committee is of the opinion that this is a valuable program that should help to advance applications in the domain of

ICT to a higher scientific level. Whilst *ToKen2000* shares some problem areas with the Special Program as proposed, its aims appear to be much more applied. The same can be said of the IOP-MMI program mentioned earlier.

# Appendix A

### Members of the Program Preparation Committee (PPC)

| | |
|---|---|
| Prof. dr. J.A. Michon, chair | Professor emeritus, Leiden University (Psychonomics) |
| Prof. dr. J.F.A.K. van Benthem | University of Amsterdam, Institute for Logic, Language and Computing (Logic) |
| Mw. prof. dr. D.I. Boomsma | Free University of Amsterdam, Faculty of Psychology and Education (Biological Psychology) |
| Prof. dr. P.H.A. Coopmans | Utrecht University, Utrecht Institute of Linguistics OTS (Language Acquisition) |
| Prof. dr. C.C.A.M. Gielen | Catholic University Nijmegen, University Medical Center 'Sint Radboud' (Biophysics) |
| Prof. dr. H.J. van den Herik | University of Maastricht Faculteit of General Sciences, and Leiden University Faculty of Law (Artificial Intelligence, Informatics and Law) |
| Prof. dr. K.L. Leenders | University of Groningen, Faculty of Medicine (Neurology) |
| Prof. dr. F.H. Lopes da Silva | University of Amsterdam, Faculty of Natural Sciences, Mathematics and Informatics, Institute for Neurobiology (Animal Physiology) |
| Prof. dr. P. Luiten | University of Groningen, Faculty of Mathematics and Natural Sciences, and Faculty of Medicine (Molecular Neurobiology) |
| Dr. N.F. Ramsey | University Medical Center Utrecht, Department of Psychiatry (Cognitive Neurosciences) |
| Prof. dr. H.J. Schriefers | Catholic University Nijmegen, Nijmegen Institute for Cognition and Information (Psycholinguistics and Cognition) |
| Prof. dr. G. Semin | Free University of Amsterdam, Faculty of Psychology and Pedagogics (Social Psychology) |
| Dr. ir. P. Zuidema | Computer Management Group (CMG) |

# Appendix B

### Research schools in the field of cognitive sciences in the Netherlands

- Advanced School for Computing and Imaging (ASCI)
- Dutch Graduate School in Logic (OZSL)
- Helmholtz School for Autonomous Systems Research (Helmholtz)
- Graduate School Neurosciences Amsterdam (ONWA)
- Groningen Graduate School for Behavioural and Cognitive Neurosciences (BCN)
- Interuniversity Centre for Education Research (ICO)
- J.F. Schouten Institute for User-System Interaction (Schouten)
- National Research School of Linguistics (LOT)
- Kurt Lewin Institute (KLI)
- Nijmegen Institute for Cognition and Information (NICI)
- Pathophysiology of the Nervous System (PNS)
- Research School Experimental Psychopathology (EPP)
- Research School for Experimental Psychology (EPOS)
- Research School Psychology and Health (P&H)
- School for Information and Knowledge Systems (SIKS)

# Appendix C

## Preliminary inventory of relevant national and international research programs in the cognitive sciences

(Entries in this table are ordered alphabetically by (i) country, (ii) city, and (iii) name).

| | |
|---|---|
| Queensland Institute of Medical Research, Genetic Epidemiology Laboratory | Brisbane, AUS |
| University of Queensland, Department of Psychology/Cognitive Physiology Lab | Herston, AUS |
| Vrije Universiteit Brussel, Artificial Intelligence Laboratory | Bruxelles, BE |
| University of Liège, College of Psychology and Education | Liège, BE |
| University of Zurich, Department of Information Technology, Artificial Intelligence Lab | Zürich, CH |
| BioMag research network | Helsinki, FIN |
| Helsinki University Central Hospital, Department of Neurology/ Helsinki University of Technology, Neurology Department | Helsinki, FIN |
| Helsinki University of Technology, Low Temperature Laboratury, Cognitive Brain Research Unit | Helsinki, FIN |
| University of Helsinki, Department of Psychology, Cognitive Brain Research Unit | Helsinki, FIN |
| CNRS Institut des Sciences Cognitives, Bron | Bron, FR |
| Université de Caen, Cyceron Centre | Caen, FR |
| L'Université de Provence (Aix-Marseille I), CNRS Centre de Recherche en Psychologie Cognitive | Marseille, FR |
| CNRS, Centre de Recherche en Neurosciences Cognitives, Equipe Dynamique | Marseille, FR |
| CNRS, Centre de Recherche en Neurosciences Cognitives, Language and Music Group | Marseille, FR |
| Université Pierre et Marie Curie, Paris, CNRS Institute Neurosciences Cognitive et Imagerie Cérébrale | Paris, FR |
| Collège de France, Laboratoire de physiologie de la perception et de l'action | Paris, FR |
| CNRS Institut de Recherche en Informatique de Toulouse (IRIT) | Toulouse, FR |
| Heinrich Heine Universität Düsseldorf, Zentrum für Anatomie und Hirnforschung | Düsseldorf, GER |
| Max-Planck Institute for Brain Reseatch | Frankfurt/M, GER |
| Max-Planck Institute for Experimental Medicine | Göttingen, GER |
| Universitat Hamburg | Hamburg, GER |
| Max-Planck Institute of Cognitive Neuroscience | Leipzig, GER |
| Max-Planck Institute for Evolutionary Anthropology | Leipzig, GER |
| Neuronord | Magdeburg, GER |
| Otto-von-Guericke Universität Magdeburg, Department of Neurology | Magdeburg, GER |
| Max-Planck Institute for Brain Research | München, GER |
| Universität Osnabrück | Osnabrück, GER |
| Universitat Potsdam, Cognitive Science Department | Potsdam, GER |
| Universität des Saarlandes, Graduate College for Cognitive Science | Saarbrücken, GER |
| Deutsche Forschungszentrum für Künstliche Intelligenz (DFKI) | Saarbrücken, GER |
| Università di Parma, Istituto Fisiologia Umana | Parma, IT |
| Laboratoire de l'IRCCS Santa Lucia à Rome le Laboratorio di Fisiologia del movimento | Roma, IT |
| University of Rome "La Sapienza" Department of Human Physiology and Pharmacology | Roma, IT |
| JAIST, Kanasawa | Kanasawa, JP |
| Institute for New Generation Computer Technology (ICOT) | Tokyo, JP |
| Keio University, Faculty of Letters, Department of Education | Tokyo, JP |
| Karolinska Intitutet, Department of Neuroscience, Division of Human Brain Research | Stockholm, SWE |
| Karolinska Intitutet, Institute of Environmental Medicine, Division of Genetic Epidemiology | Stockholm, SWE |
| University of Birmingham, School of Psychology | Birmingham, UK |
| University of Cambridge , Department of Psychiatry, Addenbrooke's Hospital | Cambridge, UK |
| Human Communication Research Centre (HCRC) | Edinburgh, UK |

| | |
|---|---|
| Edinburgh University School of Informatics | Edinburgh, UK |
| UCL, Institute of Cognitive Neuroscience/Wellcome Department of Cognitive Neurology | London, UK |
| UCL, Institute of Cognitive Neuroscience | London, UK |
| UCL, Sobell Department for Neurophysiology, Institute of Neurology | London, UK |
| UCL, Gatsby Computational Neuroscience Unit | London, UK |
| Kings College London, Institute of Psychiatry, Department of Social, Genetic & Developmental Psychiatric Research | London, UK |
| Kings College London, Institute of Psychiatry, Section of Genetic Epidemiology and Biostatistics | London, UK |
| Oxford University, Farmacology Department | Oxford, UK |
| Oxford University, Department of Psychiatry | Oxford, UK |
| Emory University, Department of Psychology | Atlanta, GA, USA |
| Georgia Institute of Technology, College of Computing/School of Public Policy/ School of Psychology | Atlanta, GA, USA |
| Johns Hopkins Department of Cognitive Science | Baltimore, MD, USA |
| Johns Hopkins Hospital, Division of Child and Adoloscent Psychiatry | Baltimore, MD, USA |
| University of California, Psychology Department | Berkeley, CA, USA |
| National Institute of Mental Health, Laboratory of Brain and Cognition | Bethesda, MD, USA |
| Clinical Brain Disorders Branch, IRP, NIMH, NIH, Bethlehem | Bethesda, MD, USA |
| Lehigh University, Departments and Programs of: Cognitive Science, Psychology, Philosophy, Biology, Counseling, and Computer Science | Bethlehem, PA, USA |
| Indiana University, Department of Psychology and Program in Cognitive Science | Bloomington, IN, USA |
| Boston University, Laboratory of Cognitive Neurobiology | Boston, MA, USA |
| Boston University, Department of Cognitive and Neural Systems (CNS) | Boston, MA, USA |
| University of Colorado, Institute for Behavioural Genetics | Boulder, CO, USA |
| Harvard University, Department of Psychology | Cambridge, MA, USA |
| MIT, Department of Brain and Cognitive Science | Cambridge, MA, USA |
| MIT, Department of Biology/ Center for Learning and Memory | Cambridge, MA, USA |
| MIT, McGovern Institute for Brain Research | Cambridge, MA, USA |
| Southern Illinois University, Life Sciences II, School of Medicine, Department of Psychology | Carbondale, IL, USA |
| Duke University, Center for Cognitive Neuroscience | Durham, NC, USA |
| University of Florida, College of Medicine | Gainesville, FL, USA |
| Dartmouth College, Center for Cognitive Neuroscience | Hannover, NH, USA |
| University of Iowa, College of Medicin, Department of Neurology | Iowa City, USA |
| University of Iowa, Mental Health Clinical Research Center | IOWA, IA, USA |
| University of Southern California (USC) Neurobiology Faculty | Los Angeles, CA, USA |
| UCLA, Department of Neurology | Los Angeles, CA, USA |
| UCLA, Cognitive Science | Los Angeles, CA, USA |
| University of Wisconsin-Madison, Center for Neuroscience | Madison, WI, USA |
| Tufts University, Center for Cognitive Studies, Medford/Somerville | Medford, MA, USA |
| Wesleyan University, Department of Psychology | Middletown, CT, USA |
| University of Minnesota, Department of Psychology, Minnesota Center for Twin and Adoption Research | Minneapolis, MI, USA |
| University of Minnesota, Department of Psychology | Minneapolis, MI, USA |
| Yale University, School of Medicine, Section of Neurobiology | New Haven, CT, USA |
| The Sackler Institute for Psychobiology, Medical College of Cornell University, Department of Psychiatry | New York, USA |
| Columbia University, Center for Neurobiology and Behavior | New York, USA |
| New York University, Center for Neural Science | New York, USA |
| California Institute of Technology (CalTech), The Sloan Center for Theoretical Neurobiology | Pasadena, CA, USA |
| California Institute of Technology (CalTech), Beckman Institute | Pasadena, CA, USA |
| California Institute of Technology (CalTech), Department of Biology | Pasadena, CA, USA |
| UPENN Research Institute for Cognitive Science (IRCS) | Philadephia, PA, USA |

| | |
|---|---|
| Carnegie Mellon University, Department of Psychology | Pittsburg, PA, USA |
| Princeton University, Center for the Study of Brain, Mind and Behavior | Princeton, NJ, USA |
| Viginia Commonwealth University, Department of Human Genetics, Virginia Institute for Psychiatric and Behavioral Genetics | Richmond, VA, USA |
| University of Rochester, Computer Science Department | Rochester, NY, USA |
| The Neurosciences Institute | San Diego, CA, USA |
| The Salk Institute for Biological Studies | San Diego, CA, USA |
| UCSD, Department of Psychology | San Diego, CA, USA |
| Washington University in St Louis, Psychology Department | St. Louis, MO, USA |
| Washington University in St Louis, Department of Neurology | St. Louis, MO, USA |
| Washington University in St Louis, Psychiatry Department School of Medicine | St. Louis, MO, USA |
| Stanford University, Psychology Department | Stanford, CA, USA |
| Stanford University, Cognitive Science | Stanford, CA, USA |
| Stanford University, Linguistics Department | Stanford, CA, USA |
| Stanford University, Computer Science | Stanford, CA, USA |
| University of Illinois, Beckman Institute | Urbana, IL, USA |
| NIMH Neuroscience Center, St. Elizabeths | Washington, DC, USA |

# Appendix D

## Budget estimates for the Special Program

**Table 1 – Provisional budget estimate in millions of Euros (M€)**

| | Total | NWO | Research Schools | Government Agencies | Industry and Others |
|---|---|---|---|---|---|
| forum | 1.0 | 1.0 | | | |
| program grants | 20.0 | 8.5 | 4.0 | PM | PM |
| project grants | 5.5 | 2.0 | 2.0 | | |
| international | 1.0 | 1.0 | | | |
| networks | 1.0 | 0.5 | 0.5 | | |
| program management | 1.0 | 0.7 | | | |
| **Total** | **29.5** | **13.7** | **6.5** | **5.0** | **4.3** |

**Table 2 – Annual expenditure of NWO budget for grants in millions of Euros (M€)**

| Year | 1 | 2 | 3 | 4 | 5 | 6 | Total |
|---|---|---|---|---|---|---|---|
| **Annual Expenditure** | | | | | | | |
| forum | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | | 1.0 |
| program grants | 1.6 | 2.0 | 1.8 | 1.6 | 1.0 | 0.5 | 8.5 |
| project grants | | 0.5 | 0.5 | 0.6 | 0.2 | 0.2 | 2.0 |
| international | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | | 1.0 |
| networks | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | | 0.5 |
| program management | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.7 |
| **Total** | **2.3** | **3.1** | **2.9** | **2.8** | **1.8** | **0.8** | **13.7** |

# Appendix E

**List of acronyms used in this report**

| | |
|---|---|
| ADHD | AttentionDeficit/Hyperactivity Disorder |
| ALLEA | All European Academies of Science |
| CERN | Centre Européen de Recherche Nucléaire (European Laboratory for Particle Physics) |
| ESA | European Space Agency |
| ESF | European Science Foundation |
| FMRI | functional Magnetic Resonance Imaging |
| ICT | Information and Communication Technologies |
| IOP-MMI | Innovatiegericht Onderzoeksprogramma Mens-Machine Interactie (Innovation-oriented Research Program on Human-Machine Interaction) |
| MIT | Massachusetts Institute of Technology |
| NWO | Nederlandse Organisatie voor Wetenschappelijk Onderzoek (Netherlands Organisation for Scientific Research) |
| OCV | Overlegcommissie Verkenningen (Steering Committee for Research Surveys) |
| PET | Positron Emission Tomography |
| PPC | Program Preparation Committee (Programmavoorbereidingscommissie) |
| SCP | Sociaal-Cultureel Planbureau (Netherlands Social and Cultural Planning Bureau) |
| ToKeN2000 | Toegankelijkheid en Kennisontsluiting in Nederland 2000 (Accessibility and Knowledge Retrieval in the Netherlands 2000) |
| VNO/NCW | Verbond van Nederlandse Ondernemingen/Nederlands Christelijk Werkgeversverbond (Confederation of Netherlands Employers) |
| VSNU | Vereniging van Samenwerkende Nederlandse Universiteiten (Association of Cooperating Universities in the Netherlands) |