BICA

Biologically-Inspired Cognitive Architectures

Proposer Information Pamphlet (PIP)

for

Broad Agency Announcement 05-18

Defense Advanced Research Projects Agency
Information Processing Technology Office
3701 North Fairfax Drive
Arlington, VA 22203-1714

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1 PROGRAM OBJECTIVE

The goal of the Biologically-Inspired Cognitive Architectures Program via this BAA is to develop, implement and evaluate psychologically-based and neurobiologically-based theories, design principles, and architectures of human cognition. In a subsequent phase, the program has the ultimate goal of implementing computational models of human cognition that could eventually be used to simulate human behavior and approach human cognitive performance in a wide range of situations.

2 BACKGROUND & MOTIVATION

The traditional approach to machine intelligence pursued by the Artificial Intelligence (AI) community has provided many achievements, but has fallen short of the grand vision of integrated, versatile, intelligent systems. Revolutionary advances may be possible by building upon new approaches inspired by cognitive psychology and neuroscience. Such approaches have the potential to help us understand and model significant aspects of intelligence thus far not attained by classic formal knowledge modeling technology. This program seeks to advance the design and development of computational models of human cognition based on architectures using both approaches.

During the past 15 years, intensive research in neuroscience, enabled by advances in experimental techniques and instrumentation, has led to substantial progress in our understanding of the brain's physical structure and function. It is now feasible to develop cognitive architectures, rooted in neuroscience, which may offer important insight into the understanding and modeling of human cognition.

At that same time, cognitive psychologists have continued to develop increasingly robust computational theories and architectures based on modeling the functions of human cognition (e.g., perception, memory, learning, decision making, and problem solving) at a high level. Many of these psychologically-based models of cognition, such as ACT-R, SOAR, and others, have demonstrated impressive simulations of human-like cognitive behavior. While these models have captured significant aspects of perceptual processing, semantic and procedural memory, skill acquisition and problem solving, they need to be extended, improved, and perhaps redesigned to cover the full range of human cognition.

This program seeks to take a fresh look at the design (in Phase 1) and implementation (in Phase 2) of architectures of human cognition. Revolutionary new ideas and technology to enhance learning performance is especially of interest. This program seeks to make a dramatic leap in learning by machines through new theoretical work, design of integrated architectures, and ultimately the implementation and evaluation of advanced cognitive models. For purposes of this program, learning is regarded as "organizing data for creative and adaptive uses."[1] Thus the result of learning is the ability to deal effectively with new and novel situations. The vision guiding this program is excellent support for a broad range of military applications via breakthrough performance of intelligent machines.

3 SCOPE

3.1 Phasing

This program consists of 2 phases. This BAA is for Phase 1 only, which will span 13 months. The objective for Phase 1 is to produce and assess specific cognitive architectures based on cognitive psychology and neuroscience. In addition, cognitive challenge problems will be developed in Phase 1 that will be used for evaluation during Phase 2. The objective of Phase 2 is to implement and evaluate several of the architectures produced during Phase 1. Phase 2 will be procured under a separate, future BAA.

3.2 Organization

The program solicits research contributions drawn from all applicable fields, particularly cognitive psychology and cognitive neuroscience. As shown in Figure 1, Phase 1 of this program is divided into three parallel thrusts.

- Thrust A - this thrust seeks to make dramatic advances in the breadth and performance of cognitive models based primarily on modeling the functional psychological components of cognition. Examples of such psychological components include short-term, episodic, procedural, and semantic memories.
- Thrust B - this thrust seeks to develop neurobiologically-inspired (neuromorphic) theories, designs, and resulting architecture(s). These would include sets of neuromorphic design principles, descriptions of important neural computations and mechanisms, and a mapping of the brain's functional and representational features across its structure.
- Thrust C – this thrust seeks development of a framework for testing and evaluating subsequent implementations of the cognitive architectures created in Thrusts A and B. We envision the development of two test batteries: first, a *cognitive decathlon* for assessing specific skills associated with cognition (e.g., visual perception, memory); and second, a set of *challenge problems*, each of which will require a complex range of cognitive functions in order to be successfully negotiated. Thrust C performers will be independent of other performers.

Each of these thrusts is discussed in detail in Section 4, below.

Within each thrust, we anticipate three sequential tasks. As shown in Figure 1, each task will be uniquely identified by its thrust and sequential number. (Example: Task A1 refers to the first task in Thrust A.) Within each thrust, task 1 will have a duration of six

[1] With appreciation to Howard Eichenbaum, Boston University for suggesting this definition.

months. Task 2 – a series of technical exchange meetings common to all thrusts – will span a period of about one month. Task 3 will have a duration of six months. Thrust A and B research teams may participate in Tasks 1 and 2 or Tasks 1, 2, and 3 as appropriate. Thrust C research teams may participate in Tasks 1 and 2, 2 and 3, or 1, 2, and 3.

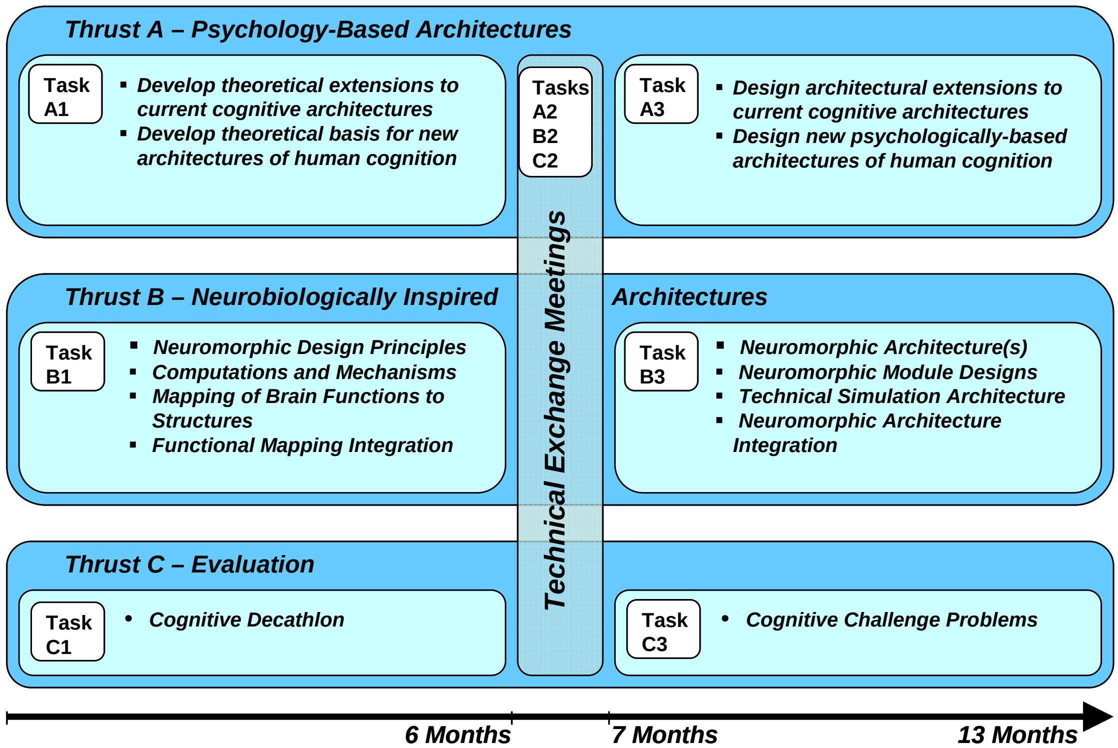

Figure 1. Organization of Program Phase 1

Throughout the program, it is DARPA's intent to promote scientific exchange among and between highly specialized research teams working in cognitive psychology and cognitive neuroscience. At the midpoint of Phase 1 we plan a series of technical exchange meetings among participants within each thrust, as well as, across the thrusts.

Representatives from all teams must participate in Task 2 technical exchange meetings. We expect that these meetings will be held in the Washington, DC area. We plan for a technical exchange of results obtained in Tasks A1, B1, and C1. We anticipate publishing a proceedings based on meeting presentations.

3.3 Awards

The dollar amount of awards will be determined by the quality of proposals and funds available. Staff years below are shown to only to illustrate the relative emphasis among the different program elements. DARPA reserves the right to modify the size and composition of the Phase 1 awards, based upon the merits of the proposals received.

Offerors may propose against Thrust A, Thrust B, or a combination of the two. Within Thrust A or Thrust B, offerors may propose Tasks 1 and 2 or Tasks 1, 2, and 3. As outlined in Section 4, teams performing Tasks 1, 2, and 3 should anticipate more theoretical work in Task 1 and more design work in Task 3. All performers must participate in the Task 2 technical exchange meetings.

Because Thrust C involves the evaluation framework, we will not award a Thrust C contract to a performer awarded a Thrust A or B contract.

The architectures and challenge problems developed in Phase 1 will serve as the basis of the Phase 2 procurements. There shall be no intellectual property rights precluding the publication of Phase 1 results as part of the Phase 2 solicitation.

Thrust A

Task A1 - DARPA anticipates a number of six-month awards for the theory development in Thrust A. We will consider proposals either to develop theoretical extensions to existing cognitive models or to develop a new theoretical basis for novel approaches to modeling human cognition that could be used as the basis for designing complete architectures for human cognition in the second six months. We anticipate that the total funding for the Thrust A theory development task will support about 8 FTEs for 6 months.

Task A2 – Technical Exchange Meetings. See description in Section 3.2.

Task A3 - Similarly, DARPA anticipates one, two, or three, six-month awards for the design of complete, psychologically-based, architectures of human cognition. Please see Section 4.1 for more detail. Again, we will consider proposals either to design extensions to existing cognitive architectures or to design completely new architectures of human cognition. We anticipate that the total effort for the Thrust A architecture development and design task will be about 16 FTEs for six months.

Thrust B

Task B1 - DARPA anticipates a number of six-month awards for the development of neuromorphic theories of cognition in Thrust B. We will consider proposals from knowledgeable experts covering one or more of the major brain functional areas listed in Appendix 1. We also anticipate a separate six-month award for an overarching “integration” effort to compile, analyze and interpret the results from multiple expert submissions. We anticipate that the total effort for Thrust B theory development will be about 8 FTEs for 6 months.

Task B2 – Technical Exchange Meetings. See description in Section 3.2.

Task B3 – Similarly, DARPA anticipates a number of six-month awards for module design and architecture. Please see Section 4.2 for more detail. Again, we will consider proposals from knowledgeable experts covering one or more of the major brain functional areas listed in Appendix 1. We also anticipate a separate six-month award for an overarching integration effort. We anticipate that the total effort for Thrust B module design and architecture development will be about 16 FTEs for 6 months.

Thrust C

We envision awarding one or two contracts totaling about 4 FTEs for 13 months for development of a cognitive decathlon and set of cognitive challenge problems. Offerors may propose against Task C1 or Task C3 or both. All proposals must include participation in technical exchange meetings (Task C2 - See description in Section 3.2.). Teams selected for Thrust C awards will not be selected for Thrust A or B awards.

4 TECHNICAL APPROACH

This program brings together research teams that historically have developed and operated apart from one another. Indeed, the two approaches are sometimes termed “brainless mind” and “mindless brain.” While wishing to make revolutionary progress in each of the two major thrust areas, we also encourage fusion between psychology- and neurobiologically-based approaches. In addition, DARPA wishes to encourage approaches that take into account the role of development and interaction with the environment in "growing" (vice "building") cognitive systems, especially the computational modeling of such processes. DARPA would be happy to entertain proposals for joint or hybrid efforts spanning Thrusts A and B below as well as individual proposals in either thrust area.

4.1 Thrust A - Psychology-Based Architectures:

The objective of this research thrust is the development for comprehensive functional models of human cognition that can be simulated by computer and that exhibit human-like behavior. It is the goal of Thrust A to design computational models of human cognition by modeling functions of the human mind such as (1) perception and attention, (2) learning and memory, and (3) decision making and problem solving. Each functional area will be further decomposed into interrelated sub-elements. For example memory may be subdivided into short-term memory, episodic memory, procedural memory, and semantic memory. There may be separate memory components for visual and auditory imagery. There may be separate subsystems for language understanding and visual-spatial reasoning.

The individual sub-elements will be further defined by mathematical equations, algorithms and/or heuristics that can be employed to simulate each component. These sub-element definitions will have a theoretical or empirical grounding in psychology and justification that they function or perform in a manner similar to humans.

Basic computational models have been developed of numerous aspects of cognition including the recognize-act cycle; working and long-term memory; procedural learning;

goal-driven behavior; and limited, minute-sized tasks and behavior. We seek to extend and scale up these models to a much larger range of more complex behavior by incorporating such elements as episodic memory and learning; enhanced semantic and procedural learning; and integrated models of affect, e.g., emotion. Researchers may choose to extend existing models such as SOAR and ACT-R or propose entirely different models.

DARPA is seeking cognitive models that result in human-like behavior on real world problems that are not merely "toy" problems. As discussed above, we intend to award an independent evaluation contract. During the course of the program, researchers shall interact with the evaluation contractor and propose validation tests for their respective models. Test problems should be recommended for both testing individual cognitive skills (e.g., perception, memory, reasoning) as a part of the Cognitive Decathlon (Task C1) and for testing more comprehensive problem solving as a part of the Challenge Problem Set (Task C3).

Three tasks are envisioned under Thrust A: (1) Theory Development, (2) Technical Exchange, and (3) Architecture Development.

4.1.1 Task A1 - Psychologically-Based Theories of Cognition

Under Task 1, developers will produce psychologically-based theories of cognition covering as broad a range of cognitive activities as possible. It is recognized that some aspects of these initial theories will be "descriptive" rather than computational. Computational approaches for simulation should be described wherever feasible. Aspects or properties of cognition that may influence engineering design and implementation such as hybrid massive parallel (subconscious) and limited serial (conscious) reasoning should also be articulated. Developers will be encouraged to map individual cognitive functions to potential areas of the brain where such cognitive functioning is believed to occur.

4.1.2 Task A2 - Deliver results of Task 1 in Technical Exchange Meetings

DARPA is promoting a series of broad exchanges among researchers across highly specialized theoretical areas to insure that all teams are aware of the progress and findings of parallel efforts.

4.1.3 Task A3 - Computational Architectures

Under Task A3, computational architectures will be defined that embody the theories in a computational form. Complementary teams can be organized that develop comprehensive and unified architectures from component models. As stated previously, the computational architecture can be either a dramatic extension to existing architectures such as SOAR or ACT-R, or can be an entirely new approach.

4.2 Thrust B - Neurobiologically Inspired Architectures

In Thrust B, DARPA seeks a dramatic improvement in our understanding of the brain's functions and processes. Initially, we seek a major leap in the learning performance of traditional AI systems by augmenting and informing their designs with neuroscience principles. Such machines might demonstrate functions such as imagination, social intelligence and/or the anticipation of behavior of other intelligent agents. “Learning” (in the sense of interest in this BAA) involves the intense interaction of three processes: attending, remembering, and reasoning. Because of the highly integrated nature of the brain, learning cannot be viewed separately from other brain activities. In the follow-on phase, we expect to implement a new class of *hybrid* AI systems – using a mixture of psychology-based and neuroscience-based architectures. Our ultimate goal is to approach brain-like performance in learning, use of experience, sensorimotor integration and other complex processes. At the same time we expect to develop a global theory of cognition and one or more neurobiologically-inspired, integrated cognitive architectures.

4.2.1 Task B1 - Development of a Neuromorphic Theory of Cognition.

In this task we seek to integrate research results from the past decade to produce the best possible understanding of the structure and function of the brain. Based on results to date, we expect to find gaps in our understanding as well as competing interpretations of the nature and activities of structures.

The theory of cognition developed under this task will have three primary components:

a. A set of neuromorphic design principles
b. A set of descriptions of important neural computations and mechanisms
c. An allocation (mapping) of the brain’s function and representational features across the brain’s structure

Neuromorphic design principles will be used to guide the design and architecture for follow-on modeling and simulation. These principles should capture the remarkable and – to the digital computer designer, unusual – design features of the brain. Examples of neuromorphic *design principles* include, but are not limited to, the following:

- *Local and distributed circuits*
- *Recurrent loop architectures*
- *Feedforward and feedback connectivity*
- *Multiple representational maps*
- *Iterated modularity*
- *Structural delineation of functional subsystems*

Examples of *computations and mechanisms* might include, among others:

Computations

- *Pattern completion*
- *Feature detection*
- *Prediction error signaling*
- *Coordinate transformations*
- *Receptive field synthesis*

Mechanisms

- *Excitatory and inhibitory transmission*

- *Nonlinear thresholding*
- *Synchronized oscillations*
- *Response adaptation*
- *Timing-dependent plasticity*

Perhaps most important is the *allocation* (mapping) of the brain's function and representational features across the brain's structure. In this task, the program is assembling a global integrated view of the functioning of the brain linked to its structures. The Appendices provide listings of brain functions and structures as a starting point. Performers may add to these lists as they see fit. While valuable in their own right, the products of this task are intended to lay the groundwork for modular designs and architecture to follow in Task B3.

Task B1 Milestones:

- Functional Allocation Completeness: At least 80% of the brain's structures must be mapped to functions. DARPA understands that a consensus may not exist among neuroscientists as to the precise functional role of any given structure. We understand also that achieving 100% mapping would require significant new research in basic neuroscience, which is neither a goal of this program nor feasible within the planned program scope. However, an underlying assumption of this program is that the 80% criterion is a realizable goal given recent achievements in the field of neuroscience, and that in order for a neuromorphic theory of cognition to be truly comprehensive it must incorporate a large majority of the brain's known structures and functions.

4.2.2 Task B2 - Deliver results of Task B1 in Technical Exchange Meetings

DARPA is promoting a series of broad exchanges among researchers across highly specialized theoretical areas to insure that all teams are aware of the progress and findings of parallel efforts.

4.2.3 Task B3 - Development of Neuromorphic Architectures and Designs

Using products of Tasks B1 and B2, DARPA seeks to synthesize a neuromorphic architecture for cognitive simulation of the brain functions identified in Task B1.

Research teams will design the basic processing elements (modules) necessary to implement neuromorphic cognitive simulations which augment performance of traditional AI systems.

At the same time, researchers will develop an appropriate joint *technical* architecture for simulating the modules and their interactions.

A separate team will integrate the designs and technical architecture.

As a byproduct of the designs and architectures developed under Task B3, researchers will identify an initial set of requirements which may be achievable using nanotechnology and other novel technologies.

4.3 Thrust C - Evaluation Framework

Under Thrust C, DARPA is seeking the development of an evaluation framework for the cognitive architectures developed under Thrusts A and B. These evaluations will not be conducted until Phase 2 of the project, which will be covered in a separate, subsequent BAA. However, we would like to develop the evaluation framework for Phase 2, as the architectures are being designed, and with interaction and dialog between the developers and the evaluator.

We envision that two test batteries will be developed: a suite of tests of individual cognitive functions (i.e., the *cognitive decathlon)* and a set of *challenge problems* that would require the integrated use of multiple cognitive functions.

4.3.1 Task C1 - Cognitive Decathlon

DARPA is seeking the development of a suite of tests (not necessarily 10) of essential cognitive functions in order to evaluate the designs of the cognitive architectures developed in Thrust A and B. This test suite will be used in Phase 2 of the project to evaluate the computational versions of these architectural designs as those architectures are implemented in Phase 2. In this phase, Phase 1, DARPA is seeking proposals to design and develop the suite of tests for the Cognitive Decathlon. We envision a test that will cover the major functions of human cognition: perception, attention, learning, memory, reasoning, decision-making, and problem solving. The exact definition of this test suite will be the responsibility of successful bidders to Task C1, but we envision a suite of tests that would be implemented in a simulation environment, cover the range of major functions of human cognition, and require the cognitive models under test to provide a relatively unified and complete set of cognitive components (and NOT be able to succeed on the test by providing separate, optimized components for each decathlon test).

A wide range of tests of cognitive skills has been recommended over the years. Allen Newell proposed 13 criteria[2] that a human cognitive architecture would have to satisfy. These criteria include, among others, flexible and adaptive behavior, vast knowledge, learning and language ability. Performers under this task must analyze various approaches to defining and measuring cognition and develop a set of criteria like Newell's that are central to cognition. These criteria would lead to the development of cognitive tasks such as recalling an episode from memory, explaining a conclusion or acquiring a problem solving skill. Each task may require one or more essential cognitive functions such as perception, memory, reasoning, etc. For each cognitive task, bidders need to define test procedures and performance metrics for grading architectures and their component functions.

We envision two sets of grading schemes: The first grading scheme is how well each architecture's performance matches human performance. The second scheme is to measure the architectures' absolute performance on each individual test. Similar to a decathlon, individual architectures will perform all the tests but may perform better on

[2] Newell, A. (1990). Unified Theories of Cognition. Cambridge, MA: Harvard University Press

some than others. We believe this “decathlon” will insure that architectures are broad in scope, exhibit human-like behavior and provide reliable measures of research progress.

4.3.2 Task C2 - Deliver results of Task C1 in Technical Exchange Meetings

DARPA is promoting a series of broad exchanges among researchers across highly specialized theoretical areas to insure that all teams are aware of the progress and findings of parallel efforts.

4.3.3 Task C3 - Challenge Problem Set

In Task C3, DARPA seeks a set of ten general cognitive challenge problems for use in comparing and evaluating cognitive simulations. Our goal is to create challenges problems relevant to military situations that will serve this program and others as cognitive simulations evolve. The set of problems must be progressively more challenging, must involve both embedded and non-embedded problems. “Embedded” refers to problems in which an embodied cognitive agent is situated within, and interacts with, a physical environment which, may or may not contain other cognitive agents. Included in each challenge problem definition will be a list of neuromorphic functions that are potentially part of hybrid designs. (That is, computational simulations based on traditional AI system design, but augmented by neuromorphic modules.) At least half of the challenge problems must involve functions in which traditional AI methods have not excelled.

The following examples serve as a starting point:

- Examples of Non-embedded Problems
  - Successfully completing the Ing Challenge (a Go challenge)
  - Beyond playing games
    - Matching the performance of a human analyst/color commentator on
      - Chess matches
      - Military engagements
      - Political campaigns
    - Matching the performance of a human teacher/coach
  - Solving a standard set of “word problems” involving algebra

- Examples of Embedded Problems
  - Successful soccer team play with other robots (or against humans)
  - Successful play in paintball or laser tag with other robots (or against humans)
  - Demonstrate achievement of kindergarten (or grade school) Learning Objectives
  - Successful completion of the DARPA Grand Challenge (autonomous motoring via on-road and off-road waypoints)

The specification of each challenge problem shall detail the initial conditions, the desired level of performance, and metrics to be used for comparing different cognitive simulations.

Task C3 Milestones:

- Challenge Problem Set Diversity: For the chosen challenge problem-set (in the aggregate) at least 33% of the functions must be relevant. This will ensure that our designs are not confined to one functional area, e.g., vision.
- (Jointly with Thrust B Task B1) Functional Allocation Relevance: At least 50% of the brain functions potentially relevant to the challenge problem set must have been mapped to structures. This will ensure that we have substantial usable neuromorphic content for the Phase 2 designers and have achieved an acceptable fit between the mapping and challenge problem definition work.

Offerors may tender proposals for the Cognitive Decathlon (Tasks C1 and C2), the Challenge Problems (Tasks C2 and C3), or both (Tasks C1, C2, and C3). Note that we expect all performers to participate in the Technical Exchange Meetings (Task C2).

5 GENERAL INFORMATION

Proposals not meeting the format described in this pamphlet may not be reviewed. Proposals MUST NOT be submitted by fax or e-mail; any so sent will be disregarded. This notice, in conjunction with the BAA 05-18 FedBizOpps Announcement and all references, constitutes the total BAA.

A Frequently Asked Questions (FAQ) list may be provided. If so, it will be found on the DARPA/IPTO Solicitation page at http://www.darpa.mil/ipto/solicitations/solicitations.htm.

No additional information is available, nor will a formal Request for Proposal (RFP) or other solicitation regarding this announcement be issued. Requests for same will be disregarded.

All responsible sources capable of satisfying the Government's needs may submit a proposal that shall be considered by DARPA. Historically Black Colleges and Universities (HBCUs) and Minority Institutions (MIs) are encouraged to submit proposals and join others in submitting proposals. However, no portion of this BAA will be set aside for HBCU and MI participation due to the impracticality of reserving discrete or severable areas of this research for exclusive competition among these entities.

The Government anticipates that proposals submitted under this BAA will be unclassified. In the event that a proposer chooses to submit a classified proposal or submit any documentation that may be classified, the following information is applicable. Security classification guidance on a DD Form 254 will not be provided at this time since

DARPA is soliciting ideas only. After reviewing incoming proposals, if a determination is made that the award instrument may result in access to classified information, a DD Form 254 will be issued and attached as part of the award. Proposers choosing to submit a classified proposal must first receive permission from the Original Classification Authority to use their information in replying to this BAA. Applicable classification guide(s) should be submitted to ensure that the proposal is protected appropriately.

6 SUBMISSION PROCESS

This Broad Agency Announcement (BAA) requires completion of a BAA Cover Sheet for each Proposal prior to submission. This cover sheet can be accessed at the following URL:

http://www.dyncorp-is.com/BAA/index.asp?BAAid=05-18

After finalizing the Cover Sheet, a BAA Confirmation Sheet will automatically appear on the web page. Each proposer is responsible for printing the Confirmation Sheet and attaching it to every copy. The Confirmation Sheet should be the first page of the Proposal and every copy. If a proposer intends on submitting more than one Proposal, a unique UserId and password must be used in creating each BAA Cover Sheet. Failure to comply with these submission procedures may result in the submission not being evaluated.

Proposers must submit the original and 2 copies (3 total) of the full proposal and 2 electronic copies (i.e., 2 separate disks) of the full proposal (in PDF or Microsoft Word 2000 for IBM-compatible format on a 3.5-inch floppy disk, 100 MB Iomega Zip disk or CD). **Mac-formatted disks will not be accepted**. Each disk must be clearly labeled with BAA 05-18, proposer organization, proposal title (short title recommended) and "Copy ___ of 2". The full proposal (original and designated number of hard and electronic copies) must be submitted in time to reach DARPA by 12:00 PM (ET) Mar 1, 2005, in order to be considered during the initial evaluation phase. However, BAA 05-18, Biologically-Inspired Cognitive Architectures (BICA) will remain open until 12:00 NOON (ET) Jan 17, 2006. Thus, proposals may be submitted at any time from issuance of this BAA through Jan 17, 2006. While the proposals submitted after the Mar 1, 2005 deadline will be evaluated by the Government, proposers should keep in mind that the likelihood of funding such proposals is less than for those proposals submitted in connection with the initial evaluation and award schedule. DARPA will acknowledge receipt of submissions. The acknowledgement receipt (sent via email) will contain a control number that should be used in all correspondence regarding your proposal.

Restrictive notices notwithstanding, proposals may be handled for administrative purposes by support contractors. These support contractors are prohibited from competition in DARPA technical research and are bound by appropriate non-disclosure requirements. Input on technical aspects of the proposals may be solicited by DARPA from non-Government consultants/experts who are also bound by appropriate non-disclosure requirements. However, non-Government technical consultants/experts will not have access to proposals that are labeled by their offerors as “Government Only.” Use of non-government personnel is covered in FAR 37.203(d).

7 REPORTING REQUIREMENTS/PROCEDURES

The Award Document for each proposal selected and funded will contain a mandatory requirement for submission of DARPA/IPTO Quarterly Status Reports and an Annual Project Summary Report. These reports, described below, will be electronically submitted by each awardee under this BAA via the DARPA/IPTO Technical - Financial Information Management System (T-FIMS). The T-FIMS URL will be furnished by the Government upon award. Detailed data requirements can be found in the Data Item Description (DID) DI-MISC-81612A available on the Government's ASSIST database (http://assist.daps.dla.mil/quicksearch/). An outline of T-FIMS report requirements is as follows:

8 PROPOSAL FORMAT

Proposals shall consist of a cover page, a technical volume, and a cost volume. The submission of other supporting materials—including bibliographies, technical papers, and research notes—along with the proposal is strongly discouraged.

A "page" is 8-1/2 by 11 inches with type not smaller than 12 point, and with text on one side only.

8.1 Cover Page

The cover page shall be a single page containing the following information.

1. BAA number
2. Proposal title
3. Lead Organization submitting proposal
4. Contractor's type of business, selected from among the following categories: "WOMEN-OWNED LARGE BUSINESS," "OTHER LARGE BUSINESS," "SMALL DISADVANTAGED BUSINESS [Identify ethnic group from among the following: Asian-Indian American, Asian-Pacific American, Black American, Hispanic American, Native American, or Other]," "WOMEN-OWNED SMALL BUSINESS," "OTHER SMALL BUSINESS," "HBCU," "MI," "OTHER EDUCATIONAL," "OTHER NONPROFIT", or "FOREIGN CONCERN/ENTITY."
5. Other team members (if applicable) and type of business for each
6. Technical point of contact to include: salutation, last name, first name, street address, city, state, zip code, telephone, fax (if available), electronic mail (if available)
7. Administrative point of contact to include: salutation, last name, first name, street address, city, state, zip code, telephone, fax (if available), electronic mail (if available)
8. Total funds requested from DARPA, and the amount of cost-share (if any)

9. Summary of the costs of the proposed research, including total base cost, estimates of base cost in each year of the effort, estimates of itemized options in each year of the effort, and cost sharing if relevant;
10. Date proposal was prepared

8.2 Volume I. Technical

This volume provides the detailed discussion of the proposed work necessary to enable an in-depth review of the specific technical and management issues. Specific attention must be given to addressing both the risk and payoff of the proposed work that make it desirable to DARPA.

The Technical Volume shall not exceed 30 pages, and shall include sections A through J, each beginning on a new page. Maximum page lengths for each section are shown in braces { } below, where applicable.

A. Innovative claims for the proposed research{1 Page}. This page is the centerpiece of the proposal and should succinctly describe the unique proposed contribution.

B. Proposal Roadmap{1 Page}. The roadmap provides a top-level view of the content and structure of the proposal. It contains a synopsis (or “sound bite”) for each of the nine areas defined below. It is important to make the synopses as explicit and informative as possible. The roadmap must also cross-reference the proposal page number(s) where each area is elaborated. The nine roadmap areas are:

1. Main goals of the proposed research.
2. Tangible benefits to future efforts (i.e., benefits of the capabilities afforded if the proposed technology is successful).
3. Critical technical barriers (i.e., technical limitations that have, in the past, prevented achieving the proposed results).
4. Main elements of the proposed approach.
5. Rationale that builds confidence that the proposed approach will overcome the technical barriers. ("We have a good team and good technology" is not a useful statement.)
6. Nature of expected results (unique/innovative/critical capabilities to result from this effort, and form in which they will be defined).
7. The risk if the work is not done.
8. Criteria for scientifically evaluating progress and capabilities on an annual basis.
9. Cost of the proposed effort for each performance year.

C. Statement of Work {3 Pages}. Detailed statement of work, written in plain English, outlining the scope of the effort and citing specific tasks to be performed, references to specific subcontractors if applicable, and specific contractor requirements.

D. Research Objectives {2 Pages}

1. Problem Description. Provide concise description of problem area addressed by this research project.

2. Research Goals. Identify specific research goals of this project. Identify and quantify expected performance improvements from this research. Identify new capabilities enabled by this research. Identify and discuss salient features and capabilities of developmental hardware and software prototypes. Provide a set of metrics and success criteria for the concepts proposed under Phase I.
3. Expected Impact. Describe expected impact of the research project, if successful, to problem area.

E. Technical Approach:

1. Detailed Description of Technical Approach {10 Pages}. Provide detailed description of technical approach that will be used in this project to achieve research goals. Specifically identify and discuss the innovative aspects of the BICA technical approach. Note: An optional technical viewgraph summary in MS Power Point format (maximum of 8 viewgraphs) may also be included as part of the Technical Volume and will not be considered as part of the volume page count.
2. Comparison with Current Technology {2 Pages}. Describe state-of-the-art approaches and the limitations within the context of the problem area addressed by this research.

F. Schedule and Milestones

1. Schedule Graphic {1 Page}. Provide a graphic representation of project schedule including detail down to the individual effort level. This should include but not be limited to, a multi-phase development plan, which demonstrates a clear understanding of the proposed research. Show all project milestones. Use absolute designations for all dates.
2. Detailed Individual Effort Descriptions {3 Pages}. Provide detailed task descriptions for each individual effort and/or subcontractor in schedule graphic.

G. Deliverables Description {2 Pages}. List and provide detailed description for each proposed deliverable. Include in this section all proprietary claims to results, prototypes, or systems supporting and/or necessary for the use of the research, results, and/or prototype. If there are no proprietary claims, this should be stated. The offeror must submit a separate list of all technical data or computer software that will be furnished to the Government with other than unlimited rights (see DFARS 227.) Specify receiving organization and expected delivery date for each deliverable.

H. Technology Transition and Technology Transfer Targets and Plans {1 Page}. Discuss path for technology transition and transfer to Phase 2 of the program. Offerors should also provide a plan for transition of appropriate technology components and information to the user community.

I. Personnel and Qualifications {3 Pages}. List of key personnel, concise summary of their qualifications, and discussion of proposer's previous accomplishments and work in this or closely related research areas. Indicate the level of effort to be expended by each person during each contract year and other (current and proposed) major sources of support for them and/or commitments of their efforts. DARPA expects all key personnel associated with a proposal to make substantial time commitment to the proposed activity.

J. Facilities {1 Page}. Description of the facilities that would be used for the proposed effort. If any portion of the research is predicated upon the use of Government Owned Resources of any type, the offeror shall specifically identify the property or other resource required, the date the property or resource is required, the duration of the requirement, the source from which the resource is required, if known, and the impact on the research if the resource cannot be provided. If no Government Furnished Property is required for conduct of the proposed research, the proposal shall so state.

8.3 Volume II. Cost

Cost proposals are subject to no page limits, and shall provide a detailed cost breakdown of all direct costs, including cost by task, with breakdown into accounting categories (labor, material, travel, computer, subcontracting costs, labor and overhead rates, and equipment), for the entire contract and for each calendar year, divided into quarters. Where the effort consists of multiple portions that could reasonably be partitioned for purposes of funding, these should be identified as contract options with separate cost estimates for each.

Offerors should expect to participate in teams and workshops to provide specific technical background information to DARPA, attend semi-annual Principal Investigator (PI) meetings, and participate in numerous other coordination meetings via teleconference or Video Teleconference (VTC). Funding to support these various group experimentation efforts should be included in technology project bids

Offerors requiring the purchase of information technology (IT) resources as Government Furnished Property (GFP) MUST attach the following information:

1. A letter on Corporate letterhead signed by a senior corporate official and addressed to Tom Armour and Dave Gunning, PMs BICA, DARPA/IPTO, stating that you either can not or will not provide the information technology (IT) resources necessary to conduct the said research.
2. An explanation of the method of competitive acquisition or a sole source justification, as appropriate, for each IT resource item.
3. If the resource is leased, a lease purchase analysis clearly showing the reason for the lease decision.
4. The cost for each IT resource item.

IMPORTANT NOTE: IF THE OFFEROR DOES NOT COMPLY WITH THE ABOVE STATED REQUIREMENTS, THE PROPOSAL WILL BE REJECTED.

8.4 Organizational Conflict of Interest

Awards made under this BAA may be subject to the provisions of the Federal Acquisition Regulation (FAR) Subpart 9.5, Organizational Conflict of Interest. All offerors and proposed subcontractors must affirmatively state whether they are supporting any DARPA technical office(s) through an active contract or subcontract. All affirmations must state which office(s) the offeror supports, and identify the prime contract number. Affirmations should be furnished at the time of proposal submission. All facts relevant to the existence or potential existence of organizational conflicts of interest, as that term is defined in FAR 2.101, must be disclosed in Section II, I. of the proposal, organized by task and year. This disclosure shall include a description of the action the Contractor has taken, or proposes to take, to avoid, neutralize, or mitigate such conflict.

9 EVALUATION AND FUNDING PROCESSES

Proposals will not be evaluated against each other, since they are not submitted in accordance with a common work statement. DARPA's intent is to review proposals as soon as possible after they arrive; however, proposals may be reviewed periodically for administrative reasons. For evaluation purposes, a proposal is the document described in Proposal Format. Other supporting or background materials submitted with the proposal will be considered for the reviewer's convenience only and not considered as part of the proposal.

Evaluation of proposals will be accomplished through a scientific review of each proposal using the following criteria, which are listed in descending order of relative importance:

(1) Overall Scientific and Technical Merit: The overall scientific and technical merit must be clearly identifiable and compelling. The technical concepts should be clearly defined and developed. The technical approach must be sufficiently detailed to support the proposed concepts, technical claims, and applicability to follow-on work including Phase 2 of the program.

(2) Innovative Technical Solution to the Problem: Offerors should apply new and/or existing technology in an innovative way that supports the objectives of the proposed effort. The proposed concepts and systems should show breadth of innovation across all the dimensions of the proposed solution. Offerors must also specify quantitative experimental methods and metrics for measuring progress of the effort.

(3) Potential Contribution and Relevance to DARPA/IPTO Mission: The offeror must clearly address how the proposed effort will meet the goals of the undertaking and how the proposed effort contributes to significant advances to DARPA/IPTO.

(4) Offeror's Capabilities and Related Experience: The qualifications, capabilities, and demonstrated achievements of the proposed principals and other key personnel for the primary and subcontractor organizations must be clearly shown.

(5) Plans and Capability to Accomplish Technology Transition: The offeror should provide a clear strategy and plan for transition to Phase 2 of program. Offerors should also provide a plan for transition of appropriate technology components and information to the user community.

(6) Cost Realism: The overall estimated costs should be clearly justified and appropriate for the technical complexity of the effort. Evaluation will consider the value of the research to the government and the extent to which the proposed

management plan will effectively allocate resources to achieve the capabilities proposed.

The Government reserves the right to select all, some, or none of the proposals received in response to this solicitation and to make awards without discussions with offerors; however, the Government reserves the right to conduct discussions if the Source Selection Authority later determines them to be necessary. Proposals identified for funding may result in a contract, grant, cooperative agreement, or other transaction depending upon the nature of the work proposed, the required degree of interaction between parties, and other factors. If warranted, portions of resulting awards may be segregated into pre-priced options.

10 Administrative Addresses

The administrative addresses for this BAA are:

Fax: 703-741-7804 Addressed to: DARPA/IPTO, BAA 05-18

Electronic Mail: baa05-18@darpa.mil

Electronic File Retrieval: http://www.darpa.mil/ipto/Solicitations/solicitations.htm

Mail to: DARPA/IPTO
ATTN: BAA 05-18
3701 N. Fairfax Drive
Arlington, VA 22203-1714

Appendix One:

FUNCTIONAL PRIMITIVES OF THE HUMAN BRAIN

(An Initial List)

I. Memory

A. Types of memory:
- 1. Declarative (explicit)
  - a. Episodic (events)
  - b. Semantic (facts)
    - i. Categorical
    - ii. Item
- 2. Non-declarative (implicit)
  - a. Procedural
    - i. Skill memory
    - ii. Habit memory
  - b. Priming
  - c. Perceptual memory
    - i. Visual memory
    - ii. Auditory memory
    - iii. Tactile memory
    - iv. Olfactory memory
    - v. Gustatory memory
  - d. Emotional memory
- 3. Spatial
- 4. Short-term memory store
- 5. Long-term memory store
- 6. Intermediate-term memory store
- 7. Working memory
- 8. Relational memory

B. Memory processes:
- 1. Active recall / retrieval
- 2. Passive recall / recognition
  - i. Object recognition
  - ii. Pattern recognition
  - iii. Recognition of multimodal stimuli
- 3. Active maintenance (working memory)
- 4. Storage
- 5. Consolidation

II. Learning

A. Stimulus-response learning
   1. Classical conditioning (associative learning)
      a. Configural learning
   2. Instrumental conditioning (operant conditioning)
B. Non-associative learning (single-trial learning)
C. Social learning
D. Procedural learning
E. Motor sequence learning
F. Episodic learning
G. Observational learning
H. Perceptual learning
   1.Visual learning
   2. Auditory learning
   3. Somatosensory learning
   4. Olfactory learning
   5. Gustatory learning
I. Relational learning
J. Declarative learning
K. Semantic learning
L. Absolute learning
M. Dimensional learning
N. Serial learning
O. Serial reversal learning
P. Habituation
Q. Sensitization
R. Reinforcement learning
   1. Positive reinforcement
   2. Negative reinforcement
S.Aversion learning
T. Imprinting
U. Latent learning
V. Rule learning

III. Executive processes

A. Maintenance of task-relevant (context-relevant) information
B. Context interpretation
   1. Social context
   2. Task context
C. Attentional shift
D. Working memory
E. Action selection (decision making)
F. Behavioral inhibition (action suppression)
G. Performance monitoring
H. Provisional planning

I. Long-term planning
J. Short-term planning
K. Movement planning
L. Goal formation
M. Action initiation
N. Action feedback monitoring
O. Decision making
    1. Estimating probability
        a. Estimating value
        b. Estimating utility
        c. Estimating likely consequences of actions
            i. Estimating short-term consequences
            ii. Estimating long-term consequences
    2. Comparing multiple options
        a. Comparing costs among possible actions
            i. Comparing short-term costs
            ii. Comparing long-term costs
        b. Comparing benefits (e.g. value, utility) among possible actions
            i. Comparing short-term benefits
            ii. Comparing long-term benefits
        c. Comparing cost/benefit relationships among possible actions
            i. Comparing short-term cost/benefit relationships
            ii. Comparing long-term cost/benefit relationships

IV. Language / Symbolic Communication

A. Language comprehension
    1. Application of:
        a. Phonological knowledge
        b. Morphological knowledge
        c. Lexical knowledge
        d. Semantic knowledge
            i. Application of case frames
                a. Identification of:
                    i. Agent
                    ii. Object
                    iii. Location
                    iv. Source
                    v. Goal
                    vi. Beneficiary
        e. Syntactic knowledge
        f. Grammatical knowledge
        g. Pragmatic knowledge (contextual knowledge)
        h. Discourse knowledge
B. Language production
    1. Phoneme generation

2. Word generation
3. Phrase generation
    a. Application of syntax
    b. Application of grammar
    c. Application of semantics
4. Sentence generation
    a. Statements
    b. Imperatives
    c. Questions
5. Generation of higher-order structuring
    a. Conversational structure
    b. Narrative structure
    c. Expository structure

V. Social / Emotional

A. Emotional recognition
1. Fear
2. Surprise
3. Humor
4. Happiness
5. Excitation
6. Agitation
7. Affection
8. Sadness
9. Anxiety
10. Frustration
11. Grief
12. Regret
13. Anticipation
14. Embarrassment
15. Shame
16. Humiliation

B. Emotional expression
1. Fear
2. Surprise
3. Humor
4. Happiness
5. Excitation
6. Agitation
7. Affection
8. Sadness
9. Anxiety
10. Frustration
11. Grief
12. Regret

13. Anticipation
14. Embarrassment
15. Shame
16. Humiliation

C. Startle
D. Deception
   1. Emotional mimicry
   2. Emotional suppression
   3. Misdirection of others' attention(s)
   4. Confabulation

E. Recognition of deception
F. Relationship formation
G. Emotional bonding
   1. Sympathy
   2. Empathy

H. Identification of others' intentions

VI. Consciousness

A. Awareness of time
B. Awareness of self
   1. Self criticism
   2. Self approval

C. Awareness of others' perspectives
D. Spatial awareness
E. Situational awareness (context awareness)
F. Appreciation of aesthetics
   1. Visual aesthetics
   2. Tactile aesthetics
   3. Auditory aesthetics
   4. Olfactory aesthetics
   5. Gustatory aesthetics
   6. Polysensory aesthetics

G. Long-term planning
H. Short-term planning
I. Movement planning
J. Goal formation

VII. Knowledge representation

A. Syntactic knowledge
B. Semantic knowledge
C. Pragmatic knowledge
D. World knowledge

VIII. Logic / Reasoning

A. Reasoning types:
   1. Causal
   2. Statistical
   3. Structural
   4. Metaphoric
   5. Intersection
   6. Example- or case-based
   7. Symbolic play
   8. Symbolic mnemonics
   9. Distributed
   10. Logical
      a. Syllogistic
         i. Categorical
         ii. Hypothetical
         iii. Disjunctive
   11. Inferential rules
      a. Procedural rules
         i. Inference
         ii. Mapping
         iii. Application
      b. Declarative rules
         i. Semantic rules
            a. Set-subset
            b. Set-superset
            c. Static properties
            d. Functional properties
   12. Abductive reasoning
   13. Deductive reasoning
   14. Inductive reasoning
      a. Analogical reasoning
      b. Category-based induction
      c. Generalization from:
         i. Temporal stimulus patterns
         ii. Spatial stimulus patterns

B. Parsing

C. Semantic translation

D. Disambiguation

E. Symbolic reasoning
   1. Counting
   2. Mathematical reasoning

F. Simple logical operations
   1. Negation
   2. Conjunction
   3. Disjunction
   4. Implication

IX. Elementary Vision

A. Detection and processing of visual stimulus parameters:
  1. Position
  2. Color
    a. Chromatic contrast
  3. Motion
    a. Direction
    b. Velocity
    c. Acceleration
  4. Depth (stereopsis)
  5. Intensity (luminance)
    a. Absolute luminance
    b. Spatial luminance contrast
    c. Temporal luminance contrast
  6. Spatial frequency
  7. Temporal frequency
  8. Edge detection
  9. Edge orientation

X. Higher Vision – Object Perception

A. Feature extraction
  1. Extrapolation of:
    a. Contours
    b. Surfaces
    c. Textures
    d. 3-dimensional form
    e. Form-from-motion

B. Figure-ground separation

C. Object detection

D. Object recognition

E. Pattern recognition (same thing)

F. Perceptual binding of visual stimulus features

XI. Higher Vision – Spatial Perception

A. Perception of:
  1. Object size
  2. Inter-object distances
  3. Inter-object spatial relationships
  4. Distance of object from observer
  5. Object location within multiple coordinate frames
    a. Eye-centered coordinates
    b. Head-centered coordinates

c. Body-centered coordinates
d. World-centered coordinates

XII. Somatosensation

A. Detection and processing of tactile stimulus parameters
1. Stimulus position
2. Stimulus duration
3. Stimulus amplitude/intensity
4. Stimulus motion
a. Direction
b. Velocity
c. Acceleration
B. Detection and discrimination via multiple submodalities
1. Thermosensation
a. Cold
b. Heat
2. Nociception
a. thermonociception
b. chemonociception
c. mechanonociception
3. Mechanosensation
a. Low-threshold
b. High-threshold
c. Flutter sense
d. Vibratory sense
e. Visceral sense

XIII. Olfaction

A. Detection and processing of olfactory stimulus parameters
1. Odor intensity
2. Odor duration
B. Odor discrimination (type or source of odor)

XIV. Gustation

A. Detection and processing of taste parameters:
1. Sweetness
2. Saltiness
3. Sourness
4. Bitterness
5. Taste intensity
6. Taste duration

XV. Audition

A. Detection and processing of auditory stimulus parameters:
1. Intensity (loudness/volume)
2. Frequency (timbre)
    a. Frequency decomposition (Fourier analysis)
3. Duration
4. Source location
5. Source movement
    a. Direction
    b. Velocity
    c. Acceleration
6. Change in frequency
    a. Direction
    b. Rate
    c. Acceleration
7. Change in intensity
    a. Direction
    b. Rate
    c. Acceleration

XVI. Proprioception

A. Awareness of:
1. Static limb position
2. Static head position
3. Static trunk position
4. Joint angle
5. Movement (kinesthesia)
    a. Direction
    b. Velocity
    c. Acceleration

XVII. Vestibular function

A. Pitch sensation
B. Yaw sensation
C. Roll sensation
D. Postural reflex responses
E. Balance reflexes

XVIII. Polysensory integration

A. Perceptual binding of multimodal (polysensory) stimulus features based on:
1. Spatial co-localization
2. Temporal coincidence
3. Common dynamics:

        a. Velocity
        b. Direction
        c. Acceleration
    4. Previous experience (memory)

XIX. Spatial cognition

A. Navigation
B. Spatial mapping
C. Spatial memory
D. Object detection
E. Object avoidance
F. Object rotation
G. Visually guided movement
H. Coordinate transformations
    1. Eye-centered coordinates
    2. Head-centered coordinates
    3. Body-centered coordinates
    4. World-centered coordinates

18. Attentional mechanisms

A. Preattentive mechanisms (perceptual salience)
B. Arousal (global changes in alertness)
C. Voluntary attention (active)
D. Involuntary attention (passive)
E. Orientation behavior
    1. Posture/body orientation
    2. Orientation of sensory organs
F. Stimulus localization
G. Stimulus selection
H. Stimulus tracking (smooth pursuit)
I. Attention shift
J. Suppression of irrelevant stimuli
K. Flexible allocation of processing resources

18I. Creativity

A. Combinational creativity
B. Auditory creativity
C. Visual creativity
D. Gustatory creativity
E. Olfactory creativity
F. Tactile creativity
G. Motor creativity
H. Spatial creativity

I. Analytical creativity
J. Mathematical creativity
K. Exploratory creativity
L. Transformational creativity
M. Linguistic creativity
    1. Metaphor
    2. Narrative

18II. Motivation

A. Reward optimization
B. Avoidance of aversive stimuli
C. Appetitive motivation
D. Homeostatic motivation
E. Reproductive motivation
F. Altruistic motivation
G. Hedonic motivation

Appendix Two:

STRUCTURAL PRIMITIVES OF THE PRIMATE CENTRAL NERVOUS SYSTEM

(An initial list)

I. Limbic System and Related Structures (subcortical)

A. limbic lobe
  1. cingulate gyrus
  2. subcallosal gyrus
  3. parahippocampal region
    a. parahippocampal gyrus
    b. perirhinal cortex
    c. entorhinal cortex
  4. hippocampal complex
    a. dentate gyrus
    b. subicular complex
      i. parasubiculum
      ii. presubiculum
      iii. subiculum
    c. Ammon's horn (hippocampus proper)
      i. CA1
      ii. CA2
      iii. CA3
      iv. CA4
B. anterior thalamic nuclei
C. medial dorsal nucleus of thalamus
D. habenula
E. mammillary body
F. amygdala
  1. corticomedial nuclei
  2. basolateral nucleus
  3. central nucleus
G. olfactory bulb
H. prominent hippocampal pathways
  1. mossy fiber pathway
  2. perforant pathway
  3. schaffer collateral fiber pathway
I. prominent limbic pathways
  1. cingulum
  2. stria terminalis

    3. stria medullaris
    4. dorsal longitudinal fasciculus
    5. mammillotegmental tract
    6. medial forebrain bundle
    7. habenulo-interpeduncular tract
    8. mammillary peduncle
    9. ventral amygdalofugal pathway
    10. lateral olfactory stria
    11. anterior commissure
    12. mammillothalamic tract
    13. fornix

J. hypothalamus
    1. lateral hypothalamic area
    2. supraoptic nucleus
    3. ventromedial hypothalamic nucleus
    4. arcuate nucleus
    5. median eminence
    6. arcuate nucleus
    7. lateral tuberal nucleus
    8. periventricular nucleus
    9. dorsomedial hypothalamic nucleus
    10. posterior hypothalamic area
    11. pituitary
    12. infundibulum
    13. supraoptic nucleus
    14. lateral preoptic nucleus
    15. anterior hypothalamic nucleus
    16. medial preoptic nucleus
    17. paraventriclar nucleus

II. Subcortical Motor Systems: Basal Ganglia and Thalamus

A. striatum (striosomes and matrix)
    1. caudate nucleus
    2. putamen

B. globus pallidus
    1. internal segment
    2. external segment
    3. ventral pallidum

C. subthalamic nucleus

D. substantia nigra
    1. pars reticulata
    2. pars compacta
    3. pars lateralis

E. ventral lateral nucleus of the thalamus
    1. oral portion

        2. caudal portion
F. ventral posterior nucleus of the thalamus
        1. oral portion
G. centromedian nucleus of the thalamus
H. nucleus X of the thalamus

III. Subcortical Motor Systems: Cerebellum

A. cerebellar peduncles (contain input-output tracts)
    1. superior
    2. middle
    3. inferior
B. flocculonodular lobe
    1. nodulus
    2. floculus
C. vermis
    1. culmen
    2. declive
    3. folium
    4. tuber
    5. pyramis
    6. uvula
D. deep nuclei
    1. fastigial
    2. interposed
        a. globose
        b. embiloform
    3. dentate

IV. Other Subcortical Motor Systems/Structures

A. spinal cord
    1. lamina VIII
    2. lamina IX
B. brainstem and midbrain
    1. pontine reticular formation
    2. red nucleus
    3. medullary reticular formation
    4. superior colliculi
    5. vestibular nuclei
    6. trigeminal motor nucleus (V)
    7. facial motor nucleus (VII)
    8. dorsal motor nucleus of vagus (X)
    9. hypoglossal nucleus (XII)

V. Cortical Motor Systems

A. premotor cortex (area 6)
B. supplementary motor area (area 6)
C. primary motor cortex (area 4)
D. parietal cortex (sensorimotor cortex)
    1. area 5 (area PE in von Economo nomenclature)
    2. area 7a (area PG in von Economo nomenclature)
    3. area 7b (area PF in von Economo nomenclature)
    4. area 39 (human)
    5. area 40 (human)
    6. cortical areas of the intraparietal sulcus
        a. AIP (anterior intraparietal)
        b. LIP (lateral intraparietal)
        c. VIP (ventral intraparietal)
        d. MIP (medial intraparietal)
E. prominent tracts
    1. lateral corticospinal tract
    2. ventral corticospinal tract
    3. corticobulbar pathway

VI. Thalamic Nuclei

A. internal medullary lamina (divides thalamus into six subregions)
B. medial dorsal
C. intralaminar
D. pulvinar
E. medial geniculate
F. lateral geniculate
G. centromedian
H. ventral posterior medial
I. lateral posterior
J. lateral dorsal
K. ventral lateral
L. ventral intermediate
M. ventral posterior
N. ventral posterior inferior
O. ventral anterior
P. reticular
Q. anterior

VII. Brainstem: Cranial Nerve Nuclei (Sensory and Motor)

A. mesencephalic trigeminal nucleus (V)
B. principal sensory trigeminal nucleus (V)
C. spinal trigeminal nucleus (V, VII, IX, X)
    1. oralis

        2. interpolaris
        3. caudalis
C. vestibular nuclei (VIII)
        1. superior vestibular nucleus
        2. lateral vestibular nucleus
        3. inferior vestibular nucleus
                a. rostral part
                b. caudal part
        4. medial vestibular nucleus
                a. rostral part
                b. middle part
                c. caudal part
D. cochlear nucleus (VIII)
E. solitary nucleus (VII, IX, X)
F. accessory nucleus (XI)
G. dorsal motor nucleus of vagus (X)
H. hypoglossal nucleus (XII)
I. nucleus ambiguus (IX, X, XI)
J. salivatory nuclei
        1. superior (VII)
        2. inferior (IX)
K. facial motor nucleus (VII)
L. abducens (VI)
M. trigeminal motor nucleus (V)
N. trochlear nucleus (IV)
O. oculomotor nucleus (III)
P. Edinger-Westphal nucleus (III)

VIII. Arousal / Neuromodulatory Systems

A. cholinergic system (in basal forebrain)
        1. nucleus basalis of Meynert
        2. substantia innominata
        3. medial septal nucleus
        4. diagonal band of Broca
B. brainstem reticular formation (3 major monoaminergic systems)
        1. noradrenergic system
                a. locus ceruleus
                b. lateral tegmental neurons (scattered diffusely)
        2. dopaminergic system
                a. mesostriatal system
                        i. ventral part
                                a. ventral tegmentum (area A10)
                                b. retrorubral nucleus (area A8)
                        ii. dorsal part
                                a. substantia nigra (area A9)

        b. mesolimbic and mesocortical systems
            i. area A10
            ii. area A9
    3. serotonergic system
        a. raphe nuclei
            i. nucleus raphe pallidus
            ii. nucleus raphe obscurus
            iii. nucleus raphe magnus
            iv. nucleus raphe pontis
            v. nucleus raphe dorsalis
            vi. nucleus paragigantocellularis
            vii. nucleus centralis superior
            viii. nucleus tegmenti reticularis pontis and adjacent tegmentum

IX. Olfactory Structures

A. peripheral structures
    1. olfactory epithelium
    2. olfactory bulb
B. cortical structures
    1. olfactory cortex
        a. anterior olfactory nucleus
        b. olfactory tubercle
        c. pyriform cortex
        d. cortical nucleus of the amygdala
        e. entorhinal area

X. Gustatory Structures

A. peripheral structures
    1. geniculate ganglion (VII)
    2. petrosal ganglion (IX)
    3. nodose ganglion (X)
    4. solitary nucleus (VII, IX, X)
B. thalamic structures
    1. ventral posterior medial nucleus
        a. parvocellular portion
C. cortical structures
    1. taste area I
    2. taste area II

XI. Auditory Structures

A. cochlea (peripheral sensory apparatus)
B. auditory nerve (VIII) (fiber tract)
C. cochlear nucleus (VIII)

1. dorsal
2. ventral
    a. three dominant pathways exiting cochlear nucleus:
        i. dorsal acoustic stria
        ii. intermediate acoustic stria
        iii. trapezoid body

D. medial superior olive
E. lateral superior olive
F. spiral ganglion
G. lateral lemniscus (fiber tract)
H. Probst's commissure (fiber decussation)
I. nucleus of lateral lemniscus
J. inferior colliculus
K. auditory thalamus
    1. medial geniculate nucleus
        a. medial division
L. cortical auditory structures
    1. AI (primary auditory cortex) (areas 41 and 42)
        a. laminated columnar structure similar to other sensory cortices
            i. summation columns
            ii. suppression columns
    2. anterior lateral auditory field
    3. rostral auditory field
    4. posterior lateral auditory field

XII. Visual Structures (cortical areas correspond to Macaque)

A. retina
B. superior colliculus
    1. stratum zonale
    2. stratum griseum superficiale
    3. stratum opticum
    4. stratum album intermedium
    5. stratum griseum intermedium
    6. stratum griseum profundum
    7. stratum album profundum
C. pretectal area
D. visual thalamus
    1. lateral geniculate nucleus (6 layers)
        a. parvocellular layers (3,4,5,6)
        b. magnocellular layers (1,2)
        c. ipsilateral layers (2,3,5)
        d. contralateral layers (1,4,6)
    2. pulvinar
        a. medial
        b. lateral

        c. dorsal
E. cortical areas – occipital lobe
    1. V1 (primary visual cortex) (area 17)
        a. hypercolumns
            i. ocular dominance columns
            ii. orientation columns
                a. layer 1
                b. layer 2
                c. layer 3
                d. layer 4
                    i. layer 4A
                    ii. layer 4B
                    iii. layer 4Cα (magno)
                    iv. layer 4Cβ (parvo)
                        a. blobs
                        b. interblobs
                e. layer 5
                f. layer 6
    2. V2 (secondary visual cortex) (area 18)
        a. thin stripes
        b. pale stripes
        c. thick stripes
    3. V3 (area 18)
    4. V3A (area 18)
    5. V4v (ventral) (area 19)
    6. V4d (dorsal) (area 19)
    7. V4t (transitional) (area 19)
    8. VP (ventral posterior)
    9. VOT (ventral occipitotemporal)
    10. MT (middle temporal, V5) (area 19)
F. cortical areas – temporal lobe
    1. FST (floor of superior temporal)
    2. PITv (posterior inferotemporal ventral)
    3. PITd (posterior inferotemporal ventral)
    4. CITd (central inferotemporal dorsal)
    5. CITv (central inferotemporal ventral)
    6. AITd (anterior inferotemporal dorsal)
    7. AITv (anterior inferotemporal ventral)
    8. STPa (superior temporal polysensory anterior)
    9. STPp (superior temporal polysensory posterior)
    10. TF
    11. TH
G. cortical areas – parietal lobe
    1. MSTd (medial superior temporal dorsal)
    2. MSTl (medial superior temporal lateral)
    3. PO (parieto-occipital)

4. PIP (posterior intraparietal)
5. AIP (anterior intraparietal)
6. LIP (lateral intraparietal)
7. VIP (ventral intraparietal)
8. MIP (medial intraparietal)
9. MDP (medial dorsal parietal)
10. DP (dorsal perlunate)
11. area 7a

H. cortical areas – frontal lobe
1. FEF (frontal eye field) (area 8)
2. area 46

I. other cortical area designations
1. dorsointermediate visual area
2. dorsolateral visual area
3. dorsomedial visual area

XIII. Somatosensory Structures

A. peripheral structures
1. dorsal root ganglia

B. spinal cord
1. gray matter
a. dorsal horn
i. lamina I (marginal zone)
ii. lamina II (substantia gelatinosa)
iii. lamina III (nucleus proprius)
iv. lamina IV (nucleus proprius)
v. lamina V (nucleus proprius)
vi. lamina VI (nucleus proprius)
b. intermediate zone
i. lamina VII
a. Clarke's nucleus
c. lamina X
2. white matter (fiber tracts)
a. dorsal columns
b. lateral columns

C. brainstem
1. principal sensory nucleus (V)
2. spinal trigeminal nucleus (V, VII, IX, X)
i. oralis
ii. interpolaris
iii. caudalis
3. dorsal column nuclei
i. gracile nucleus
ii. cuneate nucleus

D. medial lemniscus (fiber tract)

E. somatosensory thalamus
- 1. ventral posterior medial nucleus (thalamus)
- 2. ventral posterior lateral nucleus (thalamus)
- 3. ventral posterior inferior nucleus (thalamus)
- 4. ventral posterior nucleus (thalamus)

F. cortical areas
- 1. SI (primary somatosensory cortex)
  - a. area 1
  - b. area 2
  - c. area 3a
  - d. area 3b
- 2. SII (secondary somatosensory cortex)
  - a. area 2a
- 3. posterior parietal cortex (sensorimotor cortex)
  - a. area 5
  - b. area 7

G. structures involved in descending pain modulation
- 1. periaquaductal gray
- 2. locus ceruleus
- 3. lateral reticular nucleus
- 4. nucleus raphe magnus
- 5. nucleus of the solitary tract

XIV. Association and Polysensory Cortices

A. parietal- temporal-occipital association cortex
- 1. area 39 (Wernicke's Area)
- 2. area 40 (Wernicke's Area)
- 3. portions of areas:
  - a. 19
  - b. 21
    - i. posterior portion (Wernicke's Area)
  - c. 22
    - i. posterior portion (Wernicke's Area)
  - d. 37
    - i. subportion (Wernicke's Area)

B. limbic cortex
- 1. area 23
- 2. area 24
- 3. area 38
- 4. area 28
- 5. area 11

C. frontal cortical areas
- 1. dorsolateral prefrontal cortex
  - a. area 8a
  - b. area 8b

- c. area 9
- d. area 44 (Broca's Area)
- e. area 45 (Broca's Area)
- f. area 46
- g. area 47

2. anterior cingulate cortex
    - a. area 24
    - b. area 32
3. orbitofrontal cortex
    - a. area 11
    - b. area 12
    - c. area 13
    - d. area 14
4. frontopolar
    - a. area 10

XV. Autonomic Structures

A. parasympathetic system
- 1. central structures
    - a. midbrain
        - i. Edinger-Westphal nucleus (III)
    - b. pons
        - i. lacrimal
        - ii. salivatory nuclei
            - a. superior
            - b. inferior
    - c. medulla
        - i. inferior salivatory nucleus
        - ii. dorsal vagal nucleus
        - iii. nucleus ambiguus
    - d. sacral spinal cord
- 2. peripheral structures
    - a. ciliary ganglion
    - b. pterygopalatine ganglion
    - c. submandibular ganglion
    - d. otic ganglion
    - e. terminal ganglion
    - f. pelvic plexus

B. sympathetic system
- 1. central structures
    - a. spinal cord
        - i. intermediolateral gray matter
- 2. peripheral structures
    - a. superior cervical ganglion
    - b. middle cervical ganglion

        c. stellate ganglion
        d. sympathetic chain ganglia
        e. adrenal gland
        f. celiac ganglion
        g. aorticorenal ganglion
        h. superior mesenteric ganglion
        i. inferior mesenteric ganglion
    3. enteric system
        a. myenteric plexus
        b. submucous plexus

XVI. Spinal Structures

A. gray matter
    1. dorsal horn
        a. lamina I (marginal zone)
        b. lamina II (substantia gelatinosa)
        c. lamina III (nucleus proprius)
        d. lamina IV (nucleus proprius)
        e. lamina V (nucleus proprius)
        f. lamina VI (nucleus proprius)
    2. intermediate zone
        a. lamina VII
            i. Clarke's nucleus
            ii. intermediolateral nucleus
    3. ventral horn
        a. lamina VIII
        b. lamina IX (motor nuclei)
    4. lamina X
B. white matter (fiber tracts)
    1. dorsal columns
    2. lateral columns
    3. ventral columns
C. tract of Lissauer
D. fasciculus proprius