NESTCOM

What it Means to Communicate

Project reference
Contract No: 043374 (NEST)

Analysis of Communication Processing in the Brain based on selected NEST Projects (WP1)

NESTCOM Report 1

Deliverable 1

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Report Version: 1

Report Preparation Date: 29 June 2007

Classification: Public

Contract Start Date: 1st January 2007 Duration: Two Years

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Partners: University of Sunderland, Medical Research Council, Universita degli Studi di Parma

Project funded by the European Community under the Sixth Framework Programme NEST -
New and emerging science and technology

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1. Introduction

This document forms the first part of the first Deliverable for the NESTCOM project. It forms an analysis of the current state of research on multimodal communication. While the document gives a broad overview of the subject, we have applied particular focus to:

- European research – particularly research funded by the European Union (EU) under the NEST initiative
- Research into communication processing in the brain, in particular neural architectures
- Research on the fusion and merging of multiple modes of communication.

This document is structured as follows; first a summary of relevant projects funded under the NEST 'What it means to be human' initiative. This is followed by an overarching review of previous research into communication. An alphabetical list of previous EU funded projects completes the document. This deliverable is complemented by two further reports which focus in more detail on neural architectures and mechanisms related to language processing.

2. Summary of NEST Projects under the 'What it means to be human' initiative which are relevant to Communication

2.1. ABSTRACT

Full Title: The Origins, Representation and Use of Abstract Concepts

URL: http://www.psychol.ucl.ac.uk/language/research.html

Aims:

- To understand the underlying internal representations of abstract concepts

Methodology/Areas of Investigation:

- Behaviour
- Development
- Cognitive Neuroscience

Expected Results:

- Evaluation of two relevant hypotheses on abstract concepts:
    - Embodiment Hypothesis
    - Abstraction from Language Hypothesis

Abstract:

The ability to understand and use language referring to abstract entities, events, and qualities (e.g., contempt, respect, kindness) is arguably a uniquely human faculty. The objective is to deepen our understanding of the acquisition and representation in the mind/brain of abstract concepts. We adopt: (1) a cross-linguistic perspective, motivated by the existence of culturally-bounded abstract concepts, expressed in languages with words that cannot be easily translated; (2) an interdisciplinary perspective, motivated by our aim to explore systematically the developmental, cognitive, computational and neural aspects of abstract knowledge. We contrast two explicit working hypotheses: the Embodiment Hypothesis (EH) and the Abstraction from Language Hypothesis (ALH). According to the former, abstract knowledge originates in "conceptual metaphors": the use of a concrete conceptual domain of knowledge to describe an abstract conceptual domain. The latter proposes that abstract concepts are learned by way of the statistical properties of language, since words that behave similarly within a language (in terms of statistical co-occurrence) are also often conceptually related. These two hypotheses are associated with largely different predictions: according to ALH (but not EH) language development is a phylogenetic and ontogenetic prerequisite to the development of abstract concepts. Regarding neural implementation, a close connection of abstract concepts with sensorimotor representations is predicted by EH, while ALH is compatible with a main involvement of the left hemispheric classical language areas. We develop these hypotheses using tools from linguistics and computational modelling. We test predictions in (1) behavioural studies; (2) developmental studies of typically developing and cognitively impaired children and (3) cognitive neuroscience (in ERP, fMRI, TMS and patients' studies.

2.2. ANALOGY

Full Title: Humans - The analogy-making species

URL:

Aims:
- To understand the human mechanisms of analogy making

Methodology/Areas of Investigation:
- Computational Modelling
- Psychological Experimentation
- Comparative Studies
- Developmental Studies
- Brain Imaging

Expected Results:
- Understanding of the evolution, development and mechanisms for analogy making
- How analogy making in humans differs from that in animals.
- Improved educational strategies based on the results above.

Abstract:

The ability to make analogies lies at the heart of human cognition and is a fundamental mechanism that enables humans to engage in complex mental processes such as thinking, categorization, and learning, and, in general, understanding the world and acting effectively on it based on her/his past experience. This project focuses on understanding these uniquely human mechanisms of analogy-making, and exploring their evolution and development. A highly experienced, interdisciplinary, and international team will study and compare the performance of primates, infants, young children, healthy adults, as well as children and adults with abnormal brain functioning. An interdisciplinary methodology will be used to pursue this goal, one that includes computational modelling, psychological experimentation, comparative studies, developmental studies, and brain imaging. The ability to see a novel experience, object, situation or action as being "the same" as an old one, and then to act in an approximately appropriate manner (and then fine-tuned to fit the novel experience), is, almost unquestionably, one of the capacities that sets humans apart from all other animals. What are the underlying mechanisms that allow us to do this? How did they evolve in the population? How do they develop in an individual? How do they differ from "the same" mechanisms in primates? The results from this project will contribute to a better understanding of the mechanisms of analogy-making, their origin, evolution and development and will lead to advances, not only in our basic knowledge of human cognition, but also in the development of educational strategies to help children and young people to be more efficient learners and to achieve a better and deeper understanding of the world in which they live.

2.3. APES

Full Title: Comparative analysis of primate genomes, transcriptomes and proteomes with an emphasis on cognitive capabilities

URL:

Aims:
- To identify the genetic differences responsible for unique human features.

Methodology/Areas of Investigation:
- Genetic comparison of the genome of various species.

Expected Results:
- Database of information outlining the role and effect of genetic differences

Abstract:
The biological basis of the unique human features separating us from even our closest relatives, the chimpanzee, constitutes one of the most fascinating problems in biological research. Based on the sequence of the human genome, the recently

completed finished sequence of chimpanzee chromosome 22, the recently released draft sequence of the chimpanzee genome, as well as additional gene sequences in other primates (e.g. Clark et. al. 2003), we plan to identify likely candidates for playing an essential role in the molecular basis of these differences. This will particularly include genes with potentially novel functions in man, formed by fusion events between pre-existing genes or pre-existing genes with repetitive elements, genes showing accelerated evolution in the human lineage, with appropriate expression patterns (or human specific changes in expression patterns), and appropriate molecular or cellular function, as well as the orthologs of genes identified as being involved in cognition differences in the mouse. Candidate genes selected by this process will be analysed by evolutionary shadowing of their promoters, as well as, in some cases, coding and other regulatory regions, by in-situ hybridization of mouse orthologues in the postnatal mouse brain, and where appropriate, by in-situ hybridization in the brains of selected primates, complemented by a range of other techniques available at the different centres. Moreover, selected candidate genes for higher cognitive capabilities will be studied in vivo in the common marmoset monkey. Data generated within this project will be made available to collaborating groups in a special project data base, analogous to genome-matrix (www.genome-matrix.org), a common functional genomics database developed jointly by the MPI-MG and the resource centre of the German genome project (RZPD).

2.4. CALACEI

Full Title: Universal and Specific Properties of a uniquely Human Competence. Tools to study language acquisition in early infancy: Brain and Behavioural Studies

URL: http://www.sissa.it/cns/lcd/calacei/calacei/Site/CALACEI-2006.html

Aims:
- To understand the development of syntax and learning of semantics in a developing brain

Methodology/Areas of Investigation:
- Psychology
- Physiology
- Linguistics
- Brain Imaging

Expected Results: Tools to study language acquisition in early infancy

Abstract:
Knowledge on functional-anatomical prerequisites to acquire language has grown exponentially due to the discovery of behavioural methods and the development of high resolution functional imaging tools. The latter link behaviour to physiological brain processes and define areas essential for the proficiency in a unique human competence: language. In adults, knowledge on cerebral processes mandatory for language competence has greatly improved. This rapidly increasing knowledge allows for the description of a model integrating behavioural and physiological findings of

how the proficient speaker masters language. However, to understand the uniqueness of human language it is imperative to understand how human infants acquire syntax and how the child learns to handle the more 'mysterious' semantic properties of a specific language. Psycholinguists must acknowledge that acquisition begins at birth when some of the prosodic and phonological properties are already set. We must also explore how and when lexical and syntactic properties are learned and we have to address the question how signals from the infant brain allow for an extension of the adult functional anatomical findings to infants. Our consortium has sketched a series of studies to clarify these issues by integrating psychologists, physiologists, linguists, and experts on brain imaging for a deeper understanding of the infant's brain function. This multidisciplinary approach is chosen since an investigation of language in the infant necessitates modifications in experimental design, data acquisition, and analysis. To unravel the human uniqueness we take the challenge to analyse signals from a rapidly developing brain, where plasticity is the rule rather than the exception. We aim at an understanding of language competence by enhancing our knowledge on the development within the first months of life. Thus we address the question what it means to be human by investigating a uniquely human competence: language.

2.5. CHLaSC

Full Title: Characterizing Human Language by Structural Complexity

URL: http://www.zas.gwz-berlin.de/chlasc/

Aims:
- To determine the role of complex syntactic processing in distinguishing humans from animals.

Methodology/Areas of Investigation:
- Linguistics
- Cognitive science

Expected Results:
- Understand the difference in syntactic processing ability
- Model the relationship between language and other cognitive domains
- Investigate the correlation between structural complexity in language and structural complexity in social cognition.

Abstract:
What makes us smart? Human body cells function in the same way as those of animals, and even the core cognitive competencies for vision, quantity perception, object mechanics, and other domains are virtually the same in humans as in some animals. Nevertheless humans have addressed the basic problems of life (food, shelter, mating, locomotion, etc.) in completely different ways from even their closest animal kin, and have risen to dominate the planet. Recently complex syntactic processing has been identified as one core area where humans differ from primates. The central question of the CHLaSC project is: How much of human uniqueness can be traced back to this one basic difference? Addressing this question is a team from

five different fields (biology, semantics, language acquisition, cognitive development, and anthropology). We focus on structural complexity in language and in other cognitive systems, and the question whether extra-linguistic structural complexity is derived from language. The three core objectives we pursue are: 1) Describe precisely the difference in syntactic processing ability from a comparative, developmental, and socio-cultural perspective. 2) Develop formal models of the semantic mechanisms relating language to other cognitive domains. 3) Investigate how variation in the use of structural complexity in language correlates with the availability of structural complexity in social cognition. This project complements the already funded Neurocom project in the behavioural and socio-cultural domain. The CHLaSC project integrates linguistic semantics with the cognitive sciences, which is expected to broadly impact both fields and open up many new research opportunities. A broader social impact arises from the work on cognitive disorders, where opportunities for applications in diagnosis, therapy, and genetic research arise.

2.6. EDCBNL

Full Title: Evolution and Development of Cognitive, Behavioural and Neural Lateralization

URL:

Aims:
- To understand the causes and effects of brain lateralization

Methodology/Areas of Investigation:
- Genetic science
- Evolutionary science
- Behavioural science

Expected Results:
- Understand the evolutionary and developmental roots of lateralization
- Understand the links between lateralization and social behaviours

Abstract:
The study of brain asymmetries, that were once believed to be a typically human trait subserving linguistic functions and handedness, has recently undergone a dramatic transformation. The knowledge that was gathered until a few decades ago by human neuropsychology alone became greatly complemented and extended by data from comparative psychology, neuroscience, and developmental biology. This contribution provided a more complete picture of the phylogenetic, ontogenetic, and ecological factors that confer advantages to organisms exploiting neural and cognitive lateralization as a general biological trait. Game theory and population genetics contribute to the understanding of these advantages in terms of alignment of interactions between individuals, at a social and communicative level. A comparative approach, combining ethological, developmental, and game-theoretical research will investigate the co-evolution of neural and morphological lateralization with social

behaviours, and its impact on the evolution of higher cognitive abilities like language. The proposed research program will intensify the collaboration between insofar-isolated research domains, creating reciprocity between the biological and the behavioural sciences around a topic that is revealing a most promising tool for the understanding of the origins of the human mind.

2.7. EDICI

Full Title: Evolution, development and intentional control of imitation

URL: http://www.univie.ac.at/edici/

Aims:

- To understand the origins and mechanisms of imitation

Methodology/Areas of Investigation:

- Ethology
- Evolutionary biology
- Evolutionary neurophysiology
- Comparative, developmental and cognitive psychology

Expected Results:

- Major breakthroughs in understanding the evolutionary, developmental, cognitive and neurological bases of imitation
- Impacts in the design of training programmes
- Treatments for those with impairments in imitative ability

Abstract:

The human capacity for imitation provides the foundation for language acquisition, skill learning, socialisation, and enculturation. The dominant North American model claims that imitation is innate. The EDICI project replaces this conception with a model incorporating evolutionary, developmental and cultural inputs to imitation. In the case of imitation, being human means sharing core neurocognitive mechanisms with other species, and, as a result of culture-dependent interactions during development, being unique in ones ability to harness these mechanisms for the pursuit of individual and social goals. To test a multi-level model of this kind, interdisciplinary work is essential. The consortium represents internationally leading expertise in ethology, evolutionary biology and neurophysiology, comparative, developmental and cognitive psychology. Methods and insights from these fields will be applied in studies of children, healthy adults and neurological patients, and of animals that are closely related to humans phylogenetically (marmosets), ecologically (social birds) and culturally (dogs). Europe is the home of evolutionary theory, ethology and genetic epistemology, and was the site of the earliest scientific research on imitation. Our project builds on these historical strengths by testing a distinctively European model of imitation, using world-class European facilities and expertise. We expect major breakthroughs in understanding the evolutionary, developmental, cognitive and neurological bases of imitation, and that our integrative approach will have a broader impact on model-building in evolutionary psychology and cognitive

neuroscience. In contrast with the North American conception, our model emphasises the role of experience in the development of imitation. Therefore, our work will contribute to the design of social and technological skills training programmes, and to interventions for children and adults with impairments in imitative ability.

2.8. FAR

Full Title: From Associations to rules in the development of Concepts

URL:

Aims:

- To study the transition from association based reasoning to rule based reasoning.

Methodology/Areas of Investigation:

- Animal Cognition
- Evolutionary Theory
- Infant and Child Development
- Adult Concept Learning
- Neuroimaging
- Social Psychology
- Neural Network Modelling
- Statistical Modelling

Expected Results:

- Determine when and how the transition from association based reasoning to rule based reasoning occurs
- Determine whether there is a continuity between the cognitive processes of non-linguistic species and pre-linguistic children, and human adults

Abstract:
Human adults appear different from other animals by their ability to use language to communicate, their use of logic and mathematics to reason, and their ability to abstract relations that go beyond perceptual similarity. These aspects of human cognition have one important thing in common: they are all thought to be based on rules. This apparent uniqueness of human adult cognition leads to an immediate puzzle: WHEN and HOW does this rule-based system come into being? Perhaps there is, in fact, continuity between the cognitive processes of non-linguistic species and pre-linguistic children on the one hand, and human adults on the other hand. Perhaps, this transition is simply a mirage that arises from the fact that Language and Formal Reasoning are usually described by reference to systems based on rules (e.g., grammar or syllogisms). To overcome this problem, we propose to study the transition from associative to rule-based cognition within the domain of concept learning. Concepts are the primary cognitive means by which we organise things in the world. Any species that lacked this ability would quickly become extinct (Ashby & Lee, 1993). Conversely, differences in the way that concepts are formed may go a long way in explaining the greater evolutionary success that some species have had

over others. To address these issues, this project brings together teams of leading international researchers from 4 different countries, and with combined and convergent experience in Animal Cognition and Evolutionary Theory, Infant and Child Development, Adult Concept Learning, Neuroimaging, Social Psychology, Neural Network Modelling, and Statistical Modelling.

2.9. GEBACO

Full Title: Toward the Genetic Basis of Cooperation

URL:

Aims:

- To discover genetic influences on distinct aspects of cooperative behaviour that have been conserved through evolution.

Methodology/Areas of Investigation:

- Genetic study of siblings demonstrating certain traits

Expected Results:

- Identifying genes that influence strategic and communicative elements of 'cooperation'
- Test the hypothesis that syntenic gene function is conserved in other species

Abstract:

Cooperation has been described as an 'enduring evolutionary conundrum'. Our primary objective is to discover genetic influences on distinct aspects of cooperative behaviour that have been conserved through evolution. We aim to distinguish the strategic (economic) from the social dimension of the behaviour within dyadic interactions. We further aim to identify the genetic substrates of these dimensions. Our internationally reputed group of experts will study cooperation in diverse species (humans, primates, rats, mice, crows and titmice) from a variety of perspectives. The operational definition of 'cooperation' has recently been called into question. The use of simple game-theoretical models to study cooperative behaviour has been criticised on the grounds that it is unduly artificial and restrictive. We will devise novel empirical methodologies, which take greater account of the role of communication between conspecifics than traditional game-theoretic models. We propose a set of empirical studies, guided by two overarching theoretical imperatives. First, the notion of cooperation is reassessed. Second, an alternative model is derived, incorporating unique aspects of human cooperative behaviour. Genetic influences on cooperative behaviour may have been conserved through evolution.

We aim to find genes that influence strategic and communicative (social-reward) elements of 'cooperation', initially in humans. A novel internet-based testing strategy will identify subjects for genomic linkage studies. Quantitative trait loci will be discovered using identity-by-descent allele sharing between sibships, conditional on observed trait values. Candidate genes will then be identified. The hypothesis that syntenic gene function is conserved in other species will be tested. Individual variability in the propensity to cooperate within species, and genetic influences on

diversity, has implications for the evolution of not just cooperation, but social behaviour in general.

2.10. HANDTOMOUTH

Full Title: Hand to Mouth: a framework for understanding the archaeological and fossil records of human cognitive evolution

URL: http://www.handtomouth.ucl.ac.uk/home/

Aims:
- To understand archaeological and fossil evidence for the evolution of speech and manual dexterity

Methodology/Areas of Investigation:
- Physical and digital modelling of vocal tracts of extinct hominins
- Comparative anatomical study of primate cranial nerves
- Activation analysis of cortical motor circuits in the action system of nonhuman primates

Expected Results:
- re-evaluation of the possibility that tool use may have co-evolved with speech

Abstract:
HANDTOMOUTH develops a framework for understanding archaeological and fossil evidence for the evolution of speech and manual dexterity. We focus on low-order parameters which can potentially be assessed in fossil and archaeological evidence. The focus will be on motor control in complex, serially ordered, goal-directed movements, with two sub-themes: Speech production. This will include physical and digital modelling of vocal tracts of extinct hominins based on anatomical parameters, to recover the range of articulatory manoeuvres and acoustic characteristics. There will also be a comparative anatomical study of primate cranial nerves, which will address a neural substrate for speech motor control and sensory feedback regulation. The modelling will include small-scale perturbations of the model system to determine which components of the vocal tract are most sensitive in terms of effects on sound characteristics, and this will enable prediction of which cranial nerves may have increased sensory fibres as a speech-related adaptation. Tool use. This will address the relationship between action understanding and the self-generation of action sequences in human and non-human primates. It will include activation analysis of cortical motor circuits in the action system of nonhuman primates in sequentially complex action observation tasks, and kinematic analysis movement control in stone tool-making and other tool-using tasks in healthy and apraxic human subjects. As a unifying framework, we intend to re-evaluate the possibility that tool use may have co-evolved with speech, reflecting shared features of neural architecture. We identify possible areas of convergence and/or homology in behavioural organization and in neural architecture in the two systems. HANDTOMOUTH will enable us to evaluate the extent to which their co-evolution in

humans was necessary or contingent (and with a better understanding of the evidential controls).

2.11. NEUROCOM

Full Title: Neural origins of language and communications

URL: http://neurocomm.free.fr/

Aims:

- To compare the neural substrate of language and communication faculties in adult humans, babies and monkeys

Methodology/Areas of Investigation:

- Neural imaging
- Behavioural studies
- Psychology
- Linguistics
- Ethics
- Cognitive science
- Neuroscience

Expected Results:

- An informed view on what is uniquely human in the language faculty
- A deeper understanding of the neural substrate of language and communication

Abstract:
The Neurocom proposal compares the neural substrate of language and communication faculties in adult humans, babies and monkeys, using recently developed fMRI in babies and awake monkeys together with adult fMRI and NIRS in babies. The project investigates the neural substrates of different communication channels (speech, calls, emotional utterances and gestures) and of speaker invariance. It studies the neural processing of action interpretation in particular intentions and rational interpretation. Development and neural substrate of communicative referential cues will be studied. The final part addresses the core of language (recursion) by studying hierarchical structure in language and grammar at the behavioral and neural level. The imaging experiments will be supplemented with behavioral studies to calibrate the stimuli and tasks. The consortium brings together psychologists, linguists, ethologists, cognitive scientists and neuroscientists from four countries, including one new member state. The expected result is an informed view on what is uniquely human in the language faculty and a deeper understanding of the neural substrate of language and communication and its development as well as of the homology between human and monkey cortex.

2.12. Paul Broca II

Full Title: Evolution of Cerebral Asymmetry in Homo Sapiens

URL:

Aims:

- Consider the questions:
  - what is the neural correlate of the capacity for language?
  - what was the genetic nature of the transitions from a great ape-hominid precursor to modern H sapiens?

Methodology/Areas of Investigation:

- great ape-human comparisons of skull structure
- great ape-human comparisons of asymmetries of the cellular structure of association cortex
- great ape-human comparisons of the structure and organization of inter-hemispheric connexions
- studies of the splice structure and expression of ProtocadherinX and Y
- investigations of the epigenetic control of sapiens-specific regions of homology
- studies of brain structure and the lateralisation of language in individuals with sex chromosome aneuploidies

Expected Results:

- Evaluation of Paul Broca's hypothesis that asymmetry is the feature that defines the human brain

Abstract:
The essence of being human is the ability to communicate with language. This project addresses the questions what is the neural correlate of the capacity for language and what was the genetic nature of the transitions from a great ape-hominid precursor to modern H sapiens? Paul Broca's hypothesis that asymmetry is the feature that defines the human brain will be investigated in skull and brain structure and followed through the lead that a genetic determinant is located in a region of X-Y homology subject to change in the hominid lineage. It is argued that a series of changes influenced the timing of brain development. The Xq21.3/Yp sapiens-specific region of homology that includes the ProtocadherinX and ProtocadherinY gene pair is the salient candidate genomic region. The project investigates these hypotheses through i) great ape-human comparisons of skull structure including asymmetries, ii) great ape-human comparisons of asymmetries of the cellular structure of association cortex, iii) great ape-human comparisons of the structure and organization of inter-hemispheric connexions, iv) studies of the splice structure and expression of ProtocadherinX and Y, and investigations of the epigenetic control of sapiens-specific regions of homology, and v) studies of brain structure and the lateralisation of language in individuals with sex chromosome aneuploidies as exemplar anomalies of expression of the asymmetry determinant.

2.13. PKB140404

Full Title: Molecular evolution of human cognition

URL: http://www.eva.mpg.de/

Aims:

- identify and characterize recent molecular innovations involved in cognitive abilities unique to humans

Methodology/Areas of Investigation:

- Molecular evolution
- Bioinformatics
- Molecular neuroscience
- Clinical psychiatry

Expected Results:

- Identify "human cognition" genes
- Comparative expression analyses between human and ape brains
- Pinpoint genes associated with higher cognitive function in humans

Abstract:
Major changes in the structure, functional complexity, and size of the brain led to the cognitive abilities of extant humans. Adaptive changes in early hominoid evolution likely laid the foundation for more recent changes on the human lineage. We will use an integrated approach – bridging cognitive neuroscience and molecular evolution – to identify and characterize recent molecular innovations involved in cognitive abilities unique to humans. We will achieve this by comparing humans and apes using the following three complementary strategies: 1) We will identify "human cognition" genes that originated recently on the primate lineage by gene duplication and show signatures of adaptive evolution (genome level). 2) Comparative expression analyses between human and ape brains will shed light on differences that evolved at the transcriptome and proteome levels. We will distinguish between neutral and selective expression changes. 3) We will pinpoint genes associated with higher cognitive function in humans by a comparative study of a complex neurocognitive disorder (schizophrenia) and normal controls (transcript level, proteome level). The functional relevance of changes in candidate genes derived from approaches 1-3 will be elucidated using transgenic mice. We will cross different transgenic mouse lines to combine candidate genes with the long-term goal to reconstruct adaptive changes that led to the emergence of neurological functions that form the basis of aspects of human cognitive abilities. Our approach and the groups involved provide a highly interdisciplinary framework (molecular evolution, bioinformatics, molecular neuroscience, and clinical psychiatry). Thus, it reflects the spirit of the program and is likely to foster to high-quality research that is likely to attract wide interest in society at large.

2.14. REFCOM

Full Title: Origins of Referential Communications

URL: None found

Aims:
- To understand the origins of referential communication.

Methodology/Areas of Investigation:
- Observational and experimental studies in the wild and in captivity exploring:
    - the semantic flexibility of referential calls in monkeys, dolphins, and parrots
    - the use of referential calls and referential gestures in great apes and canids, and their combination with skills such as Theory of mind to govern their strategic use.

Expected Results:
- reassessment of the notion of referential communication
- A model of how and why the unique ways of human referential communication evolved.

Abstract:
This proposal brings together scientific teams working from a variety of perspectives on one of the defining features of human cognition —referential communication. This ability was once thought to be uniquely human. But recent research suggests that other species, including not only primates but also more distant evolutionary relations, have evolved referential signals. Our starting point is that human referential communication should be conceived of not as one ability supported by a single mechanism, but as a complex function that results from the integration of diverse mechanisms that may have different evolutionary origins. Understanding referentiality requires an analysis of its component skills and how they can be articulated into systems of varying complexity. This can be best achieved through a crossdisciplinary comparative evolutionary approach. Our aim is to implement such an approach tracking the evolutionary origins of some of the key components of referentiality and the diverse ways in which they are realised and combined by evolution. We propose a set of empirical projects aimed at gathering innovative evidence on referential signals in various species of primates (including humans) and non-primates. These combine observational and experimental studies in the wild and in captivity exploring the semantic flexibility of referential calls in monkeys, dolphins, and parrots, the use of referential calls and referential gestures in great apes and canids, and their combination with skills such as Theory of mind to govern their strategic use. Our proposal unifies concepts and methods, and applies similar tests across species to guarantee the comparability of data. The empirical studies are integrated with two overarching theoretical projects aimed at reassessing the notion of referential communication and proposing a model of how and why the unique ways of human referential communication evolved.

2.15. SEDSU

Full Title: Stages in the evolution and development of sign use

URL: http://www.sedsu.org/

Aims:

- To evaluate the hypothesis that it is not language per se, but an advanced ability to engage in sign use that constitutes the characteristic feature of human beings

Methodology/Areas of Investigation:

- Investigate the role of
    - perception and categorization
    - iconicity and pictures
    - spatial conceptualisation and metaphor
    - imitation and mimesis
    - intersubjectivity and conventions

  in the development of sign use.

Expected Results:

- To find similarities and interactions between development of sign use in the above domains
- A coherent theory of semiotic development.

Abstract:

There remains, despite centuries of debate, no consensus about what makes humans intellectually and culturally different from other species, and even less so concerning the underlying sources of these differences. The main hypothesis of the project Stages in the Evolution and Development of Sign Use (SEDSU) is that it is not language per se, but an advanced ability to engage in sign use that constitutes the characteristic feature of human beings; in particular the ability to differentiate between the sign itself, be it gesture, picture, word or abstract symbol, and what it represents, i.e. the "semiotic function" (Piaget 1945). The project is highly interdisciplinary and the single research effort will afford new possibilities for methodological innovation, and the collection and analysis of new types of comparative data. The central research objective of the project is to investigate the developmental and comparative distribution of semiotic processes, and their effect on cognition. For this purpose we single out five cognitive domains, and propose to study their interrelations and role in the development of sign use. They are: (a) perception and categorisation, (b) iconicity and pictures, (c) spatial conceptualisation and metaphor, (d) imitation and mimesis and (e) intersubjectivity and conventions. They are all characterised by stage-like developmental profiles which we expect to correlate with differences in sign use. The investigations in the different domains will be carried out in parallel, with extensive sharing of methodologies and results. Since we hold that each domain plays a key role in providing cognitive prerequisites for the development of sign use, and at the same time is transformed by the acquisition of the latter, we expect to find considerable similarities and interactions between developments in the domains. Finally, we intend

to integrate all the results of the SEDSU project in a coherent theory of semiotic development.

2.16. Wayfinding

Full Title: Finding your way in the world: on the neurocognitive basis of spatial memory and orientation in humans

URL: http://wayfinding.fss.uu.nl/

Aims:

- An ambitious, exhaustive examination of:
  - the cognitive organization of spatial memory and orientation
  - how this important ability is implemented in the human brain
  - how this contrasts to similar abilities in other species
  - delineating which spatial functions are uniquely human and why they are so
  -

Methodology/Areas of Investigation:

Expected Results:

- Mapping of the individual differences in spatial ability (e.g. gender, age and cultural)
- Identification of the needs and preferences different individuals have in dealing with the spatial structure of their environments (women/ men, blind, elderly and brain damaged individuals).

Abstract:
Spatial memory and orientation – knowing what is where and how to get there – are vitally important for our daily life. Without it we would continuously be searching for our keys and glasses, and we would not be able to find our way back home or navigate through our surroundings. It has been estimated that spatial memory and orientation are among the prime functions affected by normal and pathological aging such as in the case of Alzheimer disease. Partly, this is not surprising because these functions are relatively complex, requiring planning, mental manipulation and synthesis, and decision making. Interestingly, the ability to construct spatial representations of the outside world and to store them in memory has been argued to have formed the driving force behind the evolution of all higher cognitive functions in men. While several species of birds, mammals and nonhuman primates appear to posses clear spatial abilities, these never reach the variety and complexity of the human system. This STREP proposal aims for an ambitious, exhaustive examination of the cognitive organization of spatial memory and orientation; of how this important ability is implemented in the human brain and how this contrasts to similar abilities in other species; of delineating which spatial functions are uniquely human and why they are so. These higher order spatial functions include perspective taking, verbally communicating spatial information, and planning one's way through complex

environments. Today's modern society places enormous loads upon our ability to navigate through the world. Understanding how the human navigational and updating system works has direct practical, social gains. We specifically will try to map the individual differences in spatial ability (e.g. gender, age and cultural) and the needs and preferences different individuals have in dealing with the spatial structure of their environments (women/ men, blind, elderly and brain damaged individuals).

3. Review of Selected Research into Communication

Communication has been a subject of interest for centuries. As far back as ancient Greece and Ancient Rome effective communication was crucial [Gleason 95], [Laird 99] and [Newbold 90]. In the context of this single restricted project NESTCOM a disclaimer is therefore in order: we cannot aim at covering all aspects of communication but we select some representative pieces of research which address the underlying principles of what it means to be human and what it means to communicate where language certainly plays an important role.

The advent of modern computational modeling has increased not only the number of methods, or modes, which we can use to communicate effectively but also means there is now communication between humans and computers. This has led to a parallel diversification in the study of communication, matched by the diverse fields which are involved in research into communication. This has implications in psychology, anthropology, computer science, neuroscience and ergonomics, as well as many other fields.

The general aim of the NEST initiative has been to understand what it means to be human—to develop an understanding of the cognitive, evolutionary, neural, social, computational and developmental features that have led to differences between humans and animals. A number of interesting and successful projects have been supported under the NEST initiative including for instance learning by imitation (EDICI), examining the origin of human rule based reasoning (FAR), studying the neural origins of language (NEUROCOM), exploring the evolutionary origins of human mind (PKB140404), researching into verbal and nonverbal communication (REFCOM), using and interpreting signs (SEDSU), characterising human language by structural complexity (CHLASC), and representing abstract concepts (ABSTRACT).

The range of potential benefits from understanding how we communicate is wide. There are educational benefits from some projects of the EU NEST initiative, for example the ANALOGY project, the CALACEI project and the EDICI project. Some work offers benefits for the cognitively impaired such as the CHLaSC project and again the EDICI project. Other projects offer the opportunity to improve the way we interact with technology, such as the Wayfinding project which aims to produce better navigational aids.

Much of the previous research has focussed on the topic of communication solely from the specific point of view of the researchers performing the work, with little or no attempt to integrate their work into a wider context. In this review we describe their work and analyse links between complementary research. We shall begin by looking at the neural architectures and mechanisms involved in communication, then examine the different modes of communication and finally look at how cross modal communication.

3.1. Neural Organisation covered by NEST Projects and Beyond

In this section we shall study the structure of the brain as related to communication. We shall first consider the brain at a regional level before moving to the structures and arrangements at the individual neuron level. The trend that emerges is one where the traditional view of the brain as a modularised entity with highly specific regions dealing with certain responsibilities is being replaced by a more distributed model of processing of cognitive functions. The objective here is to present an overview of current research with a focus on NEST projects and as such, there is much more research which could be cited.

3.1.1. Lateralisation of Cognitive and Communicative Functions

For many years the study of the human brain and its structure was based around the principle of lateralisation which suggests that brain is split into two halves, the cerebral hemispheres, and that each is responsible for a particular set of functions. Recent research suggests that this is less of a hard rule, and more a trend that is present in the majority of individuals in the majority of cases [Shytrov 04].

In the case of speech and language, it was generally accepted that these functions were handled by the left hemisphere of the brain, specifically in Broca's region [Broca 1861] and Wernicke's region [Wernicke 1874]. Recent research has refined this view. Shtyrov et al [Shtyrov 04] propose that the semantic processing of certain words and phrases does not occur in the aforementioned language centres, but rather it occurs in the motor control regions of the brain associated with that word. The word 'kick' for example, may be processed in the region of the brain associated with the leg or foot. Shtyrov et al [Shtyrov et al 05] go on to present a refined view of communication in terms of lateralisation, proposing that sounds involving language are dealt with in the left hemisphere, while non-speech sounds are processed in the right hemisphere, and underline the assertion that lateralisation of speech is based on the underlying mechanisms such as memory traces. Zatorre and Berlin [Zatorre and Berlin 02] have found that the left hemisphere is capable of processing sound with greater temporal resolution than the right hemisphere reinforcing this view of lateralisation. The lateralisation of language processing is further discussed in [Binder et al 00].

Further research on the lateralisation of the human cortex is being performed as part of the PAUL BROCA II project; a study of lateralisation in individuals with anomalies in the sex chromosomes is being performed. Additionally the interhemispheric connections between the two halves of the brain are studied in comparison with great apes. The Wayfinding project has discovered that there are differences in the lateralisation of spatial awareness and haptic orientation which is found to be dependent on hand orientation only in right-handed males [Zuidhoek et al.]. The EDCBNL project is focussing on bringing all of this lateralisation research together to form a complete understanding of brain lateralisation against the context of modern research from an evolutionary, developmental and genetic standpoint.

3.1.2. Regional Division of Communicative Functions

Recent research has moved our understanding of the regional division of cognitive and communicative functions. The brain is now considered to be far less modular than it once was. An example of this is in the processing of language; for example action words such as 'kick' fire neurons in the part of the brain that control the motor action associated with the word i.e. the foot in this case [Pulvermuller 05]. However, the structure in the brain is far from random in its organisation and there is still an underlying language system with different 'modules' performing various functions [Friederici 02].

Scott and Johnsrude [Scott and Johnsrude 05] discuss the different pathways through the brain that are involved in processing speech and propose that the different pathways perform different functions. For example the anterior routes, involving the anterior belt and parabelt, the polymodal cortex of the anterior STS, and ventrolateral and dorsolateral frontal cortex seem to be responsible for mapping acoustic–phonetic cues onto lexical representations. Price [Price 00] also studies the areas of the brain involved in language, including which regions are involved in reading and supports regional division of communicative reading functions.

Other studies have isolated particular brain regions which are responsible for certain cognitive traits. The FAR project is investigating rule-based learning. It has established that the frontal lobe and basal ganglia are responsible for rule-based learning, while similarity-based learning occurs in the frontal temporal lobe [Opitz 04]. The project is working on developing a deeper understanding of these modes of learning. Several discoveries have already been made as to the processes and mechanisms involved in rule-based learning and categorization, such as the relationship between infant perceptual categorisation and adult auditory classification, which appear to use the same mechanisms, and that adult associative concept learning is determined by automatic neurological processes [FAR].

The NEUROCOM project is aimed at mapping the neural substrate of the brain responsible for speech, gestures and calls with the aim to developing new knowledge of the functional architecture of the brain. It is already known that the Superior Temporal Sulcus (STS) contains voice-selective areas and is generally more active in response to speech sounds than non-speech stimuli [Berlin 00], and that certain regions of the STS react more strongly to familiar voices than to those of strangers [Kriegstein 04]. Furthermore it seems likely that this response is human-specific [Fecteau 04].

The NEUROCOM project is also investigating the Visual Word-Form Area (VWFA) which is an extended strip of the left fusiform gyrus. This region is activated by visual words but only when they are presented in a written context and not when they are spoken [Cohen 02][Dehaene 04].

The CALACEI project is studying the areas of the brain which are key for language acquisition and their development in infants. The Wayfinding project also has objectives for isolating the regions of the brain concerned with spatial cognition. The current research is based on the proposition that spatial processing occurs in the hippocampus and parahippocampus, fronto-parietal cortex, anterior cingulate, and the vestibular system [Wayfinding http://wayfinding.fss.uu.nl/index.php?option=com_content&task=view&id=23&Itemid=92].

3.1.3. Multimodal Neural Communication Structures within the Brain

The role of the superior colliculus has been the subject of recent research since it is the first midbrain area where multimodal neural integration occurs. This area of the brain is best known for being responsible for saccadic eye movements and eye head coordination. Recent research has suggested that it is also responsible for multisensory integration of the senses, specifically with respect to orientation and attention [Konishi 86][Stein 93].

Besides the midbrain and superior colliculus, recent research into cortical neural structures within the brain has uncovered the importance of networks of so-called mirror neurons. These are neurons which fire either when a subject performs a given action or witnesses that action being performed. Such neurons have been identified in monkeys, in the inferior frontal gyrus and inferior parietal lobe. It is not possible to study individual neurons and their activation in humans but brain imaging experiments have, however, revealed regions within the inferior frontal cortex and superior parietal lobe which are active during both the subject performing, and witnessing a given act, suggesting the presence of a mirror neuron mechanism, as described in [Rizzolatti 04]. The mirror neuron system also plays an important part in imitation, as discussed by Rizzolatti et al [Rizzolatti 99][Rizzolatti 04].

The mirror neuron system is discussed in the work by Gallese [Gallese 05], which discusses the firing of mouth-related mirror neurons in monkeys. Witnessing actions which belong to or are similar to the observers motor repertoire, in this case monkey-style lip-smacking and biting, causes firing in the motor regions of the brain whereas actions unrelated to this repertoire lead to firing in visual areas of the brain. Similar principles apply to hearing certain sounds, as discussed in [Kohler 02]. Mirror neurons and the capacity for imitation seem to play a part in the learning of language [Rizzolatti 04] and in the neural coding of abstract concepts [Kohler 02].

Mirror neurons seem to play a part in the human capacity to understand or develop an insight in to the goals or motivations when observing others performing a task, rather than passively watching [Gallese 04]. This capacity for action understanding and even empathy on a higher cognitive level involving mirror neurons may offer an insight into what distinguishes humans from other species.

The overall goal of the MirrorBot project was the development of biomimetic multimodal learning and language instruction in a robot. Based on cognitive neuroscience evidence of cell assemblies and mirror neurons, neural architectures were designed and trained to perform basic actions. Neuroscience experiments were also carried out to aid understanding on how the brain processes words and how the mirror neuron system aids the recognition and understanding of actions.

The EDICI project is focussed on studying imitation, including 'neurological effects of perceptual-motor experience' and a 'review of comparative neuroanatomy'. Similarly, the NEUROCOM and REFCOM projects are likely to find mirror neurons relevant to their work. NEUROCOM is concerned with mapping the parts of the brain which are active when the subject is exposed to speech, gestures and calls, and REFCOM is studying referential communication.

The layout of visual neurons in the brain is of interest to the MCCOOP project [MCCOOP http://www.pspc.dibe.unige.it/Projects/MCCOOP.html] which suggests that the layout of neurons processing visual information is topological, within groups related to certain functions such as 3-dimensional motion or edge detection which is a theory supported by earlier research [Stein 93]. Besides visual processing, topological organisation can also be found for auditory processing which is performed in the midbrain in the inferior colliculus which appears to be structured by frequency [Schreiner 88]. In general, neurons dealing with early sensory and motor processing are laid out in map-like structures within their respective regions of the brain [Stein 93]. It is suggested in [Stein 04] that this organisational structure is reflected in regions of the brain where integration of the senses occurs.

3.2. Verbal Communication

In this section we shall outline research into language and communication. We shall first summarise how linguistic abilities develop, then consider various models of how language is processed both within the human brain, and in biologically inspired computer systems.

3.2.1. Elements of Language and Broca's Region

When studying language and linguistic communication, most researchers distinguish between semantic properties and syntactic properties of language [Morris 71] [Silverman 83]. Semantic properties are those concerned with the meaning and content which is to be conveyed, while the syntax is the set of rules which is used to give structure to the lexical units.

The role of Broca's area in processing these elements of language is explored in [Fiebach 05] which concludes that this region plays a part in the working memory associated with syntactic processing. This is supported by [Musso 03] who concludes that Broca's area is more responsive to attempts to learn real languages which involve real syntax rules, as opposed to artificial languages which do not conform to such rules. Further support is found in the Positron Emission Tomography (PET) studies carried out in [Stromswold 96] who record increased blood flow to Broca's area when processing sentences which are syntactically more advanced, and in [Tettamanti 02] which uses fMRI to observe increased activiation in Broca's area during the acquisition of grammatical rules. The neural basis for syntax and the involvement of

Broca's area is also explored in [Friederici 03], [Kaan 02] and [Jacquemot 03] and the ability to detect sentences that are well formed grammatically, and the mechanisms involved in this process are discussed in [Pulvermuller and Knoblauch 05]. There is also research suggesting that Broca's area is involved in certain other activities such as finding a target in a complex geometric pattern, action recognition and movement preparation [Hagoort 05].

Wernicke's area is connected to Broca's area by the arcuate fasciculus and encircles the auditory cortex. [Wernicke 1874]. Wernicke's area is primarily focussed on the semantic processing of spoken language. While in the Broca's area certain motor and action areas are active in processing language, other areas deal with the syntactic component. Perani et al [Perani et al 01] suggest that this syntactic processing takes place in several areas of the brain including the left and right neocortical areas, as well as other portions of the brain, such as the basal ganglia and the cerebellum.

As previously stated, recent research has refined the current understanding of language processing. Shtyrov et al [Shtyrov 04] propose that the semantic processing of certain words and phrases does not occur in the aforementioned language centres, but rather it occurs in the motor control regions of the brain associated with that word. The word 'kick' for example, may be processed in the region of the brain associated with the leg or foot.

[Price et al 96] discusses the relationships between the regions involved in processing heard spoken language and generating speech. The organisation of the various language processes in the brain is the subject of the RTN:LAB research network.

3.2.2. Linguistic Development

The development of language skills in human beings is one of the key factors distinguishing humans from non-humans. The evolutionary origins of language remain controversial, and shall not be covered here, but neural systems involved in language which might explain the difference in linguistic abilities is discussed in [Friederici 03]. The development of language in children is one of the key stages in infant development, indeed some researchers group pre-linguistic infants with non-linguistic species emphasising the importance of language skills in human development.

One of the key aims of the FAR project is to establish whether the use of language is responsible for differences between humans and non-humans. Other research into the development of language skills includes the CALACEI project which is investigating the cerebral processes involved in speech, and investigating the mechanisms involved in infants acquiring semantic and syntactic elements of a language. The EDICI project is looking at the role imitation plays in human acquisition of language while the development of grammatical relations in children is described in [Morris 00]. The development of language during childhood was the subject of the EU funded EURESCO project on 'The Structure of Learner Language". Language disorders which appear during language development was investigated by the NEUROGENETICS project in an attempt to identify the genes involved in linguistic development and improve understanding of the basic molecular mechanisms involved in speech and language development. Genetic issues in language development were also discussed at the INFANTSPEEP WORKSHOP. The perception of speech during language development was investigated as part of the ROPP project.

3.2.3. Models of Syntactic and Semantic Linguistic Processes

As previously stated, language processing generally involves the interaction of semantic and syntactic processes. Some studies of language processing in humans suggest that the brain handles these processes of linguistic communication separately. For instance, the CHLaSC project is studying syntactic and semantic mechanisms linking language to other areas related to our non-linguistic representation of the environment [Ludwig 06]. It is suggested that these semantic models could be mapped into the syntactic structures associated with a certain language. There is also a possibility that certain linguistic elements and syntactic structures exist in these semantic models. Such a structure could simplify the complexity of semantic models [Ludwig 06].

On the other hand, there is work which has suggested that it is possible to extract semantic meaning from sentences without knowledge of grammar [Morris00][Moisl 01]. The associations between language and neural regions related to certain words are explored in [Markert 05], [Fay 05] and [Honkela 00]. The effect of quick presentation of visually related words is explored in [Dehaene 98], which discusses masked priming where such words may not be visualised but may prime and facilitate the visualisation of subsequent words. A model including the integration of visual and auditory processes is described in [Panchev 05] [Panchev and Wermter 06], where this model is evaluated in a robot which has to deal with real instructions.

There are some other recent relevant project which should be mentioned. The way in which we segment speech, detecting the boundaries between words was the focus of the SPEECHSEG project which considered the role of prosodic and multi-sensory cues such as observation of the speakers mouth movements in this task. The segmentation of speech in infants during linguistic development was the subject of the ISS project. On a higher level of abstraction, the DANDI project looked at the structure and nature of dialog, including what constitutes an answer to a question, the focus of conversations and the role of intonation. The DPSP project used speech errors as an indicator for the mechanisms involved in speech production.

3.2.4. Linguistic Human-Computer Interaction

The use of speech and language has been researched for potential improvements to human computer interaction. Rudimentary speech recognition software exists, which is based largely on recognising phonetic sounds. This is usually aided by some linguistic modelling. A number of refinements are being developed to address some of the difficulties involved is speech recognition. The PF-STAR project looked at extending speech recognition using techniques for emotion recognition and classification [Steidl 05] [Batliner 04]. This project also studied speech technologies for children, where language skills were not as highly developed which causes difficulties in automatic recognition.

The ACORNS project is developing, integrating and testing mathematical models and mechanisms for acquiring verbal communication skills by learning dynamic patterns of speech, as well as non-speech sounds, while the DYANA and DYANA-2 projects focused on the underlying structure of grammar, architectures and models for improving natural language processing. The ACCOR and ACCOR II projects looked at representing the articulatory mechanisms involved in speech production and set up a database of articulations. The Molecular Linguistic Networks for Natural Language Processing project looked at using molecular biology models and their application to model semantic and syntactic mechanisms in language. The CORETEX project addressed various aspects of speech technology with the aim of making speech technologies less domain- and language- specific.

Various approaches are taken to account for different spectral qualities in childrens speech in [Stemmer 03] and [Giuliani 03]; and adaptation of the models used in recognition [Steidl 03],[D'Arcy 04a]. The effects of non-native infant speakers is considered in [Gerosa 04a] and [Gerosa 04b]. Other work on speech recognition for children is described in [Batliner04], [Blomberg 03] and [Blomberg 04].

One of the other major sources of variation in speech which hinders successful recognition is regional accents, an area which was studied as part of the ABI project [D'Arcy 04b]. Speech recognition is further influenced by the effects of non structured, conversational speech, an area addressed as part of the PF-STAR project [D'Arcy 04a]. The understanding of spontaneous speech in the context of a telephone conversation is the subject of the LUNA project. Where difficulties are encountered in speech recognition, it is useful to be able to detect inaccurate recognition, which was addressed as already in the late 1980s by the CFID project and was also addressed as part of PF-STAR [Batliner 04][Stiedl 04] and the current DEAWU project which is focussed on clarifying misunderstandings in speech recognition.

Text-To-Speech (TTS) and Speech-To-Text (STT) systems are another area of research into linguistic human-computer interaction. A major project to develop these technologies for Slavonic languages has recently been completed which covered aspects such as the prosodic nature of the speech involved and its syntactic nature. The VAESS project dealt with improving speech generation technologies by replacing artificial-sounding voices with more natural ones by including a range of attitudes and emotions in the synthesiser. The LC-STAR project developed lexica and corpora to allow components of translation, TTS and STT systems to be converted to different languages. The use of linguistically-enabled computer systems for translation was the subject of the METIS project and is being continued by the METIS-II project. Research into developing a complete dialog system was undertaken as part of the SIRIDUS project and much work has been done on multiple language information retrieval systems, including the SPARKLE project.

3.3. Visual Communication

Human beings acquire a vast amount of information about the world around them from what they can see, and this reliance on vision extends to communication. Visual communication is not always explicit or voluntary – humans are able to infer and interpret signals from people with whom they converse, such as the emotional state of the person they are conversing with. As such our discussion of visual communication shall be analysed as either implicit or explicit.

3.3.1. Implicit Visual Communication

Implicit visual communication refers to unintended, non-deliberate communication. This can be split into two categories: Facial expressions and body language. The study of facial expressions and the interpretation and understanding of facial features, Physiognomics has been an area of study for hundreds of years [Ekman 73],[Evans 69]. Research is currently underway into techniques to recognise and classify facial expressions. Researchers at the University of Surrey [CVSSP http://www.ee.surrey.ac.uk/Personal/N.Nadtoka/] are advocating the use of principal component analysis for this. The PF-STAR project studied the use of synthetic faces to convey emotions as part of wider research into emotional aspects of communication, and mechanisms for capturing emotional expressions from human test subjects using the relative positions of facial features [Cosi 04], [Beskow 04],[Nordstrand 03a] and [Nordtrand 03b].

3.3.2. Explicit Visual Communication

Explicit visual communication can occur in many forms. There are many sub-modes that can be associated with visual communication, to include written language, sign language and various forms of image-based communication. Here we shall focus on the later category; written communication overlaps heavily with the section on verbal communication since the salient meaning is embedded in the linguistic content. Sign language is considered as a gesture-based mode of communication since the design of many sign languages is based on efficiency of 'speech'.

One of the key benefits of communicating information visually is the ease of conveying spatial information. One of the early objectives of the Wayfinding project [Wayfinding http://wayfinding.fss.uu.nl/] is to study the development of the capacity for mental imagery and its formation in infants and how this interacts with spatial cognition. The ability to form mental images is considered by this project team to be uniquely human [Salvesen 65]. The amount of information that is obtained and inferred by the human vision system and related cognitive processes about the world around us is vast, and could not be easily transmitted by any other means. The FAR project has already discovered that children as young as 8 years can form categories of objects based on abstract spatial rules.

Another advantage of vision as a mode of receiving information is that it is possible to acquire many different 'channels' of information. Examples for such channels are colour and form. The Mirrorbot project looked at the processing of colour as well as form information, studying brain activity related to the processing of colour and form concepts and found that these concepts are handled in a similar manner to certain abstract concepts and are linked to certain semantic models and motor responses [Fay 05].

The direction of visual attention is crucial to such forms of communication. The GAZECOM project is studying ways in which the direction of gaze, and as such visual attention, can be exploited to improve visual communication using an understanding of neural mechanisms that control gaze.

3.4. Gesture-based Communication

Human beings use gestures in a variety of ways. Sometimes this is deliberate, particularly if there is some form of spatial information such as a direction to be conveyed. Sometimes the gesture is less deliberate, such as a shrug of the shoulders or a nod of the head to convey uncertainty or an affirmative, or in some cases, a negative response respectively. The neural architectures involved in gestures were investigated and modelled as part of the DYGEST project.

Involuntary gestures include actions such as nodding or shaking the head, waving, shrugging the shoulders, and facial expressions. David McNeill at the Center for Gesture and Speech Research considers gestures to be integral with speech, and experimental evidence supports this assertion suggesting a common cognitive basis [McNeill http://mcneilllab.uchicago.edu/topics/topics.html]. Research on language acquisition in infants suggests that gesture is a key facet based on the EDICI project into communicative referential cues. This is also supported by the presence of links between the neural regions involved in language and motor regions [Buccino 05] and work performed as part of the HANDTOMOUTH project investigating the part that gesture played in the evolution of language. The GESTURE project is investigating the link between gesture and speech and the temporal coordination between these modes of communication, while the PF-STAR project also studied the link between the timing of speech and gesture and concluded that the use of gestures has implications on the timing of speech [House 04],[Burger 03]. This project also found that head movements are a crucial mechanism for conveying feedback in face to face conversation [Skhiri 03]. Care must be taken when interpreting such head-based gestures since regional differences exist in meaning, the nod of the head can be used to convey a negative response in some parts of the world, for example eastern Europe and Sri Lanka [Wikipedia, http://en.wikipedia.org/wiki/Nod_%28gesture%29].

One of the most sophisticated forms of gesture-based communication is the use of sign language, particularly in individuals with some impairment preventing other forms of communication, such as deafness. Martha's Vineyard Sign Language is an example of where such a language has developed due to a high density of deaf people, and became widely used amongst the entire community due to its isolated nature and the lack of external influences. The cortical mechanisms involved in sign language, specifically Spanish sign language, has also been investigated as part of an EU project. The SIGNBASE project investigated the development of a multimedia multilingual sign language database, containing sign language and written language. An automatic means of translating sign language into English language was developed by the TALKING HANDS project. Alternate means of communication for those with hearing impairment are available and have been the subject of research. The SPLIT project looked at ways to convert speech from a telephone signal into a synthetic, animated head that a hearing-impaired person can lip-read from, while the COGAIN project is researching the use of gaze as a means for people with motor-impairments to control voice synthesisers/TTS systems when other means of gesture and interaction are not available.

One of the other major uses of gestures is to convey spatial information, such as when pointing to direct attention. A simple system for interpreting such gestures automatically is described in [Hafner 05]. The HISCORE and ongoing INTERACT project looked at extending gesture technologies to allow for 3D representations.

3.5. Integrated Approaches to Communication

Throughout the course of this review we have encountered links between modes of communication, and between modes of communication and other cognitive processes. Here we shall summarise these links.

3.5.1. Architectural Support for Cross-modal Communication

A range of evidence has been discussed for neurological relationships that facilitate cross-modal communication. Buccino observed links between language and motor regions of the brain, with certain 'action' words modulating areas of the brain concerned with performing those actions [Buccino et al. 05]. Hauk et al [Hauk 06] extended this work by subjecting subjects to the sounds of finger clicking and tongue movements and similarly observing a response in related regions of the brain. The case for such a structure is described by Pulvermuller [Pulvermuller 05b], and by Shytrov [Shytrov 04]. Further support for the links between the neural substrates for different modes of communication is found in the previously mentioned works by [Gallese 05], [Markert 05] and [Fay 05]; and in the work of the CONTACT project [CONTACT http://www.liralab.it/contact/]. Current research into this neural substrate includes the HANDTOMOUTH project, which is investigating the neural substrate for speech motor control. A computational architecture which simulates the neural integration of language, vision and motor control is described in [Wermter et al. 04].

As previously discussed, the superior colliculus plays an important part in integrating information from the various senses. Stein et al [Stein 04] suggest that the map like topological organisation of the various sensory inputs to the superior colliculus allows integration to take part at the level of single, multimodal neurons with overlapping receptive fields. It is suggested that such an architecture could be present in other parts of the brain.

3.5.2. Cross-Modal Communication

Perhaps the most widespread example of cross-modal communication is the link between speech and gesture. Research exploring this link includes work carried out by the Center for Gesture and Speech Research [McNeill http://mcneilllab.uchicago.edu/topics/topics.html], the EDICI project, the GESTURE project and the HANDTOMOUTH project. Another example of cross modal communication is the combination of written language and images of some variety, which has been available for many years in printed media [Mitchell 86], and more recently on the world wide web.

Some researchers consider speech to be a multimodal process, as outlined by several chapters in the book by Calvert, Spence and Stein [Calvert 04]. Massaro details the integration between speech and vision and considers the effect of vision on speech for subjects with impaired hearing [Massaro 04]. Munhall and Vatikios-Bateson suggest that it is the low frequency information from all relevant modes that is important for speech perception, whether this is low spatial frequency in visual information or low audio frequency in speech itself [Munhall 04]. Fowler [Fowler 04] explores the need for a ‘common currency’ across the modes used for speech perception and suggests that this is also required for speech itself. Bernstein et al consider two paradigms for the integration of speech, and favours association of separately processed modal outputs rather than a converged, integrated processing [Bernstein 04].

3.5.3. Human – Computer Cross-modal Interaction

Much research has occurred in recent years on integrating various modes of communication into human-computer interaction. This is relevant not only in our interactions with technology, but also as a means of human-human interaction which increasingly involves technology. The PFSTAR project was involved in work to develop emotive talking heads, [Cosi 03] and [Cosi 04], which express emotions facially, and means in which to add emotion and prosody into speech [Tesser 04] and [Drioli 03]. Further methods have been developed to allow computers to detect these communicative features [Steidl 05][Batliner 04].

The use of gestures in human computer interaction, in the context of automatic speech translation is explored in [Burger 03], while a practical system integrating speech recognition and interactive maps and webpages was developed as part of the NESPOLE project [Constantini 02]. As previously stated, the links between gesture and speech have been researched intensively, e.g. the ERMIS project looked at the detection of a users emotional state through their use of language and gesture. The fusion of gestures with speech to form a multimodal understanding of a scene was the focus of the CHAMELEON project. The INTERACT project is bringing together 3D visualisation and sensing technologies for gesture based interaction with speech recognition.

Several projects have looked at the role of computers as a means of human – human communication. The Eye-2-Eye project was based around human to human multimodal telecommunication using computers and other equipment. This project evaluated technologies such as virtual reality in this context. The AVATAR-CONFERENCE project studied the use of virtual 3D representations of users in virtual online conferences. The NECA project also explored the use of these avatars for ‘social behaviour by proxy’. The PASION project is studying how communication within a community using technology can be made more suitable for social communication. The NICE project developed an online world for Edutainment with which children could interact through spoken language and with simple 2D gestures.

Robotics is a field where human-machine interaction and communication is rapidly progressing. The SPEECH MAPS project looked at developing a robot arm which could learn to associate gestures with speech and produce gestures to complement speech. The current COMMROB project involves multimodal interaction using speech and action which included movement and gestures. The ethics of increasing integration between humans and robots is being explored as part of the ETHICBOTS project.

Finally, the correct and most appropriate choice of communication mode is crucial in human-machine interaction. The GRACE project looked at techniques for automatically selecting the most appropriate combination of language, graphics and animation.

3.5.4. Integration of Communicative and other Cognitive Processes

Links have been established between communicative processes and other cognitive areas. The Wayfinding project is examining the links between linguistic communication and spatial cognition. The CHLaSC project is studying the links between areas of the brain related to language and those associated with the semantic models of the world around us. This is mirrored by the previously mentioned work by Shtyrov et al [Shtyrov 04] which discusses links between language areas of the brain and motor areas of the brain. This concept is further reinforced by the binding nature of the mirror neuron system and it's role in coding abstract concepts [Kohler 02]. The Mind and Languge conference series and the Mind, Language and Metaphor conference series explored the relationship between consciousness, metaphor, creative imagination and language.

The Mirrorbot project explored the role of mirror neurons within the context of associating verbal communication, vision and actions experimentally, incorporating a mechanism for learning the nature of such associations.

3.6. Conclusion

The traditional view of cognitive processing of communication and other processes was based on a highly modular architecture, where certain areas of the brain were considered responsible for certain cognitive traits. While many of the responsibilities and functions assigned to certain regions were at least partly correct, a more distributed pattern now seems to be the case. Throughout this review we have uncovered evidence that no cognitive process occurs in isolation. It can be shown from the examples discussed that speech modulates action, that language is related to spatial and semantic models of the world around us, that gestures are part of the same mechanism that manages speech and that speech is processed alongside visual cues.

Appendix A Details of EU Funded Projects relevant to Communication.

ACCOR Articulatory-Acoustic Correlations in Coarticulatory Processes: a Cross-Language Investigation	
Duration:	
Dates:	01/04/1989 – 31/05/1992
Funding Scheme:	Second Framework Programme
Coordinator:	Centre National de la Recherche Scientifique (CNRS)

ACCOR II Articulatory-Acoustic Correlations in Coarticulatory Processes: a Cross-Language Investigation	
Duration:	
Dates:	01/07/1992 – 30/06/1995
Funding Scheme:	Third Framework Programme
Coordinator:	Queen Margaret College

ACORNS Advanced behaviour and high-level multimodal communication with and among robots	
Duration:	36 months
Dates:	01/12/2006 – 30/11/2009
Funding Scheme:	Sixth Framework Programme
Coordinator:	STICHTING KATHOLIEKE UNIVERSITEIT

AVATAR-CONFERENCE Avatar based Conferencing in Virtual Worlds for Business Purposes	
Duration:	24 months
Dates:	01/01/2001 – 31/12/2002
Funding Scheme:	Fifth Framework Programme
Coordinator:	FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.

CFID Communication Failure in Dialogue: Techniques for Detection and Repair	
Duration:	39 months
Dates:	01/01/1985 – 01/01/1989
Funding Scheme:	First Framework Programme
Coordinator:	ST PATRICK'S COLLEGE

CHAMELEON Language and image data fusion using stochastic models and spatial context modelling

Duration:	10 months
Dates:	15/09/1997 – 14/07/1998
Funding Scheme:	Fourth Framework Programme
Coordinator:	Bertin & Cie Sa

COGAIN Communication by Gaze Interaction	
Duration:	Not Listed
Dates:	06/08/2004
Funding Scheme:	Sixth Framework Programme
Coordinator:	UNIVERSITY OF TAMPERE

COMMROB Advanced behaviour and high-level multimodal communication with and among robots	
Duration:	39 months
Dates:	01/02/2007 – 30/04/2010
Funding Scheme:	Sixth Framework Programme
Coordinator:	TECHNISCHE UNIVERSITAET WIEN

CORETEX Improving Core Speech Recognition Technology	
Duration:	36 months
Dates:	01/04/2000 – 31/03/2003
Funding Scheme:	Fifth Framework Programme
Coordinator:	RHEINISCH-WESTFAELISCHE TECHNISCHE HOCHSCHULE AACHEN

The cortical representation of comprehension and production in Spanish sign language.	
Duration:	48 months
Dates:	01/07/2002 – 30/06/2006
Funding Scheme:	Fifth Framework Programme
Coordinator:	Manuel NORTE (No affiliation listed)

DANDI Dialogue and Discourse	
Duration:	36 months
Dates:	01/05/1989 – 01/05/1992
Funding Scheme:	Second Framework Programme
Coordinator:	University of Edinburgh

DEAWU Dealing with Uncertainty in Spoken Language Processing: Reasoning and Problem-Management	
Duration:	36 months

Dates:	01/01/2005 – 31/12/2007
Funding Scheme:	Sixth Framework Programme
Coordinator:	UNIVERSITY OF POTSDAM

Development of multi-voice and multi-language Text-to-Speech (TTS) and Speech-to-Text (STT) conversion system (languages: Belarussian, Polish, Russian)	
Duration:	24 months
Dates:	01/04/2005 – 31/03/2007
Funding Scheme:	International Cooperation
Coordinator:	Dresden University of Technology

DPSP Dynamic Principles in Speech Production: Evidence From Speech Errors and Speech Disorders	
Duration:	24 months
Dates:	01/12/2004 – 30/11/2006
Funding Scheme:	Sixth Framework Programme
Coordinator:	THE UNIVERSITY OF EDINBURGH

DYANA Dynamic Interpretation of Natural Language	
Duration:	
Dates:	01/02/1989 – 31/01/1992
Funding Scheme:	Second Framwork Programme
Coordinator:	University of Edinburgh

DYANA-2 Dynamic Interpretation of Natural Language	
Duration:	36 months
Dates:	01/10/1992 – 30/09/1995
Funding Scheme:	Third Framework Programme
Coordinator:	UNIVERSITEIT VAN AMSTERDAM

ERMIS Emotionally Rich Man-Machine Interaction Systems	
Duration:	36 months
Dates:	01/01/2002 – 31/12/204
Funding Scheme:	Fifth Framework Programme
Coordinator:	ALTEC INFORMATION AND COMMUNICATION SYSTEMS S.A.

ETHICBOTS Emerging Technoethics of Human Interaction with Communication, Bionic and Robotic Systems	
Duration:	24 months
Dates:	01/11/2005 – 31/10/2007
Funding Scheme:	Sixth Framework Programme
Coordinator:	UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

Eye-2-Eye	
Duration:	36 months
Dates:	02/04/2000 – 01/04/2003
Funding Scheme:	Fifth Framework Programme
Coordinator:	SINTEF Telecom and Informatics

F.M.P. C.N.M.P. Computational Neuroscience of Morphological Processing	
Duration:	
Dates:	22/02/2005 -
Funding Scheme:	Sixth Framwork Programme
Coordinator:	MRC COGNITION & BRAIN SCIENCES UNIT

GAZECOM Gaze-based communication	
Duration:	36 months
Dates:	01/11/2006 – 31/10/2009
Funding Scheme:	Sixth Framework Programme
Coordinator:	UNIVERSITAET ZU LUEBECK

GESTURE The role of gesture speech synchronisation in interaction and cognition	
Duration:	36 months
Dates:	07/10/2004 – 06/10/2007
Funding Scheme:	Sixth Framework Programme
Coordinator:	MAX-PLANCK-GESELLSCHAFT ZUR FOERDERUNG DER WISSENSCHAFT VERTRETEN DURCH DAS MAX-PLANCK-INSTITUT FUER PSYCHOLINGUISTIK

GRACE Graphical Communication in Human-Computer Interaction	
Duration:	36 months
Dates:	01/08/1992 – 31/07/1995
Funding Scheme:	Third Framework Programme
Coordinator:	University of Edinburgh

HISCORE High Speed 3D- and Colour Interface to the Real World	
Duration:	36 months
Dates:	01/01/2000 – 31/12/2002
Funding Scheme:	Fifth Framework Programme
Coordinator:	SIEMENS AKTIENGESELLSCHAFT

INFANTSPEEP WORKSHOP Speech perception development in early infancy: behavioural, neural-modelling and brain-imaging data	
Duration:	18 months
Dates:	01/06/2000 – 30/11/2001
Funding Scheme:	Fifth Framework Programme
Coordinator:	UNIVERSITAT DE BARCELONA

ISS Infant speech segmentation and the role of the emergent lexicon	
Duration:	12 months
Dates:	10/01/2005 – 09/01/2006
Funding Scheme:	Sixth Framework Programme
Coordinator:	UNIVERSITY OF WALES BANGOR

INTERACT 3D and speech Interfacing technologies	
Duration:	36 months
Dates:	01/11/2006 – 31/10/2009
Funding Scheme:	Sixth Framework Programme
Coordinator:	EPTRON, S.A.

LC-STAR Lexica and Corpora for Speech-to-Speech Translation Technologies	
Duration:	36 months
Dates:	01/02/2002– 31/01/2005
Funding Scheme:	Fifth Framework Programme
Coordinator:	SIEMENS AKTIENGESELLSCHAFT

LOGHOLTOCOM Language origins and grounding: simulating the transition from holistic to compositional languages	
Duration:	24 months
Dates:	01/02/2004 – 31/01/2006
Funding Scheme:	Sixth Framework Programme
Coordinator:	THE UNIVERSITY OF EDINBURGH

LUNA Spoken language understanding in multilingual communication systems	
Duration:	36 months
Dates:	04/09/2006 – 03/09/2009
Funding Scheme:	Sixth Framework Programme
Coordinator:	LOQUENDO SPA

METIS STATISTICAL MACHINE TRANSLATION USING MONOLINGUAL CORPORA	
Duration:	12 months
Dates:	01/03/2002 – 28/02/2003
Funding Scheme:	Fifth Framework Programme
Coordinator:	INSTITUTE FOR LANGUAGE AND SPEECH PROCESSING

METIS-II STATISTICAL MACHINE TRANSLATION USING MONOLINGUAL CORPORA: FROM CONCEPT TO IMPLEMENTATION	
Duration:	36 months
Dates:	01/10/2004 – 30/09/2007
Funding Scheme:	Sixth Framework Programme
Coordinator:	INSTITUTE FOR LANGUAGE AND SPEECH PROCESSING

Mind and Language (Conf Series)	
Duration:	
Dates:	30/04/2001
Funding Scheme:	Fifth Framework Programme
Coordinator:	EUROPEAN SCIENCE FOUNDATION

Mind, Language and Metaphor (Conferences)	
Duration:	
Dates:	20/04/2002 – 23/04/2002 and 24/04/2004 – 27/04/2004
Funding Scheme:	Fifth Framework Programme
Coordinator:	

Molecular linguistic networks for natural language processing	
Duration:	24 months
Dates:	01/02/2002 – 31/01/2004
Funding Scheme:	Fifth Framwork Programme
Coordinator:	UNIVERSITÀ DEGLI STUDI DI MILANO-BICOCCA

NECA A Net Environment for embodied emotional Conversational Agents	
Duration:	30 months

Dates:	01/10/2001 – 31/03/2004
Funding Scheme:	Fifth Framework Programme
Coordinator:	OESTERREICHISCHE STUDIENGESELLSCHAFT FUER KYBERNETIK

NEUROGENETICS Dissection of neurogenetic pathways involved in speech and language disorders	
Duration:	24 months
Dates:	01/10/2004 – 30/09/2006
Funding Scheme:	Sixth Framework Programme
Coordinator:	WELLCOME TRUST CENTRE FOR HUMAN GENETICS

NICE Natural Interactive Communication for Edutainment	
Duration:	36 months
Dates:	01/03/2002 – 28/02/2005
Funding Scheme:	Fifth Framework Programme
Coordinator:	NATURAL INTERACTIVE SYSTEMS LABORATORY (NISLAB)

PASION Psychologically Augmented Social Interaction Over Networks	
Duration:	48 months
Dates:	01/01/2006 – 31/12/2009
Funding Scheme:	Sixth Framework Programme
Coordinator:	TELECOM ITALIA LEARNING SERVICES S.P.A.

RTN:LAB Research and training network: language and brain	
Duration:	48 months
Dates:	01/01/2005 – 31/12/2008
Funding Scheme:	Sixth Framework Programme
Coordinator:	THE UNIVERSITY OF EDINBURGH

ROPP The Role of Production Practise in Language Development	
Duration:	24 months
Dates:	01/02/2004 – 31/01/2006
Funding Scheme:	Sixth Framework Programme
Coordinator:	UNIVERSITY OF WALES BANGOR

SIGNBASE Development of Multimedia Signed Language Databases	
Duration:	27 months
Dates:	01/03/1994 – 31/05/1996

Funding Scheme:	Health and Safety
Coordinator:	University of Durham

SIRIDUS Specification, Interaction and Reconfiguration in Dialogue Understanding Systems	
Duration:	36 months
Dates:	01/01/2000 – 31/12/2002
Funding Scheme:	Fifth Framework Programme
Coordinator:	UNIVERSITAET DES SAARLANDES

SPARKLE SHALLOW PARSING AND KNOWLEDGE EXTRACTION FOR LANGUAGE ENGINEERING	
Duration:	24 months
Dates:	01/12/1995 – 30/11/1997
Funding Scheme:	Fourth Framework Programme
Coordinator:	Università degli Studi di Pisa

SPEECH MAPS Sound-to-Gesture Inversion in Speech: Mapping of Action and Perception	
Duration:	36 months
Dates:	01/09/1992 – 31/08/1995
Funding Scheme:	Third Framework Programme
Coordinator:	UNIVERSITE STENDHAL

SPEECHSEG Production and perception of prosodic cues to speech segmentation: multisensorial aspects	
Duration:	24 months
Dates:	29/12/2004 – 28/12/2006
Funding Scheme:	Sixth Framework Programme
Coordinator:	INSTITUT NATIONAL POLYTECHNIQUE DE GRENOBLE

SPLIT Multilingual Speech to Face-Movements Transformation for Use as a Training System in Lip-reading and Language Acquisition and as a Basis for a New Telecommunication Service	
Duration:	24 months
Dates:	01/07/1994 – 30/06/1996
Funding Scheme:	Health and Safety
Coordinator:	Association Nationale des Parents d'Enfants Déficients Auditifs (ANPEDA)

The Structure of Learner Language (Conference)	
Duration:	
Dates:	12/10/2002 – 16/10/2002
Funding Scheme:	Fifth Framework Programme
Coordinator:	

TALKING HANDS Sign Language Recognition from Real-time video	
Duration:	24 months
Dates:	01/08/2004 – 31/07/2006
Funding Scheme:	Sixth Framework Programme
Coordinator:	DUBLIN CITY UNIVERSITY

VAESS Voices, Attitudes and Emotions in Speech Synthesis	
Duration:	26 months
Dates:	01/07/1994 – 31/08/1996
Funding Scheme:	Health and Safety
Coordinator:	University of Sheffield

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