INFORMATION SOCIETY TECHNOLOGIES
(IST)
PROGRAMME

Contract for: **Shared-cost RTD**

Annex 1 - “Description of Work”

Project acronym: MIRROR

Project full title: Mirror Neurons based Robot Recognition

Proposal/Contract no.: IST-2000-28159

Operative commencement date of contract: *September 1st, 2001*

Duration: 30 months

Content list

1. Project Summary

A2.	Project Summary [20]

Objectives (maximum 1000 characters)

The goals of MIRROR are: 1) to realize an artificial system that learns to communicate with humans by means of body gestures and 2) to study the mechanisms used by the brain to learn and represent gestures. The biological base is the existence in primates’s premotor cortex of a motor resonant system, called mirror neurons, activated both during execution of goal directed actions and during observation of similar actions performed by others. This unified representation may subserve the learning of goal directed actions during development and the recognition of motor acts, when visually perceived. In MIRROR we investigate this ontogenetic pathway in two ways: 1) by realizing a system that learns to move AND to understand movements on the basis of the visually perceived motion and the associated motor commands and 2) by correlated electrophysiological experiments.

Description of the work (maximum 2000 characters)

The project will investigate the association between visual information and motor commands in the learning, representation and understanding of complex manipulative gestures. The reference scenario is that of a person performing goal driven arm/hand gestures such as pointing, scratching a body part, bringing food to the mouth etc. At the end of the project the artifact will be able to learn how to perform and recognize this kind of actions. We intend to proceed with two different methodologies: 1) implementation and use of an artificial system and 2) electrophysiological and behavioral experiments. In the initial part of the project the experimental set-ups will be realized namely 1) the artificial system (robot) and 2) the biological data acquisition. The robot is composed of a binocular head, a torso, an anthropomorphic arm with a hand. Most of these components are already available and we will concentrate on the realization of an arm and hand with elastic properties (possibly included in the actuators) and with torque/force sensors at the joints. The biological set up will consists, initially, of a "data-glove-like" and a pair of cameras. Experiments will be carried out to better understand the role of the unified visuomotor representation formed by mirror neurons in learning and recognizing motor acts, and how these acts are matched onto the observer motor repertoire. The degree of modulation of mirror neuron discharge recorded when the monkey sees its own hand will be contrasted with neuronal discharge evoked by observation of other’s hand, and during the execution of hand actions without visual feedback. The biological data will guide the artifact implementation. Finally the "artificial neurons" of the artifact "brain" will be analyzed in terms of motor, visual and visuomotor properties and the data will be compared with those obtained during recording experiments performed in monkey parietal and frontal cortices.

Milestones and expected results (maximum 500 characters)

Milestones are: 1) the artifact (month 12); 2) the demonstration that the artifact generates and understands a repertoire of manipulative actions (month 24) 3) the comparison of the results from the artifact with the data obtained by electrophysiological experiments (month 30).
Expected results are: 1) artificial system able to interact with humans by means of gestures; 2) better understanding of visuomotor representation and learning in humans; 3) new technology for actuation/control/sensing.

2. Objectives

The **main goal** of the present proposal is twofold: on one side we aim to realize an artificial system, biologically plausible, capable to act, to understand gestures and to communicate with humans by means of body gestures learned through the interaction with humans as well as by observing its own body movements. On the other side we will investigate the mechanisms used by the brain to learn and represent complex motor acts such as reaching and grasping. This will be done both with computational models and electrophysiological investigation of monkey's parieto-frontal cortex.

The major difference with respect to similar approaches [1, 2] is the fact that the proposed system will build a motor vocabulary of action representations by integrating the motor information required to generate the action (and, therefore, the action goal) and the visual information derived from looking at the resulting action while it is executed. The physiological plausibility of the present approach derives from the existence in primates' premotor cortex of a motor resonant system formed by neurons (mirror neurons, [3, 4]) that become active both during execution of goal directed actions and during the observation of similar actions performed by other individuals. It has been suggested that mirror neurons can play a role in recognizing and discriminating visually perceived actions made by others [5] and in imitation learning [6]. This becomes possible because the seen actions are mapped on a motor repertoire shared by both, the agent and the observer.

With respect to the present proposal, mirror neurons are significant because they demonstrate the existence in the brain of a common representation of visual and motor aspects of complex body motions (see [7]). This unified representation, probably elaborated in living beings during development, might subserve the learning of goal directed actions and, in parallel with the increase of motor capability, might be used to recognize the others' motor acts, when visually perceived.

In the present project we aim to reproduce a similar ontogenetic pathway in order to implement a system that, at the same time, learns to move and learns to understand others' movements. The visuomotor association necessary to this purpose will be achieved by creating a "biological artifact" able to correlate (and integrate) the motion of the limb seen through the eyes with the motor commands sent to the same controlled limb.

As far as implementation methodology is concerned we shall investigate whether the adoption of a framework similar to **biological development** is suitable for artificial systems, and does provide a better insight on: i) how to build highly complex and flexible artificial systems, and ii) how to better understand the human brain functions involved in action representation. It is worth stressing the **neuroinformatics** perspective of the project; in fact, we shall i) implement a physical artificial system condensing physiological knowledge and ii) use the artificial system to test possible alternative learning procedures and representation models and to perform related experiments in a neurophysiology laboratory.

The main objective described above will be achieved by:

1) **Realization of the artifact.** The artifact will consist of an anthropomorphic robotic setup. As a minimum it will be composed of a robot arm (possibly with **elastic actuators** [8], torque and haptic feedback) including the wrist degrees of freedom, and an anthropomorphic hand. Two cameras will be mounted on a five degrees of freedom robot head. Finally, motor encoders and inertial sensors will provide proprioception. Some of these components have already been implemented within the consortium and will be used as they are in the project. Due to the specificity of the project we will concentrate our efforts on designing and realizing the manipulative part of the artifact while we intend to use the visuomotor components already available. As anticipated before it is the intention of the consortium to investigate the relevance of a developmental approach for the fulfillment of our objectives. This

approach has been already successfully exploited by DIST (although in a simplified situation) and we intend to extend it even more and show the advantages of a “growing” artifact with respect to the classical "assembling" solution.

The role of UU in this respect is that of providing his knowledge on sensorimotor development in humans to define the artificial development framework and, if possible, to perform tests and experiments that may be suggested during the implementation of the artificial system.

2) **Investigation of the role played by visuomotor representations of actions.** Realization and modeling of an artificial “visuomotor vocabulary” (visuomotor bank) of hand actions. Both kinematic and visual aspects of hand actions will be acquired and submitted to a biologically plausible artificial learning method in order to associate the point-of-view-dependent visual percept to the invariant motor primitives at the basis of the generated (and seen) action. It is expected that this procedure will extract the “internal rules” of the visuomotor association process. The reference scenario and gesture's repertoire is that of a person sitting behind a table performing meaningful and purposive arm/hand gestures such as pointing, scratching a body part, bringing food to the mouth etc. The artifact will be able to learn how to perform and recognize this kind of actions and the same kind of actions will be used for the neurophysiology experiments.

3) **Neurophysiological investigation of the brain functions** at the basis of the mechanism that, in mirror neurons, matches the observed actions on the observer motor repertoire and study of the artifact behavior as well as of the internal structure of its “brain” and comparison of the results with those achieved in recording experiments performed in monkey brain. New experiments will be carried out in order to better understand the role of the unified visuomotor representation formed by mirror neurons in learning and recognizing motor acts:

    a) In the first part of the project we will investigate how the seen motor acts are matched onto the observer motor repertoire. The degree of modulation of mirror neuron discharge recorded when the monkey sees its own hand will be contrasted with neuronal discharge evoked by observation of other’s hand, and during the execution of hand actions without visual feedback. Behavioral experiments will also be performed with human infants to investigate the development of sensorimotor coordination with particular reference to eye-head and eye-head-hand coordination as well as the appearance of imitation abilities. The data acquired with these experiment will give important information that will guide the artifact implementation.

    b) In the second part of the project the knowledge acquired during realization of objectives 1) and 2) will be used to test the artifact and to design new electrophysiological experiments to investigate the visuomotor transformation at the basis of the mirror mechanism. In particular, the “artificial neurons” of the artifact’s “brain” will be analyzed in terms of motor, visual and visuomotor properties. The data will be compared with those obtained during recording experiments performed in monkey parietal and frontal cortices.

3. Participant List

List of Participants

Partic. Role*	Partic. no.	Participant name	Participant short name	Country	Date enter project**	Date exit project**
C	1	DIST - University of Genova	DIST	I	Start of project	End of Project
P	2	University of Ferrara	UNIFE	I	Start of project	End of Project
P	3	Instituto Superior Técnico	IST	P	Start of project	End of Project
P	4	Dept. of Psychology University of Uppsala	UU	S	Start of project	End of Project

4. Innovation

The proposal requires a very diverse know-how, which justifies also the European dimension of the project. Consequently, for the sake of clarity here, let us divide the description of the innovation potential along a few main lines: i) the biological background; ii) the robotic artifact, iii) the expected interactions between the technological and the neuroscience aspects.

The approach we describe here is novel for at least two reasons: i) what we propose is to build **biologically plausible** and **computationally significant physical** models of some brain functions (emphasis is on the word “physical”), ii) the methodology we intend to follow is new, by adopting **development** rather than **integration** as the main paradigm to implement. These major novelties will be employed on the one hand to foster integration between neurosciences and robotics, and on the other hand, to actually realize a physical system demonstrating the feasibility of the approach (which is not limited by the particular task/system we shall realize here).

What we intend to obtain at the end of the project is both a collection of new results on how the brain represents, learns and performs manipulative actions and a physical artifact behaving in a similar way and being able to effectively communicate with humans using hand and arm gestures. The scenario we intend to concentrate on is that of a person sitting behind a table and performing various manipulative actions with objects on the table such as pointing, grasping with different postures, holding, eating, scratching etc.

4.1. Biological Background

MIRROR's biological background has two "pillars": 1) recent findings on how the brain represents and recognizes motor actions; 2) studies and models of human sensorimotor development.

The first "pillar" refers to one of the most fascinating discovery of the neurophysiology in the last two decades. Neurons located in a frontal region classically considered as motor, in addition to their motor discharge, respond also to the presentation of visual stimuli. Neurons with this property mainly pertain to FEF [13] and ventral premotor areas F4 and F5 [14-18] that, taken together, represent the main target for the inferior parietal lobule projections carrying out visual information. "Mirror" neurons constitute a class of F5 visuomotor neurons that become active when the *monkey acts* on an object *and* when it *observes another monkey or the experimenter* making a similar goal directed action [3, 4]. The visual stimuli most effective in triggering "mirror" neurons discharge are actions in which the experimenter's hand or mouth interacts with objects. The mere presentation of 3-D objects or food is ineffective in evoking mirror neurons discharge. Similarly, actions made using tools, even when conceptually identical to those made by hands (e.g. grasping with a pliers), do not activate the neurons or activate them very weakly. The observed actions, which most commonly activate mirror neurons, are grasping, placing, manipulating, and holding. Most mirror neurons respond selectively to only one type of action (e.g. grasping). Some are highly specific, coding not only the type of action, but also how that action is executed. They fire, for example, during observation of grasping movements, but only when the object is grasped with the index finger and the thumb. Typically, mirror neurons show congruence between the observed and executed action. This congruence can be extremely strict, that is the effective motor action (e.g. precision grip) coincides with the action that, when seen, triggers the neurons (e.g. precision grip). More recent experiments [19] have shown that neurons very similar to the "mirror" neurons recorded in area F5 are present also in the rostral part of the inferior parietal lobule (area PFG and PF).

The present project will open new insights on different points. Mainly, it will provide new suggestions to understand the way in which visually perceived actions are mapped onto the observer motor repertoire. Several questions are still awaiting an answer. Among them the role of inferior parietal lobule in analyzing biological motion, the role of self-observation in action learning and the understanding of the brain mechanisms at the basis of the mirror resonance phenomenon are the most stringent.

The second "biological pillar" of MIRROR is "development" with particular emphasis on the development of sensorimotor coordination in the very first years of human life. From studies in this field it is becoming clearer and clearer that a newborn is not "just" a collection of relatively static motor structures (or reflexes) but that, we need to think to conceptually more dynamic functional structures that evolve during development (action systems). The preconditions for setting up an action system that may develop are the following:

1) Some pre-structuring of the perceptual and the motor systems. Muscle contractions must be organized into synergies with relatively direct correspondence to trajectory formation. Perception must be structured both spatially and temporally.

2) The perceptual and the motor sides must be joined in one or preferably several loops that overseer the movement being performed and feed information back into the system.

3) A motivational structuring of the system. The motivational part represents the goal states of the system and in addition drives the system to those goal states. Depending on the amount of prestructuring of the system, the number of learning trials that is necessary to develop reliable procedures for getting the system to the goal will vary (Anyone who has observed a young infant trying to get the hand to the

desired object will be impressed by the persistence of those attempts in spite of the fact that they, at least to begin with, are not very successful).

4) Some built-in knowledge of how to organize a movement towards the goal. Depending on how much built-in knowledge the system has of how to organize a movement towards the goal, the amount of learning trials before stable procedures develops will vary.

The manual system of the newborn infant has all that and, under the right circumstances, they will perform goal directed movements toward an object in front of them. However, the movements are not yet designed to grasp the object because of strong extension and flexion synergies (it probably simplifies the control problem). When the arm extends forward the finger of the hand extends as well and when the arm flexes the fingers flex. Grasping requires the fingers to flex when the arm is extended. However, the goal directed arm movements of the newborn infant gets the hand into the visual field and thereby closes the visual-manual loop.

The development of actions is multi-determined. Take for instance the development of reaching and manipulation. It includes the development of postural control that frees the hands from the task of supporting the trunk, the development of binocular depth perception that defines the object position precisely in space, the increase in arm strength, and the development of independent control of the arm, hand, and fingers. In order to grasp an object at reaching distance, the movements of the arm and hand must be independently controlled. In order to manipulate an object in a precise way the fingers needs to be independently controlled.

Within this framework development is best described as a dynamic system in which the development of the nervous system and the development of action mutually influence each other in the process of forming increasingly complex and sophisticated control systems. With development the different action systems become increasingly future oriented and integrated with each other and ultimately each action will engage multiple coordinated action systems.

Development of prospective control is the most important aspect of all action development. It is quite clear that these predictive abilities do not develop in a general sense. In early development, there is an important independency between action systems actions in this respect. Abilities expressed in one context do not necessarily transfer to another one and the systems of representations underlying them do not seem to do so either. Just because an infant at a certain age can track an object predictively with his or her eyes does not imply that they track predictively with their head [11]. With development, more generalized skills and more generalized systems of representations emerge form the complex interactions both within and between action systems. Little is still known about these developmental processes but even in the adult the mind is still significantly modularized.

4.2. Robotic Artifact

Although research activity linking studies on artificial systems to “brain sciences” is not new in its own [20-24], only a few researchers addressed the problem of adaptive behavior from the developmental point of view [25-27]. In some cases [28] though, development was mostly used to justify design choices rather than being the foundation of the methodology. In other cases [25], experiments, theoretically more grounded, were lacking of the necessary complexity. In none of the projects the aim was actually to foster either a real interaction between neuroscience and robotics or to improve our knowledge of the involved brain functions.

On the other hand, robotic systems are still far from achieving reasonable performance levels and task flexibility, though the production of complex autonomous systems is a long-lasting challenge not only of European industries. In our view, this difficulty arises, at least in part, from the approach followed to construct complex systems: to make the problem more tractable, sensori-motor coordination is broken down into a set of sub-problems defined by a specific sensory modality or specific motor skills. A different solution is used in humans and many other vertebrates, where flexible and efficient levels of performance are achieved through the simultaneous development of sensory, motor, and cognitive abilities. Biological systems grow rather than being constructed, and they develop rather than being the result of the integration of elementary modules.

It is worth noting that, although interesting per se, if development were a pure effect of some other "biological constraints" (which might be nonetheless present), it would not be, perhaps, worth applying for the construction of artificial systems. Conversely, we believe there are benefits whether the acquisition of a particular skill (such as recognition of body gestures) is performed through a sequence of stages where simple reflex-like controllers and/or stereotyped behaviors progressively give place to more complicated control structures and adaptive behaviors. Some relevant aspects of the approach include, for example, the role of noise during learning (i.e. lack of myelination of some brain areas/fibers at birth [29]), the use of reflex behaviors as a basis for further learning (bootstrapping the learning/development process itself [30]), and the reduced resolution of the sensory systems, which is nonetheless, amazingly balanced to the available motor precision (very rough at birth).

From the learning theory point of view, for instance, Vapnik and colleagues [31] pointed out that learning from examples is an ill posed problem. A feasible solution is that of balancing the number of available training samples (the experience) to the approximation strength of the learning algorithm. Roughly speaking, a developing system using simpler strategies at birth (when only a limited number of training samples is available), and more sophisticated strategies later on (when information is enough to guarantee convergence) is less prone to have this sort of problems.

Finally, we would like to point out again that although risky, this approach has the potential to be applied to large-scale systems, such as in our case a humanoid robot (but not only to that). Further, if we would be able to formulate a theoretical framework in this sense, an entirely new design (engineering) methodology could be possibly derived.

As far as other similar approaches are concerned (where a wide perspective has been pursued), the only activities are the so-called "humanoid" projects, which in the last years have been funded both in the USA and, particularly, in Japan [28, 32]. In some cases, however, in spite of the wide perspective, the results are more, so to speak, morphologically rather than computationally similar to a human being. Moreover, they have failed to shed significant light to a better understanding of brain functions. Although more risky the approach proposed here may suggest really new technologies and not only a successful use of technologies already available.

Our artifact would consist of an anthropomorphic robotic setup. As a minimum it will be composed of a robot arm (possibly with **elastic actuators**, torque and haptic feedback) including the wrist degrees of freedom, and an anthropomorphic hand. Two cameras will be mounted on a five degrees of freedom robot head, which is already available within the consortium.

The design requirements of the robot are not the standard industrial parameters (e.g. payload, speed, precision). On the contrary it has to be well suited to represent and imitate anthropomorphic body gestures. Consequently, we expect to develop a robot with novel characteristics, in terms of flexibility, dynamic response, compliance, and overall cost.

As mentioned above, one aspect we shall investigate thoroughly is that of elastic actuation. The most suitable technology at the moment is the so-called "series-elastic actuators", but other options will be also considered. Concerning the motor control paradigm, we shall use the so-called "force field approach" proposed by Bizzi and coworkers [33, 34]. The sensory system, beside the cameras, will be complemented by force and haptic sensors whenever necessary. Finally, motor encoders and inertial sensors will provide proprioception.

The realization of the artifacts will cover the following aspects:

- Investigation of the available actuation technologies. Evaluation of the torque/price/complexity tradeoff. Investigation of the sensory aspects (such as strain gauges, encoders, tactile sensors, etc) and materials (intrinsic compliant elements). There are not specific requirements in terms of payload, speed, etc.
- Design and construction of the anthropomorphic robot arm and hand. The arm should integrate smoothly with the existing visual system.

4.3. Interaction between neurosciences and robotics

The novelty of the neuroinformatics approach is that of bringing together neuroscientists and roboticists and to transform a robot setup in a new tool to study brain functionalities, a place where to condense our knowledge, to test new models, to suggest modifications to existing models, and to design new experiments in order to refine the implementation.

With respect to MIRROR, if on one side it is relatively understood how the brain organizes grasping movements, little is known about mechanisms underlying the recognition of actions made by others. The discovery in both monkey and human brain of motor resonant mirror systems (see [35]) give us a good biological model that can be applied to artificial systems. However, due to the fact that the intimate mechanisms of motor resonance are relatively unknown, we will simulate a learning environment (e.g. with an artificial neural approach) in which the motor invariant part of goal directed hand actions has to be linked through an artificial “visuomotor association” to the extremely variable visual percept of the moving hand. It is known, in fact, that mirror neurons discharge do not depend from the observer point of view [4] thus suggesting that a sort of “visually independent embodiment” should be present. It is expected that, after learning, it will be possible to study the characteristics of the artificial network and to apply this knowledge to both artifact programming and brain investigation. The second relevant aspect arising from the interaction between robotics and neuroscience will be the developmental approach. Our goal is to produce an artifact that, starting from some very elementary knowledge about its body representation builds up the motor knowledge 1) by interacting with objects, 2) by imitating and, 3) by communicating with others. It will be a “growth” very similar to what happens in nature and we will pose extreme care in order to ensure the “ontogenetic” plausibility of this process.

The third relevant aspect regards the benefits that neuroscience will receive from this project. Models, simulated experiments, and interchange of knowledge between robotics and neurophysiology will improve the study of the parieto-frontal circuitry involved in action recognition.

5. Economic development and S&T prospects

5.1. Economic prospects

The production of complex autonomous system is a long-lasting challenge not only to European industries. In spite of the great advances made recently, autonomous systems of reasonable complexity are still confined inside research labs and their use in unconstrained environments is limited to special cases. On the other hand there seems to be an increasing request (at least in principle) for autonomous systems capable of working in human populated areas and their interaction with humans in a safe and human-like fashion, is certainly one of the major challenge for the robotic industry worldwide. The main approach adopted so far has been "incremental'" with the implicit assumption that new skills can be added to existing systems with little effort. What we want to demonstrate in this project is that there is an alternative way to build complex autonomous systems and that this approach could also help in better understanding how human behaviors are generated and controlled (an essential knowledge if we want to build systems interacting "naturally" with humans). This goal is, therefore, far reaching but, if a systematic approach will be developed, it may prove to be a very strong technological advantage. Moreover, as new approaches are potentially good sources of new technologies, indirect advances could be obtained which, in the long run, may prove to be even more important for European technology. We see as particularly interesting the possibility of developing new sensors and actuators as well as new technologies to process sensory information.

The major challenge, at this time, is to prove that what we are proposing is really new and does offer a valid alternative to the production of adaptable complex systems. In the long run, after the project, industries producing autonomous systems for industrial as well as service use may have a much stronger position in the market.

5.2. Scientific prospects

Beside the technological aspects, as already mentioned, the project addresses a few quite interesting basic scientific questions. Of course, if the project will be successful (as we do hope), the potential for scientific exploitation would substantial.

Firstly, we could really provide a new tool to neuroscience where to condense knowledge and integrate data gathered by using different techniques. As modeling by using mathematical tools and dynamical system theory provided hints on how certain functions are carried out by the brain, robotics might be a test bed for theories. The major difference is that in the latter case, theories are firmly tested against the environment: i.e. they need to be working theories.

Secondly, by applying development rather than the traditional assembly approach (if successful), we might provide hints on a novel way of designing artifacts where the whole life cycle has to be taken into account. The whole process of design would be subject of study, not only the "adult" artifact or the final product. Comprehension of complex systems (acting in an unconstrained environment) could be improved and, as we do hope, formalized.

5.3. Technological prospects

The main goal of MIRROR is not to provide short-term technological breakthrough. However we see interesting medium/long term potentialities in, at least, the following aspects:

1) Gesture Communication. Communicating through gestures may be as complicated as using language. One of the technological goals of MIRROR (although a long-term one) is to study some new ideas and provide solutions to the problem of gesture understanding by addressing the basic issues of gesture representation and learning. Using visuo-motor representations seems to be the solution adopted in biological

systems and, if proved applicable to artificial ones, can really help accelerating this important technological field.

2) Elastic Actuators. Implementing elastic actuators is a long-time dream of many research groups. In some cases this has not only been a dream but prototypical solutions have been proposed (e.g. the series-elastic actuator proposed at MIT). Stemming from these past experiences, one of the goals of MIRROR is to build a robot arm and hand, which can be controlled as if the actuators were elastic. We want to stress the coupling between the actuator itself and its control. In particular it seems evident from these preliminary solutions that controlling an "elastic" arm may involve radically new techniques (including learning) and that, in this respect, studying how the brain does it is not simply a "copying" exercise. The need of elastic actuators is of paramount importance in all those applications where the robot has to interact closely with human beings. Only by using elastic actuators and torque, intrinsic safe artifact may be realized.

3) Development of complex systems. Following the fil-rouge implemented by nature in humans and other animals we think we could derive useful ideas on how a complex artificial system could be realized. The sequence of stages through which a learning system of high complexity has to go through to reach a "useful" level of motor and cognitive skills, may be similar to that of a natural system.

APPENDIX A – Consortium Description

One of the strong points of this proposal is the mix and complementarities of the expertise of the partners. **LIRA-Lab** at DIST has been working on biologically motivated artificial systems for many years also in collaboration with neuroscientists. **Vis-Lab** at the Instituto Superiore Tecnico (Portugal) has a long-time tradition on different aspects of control theory applied to real-world robotic systems (including flying and underwater robots). LIRA-Lab and Vis-Lab have been collaborating in international project since many years. The aspect of visuo-motor representation of human complex gestures is carried into the project by the **Department of Biomedical Sciences** of the University of Ferrara (Italy) where electrophysiological studies of "mirror neurons" is carried out (as well as many other fundamental anatomical and physiological findings of motor cortices). The group at the **Department of Psychology** of the University of Uppsala (Sweden) is a world leader in the study of human development with particular emphasis on sensorimotor development. This multidisciplinarity is in itself a challenge to the project but could be one of the major achievements to help the formation of a new scientific community. We are confident that the role of each partner is clearly defined and complementary and it is worth noting that the European dimension is not only advantageous but also essential to cover the required know-how.

All the partners have an extend experience with EC projects. LIRA laboratory has been working (and in some cases coordinating) in a number of EU-supported projects (ESPRIT projects VOILA, VAP, NARVAL, ROBVISION, SVAVISCA). It collaborates with other European research institutions through a Human Capital and Mobility Network. The IST/ISR is currently involved in several national EU-funded projects including ESPRIT, MAST, INCO-COPERNICUS and BRITE/EURAM acting as coordinator in some cases. There exists a long-term successful collaboration on EU-funded projects between LIRA-Lab and IST/ISR, e.g. currently running project NARVAL.

UNIFE was involved in both national (CNR) and international projects. The Department of Psychology at Uppsala University (UU), Sweden has a long tradition in research on perception, especially motion perception. In addition, this department is known for pioneering research on the early development of looking, reaching and postural control.

The role of each partner in the consortium

The main role of LIRA-Lab:

- Management.
- Realization of the robotic setup.
- Study on the “developmental paradigm”.
- Integration and demonstration.

The main role of IST:

- Data processing, image processing development.
- Specification and realization of the robot control schemas.
- Implementation of basic robot behaviors (especially tracking).

The main role of UNIFE:

- Carry out the electrophysiological experiments.

- Specification of the human data acquisition setup.
- Modeling.

The main role of UU:

- Study of the application of the “developmental paradigm” to the artificial world.

However, it is fair to say that although roles are clearly defined, a strict collaboration is expected among partners. This is of paramount importance in order to succeed in the project goals (for instance, the neuroinformatics aspect).

Description of the participants

DIST – University of Genova

The *Dipartimento di Informatica, Sistemistica e Telematica* (DIST) of the University of Genova is composed of approximately 47 persons including 32 persons with permanent teaching position and research position, and 15 persons providing administrative and technical support. The participation to the project will be through the LIRA-Lab (Laboratory for Integrated Advanced Robotics). LIRA-Lab main research themes are in the field of artificial vision and robotics with particular emphasis on aspects of sensori-motor coordination from the engineering as well as the computational neuroscience perspective. LIRA-Lab expertise results from past participation to national and EU-supported projects (ESPRIT projects VOILA and VAP), TIDE project IBIDEM and the participation in TMR networks. DIST has been prime contractor of many EU-supported projects and will be able to provide the administrative support required for coordination.

As to the **present project** DIST will provide its expertise on the design and control of visually guided robot systems and will use the experimental set-ups already available. In particular a binocular robot head equipped with space-variant sensors (developed by LIRA-Lab in a past collaborative project) and an anthropomorphic manipulator. DIST will be mainly involved in the definition and realization of the hardware system implementing models of sensori-motor development.

CV of Giulio Sandini

Giulio Sandini is a Full Professor at DIST where he teaches the course of "Natural and Artificial Intelligent Systems" for the biomedical, electronic, and informatics curricula offered by the Faculty of Engineering. He spent many years in neurophysiology labs in Italy (with Lamberto Maffei in Pisa) and the USA (at the Department of Neurology of the Harvard University) where he conducted electrophysiological experiments on different aspects of visual perception. He currently coordinates the activity of researchers at LIRA Laboratory. LIRA-Lab is characterized by its multidisciplinary/multinational approach where collaborative research with neuroscientists has long lasting tradition. Giulio Sandini has been a member of programme committees of international conferences and chairman and co-chairman of international conferences and workshops. He is/was principal investigator of ESPRIT Projects: P419, P2502 (VOILA) and SVAVISCA, BRA project P3274 (FIRST) and VAP-II, TIDE project IBIDEM, TMR projects VIRGO and SMART and founding Member of ECVNet.

CV of Giorgio Metta

MS Electronic Engineering and Bioengineering, Ph.D. Giorgio Metta currently holds a post-doc fellowship within LIRA-Lab at University of Genova. His Ph.D. work addressed the problem of visuo-motor coordination in a humanoid robot from a biologically motivated perspective, with the ultimate goal of learning how to model biological agents by building complex artificial systems. His research aimed at demonstrating that the adoption of a framework of biological development is suitable for the construction of artificial systems. He collaborated in some EU funded projects (ROBVISION, SVAVISCA, NARVAL, VIRGO), and he is author and coauthor of numerous scientific publications. His main research interest is sensori-motor coordination in robotics and neuroscience.

University of Ferrara – Department of Biomedical Sciences

The University of Ferrara is one of the most ancient in the world, being founded in 1391. The medical school has an old tradition and is formed by about 150 professors and teachers. The Section of Human Physiology of the Department of Biomedical Sciences of the University of Ferrara is one among the few animal electrophysiology centers in Italy equipped also for non human primates researches. It has internal facilities to host several monkeys and three neurophysiological laboratories fully equipped for electrophysiological recordings and microstimulation. It has also a complete technical staff formed by engineers and technicians and hosts 10 full time researchers plus several Ph.D. students and collaborators.

CV of Luciano Fadiga

M.D., Ph.D. Post-doctoral fellow at the University of Bologna from 1990. Senior Researcher at the University of Parma from 1992 Assistant Professor at the University of Parma from 1997. Associate Professor at the University of Ferrara from 2000. He has a long experience in electrophysiological investigation in monkeys (single neurons recordings) and humans (transcranial magnetic stimulation, study of spinal excitability and brain imaging). Among his contributions are the description of functional properties of monkey area F5, in which, in collaboration with the researchers of University of Parma, he found a set of neurons that discharge both when the monkey makes an action and observes an action made by another individual. It has been suggested that these neurons unify perception and action and are responsible for action understanding (mirror neurons). He further carried out experiments in humans both in Parma (with transcranial magnetic stimulation) and in various brain imaging centers (San Raffaele-Milano, USC-Los Angeles, UCLA) demonstrating that a mirror system exists also in humans. Other fields of his research concern attention and its neuron mechanism in normal subjects and in patients. He is reviewer of many international journals in the field of Neuroscience. Luciano Fadiga was principal investigator in CNR projects on reaching-grasping, he is co-investigator in Human Frontier Science Program and McDonnel-Pew founded projects, he published more than 30 peer-reviewed publications on international Journals.

Instituto Superior Técnico - Instituto de Sistemas e Robótica

The Instituto Superior Técnico (IST) is the largest and oldest engineering school in Portugal, with a large record of participation in international researcher projects. At the research level, the work described in this project will be carried out at the Computer Vision Lab (VisLab) of the Instituto de Sistemas e Robótica (ISR).

ISR is a national research organization established in 1991 involving a total of 127 scientists, 61 of which hold a PhD degree. ISR is an institution that intervenes in the areas of Computer Vision, Robotics, Automation, Control, Signal Processing, Aeronautics, Physical Acoustics and Energy Management and Production, with an emphasis on Systems Theory. It comprises 3 laboratories: Lisbon, Porto and Coimbra. The Lisbon laboratory is integrated in the Instituto Superior Técnico (IST).

The VisLab has been involved in various research projects in areas related to Computer Vision and Robotics. It has solid expertise in several problems, particularly in the areas of vision based control, active vision and vision-based navigation.

CV of José Santos-Victor

Jose Santos-Victor serves as an Assistant Professor at the Instituto Superior Tecnico (IST), Lisbon and as researcher at the Instituto de Sistemas e Robotica (ISR). He has founded the Computer Vision Lab (VisLab) at IST/ISR. His main research topics are Computer Vision and Robotics with emphasis to Active Vision and the relationship between visual perception and action. He was the principal investigator in a number of national and international R&D projects in the areas of Computer Vision and Robotics. He is a member of the editorial board of the *Journal of Robotics and Autonomous Systems* (Elsevier) and member of the program committee of various international conferences on computer vision and robotic.

CV of Alexandre Bernardino

Alexandre Bernardino was born in Lisboa, Portugal, in 1971. He received the MSc degree in Electrical and Computer Engineering in 1997 from the Instituto Superior Técnico (Lisboa), and is working towards the achievement of the PhD degree. He is also a teaching assistant at the Instituto Superior Técnico and a research assistant at the Instituto de Sistemas e Robótica (Lisboa). He has participated in national (JNICT PBIC/C/TPR/2550/95-2) and international (NARVAL Esprit-LTR Proj. 30185) research projects and published articles in international journals (IEEE Trans. Robotics and Automation, Elsevier Robots and Autonomous Systems) and several conferences. His main research interests focus on robot vision, autonomous systems, and real-time control.

Department of Psychology - University of Uppsala

Uppsala University is the oldest university of Sweden. It is a complete university with over 5000 employees including 3200 scientists. The department of Psychology has 12 professors and almost 100 employees. It is one of the major psychology departments in Sweden. It is well know for its research in perception that originates back to Gunnar Johansson, the founder of motion perception. Between 5 and 10 PhDs are examined from this department every year.

CV of Claes Von Hofsten

Claes von Hofsten is professor in Perception. He has founded the laboratory for the study of "perception and action" well known for its pioneering studies on the development of reaching, controlled looking and postural control in infants. He has published almost 90 articles in peer review journals and edited books. He is honoris causa at Universite de Caen and has been selected to deliver next year's Gibson Lecturer at Cornell (the 15th). He was a member of the Scientific Committee of the XXVII international congress held in Psychology in Stockholm this summer and is one of the organizers of next year's European Conference on Developmental Psychology to be held in Uppsala, Sweden.

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