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

Related to other Contract no.: *NA*

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Operative commencement date of contract: *TBD*

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. Contribution to key action objectives

This proposal addresses the action line keywords along two main lines of research:

- Neuroinformatics.
- Artifacts that live and grow.

4.1. Neuroinformatics

The project will show its neuroinformatics commitment by cross-fertilization between two processes: i) the implementation of the biologically inspired artificial system; ii) the use of the artificial system to test possible alternative biological models and further direct new experiments. The new experiments will be performed as part of the project. Experimental results will be used to improve the model thus actually tightly binding the artificial and the biological sides of the project.

UNIFE possesses the required know-how to carry on further experiments both on the neurophysiology and psychophysics of mirror cells as shown in the relevant literature [9-12]. UU has the required background to help the formulation of theoretical aspects of the developmental approach (see below).

4.2. Artifacts that live and grow

As mentioned in the “objectives” section, a novel approach to the design and realization of artificial systems will be investigated. This approach should mimic biological systems learning and adaptation processes. The key points of the approach are (if successful):

- Adaptation and growth: the artifact will show adaptation beyond “pure programming”, for instance by acquiring new gestures autonomously. The control structure will develop, starting from simple reflex-like behaviors, towards more complex strategies, which exploit the gesture recognition to foster new behaviors.
- The agent’s body and a real agent/environment interaction are the key factors of the functioning of the artifact.
- The approach allows going beyond the traditional assembly procedure.
- Aspects of mechanical compliance, materials, and the body physical structure will be investigated.

Of course, every design choice will be as much as possible biologically grounded, in order to obtain a useful model of the brain functions involved.

5. 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.

5.1. 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.

5.2. 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.

5.3. 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.

6. Community added value and contribution to EU policies

This project has two quite ambitious goals and a more practical one. Firstly, we shall seek to start integration between neuroscience and information technology. To achieve this, we propose to employ robotics as a new tool where to test hypothesis, condense our knowledge, and refine our theories. Secondly, as far as methods are concerned, we shall take a new and original point of view for what regard the design and implementation of an artificial system. If successful, we might be able to cast a new light on the design of complex "artifacts". Of course, both goals are risky, but on the other hand considering the position of the project within FET, the potential benefits are also substantial. We foresee a potential major advance in our comprehension of complex systems but also on our capacity to design them. Certainly robotics could benefit from such a new approach, but nonetheless neurosciences could possibly find a new tool.

The practical goal of the project is, on the other hand, well targeted to an interesting application. Beside the advance in knowledge per se, we believe we might use the realized system to test theories and to demonstrate the possibility for an artificial system to interact meaningfully with a human through gestures. That is, not only we propose the theory, but also we plan to apply it to a sufficiently complicated case study and long-term applications. This will provide a testable and verifiable basis, a test-bed of a high degree of complexity.

The recognition/reproduction system could also apply to situation where a friendlier man-machine interface is required. Such sort of friendly interaction is still a challenge for IT industries. Moreover, the design of learning/self-developing machines, and the application of adaptation techniques to robotics is a long lasting “dream” of IT worldwide. In spite of many advances in the area, the general problem has never been solved beyond a certain limit.

Therefore, we believe that considering the very diverse know-how required, the European dimension is a strict requirement for the project. The consortium needs to span robot design abilities, data acquisition, software development, neurophysiology and psychology. It is worth stressing the fact that the integration of neuroscience and IT is not only devoted to the construction of some electronic measuring device or a sort of database technology.

For these reasons, the competences of the partners range from control theory aspects of motion control to biologically inspired robotics, and from neurophysiology to psychology and human development. These are unlikely encountered within the national level of any of the participants. It is fair to mention though that some centers for “neuroinformatics” are being created worldwide. Our consortium represents at the European level such a synergy.

7. Contribution to Community social objectives

7.1. General considerations

The project contributes to the objectives of the Community mainly by creating a joint team of neuroscientists and engineers. Moreover, the consortium will apply this synergistic approach to the creation of both a new tool for the study of the brain functions and on the other hand to the development of a new biologically inspired design technique for artificial systems.

In this sense we expect the outcome of the project to be really applicable beyond the boundaries of the specific artifact. If successful we might imagine employing robotics to generate even more faithful models of “biological brains”. On the other side, perhaps in the long term, a new comprehension and design technique (in this case mimicking biological development) could be applied to a large range of possible artifacts (beyond the gesture recognition task).

From the neurosciences point of view, for instance, robotics could allow testing theories that are otherwise quite difficult to prove (for example, it is very simple with robots to try ablation experiments). We are aware of the risks of such approach, mostly because there is no guarantee of the “biological plausibility” of the realized models. For this reason it is important to build such a group with diverse know-how.

Of course, we expect neuroinformatics to shed some light on how our brain understands and generates body gestures. Furthermore, we do not see any theoretical difficulty in applying such an approach to modeling other brain functions.

Further, we think that going beyond the pure assembly approach (for a long time the well established procedure in engineering), and moving toward “development” could possibly lead to a real breakthrough and advance in knowledge.

For what regards the Quality of life, it is worth to note that the possibility to build artifacts able to communicate with humans in a human-like way could provide access to a wider audience of the services and benefits of the IT society. Once we comprehend how we recognize and communicate (by means of gestures, but not only that), we can build machines, which seamlessly integrate in our daily lives. Machines that would possess knowledge of our motor repertoire and thus could “behave” as if they were in our bodies and thus better understand our requests.

It is far too easy to imagine a system to help people with disabilities by, for instance, interpreting body gesture although perhaps using a different motor repertoire depending on the kind of disability (e.g. hand gesture recognition and interpretation, sign language, etc).

7.2. Ethical aspects and requirements

This project includes the use of healthy volunteers (visuomotor bank collection) and non-human primates.

All experimental studies on humans will be carried out following the ethical standards established in the Declaration of Helsinki (1964) and its successive emendations. All experiments will be performed in adequately equipped laboratories and conducted by qualified scientists. All participants will be paid volunteers. Subjects will be informed about the aims, experimental procedures and possible risks of the study. A written freely-given informed consent will be required from all of them prior to their inclusion in the study. Subjects will be free to retire their consent to participation in the experiment at any time, whatever the reason. They will be informed about the possibility before entering the study. Any effort will be made to preserve the privacy of the subjects.

All experiments on monkeys are authorized by local and national ethical Committees and will be performed in accordance to the national and international laws. Precise reference on their authorizations to make experiments can be found in the original publications of the group members. Macaque monkeys are used because of their cortical organization, and because there is evidence that their premotor cortex mediates cognitive functions, similarly to what found in humans. Other species with less complex neural organization cannot be used.

8. Economic development and S&T prospects

8.1. 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.

8.2. 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.

8.3. 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.

9. Project workplan

9.1. General Description

We expect the project to last **30 months**. A first gross subdivision could be done in terms of the biological and artificial aspects of the project. This subdivision is made here only for explanatory purposes: it is not intended to actually subdivide the work in this sense (which should be rather seen as a closed-loop process including the biological and artificial sides).

The work to be done will include the construction of an anthropomorphic robot arm/hand and data acquisition setups (the latter to be used during the initial stage of the project). Further, the project will study development as a new method to design autonomous robots, and the role of mirror neurons during hand gesture recognition and reproduction through electrophysiology in the monkey.

The first year will be devoted mainly to the realization of the hardware setups. We will deal with two setups here: i) the human subjects' data acquisition and ii) the robotic setup. The robotic setup is the objective "artifact" of the project and is also meant to be suitable to test the biologically plausible model (consequently, it involves non-trivial choices of sensors types, materials, elastic actuation, etc). As already mentioned, it is composed of an anthropomorphic robot arm and hand (it is, at the moment, hard to foresee the level of complexity required by the hand). It is clear that the realization of the robot will include a specification and design stage, where dynamics and kinematics will be defined. Consider that not the whole humanoid has to be designed and realized in the course of the project. The robot head, cameras, and controlling hardware are already available within the consortium. What we would like to design and implement is the arm and hand. Note also that both DIST and IST have already a long lasting experience on biologically inspired robotics and tasks such as gaze control, tracking and reaching.

The data acquisition setup will consist mainly of a data glove (commercially available) and one or two cameras (stereopsis might be necessary) suited to collect kinematic and visual data during manipulation actions (goal directed). The actual realization we expect to be finished at month 8. Of course, all the usual data acquisition hardware will be necessary (DAC, PC, frame grabbers, etc). The trickiest part of the data acquisition setup is the development of a semi-automatic image processing software and the appropriate synchronization with the incoming hand movement data. In order to simplify the image processing, suitable markers might be employed. This software module will be shared also by the robotic setup.

In parallel an initial study of the "developmental approach" will be carried out in order to evaluate the key aspects of the method. We expect to be able to formulate some initial predictions and a draft of the theory. This part is the most innovative of the project, and also the most risky. The main evaluation criteria will be that of comparing different learning methods with the proposed one. Also module/module comparison might be useful to highlight the differences or the merits of the approach. The biological parallelism will be maintained throughout the formulation. We expect thus to cover learning and adaptation on a global basis, encompassing the whole life cycle of the artifact. On a pure speculative basis we might imagine that the robot will be initially reflex-controlled, and successively develops new control modules aimed at voluntarily controlling actions (drives and motivations here might have an important role). The first aspect to be addressed will be the development of gaze control and reaching, being the prerequisites for the development of further abilities (gesture recognition). Further, the possibility of automatic bootstrapping from a stage to another will be investigated: i.e. the initial modules should promote (enhance) the learning of the late modules. Interrelationships and dependence will be analyzed. In particular, the aim here is also that of developing a mathematical tool to predict this sort of interaction between different learning modules (while the robot interacts with the environment).

Finally, an electrophysiology experiment will be carried out (starting at month 7 but terminating during the second year) aimed at investigating how the seen motor acts are matched onto the observer motor repertoire. This experiment will be carried out on monkeys trained to grasp and manipulate a variety of objects. 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 data acquired with these experiment will give important information on the role of self-observation in generating the mirror resonance phenomenon.

The second year will be devoted to the modeling of the data. The core subtask within the second year will focus on the use of a suitable artificial learning approach to model mirror neurons. It is important to note that the model will be biologically plausible and the results from the electrophysiology experiment described above will be taken into account because they might highlight some aspects of the role of vision of the hand during the development of mirror neurons.

Most likely the modeling will be carried out in two stages. A first stage will deal only with the kinematics information. In a second phase the visual information will be taken into account. This allows estimating carefully the relevance of the two sources of information. We expect to come out with a suitable model of the development of the "mirror neurons". Although described as a linear procedure, this part of the project will be likely a sort of loop, with refinements of the model carried out along the way on the basis of the robot implementation and the experimental data on the monkey.

The visual processing software will be enhanced in order to increase the generality of the approach. In particular a subtask will be devoted to applying the "developmental approach" to the acquisition of simple robot movements (i.e. tracking, saccading, reaching, and grasping). Coordination of behaviors will require a sort of "attentional mechanism" where global exploration strategies will be employed. For example, we expect to need the ability to generate a series of fixations (e.g. the hand, the wrist, the forearm, etc) aimed at collecting visual information. On the other hand some simplifications might be adopted on the first phase in order to focus more on the mirror neurons modeling.

During the second year, further theory on development will likely benefit from the experimental results with the robot. At this point more substantial experiments can be performed in order to validate the theoretical claims.

Finally, **the last six months** will be devoted to the final implementation and test; the artificial system will incorporate recognition and repetition of body (hand) gestures. This part should seamlessly integrate with the existing behaviors (possibly it will develop out of the existing modules). Further validation/experiments cycles might be needed in order to match real biological data, the model, and the robot results. We expect to encounter mostly technical problems at this point of the project whereas the mirror neurons based model should have been outlined during the second year. Of course, using the electrophysiological data we might carry out further validation of the model. A fine-tuning might be necessary on the basis of the robot performances.

The developmental theory might be further improved. In particular being a risky issue, some deliverables should cover the results, potential application areas, and a clear statement on whether the theory delivered its promises. At this stage, the robotic setup will be used to carry out the final experimental validation of the theory.

The end goal will be achieved if the artifact will show a reasonable level of performances and new insights will be gained on the mechanisms the brain uses to generate and recognize body gestures.

9.2. Workpackage list

The workplan is divided into 4 Workpackages as detailed in the following table.

Workpackage No	Workpackage title	Lead contractor	Person-months	Start month	End month
1	Project management and assessment	DIST	12	1	30
2	Artifact	DIST	64	1	30
3	Biological setup	UNIFE	36	1	24
4	Neurosciences experiments and integration	UNIFE	59	1	30
	Total		171		

9.2.1. Effort table (expressed in person-months)

Effort WP		DIST	UNIFE	IST	UU	Total
1	Management	6	2	2	2	12
2	Artifact	31	4	25	4	64
3	Biological Set-up	10	12	7	7	36
4	Neuroscience	3	32	1	23	59
TOTAL		50	50	35	36	171

With respect to the total effort of 171 person-months we specify that for partners UNIFE and UU, the total effort charged to the project is 45 and 31 person-months respectively. Each of the two partners will devote 5 person-months of work from permanent staff. The total effort charged by the project, is, therefore 161 person-months.

9.3. Workpackage description

9.3.1. Workpackage 1 : Management, dissemination and assessment

A detailed description of how the project will be managed is presented in section 9.7. We will concentrate here on dissemination and assessment. In a first phase we shall define and clearly state how results will be evaluated. It is hard to foresee at the moment, what sort of assessment measure will be employed besides the realization and test of the final artifact and the results of the scientific experiments. The overall assessment will very much depend on the decision to be taken at the beginning of the project and that will be reported at the first milestone. In particular we shall define on one side the exact protocol of the electrophysiological experiments and, on the other, the shape (kinematics and dynamics) of the artifact. All these factors might condition what we can reasonably expect. The study on the materials and elastic actuation should be considered part of this topic.

We expect mainly results on the novel approach to the construction (and design) of artificial agents “living, growing” and interacting in a real environment. We already pointed out that the project is twofold; consequently, the other main source of results is the use of the artifact in order to gain a new knowledge about how the brain solves a particular “recognition problem”. Of course, without any real data to be compared to, it would be very difficult to assess the biological validity of our model. For this reason new experiments, on the monkey, will be carried out during the project.

As far as dissemination is concerned we intend to follow two main paths, one for the technological achievements and one for the scientific results. In both cases, besides participating to user’s group and concertation meetings organized by the EU we will present our results to international conferences and workshops. At month 18 we intend to organize an international workshop specifically devoted to gesture recogniton/imitation. The workshop will be organized with the specific goal of gathering both robotics and neuroscience communities and compare results obtained from the two fields.

Workpackage number:	1	Start date or starting event:	Month 1	
Total Effort	12			
Lead Partner	DIST			
	DIST	UNIFE	IST	UU
Effort per Partners	6	2	2	2
Objectives: project management, coordination, workplan, assessment				

Description of work: Considering the small number of participants, their clearly defined role and the fact that some partners have a long lasting history of collaboration, all partners will participate in the management of the project.

Because of the nature of the project we do not expect major discussions on the implementation details of the artifact. What we want to keep under control, however, is the link and cross-fertilization between the more technological partners and the groups working more specifically on the neurosciences aspects. For this reason we intend to organize plenary scientific meetings twice a year and bilateral exchanges of researcher for longer period of time. The meetings will be publicized and open to external participation particularly to groups in and outside Europe working on similar aspects.

This important aspect is also stressed by the fact that workpackages involves substantial effort by all partners. The neurosciences aspects as well as the modeling, data collection, and robot implementation will be carried out in parallel. Therefore, we expect to obtain a mutual improvement from neurosciences to robotics but, more importantly, from robotics to neurosciences.

The assessment parameters will be defined during the first stages of the project, when also some initial study on both the robotics and neuroscience aspects will be available (around month 6). Some deliverables will cover both the aspects relative to the developmental approach to robotics and the “lesson learned” by the interaction of engineers and neuroscientists.

Deliverables:
D1.1: Project presentation
D1.2: Dissemination and Use Plan
D1.3: Management Report 1
D1.4 Periodic Progress Report
D1.5 Management Report 2
D1.6 Management Report 3
D1.7 Periodic Progress Report 2
D1.8 Management Report
D1.9 Technology Implementation Plan
D1.10 Final Report

Milestones and expected results: management and assessment of the approach. Conclusions of the interaction between robotics and brain sciences.

9.3.2. Workpackage 2: Artifact

This workpackage is concerned with the definition, realization, test of the robotic set-up as well as the experiment to be performed. This part of the project has to take into consideration not only the requirements from a technological point of view but also the need to make useful comparison between the artificial and the biological experiments. For example the artifact should be able to perform a set of manipulative actions that can be also studied in biological systems. Our intention is to address the study toward reaching and grasping actions. This will require the definition of a vocabulary of actions as well as the set of objects to be used during the manipulation experiments. Data that will be provided at the end of the definition phase are:

1) Kinematic structure of the arm-hand system
2) Reference set of manipulation actions
3) Reference set of objects to be manipulated
4) Definition of the visual primitives required to initiate manipulative actions on the set of objects (e.g. position, size and orientation of the objects)
5) Definition of the visual primitives required in order to characterize the motion of the arm (e.g. end-point trajectory, 3D evolution in time of the arm's joints).

From the "artificial" perspective what we intend to do during or after the artifact is built is:

1) Define how to realize a "sensorimotor" representation of manipulation acts where each action is coded by means of the motor commands used to perform the action as well as the sensory information pertaining the action (vision, proprioception). We called this an *extended representation* of the motor act. In this phase the extended representation will be developed with specific reference to the class of objects to be manipulated.
2) Teach the artifact (or having it learn) how to perform those actions and during that phase build an extended representation of each motor act associated to each object or class of objects. This could be done by having the system performing pseudo-random (but constrained) motor acts and by learning how to separate them into a subset of extended representations. Relevant here are many things. For example: what is the "error signal" during learning, how to constraint initially the motor repertoire (e.g. through initial motor synergies), how to segment complex actions in motor units and how to build a vocabulary of elementary motor acts, define how to bind sensory and motor information (using time?), the role of head-eye-hand coordination during this phase.
3) Investigate how to "transform" (or use) the self-centered extended representation into a "mirror representation". Investigate how "visual-only" information of a motor act (not in a self-centered coordinate frame) can be used to index the self-centered extended representation, coding the learned action (this indexing is the core of a mirror neuron). Relevant points here are how to cope with different visual reference using motor information (does fixation of the hand during manipulation provide some help here?).
4) Compare results from the neurophysiological experiments with those from the artificial ones. Try to see whether new experiments could cast some light on how the "mirror" representation is acquired (developed) and whether the artificial implementation might serve for the same purpose.

Workpackage number:	2	Start date or starting event:	Month 1	
Total Effort	64			
Lead Partner	DIST			
	DIST	UNIFE	IST	UU
Effort per Partners	31	4	25	4

Objectives: specification, design and implementation of the anthropomorphic robotic setup. The objective is to analyze the state of the art in terms of actuators with elastic/compliant characteristics, analysis of materials, and finally design a human-like robot arm and hand. Emphasis is on the ability to mimic and represent meaningful body gestures rather than, for example, on the payload or precision of the setup.

Description of work: In order to achieve the objectives, in a first stage, we shall investigate available actuation technologies and their application to robotics. Particular care will be given to actuators and materials, which allow realization of a compact, lightweight and efficient robotic setup. Cost might be an additional criterion for the evaluation of such technologies. Secondly, specifications of the setup will be given. The important assessment parameters here are the kinematics and dynamics of the resulting artifact. The robot arm design should allow torque control and efficient acquisition of kinesthetic information. Sensors such as strain gauges and encoders will be available on each joint. A minimum of haptic feedback will be also provided.

Once the specifications and the design are ready, we shall proceed to the implementation stage. An external specialized manufacturer will implement the system. Testing of compliance with the specifications will be carried out. The final hardware integration will be done within the consortium.

In some subtasks, we shall “implement the ontogenesis” of basic low-level behaviors (as described in the proposal). Successively, by using also the results from the modeling of mirror neurons, we shall implement the model into the robotic setup. The last six months of the workpackage will be devoted to the final demonstration and assessment of the artificial system performances.

Deliverables:
D2.1: Robot setup specifications and design (report)
D2.2: Robot setup (prototype)
D2.3: Visual primitives for object identification (software package and report)
D2.4: Basic robot behaviors (demonstration and report)
D2.5: Architecture of the learning artifact (report)
D2.6: Robot testing and technology assessment ()
D2.7: Final demonstration and results (demonstration)

Milestones and expected results:
M1: Realization of the robot setup (mechanical and electrical) as described in the objectives.
M7: Mirror neurons model implementation.
M8: Final demonstration.

9.3.3. Workpackage 3: Biological Set-ups development and test.

This Workpackage is devoted to the definition, realization and test of the experimental set-ups to be used to investigate the biological bases of the project. For the purpose of the project it will necessary to acquire information about the trajectory and posture of a human arm (and eventually a monkey arm) as well a synchronized sequence of images of the arm performing the action. It is worth stressing that we do not intend to develop “general purpose” algorithms (e.g. algorithms being able to automatically locate and extract the arm motion from visual information in unconstrained environments). For this experimental set up we will first define:

1) Number and accuracy of the kinematic data (e.g. all arm plus 3 fingers)

2) Specification of the visual data (e.g. frame rate, resolution, field of view)

6) Reference set of manipulation actions to be investigated;

3) Reference set of objects to be manipulated

Once the set-up is in place we will start investigating the architecture of the system. We intend this phase to be preliminary to the experiments using the robot and aimed at better defining how to implement an effective sensorimotor representation. This set-up could also be used as an input device for the artificial system when engaged in gesture recognition and imitation learning. The fact that both visual as well as motor information will be available will allow us to study the relative importance of the diverse source of information, eventually leading the system to being able to imitate actions on the basis of visual information alone.

More specifically the hand action acquisition set-up will be developed to acquire visual and cinematic data of a real moving hand while executing a series of goal-directed actions. A data glove together with electromagnetic sensors will be used for cinematic acquisition. Visual information will be acquired by means of TV cameras connected to a digitizing computer card. Data will be fed to an artificial learning system (e.g. neural network) according to the procedure described in the project. This objective will be reached in about 18 months. The first six months will be devoted to set-up preparation, months 7-12 will be employed to instruct the learning network by presenting a series of actions with constant or variable points of view. During this period the set-up is expected to extract the motor invariants which will produce the generalization of the naturally variable cinematic-visual inputs for each given motor command. During months 13-18 data will be analyzed and the structure of the artificial neural network after learning will be determined. It is expected that the elements of the network will differentiate with different degrees of sensorimotor specificity.

Workpackage number:	3	Start date or starting event:		Month 1
Total Effort	36			
Lead Partner	UNIFE			
	DIST	UNIFE	IST	UU
Effort per Partners	10	12	7	7

Objectives: Biological setup development. The goal of this workpackage is that of designing and implementing a setup able to acquire biological data in real-time out of hand gestures. The setup will consist of a data-glove and a pair of cameras. The data-glove will provide kinesthetic data (position of the hand and fingers). The cameras will monitor concurrently the hand gesture. The two source of information will be preprocessed and synchronized.

The collected data will be modeled by means of a suitable artificial learning method.

Description of work: The first phase will deal with specifications in terms of precision/frequency of the acquired data. The data-glove will be an off-the-shelf device. Cameras might be standard CCD cameras. Some suitable constraints will be enforced in order to simplify data processing, without compromising the quality of the recorded data. In particular, markers might be used on the hand. Further, data sources should be synchronized with respect to a common time reference. A general-purpose frame grabber and data-glove interface might be needed.

A second stage of the workpackage concerns the construction of the setup (assembling and testing). The general-purpose (low level) acquisition software will be developed in the context of this workpackage.

The data (kinesthetic and visual) will be used as input and/or teaching signals to a suitable learning method. It is hard to foresee at the moment which kind of model we will use. In any case, the “artificial neurons” and the structure of the developed architecture will be compared to the data obtained from the experiments on the monkey. These results will be used to improve the robotic model.

Deliverables:
D3.1: Biological data acquisition setup specifications
D3.2: Biological data acquisition setup
D3.2: Data collection analysis and processing software
D3.3: Modeling of the mirror neurons representation

Milestones and expected results:
M2: The biological data acquisition setup as described in the objectives
M3: Data processing software
M4: Mirror neurons representation

9.3.4. Workpackage 4: Experiments

In MIRROR we want to demonstrate mainly two things:

1) That in order to recognize/imitate someone else's action, humans are facilitated by being able to perform that action (in other words a person's ability to recognize/imitate motor acts is facilitated by having learned how to perform that action (or a close one) while observing, visually and "motorically", his/her own body).

2) That this is achieved by exploiting the sensorimotor information acquired during learning (development) in situations where the motor information is not available (because the act is "only" seen). A neuron that has learned the coding of an action (the coding being composed of visual and motor information) can be activated by using only visual information.

The way we intend to demonstrate it is by means of neurophysiological experiments investigating the above-mentioned hypotheses and by building an artifact able to learn to perform motor actions and to recognize/imitate the same acts made by others.

More specifically neurophysiological experiments on monkey aiming to demonstrate the contribution that the observation of monkey's own hand gives to the degree of activation of mirror visuomotor neurons recorded in premotor area F5. This experiment will start at month 8 after a period of experimental set-up preparation and animal training. The activity of mirror neurons will be recorded during execution of hand grasping movements a) in full vision (both object and hand visible), b) without hand vision (only the object will be illuminated) and, c) with a manipulated visual feedback (object will be illuminated and the position of finger tips will be shown to the monkey by means of markers attached to the monkey's fingers). During the experiment not only mirror neurons but also F5 motor neurons will be recorded and submitted to the same experimental paradigm. Analysis will compare the frequency of discharge in the three experimental conditions in both neuron categories. The study of F5 motor neurons is important in order to exclude that the expected modification of mirror discharge are due to difference in motor execution induced by the experimental manipulations. Experiments will be performed on 2-3 monkeys and will last from month 8 to month 20.

Finally Neurophysiological experiment on monkeys in which the data coming from the analysis of the "artificial neurons" of both artificial learning system and artifact "brain" will be analyzed in terms of motor, visual and visuomotor properties and the data will be compared with those obtained during electrophysiological recordings performed in monkey parietal and frontal cortices. Experiments will start at month 18 and will last one year.

As to behavioral studies on human infants we plan to investigate, mainly at Partner's UU, the following aspects:

1) the development of eye-head coordination in tracking objects and exploring the surrounding. Stabilizing gaze on an object during ego-motion and/or object motion require continuous adjustments of eye and head direction. These adjustments have to predict upcoming states. An important part of the development of gaze control has to do with acquiring such prospective control. We have found that the eyes and the head follow different time schedules in this respect. When the head enter seriously into the task at around 4 months of age, it lags the target quite substantially to begin with. The aim of the experiments are to find out how development proceeds in coordination eye and head movements and gearing them to the environment, and how prospectivity enters into the control of these movements.

2) the development of coordination between looking and reaching, looking and catching moving objects, and looking and tracking moving objects with the hand. In our earlier studies we have found that when approaching objects, infants preshape the hand, orient it appropriately relative to the object and, if the object is moving, direct the reach towards a future position where the object and the hand will meet. In doing that they mainly use vision for acquiring information about the object to be grasped and proprioception for controlling the arm and hand movements. However, we do not yet know what happens in fine manipulation. How important are then visual information about the movements of the hand? What are the advantages of knowing about the form and the properties of the objects to be grasped and manipulated, and what are the advantages of knowing what to do with the objects? Another related issue is to what degree gaze direction determines movements of the hand in, for instance, tracking tasks.

3) the nature of learning to imitate gestures. This is, of course, at the very heart of the MIRROR project. What can infants learn about the affordances of objects from observing other people manipulating them? In our earlier studies we have found that infants do not imitate actions blindly. They imitated the banging of a rattle but not the banging of a soft doll and they imitated the stroking of a soft doll against the chin but not the stroking of a rattle. Another issue is what infants can learn about actions themselves from observing other people do them and what errors occur when they try to perform those actions themselves. Imitating gestures improves all the way into school age. We aim to investigate how these abilities improves with age and what are the major difficulties children have when trying to learn from observation.

These three objectives will be pursued throughout the project period. They will be accomplished with precise measurements of eye direction and eye movements, measurements of position and movements of bodyparts such as head, hand and trunk, and measurements of object position and motion.

Workpackage number:	4	Start date or starting event:	Month 1	
Total Effort	59			
Lead Partner	UNIFE			
	DIST	UNIFE	IST	UU
Effort per Partners	3	32	1	23

Objectives: The goal is at least twofold: i) define an experimental protocol for data collection (i.e. what sort of experiment can highlight the mechanisms underlying the development of mirror neurons), and ii) perform the actual modeling and use the robot to further test its validity. We expect to perform two experiments, one devoted to investigating the role of visual information mapping into the motor repertoire, and a second one dedicated to the collection of data to be compared with the artificial model.

Description of work: the work shall proceed along the following guidelines:

1. Development of an experimental paradigm aimed at understanding the ontogenesis of mirror neurons. This might involve, beside the use of the setup (WP3), additional electrophysiological experiments as described in the objectives.
2. The actual execution of the experiments and the data collection.
3. The results of these experiments should on a first stage provide some highlights on the role of visual information and how this is mapped into the motor repertoire. On a second stage, the results should provide the basis of validation and assessment of the artificial model (through the already mentioned comparison).

It is worth noting that the whole procedure is not necessarily serial, conversely, some of the subtasks will be implemented in parallel with those of workpackage 2 and 3. This should facilitate the exchange of information (between robotics and biology) and the development of a common framework to understand the design and analysis of complex systems.

Deliverables:
D4.1: Experimental protocol for the monkey experiments.
D4.2: Experimental protocol for the behavior development experiments
D4.3: Preliminary results of the monkey experiments;
D4.4: Preliminary results of the behavior development experiments;
D4.5: Final results of the biological experiments
D4.6: Results on the comparison between “artificial” and “real” neurons.

Milestones and expected results:
M5: Experimental results on the role of visual information.
M6: Visuomotor transformation at the basis of the mirror mechanism.

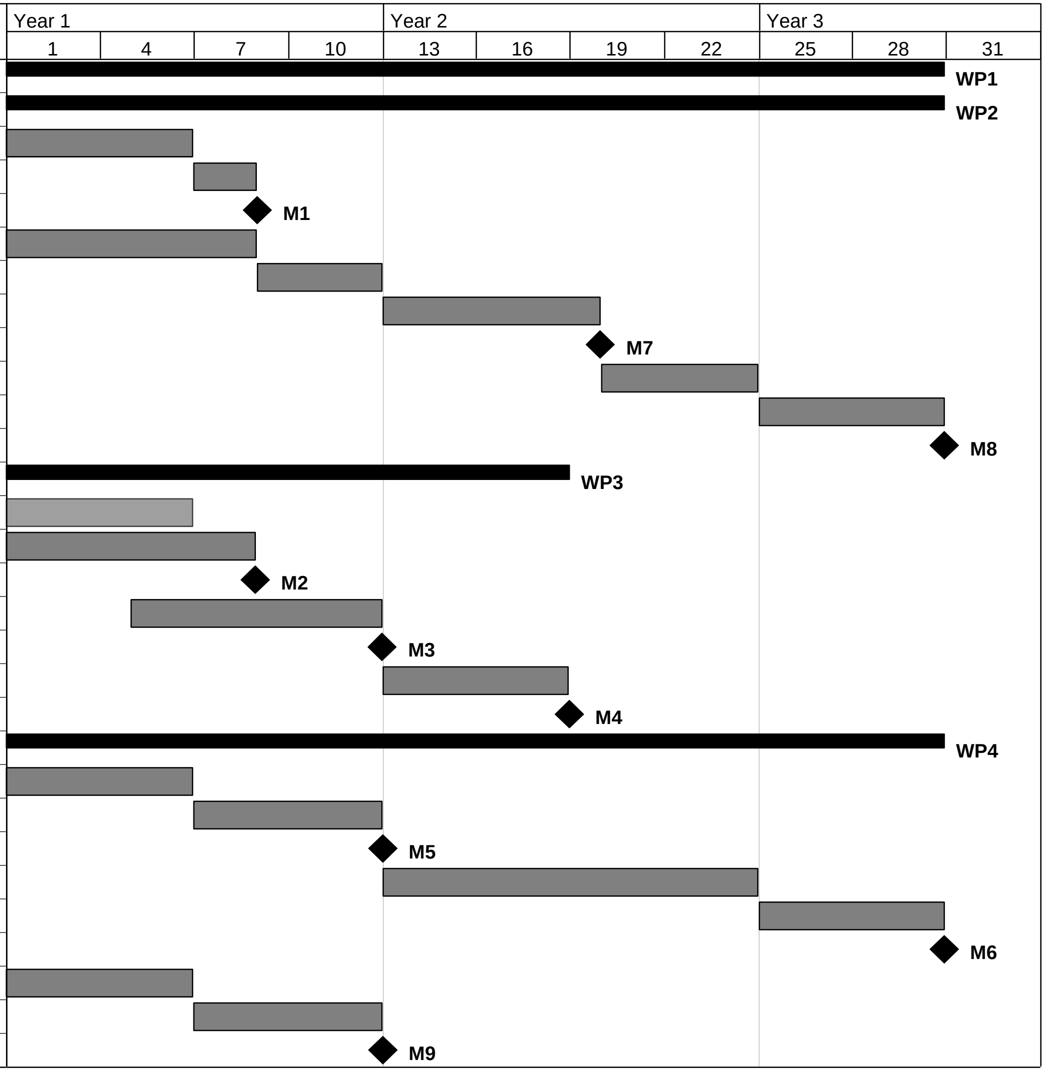
9.4. Deliverables list

Num.	Deliverable Name	WP N.	Leader	Effort	Type	Security	Delivery Date
1.1	Project Presentation	1	DIST	.5	Web Report	Public	1
1.2	Dissemination and Use Plan	1	DIST	1.9	Report	Public	6
1.3	Management Report 1	1	DIST	.5	Report	Public	6
1.4	Periodic Progress Report 1	1	DIST	1.1	Report	Public	12
1.5	Management Report 2	1	DIST	.5	Report	Public	12
1.6	Management Report 3	1	DIST	.5	Report	Public	18
1.7	Periodic Progress Report 2	1	DIST	1.1	Report	Public	24
1.8	Management Report 4	1	DIST	.5	Report	Public	24
1.9	Technology Implementation Plan	1	DIST	1.4	Report	Public	30
1.10	Final Report	1	DIST	4	Report	Public	30
2.1	Robot setup specifications and design	2	DIST	9	Report	Public	6
2.2	Robot setup	2	DIST	10	Prototype	Public	8
2.3	Visual primitives for object identification	2	IST	10	Software	Public	8
2.4	Basic robot behaviors	2	IST	7	Demo	Public	12
2.5	Architecture of the learning artifact	2	DIST	13	Report	Public	18
2.6	Robot testing and technology assessment	2	DIST	6	Demo	Public	24
2.7	Final demonstration and results	2	DIST	9	Demo	Public	30
3.1	Biological data acquisition setup specifications	3	UNIFE	7	Report	Public	6
3.2	Biological data acquisition setup	3	IST	15	Prototype	Public	8
3.3	Data collection analysis and processing software	3	IST	6	Software	Public	12
3.4	Modeling of the mirror neurons representation	3	DIST	8	Demo	Public	18
4.1	Protocol for the monkey experiments	4	UNIFE	5	Report	Public	6
4.2	Protocol for the behavior development experiments	4	UU	4	Report	Public	6

4.3	Preliminary results of the monkey experiments	4	UNIFE	10	Report	Public	12
4.4	Preliminary results of the behavior development experiments	4	UU	10	Report	Public	12
4.5	Final results of the biological experiments	4	UNIFE	16	Report	Public	24
4.6	Results on the comparison between “artificial” and “real” neurons	4	DIST	14	Report	Public	30

9.5. Gantt chart of the project

Task Name	Duration	Start	Finish
1 Project management	**30 months**	**month 1**	**month 30**
2 Artifact realization	**30 months**	**month 1**	**month30**
2.1 Robot specs & design	6 months	month 1	month 6
2.2 Implementation and hardware integration	2 months	month 7	month 8
2.3 M1			
2.4 Visual primitives for object identification	8 months	month 1	month 8
2.5 Basic robot behaviors	4 months	month 9	month 12
2.6 Architecture of the learning artifact	7 months	month 13	month 19
2.7 M7			
2.8 Robot testing and technology assessment	5 months	month 20	month 24
2.9 Final demonstration and assessment	6 months	month 25	month 30
2.10 M8			
3 Biological setup development	**24 months**	**month 1**	**month 24**
3.1 System specs & design	6 months	month 1	month 6
3.2 Implementation	8 months	month 1	month 8
3.3 M2			
3.4 Data processing software	8 months	month 5	month 12
3.5 M3			
3.6 Mirror neurons modeling (data modeling)	6 months	month 13	month 18
3.7 M4			
4 Neurosciences experiments	**30 months**	**month 1**	**month 30**
4.1 Protocol for the monkey experiment	6 months	month 1	month 6
4.2 Preliminary results on the monkey	6 months	month 7	month 12
4.3 M5			
4.4 Final results of the biological experiment	12 months	month 13	month 24
4.5 Result of the comparison	6 months	month 25	month 30
4.6 M6			
4.7 Protocol for the behavior experiment	6 months	month 1	month 6
4.8 Preliminary results on the behavior develo|	6 months	month 7	month 12
4.9 M9			

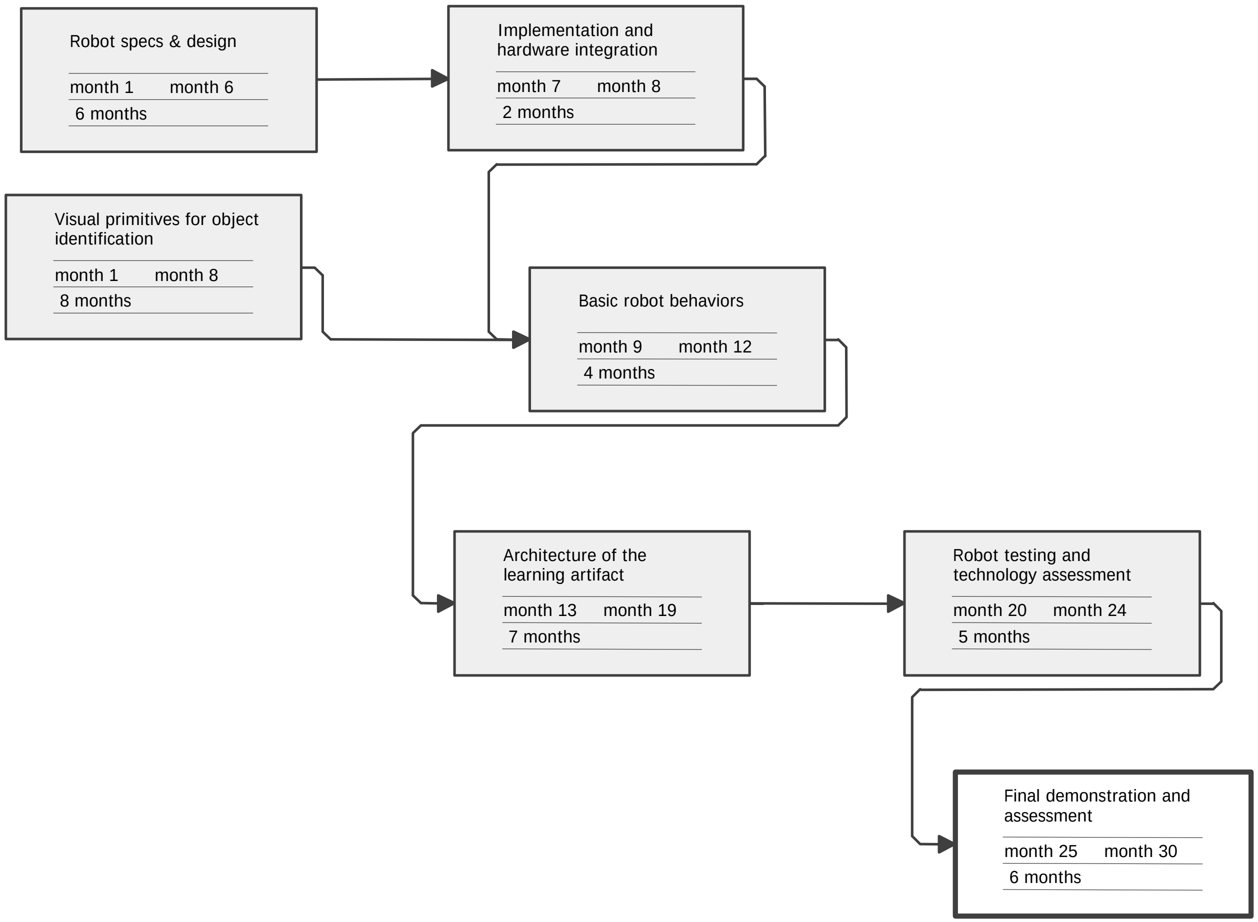


9.5.1. Milestones

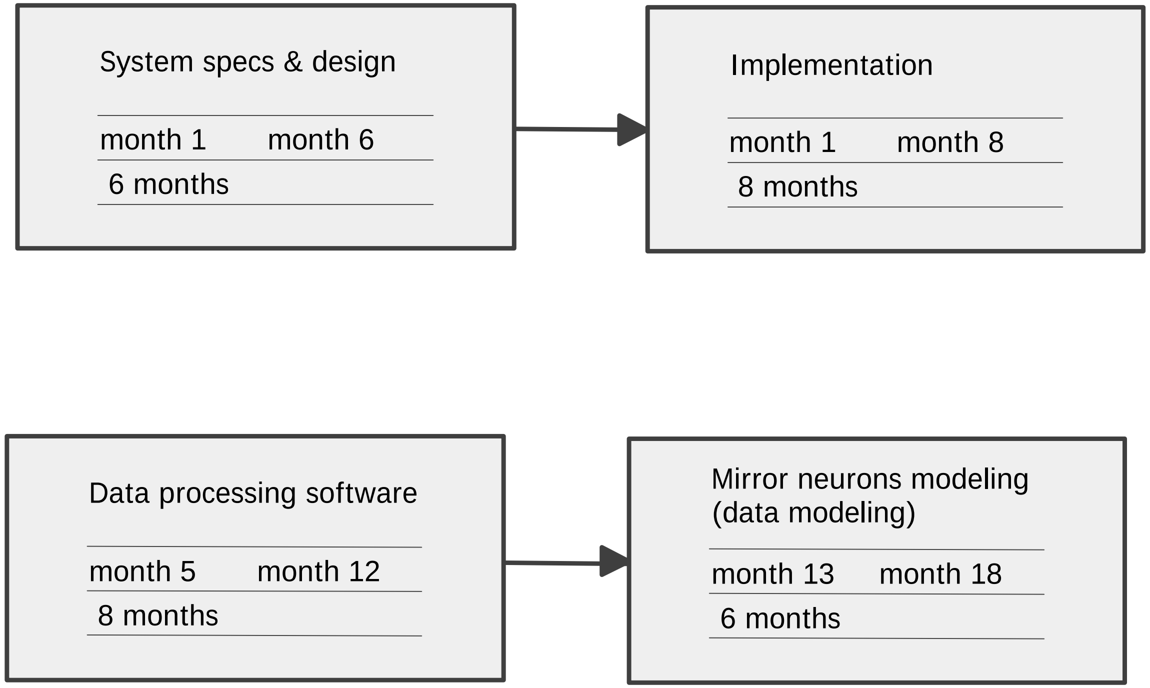
Number	**Title**	**Delivery date**
M1	The robotic experimental setup	Month 8
M2	The human data acquisition setup	Month 8
M3	Data processing software for the “visuomotor bank” (data-glove) setup	Month 12
M4	Mirror neurons modeling from biological data	Month 18
M5	Results of preliminary experiments on monkeys	Month 12
M5	The role of hand self-observation in mirror neurons modulation (neurosciences)	Month 18
M6	Mirror neurons activity and visuomotor representation	Month 30
M7	Mirror neurons model implementation on robot	Month 18
M8	Final demonstration	Month 30
M9	Results on preliminary behavioral experiments	Month 12

9.6. Pert diagrams

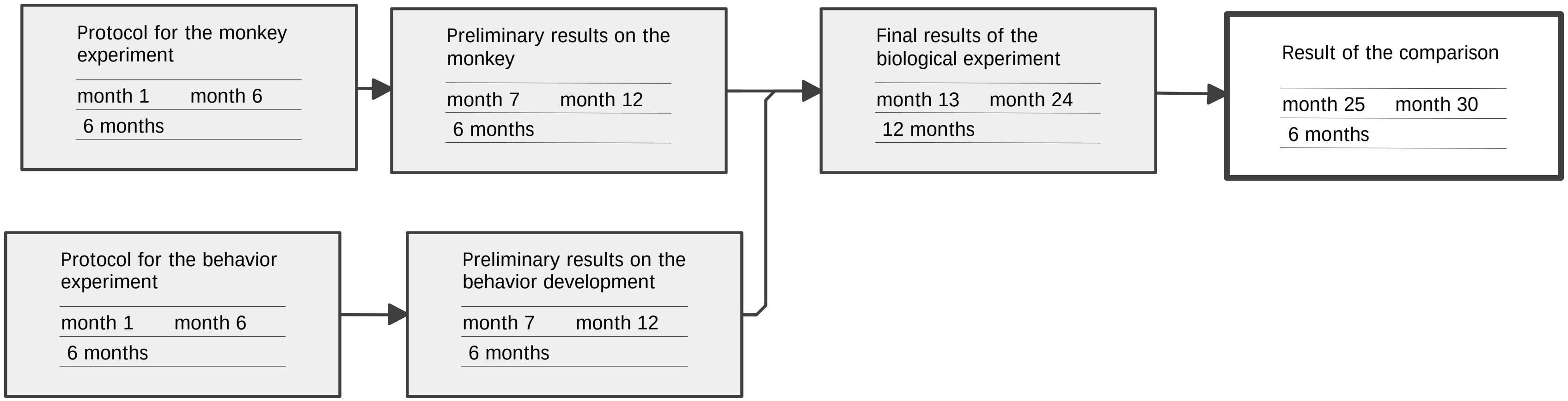
9.6.1. Pert chart (workpackage 2)



9.6.2. Pert chart (workpackage 3)



9.6.3. Pert chart (workpackage 4)



9.7. Project management

Considering the small number of participants, their clearly defined role and the fact that some partners have a long lasting history of collaboration, all partners will participate in the management of the project. DIST will be the prime contractor and Giorgio Metta and Giulio Sandini will be responsible of the project's coordination. Each partner has nominated a Principal Investigator. For IST Prof. José Santos Victor, for UNIFE Prof. Luciano Fadiga and for UU Prof. Claes Von Hofsten.

More formally we will appoint a *Project Coordination Committee* (PCC) composed of one person per partner and a *Project Scientific Committee* (PSC) composed of one person per partner (they can be the same appointed in the PCC) plus two experts not belonging to our research groups.

Decisions regarding the technical aspects will be taken by the *Project Coordination Committee* (PCC) lead by the *Project Manager* and composed of the *Principal Investigators*. It is expected the decisions will be taken unanimously but, if this will not be possible, conflicts will be resolved by the majority vote (one vote per partner). The role of the PSC is that of assessing the scientific contents of the work done and planned. This evaluation will be based on purely scientific grounds in both the Neuroscience and the Information Technology aspects.

The PCC will meet twice a year and whenever necessary to resolve unexpected problems. The meeting will be opened to other technical staff involved in the project. Smaller dedicated meeting (not necessarily involving all partners) will be called to resolve problems related to specific Work Packages or to coordinate specific joint activities. The decisions taken at these meetings will be communicated at the successive PCC meeting.

Considering the nature of the project we do not expect major discussions on the implementation details of the artifact. What we want to keep under control, however, is the link and cross-fertilization between the more technological partners (DIST and IST) and the groups working more specifically on the neurosciences aspects (UNIFE and UU). For this reason we intend to organize plenary scientific meetings twice a year and bilateral exchanges of researcher for longer period of time. The meetings will be publicized and open to external participation particularly to groups in and outside Europe working on similar aspects.

10. Clustering

A close co-operation with other projects in the Neuroinformatics for Living Artifacts initiative is foreseen as well as with those of the Life-like Perception Systems initiative and with related projects coming from the FET Open Scheme. The intended interaction with other projects will be centred around specific topics and take the form of joint events (at least one meeting per year), exchange of researchers and information. Part of this co-operation may take place within a specific network of excellence.

11. Other contractual conditions

Partners: University of Ferrara and University of Uppsala, use the “Additional Cost Basis” and, consequently, they are aware of the fact that they cannot charge permanent personnel to the project.

In relation to some of the expenses budgeted and reported in the Contract Preparation forms we specify the following in relation to equipments, subcontract, travel and consumables.

11.1. Equipments

1. Form A7.3 for partner UU, refers to a *eye-tracker* as and equipment depreciated over 36 months. Strictly speaking this device is not a “computing equipment”, however its depreciation over 36 months is justified both by the fast obsolescence of the electronic components (similar to those used in standard PC), by the fact that the measuring equipment accuracy degrades over time, finally for safety reasons requiring a frequent update of equipments used to record directly from human subjects. For the above reasons we expect the device to be discarded from the set-up after 36 months.

11.2. Subcontract Justification

1. Form A7.3 for partner DIST indicates a cost of 60.000 Euro subcontracted to the company C&M. The cost budgeted is not related to “external services” but to the actual purchase of a special-purpose device and as such no indication of effort in person/months is possible. This device is the arm/hand system of the artifact described in Workpackage 2. In past projects we already used the expertise of C&M for the realization of special-purpose robot parts (specifically a 4 degrees of freedom head) and we appreciated the skills and reliability of the company. In MIRROR we will provide them with the required specifications and participate in the design. The property rights for any novel device/components developed will remain with the Mirror consortium and it will be DIST responsibility to properly protect it.
2. Form A7.3 for partner UNIFE, indicates a total of 9,000 Euro for “Electronics and Precision Mechanics”. The cost budgeted is not related to “external services” but to the actual purchase of a special-purpose equipment and as such no indication of effort in person/months is possible. The equipment is part of the recording/stimulation set-up used for the electrophysiological experiments.
3. Form A7.3 of partner IST indicates a total of 5.000 Euros for subcontracting. This is intended as a mechanical/electronic extension to the currently used the robot head at IST. The cost is relative to the realization of a hardware device and is not configured as “external services”. As such it is not possible to estimate the effort that the subcontractor will use for the realization.

11.3. Travel

Regarding the cost of travel, besides the expenses related to traveling within the EU for project coordination, all partners may participate to scientific meetings outside the EU. In case of traveling to participate to conferences and other official scientific meetings, the contribution from EU will be duly acknowledged.

11.4. Consumables

1. Form 7.3 for Partner DIST indicates a cost of 16,000 Euro for consumables. This is intended for mechanical components, computer supplies (e.g. CD-ROM, Cables), electronic components for the realization of the experimental set-ups including sensors and actuators.
2. Form 7.3 for Partner UNIFE indicates a cost of 45,000 Euro for consumables. This is intended for laboratory supply (e.g. chemicals, electrodes, cables etc.), cost of animals, subject’s fee participation, computer supplies.
3. Form 7.3 for Partner IST indicates a cost of 10,000 Euro for consumables. This is intended for mechanical components, computer supplies (e.g. CD-ROM, Cables), electronic components for the realization of the experimental set-ups including sensors and actuators.

4. Form 7.3 for Partner UU indicates a cost of 15,000 Euro for consumables. This is intended for laboratory supply (e.g. chemicals, electrodes, cables etc.), subject's fee participation, computer supplies.

12. Ethical Considerations

Two Partners of the present proposal will carry out experiments involving human subjects (UNIFE and UU) and non-human primates (UNIFE). In the following a justification for this experiments as well as a description of the experimental procedure is contained.

12.1. University of Ferrara

The work carried out at UNIFE for the MIRROR project includes the use of healthy volunteers (visuomotor bank data collection) and non-human primates (macaque monkeys).

The first part of the present project will involve normal human participants. Experiments will be carried out following the ethical standards established in the Declaration of Helsinki (1964) and its successive emendations. Experiments will be performed in adequately equipped laboratories and conducted by qualified scientists.

Subjects will be requested to participate to behavioral tasks such as performing grasping movements toward different objects. The grasping movements will be acquired by means of a data-glove connected to a DC powered portable computer. A video-recording of the whole session will also be performed. The procedures we will use are highly standardized and the technical apparatus is built in agreement with the CE rules for use with human subjects. The risk connected to this experiment is therefore practically absent. Subjects, however, will be requested to carefully read the details of the experimental procedure, to agree with the scientific purposes of the experiment and to sign an informed consent form. Subjects will be compensated with 25∈/hour. Each experimental session will last about one hour. About 40 subjects will participate to the experiments.

In the second part of the present project *macaca nemestrina* monkeys will be involved in electrophysiological recordings of single neuron activity. Experiments on monkeys have been authorized by local and national ethical Committees and will be performed in accordance to the national and international laws (EU Directive 86/609/CEE, Italian law 12/10/93 n°413, Italian Legislative Decree 27/12/93 n°116, Italian Ministerial Decree 29/9/95 n°294).

Macaque monkeys are used because of their cortical organization, which is quite similar to the human one, and because there is evidence that their premotor cortex mediates high level cognitive functions. On the other hand, other species with less complex neural organization cannot be used for our purposes.

The hoped results coming from these experiments will open new insights on the mechanisms used by the brain to understand actions made by others. These results could be applicable to the study of normal and pathological behaviors in communicative processes and interpersonal relationships.

Due to the fact that non-human primates will be used, a special Ministerial permission has been obtained by the Department involved.

Macaque monkeys (4-6 kg), obtained from the Primatologic Center of Strasbourg (France) are housed in a fully equipped and climatized facilities. Cages are of adequate dimensions according to Italian and European rules and food and water will be fully available. Housing authorizations have been already achieved by both national and local veterinary authorities. Recording experiments will be performed in adequately equipped laboratories and conducted by qualified scientists, under veterinary supervision.

After a preliminary surgical session under general anhaestesia in which a Teflon recording chamber will be fixated on the animal’s skull, monkeys will recover from surgery and will be gently adapted to the laboratory environment. According to the standard electrophysiological procedure, neuronal recordings will be achieved by introducing a thin tungsten microelectrode (tip diameter less than 10 um) in the region of interest (frontal and parietal cortex) by means of a hydraulic micromanipulator that slowly inserts the electrode in the cortical gray matter. During penetrations the extracellular electrical activity of neurons close to the recording electrode will be amplified and recorded on a computer. Recording sessions are painless (being the nervous system devoid of sensory receptors) and will be realized under veterinary supervision (according to the Italian law on primate laboratory use). During dura mater cleaning (at the beginning of each experimental session) local anhaestesia will be employed. Each recording session will last about four hours. Monkeys will be simply requested to sit on a primate chair, to grasp food or other objects in different spatial positions and to observe similar actions performed by other individuals. Particular care will be kept in order to minimize the discomfort during recording sessions.

About six monkeys will be used for recordings in frontal and parietal cortex. At the end of the recording period (about six month for each monkey), animals will be sacrificed under general anhaestesia in order to anatomically localize the recording sites.

12.2. University of Uppsala

This research will be concerned with measuring the movements of infant subjects as indicators of perceptual, cognitive and motor competence. We have much experience with these kinds of studies. They have been going on for over 25 years. The experimental set-ups typically involve visual tracking of moving objects and reaching and grasping of stationary or moving objects under various kinds of postural supports. Three kinds of methods will be used. First, we will use a system that registers the positions of passive reflective markers to register various kinds of body movements (Qualisys, Partille, Sweden). This system uses low-level infra-red light emitted by the cameras and reflected by the passive markers. It is totally unharmful to the subjects and is routinely used in various studies of human movements. Secondly, we will use electro-oculogram, EOG, to register eye movements. This system is designed for human use and is thus totally sealed from the electric supply network by optical transfer of data to the computer. Finally, we will for certain studies also use video to record movements. There are no known risks with any of these methods.

During the project period around 200 subjects below 2 years of age will be studied. They will be recruited by letter. Before we start an experiment, letters are sent out to all the children of a certain age living in Uppsala encouraging the parents to volunteer. Those who respond positively are contacted for an appointment. When the parents and the child arrive at the lab, the parents are given detailed information about the experiment and the methods involved with opportunities for asking questions about the purpose of the research, the methods, and the possible risks and benefits of the subject. They are also informed that their participation is totally voluntary and that they can decide to discontinue the experiment at any point in time. We do not use a printed information sheet because of the interactive mode of informing the child’s parents. After the information is given and the questions answered, they give their consent by signing their names on an informed consent list. The parents are close to the child during testing. As a compensation of the cost and efforts involved in coming to the lab, the parents of the child are given either 8 bus tickets or 2 cinema tickets. If so desired, the parents are also provided with the video recording taken during the experiment. All data are locked in under code names and anonymity is guaranteed when the research is published.

The subject will not benefit personally from any of these studies, but we do assist the parents in contacting medical expertise if we discover any development problems with the children when they are examined. The studies and the methods involved have been scrutinized by several ethical committees over the years including the Ethical Committee of the Council for Research in the Humanities and Social Sciences, Sweden, and The Ethical Committee of University of Virginia, USA.

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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