SIXTH FRAMEWORK PROGRAMME
PRIORITY 2
Information Society Technologies
Cognitive Systems

Contract for:

INTEGRATED PROJECT

Annex 1 - "Description of Work"

Year 2 Revision of
Section 8 - Detailed Implementation Plan

Project acronym: **ROBOT-CUB**

Project full title: **ROBotic Open-architecture Technology for Cognition, Understanding and Behavior**

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8. Detailed Implementation Plan – Months 13-30

8.1. Introduction – general description and milestones

Based on the project objectives (PO) presented in Section 2 of Annex I, and on the general activity research plan, presented in Section 6 of Annex I, we set 6 specific objectives to be achieved within the first 18 months of the projects. These objectives are:

SO-1: A timeline description of human infants' cognitive development based on recent and well documented experimental results. The timeline description shall include, in an experimentally reproducible way, a guide as to the robotic artifact should develop over time, showing the formation of manipulation skills of varying levels. This description will be the result of joint contribution and research of all the participants with the aim of constructing a coherent description of human cognitive development within the timeframe (approximately from birth to year 3) and skills of interest to Robot-cub. Psychophysical and behavioral experiments will be planned and carried out to answer specific questions on the implementation and to acquire relevant missing information about the developmental process. This work will be carried out in the context of efforts to create a cognition architecture for the iCub, building on the developmental timeline description, neurophysiological models and psychological models, linking in the computational cognitive skills developed in WP3-6, and focusing explicitly on the creation of a cognition architecture that will enable the integration of the complete research effort.

SO-2: The complete design of all CUB components and a suitable integration plan. This includes the definition of the functional and technical specifications of the CUB mechanics, electronics and software architecture. At this stage of the project, the partners responsible for the CUB design and for testing the CUB individual components will have: a) completed the design stage, b) run a mechanical compatibility test and c) written a final plan for integration.

SO-3: The initial results of the implementation of cognitive abilities in an artificial system. This objective will be demonstrated through extensive testing of the robots' cognitive abilities in realistic situations, implemented in several of the existing robotic platforms, as well as through psychophysical and behavioral studies measuring the robots' interactions with humans. In addition to basic manipulatory and visual skills, the robots will be equipped with a number of basic social skills, enabling natural interactions between robots and humans. These social interactions are indispensable to the modeling and assessment of cognitive development. We will follow the approach outlined in section 6 of Annex I and, by month 30, we will have modeled, implemented, and understood to a certain degree the following cognitive aspects underlying the development of infants' manipulation behaviors:

a. The ability of learning and exploiting object affordances in order to correctly grasp objects on the basis of their use.

b. The ability of understanding and exploiting simple gestures to interact socially.

c. The ability of learning new manipulation skills and new communicative gestures by correctly interpreting and imitating the gestures of a human demonstrator.

d. The ability to crawl, sit up, and keep the upper torso and head stable when reaching (untested in the absence of the first iCub prototype).

SO-4: Results of the testing of new technologies to be used in the CUB platform. Particularly important for the scope and goal of Robot-cub is to monitor and to test continuously new technologies for sensors and actuators as well as the electronic (HW/SW) components of the Open System Platform.

SO-5: The Community Building activities outlined in section 2 of Annex I will be carried out all along the project's duration. During the first 30 months the following actions will be undertaken:

a. Establishment and initial results of the work of the International Advisory Board regarding the community building activities and the formal contacts with other funding agencies in relation to the launching of an international collaborative initiative on "Cognitive Systems".

b. Dissemination and networking activities, with special reference to the activation of strong links with Networks of Excellence on relevant themes, and other similar initiatives to be launched in the FP6.

c. Organization of a summer school (or contribution to a summer school) on embodied cognition, as a pilot action in the education of new generations of scientists.

d. Multidisciplinary intensive brainstorming and workshops on focused relevant topics.

e. Preparatory actions aimed at promoting the dissemination of the CUB among scientists. This will be done in strict interaction with European and national institutions and with other projects and NoE's of the Cognitive System's Initiative.

f. Establishment of formal partnerships with International Laboratories and research centers including the definition of Intellectual Property Rights rules for sharing/exchanging of artificial implementations of cognitive behavior.

SO-6: Update of the Open System legal aspects and definition of the organization.

Cognitive Manipulation

The project addresses the implementation of a humanoid robot's manipulative skills through learning, imitation and social communication. To this end, an ideal system should include at least a binocular head, two arms with hands, and a torso. However, during the first 30 months the actual systems we intend to use will necessarily be based on existing components (head and arm). This fact constrains the possible manipulation experiments to the use of one arm only. Other relevant aspects of the project (such as the architecture of social behaviors, the seeds of communication skills, and crawling/sitting) will be studied with different platforms. Any new prototype designed and realized during this period will be thought of with the longer term objective in mind of building the CUB: a robot to be effectively used to implement and test complex, human-like, manipulative behaviors.

Before entering into the details of the specific activities we describe the experimental scenario that constitutes the robot's environment and the approach we intend to follow in addressing the issues of learning, imitation and communication (refer also to section 6 of Annex I defining our longer-term scenario).

The experimental scenario of the project is that of a child learning to use toys/tools by "playing" alone and or with another animate agent (a play pal). Examples are how to use a drumstick to hit a drum, a wrench to fasten a bolt, a key to open a locker. This kind of tasks requires that robot cub learns a set of primitive actions as well as their combination. In particular the cub has to learn:

1) How to properly grasp the toy/tool (i.e. how to grasp the tool according to its affordances). By this, we mean learning the type of grasp that allows executing a given action with the given tool.

2) How to associate a certain tool to a given object/action (hitting a drum vs. inserting a key).

3) How to adjust the actions with respect to environmental conditions (e.g. the position of the nail or the orientation of the bolt) and changes (e.g. a tool of different mass or length).

4) How to combine primitive grasps and actions on the basis of past experience and or observed behaviors.

5) How to interact appropriately with the play pal in learning the game/task.

It is important to note that we do not intend to address the acquisition of grasping and manipulative behaviors in general terms, but rather by explicitly considering, from the beginning, the “goal” of the action as an essential component of both learning and understanding. Grasping an object for the sake of grasping it is just the initial step in the developmental path (to some extent we can consider this an “innate” skill) while, the driving force for learning different grasps and different manipulative actions soon becomes that of grasping the object so that it is possible to “do something” with that object.

The experiments will be carried out autonomously by the robot with occasional interaction with a human companion (the robot’s toy-pal). The “world” of the robot is composed of tools that can be manipulated (such as a drumstick, a key, and a small ball) and toys that can be acted upon (such as a bell and a “magic box”)[1]. The experimental setup is structured to generate different auditory feedback for different actions performed on the toys with different tools. For example: the sound of the drumstick hitting a bell or the sound generated by inserting the key inside the magic box through a keyhole. The overall goal is, for the robot, “to make noise” (in the sense that “making noise” is a tangible evidence of an accomplished task).

When using the tools actions that can generate a sound are limited to specific associations tool/toy. For example handling the drumstick by the handle only allows generating noise by hitting the bell while, grasping the drumstick by the head allows both hitting the bell (making a different noise) and generating the noise caused by inserting the handle into the keyhole of the magic box. The same sound is generated when inserting the key while dropping the small ball into the magic box makes a different noise.

	Tools			
Toys	Drumstick by handle	Drumstick by head	Key	Small Ball
Bell	Sound 1	Sound 2		
Magic Box		Sound 3 (insert)	Sound 3	Sound 4 (drop)

Table 1. Hypothesis of tools and toys used by the robot in the scenario.

Within this scenario we intend to follow a developmental path starting from a limited amount of “innate” knowledge in the form of motor synergies (sort of reflexes) and learning progressively more complex actions both in terms of their variety and accuracy, and with respect to achieving more complex goals (such as using an object to act on a second one).

A set of motor synergies will be hand coded in the “newborn” system: i) a grasping synergy, activated whenever an object is pressed on the palm, that triggers the closure of the hand; and ii) a set of explorative behaviors allowing the system to “discover” properties of the tool and to interact with the environment (e.g. shaking objects, approaching and touching them, etc.). The system still does not know the consequences of these exploratory behaviors but they are essential for the robot to acquire information about the world and eventually to learn the consequences of its own behavior.

The robot will be also equipped with modules devoted to the acquisition of the structure of the interaction. Aspects of the interaction that will be considered include the regulation of the interaction dynamics, turn-taking, social spaces, approach/avoidance, etc. The longer term goal is to devise plausible mechanisms for the acquisition of “social competencies”. In the 30 month timeframe we expect to develop a robotic test-bed for the design of communicative

[1] Tools are objects that can be grasped and toys are object that cannot be grasped but can be acted upon with the tools.

interactive behaviors (non-verbal), to develop a small scale user-study to evaluate the appreciation of the behaviors, and to develop very simple interaction kinesics.[2]

Starting with these elementary motor components the development of the robot will follow this path:

1) The different tools are handled by the play pal to the CUB in different ways eliciting different grasps (simply by triggering the grasping reflex). The robot learns, for each grasped object, a representation in terms of shape (approximate), color and haptic data (e.g. hand's grasping posture and the associated tactile image). At this stage the goal of the robot is "simply" to associate the grasp type to the specific tool (i.e. the haptic and visual information associated with grasping the object).

2) The successive goal is to learn how to grasp tools lying on the table and, possibly, to learn about some of their dynamic properties by applying exploratory motor behaviors (e.g. shaking the object). At this stage the goal of the robot is "to grasp" so that if unknown objects are shown the system executes the grasp associated to the most similar known object.

3) The next step is to learn affordant grasps (i.e. grasps allowing specific actions to be executed). The play pal demonstrates affordant use of tools. For example whenever a bell is present on the scene the play pal takes the drumstick by the handle and hits the bell. The cub learns the association between the presence of the specific object, the proper tool, and the specific noise (i.e. it associates consequences to actions). During this phase, the robot should discover by exploring action possibilities how to reproduce the same effect demonstrated by the play pal. For example the sound of the bell hit by the drumstick or the sound generated by correctly inserting the key into the hole. In doing this the robot learns to associate actions to their consequences: e.g. hitting the bell with the drumstick produces a sound. At this stage the robot acquires the ability to imitate "indirectly" the play pal actions in the sense that the robot learns by trying to imitate the effects of the actions without extracting or understanding the geometry or the kinematics of what it has seen.

4) When a bell is shown to the robot, the robot grasps the drumstick and hits the bell. Conversely when the magic box appears the robot grasps the key (or the small ball) and inserts it in the keyhole At this stage the goal of the robot is to "generate a specific sound" so that if unknown objects are shown the system executes the actions associated to the closest known object (e.g. proper grasping followed by proper use). It is worth stressing that by this stage the system already displays the ability to compose primitive actions such as, for example, grasping a stick and hitting the bell.

5) At this point of the developmental path different experiments can be foreseen to test/implement more complex adaptation and imitation skills. For example by changing the drumstick with a heavier/longer tool, investigating the ability of the system to adapt to dynamic changes, or by changing the profile of the hole so that the key can be inserted only with a given orientation (e.g. the key with a triangular profile). Also, the sound of the various toys could be removed, and the robot tested using vision alone

6) Finally we will investigate how the robot could learn non-affordant use of the tools by imitation. For example, the non-affordant use of the drumstick used to hit the bell while grasped by the head. This is a much more complicated skill because it requires the imitation of the gesture and not only the imitation of the effect of the action on the object.

While imitation fits nicely into this plan, communication experiments can be only in part integrated into a single setup in 30 months. Clearly some of the experiments can be

[2] Kinesics is 'the study of the role and timing of non-verbal behaviour, including body movements, in communicative and interactional dynamics'; see Robins et al., Sustaining interaction dynamics and engagement in dyadic child-robot interaction kinesics: Lessons learnt from an exploratory study intelligent life-like agents, *14th IEEE International Workshop on Robot & Human Interactive Communication, ROMAN* (2005), IEEE Press, pp. 717-724.

conducted (and integrated) on any of the humanoid platforms within the consortium (e.g. manipulation). Other experiments will be carried out separately. It is not realistic to foresee integration on such a short time scale. For example, the investigation on crawling and locomotion has initially been developed separately as part of the mechatronic effort, before being gradually integrated into more general sensorimotor coordination studies. Also in this case, for practical reasons, it is not feasible to fully integrate locomotion with the experiments on manipulation.

Consequently the first 30 months will see three different experimental efforts:

- The cognitive manipulation scenario outlined above.
- The design of the interactive behavior framework and relative analysis.
- The investigation and evaluation of mechatronic aspects such as that of the legs or the sensors.

The first and second efforts will be implemented and tested on existing setups; the third effort will specifically investigate the mechatronic aspects of the CUB.

The **first two years** will be devoted to the implementation of steps 1, 2 and 3 so that the system should be capable of:

- Learning how to grasp a set of tools either known or unknown.
- Learning about object affordances by exploration/interaction of the manipulator with a set of objects.
- Learning to elicit particular consequences given a certain object by generating a particular action.
- Studying the structure of the acquired "space": e.g. how small variations in one of the conditions/variables would change the generated action/interpretation.
- Interpreting actions executed by a human operator in terms of the observed consequences onto the environment (without extracting the geometry or the kinematics of the demonstrated action).

At month 18 we expect to have completed the implementation of a first instance of the "learning by imitation" mechanisms. During this period we expect to be able to complete steps 4, 5, and 6 described above. The final demo will show the robot repeating simple assembly actions performed by a human operator using known objects, for instance, assembling a five piece toy by imitating the sequence of operations demonstrated by a human operator. The assembly actions will be composed of simple "sub-actions" like insert, put on top, turn, etc. as well as the use of appropriate tools (such as a hammer, a wrench, etc.). Note however how aspects of communication (and of the investigated model) might be integrated at this point into the acquisition of sequences of operations or in imitating the human operator.

The following important step (from month 18 to 30) will be the implementation of bi-manual manipulation skills. Examples are the exploitation of non-trivial affordances that require e.g. grasping and holding the object with one hand while simultaneously manipulating it with the other hand. Another plausible scenario includes a wider range of object-related activities that require synchronized control of two arms such as opening a slit and inserting an object in it, handling large objects that cannot possibly be grasped appropriately with one hand only, manipulating soft materials such as textiles, etc.

The outline of the activities, in relation to the grasping primitives, will evolve in the following way:

T1.1 The initial manipulation skill will be that of learning how to associate to a specific tool a specific grasp type. In this phase the three tools will be "given" to the robot, which, through the position and touch sensors mounted on the hand, will add the haptic representation to the visual representation of the tool (mainly color). All the three tools will be used with the four affordant grasps (see Table 1).

T1.2 Successively the experimenter will demonstrate to the robot certain actions performed with the tools on the toys and generating different sounds. For example the drumstick will be shown to generate a specific sound when hitting the bell. In this way the representation of the tool will incorporate the proper context: i.e. toy-sound. The robot will be left free to experiment with each tool so that it will be able to find out which action generates which sound. At the end of this phase if the robot has a tool in his hand is able to select which action to perform.

T1.3 In the final phase, the robot, when prompted by a sound, will generate the sequence of actions (i.e. grasp and act) to generate the same sound (an example of goal-directed imitation).

Workpackage Breakdown

In order to achieve the goals we set for the first 30 months, the Robot-cub project will rely on an intensive interaction between the multidisciplinary scientific communities (human developmental psychology, cognitive robotics, mechatronic, and perceptual science).

This interaction will be boot-strapped by intensive brainstorming, meetings, and workshops, aimed at: 1) reciprocal exchange of knowledge, 2) discussion of the relevant issues, from all perspectives (neuroscientific, robotic, developmental), 3) identification of the critical issues for the design of the joint experiments and of the CUB platforms, and 4) joint formulation of a developmental model of Cognition.

Our assumption in describing this activity is that if roboticists alone lead the system design phase from the beginning perhaps no real breakthrough is possible. On the contrary we propose that psychologists and neuroscientists lead the brainstorming activities during the first 12 months of the project so to identify the crucial components of cognition and a realistic pathway for cognitive development and, in this way, defining the experimental protocols as well as the requirements for robot design.

Psychologists and neuroscientists should also help in defining the experimental activities on existing robotic platforms as well as the definition and the execution of the psychophysical and behavioral experiments. The robotic community will have the responsibility of performing the initial experiments using the existing prototypes. When detailed guidelines of the new robotic system will have been defined based on the outcome of the first "creative" phase, the robotic community within Robot-cub will start the design of the individual CUB’s components. This means that the definition of the functional specifications of the Robot-cub platform, one of the goals of this first 18-month phase, will be based on the components of cognition and on the developmental pathway defined by the psychologists. The functional specifications will be validated by a preliminary synthesis of behaviors implemented on the existing robotic platforms and including a set of relevant aspects of cognition.

Based on these guidelines, the workplan for months 13-30 of Robot-cub is structured around **9 Workpackages**, which are briefly introduced below.

WP1-Management will concentrate on all the activities related to the coordination of the work and the management of project resources. The coordination is especially intended to integrate the effort of the different partners towards the common goal, as well as to harmonize the contribution of the research activities with the accompanying actions (open system, community building training, etc.). The management activities are aimed at ensuring the proper and best usage of the project’s resources, and they are described in full detail in Section 7 of Annex I.

WP2-Cognitive Development: Contains all activities specifically devoted to the definition, and implementation of the developmental approach. Activities will start by defining the roadmap of cognitive development. This will include the definition of the cognitive components and their evolution during development. The roadmap will be expressed as a sequence of behavioral experiments to be implemented in the robotic setup. The goal of the experiments is twofold: i) demonstrate the correctness of the developmental roadmap and ii) contribute to the definition of the CUB sensorial, motor and processing requirements. Perception, cognition, and motivations develop at the interface between brain processes and actions. Biology has prepared the infant for action by investing in certain perceptual capabilities and sensorimotor skills and making those proliferate in specific ways that optimize the developmental process. Different modes of learning are recruited for the different problems at the different phases of development. To understand the accumulation of knowledge and the acquisition of skills, both the biological foundation and the mode of learning must be considered. In the initial phases of the project different "partial" implementations of the developmental process will be investigated and compared. There will be a particular focus on how different modes of learning can be applied to different developmental challenges. This activity is thought to be fundamental in defining the cognitive architecture of the robot.

This work-package then will develop a conceptual framework that forms the foundation of the RobotCub project. It will survey what is known about cognition in natural systems, particularly from the developmental standpoint, with to goal of identifying the most appropriate system phylogeny and ontogeny. It will explore neuro-physiological and psychological models of some of these capabilities, noting where appropriate architectural considerations such as sub-system interdependencies that might shed light on the overall system organization. It will present a roadmap that uses the phylogeny and ontogeny of natural systems to define the innate skills with which iCub must be equipped so that it is capable of ontogenic development, to define the ontogenic process itself, and to show exactly how the iCub should be trained or to what environments it should be exposed to accomplish this ontogenic development (this would be an extension of the six-stage development plan above). Finally, it will address the creation of an architecture for cognition: a computational framework for the operational integration of the distinct capabilities and cognitive skills developed in WP3-6, and it will investigate the (very challenging) issue of theoretical unification of distinct models.

This WP will contribute mostly to objectives SO-1, SO-2 and SO-3 described earlier.

WP3-Sensorimotor Coordination: Activities in this work package are aimed at the definition and implementation of the development of sensorimotor skills and their contribution to cognitive developments. As a result of WP2 the "innate" abilities will be defined and their implementation on the existing humanoid setups will be carried out (within the limits of the existing systems). The Neuroscience partners of the project will coordinate contribution to the activities of this WP. We would like to stress here, however, that the subdivision into the WP 2-6 does not mean that these workpackages will proceed independently one from another. On the contrary, an intensive "osmosis" is programmed between WP's, given the fact that increasing experimental evidence is challenging the traditional view of separate structures for action and perception (see section 6 in Annex I). Locomotion, although originally viewed as a simple task in autonomous relocation of the iCub, in now understood to be a complex and essential part of the complete sensorimotor capability of the iCub and is being addressed explicitly in this work-package rather than in WP7 as it was in the first year of the project.

This WP will contribute mostly to objectives SO-2 and SO-3 described above.

WP4-Object's Affordance: Activities in this workpackage are aimed at the definition and implementation of the cognitive skills required for the acquisition/exploitation of object's affordances. This will involve the analysis of the available knowledge and literature on the development of this skill (which at the moment is not particularly consistent), the definition of the experimental roadmap and identification of further investigation, and finally the test of the initial steps of the roadmap on existing platforms.

This WP will contribute mostly to objectives SO-2 and SO-3 described above.

WP5-Imitation: The activities in this workpackage will address the cognitive skills required for imitative behaviors. The cognitive skills include a) the ability to recognize and interpret somebody else's gestures in terms of its own capabilities, b) the ability to learn new gestures on the basis the observation of those of other individuals, c) the ability to learn new object affordances on the basis of a demonstration of novel means of manipulating objects, d) the ability to recognize the purpose of other people's gestures, such as the goal of manipulating objects in a certain specific way, e) the ability to predict the result of a demonstrated manipulation task and to use this ability to discriminate between good and poor demonstrations of manipulation tasks based on their affordances, and f) the ability to decide when it is good to imitate and what part of the demonstration is relevant to imitation.

This WP will contribute mostly to objectives SO-2 and SO-3 described above.

WP6-Gesture Communication: The activities of this workpackage will address the cognitive skills required to communicate through body gestures. This include the abilities a) to skillfully control its arms and body in order to produce communicative gestures , b) to track and recognize someone else's gestures, c) to generalize over different gestures and to associate with these functional or semantic meaning, d) to interpret and respond adequately to gestures, e) to understand turn taking as the underlying rhythm of gestured communication.

This WP will contribute mostly to objectives SO-2 and SO-3 described above.

WP7-Mechatronics: The activities in this workpackage are devoted to the the finalization of the design of the mechatronic components of the CUB (iCub). As for the previous period, we stress here the fact that it the responsibility of each partner involved in the design to fully test the design before submitting it to the management committee. A final decision is taken with the testing data available.

The systems will be designed according to the mechatronic paradigm: that is by smoothly integrating, since the design phase, mechanisms, proprioceptive and exteroceptive sensors, actuators, embedded processing, and any other components and interfaces needed for the functioning of the system and for connection to the other subsystems of the CUB. Body parts will be anthropomorphic and integrated into the whole design according to the specifications agreed at the beginning of the project. Their design will be based on both traditional and innovative mechanical solutions, including the use of non-conventional materials (e.g. silicone rubbers, soft polyurethane resins, carbon fibers or generic composite materials) in order to obtain lightweight mechanisms with a high level of performance.

WP7 will include the activities related to the realization of the first prototype at UGDIST, collecting the CAD drawings and testing results from all partners, smoothing and integrating the design, and fully debugging the entire platform including the mechanics, the electronics and the low-level control. Although the first prototype is built at UGDIST all partners will contribute to its completion through their initial design, through additional debugging or by examining specific issues that might arise. It will then link onto WP8 for the continuation of the software development activity.

Even though the priority activity in WP7 is to integrate all the mechatronic components into a fully-functional and complete iCub, sub-systems, such as the iCub head, will be made available for replications when complete. This will also allow other partners to develop software utilities for these sub-systems independently of the integration work on the initial prototype.

This WP will contribute mostly to objectives SO-2, SO-4 and SO-3 described above.

WP8-Open System (CUB): The main activities will be aimed at establishing the structure necessary to support the compilation, maintenance, and distribution of the CUB design including the technical as well as the legal aspects. The activities will also include the definition, design, and implementation of the software architecture.

This WP will contribute mostly to objectives SO-2, SO-4 and SO-3 described above.

WP9-Community building and self-assessment: The activities here represent the dissemination aspects of the project as well as the training activities. The main contribution will be to SO-5.

The dissemination activity shall involve two types of dissemination: internal and external. In a consortium of this size and nature it is not only required to provide external dissemination of research results. It is equally important to have dissemination of information internally so as to ensure cohesion within the consortium and to allow training of involved researcher on the interdisciplinary themes involved.

As for the *internal dissemination*, to ensure a common ground for studies and appreciation of the involved complexity a number of activities are undertaken to achieve training of the involved researchers, like:

- Tutorials on human cognition and development.
- Tutorial on relevant mechatronic aspect.
- Tutorial on modeling of human sensorimotor coordination (e.g. gaze control and grasping).
- Tutorial on robot control system.
- Annual summer school with the participation of the PhD's and postdocs involved in the project.
- Scientific workshop on an annual basis.

In a mixed consortium it is crucial that the scientists are able to access/understand the diverse literature and understand the basic terminology. For these reasons during the first three months of the project a three day workshop with tutorial presentations will be organized to bring together the involved researchers and provide them with a common basis for their studies. Subsequently, the tutorials will be made available on the consortium web site for easy access and referencing. In addition the tutorials will be updated annually to reflect progress and take feedback into account. On an annual basis a summer schools will be organized by the consortium. Each year a selected theme will be chosen as a basis for a week long event. All involved PhD students will be invited to the summer schools. An important side-effect of the summer school will be the set up a social network across the involved institutions as a basis for joint studies.

In association with the annual review a 2-day scientific workshop will be organized for the presentation of the detailed results across the set of studies. At each workshop 2-3 prominent international researchers will be invited to attend the workshop and provide an outside view of progress elsewhere. In addition the EU reviewers will be invited to attend the workshop. The formal review of the project will take place on the final days of the workshop.

As for the *external dissemination*, an important part of the project is naturally dissemination of achieved results to the scientific community in general. All studies will in the tradition of good science be published in particular in archival journals. In addition a number of events will be organised to ensure proper dissemination to the scientific community, potential end-users, and the society in general. In particular the following events/mechanisms have been foreseen:

- Cognitive Robotics workshop at a major robotics conference, during the second year.
- Special issues on international journals such as the "Journal of Interaction Studies" Published by John Benjamins Publishing Company on topics related to Social Behaviour and Communication in Biological and Artificial Systems (Yr 3).
- Setup and maintenance of a consortium www site.
- Setup and maintenance of the CUB distribution facilities.

It is here important to note that workshops will be organized to distribute results to all scientific communities contributing to Robot-cub. In addition, special issues of selected robotics and neuroscience journals will be organized. Given the lead time for call for papers, reviewing and publication it is not realistic to have such efforts completed until the end of Yr 2 and 3, respectively, but the activities aimed at such initiatives will start during this first 18-month period.

All the above activities will be coordinated with the Networks of Excellence and with similar initiatives supported by the European Commission under the 6^{th} framework.

As to the specific activities devoted to the internationalization of the project, the Advisory Board will invite international and national funding agencies to meetings specifically organized to present the strategic importance of a joint effort for the establishment of an international scientific community on "cognition" and the need for a common platform like the CUB. Among the International agencies that will be contacted are:

- Human Frontier of Science Program.

- European Science Foundation.
- Office of Naval Research.
- National Science Foundation.

Besides also funding agencies acting at national levels will be contacted at both the European and extra-European level. Among them:

- Ministries and national councils of research supporting basic research activities.
- Ministries and national organization supporting technology transfer and pre-competitive research.
- Agencies supporting specific application areas such as space, civil protection, health management.
- Agencies supporting internationalization of activities (even in the 6th framework).

This WP will contribute mostly to objectives SO-4 and SO-6 described above.

According to the proposed approach in defining the Workplan, each RC defined in Section 6 of Annex I contributes to the definition/implementation of the different Tasks to be performed within certain Workpackages. More specifically, a direct mapping of the RC contributions over the WPs has been identified and agreed with all partners in order to prioritize the relationships between different RCs and specific WPs. This RC-WP mapping used for the preparation of the present workplan is reported in the following table.

Work Package Number	Work Package Title	Lead Contractor		Input required from Research Components
		Number	Name	
WP1	Management	1	UGDIST	ALL ACTIVE RC
WP2	Cognitive Development	4	UNIUP	RC 1.1 – RC 1.2 – RC 1.3 – RC 1.4 – RC 1.5
WP3	Sensorimotor Coordination	5	UNIFE	RC 1.1 – RC 1.2 – RC 2.1 – RC 2.2
WP4	Object’s Affordance	7	IST	RC 1.1 – RC 2.1 – RC 2.2 – RC 2.3
WP5	Imitation	9	EPFL	RC 1.1 – RC 2.1 – RC 2.2 – RC 2.3
WP6	Gesture Communication	6	UH	RC 1.1 – RC 2.1 – RC 2.2 – RC 2.3
WP7	Mechatronic of the CUB	10	TLR	RC 2.1 – RC 2.2 – RC 2.3 RC 2.4 – RC 2.5
WP8	Open System	1	UGDIST	RC 3.1 – RC 3.2 – RC 3.3
WP9	Dissemination	1	UGDIST	ALL ACTIVE RC

Risk analysis

The main risks related to the activity to be performed in the next 18 months can be envisaged and managed as follows.

Particularly crucial are the next few months of the project because they will shape the architecture and structure of the iCUB mechanics, electronics, and software. The decision taken at design stages will be difficult to recover if they prove to be off the mark. A very long debug stage (more than 12 months) is planned to minimize this risk. In case of conflicts, and where it is required to choose between different implementative solutions, the final decision will be taken by the Board of Management and Project's Directorate. The principal criterion will be the advantage of the community as a whole and technological and cost issues will be taken into consideration only as secondary criteria.

In addition, the risk in integrating multiple design solutions in a single coherent robotic platform has to be considered. We are well aware of this potential problem, and we are ready to take alternative avenues and contingent realization plans if needed. In particular, since within the consortium we have analyzed already various solutions for each component, we are confident we will have fall back solutions if needed. The long debug phase is also justified in this respect.

The design of the cognition architecture is clearly another difficult task. In this case, our modus operandi is that of taking informed choices from analyzing the development of human cognition both from the psychological and neuroscientific point of view. Our belief is that it will keep the final architecture very well grounded into what is known about the human brain. Experiments are also planned to elucidate specific aspects or brain functions for which details are not yet available in the literature.

Milestones

Milestone No	Milestone Description	Month
M1.1	Initial design of the robot parts and plan for integration	30
M1.2	Implementation of the scenario described in section 8.1	30
M1.3	Creation of the core components of the international community and plans for the international project	30
M1.4	Definition of the iCub roadmap of development	24
M1.5	Definition of the cognitive architecture	30

8.2. Work packages list/overview

Work-package No	Workpackage title	Lead contractor No	Person-months	Start month	End month	Deliv-erable No
WP 1	Management	1	26	13	30	D1.1-1.5
WP 2	Cognitive Development	4	56	13	30	D2.1
WP 3	Sensorimotor Coordination	5	103	13	30	D3.1
WP 4	Object's Affordance	7	57	13	30	D4.1
WP 5	Imitation	9	75	13	30	D5.1-5.3
WP 6	Gesture Communication	6	53.5	13	30	D6.1
WP 7	Mechatronic of CUB	10	88.8	13	30	D7.1-7.3
WP8	Open System	1	49.6	13	30	D8.1
WP 9	Dissemination	1	26	13	30	D9.1-9.3
	TOTAL		534.9			

8.3. Deliverables list

Deliverable No	Deliverable title	Delivery date	Nature	Dissemi nation level
D 1.1	Periodic Progress Reports	6,12,18, 24, 30	R	PU
D 1.2	CUB's Licensing Strategy	3	R	PU
D 1.3	Periodic Cost Statements	12, 24	R	PU
D 1.4	Project's Meeting	6,12,18, 24, 30	O	PU
D 1.5	Audit Review Meetings	12, 24	O	PU
D 2.1	A Roadmap for the Development of Cognitive Capabilities in Humanoid Robots	12, 18, 24, 30	R	PU
D 3.1	Models of Sensorimotor Coordination Primitives	24, 30	R+D	PU
D 3.2	Results of experiments on the autonomous development of cortex-like somatosensoritopic maps and directed sensorimotor behaviour	18, 30	R	PU
D 4.1	Results of experiments on affordant behaviors.	18	R+D	PU
D 5.1	Interpreting the Kinematics of Arm Motion	6	R	PU
D 5.2	Visual recognition and Imitation	12, 24	D	PU
D 5.3	Algorithms for functional Imitation	18	R+D	PU
D 5.4	First results of experiments on mirroring and communicative aspects of imitation.	24, 36	R	PU
D 6.1	Results from computational/robotic models of gesture communication	12, 24	R	PU
D 7.1	Specifications of the single components of the mechatronic platform with a preliminary integration compatibility analysis	18, 30	R	PU

D 7.2	Analysis and pre-selection of the sensor's and actuator's technologies	12, 24	R	PU
D 7.3	Experimental results of tests with existing platforms	12, 24	D	PU
D 8.1	Initial Specification of the CUB Open System	30	R	PU
D 8.2	Definition of Documentation and Manufacturing Procedures	6	R	PU
D 8.3	Software Architecture	18, 30	R	PU
D 9.1	Proceedings of the Initial Scientific Meeting	18, 30	R	PU
D 9.2	Material produced for the training activities		R	PU
D 9.3	Progress report on Internationalization activities		R	PU

8.4. Table of responsibilities

The following table contains the names of the persons responsible of the individual tasks and work-packages. The names are only given as a reference at the time of start of the project. As such they do not constitute a formal commitment on the partners and the change of names will not require a formal amendment of the contract but will only be subject to the approval of the Research Director as detailed in the management section and ruled by the Consortium Agreement.

Work Packages	Responsible Partner	Responsible Person	UGDIST	SSSA	UNIZH	UNIUP	UNIFE	UH	IST	UNISAL	EPFL	TLR	EBRI
WP-1 Management	UGDIST	Giulio Sandini	G. Sandini	P.Dario	R. Pfeifer	C.v .Hofsten	L. Fadiga	K. Dautenhahn	J. Santos-victor	D. Caldwell	A. Billard	F.Becchi	E.Bizzi
WP2 Cognitive Development	UNIUP	Claes von Hofsten	D. Vernon	P.Dario	R. Pfeifer	C.v .Hofsten	L. Fadiga	K. Dautenhahn	J. Santos-victor		A. Billard		
WP3 Sensorimotor Coordination	UNIFE	Luciano Fadiga	G. Metta	P.Dario	R. Pfeifer	K. Rosander	L. Craighero	K. Dautenhahn	A. Bernardino	D. Caldwell	A. Billard		E.Bizzi
WP4 Object's Affordance	IST	Josè Santos-Victor	G. Metta		R. Pfeifer	K. Rosander	L. Fadiga	K. Dautenhahn	A. Bernardino	D. Caldwell			
WP5 Imitation Behaviors	EPFL	Aude Billard	G.Metta	P.Dario	R. Pfeifer		L. Fadiga	C. Nehaniv	J. Santos-victor		A. Billard		
WP6 Gesture Communication	UH	Kerstin Dautenhahn					L. Craighero	K. Dautenhahn			A. Billard		
WP7 Mechatronics	TLR	Francesco Becchi	G.Metta	P.Dario					J. Santos-victor	D. Caldwell	A. Ijspeert	F.Becchi	
WP8 Infrastructure of Open System (CUB)	UGDIST	David Vernon	D. Vernon	P.Dario					A. Bernardino	D. Caldwell	A. Ijspeert	F.Becchi	
WP9 Community Building and Assessment	UGDIST	Giulio Sandini	G. Sandini	P.Dario	R. Pfeifer	C.v .Hofsten	L. Fadiga	K. Dautenhahn	J. Santos-victor	D. Caldwell	A. Billard	F.Becchi	E.Bizzi

8.5. Work package descriptions

WP1 – Management

Workpackage number		1		**Start date or starting event:**					Month 1	
Partner	**ugdist**	**sssa**	**Unizh**	**uniup**	**unife**	**uniher**	**Ist**	**unisal**	**epfl**	**tlr**	**ebri**
PM	9	1.5	1.5	1.5	1.5	2.5	1.5	1.5	1.5	1.5	1.5

Objectives

1) Control of the scientific and technological development of the project.
2) Project's self-assessment.
3) Internationalization and community building. The related activities will be managed by the Research Director and Technical Coordinator with the International Research Panel.
4) Coordination of training and dissemination.
5) Definition of the legal aspects of the licensing strategy.

Description of work - The project's objectives will be pursued through three complementary organizational activities.

1. Monthly assessment meetings of the project directorate primarily concerned with project management, open-systems support and licensing, management of IPR, and formulation of occasional calls for expansion of the partner base.
2. Three-monthly meetings of the Board of Management mainly concerned with assessment of progress, cross-area integration, and scientific innovation.
3. Six-monthly workshops involving everyone directly involved in the project, from graduate students right through to the research director. These workshops will concentrate on relatively polished presentations of current results, assessment of scientific progress by external experts, and open 'think-tank' scientific exploration of new avenues of enquiry.

Deliverables

D 1.1 Periodic Progress Reports (month 6, 12, 18, 24, 30).

D 1.2 CUB's Licensing Strategy (month 3).

D 1.3 Periodic Cost Statements (as defined in the table of deliverables).

D 1.4 Project Meetings (see section 7 of Annex I for more details).

D 1.5 Audit/Review Meetings with the EC representative(s).

Milestones and expected result

We expect a smooth operation of the project and its evolution toward a larger project.

WP2 – Cognitive Development

Workpackage number	2		Start date or starting event:							Month 1	
Partner	**ugdist**	**sssa**	**unizh**	**uniup**	**unife**	**uniher**	**ist**	**unisal**	**epfl**	**Tlr**	**ebri**
PM	10	4	10	12	6	3	3		2		

Objectives: In this workpackage, we will study the development of early cognition and how to model the relevant aspects of such process within the boundaries of an artificial system. In particular, we will investigate the timeframe of a developmental process that begins to guide action by internal representations of upcoming events, by the knowledge of the rules and regularities of the world, and by the ability to separate means and end (or cause and effect). We will study and model how young children learn procedures to accomplish goals, how they learn new concepts, and how they learn to improve plans of actions. This research will be strongly driven by studies of developmental psychology and cognitive neuroscience and it will result in a physical implementation on an artificial system.

This work-package then will develop a conceptual framework that forms the foundation of the RobotCub project. It will survey what is known about cognition in natural systems, particularly from the developmental standpoint, with to goal of identifying the most appropriate system phylogeny and ontogeny. It will explore neuro-physiological and psychological models of some of these capabilities, noting where appropriate architectural considerations such as sub-system interdependencies that might shed light on the overall system organization. It will present a roadmap that uses the phylogeny and ontogeny of natural systems to define the innate skills with which iCub must be equipped so that it is capable of ontogenic development, to define the ontogenic process itself, and to show exactly how the iCub should be trained or to what environments it should be exposed to accomplish this ontogenic development (this would be an extension of the six-stage development plan above). Finally, it will address the creation of an architecture for cognition: a computational framework for the operational integration of the distinct capabilities and cognitive skills developed in WP3-6, and it will investigate the (very challenging) issue of theoretical unification of distinct models.

Description of work: We will develop functionally biologically plausible models of how early cognition evolves, taking into account both the brain mechanisms underlying the modeled cognitive processes and the learning procedures used by the child to accommodate new concepts and assimilate already acquired ones to better fit the outside world. These models will be validated against behavioral studies of how young children solve problems of various kinds and how they use internal representations of objects and events to plan actions. In particular, we will investigate infants' emerging ability to represent temporarily occluded objects, their ability to mentally rotate objects when fitting them into apertures, and how they learn to execute complex and sequential actions.

Task 2.1: Survey of what is known about cognition in natural systems, particularly from the developmental standpoint, with to goal of identifying the most appropriate system phylogeny and ontogeny (note, this is well under way at present; see Claes's paper on development).

Task 2.2: Explore neuro-physiological and psychological models of these capabilities, noting where appropriate architectural considerations such as sub-system interdependencies that might shed light on the overall system organization.

Task 2.3: iCub developmental roadmap: using the phylogeny and ontogeny of natural systems to define the innate skills with which iCub must be equipped so that it is capable of ontogenic development, to define the ontogenic process itself, and to show exactly how the iCub should be trained or to what environments it should be exposed to accomplish this ontogenic development (this would be an extension of the six-stage development plan above).

Task 2.4: Create a cognitive architecture: a computational framework for the operational integration of the distinct capabilities and cognitive skills developed in WP3-6; also investigate the issue of theoretical unification of distinct models. This task will also address the mapping of this computational framework for cognitive processing onto the software architecture being developed in Task 8.6.

Task 2.5: contribution to the definition of functional CUB requirements.

Deliverables

D2.1 – Month 12, 18, 24, 30: A Roadmap for the Development of Cognitive Capabilities in Humanoid Robots

Contribution to the document of specification of the CUB (month 18)

Milestones and expected result

Contribution to Milestone M2 (Definition of the Cognitive Architecture and Initial Validation with Cognitive Behaviors).

WP3 – Sensorimotor Coordination

Workpackage number	3	**Start date or starting event:**								Month 1	
Partner	**ugdist**	**sssa**	**unizh**	**uniup**	**unife**	**uniher**	**ist**	**unisal**	**epfl**	**Tlr**	**ebri**
PM	15	10	9	6	12	10.5	8	12	12		3

Objectives: In this work package, we will study and model the development of sensorimotor coordination and sensorimotor mapping. We will identify in what ways the sensorimotor system is determined by biology, how this is expressed in development, and how experience enters into the process in forming reliable and sophisticated tools for exploring and manipulating the outside world. Sensory information (visual, proprioceptive, auditory) necessary to organize goal-directed actions will be considered. These aspects will be investigated in humans and transferred into the cognitive architecture of the artificial system. There are two main objectives of WP3:

1. Model how sensorimotor systems evolve from sets of relatively independent mechanisms to unified functional systems. In particular, we will study and model the ontogenesis of looking and reaching for example by asking the following questions: How does gaze control evolve from the saccadic behavior of newborns to the precise and dynamic mode of control that takes into account both the movement of the actor and the motion of objects in the surrounding? How does reaching evolve from the crude coordination in newborns to the sophisticated and skillful manipulation in older children?

   In addition, we will model how different sensorimotor maps (for gaze/head orienting, for reaching, for grasping, etc.) can be fused to form a subjectively unitary perception/action system. Among our investigations, the way by which the brain coordinates the different effectors, to form a pragmatic representation of the external world will be modeled by using neurophysiological, psychophysical, and robotics techniques.

2. Investigate and model the role of motor representation as tools serving not only to act but also to perceive. This topic, partially covered by WP4, WP5 and WP6, clearly benefits from a unifying vision based on the idea that the motor system (at least at its representational level) forms the "active filter" carving out the passively perceived stimuli by means of attentional or "active perception" processes.

The contribution of WP3 to the implementation of sensorimotor coupling in the artificial system concerns, in more detail, (i) the ability of learning and exploiting object affordances in order to correctly grasp objects on the basis of their use; (ii) the ability of understanding and exploiting simple gestures to interact socially; (iii) the ability of learning new manipulation skills and new communicative gestures; (iv) the ability of correctly interpreting and imitating the gestures of a human demonstrator; (v) the ability to allocate attention and to predict own and others' action outcomes. These objectives will be demonstrated through neurophysiological experiments in animal models, through psychophysics and neuroimaging in humans, through the testing of the robot's cognitive abilities in realistic situations, such as the interactions with humans.

Description of work: We will develop functional biologically plausible models of how sensorimotor coordination evolves, taking into account both how it is determined by the maturation of brain processes and how it is altered and refined by experience. In the period from month 13 to 30 we are planning to organize the activity of WP3 according to the following schema:

1) Sensorimotor coordination: **phylogenetic cues**. Animal models will be studied to understand the role of visual inputs to the premotor cortex, the cortical representation of kinematics, dynamics and muscle synergies during reaching grasping, and the phylogenetic development of the mirror-neuron system for others' action understanding. More in detail, we will investigate in reaching-grasping tasks by standard electrophysiological techniques (i.e. single neuron and local field potential recordings) the modulation of the discharge of hand-related premotor neurons due to the vision of the acting hand and of the to-be-grasped object. In addition, a map relating local

field potential to pointing/manipulation movements directed at targets placed in different workspace locations will be drawn on the basis of multielectrode, subdural, recordings of cortical local field potentials. Finally, we will explore the possibility that a mirror-neuron system exist not only in primates but also in simpler animals such as rats, characterized by an intense social interaction.

2) Sensorimotor coordination: **ontogenetic cues**. First, we will address the development of the oculomotor system. This system involves both the head and the eyes and is driven by visual and vestibular information. The different parts of the system have to collaborate precisely in order to control gaze and we will study how this is accomplished. The possibility that gaze allocation may reveal prospective planning and others' action understanding will be studied in infants during their development. Secondly, we will study how sensorimotor maps are established in various domains and especially those associated with vision. From birth on, infants like to view their own hands and we will study the importance of this activity to build a visuomotor map for the establishment of manual coordination. Thirdly, we will study the contribution of the different factors responsible for the establishment of new modes of behavior, like the onset of functional reaching and grasping. We will be answering to the question of what are the contributions of improved postural and gaze control, binocular depth perception, increase in arm strength, the differentiation of arm, hand movements, and the establishment of relatively independent finger control. The investigation of the motion parameters of "biological motion" will be among the argument that UGDIST will afford within this workpackage. Fourthly, we will model the mechanisms by which sensorimotor coordination improves with experience. What characterizes this kind of learning in early development and what kind of memory processes are associated with it. Finally, we will explore visuospatial and object-related attentional mechanisms allowing the selection in the environment of the target for a reaching-grasping action. Psychophysical and brain imaging techniques (i.e. fMRI and NIRS) will be employed in these experiments.

3) Sensorimotor coordination: **schemas in artifacts**. During the period from month 13 to 30, we will extend the work done by EPFL on the development of controllers for visuo-motor coordination in the iCub, in particular for robust goal-directed reaching motions without singularities [Hersch & Billard 2006b]. The controller combines a dynamical systems approach with classical control theory, such as Lagrange optimization of the inverse kinematics. This extension will address the robust visuo-motor control of the full torso (2 arms and the torso) for simple manipulatory tasks. Experimental support for the model will be provided by UNIFE. Similarly, work to be done in this period will include studies of the autonomous development of sensorimotor control by elaborating the informational-metric methodology developed by UNIHER to create somatosensory maps, extract sensorimotor laws, and to use these laws to guide behavior, while exploiting fusion amongst sensory sources from different modalities. A strict interaction with EBRI, mainly involved in the study of cortical maps of reaching grasping through local fild potentials in animal models, will continuously validate the model. The work done at IST, regarding on-line learning of visuo-motor maps [Lopes et al. 06], will be further developed from months 13 to 30. On one hand we will evaluate the application of such maps for efficient reaching and grasping of static and moving objects. On the other hand, based on current work on redundant manipulation [Lopes & Santos-Victor 05], we will study how the learning of such maps depend and constrain the particular robot developmental stage. Finally, we include explicitly in this work-package, from month 13 on, the important and complex issue of locomotion: the autonomous repositioning of the iCub by crawling, the transition to a sitting position, and the balancing that is required when the iCub plays and interacts with its environment. Our approach is based on models of central pattern generators (CPGs) based on systems of coupled nonlinear oscillators. Similarly to what is known from vertebrate locomotion control, the CPG models will require only simple control signals to initiate and modulate locomotion, and should therefore be fairly easily integrated and modulated by higher level controllers.

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Note that although the iCub will be designed so that several control strategies could be implemented, it is our intention to address specifically force control based on the use of the so-called "force fields".

To preserve the unity of the models developed, the activity is broken down into tasks referring to specific sensorimotor subsystems and their development. In particular:

Task 3.1: Modeling the ontogenesis of gaze control and eye-head coordination, for example to study and model oculomotor involvement in orienting of visuospatial attention and visuomotor priming in object-directed actions.

Task 3.2: Modeling the ontogenesis of functional reaching and grasping of arm-hand cooperation (Grasping - haptic) to study aspects such as how to predict reaching/grasping outcomes and how to code action goals.

Task 3.3: Bimanual Coordination. Activity here will be devoted to a relatively unexplored area (at least with respect to the scientific literature on manual reaching and grasping) of how bimanual coordination develops.

Task 3.4: Contribution to definition of functional CUB requirements.

Task 3.5: Neuroscience and robotic experiments on the functional development of cortical representations (i.e. sensorimotor synergies and somatotopy).

Task 3.6: Modelling of locomotion and transitions between locomotion and rest (sitting) states; including simulation and robotic experiments on the autonomous exercise of locomotive behaviour.

Deliverables

D 3.1 – Month 24, 30: Initial implementation of models of sensorimotor coordination primitives (report and demo)

D 3.2 – Month 18, 30: Initial results of experiments on the functional organization of the somatotopic maps and on the cortical representation of movements (report)

Contribution to D 2.1 and Contribution to the document of specification of the CUB (month 18).

Milestones and expected result

Contribution to Milestones M1, M2 and M3. This WP should provide all baseline information and modeling regarding the sensorimotor primitives required to address the cognitive manipulation aspects of the project in WP4, WP5 and WP6.

WP4 – Object's Affordance

Workpackage number			4		Start date or starting event:				Month 1	
Partner	**ugdist**	**sssa**	**unizh**	**uniup**	**unife**	**uniher**	**Ist**	**unisal**	**epfl**	**Tlr**	**ebri**
PM	15		6	6	12	3	6	6			

Objectives: The goal of this WP is that of exploring and modeling the mechanisms underlying the acquisition of object's affordances. This investigation can be seen developmentally as an extension of WP3. Specific models of how the primate's brain represents affordances will be considered (for example the parietal-frontal circuit) as well as results from psychological sciences. Note how much this is linked to aspects of sensorimotor coordination on one side (WP3) and of imitation and the understanding of goals on the other (WP5 and WP6). Specifically, we will investigate:

1. What exploratory behaviors support the acquisition of affordances, what is the relevant information (visual, haptic, motor, etc.)?
2. We will develop a model of the acquisition of object affordances and how the motor information enters into the description of perceptual quantities.
3. In analogy to what observed in the brain, we will investigate how the definition of purpose (or goal) participates into the representation of the actions an object affords.

Description of work: Continuing the work of WP3, this workpackage will investigate how certain actions (e.g. manipulative) support a multi-modal representation of both the action itself and the object involved in the action. Based on the abundance of experimental results of neural sciences we will develop and implement a model of how this representation of objects is acquired during development.

We will study to what extent motor information participates in this representation and whether there are computational advantages in learning and recognizing actions by virtue of the use of motor information. Further, we will specifically study how the ability of performing certain actions influences the ability of recognizing the same action when performed by somebody else.

For the acquisition of affordances two fundamental means will be considered: by self-exploration and by observing others' actions (learning from examples). Learning of object affordances can start by self-interacting with objects in the world and incorporating invariant cause-effect relationships. Once a sufficiently sophisticated representational level has evolved, learning can also happen by observing others interacting with objects. Therefore, this workpackage has strong correlations with WP3 on whose results – providing supporting cognitive and sensorimotor capabilities – it relies and with WP5 and WP6 to which it could provide the basis for interaction and imitation.

Note that this workpackage tackles a central issue of the larger questions related to manipulation, in practice, bridging the gap between the effecting of certain actions (motor aspect) and the perception of the same set of actions (perceptual aspect). This direction of study and its expected results clearly have profound impact on how we define and analyze Cognition. Also, more philosophical aspects of the question of "what is Cognition" and "how relevant is embodiment" are somewhat addressed although indirectly.

Task 4.1: Define roadmap of affordance-based experiments.

Task 4.2: Early affordant behaviors. Initial experiments will focus on self-exploration, to understand the development of the "basic" repertoire upon which an imitation system can develop. Successively the recognition of other individuals' actions will provide examples for acquiring new affordances.

Task 4.3: Contribution to definition of functional CUB requirements.

Deliverables

D 4.1 – Month 18, 30: Results of experiments on affordant behaviors.

Contribution to D 8.1.

Milestones and expected result

Contribution to milestones M1 and M2.

The expected results will be the implementation of affordant behaviors and the resulting contribution to the definition of the Cognitive Architecture.

WP5 – Imitation

Workpackage number	5	**Start date or starting event:**							Month 1		
Partner	**ugdist**	**sssa**	**unizh**	**uniup**	**unife**	**uniher**	**ist**	**unisal**	**epfl**	**Tlr**	**ebri**
PM	3	16	3		6	16.5	8		18		

Objectives: In this workpackage, we will study the early developmental stages of infant imitation. In particular, we will look at imitation of goal-directed manipulation task and imitation of simple gestures, such as pointing, waving and simple miming. This research will be strongly driven by studies of developmental psychology and cognitive neuroscience. In particular, we will look at the following cognitive stages underlying children imitative behavior: a) imitation of goal-directed arm motions (pointing and reaching for objects), b) imitation of the functional goal of arm motion (grasping, pushing, dropping objects), c) understanding the communication effect of imitation or the passage from being an imitator to become a demonstrator.

Description of work: We will develop functionally biologically plausible models of the brain mechanisms underlying the cognitive processes behind imitation and will validate those against behavioral studies from child imitation (from newborn to 2 years old). We will follow two major approaches: The first approach will use methods from computational neuroscience (neural networks modeling) to give an account of the functionality and connectivity of the brain areas (Broca, PMd, STS, AIP, etc) involved in imitation, using recent data from brain imaging and neurological studies in humans and monkeys. The neural model will have to account for the child's ability to proceed to the required frame of reference transformation in order to interpret the motion of the demonstrator's hand towards an object with respect to its own body referential. It will also have to account for the differentiated pathway taken by visual information to differentiate between goal-directed imitation, where tracking of the hand-object relationship alone is sufficient, and functional imitation, where tracking of the whole arm motion is required. The second approach will develop behavioral and functional models of the cognitive processes underlying children imitation. These models will investigate different metrics for the evaluation of success of imitation in order to account for the hierarchical and differential nature of children imitation. The more cognitive approach will also tackle the issues of when and who to imitate, and when to become a demonstrator, through discussions. It will define scenarios in which these issues could be investigated at a later stage in the project.

During the period from month 13 to 30, we will continue taking two approaches to modeling imitation. The first approach develops biologically plausible models, based on sequences of associative memory, for the recognition and reproduction of gestures [Maurer, Hersch & Billard, 2005]. In the next workplan, we will extend the model to allow learning of sequential and hierarchical acquisition of combined set of gestures and will apply the model to explain a well-documented imitation task in children and chimpanzees [Whiten et al, 1996] whereby subjects learn by imitation a hierarchical sequences of action to open a complex box (the artificial fruit).

The second approach develops controllers for visuo-motor imitation that have no biological basis. The controllers combine dynamical systems and classical control theory. They produce robust and adaptive visuo-motor control (see WP3) [Hersch & Billard, 2006a]. In the next 18 months, we will further develop and analyze these models. In particular, we exploit their properties at predicting the outcome of a motion to prompt the robot's recognition of others' actions. We will investigate how such mechanisms can enhance learning from observing other's actions, and, especially learning from others' mistakes [Harris & Want, 2001].

The learning of sequential and hierarchical tasks require some form of perceptual temporal segmentation and analysis. IST will extend some current work on video event analysis [Lopes et al 05], in order to segment the tasks into elemental actions for efficient description and imitation.

During the second phase of Robotcub, UNIHER will study synchronization and interaction kinesics in collaboration with WP6. Within WP5 aspects of mirroring and communicative aspects of imitation in imitative behaviour between a robot and people interacting with it will be investigated, in line with developmental psychology research e.g. by J. Nadel emphasizing the social and communicative function of imitation, as opposed to a machine learning perspective focussing on the acquisition of skills.

The work will be divided into the following tasks:

Task 5.1: Design and experimentally study aspects of mirroring and communicative aspects of imitation

Task 5.2: Imitative Learning of Simple Manipulation Tasks

Deliverables

D 5.1 - Month 6: Evaluation of an algorithm for interpreting the kinematics of arm motion and its relationship to object motion.
D 5.2 - Month 12: Implementation of visual recognition and imitation of goal-directed reaching motion.
D 5.3 - Month 18: Implementation of goal-directed and functional imitation of simple manipulation of objects.

D 5.4 - Month 24, 36: First results of experiments on mirroring and communicative aspects of imitation.

Milestones and expected result

Contribution to Milestone M2. WE expect this WP to implement initial imitation behaviors from both kinematics information and the understanding of the action's goals.

WP6 – Gesture Communication

Workpackage number	6				**Start date or starting event:**					Month 1	
Partner	**ugdist**	**sssa**	**unizh**	**uniup**	**unife**	**uniher**	**ist**	**unisal**	**epfl**	**Tlr**	**ebri**
PM	4				12	27			6		

Objectives:

This WP focuses on the regulation of interaction dynamics of social interaction during human-robot play. The pre-requisites for interactive and communicative behaviour grounded in sensorimotor experience and interaction histories will be investigated and developed with specific consideration of interaction kinesics (including gestures, synchronization and rhythms of movements etc.). This work includes, inter alia, information theoretic methods applied to characterizing and identifying experience, mapping sensor space and learning motor capabilities.

The objectives of this WP are three-fold:

1. Development of the pre-requisites for (non-verbal) interactive and communicative behaviour grounded in sensorimotor experience and interaction histories
2. Development of a robotic test-bed for the investigation of interaction kinesics
3. Small scale user-study to investigate the space of interaction kinesics in WoZ studies

Description of work:

1) During the second year of the project, the work of UNIHER in WP6 will extend the studies during the first year on the development of sensorimotor control based on broader temporal horizons by extending our informational-metric grounded dynamical systems approach, moving up the scale from optical/tactile flow to guided action based on somatosensory maps and to experiential maps of broader temporal scope. Interaction games will now be pursued to approach known "attractors" in an (informational, metric) experiential space. Development will be studied as a trajectory in this space that trades-off and balances between exploitation of familiar experience and tentative exploration of new experiences and competencies in environmental and social interaction. The dynamics of internal "physiological variables" will be studied, which link to the social dimension of engagement during interaction. WP6 will also develop a robotic framework for studying interaction kinesics including timing, synchronization and responsiveness in social interaction games, (this work is related to WP5 as far as mirroring and communicative aspects of imitation are involved).

EPFL will further investigate the communicative aspects of gesture recognition and its role in building up social cognition. In particular, the role that gestures play in conveying information and in directing the robot's focus of attention to the aspect of the context that are relevant to learning a given task will be investigated. Also, the relationship between recognizing and predicting the outcome of gestures and the effects this has on supporting communication will be studied.

Results of this work will impact the social behaviour capabilities to be developed as part of the iCub's software architecture.

2) A wizard-of-oz (WoZ) approach will be used by UNIHER to investigate the space of interaction kinesics (gestures, timing etc.) in a small scale user study. This work will, on a conceptual level, further contribute to defining interaction capabilities for the iCub. The extent of using robot facial expressiveness, which is an important aspect in human-human interaction, will be explored as part of

a robot's behavioural expressiveness.

3) UNIHER will continue to work into investigating different (developmental) levels of play in human-robot interaction games.

Overall, research within WP6 will contribute to the definition of functional CUB requirements.

WP6 will produce an updated deliverable at M24: Results from robotic experiments on gesture communication.

UNIHER will contribute to Tasks 6.1-6.4, EPFL will contribute to task 6.3.

The establishment of eye-contact is common prerequisite for peer-to-peer interaction among cognitive agents. During the second year of the project, UGDIST will coordinate and participate in the development of an eye-contact detection capability for the iCub.

Task 6.1: Setup robotic experiments on the geometry and dynamics of interaction histories.

Task 6.2: Investigate interaction histories in robotic experiments to scaffold learning and development in a social context.

Task 6.3: Design and experimentally investigate aspects of interaction kinesics (gestures, timing, synchronization and responsiveness in social interaction games) as pre-requisites for interactive and communicative (non-verbal) behaviour in social interaction games.

Task 6.4: Plan, conduct and analyse human-robot interaction experiments in order to specify desirable social behaviour capabilities to be developed for the iCub

Task 6.5: Eye-contact detection capability for the iCub

Deliverables

D 6.1 – Month 12, 24: Results from computational/robotic models.

Milestones and expected result

Contribution to Milestones M1, M2 and M3.

WP7 – Mechatronics of CUB

Workpackage number	7		**Start date or starting event:**						Month 1		
Partner	**ugdist**	**sssa**	**unizh**	**uniup**	**unife**	**uniher**	**ist**	**unisal**	**epfl**	**Tlr**	**ebri**
PM	22	28					8	24	3	3.8	

Objectives

- The realization of the first prototype of the iCub at month 30.

Description of work

In the first six months the effort will be devoted mainly to the finalization of the design, with some activities starting in parallel for the realization of the first complete prototype of the iCub. The realization of the robot will proceed from the head, then shoulders and one arm (for testing) and eventually by completing with the lower body.

The integration will always be done through the supervision of TLR and the final integration of the mechanics with electronics and control will be initially carried out at UGDIST. Contributions from all partners involved in the design are expected through frequent exchange of information and additional meetings (as during the design stage).

The long construction activity accommodates a debugging period of not less than a year. During this period, parts might need to be rebuilt and solutions to unexpected problems found by redesign and additional testing. The mechanical solutions will be checked together with the final electronics and controller.

It is expected that the upper torso is finished by approximately month 18-19 and the debugging started. During the same period, the realization of the lower body will start at UNISAL including the debugging. At month 22-23 the realization of the debugged lower body will also begin at UGDIST for the integration with the upper body. A final round of debug activity is foreseen to complete the construction of the robot.

More specifically the activities will be divided into the following tasks each of them addressing the mechanical, electronic and the control aspects of the sub-part:

Task 7.1: The Head-Eye system (including the final definition of the sensory system).

Task 7.2: The Arm-hand system (including the final definition of the haptic system).

Task 7.3: The Spine and Leg system (including a study on the torque/force sensors).

Task 7.4: Realization of the iCub.

Even though the priority activity in WP7 is to integrate all the mechatronic components into a fully-functional and complete iCub, sub-systems, such as the iCub head, will be made available for replications when complete. This will also other partners to develop software utilities for these sub-systems independently of the integration work on the initial prototype.

Deliverables

D 7.1 – Month 18, 30: Specifications of the single components of the mechatronic platform with a preliminary integration compatibility analysis.

D 7.2 – Month 12: Analysis and pre-selection of the sensor’s and actuator’s technologies.

D 7.3 – Month 18, 30: Experimental results of tests with existing platforms.

Milestones and expected result
Milestone M1
Milestone M2 (month 30) : Cub Prototype

WP8 – Open System (CUB)

Workpackage number	8	**Start date or starting event:**							Month 1		
Partner	**ugdist**	**sssa**	**unizh**	**Uniup**	**unife**	**uniher**	**ist**	**unisal**	**epfl**	**Tlr**	**ebri**
PM	23	8.6					4	6	2	6	

Objectives

1. Define the activity related to the creation, licensing, and distribution of the "Open Platform".
2. Define the mechanical, documentation, and software standards to ensure the widest acceptability of the platform.
3. Help in defining the platform and coordinate with WP2 for requirements and WP7 for mechatronic and technological aspects.

Description of work

The activity of this workpackage is devoted to the creation and support of the community of "end-users" of the "Open Platform". In the initial phases of the project the main activity will be to define and establish the infrastructure of the CUB initiative. In this respect, the workpackage will define the various standard and requirements.

Although the work with WP8 is easily described amounting to a few sentences, its role should not be underestimated since one of the achievements of Robot-cub as a whole is the creation of a community around a common platform.

Especially important are the acceptance of the standards and the will of sharing upgrades and improvements within the community. The real measure of success is in our view mostly related to the possibility of creating a self-supporting initiative that will extend naturally well beyond the Robot-cub project.

Also, this workpackage will work on the definition of the licensing and legal aspects, in particular, when non-EU partners and/or collaborations are considered. Along the same line, collaborations with industries interested in the "packaging and re-selling" of the CUB will be thoroughly evaluated/considered.

Task 8.1: Definition of the documentation's and CAD's standards.

Task 8.2: Documentation of mechanical design and components.

Task 8.3: Documentation of the design of the electronics and components.

Task 8.4: Software documentation.

Task 8.5: Legal and administrative issues.

Task 8.6: Software Architecture

Deliverables

D 8.1 – Month 12, 30: Initial Specification of the CUB Open System.

D 8.2 – Month 12, 30: Definition of Documentation and Manufacturing Procedures.

D 8.3 – Month 18, 30: Software Architecture

Milestones and expected result
Milestone M1.

WP9 – Community Building and Self Assessment

Workpackage number	9			**Start date or starting event:**						Month 1	
Partner	**ugdist**	**sssa**	**unizh**	**uniup**	**unife**	**uniher**	**ist**	**unisal**	**epfl**	**Tlr**	**ebri**
PM	10	2.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1	1.5

Objectives

- Extend the base of knowledge for the definition of the CUB cognitive and mechatronic architectures and the adopted technologies by co-opting EU and non-EU scientists.
- Promote an international project on Embodied Cognition supported by national and international funding agencies.
- Monitor the advancement of the project toward the fulfillment of the project's objectives.
- Organize training and dissemination activities.
- Design, implement, and maintain a website to facilitate dissemination of all RobotCub-related information both between members of the consortium, and between the consortium and outside parties.

Description of work

The work in this WP will be mostly related to organizations of meetings and workshop to reach the three objectives described above. The meetings will be organized as internal or open to the scientific and industrial communities. The management bodies relevant for this Workpackage are the International Research Panel (IRP) and the Board of Management (BM). Jointly they will decide on the topics to be discussed and the format of the meeting. The members of the IRP will be responsible of contacting funding agencies that may be interested in joining the International Project as well as industrial organizations potentially interested in monitoring the results of Robot-Cub.

The work will be organized in the following tasks:

Task 9.1: Internationalization: organize meetings with scientists and funding agencies.

Task 9.2: Training: organize training sessions for the project's participants as well as summer school on topics relevant to Cognitive Robotics.

Task 9.3: Assessment. At least once a year organize a formal assessment of the project.

Task 9.4: RobotCub website re-design.

Deliverables

D 9.1 – Month 6: Proceedings of the Initial Scientific Meeting.

D 9.2 – Month 18, 30: Material produced for the training activities.

D 9.3 – Month 18, 30: Progress report on Internationalization activities.

Milestones and expected result

Milestone M3