SIXTH FRAMEWORK PROGRAMME
PRIORITY 2
Information Society Technologies
Cognitive Systems

Contract for:

INTEGRATED PROJECT

Annex 1 - "Description of Work"

Year 4 Revision of Section 8 - Detailed Implementation Plan Months 49-65

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 48-65

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 5 specific objectives to be achieved within the full duration of the project (65 months). 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 how the robotic artefact should develop over time, showing the formation of manipulation skills of varying levels. This description is 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 RobotCub. In the next period (M49-65), we will concentrate on improving the existing timeline (D2.1) and the mapping of the proposed cognitive architecture into the software architecture. Psychophysical and behavioural experiments will be continued as already planned, in the attempt to answer specific questions on the implementation and to acquire relevant missing information about the developmental process. This work is carried out in the context of efforts to create a cognitive architecture for the iCub, building on the developmental timeline description, neurophysiological models and psychological models, linking in the computational cognitive skills developed in WP3-5N, and focusing explicitly on the creation of a cognitive architecture that enables the integration of the complete research effort.

SO-2: The finalization of the complete design, fabrication, assembly, test, and documentation of the iCub and its duplication in a number of copies for the winners of a competitive call. In particular, this includes the definition of the functional and technical specifications of the iCub mechanics, electronics and software architecture. By month 65, the goal is to have the complete validated design including: the iCub mechanics with 53 degrees of freedom (as per D7.1 and D7.5), control electronics, PC104 interface card, force/torque sensor feedback (not control) including miniaturized electronics, face and expression design, complete plastic covers. In addition, by month 65, up to nine iCub kits will have been fabricated to support the launch of the projects arising from the open call for new research (seven robots assigned as the result of the RobotCub Open Call and two internal to the Consortium). In the next 17 months the documentation will be improved.

SO-3: The implementation of a set of cognitive abilities in the iCub. This objective will be demonstrated through extensive testing of the robots' cognitive abilities in realistic situations, implemented in the iCub. In addition to basic manipulatory and visual skills, the robots will be equipped with a number of basic social skills, enabling natural interactions between the robot and the experimenters. We will follow the approach outlined in section 6 of Annex I and, by month 65, we will have modelled, implemented, and understood to a certain degree the following cognitive aspects underlying the development of infants' manipulation behaviours:

a. The ability of learning and exploiting object affordances in order to correctly manipulate objects on the basis of the goal of the experiment.

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.

These four elements will be integrated in the iCub platform and demonstrated. The experiments will be linked to the description of the cognitive developmental roadmap (SO-1).

SO-4: Results of the testing of new technologies. Clearly, at this stage of the project, the result of this activity will not influence the actual iCub fabrication. It is important though to understand whether new components, compatible elements, sensors or motors will be available in the near future. These replacement components can go either in the direction of improving performance or in reducing the price of the robot.

SO-5: The Community Building activities outlined in section 2 of Annex I will be continued, and in particular:

a. Invite the International Advisory Board to the final review meeting. Invite the sever winners of the Open Call to attend the final review meeting presenting initial results and commenting on the use of the iCub.

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 and FP7, such as the euCognition 2 network.

c. Organization of the 2009 Summer School.

d. Participation to selected conference and other EU-ICT related events with the aim of continuing the construction of the iCub community

e. Establishment of formal partnerships with other laboratories, research centers, and other EU funded projects to promote the use of the iCub or exchange of people, collaborations on the advancement of the Cognitive Systems research.

f. Promote the Open Source nature of the iCub and RobotCub in general.

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 requires at least a binocular head, two arms with hands, and a torso. The iCub now fits entirely within these requirements and in fact it delivers even more by allowing locomotion (crawling) and bimanual manipulation. The iCub has been designed exactly to be used to implement and test complex, human-like, manipulative behaviours.

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. Note that this scenario is described in more detail in Deliverable D2.1, Section 16, and it modifies and extends the scenario envisaged in the original version of Annex I, Section 6. This scenario is not yet completed and will continue to be developed over the coming months.

The primary focus of the early stages of ontogenesis is to develop manipulative action based on visuo-motor mapping, learning to decouple motor synergies (e.g. grasping and reaching), anticipation of goal states, learning affordances, interaction with other agents through social motives, and imitative learning. Needless to say, ontogenesis and development are progressive. In the following, we emphasize the early phases of development, building on enhanced phylogenetic skills and scaffolding the cognitive abilities of the iCub to achieve greater prospection and increased (action-dependent) understanding of the iCub of its environment and mutual understanding with other cognitive agents.

It is important to emphasize that the ontogenetic training program that facilitates the development of the iCub is biologically inspired and tries to be as faithful as possible to the ontogenesis of neonates. Consequently, the development of manipulative action will build primarily on visual-motor mapping.

The following are the scenarios that will be used to provide opportunities for the iCub to develop, in order of their deployment over time.

Reaching for Objects

The most basic skill is not to grasp the object but to get the hand to the object. In order to do that, the visual system has to define the position of the object in front of it in motor terms. The newborn infant has such ability. Newborns can monitor the position of the hand in front of them and guide it towards the position of an object. The visual guidance of the hand is crude to begin with and it needs to be trained. Putting the hand into the visual field opens up a window for such learning. When newborn infants approach an object, the extensors of the arm and hand move in extension synergy. In order to grasp the object, the infant has to overcome this synergy and flex the fingers around the object when the arm is in an extended position. Note that human infants do not master this decoupling of extension and flexion until 4 months of age.

Grasping Objects

Once the iCub masters the extension of the hand towards objects in the surroundings and can flex the fingers around them, grasping skills can develop. However, the iCub must have some kind of motive for grasping objects in order to make this happen. Note that it is the sight of the object that should elicit anticipation of the sensory consequences of the action. Infants who are at the transition to mastering the grasping of objects anticipate crudely the required orientation of the hand. They open the hand fully when approaching an object which optimizes the chances of getting the object into the hand. Adjusting the opening of the hand during the approach to the size of the object to be grasped develops as the infant becomes experienced with object manipulation. The timing of the grasp is controlled visually but, to begin with, at the expense of interrupting the flow of the action (the movement is temporarily stopped before closing around it). This coordination also improves as a function of experience.

Affordance-based Grasping

Grasping objects as a function of their use only develops after infants master reaching and grasping objects in a versatile way (towards the end of the first year of life). The first manipulative actions are general and explorative: squeezing, turning, shaking, putting into the other hand etc. The purpose is to learn about object properties. More specific and advanced object manipulation skills only develop after the end of the first year of life, like putting objects into apertures, inserting one object into another, position lids on pans, building towers of blocks. Mastering actions relies on anticipation of goal states of manipulatory actions. This is how we intend the iCub to develop its manipulatory action. The sensory effects of manipulatory action should be primarily visual, like the disappearance of the object into the hole.

Imitative Learning

Social motives in the training of manipulatory action are very important. Attending visually to the play-pal and the object the play-pal[1] is demonstrating is crucial. Goals of the play-pal's actions and intentions must be considered. Sensitivity to such social stimuli as faces should be prioritized. When the iCub sees a face, it should activate attentional mechanisms for communication with and learning from the play-pal. There is an extensive literature on face perception in neonates and infants and it shows that visual sensitivity to faces and eye contact is innate. Furthermore, the ability to interpret gaze direction and pointing of the play pal must be considered.

Learning to Locomote

[1] The scenario in Annex I describes the iCub learning by interacting with a benevolent human companion: the play-pal.

In addition to these scenarios, it is also intended that the iCub will learn to locomote (e.g. for example to crawl and to transition from crawling to sitting or standing). In this context, we will explore the possibility of sharing the same control circuitry for reaching with the forearms and for modulating the forearms during crawling (e.g. to do visually-guided hand placements).

In summary, our framework for the development of the iCub is as follows.

- The iCub starts with an innate visual-motor map that enables it to get the robot hand into the visual field. Thus, the robot also needs to have an innate conception of space in motor coordinates. We will investigate the possibility of developing this map or deploying one that is pre-programmed. When the hand is in the visual field, the iCub tries to maintain it there. The iCub should also be able to move its hand towards graspable objects in the visual field. In order to do all this, the robot should be equipped with motives to move the hand into the visual field and towards objects that can be grasped. These motives will be based on some reward function such as the long-term decrease in entropy of some function of the iCub's behaviour, a decrease which may not be monotonic.

- When the robot can move the arm to the vicinity of objects in space, the visual system should begin to dock the hand onto the objects of interest. Certain anticipatory skills need to be built in to do this: the relationship between hand-orientation and the opposition spaces of objects, anticipation of when the object is encountered and a preparedness to grasp the object in preparation of this encounter. To begin with the object is grasped with the whole hand and the grasp is visually guided. Already at this developmental stage, the iCub should try to catch moving objects.

- The next step is to enable more exact control over the grasping action by controlling individual finger movements. In infants this occurs at around 9 months of age. The iCub will exercise to reach and grasp small artefacts like peas and objects of more complex forms. It will examine objects by squeezing, turning, and shaking them, and moving them from one hand to the other.

Once the iCub has mastered these skills, we will move on to experimental scenarios in which the iCub learns to develop object manipulation by playing on its own or with another animate agent, that is, grasping objects and doing things in order to attain effects, like inserting objects into holes, stacking blocks, etc. At this stage, social learning of object affordances becomes crucial. These scenarios will focus on the use of more than one object, emphasizing the dynamic and static spatial relationships between them. In order of complexity, examples include:

- Learning to arrange block on a flat-surface;

- Learning to stack blocks of similar size and shape;

- Learning to stack blocks on similar shape but different size;

- Learning to stack blocks of different shape and size.

The chief point about these scenarios is that they represent an opportunity for the iCub to develop a sense of spatial arrangement (both between itself and objects and between objects), and to arrange and order its local environment in some way. These scenarios also require that the iCub learn a set of primitive actions as well as their combination.

Within this scenario we intend to follow a developmental path starting from a limited amount of innate knowledge in the form of motor synergies 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).

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 65 month timeframe we expect to develop a robotic test-bed for the design of communicative interactive behaviours (non-verbal), to develop a small scale user-study to evaluate the appreciation of the behaviours, and to develop very simple interaction kinesics.[2]

While imitation fits nicely into this plan, communication experiments can be only in part integrated into the iCub at month 65. For certain experiments it is not realistic to foresee integration within the duration of the project. 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. In this case, for practical reasons, it is not feasible to fully integrate locomotion with the experiments on manipulation.

Consequently we plan three different demonstrations:

1. The cognitive manipulation scenario outlined above (including grasping, affordances and imitation).
2. The design of the interaction behaviour and relative analysis.
3. The crawling and sitting behaviour.

These three demonstrations will be implemented and tested on the iCub. It is foreseeable that the first and second demonstrations will be integrated via a simple action selection and motivational system (to switch between the various tasks and working modes). The third demonstration is still too demanding, especially from the mechanical/control point of view, to be mixed with the other two.

In the first four years RobotCub has implemented enough elements towards these demonstrations. Some of these elements are:

- A bottom-up attention system.
- Autonomous acquisition of a body map.
- Control of rhythmic and reaching movements.
- Learning how to grasp, tap, or poke a set of objects.
- Learning about object affordances by exploration/interaction of the manipulator with these set of objects.
- Learning to elicit particular consequences given a certain object by generating a particular action.
- 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).
- Store action sequences via interaction histories.

At month 60 we expect to have completed the implementation of a sufficient number of these modules and start the integration into the three demonstrations. Integration will happen starting from month 60 and will be completed by month 65.The last period of the project is substantially devoted to full integration and improvement of the existing modules: i.e. sensorimotor coordination, affordances, imitation, and communication.

[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.

Workpackage Breakdown

In order to achieve the project goals, RobotCub has relied and will continue to rely on an intensive interaction between the multidisciplinary scientific communities (human developmental psychology, cognitive robotics, mechatronic, and perceptual science).

This interaction is maintained alive 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 iCub 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 in RobotCub psychologists and neuroscientists lead the brainstorming activities 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 also help in defining the experimental activities on the iCub platforms (see D2.1 section 16 and 17) as well as the definition and the execution of the psychophysical and behavioural experiments.

Based on these guidelines, the workplan for months 48-65 of RobotCub is structured around 8 Workpackages, which are briefly introduced below.

WP1 - Management concentrates 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 behavioural 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 iCub 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 architecture were investigated. The last period of RobotCub will focus on integration. In particular, WP2 will revise the developmental roadmap (to keep it up to date) and help in matching the cognitive architecture, derived from the roadmap, to the actual software implementation.

This workpackage has developed a conceptual framework that forms the foundation of the RobotCub project. It has surveyed 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 explored 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 presented 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. Finally, it addressed 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 (WP3-5N in the current implementation plan), and it investigated the challenging issue of theoretical unification of distinct models. The cognitive architecture will be implemented using the software architecture being developed in WP8.

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

Task 2.4 and 2.5 are completed. No new tasks are foreseen in WP2.

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 development. As a result of WP2 the “innate” abilities will be defined and the focus of the effort in months 49-65 is the implementation of these phylogenetic abilities specifically for the iCub. No new tasks have been added in the period month 49 to month 65. Existing tasks will continue to address the implementation and integration of sensorimotor skills in the cognitive architecture. The Neuroscience partners of the project will coordinate contributions to the activities of this WP.

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.

Task 3.4 is completed since the iCub design is now fixed. Task 3.8 will not continue. Task 3.9 will continue instead and include the integration of sensorimotor skills into a solid layer for the iCub. A new version of deliverable 3.6 resulting from Task 3.9 has been added at month 65.

WP4 - Object Affordances: Activities in this workpackage are aimed at the definition and implementation of the cognitive skills required for the acquisition/exploitation of object affordances. This involves 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. There are not new tasks from the previous period.

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

Two deliverables are foreseen at M65 addressing the scientific results of the experiments (this can be a published paper) and the delivery of the latest software release.

WP5N – Imitation and Communication: This merges the previous WP5 and WP6 to address the goal of integrating Imitation and Communication and other work in an ontogenetic framework on the iCub platform. Imitation plays a central role and communication is strongly related to imitation as regards social cues, turn-taking, and communicative functions. The activities in this workpackage will address the cognitive skills required for imitative behaviours and the cognitive skills required to communicate through body gestures. The cognitive skills include:

- the ability to recognize and interpret somebody else’s gestures in terms of its own capabilities, and the ability to learn new gestures on the basis of the observation of those in other individuals.
- the ability to recognize the purpose of other people’s gestures, such as the goal of manipulating objects in a certain specific way, 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 finally the ability to decide what part of the demonstration is relevant to imitation.

On the other hand, these include the abilities:

- to skilfully control its arms and body in order to produce communicative gestures reflecting communicative timing or turn-taking,
- to track and recognize someone else's gestural timing, synchrony, and social engagement,
- to generalize and acquire simple communicative behaviours making use of social cues,
- to respond adequately to timing and gesturing of an interaction partner,
- and to harness turn taking as the underlying rhythm of gestured communication.

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

Scientific work will be reported in a new joint deliverable D5N.1 at month 65 [subsuming an update of D6.5 and D5.9 (the latter moved from month 54)], and other relevant work] and thus collect all results from this workpackage. Software development on imitation and communication will be demoed in D5N.2 and delivered as a software release in the iCub repository as part of a new Deliverable D5N.3 (including updates of D5.7, D6.3, and other relevant modules).

WP7 - Mechatronics: The activities in this major workpackage are devoted to the finalization of the design of the mechatronic components of the iCub, their fabrication, assembly, test, and documentation. Most of the activity in WP7 is now devoted to the debugging of minor issues as the robot is used more extensively, to the integration of components and the improvement of the assembly and wiring procedures.

WP7 includes activities related to the realization of the copies of the iCub to be delivered to the Open Call winners, 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. WP7 also includes the production of suitable documentation of the iCub.

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

An update of Deliverable 7.5 has been scheduled reporting on the whole workpackage.

WP8 – iCub Open System: The main activities of WP8 are aimed at establishing the structure necessary to support the compilation, maintenance, and distribution of the iCub design including the technical as well as the legal aspects. The activities will also include the definition, design, and implementation of the software architecture using Yarp (http://yarp0.sourceforge.net).

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

An update of Deliverable 8.5 has been scheduled at month 65. This seems to be enough since it is the robot manual which encompasses everything about the platform (also relating to WP7).

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 researchers 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 (described in D2.1).
- Tutorial on modelling of human sensorimotor coordination (e.g. gaze control and grasping) (also in D2.1).
- Annual summer school with the participation of the PhD's and postdocs involved in the project (on the RobotCub website).
- Distribution of information about the iCub (technical).

These documents are updated annually and the summer school is now a recurring event that has proven to be very effective in bringing the Consortium together on specific practical problems.

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. For the final project review, we will invite the Open Call winners to report about their work on the iCub and the International Advisory Panel for their final appreciation of the project. At this workshop 2-3 prominent international researchers will be invited to attend 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 (ICDL, ICRA and IROS to name a few).
- Special issues on international journals on topics related to cognitive architectures.
- Setup and maintenance of a RobotCub Wiki and website.
- Setup and maintenance of the iCub distribution facilities (which have grown considerably during the last four years).

It is here important to note that workshops will be organized to distribute results to all scientific communities contributing to RobotCub.

All the above activities will be coordinated with similar initiatives supported by the European Commission under the 6th and 7th 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 iCub. 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-2, SO-4, and SO-5 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.

Deliverable 9.2 and 9.3 will be updated with the reports of the 4th Summer School and the internationalization activities respectively.

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
WP5N	Imitation and communication	9	EPFL	RC 1.1 – RC 2.1 – RC 2.2 – RC 2.3
WP7	Mechatronic of the iCub	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 17 months can be envisaged and managed as follows.

The robot is consolidated at release 1 (design "frozen" and the copies are under production). Most of the risk is now on software development - especially on integration - and on the residual management of the Open Call.

To mitigate the risk related to software development we plan to organize workshops (programming workshop in the style of the RobotCub summer school) on specific workpackages (or even tasks) to be held in Genoa. Each workshop might last from one week to four weeks during which researchers will work on the real platform (the iCub prototypes) in Genoa using the computational architecture already available at the RTS/IIT/University of Genoa. In practice, each workpackage leader will collect the available software and attempt the integration on the whole software source repository. Each module will have to coexist and function with all other behaviours and modules.

To minimize the risk related to the fabrication of the copies of the iCub, we have completed the acquisition of the material for the Open Call robots (9 copies) at the end of Y4.

Unfortunately, the risk of delays is high since almost all components of the iCub were custom designed and built. Clearly this might affect the scheduled delivery of the Open Call robots. At the moment of writing this activity is delayed by a couple of months (mostly due to the final calibration of the robots and further last-minute modifications).

Usability of the iCub is also a concern, especially in light of the Open Call participants. This risk is mitigated by the phasing out of the robot delivery. Delivering in phases has the two-fold advantage of allowing more time for assembly/debugging of the iCub kits and of allowing targeting groups with different skills and background. For example, having more robotics in the first stage and cognition towards the end of the Open Call. The Summer School has proven useful to Open Call participants and we will invite them again next July 2009. The Summer School will also help the software integration task and its connected risk mentioned earlier.

Integration of workpackages

The strategy for integrating the software on the iCub will include several small workshops. One partner at the time will travel to Genoa and work full time on porting their specific modules on the iCub. UGDIST/IIT will help with the integration with existing running modules. We do not have a schedule yet for 2009.

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	36
M2.1	Final design and construction of the first complete validated prototype of the iCub	36
M2.2	Launch of call for proposals for 3rd party research projects	36
M2.3	Opening of the Research and Training Site (RTS)	36
M3.1	Release of version 1.0 of the iCub software[3]	42
M3.2	Release the iCub robot kit	42
M3.3	Launch of 3rd party research projects	48
M4.1	Open Call robot completed	64
M4.2	Open Source software self supporting (continuing)	65
M4.3	Release of version 2.0 of the iCub software	65

[3] Yarp-based software architecture and minimal cognitive architecture (phylogenetic abilities and ontongenetic mechanisms).

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		49	65	D1.1-1.5
WP 2	Cognitive Development	4		49	65	D2.1-2.2
WP 3	Sensorimotor Coordination	5		49	65	D3.1-3.8
WP 4	Object's Affordance	7		49	65	D4.1-4.2
WP 5N	Imitation and Communication	9		49	65	D5N.1-D5N.3
WP 7	Mechatronic of the iCub	10		49	65	D7.1-7.5
WP8	Open System	1		49	65	D8.1-8.5
WP 9	Dissemination	1		49	65	D9.1-9.4
	TOTAL					

8.3. Deliverables list

Deliverable No	Deliverable title	Delivery date	Nature	Dissemination level	Responsible person/ partner
D 1.1	Periodic Progress Reports	6,12,18, 24, 36, 48, 65	R	PU	UGDIST
D 1.2	iCub's Licensing Strategy	3	R	PU	UGDIST
D 1.3	Periodic Cost Statements	12, 24, 36, 48, 65	R	PU	UGDIST
D 1.4	Project's Meeting	6,12,18, 24, 30, 36, 42, 48, 54, 65	O	PU	UGDIST
D 1.5	Audit Review Meetings	12, 24, 36, 48, 65	O	PU	UGDIST
D 2.1	A Roadmap for the Development of Cognitive Capabilities in Humanoid Robots	12, 18, 24, 30, 36, 42, 48, 65	R	PU	Vernon
D 2.2	Software Implementation of the iCub Cognitive Archicture (version 2.0)	48, 65	R+D	PU	UGDIST
D 3.1	Models of Sensorimotor Coordination Primitives	24, 30, 48	R	PU	Fadiga
D 3.2	Results of experiments on the autonomous development of cortex-like somatosensoritopic maps and directed sensorimotor behaviour	18, 30	R+D	PU	//
D 3.3	A report reviewing experiments, data, and theories related to the superposition of rhythmic and discrete movement control in animals	36	R	PU	//
D 3.4	A controller architecture for the iCub for the superposition and switch between rhythmic and discrete movements using attractor properties of nonlinear dynamical systems.	42	R+D	PU	Ijspeert
D3.5	Robotic implementation of models of sensory-motor coordination for reaching and grasping tasks	42	R+D	PU	Laschi
D3.6	Software implementation of the phylogenetic abilities specifically for the iCub & integration in the iCub Cognitive Architecture.	42, 65	R+D	PU	UGDIST

D3.7	Results from Electrophysiological study of human sensorimotor representations	60	R	PU	Fadiga
D3.8	Demo of the iCub crawling and switching to a sitting position.	60	D	PU	Ijspeert
D 4.1	Results of experiments on affordant behaviours.	18, 30, 65	R+D	PU	
D 4.2	Software for the iCub & integration in the iCub Cognitive Architecture.	42, 65	R+D	PU	UGDIS T/IST
D 5N.1	Imitation and communication for the iCub	65	R	PU	EPFL/U NIHER
D 5N.2	Imitation and communication on the iCub	65	D	PU	EPFL/U NIHER
D 5N.3	Imitation and communication software release for the iCub	60	R+D	PU	EPFL/U NIHER
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	R	PU	//
D 7.3	Experimental results of tests with existing platforms	12, 24	D	PU	//
D 7.4	Novel bio-inspired sensory system for the open-loop to closed-loop transition in manipulation tasks	42	R+D	PU	Stellin/ SSSA
D7.5	Status of the platform: major changes, debugging activities, problem report	48, 65	R	PU	UGDIS T/IIT
D 8.1	Specification of the iCub Open System	12, 42	R	PU	UGDIS T/IIT
D 8.2	Definition of Documentation and Manufacturing Procedures	6	R	PU	//
D 8.3	Software Architecture	18, 30	R	PU	//
D 8.4	Safety notice & disclaimer warning of the hazards of using the iCub	36	R	PU	//
D 8.5	Robot Documentation	48, 65	R	PU	IIT
D 9.1	Proceedings of the Initial Scientific Meeting	6	R	PU	//
D 9.2	Material produced for the training activities	18, 30, 48, 65	R	PU	UGDIS T

D 9.3	Progress report on Internationalization activities	36, 65	R	PU	UGDIST
D 9.4	Text of Competitive Call for Research Proposals	36	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	UNIHER	IST	USFD	EPFL	TLR	IIT
WP-1 Management	UGDIST	Giulio Sandini	G. Sandini	C. Laschi	R. Pfeifer	C.v .Hofsten	L. Fadiga	K. Dautenhahn	J. Santos-victor	J.Grey	A. Billard	F.Becchi	
WP2 Cognitive Development	UNIUP	Claes von Hofsten	G. Metta	C. Laschi	R. Pfeifer	C.v .Hofsten	L. Fadiga	K. Dautenhahn	J. Santos-victor		A. Billard		
WP3 Sensorimotor Coordination	UNIFE	Luciano Fadiga	G. Metta	C. Laschi	R. Pfeifer	K. Rosander	L. Craighero	C. Nehaniv	A. Bernardino	J.Grey	A. Billard		
WP4 Object's Affordance	IST	Josè Santos-Victor	L. Natale		R. Pfeifer	K. Rosander	L. Fadiga	K. Dautenhahn	A. Bernardino	J.Grey			
WP5N Imitation & Communication	EPFL	Kerstin Dautenhahn	L. Natale	C. Laschi	R. Pfeifer	K. Rosander	L. Fadiga	K. Dautenhahn	J. Santos-victor		A. Billard		
WP7 Mechatronics	TLR	Francesco Becchi	F. Nori	C. Laschi					J. Santos-victor	J.Grey	A. Ijspeert	F.Becchi	G. Metta
WP8 Infrastructure of Open System (iCub)	UGDIST	Giorgio Metta	L. Natale	C. Laschi					A. Bernardino	J.Grey	A. Ijspeert	F.Becchi	G. Metta
WP9 Community Building and Assessment	UGDIST	Giulio Sandini	G. Sandini	C. Laschi	R. Pfeifer	C.v .Hofsten	L. Fadiga	K. Dautenhahn	J. Santos-victor	J.Grey	A. Billard	F.Becchi	G. Metta

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**	**usfd**	**epfl**	**Tlr**	**iit**
PM	3	0.7	1.2	1	0	1.5	1	0	0	1	4

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.
6) Management of the Open Call activities, delivery of the Open Call robots.

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-system 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, 36, 48, 65).

D 1.2 iCub 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**	**usfd**	**epfl**	**tlr**	**iit**
PM	6	1	1	5	4.8	2	4	0	0	0	0

Objectives: In this workpackage, we 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 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 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 is 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 has developed a conceptual framework that forms the foundation of the RobotCub project. It surveyed 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 explored 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 prepared 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. Finally, it addressed the creation and implementation of an architecture for cognition: a computational framework for the operational integration of the distinct capabilities and cognitive skills developed in WP3-5N, 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 modelled 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 behavioural studies of how young children solve problems of various kinds and how they use internal representations of objects and events to plan 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 von Hofsten's paper on development and D2.1).

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.

Task 2.4: Create a cognitive architecture: a computational framework for the operational integration of the distinct capabilities and cognitive skills developed in WP3-5N; 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. (COMPLETED).

Task 2.5: contribution to the definition of functional iCub requirements (COMPLETED).

Task 2.6: Software implementation of the iCub cognitive architecture.

Deliverables

D2.1 – Month 12, 18, 24, 30, 36, 42, 48, 65: A Roadmap for the Development of Cognitive Capabilities in Humanoid Robots.

D2.2 – Month 48, 65: Software Implementation of minimal iCub Cognitive Architecture – version 1.0 and 2.0 (M65) phylogenetic abilities and ontogenetic mechanisms.

Milestones and expected result

Contribution to Milestone 4.3 (Release of version 2.0 of the iCub software)

WP3 – Sensorimotor Coordination

Workpackage number		3		**Start date or starting event:**					Month 1		
Partner	**Ugdist**	**sssa**	**Unizh**	**uniup**	**unife**	**uniher**	**Ist**	**usfd**	**epfl**	**tlr**	**iit**
PM	6	9.5	8	5	15.6	0	4	15	6	0	2

Objectives: In this work package, we study and model the development of sensorimotor coordination and sensorimotor mapping. We 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 is considered. These aspects are 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 behaviour 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 skilful 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 modelled by using neurophysiological, psychophysical, and robotics techniques.

2. Investigate and model the role of motor representation as tools serving not only action but also perception. This topic, partially covered by WP4, WP5N, 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.

The effort in months 49-65 is devoted to the implementation of these phylogenetic abilities specifically for the iCub in a fully integrated manner implementing the empirical investigations defined in Deliverable 2.1 (only the part described in section 8.1).

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 49 to 65 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 in humans (neurosurgery patients). Finally, we will explore the possibility that a mirror-neuron system exists 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 behaviour, 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. 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 49 to 65, we will continue to 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. The work done at IST, regarding on-line learning of visuo-motor maps, will be further developed from months 49 to 65. 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, we will study how learning of such maps depends and constrains the particular robot developmental stage. Finally, we include explicitly in this workpackage, from month 37 (and continuing to month 65) 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.

4) Superposition of rhythmic and discrete movements. Mammals and in particular humans have no difficulties in combining rhythmic and discrete movements. For instance, during many rhythmic movements such as locomotion, drumming, cutting vegetables, etc. limbs make movements that are rhythmic, i.e. which repeat themselves with some intrinsic period, while also undergoing discrete, i.e. punctual, modifications from time to time to reach particular targets. Both from a neurobiological and from a robotics point of view, it is interesting to explore how these movements can be controlled. The goal of this task is therefore two-fold: (1) to explore to which extent motor control in animals share the same substrate for rhythmic and discrete movements,

and (2) to design controllers for the iCub which can superpose and switch between rhythmic and discrete movements using attractor properties of nonlinear dynamical systems. A particular interesting aspect of this work will be to relate research in locomotion (crawling) to research in reaching/grasping, and to address questions such as when a baby or a cat switches from visually guided locomotion (i.e. using vision to place limbs at particular places) to play with an object with its forelimbs does it switch between two completely different control schemes or does it reuse the same controllers for both situations? We will explore these questions in a dynamical systems framework with tight interactions with the task addressing functional reaching and grasping (Task 3.2), the task on bimanual coordination (Task 3.3), and the task on locomotion (Task 3.6). Our approach will reuse the CPG models developed for Task 3.6 and extend them with additional discrete controllers such as to add the possibility to discretely modulate the rhythmic patterns. At first, the discrete controllers will be implemented as simple single-point attractor systems. Later, we will try to incorporate the more sophisticated controllers developed in Tasks 3.2 and 3.3. Several control architectures will be explored including *parallel* architectures in which the rhythmic and discrete controllers are completely independent and only fuse their control signals at the output level, as well as *in-series* architectures in which one system (e.g. the discrete one) provides input signals to the other one (e.g. the rhythmic one).

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: Modelling 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: Modelling 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 iCub requirements [COMPLETED].

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.

Task 3.7: Superposition of rhythmic and discrete movements.

Task 3.8: Robotic implementation of models of sensorimotor coordination for reaching and grasping tasks: models based on self-organizing maps will be implemented on the upper body of the iCub platform to investigate the generation of visuo-tactile-motor correlations by learning. [COMPLETED and activity joined Task 3.9]

Task 3.9: Software implementation of the phylogenetic abilities specifically for the iCub & integration in the iCub Cognitive Architecture.

Task 3.10: Electrophysiological study of human sensorimotor representations.

The EPFL locomotion controller will be further extended and tested (after the initial experiments) until month 65 (one of the demonstrations described in section 8.1).

Deliverables

D 3.1 – Month 24, 30, 48: 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).

D3.3 – Month 36: A report reviewing experiments, data, and theories related to the superposition of rhythmic and discrete movement control in animals.

D3.4 – Month 42: A control architecture for the iCub for the superposition and switch between rhythmic and discrete movements using attractor properties of nonlinear dynamical systems.

D3.5 – Month 42: Robotic implementation of models of sensory-motor coordination for reaching and grasping tasks.

D3.6 – Month 42, 65: Software implementation of the phylogenetic abilities specifically for the iCub & integration in the iCub Cognitive Architecture.

D3.7 – Month 60: Results from Electrophysiological study of human sensorimotor representations.

D3.8 – Month 60: Demo of the iCub crawling and switching to a sitting position.

Workpackage 3 contributes also to the continuous update of D2.1.

Milestones and expected result

Contribution to Milestones M4.3. This WP should provide all baseline information and modelling regarding the sensorimotor primitives required to address the cognitive manipulation aspects of the project in WP4 and WP5N.

Contribution to Milestone 4.3 (Release of version 2.0 of the iCub software)

WP4 – Object Affordances

Workpackage number		4		**Start date or starting event:**					Month 1	
Partner	**ugdist**	**sssa**	**unizh**	**Uniup**	**unife**	**uniher**	**Ist**	**usfd**	**epfl**	**tlr**	**iit**
PM	5	0	3	3	6	0	4	0	0	0	1

Objectives: The goal of this WP is that of exploring and modelling the mechanisms underlying the acquisition of object 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 (WP5N). Specifically, we will investigate:

1. What exploratory behaviours 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 investigates 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 developed and implemented a model of how this representation of objects is acquired during development.

We studied 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 specifically studied 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 are 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 it relies – providing supporting cognitive and sensorimotor capabilities – and links to WP5N 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 behaviours. 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 iCub requirements [COMPLETED].

Task 4.4: Software implementation for the iCub & integration in the iCub Cognitive Architecture.

Deliverables

D 4.1 – Month 18, 30, 65: Results of experiments on affordant behaviours.

D 4.2 – Month 42, 65: Software implementation for the iCub & integration in the iCub Cognitive Architecture.

Contribution to D8.1.

Milestones and expected result

Contribution to milestones M4.3 and M4.2.

Contribution to Milestone 4.3 (Release of version 2.0 of the iCub software)

WP5N (NEW) – Imitation and Communication

Workpackage number		5N		Start date or starting event:					Month 49	
Partner	**ugdist**	**Sssa**	**unizh**	**uniup**	**unife**	**uniher**	**Ist**	**usfd**	**epfl**	**tlr**	**iit**
PM	0	0.75	0	2	14	18	3.5	0	6	0	1

Objectives:

This new WP has been created in response to suggestions by project reviewers to merge the closely related WP5 on imitation and WP6 on gesture communication. The main emphasis during the final phase of Robotcub (project year 5) will be on a) the integration of previous results on the iCub platform, b) to use a common developmental framework (the IHA Interaction History Architecture previously developed in WP6) as a basis for the integration of gesture communication interaction games (previously WP6) to be demonstrated on the iCub, and c) to investigate the integration of skill acquisition through imitation (previously WP5).

This WP investigates the regulation of interaction dynamics of social interaction during human-robot play and its development in ontogeny. 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.). Social drives for interaction, imitation and communication will be exploited to make use of non-verbal social cues in ontogeny in the course of human-robot interaction.

Description of work:

EPFL and IST will continue developing functionally biologically plausible models of the brain mechanisms underlying the cognitive processes behind imitation and will validate those against behavioural studies from human imitation (in collaboration with UNIFE for EPFL). In addition, UNIHER and EPFL will work on the integration of WP5 and WP6 research to combine the Interaction History Architecture (IHA), as previously developed by Mirza et al. at UNIHER within WP6, and the EPFL imitation learning behavior, to show ontogenic development of various behaviours using episodic memory. A large part of the efforts of the 3 partners involved in this WP (IST, UNIHER and EPFL) will be devoted to porting the results on the iCub,

The work will be divided into the following tasks:

Task 5N.1: Investigation of the effect of physical presence on human-human gesture interaction games.

Task 5N.2: Investigation of using cues in the regulation of human-humanoid interaction games.

Task 5N.3: Implementation of gesture communication interaction games integrated with IHA architecture demonstrable on a humanoid robot, release in the iCub software repository and demo on the iCub.

Task 5N.4: Human-robot imitative learning release in the iCub software repository and demo on the iCub.

Deliverables

D 5N.1 – Month 65: Imitation and communication for the iCub (report)

D 5N.2 – Month 65: Imitation and communication on the iCub (demo)

D 5N.3 – Month 60: Imitation and communication software release for the iCub

Milestones and expected result

Contribution to Milestone M4.2 and M4.3 (Release of version 2.0 of the iCub software)

WP7 – Mechatronics

Workpackage number		7		**Start date or starting event:**					Month 1	
Partner	**ugdist**	**Sssa**	**unizh**	**uniup**	**unife**	**uniher**	**Ist**	**usfd**	**epfl**	**Tlr**	**iit**
PM	26	13.7	0	0	0	0	1	7	0	25	20

Objectives

- The realization of the first prototype of the iCub at month 30.
- The realization of the final prototype of the iCub at month 36.
- The realization of several copies of the iCub by month 65.

Description of work

In the next 12 months the effort will be devoted mainly to the construction of the copies of the iCub for the Open Call while standardizing and documenting the assembly and construction methods. Some additional activities will be dedicated to debugging. In parallel, we will study specific improvements and continue the technology testing activities: for example in the field of impedance (force/torque) control.

The integration and assembly will continue through the supervision of TLR and the final integration of the mechanics with electronics and control with UGDIST and IIT. 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 of the copies of the iCub accommodates a debugging period. 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 planned to complete the Open Call assembly approximately at month 64 (one more robot will be delivered with respect to what stated in the Implementation Plan M37-48). During the same period, the realization of two extra copies will be supervised to be allocated to two of the partners.

More specifically the activities will be divided into the following tasks each of them addressing the major phases of the realization of the iCub.

Task 7.1 Complete design
Task 7.2 Debugging of existing components
Task 7.3 Realization of multiple copies of the iCub

An additional task will be undertaken by SSSA:

Task 7.4: Development of a the hand sensory system

In this task sensors for the low-level control of manipulation will be developed and integrated in the SSSA hand (a variant, compatible version of the iCub hand). A controller using these sensors will be developed and tested. SSSA is building an iCub arm with the variant of the hand.

Task 7.5: Optimization and fine tuning of the electronics, wiring and assembly of the iCub. Debugging of pc104 interface card, design and fabrication of force/torque sensor control card, finalization of the hall-effect sensor acquisition card to be mounted on the hand, finalization of the plastic covers of the iCub. Documentation of this activity and inclusion into the main documentation site. This work will be the responsibility of IIT.

Task 7.6: Investigation on tactile sensors and artificial skin. Production of a first prototype of artificial skin (low resolution) and a fingertip, including electronics, sensors and software. This will be integrated *a posteriori* into the robot design and possibly added to the 8 copies of the Open Call. This work will be the responsibility of IIT. At the minimum, we expect to integrate the fingertips in the iCub hands.

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 12, 24: Experimental results of tests with existing platforms.

D 7.4 – Month 42: Novel bio-inspired sensory system for the open-loop to closed-loop transition in manipulation tasks.

D 7.5 – Month 48, 65: Status of the platform: major changes, debugging activities, problem report.

Milestones and expected result

Milestone M4.1 (completion of the Open Call) and M4.2 (self supporting Open Source project).

WP8 – Open System (iCub)

Workpackage number	8			Start date or starting event:					Month 1	
Partner	**ugdist**	**sssa**	**unizh**	**Uniup**	**unife**	**uniher**	**ist**	**usfd**	**epfl**	**tlr**	**iit**
PM	23	3.95	3	0	0	0	2	2	0	4	30

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.
4. Supporting the software development on the iCub and its architecture.

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 iCub initiative. In this respect, the workpackage will continue to define and support the various iCub standards 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 RobotCub 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 RobotCub 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 iCub will be thoroughly evaluated/considered.

The IIT will take responsibility for the documentation of the iCub, organizing all information to keep it updated and easily accessible. It will also address the creation of simulation tools, specifically the design and realization of a first prototype of a simulation platform aimed ad reproducing both the kinematics and the dynamics of the robot. The simulation might include the motors and electric apparatus of the robot, thus providing information about the energy flows during the robot functioning.

IIT also will take responsibility for the testing and delivery of the 9 copies of the robot (7 for the Open Call and 2 for the Consortium). IIT will verify that the integration proceeds according to schedule: it will take care of the final checks of the mechanical parts, of the fine tuning of the assembly, calibration, testing, and final delivery of the robots including a basic software level. It will also host the Open Call winners for various training activities (both mechanical and electronics) and organize training sessions to use the iCub software effectively. Spare parts will be purchased to continue the support of the iCub to the Open Call winners.

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

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.

Task 8.7: Preparation of the documentation for the duplication of the robot.

Task 8.8: Initial analysis of simulation tools.

Task 8.9: Open Call.

Deliverables

D 8.1 – Month 12, 42: Specification of the iCub Open System

D 8.2 – Month 6: Definition of Documentation and Manufacturing Procedures

D 8.3 – Month 18, 30: Software Architecture

D 8.4 – Month 36: Safety notice & disclaimer warning of the hazards of using the iCub

D 8.5 – Month 48, 65: Robot documentation

Milestones and expected result

Milestone M4.1: Completion of the Open Call.

Milestone M4.2: This WP is expected to contribute to the support of the Openness of the project and future self-supporting of the iCub as a standard platform.

Milestone M4.3: Release of version 2.0 of the iCub software (Month 65)

WP9 – Community Building and Self Assessment

Workpackage number		9		Start date or starting event:					Month 1	
Partner	**ugdist**	**sssa**	**unizh**	**uniup**	**unife**	**uniher**	**ist**	**usfd**	**epfl**	**tlr**	**lit**
PM	2	3	0.4	0	0	2	0.5	1	0	2	4

Objectives

- Extend the base of knowledge for the definition of the iCub 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 fulfilment 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. In consideration of the large investments that have been made in IIT, Department of Robotics, Brain and Cognitive Science in terms of instrumentation, human resources and facilities, IIT will set up a RTS within its Genova premises. According to the project, the RTS will be specifically addressed the maintenance of the Open-system; the creation of a training facility in order to generate the conditions for student exchanges and collaborative research; gather research activities on original topics closely related to the Open-system.

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 and maintenance.

Task 9.5: Open call for research projects.

Task 9.6: Start up the Research and Training Site (RTS).

Task 9.7: Investigate the opportunity of commercialization and/or creation of a spin-off company for the iCub.

Deliverables
D 9.1 – Month 6: Proceedings of the Initial Scientific Meeting.
D 9.2 – Month 18, 30, 48, 65: Material produced for the training activities.
D 9.3 – Month 36, 48, 65: Progress report on Internationalization activities.
D 9.4 – Month 36: Text of Competitive Call for Research Proposals.

Milestones and expected result
Milestone M 4.1 – M64, Completion of the Open Call robot construction.
Milestone M 4.2 – M65, Support for self-supporting of the iCub after the end of RobotCub.
Milestone M 4.3 – M65, Release 2.0 of the Cognitive Architecture.