INFORMATION SOCIETIES TECHNOLOGY
(IST)
PROGRAMME

Contract for:

Shared-cost RTD

Annex 1 - "Description of Work"

Project acronym:	**ADAPT**
Project full title:	Artificial Development Approach to Presence Technologies
Contract no.:	IST-2001-37173
Related to other Contract no.:	n/a

Date of preparation of Annex 1: **June 2002**

Operative commencement date of contract: *see Article 2.1 of contract*

Content list

1. Project Summary ... 2
2. Objectives ... 3
3. Participant List ... 6
4. Contribution to key action objectives ... 6
   - 4.1. Brain processes and the theory of presence ... 6
   - 4.2. Haptic Presence and sensory-motor coordination ... 7
   - 4.3. Cognitive parameters and representation systems for presence ... 7
5. Innovation ... 8
   - 5.1. A theory of intentionality and the sense of being-there. ... 8
   - 5.2. Embodiment and body morphology ... 9
   - 5.3. Development of coherent representations ... 10
   - 5.4. System's architecture ... 11
6. Community added value and contribution to EU policies ... 13
7. Contribution to Community social objectives ... 13
   - 7.1. General considerations ... 13
   - 7.2. Ethical aspects and requirements ... 14
8. Economic development and S&T prospects ... 14
   - 8.1. Economic prospects ... 14
   - 8.2. Scientific prospects ... 15
   - 8.3. Technological prospects ... 15
9. Project workplan ... 16
   - 9.1. General Description ... 16
     - 9.1.1. Research Methodology and Assessment ... 17
   - 9.2. Workpackage list ... 19
     - 9.2.1. Effort table (expressed in person-months) ... 19
   - 9.3. Workpackage Description ... 20
     - 9.3.1. Workpackage 1 : Management, dissemination and assessment ... 20
     - 9.3.2. Workpackage 2: Theory of intentionality and sense of being there ... 22
     - 9.3.3. Workpackage 3: Embodiment and body morphology. ... 24
     - 9.3.4. Workpackage 4: Development of coherent representations ... 25
     - 9.3.5. Workpackage 5: System's Architecture ... 27
   - 9.4. Deliverables list ... 29
   - 9.5. Gantt chart of the project ... 30
     - 9.5.1. Milestones ... 31
   - 9.6. Pert diagram (workpackages) ... 32
     - 9.6.1. Pert chart (workpackage 1) ... 33
     - 9.6.2. Pert chart (workpackage 2) ... 34
     - 9.6.3. Pert chart (workpackage 3) ... 35
     - 9.6.4. Pert chart (workpackage 4) ... 36
     - 9.6.5. Pert chart (workpackage 5) ... 37
   - 9.7. Project management ... 38
10. Clustering ... 38
11. Other Contractual Conditions ... 38
   - 11.1. Financial Remarks ... 38
   - 11.2. Travel ... 39
   - 11.3. Subcontracts ... 39

APPENDIX A – Consortium Description ... 40

References ... 48

1. Project Summary

A2.	Project Summary [20]

Objectives (maximum 1000 characters)

The sense of presence arises from the perception of the relationship between our body and the environment and originates from our senses as well as from our past experiences. The main objective of ADAPT will be to study how the perception of self in the environment emerges during the early stages of human development and to implement an artificial instance of such developmental processes in an embodied artifact. In particular we propose to investigate the process of building a coherent representation of visual, auditory, haptic sensations. To achieve this a twofold strategy is pursued. On one side we aim to realize an artificial system capable of building internal representations. On the other side we will investigate when and how the developing brain starts to produce the unique experience-based repertoire of intentional percepts and actions;

Description of the work (maximum 2000 characters)

The main objective of ADAPT is to study the process of building a coherent representation of visual, auditory, haptic sensations and how this representation can be used to describe/elicit the sense of presence. The goal is the "understanding" of representation in humans and machines. We intend to pursue this in the framework of development i.e. by studying the problem from the point of view of a developing system. Within this framework we will use two methodologies: on one side we will investigate the mechanisms used by the brain to learn and build this unified representation by studying and performing experiments with human infants; on the other side we intend to use artificial systems (i.e. robots) as models and demonstrators of perception-action representation theories. We will employ a synthetic methodology (i.e. a methodology of "understanding by building") which consists of three parts or steps: (i) modeling aspects of a biological system, (ii) abstracting general principles of intelligent behavior from this model, and (iii) applying these principles to the design of intelligent artifacts. These steps are not performed in sequence but rather in parallel and iteratively. The work will be organized along 4 main lines (corresponding to the 4 technical workpackaes of the project):

1) Study and propose a theory of presence from a multidisciplinary perspective spanning cognition, perception and robotics; 2) study the sense of presence with the framework of embodiment and body morphology; 3) study how the perception of self evolves during the early stages of human development; 4) implement an artificial instance of such developmental process in an embodied artifact as a synthetic model and demonstrator.

Milestones and expected results (maximum 500 characters)

At the end of the project we expect to have a functional artifact incorporating model of the sense of presence and a demonstrable theory of the development of coherent multisensory representation in humans. The major milestones will be: 1) Realization of different robotic setups to test the effect of morphology; 2) Experiments on the effects of changes in the morphology of the artifacts; 3) Results of behavioral experiments in infants; 4) Modeling of coherent representations; 5) Artificial intentional architecture.

2. Objectives

The objective of the *Presence Initiative* is to study the cognitive, affective, and perceptual issues at the base of the sense of "being there", to promote, in the longer term, the design of a novel set of media and communication technologies capable of offering richer, and more natural experiences. The sense of "being there" (the sense of presence) is an holistic sensation where the single perceptual and affective components, even if mediated by different sensory channels, give rise to unified sensations (like the smell of sea composed of a mix of different fragrances yet generating a single percept). How this holistic sensation is formed is the issue we want to address in ADAPT [1]. More specifically our interest is in *the process of building the coherent representation*, which forms the basis of the sense of presence [2]. A "salty" smell, the sound of waves, the color blue, the texture of sand under the feet is a coherent representation of the "sense of being at the beach". The process of building this representation is the same process of giving a meaning to a particular situation or sense of presence.

In other words, the subjective feeling of being in a given place arises from the perception of the *relationship* between the subject and the environment (including the objects the subject interacts with) and this relationship originates from our senses as well as from our past experiences [3]. From this requirement it follows that the system must be situated, which means that it must have the ability to acquire information about the environment through its own sensory systems, and it must be capable of building its history and shaping its internal structure through the interaction with the environment over extended periods of time [4-7]. The taste of lemon ice cream is sensed by the tongue, but the fact that a lemon ice cream "brings you back" to a special summer night, is a feeling generated internally. While sensory information is "immediate", the meaning we attach to it depends substantially on our past subjective experience.

The true challenge of the *Presence initiative* is, in our view, not to study how to generate artificially the taste of lemon ice cream but to how to give the feeling of being in a special summer night. Therefore it is fundamental to study the process by which we attach meaning to sensorial situations and we think this can be better investigated by studying how very young children organize sensorial information in a meaningful and coherent way postnatally. One of the first challenges for a newborn is, in fact, exactly that of strengthen and/or discovering the relationships among sensory stimuli and between perception and action. Of course the same issues can be investigated in adults but we believe that by following the footsteps of human development it is possible to study how the cognitive structure supporting the acquisition of meaning emerges. This approach, in our view, is better posed to understand the process of the creation of meaning in the adult brain [8]. The coupling between different sensory modalities evolves during the first four months of life. During this period the infant is constrained in many ways and its immaturity, instead of being an obstacle, actually simplifies the interaction with environment by limiting the sensory input as well as the motor repertoire.

We propose to investigate this process of development along two complementary routes: by employing a synthetic approach – that is by using/building a physical device – and by means of behavioral experiments on young children.

Because this developmental procedure depends necessarily on the active exploration of the environment, the artificial implementation needs to take into account the properties and the morphology and the materials of the agent [9, 10]. They constrain in complicated ways the physical interaction of the system with its environment, but more importantly the "quality" of the training data. It might be a better approach to have the system learn its skills so that the constraints given by the morphology and the materials can be exploited. Moreover, in this way, the organism is continuously adapting to changes in the environment and continues to do so even if it has reached its "adult" stage. Systems that start with low-resolution sensors and low-precision motor systems, whose resolution and precision are then successively increased during development, learn faster than systems starting with full high-resolution – high-precision [11-13]. This is because convergence is improved by a process of bootstrapping: at later stages in development, the system is "helped" by what it already knows, or put differently, by its current level of "presence".

To recapitulate, the **main objective** of ADAPT is to study ***the process of building*** a coherent representation of visual, auditory, and haptic sensations and how this representation can be used to describe/elicit the sense of presence. The goal is the "understanding" of representation in humans and machines. We intend to pursue this in the framework of development i.e. by studying the problem from the point of view of a developing system. Development, in addition to learning, includes the growth and maturation of the organism that is structural changes in addition to parametric changes. Within this framework we will use two methodologies: on one side we will investigate the mechanisms used by the brain to learn and build this unified representation by studying and performing experiments with human infants; on the other side we intend to use artificial systems (i.e. robots) as models and demonstrators of perception-action-representation theories. We will employ a synthetic methodology (i.e. a methodology of "understanding by building") which consists of three parts or steps: (i) modeling aspects of a biological system, (ii) abstracting general principles of intelligent behavior from this model, and (iii) applying these principles to the design of intelligent artifacts. These steps are not performed in sequence but rather in parallel and iteratively.

Within the *Presence Initiative*, what we claim is that in order to be able to elicit meaning for humans, one has to understand the process that builds that specific meaning. In recreating meaning machines should use this same human-like representation. Studying development in the presence framework has the goal of understanding how humans learn to attribute or extract a stable meaning from the continuously changing sensory stimulation.

The main objective described above will be achieved by four sub goals.

- **A theory of intentionality and the sense of being-there.** It can be argued that the sense of being-there depends on the capability of having semantic representations. Representations depend on the capability of developing epigenetically new motivations [3]. Yet a convincing framework must be developed in order to have an objective definition of representation: something that refers to something else. Intentionality (aboutness) is an obvious candidate but it must be shown how intentionality can be embodied into a physical agent (artificial or biological). Implementing a complete epigenetic structure will therefore be the first step in building architecture for studying the sense of being there. To develop epigenetically a new motivation means that the system will try to achieve a result that no designer has put into it. This is the main difference with respect to current artificial systems; they learn to achieve a specified goal, while a true artificial intentional architecture should be able to generate internally its motivations. A motivation is capable of producing new behavior. In this way the loop between actions, development of new representations, and use of these representations as motivations to control the actions, will be systematically exploited and analyzed as a possible basis to embody intentionality and the sense of being there. This process of acquiring new behaviors (or new functionality) is driven by the value system discussed in the section on the systems architecture (the set of developed motivations). This theory will be formulated and validated jointly by all partners.
- **Embodiment and body morphology.** To be both situated and embodied a system needs to possess a physical body equipped with enough sensor and motor capabilities to interact with the environment in significant ways. The target setup will be composed of a robot arm with torque and haptic feedback equipped with tactile sensors, a tactile surface (corresponding to the frontal part of the body) and a five

degree of freedom head. The head will use cameras for vision and microphones for acoustic perception. Motor encoders and inertial sensors will provide proprioception and the sense of kinesthesia. Most of these components have already been implemented within the consortium and will be used as they are in the project. The developmental approach has already been successfully exploited by partner 1 (although in a simplified situation [11-16]) and we intend to extend it even more and show the advantages of a "growing" artifact over one assembled in the classical way (e.g. by building blocks). On the other hand, the morphological and ecological aspects have been analyzed by partner 2 [2, 5, 6, 9, 10].

- **Development of coherent representations.** We already stated our intention to concentrate on visual, haptic, and auditory sensations and to study how they are used, by a developing system, to learn how to actively explore the world. Exploration is needed in order to build a unified, coherent, meaningful, representation of the self and of the external world (in the ecological sense of von Uexkull's *umwelt* [30]). We will investigate this multimodal integration not only by merging sensory information but also by studying how coordinated sensorimotor synergies are built as parts of the unified and coherent representation. There is a considerable amount of work done on how children acquire the ability to speak and to understand spoken language but there is comparatively much less work done on how children develop their ability to actively explore the environment. Is there a visuo-acoustic-haptic language to be learned? Is there a phase of "haptic babbling" during which single components of exploration strategies are tested? Are there visuo-haptic exploration strategies used by humans to build a representation of a specific object? Are there exploration strategies used in relation to specific object features? If an object is seen as "spiky" haptic exploration strategies certainly change in adults. When does this ability appear in children? When it appears does it mean that the baby has reached a level of understanding where visual and haptic properties of the objects are merged? In line with the robotic investigations, developmental experiments will be conducted with infants of different ages so to specify the developmental sequence of intersensory integration. These issues have been the subject of investigation of partner 3 [21, 23, 24].

- **System's architecture.** The goal of the architecture is to develop an internal hierarchy of representations and actions. By hierarchical we mean that the system should be able to develop new representations (the ontogenetic ones) by interacting with the environment and exploiting the cues given by a smaller set of innate representations (the philogenetic ones) [3, 17]. By representation we do not mean a symbol or a node in a connectionist network, but complex sensorimotor mappings pertaining also to the potential use of an object. To ensure grounding and to avoid arbitrariness, a close connection of the internal processing to the sensorimotor patterns will be of central importance for the presence of the system. Each representation could be used as a reinforcement signal for further ontogenetic development. The hierarchy of representations is arranged in such a way to produce internally its reinforcement signals, thereby generating something equivalent to a value system: aspects of the architecture or components in the system that make things happen. The difference with other value systems (for instance [18-20]) is the generality of the architecture: any representation can become a new value. The advantages of this structure are many: the possibility to split sensory perception in many separate modules that can work in parallel; the uniformity of internal representations; the run-time engagement of each intentional unit to its stimulus. The role of intentionality and motivations pertains to all partners, however partner 1 and 2 have already tested a series of artificial models [2, 3, 10, 12, 17].

3. Participant List

List of Participants

Partic. Role	Partic. no.	Participant name	Participant short name	Country	Date enter project**	Date exit project**
C	1	DIST - University of Genova	DIST	I	Start of project	End of Project
P	2	University of Zurich – Dept. Information Technology	UNIZH	CH	Start of project	End of Project
P	3	CNRS – UMR7593	CNRS	F	Start of project	End of Project
P	4	Univ. Pierre and Marie Curie – UM7593	UPMC	F	Start of project	End of Project

4. Contribution to key action objectives

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

- Brain processes and the theory of presence
- Haptic presence
- Cognitive parameters and representation systems for presence

4.1. Brain processes and the theory of presence

It can be argued that a true feeling of ”being there” cannot be the result of just one sensory modality and that a tight integration of multiple sensory modalities together with the sensorimotor contingencies is necessary to produce an elementary sense of being. Yet a series of questions remains to be answered. Is there a right way to link an external event to the internal processing of a system in order to have meaning? Is there a threshold in the number of external events in order to produce a sense of being? Are there particular classes of events? Can they be classified according to their contribution to the formation of the self? In ADAPT we intend to address some of these questions by investigating how we can create a rich coherent perceptual experience through the merging and understanding of visual, auditory, haptic and kinesthetic information [25].

The activity of the brain shows one remarkable property: its unity. “Signals from large numbers of functionally specialized groups of neurons distributed over many brain regions are integrated to generate a coherent, multimodal scene. Signals from the environment are integrated with ongoing, patterned neural activity that provides them with a meaningful context.” [27, p. 474]. The activity of thousands if not millions of separate neural cells becomes unified in one meaningful sense of being which can direct and control the action of the corresponding human being. The same happens in perception: multiple and apparently separate streams of information incoming from separate sensory modalities are unified in one single perceptual meaning. A phenomenon sometimes referred to as ‘binding problem’.

4.2. Haptic Presence and sensory-motor coordination

With respect to haptic presence we will take a rather broad view. We will investigate the role of haptic perception in conjunction with vision and auditory perception, and how they are combined through and with sensorimotor coordination. Within our developmental framework, in fact, it is impossible to decouple *a priori* the role of vision, audition, and proprioception in the building of the sense of presence. Is there a predominant role of vision, olfaction, audition, touch, kinesthesia in building up the sense of "being there" [25]? If such a predominant modality exists (we doubt it) how is it selected? Does it vary with time, and specific environmental conditions? Does is vary with experience? How does the "visual" representation of fire change after I burn my finger for the first time? Is it reasonable to think of different sensory modalities as supporting synergistically the building of the sense of presence and if so, how? How is the coherence between the visual, auditory, haptic space developed and maintained? How is it exploited? I can build an internal representation of a desk using vision only but, if there is no light, I can do it trough haptic exploration. Certainly I can haptically explore an object and then recognize it by vision only. How does this ability develop? Can I recognize a haptically explored object by hearing the noise it makes when dropped or hit? All these issues, which we will investigate using artificial implementations as well as behavioral experiments in children, are crucial to *Presence* because address the issue of how to build unified and coherent representations of events that can be used to store and recall the sense of being somewhere.

As an illustration of the part that the experts in human development will play in this project, consider neonatal reflexes governing the exploration of objects. Contrary to the classical claim that manipulation of objects by infants younger than 4 months is limited to a strong grasping reflex, without fine digital exploration, recent analyses have revealed that newborns, do not only exhibit strong grasps, but also slight movements of the fingers during habituation and test [21]. This can explain why neonates detect some discrepancies between shapes by only closing their palm and fingers around objects. It is now well known that enclosure is an exploratory procedure exhibited by adults for extracting both volumetric and global shape [22]. But the fingers and the palm mould to the contours of the object, leading to the idea that the enclosure procedure can also be viewed as a minimal exploratory procedure, which allows newborns to extract information about global shape, without however allowing the neonate to obtain complete information about shape. Following a contour is a more precise procedure, which is not used by young infants. Moreover, when adults take in and process information with their hand, the haptic information gathered is always sequential and requires an important working memory load. Plausibly, neonates and young infants cannot perform the mental work of integration of information. Further studies of higher cognitive functions are needed, where haptic discrimination can be viewed as a prerequisite for showing, for example, intermodal transfer from manual haptic touch to vision in newborns.

4.3. Cognitive parameters and representation systems for presence

We start from the assumption that the ability for categorization is the most fundamental cognitive ability: food must be distinguished from non-food, conspecific from members of other species, and mine-sweeping robots must be able to distinguish mines from rocks, otherwise they are not going to be very useful. In the developmental approach the experience or the knowledge of the agent is used to bootstrap from elementary sensorimotor coordination activities to categorization behavior. The representations will thus not be in the form of symbols or nodes in the categorization layer of a connectionist network, but distributed in the sensorimotor mapsThe cognitive parameters and representation systems will be implicitly contained in the structures that have developed over time.

Furthermore, the sense of being there can be seen as the beginning of the phenomenon of consciousness [18, 26, 28]. So far this phenomenon has been extraordinarily elusive to study because of the difficulty to make experiment with real human being. The project will address the problem in a different way along two parallel threads: i) the implementation of an artificial intentional architecture embodied in a real robotic setup; ii) the use of the artificial system to test possible alternative psychological models and further direct new experiments. The new experiments will be performed as part of the project. Experimental results will be used to improve the model thus actually tightly binding the artificial and the psychological sides of the project. This embodied view on the cognitive parameters and representation systems is important since it not only focuses on information processing but takes the entire agent into account.

5. Innovation

As stated before the **main objective** of ADAPT is to study *the process of building* a coherent representation of visual, auditory, haptic sensations and how this representation can be used to describe/elicit the sense of presence. So far there has not been a concentrated effort to show how meaning is attached to sensory-motor activities and information processing (by a concentrated effort we mean an effort involving a theoretical model, a behavioral/psychological analysis and an artificial physical implementation). The approach we intend to follow aims at satisfying these properties: to develop a theoretical model of meaning and then to apply it both to the implementation of an artificial system and to the analysis of infant development.

The distinctive, and we believe most innovative, characteristics of our approach are the following:

- Study and propose a theory of presence from a multidisciplinary perspective spanning cognition, perception and robotics;
- The notion of embodiment. We believe that the sense of presence is based on the complex interplay between morphology (which includes the physical characteristics and the positioning of the sensors and the motor components of the agent), the materials, and the control.
- Frame embodiment within sensorimotor and cognitive development and, more precisely, to study how the *perception of the self* (which is at the basis the sense of being-there) evolves during the early stages of human development.
- Implement an artificial instance of such developmental process in an embodied artifact as a synthetic model and demonstrator. This synthetic methodology, which implies the use of robots to model biological systems (a field referred to as biorobotics), has proved enormously productive because it provides a platform for interdisciplinary research

5.1. A theory of intentionality and the sense of being-there.

In order to implement the sense of ‘being there’ it is important to present a working model of what can give rise to a sense in general; hence it will be possible to specialize that sense into what is referred to as presence.

In the process of understanding how subjects ‘attach meaning to a sensorial situation’ a working model of ‘what meaning is’ must be provided. It is necessary to suggest both aspects as well as the series of phases in which it could be possible to link this model to the development of visual-haptic-auditory affordances. A series of concepts must be defined, albeit for working purpose: representation, meaning, unified representation, attaching of meaning to sensorial information, sense of being there.

The theoretical framework must provide a working model, which is general in purpose yet capable to become very specialized thanks to development. This working model must be implemented and practically tested. A set of hardwired, low-level, functions is implemented in order to extract as much relevant information as possible from the environment.

Afterwards the model should build up representations corresponding to more complex combinations of sensory-motor loops. No information about the particular kind of stimuli must be part of the model. The external stimulus is the responsible of the corresponding processing function inside the sensory-motor system: a representation is implemented as a new motivation: that is a new reinforcement signal in the system. For instance, a stimulus corresponding to an image of a star modifies, under the right conditions, the system (which implements the model) in such a way as to elicit a response to that particular stimulus. This approach will be used for visual-haptic-auditory stimuli to produce a final unified representation ('Presence').

For these reasons, the architecture, which is to be built, has a series of constraints:

- the architecture, on which the sensory-motor system is based, must be built as a series of very flexible general-purpose units (intentional units) capable of being the repository of each meaning;
- the architecture depends for its development on two separate sources of information: the filogenetic bootstrap inserted at the design time and the ontogenetic set of events occurring during the history of the system.

The architecture helps in seeking a unified representation: a unified representation occurs whenever a set of elementary representations becomes one of the goal of the system; in other words, when a representation of higher order is built that have, as content, the lower order representations.

5.2. Embodiment and body morphology

To be tenable, the proposal to use robots requires a further justification. We endorse the view, as many neuroscientists, that action is a fundamental component of perception. By acting, we structure our world in a particular way; we generate in a constrained way (constrained by the movements themselves) the basis (the primitives) of perception. Movement can be exploited to distinguish between our own body and the external environment, to understand the property of objects and their affordances, and eventually to attach meaning to a particular combination of object/action/context. Further, the use of action also disambiguates the sensory information, for example, by defining the boundaries of objects. In the context of ADAPT the artificial system is exploited to build a compatible representation. The representation is compatible if it can be played back by a machine – not necessarily the same robot/device which built it – to elicit the sense of presence in a human being. It is clear we are not even close to this goal but, in general, a first sensible step in this direction is to understand how the representation is formed and what it looks like. The compatible representation is what we are interested in, and we proposethat the best way to endow a machine with the appropriate knowledge is to have it learn by interacting with the environment as humanly as possible.

More specifically we intend to concentrate on visual, haptic and auditory sensations and how they are used by a developing system to learn how to actively explore the world in order to build a unified representation. We will investigate this multimodal integration not only by merging the sensory information but also by studying how coordinated sensorimotor synergies are built as parts of the unified representation. The starting point will be the use of action to learn the affordances of objects. The multimodal sensory information can be structured around this initial affordant discrimination. This leads naturally to the development of categorization. Categorization, as mentioned before, is thought to be one of the basic cognitive abilities.

One of the novel ideas in ADAPT is to focus on the notion of body morphology [5, 9, 10]. Categories, for example, can only be formed if the agent has the proper morphology and can apply the proper sensory-motor loops. For example, I may be able to grasp a large cup, but I will not even see a small crumb on the table, because I don't have the ability for a pinch grasp. So the ability to categorize the crumb would depend not only on the neural system, but also on the materials of the motor system, which may make it easier or harder to control for pinch grasp. Moreover, grasping rigid objects is easier if the surfaces are deformable, etc. The relation between morphology, materials, and control, and between the complexity of the sensory, the motor, and the neural system is also called “ecological balance”.

In order to be embodied, situated, and in ecological balance a machine is likely to need a body equipped with human-like sensory and motor capabilities. For this part the project will exploit the know-how of partner 1 and 2. A sufficient setup consists of a robotic head with four degrees of freedom, a body with one degree of freedom and a six degree of freedom arm with an end-effector. Other setup can be used as well to test different morphological and ecological combinations. The sensory capabilities will be provided by means of a couple of video cameras providing stereo images, a pair of microphones, a tactile surface to provide the sensation of the body, proprioception thanks to the encoder of the joints and possibly an inertial sensor. This robotic setup is already partially implemented by partner 1. Robotic setups with alternative morphology are provided by partner 2.

5.3. Development of coherent representations

How are the different sensory aspects of an object merged into a unified representation which includes action? This question is viewed as central to an understanding of mature human perception and knowledge. More specifically, the integration of action, vision, touch and proprioception is required for, at least, two major reasons: the first is to control coordinated eye-head-hand movements, the second to merge the visual and haptic (or tactilokinestetic) perception of an object. In a developing system, the former is essential in order to learn how to control the motion of the limbs, the latter is essential to build a coherent representation of objects spanning the multisensory nature of their physical properties. The adult “knows” that the visual and haptic impressions of, for example, a cup, specify the existence and properties of one and the same objects. Adults are also able to transfer information from one modality to another (e.g. touching, but not seeing, a cup can elicit a mental visual image of the cup).

What about infants? When and how are these skills achieved during development? Perception is narrowly linked to memory. The habituation paradigm currently used in infant studies provides evidences of both perception and memory abilities from birth and probably in fetal period. Recent studies have revealed that neonates perceive a world of multimodally unified objects and events from auditory/visual system or from the haptic/visual mode. These unified perceptions are highly adaptive because an organism that can perceive objects and events in an intermodally integrated mode reduces the overall amount of information that has to be processed in order to act on the world.

However in the neonate these correspondences between senses are weak, fragile and should be seen only as a first step, a prerequisite for a slow development of a coherent perception of the world. Indeed, intersensory integration depends mainly on characteristics of objects, on their complexities, on the developmental speed of each sensory mode that comes to be mature in a heterochronic manner, and also on capacities of memory and retrieval, as well as on the amount of sensory interactions experienced with objects, etc. Unified representations are *sine qua non* conditions for the access to an explicit understanding of perceptual sources of knowledge, although they can be seen also as a temporary obstacle. As an example, several studies have revealed that young children do not understand the informational origin of knowledge. They do not know how they know. Furthermore, they cannot link a specific knowledge to a specific sensory experience. They do not know if they have seen or if they have touched or if they have been told about an object. Their unified representations therefore, act more like an obstacle for a clear analysis of their sensory experiences. For instance, even at age 3, children do not differentiate the specific sensory origin of their knowledge: they do not know that the blue color of an object is captured via the eyes or that temperature is captured via touch, and so on. One year later or two however, the access to a metarepresentational understanding of knowledge enables children not only to keep a unified representation of objects (this time an explicit one) but also to disentangle their multiple properties captured by different senses, and to achieve a representational redescription of objects properties, leading to novel and creative relationships between actions and objects beyond affordances. The experiments planned are aimed at exploring the nature and strength of unified representations in infants of different ages via the presentation of contexts triggering actions with ambiguous objects likely to generate conflicts between their expected haptic properties (derived from visual information) and real haptic properties. The reactions to conflict between expectancies and reality will inform about the sequential development of intersensory integration.

How is it possible to design a process able to build and represent coherent spatial knowledge on the basis of a single fused space? What is known from humans is that from a very early stage both the eye and the hand are independently capable of apprehending and processing information about the spatial properties of the environment. But what about their coordination? For many years the prevalent hypothesis has been that visual and tactile sensory spaces were radically separated at birth and that they could be related only very gradually through the effect of simultaneous multimodal experience with the same object. Recently, however, it has been shown not only that some form of eye-hand coordination does exist at birth, but also that it persists during the first year of life. Interestingly, the way this coordination works changes from one month to the next, because of the effect of new emerging perceptual and cognitive abilities. Since the pace of development of the visual and manual systems are quite different (the former evolves much faster than the latter), the appearance of a new ability in one or the other of these two systems will at first destabilize the fragile level of cross-modal organization which existed before. This organization is later reconstructed, at a higher level of articulation, but, meanwhile, it is possible for other forms of coordination to emerge. From these and other observations, it is becoming clear that visuo-haptic integration is not a simple process of cross-modal transfer of information (for example there are asymmetries in the transfer of haptic information to vision and vice versa [23]. Although this is certainly one aspect of the process, the role of motor commands and eye-head-arm-hand coordination is the common substrate to all sensory information and, as such, the development of motor and sensory skills have to be investigated together.

5.4. System's architecture

The goal of the architecture controlling the robotic setup is twofold: on the one hand the system has to learn how to extract a coherent meaning from the multimodal source of information deriving from active exploration (e.g. it has to understand that an object falling has visual and acoustic components which are part of the same event) and on the other it has to develop and refine its own exploration strategies to augment its exploratory repertoire (e.g. learning that releasing a grasped object will elicit the “falling object” event). The system will be initialized with the goal of exploring and acquiring new representations. Perceptually the system will be initialized with a set of visual, auditory and haptic primitives as well as a very simple repertoire of motor actions represented as coordinated motor synergies similar to motor reflexes.

Most of these perceptual primitives and motor synergies have been already implemented in robotic systems at Partner 1 and 2. On the other hand it is well known from empirical evidence that in order to get what is called presence a large amount of sensorial information obtained by separate sources must be provided. It is therefore reasonable to expect that our agents have to be equipped with a rich sensory and motor system so that the combination of the two (sensors and action) is able to deliver a “critical mass" of sensory stimulation.

The robotic system and its computational architecture will be used to test how sensorial information becomes organized in a meaningful and coherent way. To test the dynamics of the process a series of experiments will be planned in which an increasing number of stimuli is presented and an increasing number of motor actions are learned.

The crucial feature is the fact that the robot can act on its environment by means of its sensors and actuators. With this setup (largely present in the lab of Partner 1) we will investigate the building of the "sense of being" along the following two developmental phases (and related experiments):

1) Building of internal representation of the robot's body. This phase is essential for the system to become aware of its own subjective existence as a separate entity of the world. The system has to become aware of the fact that some sensorial input can be elicited by self-generated actions (e.g. moving the arm in front of the eyes generates visual motion or moving the arm to the body generates tactile feedback). Initially the system will be motivated by the basic motivation(s) to elicit new perceptual sensations without any particular "value" attached to it(them). In this phase the system learns to represents in a unique way the result of its perceptual processes and builds a series of representations of the sensorimotor contingencies between itself and the environment.

2) In the second phase the system should be able to "invent" and purposively repeat exploratory strategies on the basis of its past experience. This will require the system to learn that repeating given actions produces similar perceptual effects (driving principles here are similarity and regularity of sensorimotor situations). In our view this is the "seed" of presence because it allows the system to start experimenting with the sense of being in a given situation: if I want to put myself in a given state (i.e. I want to be "present" in a situation), I have to perform this action. It is worth noting that among the incoming stimuli, the system also receives sensory stimulation pertaining to a representation of its own body and internal state and it is this part of the incoming sensations that allows the system to become self-aware (i.e. the joint, simultaneous representation of the external events and the internal state). Being self-aware means, in this sense, to be capable of to be capable of interpreting a given external stimulus in different ways depending on its current internal state. This is the very core of presence: the sensation elicited by the taste of lemon ice cream is different because of its internal link with a summer night.

Each phase (which should not be considered as strictly sequential) is triggered by sensory information, which is not elementary in the sense that can be the result of very complex and sophisticated processing (blob detectors, movement estimations, shape and color segmentation modules). As a matter of fact, the quality of the incoming information is crucial to the subsequent stages of processing: if the information provided is incomplete or too raw, the system will not be able to produce the right categorization. Yet, there is a difference between the hard-wired a priori information processing of the early states of the system and the one at later stages. The former is independent of the meaning a system can acquire along the way; the latter is built during development on the basis of experience.

To produce a sense of being there (*PRESENCE*) a system must be provided with the capability of representing its environment and its position in that environment.

6. Community added value and contribution to EU policies

This project has two quite ambitious goals. Firstly, we shall seek to start integration between neuroscience and information technology and more specifically between developmental psychology and developmental robotics. To achieve this, we propose to employ robotics as a new tool to test hypotheses, condense our knowledge, and refine our theories. Secondly, as far as methods are concerned, we shall take a new and original point of view with regard to design and implementation of artificial systems, namely "developmental robotics". Rather than designing the final structure of the system, only the initial setup and the mechanisms of learning and development will be designed. The final structure will then be the result of the system's interaction with its environment over extended periods of time. If successful, we might be able to cast new light on how this methodology can be used to study the sense of "presence". Of course, both goals are risky, but on the other hand considering the position of the project within FET, the potential benefits are also substantial. We foresee a potential major advance in our comprehension of how a sense of presence arises "naturally" in humans and how it could be artificially elicited. Certainly presence technology could benefit from such a new approach. Moreover, the neurosciences could profit by using this technology as a research tool.

The approach we intend to follow is multidisciplinary in the sense that it involves engineers/designers and perception/cognition researchers. Considering that we intend to address issues of multisensory integration and how a coherent and rich representation can be built through these mechanisms, the transnational nature of the project is essential to gather the required expertise at the required high level.

The design of learning/self-developing machines, and the application of adaptation techniques to advanced technologies is a long lasting "dream" of IT worldwide. In spite of many advances in the area, the general problem has never been solved beyond a certain limit. Therefore, we believe that considering the very diverse know-how required, the European dimension is a strict requirement for the project. The consortium needs to span engineering and design abilities, data acquisition, software development, neurophysiology and psychology. It is worth stressing the fact that the integration of neuroscience and IT is not only devoted to the construction of some electronic measuring device or a sort of database technology.

For these reasons, the competences of the partners range from control theory aspects of motion control to biologically inspired robotics, and from neurophysiology to psychology and human development. These are unlikely encountered within the national level of any of the participants. We should mention though that some centers for "neuroinformatics" where interdisciplinary research is conducted, have been established worldwide. But in "neuroinformatics" the focus is on the computational aspects of brain processing rather than on entire agents. Our consortium represents at the European level such a synergy.

7. Contribution to Community social objectives

7.1. General considerations

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

In this sense we expect the outcome of the project to be applicable beyond the boundaries of the specific artifact. If successful we might imagine employing robotics to generate even more faithful models of "biological brains". On the other side, perhaps in the long term, a new comprehension and design technique (in this case mimicking biological development) could be applied to a large range of possible artifacts. We are thinking, for example, of large, distributed systems (communications networks, large complexes of buildings) that have to interact continuously with the environment and cannot be switched off for redesign. Rather, the systems have to adapt to environmental changes while always maintaining their full functionality. (beyond the gesture recognition task (I am not sure this task has been mentioned before)).

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

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

7.2. Ethical aspects and requirements

This project includes the use of healthy volunteers.

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

8. Economic development and S&T prospects

8.1. Economic prospects

The understanding of how humans become self-aware is a long time scientific challenge and, in our view, it is an essential step toward the production of artificial systems being able to convey the sense of being there. A theory of presence, emerging as in our case, from interdisciplinary research exploring the cognitive roots of multisensory perception and sensorimotor coordination could give rise to the design of innovative systems offering much richer experiences than any current media and communication technologies. There is no doubt, that, if projects in the “presence” framework will be successful that new possibilities will be offered in different fields from education to industrial maintenance to entertainment.

Furthermore we think that our approach to the study of how the ability to take advantage of the sense of presence develops through experiments with a body and its interactions with the environment carry a much broader value. In fact the main approach adopted so far has been “incremental'“ with the implicit assumption that new skills can be added to existing systems with little effort. What we want to demonstrate in this project is that there is an alternative way to study the emergence of self-awareness and that this approach could also help in understanding the nature of human consciousness. This goal is, therefore, far reaching but, if a systematic approach will be developed, it may prove to be a very strong technological advantage. Moreover, as new approaches are potentially good sources of new technologies, indirect advances could be obtained which, in the long run, may prove to be even more important for European technology. We see as particularly interesting the possibility of developing new sensors and actuators as well as new technologies for memories and knowledge representation.

The major challenge, at this time, is to prove that what we are proposing is really new and does offer a valid insight into the problem of how to generate the sense of being there.

8.2. Scientific prospects

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

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

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

8.3. Technological prospects

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

1) Multimodal sensory integration. One of the goals of ADAPT is to study how different sensorial information coming from the same “event” are merged into a coherent representation. In particular we believe that the integration of visual and haptic information could prove very relevant in different application areas not limited to industrial robotics.
2) Technology of touch sensors. The technology of touch sensors, moreover, has very rarely been tested over large surfaces of “artificial skin” covering articulated bodies and we think our goals in this respect could also be very important to direct research on this aspect of technology.
3) Elastic Actuators. Implementing elastic actuators is a long-time dream of many research groups. In some cases this has not only been a dream but prototypical solutions have been proposed (e.g. the series-elastic actuator proposed at MIT). Stemming from these past experiences, one of the goals of ADAPT is to use a robot arm, which can be controlled as if the actuators were elastic. We want to stress the coupling between the actuator itself and its control. In particular it seems evident from these preliminary solutions that controlling an "elastic" arm may involve radically new techniques (including learning) and that, in this respect, studying how the brain does it is not simply a "copying" exercise. The need of elastic actuators is of paramount importance in all those applications where the robot has to interact closely with human beings. Only by using elastic actuators and torque/force control, intrinsic safe artifact may be realized.
4) Development of complex systems. Following the fil-rouge implemented by nature in humans and other animals we think we could derive useful ideas on how a complex artificial system could be realized. The sequence of stages through which a learning system of high complexity has to go through to reach a "useful" level of motor and cognitive skills, may be similar to that of a natural system.

9. Project workplan

9.1. General Description

We expect the project to last **36 months**. A first coarse subdivision could be done in terms of the psychological and artificial aspects of the project. This subdivision is made here only for explanatory purposes: it is not intended to actually subdivide the work in this sense (which should be rather seen as a closed-loop process including the psychological and artificial sides at all times during the project).

The workplan is divided into 5 Workpackages (WP) one pertaining management (WP1) and dissemination and the remaining devoted technical work. In particular the technical parts are organized in the following 4 Workpackages: WP2: Theory of intentionality and the sense if being-there; WP3: Embodiment and body morphology; WP4: Development of representations and motivations; WP5: System's architecture. The description of the activities planned in each WP is given in section B6.15.

Considering our multidisciplinary approach and the intrinsic difficulties of the issues addressed, the **initial 6 months** of activity will be devoted to the definition of the detailed experiments to be performed in children and with artificial systems and to set the basis of the theory of presence. From the initial theory and the definition of the experiments, the requirements of the experimental set-ups will be derived and the physical systems realized. Starting from the second year the specific experimental activity will begin. It is worth noting that only a small part of the activity will be devoted to the actual realization of the set-ups because most of the devices we intend to use are already available in the laboratories of the partners.

The first year will be devoted to implement the setup for the developmental studies and the robotic setup for the embodiment, in the meanwhile an initial implementation of the system's architecture will be proposed and implemented. In parallel an initial study of the relation between ontogenetic development and symbol grounding (the capability to have representations with true intentionality) will be carried out in order to evaluate the key aspects of the method. A common vocabulary will be defined in order to be able to compare human and artificial behavior. At the end of the first year we expect to be able to formulate some initial predictions to be tested in experiments with human infants and a draft of the theory. A software implementation of an intentional unit will be written and tested with a series of different stimuli from different sensory modalities. Further a series of experiments will be defined to test the behavior of the system's architecture. The system should be capable of recognizing a series of combinations of elementary stimuli coming from different sensory modalities and subsequently of using them as motivations. At this early stage it will be important to develop and test the single sensory modalities. These experiments will require an analysis of the structural property of the environment and of the body morphology. This research will act as a bridge between natural and artificial approaches since both domains must cope with the 'ecological balance' between the body and its environment. A mutual feedback will provide the input for modifying the artificial structure as well as the experiments on the infants in order to integrate the results.

The second and third years will be devoted to the main experiments, the refinement of the theory and the implementation of the final demonstration. Considering the advanced research nature of the proposal it is impossible to predict in details how the project will develop. However one of our guiding principles will be to meet often and to perform joint experiments to verify the plausibility of the theories, the efficacy of the experimental activities and the fitting of the physical models to human sense of presence. This procedure will be repeated iteratively during the second and third year of the project.

In the experiments the systems will be exposed to different ecological situation. These experiments will give us the opportunity to verify the effect of several combinations of morphological and environmental factors. This will permit to measure the importance of ecological factors during development. Several modules will be devoted to each sensory modality and to their integration. The development of more complex behaviors based on more complex motivations should provide the basis for a functional integration of separate low-level representations into coherent higher-level representations. Their final integration will correspond to a model for *Presence*: an internal representation that derives its meaning from its history of interactions with its environment. At the same time the experiments with the human infants should continue to verify how and when the philogenetic instincts in baby produces ontogenetic or epigenetic motivations and how the new motivations interact with the older ones. The tentative theory of intentionality and sense of being-there will be validated on the basis of the collected data, both on the artificial and the psychological side.

9.1.1. Research Methodology and Assessment

In a first phase we shall plan in detail the experiments in both the artificial and natural domain. Yet the general methodology and assessment criteria can already be stated.

The design and the building of the architecture will be successful on the basis of a few observable parameters: the overall behavior of the robot on a set of tasks, the degree to which its behavior is compatible with that of humans, the degree of integration (how complex and how effective the final representation will be), how the behavior of the robot can be seen as “subjective” meaning, in this case, that the behavior will not be totally predictable on the basis of its initial state and bootstrapping parameters.

As stated earlier, our main goal is to study the process of building a coherent multimodal representation at the basis of the sense of presence, therefore our assessment criteria will be based on how convincingly we can demonstrate that our robot has build such a representation, how much biologically grounded is the “building” process and how this can help in advancing the technology of “presence”. Following our approach we will study, in parallel with the artificial implementation, when the ability of building such representations appears and how it develops during the initial months/years of human life. In order to do that we will define and implement quantitative measure of subjective criteria very much like developmental psychologists do when demonstrating the appearance/maturation of cognitive and motor skills. These criteria will be based on experimental observations of the behavior of robots and infants engaged, as much as possible, in similar tasks. The crucial parameter here is the measure of the sense of novelty (*or surprise*). This factor is what psychologists estimate, for example, through preferential looking experiments where the novelty (i.e. the causal factor of surprise) is quantitatively measured through the percentage of time the subject (usually an infant) is looking at one of two situations. Surprise, can be seen as both a probe to measure the internal state of the system and as a general purpose, non-specific goal of the system: the system’s general goal is to maximize “surprise”, to act so that new events take place.

Further, with the robotic setup we can look at the shape of the representation and statistically analyze its internal structure. In this hypothetical representation we can look for paths and observe the resulting behaviors in a series of artificial situations which are in any case outside the reach of biological experimentation. Eventually this analysis should provide clues on how the organization of information leads to specific behaviors given the state of the system.

To translate these ideas into a more practical framework we will investigate, for example, how visual, haptic and auditory sensations are combined, in a behaving system, to produce coherent representations of external events. The experimental situation will be composed of objects than can seen, touched and that can generate sounds either autonomously and/or when acted upon. The set of objects will allow generating coherent as well as un-coherent stimuli (hallucinations). For example:

a) Objects with the same shape but different tactile texture and/or making a different noise when manipulated (a glass ball, a metal ball, a wooden ball);

b) Objects with the same superficial texture but different shape or making different noises or “behaving” differently when manipulated or touched (a ball vs. a cubic block or a cylinder).

c) Objects with “hallucinating” properties such as object with a “glassy” look but a “velvety” tactile texture, or 3D visual properties but 2D haptic properties (such as holograms)

d) Objects that look and feel normal but behave abnormally (e.g. a glassy object that does not brake or a ball that does not roll when pushed).

Based upon these general guidelines specific assessment criteria can be the following

1) The quantified performance of the robot system. By this we mean the possibility of designing a system capable of acquiring visual, haptic and acoustic information and make use of it. The system should be a meaningful model of a human infant in the sense that should be able to acquire and process a sufficiently rich representation of the outside world (even if, of course, much simpler than that of a human).

2) The quantified performance of a developing human being. By this we mean the results of behavioral experiments investigating, in humans, the appearance and development of coherent multimodal representations.

3) The demonstration that the implemented system is able to develop new, coherent multimodal representations of external events. We will do that by measuring the ability of the system of “being surprised”. The rationale being the fact that if a given sensation is perceived as “surprising” it means that the system has detected a property that does not belong to the “usual” representation of that particular event (i.e. does not belong to the “coherent representation” of that event).

4) The demonstration that the system becomes able to learn the causal relationships between sensorial and motor quantities (or however complicated combinations of these and/or past experience, and/or any possible internally generated quantity - memory, etc.). This is achieved, for example, by leaving the system to interact (“play”) with objects in a number of different ways (pushing, poking, tapping, throwing, grasping, breaking, etc.) and extract affordances (for example the fact that a ball can be rolled). A criterion here will be the observation that the ability to properly act on an object appears (e.g rolling a round object).

5) The demonstration that it is possible to “initialize” the system so that it can internally generate its own motivations. By this we mean the ability of seeking new internal representations on the basis of past experience.

As shown in the following sections a series of deliverables allows monitoring all the phases of the project and although workpackages are clearly distinct they mainly develop in parallel. We expect a tight collaboration and exchange of data between partners that allows mutually benefiting of the diverse know-how the consortium possesses.

9.2. Workpackage list

Number	Title	Lead Contractor	Person-months[1]	Start month	End month	Deliverable No
1	Project management	1	5.2	0	36	
2	Theory of intentionality and the sense of being-there	1	26	0	36	1,2,3
3	Embodiment and body morphology	2	48	0	30	4,5,6,7
4	Development of Coherent Representations	3	65	0	31	8,9,10,11
5	System's architecture	1	28	0	33	12,13,14,15,16,17,18
	Total		172.2			

9.2.1. Effort table (expressed in person-months)

Effort WP	Name/Partner No.	1	2[2]	3-4	Total
1	Project management	3	1 (1)	1.2	5
2	Theory of intentionality and the sense of being-there	12	10 (5)	4	26
3	Embodiment and body morphology	12	24 (10)	12	48
4	Development of Coherent Representations	14	25 (10)	26	71
5	System's architecture	12	12 (3)	4	28
TOTAL		53	72 (29)	47.2	172.2

[1] These person-months do not include the persons/month spent by permanent staff at UNIZH and not charged to the project. This figure is about 29 persons/month and will be distributed as shown in the successive table.

[2] The number between brackets report the persons/month spent by permanent staff at UNIZH and not charged to the project.

9.3. Workpackage Description

9.3.1. Workpackage 1 : Management, dissemination and assessment

Workpackage number:	1	Start date or starting event:	Month 1
Total Effort			
Lead Partner			
	DIST	UNIZH	CNRS-UPMC
Effort per partner			
Objectives: *Project management* (coordination, assessment).			

Description of work:

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

We already pointed out that the project is twofold; consequently, the other main source of results is the use of the artificial system in order to gain a new knowledge about how the brain solves the problem of representing/maintaining coherent representations of external events.

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

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

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

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

Of course many of the problems addressed here have a considerable impact also on philosophical issues regarding linguistics, philosophy of mind, and psychology. It could be worth to have a feedback from experts from these areas as well as transferring to them the results of our research.

The assessment parameters will be defined during the first stages of the project, when also some initial study on both the robotics and neuroscience aspects will be available (around month 6). Some deliverables will cover both the aspects relative to the developmental and epigenetic approach to robotics and a theory of intentionality and sense of being-there.

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

Milestones and expected results:

9.3.2. Workpackage 2: Theory of intentionality and sense of being there

Workpackage number:	2	Start date or starting event:	Month 1
Total Effort			
Lead Partner			
	DIST	UNIZH	CNRS-UPMC
Effort per partner			
Objectives: Define a theory of intentionality and the sense of being-there and produce a common vocabulary			

Description of work:

A series of terms used in psychological language don't have a direct correspondence to robotics and physical sciences (for instance, representation, intentionality, meaning). An attempt at dealing with the sense of being-there must challenge these concepts by providing a unitary framework in which these terms can be used. A tentative theory of intentionality and sense of being there will be formulated as a working background at the beginning of the projects (*a tentative theory of meaning and intentionality*).

This theory will make a series of hypothesis in order to bridge the gap between cognitive systems and physical systems. These hypotheses must propose a candidate structure as the structure responsible for the occurrence of meaning and representation. They must provide necessary and sufficient criteria to locate the occurrence of meaning and representation.

This theory must propose a structural difference that will be used to test if an artificial system is processing information and if it develops intentional motivations. A possible way to this is by defining in physical terms what we mean by sensory-motor loop and by defining the role of ontogenetic and philogenetic development in a system. We believe that a crucial factor in developing true meaningful representation is the capability of a system of producing internal ontogenetic criteria for further development. Therefore the success of the candidate theory will be evaluated by checking its capability of expressing cognitive and mental jargon in terms of objective structural conditions (like sensory-motor loops, causal relation between experiential events and subsequent system development).

Unification, causality, correlation are all names that refer to the ability of putting together stimuli according to some internal criterion. 'Being in relation' is the core concept. Expectancies, prediction, etc. can be derived from it. E.g. prediction is just another name for building causal relationships between a sort of 'current state' and a future state. Learning can be derived from the ability of putting stimuli in relation.

The theory of meaning we are proposing tries to pose the foundations for the concept of meaning in development where development is the ability to represent increasingly complicated relations among events. This theory will be tested on the experiments described in WP3, WP4 and WP5 (*a validated theory of meaning and intentionality*). The challenge is to find a way to express the concept of 'meaning', 'representation', 'intentionality' and such in terms of the developmental approach.

Deliverables:
D2.1 A tentative theory of intentionality and the sense of being-there
D2.2 A validated theory of intentionality and the sense of being-there
D2.3 A common psycho-physical vocabulary

Milestones and expected results:
M1 Tentative Theory formulation
M2 Validated theory and common vocabulary

9.3.3. Workpackage 3: Embodiment and body morphology.

Workpackage number:	3	Start date or starting event:	Month 1
Total Effort			
Lead Partner			
	DIST	UNIZH	CNRS-UPMC
Effort per partner			

Objectives: Investigate the role of morphological changes of the agent's body on building/maintaining coherent representation of the world's events.

Description of work:
Traditionally, categorization, intentionality, and object recognition are considered only at the level of the control architecture. However, it is one of the basic underlying tenets of our approach that representations are the result of repeated sensory-motor interactions of the agent with its environment. This implies that representations cannot be understood without understanding the agent's morphology, which includes body, motor system and sensory system, and the specific kinds of interactions. The goal of this work package is to test the nature and the robustness of the representations with respect to morphological change (e.g. change of the type of the sensors, change of the resolution, change of their positioning, change of characteristics of the limbs (length, joint characteristics, materials). We also expect the control of the system to vary significantly if the morphology changes. Moreover, we anticipate that for certain tasks the control can become very simple if the morphology is appropriate. For example, the control of a pinch grasp for a robot hand may not be very hard if the hand morphology is appropriate and the finger tips consist of deformable materials. The data collected from the experiments will be subjected to various kinds of formal analyses (statistical, information theoretic).

As the morphology of human infants changes significantly during development, we will explore to what extent our results can be related to experimental results on babies. This may in fact be highly revealing and may shed light on the robot's and the baby's level of presence.

Deliverables:
D3.1 Definition and implementation of a human-like robotic setup
D3.2 Hardware and software in place to run experiments on changing morphologies (e.g. changing resolution and motor precision)
D3.3 A set of formal methods for the analysis of the interplay of morphology, materials and control

Milestones and expected results:
M3 Different robotic setups to test the effect of morphology
M4 Formal analyses and first setup of conclusions
M5 Final evaluation of morphology changing experiments
M6 Human like robotic setup

9.3.4. Workpackage 4: Development of coherent representations

Workpackage number:	4	Start date or starting event:	Month 1
Total Effort			
Lead Partner			
	DIST	UNIZH	CNRS-UPMC
Effort per partner			

Objectives: This workpackage will study how the process of building coherent multisensory representations develops in babies and how this process can be modeled in an artificial system.

Description of work:

The work will be based on what is know in humans about how different sensory aspects of an object are merged into a coherent representation including “actions” possibly performed on the object (affordant use) or in a given situation. More specifically we will concentrate on visual, haptic and auditory perception and on their integration during the first years of life. Developmental experiments will be conducted with infants from birth to twelve months so as to specify the developmental sequence of intersensory integration in two conditions: production and reproduction (imitation). Three series of experiments will be designed to this aim: one focusing on the development of haptic strategies of object exploration, the second on the building of multimodal relationships, especially tactile, auditory and visual relationships, and the third on intermodal transfer.

Development of haptic strategies in the six first months

Haptic discrimination can be viewed as a prerequisite for showing, for instance, intermodal transfer from manual haptic to vision in newborns and older. Haptic strategies come to be more numerous and diversified throughout the first semester of life and without visual control because before six months, coordination between vision and prehension is not well established. The examination of this “haptic babbling”, during which components of exploration strategies will be described, will allow to explore the development of these specific exploratory procedures. By using finger sensors for pressure as an index of an ongoing search for details that are relevant to intake information about shape or texture or size of objects we will determine necessary information to visual identification of these objects and thus account for the building of intermodal relationships. Parameters such as palm and finger enclosure and digit movements for sequential processing of haptic information will be measured.

This experiment is based on observation that in the first 6 months babies are more “haptic” than visual in their exploration strategies. What you will measure is some parameters of haptic exploration procedures that may be related to visual properties and see if this relationship is established.

Development of intermodal relationships at birth, and at 2, 4 and 6 months of age.

Texture and shape are amodal properties initially shared between the visual and tactile modalities, but not between the auditory and tactile modalities. Experiments will be designed using habituation and preferential choice procedures to study the process leading to establish relationships between the tactile, auditory and visual modes. The infant will be habituated to a texture (i.e. rough vs fine) or to a size (i.e. small vs big) to which will be arbitrarily associated a sound (i.e. low vs high pitch). When presented another texture (or another size), two sounds will be proposed (low/high pitch): if the infant has formed relationships, s/he will choose the familiar pitch. The development of such associations between modalities is suggested to be the first step toward generalized intermodal transfer.

Toward unified intermodal representation and generalized transfer at 6, 9 and 12 months

Once intersensory relationships start to be established, the experimental introduction of intersensory conflicts will allow testing the stability and consistency of such relationships. An object looking as smooth will be acted upon differently than if an object looks pointed or “spiky”. The grasping should then be adapted to the object properties, thus demonstrating that the process of generalized transfer is established and leads to anticipate haptic properties via visual modality. (for example if you “see” a piece of glass you expect to “feel it” as smooth and you grasp it accordingly). Grasping procedures will be recorded and analyzed as a function of developmental process and nature of discrepancy. Facial expressions, number of trials, failure to capture the objects will be additional dependent variables. How these new capacities influence the interaction with the world will be explored via videorecorded experimental situations triggering conflicts in sensorimotor coordination between hand and eye when infants attempt to reach and catch an object seen. If this object was expected to present haptic properties that are not confirmed, thus posturomotor and emotional reaction to the discrepancy should be observed. The aim is to investigate intermodal integration by observing the behavior (manipulation) of the infant in the presence of conflicting situations. The same same experimental procedure could be used to quantify the behavior of our developing robot.

The comparison between 2 experimental conditions: production and reproduction will provide information about the influence of intermodal processing in others on the building of unified representations of objects. By 9 months of age indeed, infants prefer imitate affordant uses of objects, which is a good indicator of unified intermodal representation. The interesting aspect is that to do so, they need a unified representation of the different uses linked to the different modalities. For example infants prefer to imitate you when you drink from a glass-like container than when you drink from a dish-like container. It means that they have established a link between what they see and what they can do with it (affordant use). In this sense the concept of affordance is a dynamic one and an “affordant use” requires a representation containing all different modes in which the object can be used (e.g. the system can tap, push, hear, smell, feel etc.).

Deliverables:
D4.1 Definition of experimental paradigm
D4.2 Definition and implementation of set-up for the investigation of child development
D4.3 Results of behavioral experiments with babies
D4.4 Results of behavioral experiments with the robot.

Milestones and expected results:
M7 Experimental setup and paradigm
M8 Result of behavioral experiments (C4)
M9 Modelling of coherent representations

9.3.5. Workpackage 5: System's Architecture

Workpackage number:	5	Start date or starting event:	Month 1
Total Effort			
Lead Partner			
	DIST	UNIZH	CNRS-UPMC
Effort per partner			

Objectives: The work here will be devoted to the definition and implementation of the "control" architecture of the artificial system on the basis of the theory proposed and the results of the developmental experiments.

Description of work:

The architecture will implement an ontogenetic intentional structure. Ontogenetic means that the development of the structure is not completely dependent on the initial design (such as the process of imprinting or conditional learning in biological systems). Intentional means that the possible content of the structure is not defined *a priori* but it is a result of the actual occurrence of an event.

The following setup will be implemented: on one side the robotic setup equipped with a stereo head and an arm, cameras, a simple form of proprioception and force feedback, sound microphones; on the other side a set of objects with perceivable physical properties in at least three different sensor modalities: i) color, texture, reflectance, shape (visual domain); ii) sound (auditory domain); iii) haptic-kinestetic inertia, heaviness, things that roll, thing that can be pushed (haptic domain).

The robot will be provided (at the beginning, philogenetic part) with three basic ingredients. First, a set of bootstrapping motivations (something which the robot likes). For instance a motivation could be 'trying to have something colored moving in front of him or hearing jiggling sounds (something he can obtain easily by pushing objects)'. Second, a sense of surprise. Third, a set of elementary modules, which extract some kind of higher order information from visual domain (optical flow, segmentation, dominant color), from haptic-kinestetic domain (classes of movements, kind of force-feedback, push-pulling pattern), from the auditory domain (pattern of sounds/noise, vowels, sound position in subjective space).

With these three ingredients the robot will start to interact with the objects and will start building a very large quantity of possible *correlations* between sensory combinations (sound + vision + haptic) and in each of the three separate modalities. By *correlation* here we mean the process that builds a coherent representation of an event. This can be based on actual cross-correlation procedures as well other processes looking for regularities in the sensorial and sensorimotor domains (for example the fact that a given shape is always associated to specific color and/or the fact that a given object makes a special noise when hit).

After a while the robot will store a set of patterns (visual, auditory, haptic-kinesthetic, visual + haptic/kinesthetic + auditory), which will be used to tune its surprise/expectation sense. The robot will try to maximize surprise (its driving motivation) to acquire new representations. The robot will use these new representations to extend the class of stimuli with which it is able to interact (the robot will be able to cope in a proper way with an increasing number of objects and events). As an example of what we mean if we will be successful, we expect to be able to demonstrate that the behavior of the robot with respect to a specific object or event will change with time not only because the robot become motorically or sensorially more skilled but because it has established a deeper link between the external event and the internal representation. For example not only learning how to poke or push an object but learning to poke a ball to make it roll and to push a box to make it move (and being able to do this consistently).

Deliverables:
D5.1 System's architecture specifications and design
D5.2 Basic unit design and implementation
D5.3 Initial implementation of the integration model
D5.4 Initial Experiments with multiple sensory modalities integrations
D5.5 Validation of multisensensory representations

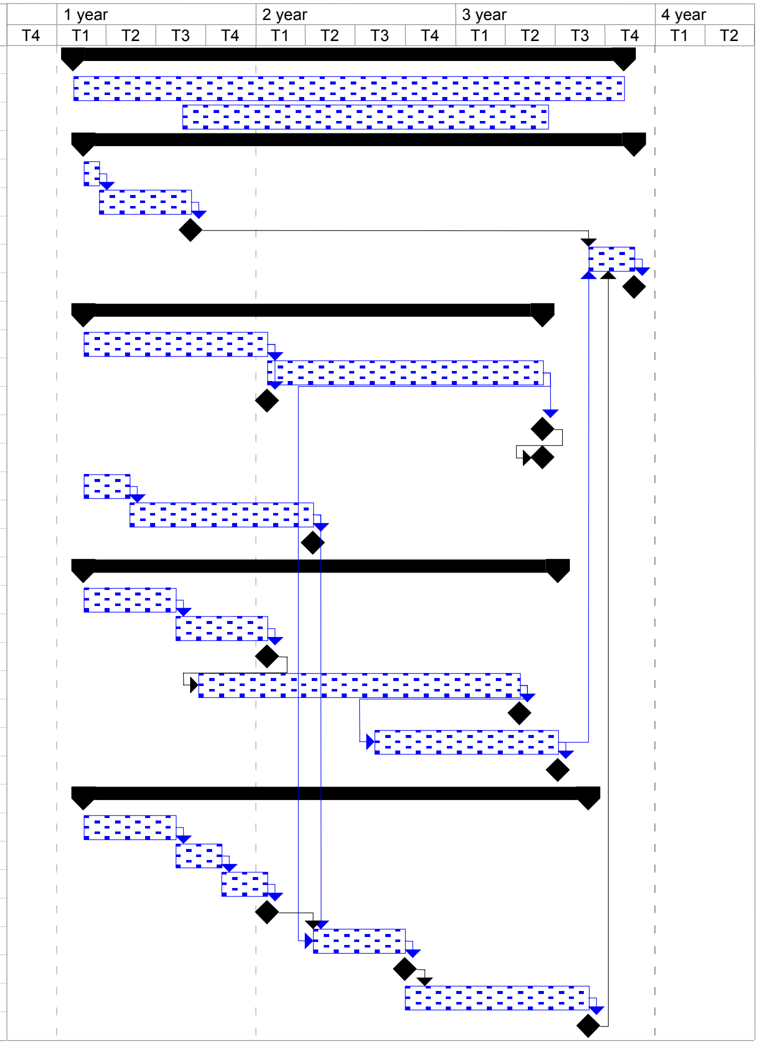
Milestones and expected results:
M10 Basic units design and implementation
M11 Multi sensory modalities integrations
M12 Artificial intentional architecture (C3)

9.4. Deliverables list

Deliverable No	Deliverable title	Delivery Date	Nature	Dissemination level
D1.1	Project Presentation	3	R	PU
D1.2	Dissemination and Use Plan	6	R	PU
D1.3	Management Report 1	6	R	PU
D1.4	Periodic Progress Report	12	R	PU
D1.5	Management Report 2	18	R	PU
D1.6	Periodic Progress Report	24	R	PU
D1.7	Management Report 3	30	R	PU
D1.8	Technology Implementation Plan	32	R	PU
D1.9	Final Report	36	R	PU
D2.1	A tentative theory of intentionality and the sense of being-there	7	R	PU
D2.2	A validated theory of intentionality and the sense of being-there	36	R	PU
D2.3	A common psycho-physical vocabulary	36	R	PU
D3.1	Definition and implementation of a human-like robotic setup	12	R	PU
D3.2	Hardware and software in place to run experiments on changing morphologies (e.g. changing resolution and motor precision)	15	P	PU
D3.3	A set of formal methods for the analysis of the interplay of morphology, materials and control	30	R	PU
D4.1	Definition of experimental paradigm	12	R	PU
D4.2	Definition and implementation of set-up for the investigation of child development	12	P	PU
D4.3	Results of behavioral experiments with babies	30	O	PU
D4.4	Results of behavioral experiments with the robot	30	R	PU
D5.1	System's architecture specifications and design	6	R	PU
D5.2	Basic unit design and implementation	9	P	PU
D5.3	Initial Implementation of the integration model	12	P	PU
D5.4	Initial experiments with multiple sensory modalities integrations	18	R	PU
D5.5	Validation of multisensory representations	33	R	PU

9.5. Gantt chart of the project

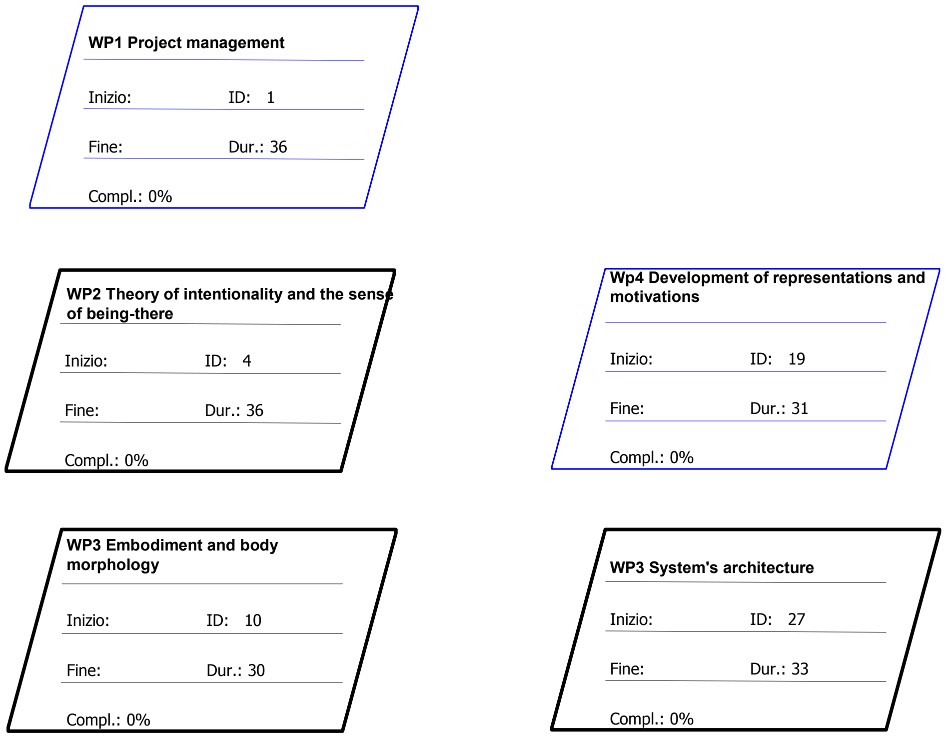
ID	Activities	Deliverables	Duration
1	**WP1 Project management**		**36**
2	Coordination	D1.1, D1.2, D1.3, D1.5, D1.7, D1.8	36
3	Assessment	D1.4, D1.6, D1.9	24
4	**WP2 Theory of intentionality and the sense of being-there**		**36**
5	Analysis of key concepts		1
6	Development of psychological-robotics uniform vocabulary		6
7	M1 Tentative Theory formulation	D2.1	
8	Final analysis of biological and artificial result		3
9	M2 Validated theory and common vocabulary	D2.2, D2.3	
10	**WP3 Embodiment and body morphology**		**30**
11	Design of a set of possible robot morphologies		12
12	Hardware and software implementation for different morphologies		18
13	M3 Different robotic setups to test the effect of morphology	D3.2	
14	M4 Formal analyses and first conclusions		
15	M5 Final evaluation of morphology changing experiments	D3.2	
16	System specific and design human robotic setup		3
17	Hardware and software implementation		12
18	M6 Human like robotic setup	D3.1	
19	**Wp4 Development of representations and motivations**		**31**
20	Definition of experimental paradigm	D4.1	6
21	Definition and implementation of setups	D4.2	6
22	M7 Experimental setup and paradigm		
23	Experimental activity		21
24	M8 Result of behavioral experiments	D4.3, D4.4	
25	Assesment and interpretation of results		12
26	M9 Modelling of coherent representations		
27	**WP3 System's architecture**		**33**
28	Architecture's specifications and design	D5.1	6
29	Basic unit design and implementation	D5.2	3
30	Basic unit test in a simulated environment		3
31	M10 Basic units design and implementation	D5.3	
32	Multi sensory modality sensor integration on robotic setups		6
33	M11 Multi sensory modalities integration	D5.4	
34	Intentional Units Integration		12
35	M12 Artificial intentional architecture	D5.5	



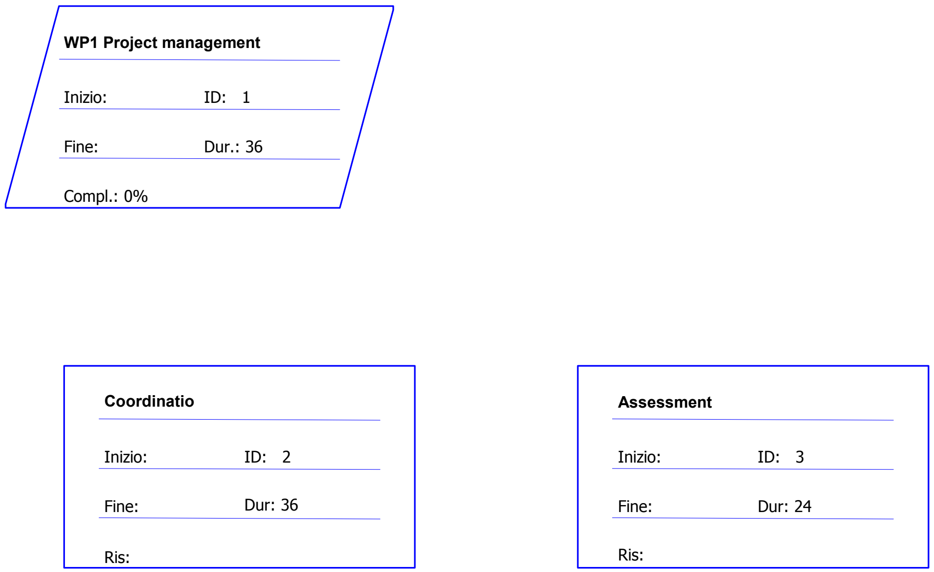
9.5.1. Milestones

Number	Title	Delivery date (months)
M1	Tentative Theory formulation	7
M2	Validated theory and common vocabulary	36
M3	Different robotic setups to test the effect of morphology	12
M4	Formal analyses and first setup of conclusions	30
M5	Final evaluation of morphology changing experiments	30
M6	Human like robotic setup	15
M7	Experimental setup and paradigm	12
M8	Result of behavioral experiments	30
M9	Modeling of coherent representations	33
M10	Basic units design and implementation	12
M11	Multi sensory modalities integrations	21
M12	Artificial intentional architecture	33

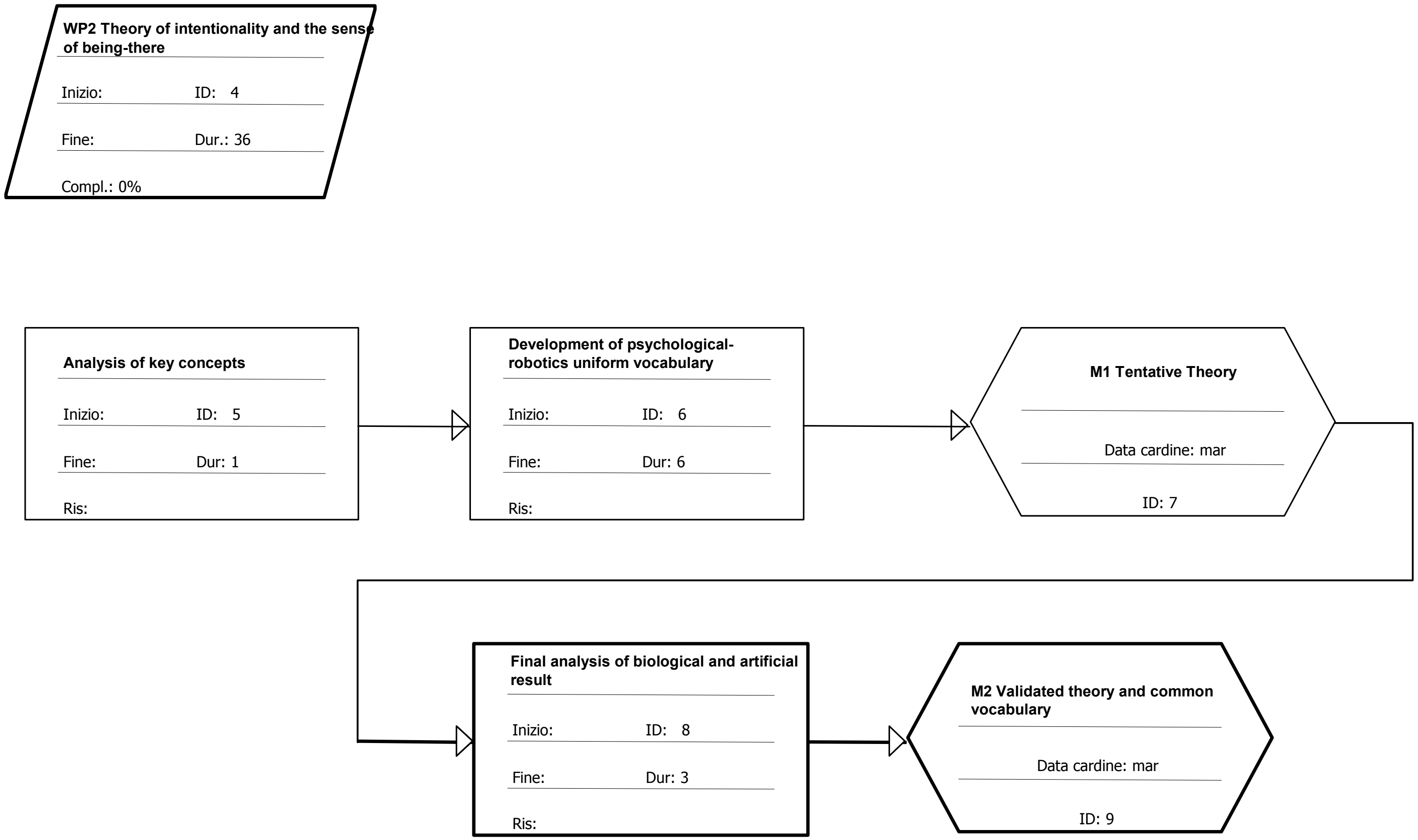
9.6. Pert diagram (workpackages)



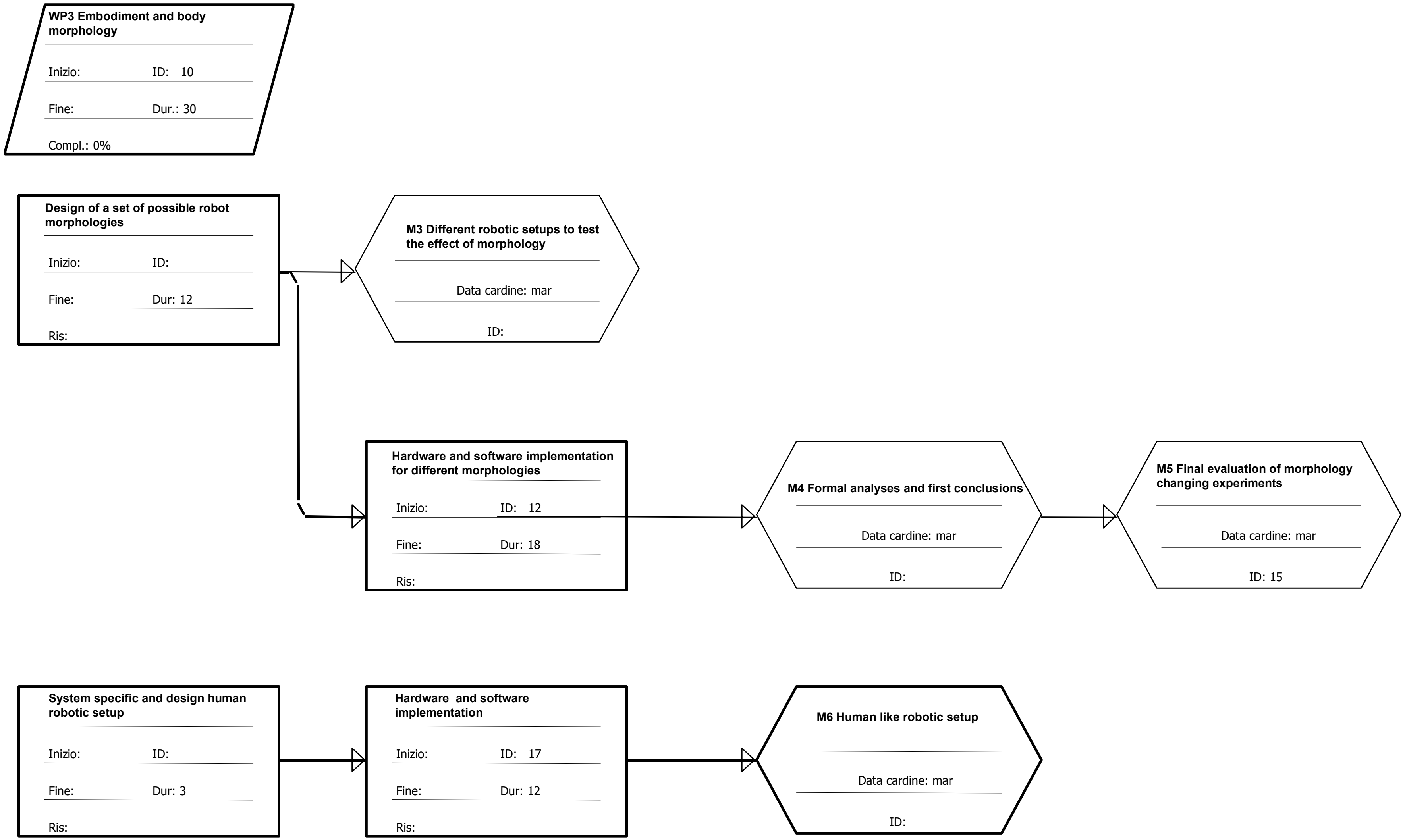
9.6.1. Pert chart (workpackage 1)



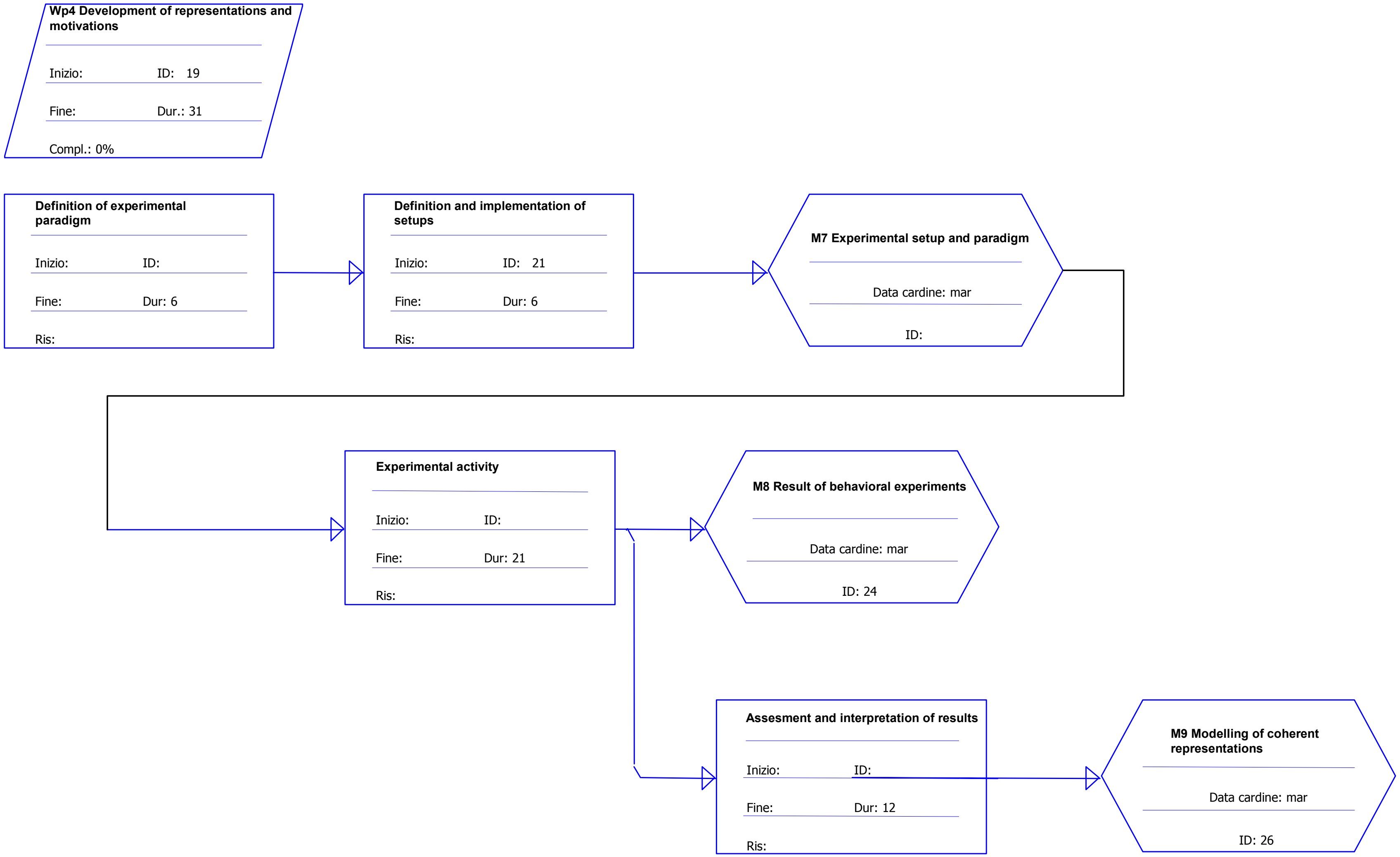
9.6.2. Pert chart (workpackage 2)



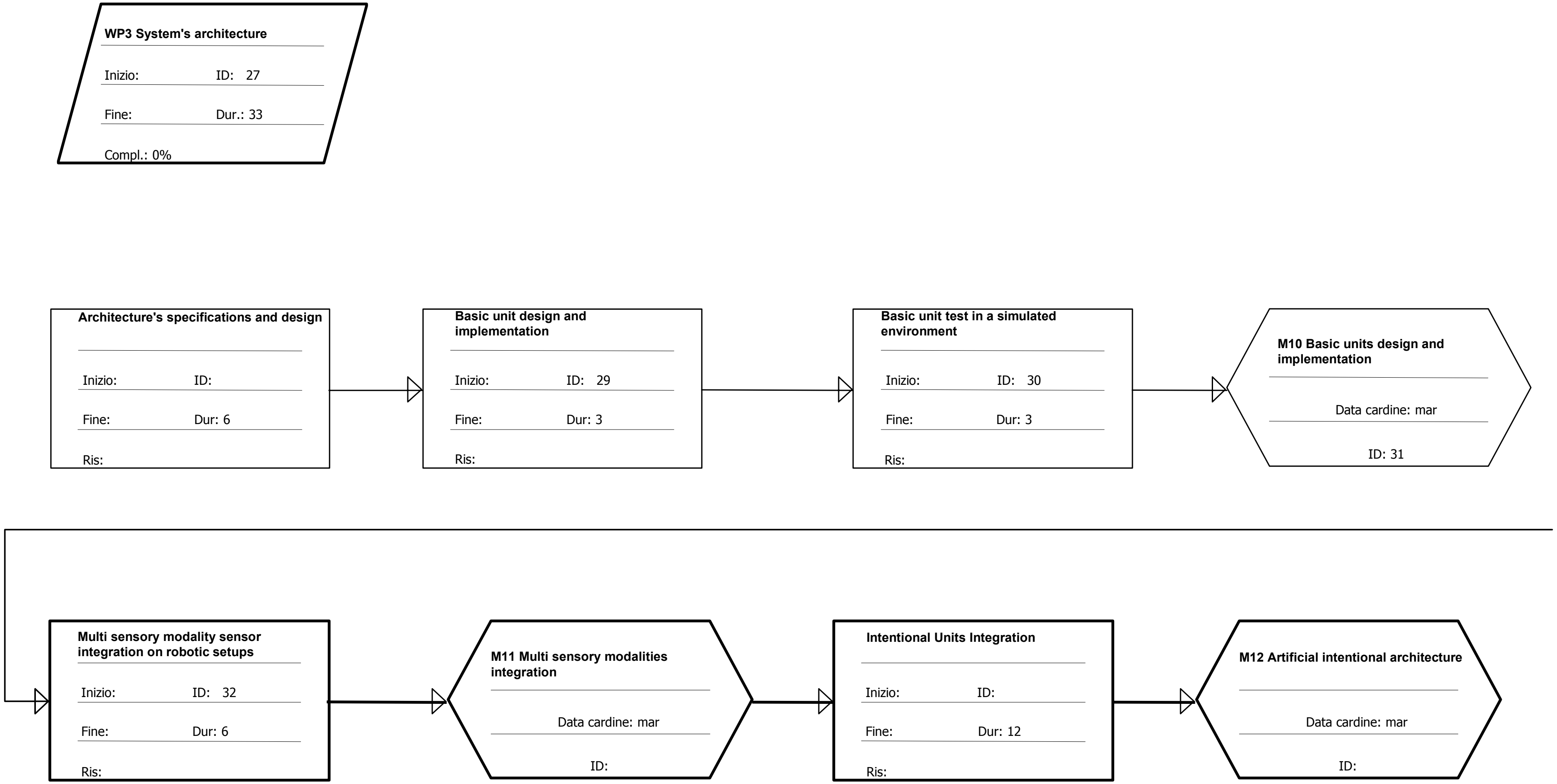
9.6.3. Pert chart (workpackage 3)



9.6.4. Pert chart (workpackage 4)



9.6.5. Pert chart (workpackage 5)



9.7. Project management

Considering the small number of participants, their clearly defined role and the fact that some partners have a long lasting history of collaboration, all partners will participate in the management of the project. DIST will be the prime contractor and Riccardo Manzotti and Giulio Sandini will be responsible of the project's coordination. Each partner has nominated a Principal Investigator. For UNIZH Prof. Rolf Pfeifer, for CNRS and UPMC Prof. Jacqueline Nadel and Prof. Arlette Streri respectively.

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

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

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

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

10. Clustering

This project agrees to contribute fully to the Presence Research Initiative. The OMNIPRES project will track advances in theory and measurement across the FET PR Initiative. Interaction of this project with OMNIPRES will include(i) attendance by a nominated representative of this project to the joint Research and Planning Board meetings (to be held at 6 monthly intervals at times and venues agreed by all)(ii)providing short written project updates as required to allow OMNIPRES to maintain an up to date and informative web site for the entire FET PR.(iii) in the last two months of our project a summary contribution will be provided to OMNIPRES as input for a chapter briefly summarizing all the important findings of the Presence Research projects (this chapter will be included in the volume on the Presence Initiative tentatively titled, "Handbook of Presence Research.")

11. Other Contractual Conditions

11.1. Financial Remarks

The Swiss Government will provide the funding for UNIZH.

CNRS and UPMC will participate in the project through the joint laboratory: "Laboratoire de Vulnerabilite et Adaptation Psychopathologie". The financial arrangement presented in PART-A of the proposal (i.e. one partner appearing at cost zero) is already agreed with the EU.

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

11.2. Travel

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

11.3. Subcontracts

The costs included in the category "subcontract" for both DIST and UNIZH are for the realization of electro-mechanical prototypes, such as a robot hand, that will be used for the experimental activities in ADAPT (specifically for Workpackages 2 and 4). The detailed configuration of the systems will be defined as part of our initial research activity. The work will be subcontracted from DIST to an Italian SME (probably to Telerobot S.r.l.) and from UNIZH to the mechanical workshop of the University of Zurich. The cost of the prototypes will be defined on the basis of its components and the assembly costs and not on the basis of the number of hours spent on design and fabrication.

APPENDIX A – Consortium Description

One of the strong points of this proposal is the mix and complementarities of the expertise of the partners.

Research on embodied cognition has been going on at DIST and UNIZH for many years specifically in relation to "biologically inspired" robotics. Issues such as development, cognition, sensorimotor coordination, are not new and the robots working presently in these laboratories show that we have been able to develop and test theories on physical set-ups such as robot heads, arms, mobile vehicles up to existing prototypes of developing humanoids.

Furthermore, collaborations with scientists working on neurophysiological aspects, and developmental psychology has already been established, demonstrating that what we propose here is not based on strategic considerations, but it is indeed grounded on the consortium's approach to the study of intelligent systems.

The groups involved in the project from a neuroscience and developmental psychology point of view are certainly among the world leaders in all crucial aspects of ADAPT, such as development of visual and haptic perception in infancy, manipulation and grasping in young infants [Streri 1993; Nadel 1999].

This multidisciplinarity is in itself a challenge to the project but could be one of the major achievements to help the formation of a new scientific community. We are confident that the role of each partner is clearly defined and complementary and it is worth noting that the European dimension is not only advantageous but also essential to cover the required know-how.

All the partners have an extend experience with EC projects. LIRA laboratory has been working (and in some cases coordinating) in a number of EU-supported projects (ESPRIT projects VOILA, VAP, NARVAL, ROBVISION, SVAVISCA). It collaborates with other European research institutions through a Human Capital and Mobility Network. The UNIZH is currently a partner in the network EURON (European Robotics Research network) and projects AMOUSE and HYDRA.

The role of each partner in the consortium

The main role of LIRA-Lab:

- Management.
- Investigation of visuo-haptic-auditory perception in artificial system
- Integration and demonstration.

The main role of UNIZH:

- Multimodal integration
- Exploration of changing morphologies
- Providing the theoretical and formal foundations of embodiment

The main role of CNRS and UPMC:

- Carry out the human psychophysics experiments.
- Specification of the human data acquisition setup.
- Modeling.

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

Description of the participants

DIST – University of Genova

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

As to the **present project** DIST will provide its expertise on the design and control of visually guided robot systems and will use the experimental set-ups already available. In particular a humanoid system (Babybot) composed of a head equipped with space-variant sensors (developed by LIRA-Lab in a past collaborative project) and an anthropomorphic manipulator. DIST will be mainly involved in the definition and realization of the hardware system implementing models of sensori-motor development. Work done in these areas is documented by the following references [1-5].

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

Giorgio Metta has a joint position as a post doctoral associate at MIT AI-Lab and as a senior researcher at the LIRA-Lab in Genova. During the last 1.5 years, after receiving his PhD from the University of Genova in Italy, Giorgio spent most of his time in the USA working on manipulation an learning aspect of the humanoid robot CoG. His Ph.D. work addressed the problem of visuo-motor coordination in a humanoid robot from a biologically motivated perspective, with the ultimate goal of learning how to model biological agents by building complex artificial systems (project Babybot). His research aimed at demonstrating that the adoption of a framework of biological development is suitable for the construction of artificial systems. He collaborated in some EU funded projects (ROBVISION, SVAVISCA, NARVAL, VIRGO), and he is author and coauthor of numerous scientific publications. His main research interest is sensori-motor coordination in robotics and neuroscience

Riccardo Manzotti is a researcher at the LIRA-Lab, DIST. His main interest deals with the design of artificial intentional architectures and the relation between cognition and consciousness. He obtained his PhD with a thesis focused on the implementation of a motivations-seeking, environment-driven intentional robot. Previously he worked on sensory integration as well as on the implementation of visual-motor control algorithms (basic control systems of vergence, saccadic movements, image fusion and smooth pursuit). He is the author of a book on the theoretical issues entailed by building and designing an intentional agent. He has been involved in collaborative projects supported by the EU (ROBVISION, MIRROR, CVS)

Relevant Publications

[1] Metta, G., G. Sandini, and J. Konczak, A Developmental Approach to visually-guided reaching in artificial systems. Neural Networks, 1999. 12(10): p. 1413-1427.

[2] Panerai, F., G. Metta, and G. Sandini, Visuo-inertial Stabilization in Space-variant Binocular Systems. Robotics and Autonomous Systems, 2000. 30(1-2): p. 195-214

[3] Sandini, G., G. Metta, and J. Konczak. Human Sensori-motor Development and Artificial Systems. in AIR&IHAS '97. 1997

[4] Sandini, G., F. Panerai, and F.A. Miles, The Role of Inertial and Visual Mechanisms in the Stabilization of Gaze in Natural and Artificial Systems, in Motion Vision, Computational, Neural, and Ecological Constraints, J.M. Zanker and J. Zeil, Editors. 2000, Springer. p. 189-218

[5] Manzotti, R., Gasteratos A, Metta G. and G. Sandini, Disparity estimation in log polar images and vergence control. Computer Vision and Image Understanding, 2001. 83: p. 97-117.

[6] Manzotti, R., Intentional robots. The design of a goal seeking, environment driven, agent, in DIST. 2001, University of Genoa: Genova.

[7] Manzotti, R., G. Metta, and G. Sandini. Intentionalizing nature. Proceedings of Tucson 2000. 2000. Tucson, Arizona.

[8] Manzotti, R. On building a conscious being. Proceedings of In search of a science of consciousness. 2001. Skovde (Sweden).

[9] Manzotti, R. and V. Tagliasco, Coscienza e Realtà. Una teoria della coscienza per costruttori e studiosi di menti e cervelli. 2001, Bologna: Il Mulino.

UNIZH: The Department of Information Technology, University of Zurich

Founded in 1962, the Department of Information Technology of the University of Zurich employs eight professors and about 80 research staff, mostly from computer science, but there is a significant number from other areas such as engineering, mathematics, business administration, biology, physics, medicine, mathematics, and linguistics. The department which is associated with the Faculty of Economics, Business Administration, and Information Technology, is active in the following research areas: information and communication systems, software and database technology, multimedia, artificial intelligence, and cognitive sciences. In addition to funding from private companies, the main funding partners are the Swiss National Science Foundation, the Swiss Commission of Technology and Innovation, and the Commission of the European Union. There is a widespread network of partnerships in Europe and worldwide. The Department of Information Technology will participate in the proposal with the Artificial Intelligence Laboratory whose director is Rolf Pfeifer.

The AILab with its 25 researchers has been employing a synthetic methodology, i.e. designing and building robots that mimic certain aspects of the behavior of natural systems in close cooperation with biologists, neuroscientists, and engineers, since 1991. Through a large number of projects involving the development of robots for wheeled, legged and flying locomotion (including sensory and motor systems, electronics, mechanics) in the AILab, we have acquired a lot of expertise in robot engineering and experimentation. Moreover, a research program has been established, applying the synthetic methodology to sensory-motor coordination for multi-model integration and categorization (refs 3, 4, 5). Recently, the AILab has developed an interest in the relation between materials, morphology, and control (refs 1, 2) and in this context has started with the information theoretic analysis of sensory data in humanoid systems (ref. 6). On a more general level, the laboratory has been instrumental in promoting an embodied perspective to artificial intelligence and cognitive science by providing an advanced textbook on the topic (ref. 3). Finally, the AILab has nearly 15 years of experience with transdisciplinary research, as it unites researchers from biology, neuroscience, psychology, mechanical and electronics engineering, computer science, and physics.

Should the financial provisions of the bilateral research agreement not be in force when the European Commission definitively decides to support the project, the Swiss Government will fund the Swiss project partner(s).

Involvement of the AILab in other EU projects

2000 Partner of EURON (European Robotics Research network)

1997-2001 Partner of VIRGO TMR Network (Vision-based robot navigation)

2001-2005 Partner of AMOUSE

2001-2004 Partner of HYDRA

Rolf Pfeifer is a full professor of computer science at the Department of Information Technology, University of Zurich, and director of the Artificial Intelligence Laboratory (AILab). He is at the same time a member of the faculty of Mathematics and Science, and the faculty of Economics, Business Administration, and Information Technology. He received his masters degree in physics and mathematics from the Swiss Federal Institute of Technology (ETH) in Zurich and his PhD in Computer Science from the same institution in 1979. He spent three years as a post-doctoral fellow in the US at Carnegie-Mellon University and Yale University working in the areas of Artificial Intelligence and Cognitive Science. He then joined the Department of Information Technology of the University of Zurich first where he was elected professor of computer science and founded the AILab in 1987. Among others, he was a visiting professor/researcher at the Free University of Brussel, the MIT Artificial Intelligence Laboratory, and at the Neurosciences Institute in San Diego.

Max Lungarella (1973) has a master's degree in Electrical Engineering from the University of Perugia, Italy (1999). He has been a member of the AILab since 1999. He has been involved in robot development projects (legged locomotion, arm control for sensory-motor coordination, flying robots) and sensor development (haptic sensor arrays, whisker sensors, active vision systems). He has developed many controller boards for sensors and actuators build in our laboratory. He has also been involved in the experiments on categorization and information theoretic analysis of sensor data. In addition, his research interests include embodied models of intelligence and developmental robotics.

Relevant Publications

[1] Pfeifer, R. (2001). Morpho-functional machines: Basics and research issues. Proc. of the International Workshop on Morpho-Functional Machines. In: F. Hara, and R. Pfeifer (eds.). Lecture Notes in Computer Science; Springer-Verlag.

[2] Pfeifer, R. (2000). On the role of morphology and materials in adaptive behavior. Proc. 6th International Conference on the Simulation of Adaptive Behavior. Cambridge, Mass.: MIT Press, 23-32.

[3] Pfeifer, R., and Scheier, C. (1999). Understanding intelligence. Cambridge, Mass.: MIT Press (paperback edition, 2001).

[4] Pfeifer, R., and Scheier, C. (1998). Representation in natural and artificial agents: a perspective from embodied cognitive science. Zeitschr. f. Naturforschung 53c:480-503.

[5] Scheier, C., Pfeifer, R., and Kuniyoschi, Y. (1998). Embedded neural networks: exploiting constraints. Neural Networks 11, 1551-1569.

[6] Lungarella, M., and Pfeifer, R. (in press). Robots as cognitive tools: Information theoretic analysis of sensory-motor data. Proc. IEEE-RAS Int. Conference on Humanoid Robots.

CNRS: French National Centre of Scientific Research

The French National Centre of Scientific Research (CNRS), will participate in ADAPT with the “Development and Psychopathology” group. Ongoing research projects of the group are:

Planning and Imitation in healthy persons and persons with autism: an interdisciplinary program, French Ministry of Research (principal investigator, coordinator responsible for the interdisciplinary program with neuroimaging (includes Jean Decety & Julie Grèze), neurocybernetics (includes: Philippe Gaussier, Arnaud Revel, & Pierre Andry), clinical psychology (includes Bernadette Rogé & Loetitia Rinaldi) and experimental developmental psychology (includes: Jacqueline Nadel, Caroline Potier, Nadra Aouka etr Pierre Canet): 1999-2001

Brain and Behavior in Autism: behavioural measures and neuroimaging, Fondation de France, (investigator for behavioural measures) (includes Monica Zilbovicius for neuroimaging and M-C Mouren-Simeoni, for medical assessment): 1999-2001

Precursors of intentionality in schizophrenic patients and children with autism, compared to healthy adults and children, French Ministry of Research (investigator for children with autism and healthy children): 1999-2001

Jacqueline Nadel is a Research Director at the French National Centre of Scientific Research (CNRS) in the area of cognitive developmental psychology and psychopathology. She coordinates the group “Development and Psychopathology” in a CNRS unit of the hospital La Salpêtrière. One of her main contributions concerns the functional use of cross-modal capacities as evidenced by imitation and detection of imitation in young infants and children with autism. She is the co-editor of *Imitation in infancy*, 1999, Cambridge University Press., the first book to bring together the extensive modern evidence for innate imitation in babies. She has created a scale measuring early imitation and early detection of imitation in cases of affordant versus non-affordant relationships between objects and actions. Another aspect of her work focuses on early perception of contingency as a precursor of inferential capacities. Within this framework, she contributes to the demonstration of early expectancies for social contingency via an experimental design which allows to present to the infant through TV monitors either a live image of her mother or a delayed image in a seamless shift (see Nadel *et al.*, 1999, *Developmental Science, 2*, 164-174). She explores expectancies for contingency in low-functioning children with autism. She is the editor of the French journal *Enfance*.

Arlette Streri is Professor of developmental psychology, Université René Descartes Paris V. She is the director of the graduate school of Paris5 University for: “cognition and behaviour”. Her main topics are: Intermodal transfer between touch and vision in infancy, haptic perception of object, handedness and haptic perception; laterality, haptic memory, self-knowledge in infancy

Relevant Publications

[1] Nadel, J. & Butterworth, G. (Eds) (1999). *Imitation in infancy*. Cambridge: Cambridge University Press.

[2] Nadel, J., Carchon, I., Kervella, C. *et al.* (1999). Expectancies for social contingency in 2-month-olds. *Developmental Science*, *2*, 164-174.

[3] Nadel, J., Guérini, C., Rivet, C., & Pezé, A. (1999). The evolving nature of imitation as a communicative format. In J. Nadel & G. Butterworth (Eds), *Imitation in infancy*, 209-234. Cambridge: Cambridge University Press.

[4] Nadel, J. & Tremblay-Leveau, H. (1999). Early interpersonal timing and the perception of social contingencies. In P. Rochat (Ed.). *Early social cognition,* (pp.189-212*).* Mahwah, N.J.: Lawrence Erlbaum

[5] Muir, D. & Nadel, J. (1998). Infant social perception. In A. Slater (Ed.), *Perceptual development,* (pp. 247-285). Hove, East Sussex: Psychology Press.

[6] Nadel, J., Croué, S., Mattlinger, M-J. *et al.* (2000). Do children with autism have ontological expectancies concerning human behaviour? *Autism*, *2,* 133-145.

[7] Andry, P., Moga, S., Gaussier, P., Revel, A., & Nadel, J. (2000). Imitation: learning and communication. *SAB 2000 (pp.*353-362). Cambridge, MA: MIT Press.

[8] Nadel, J., & Melot, A-M (2001). How clear is the four-year-olds' "clear-cut change" in understanding mind? *Cognitive Development*, 15, 153-168.

[9] Field, T., Field, T, Sanders, C., & Nadel, J. (2001). Children with autism become more social after repeated imitation sessions. *Autism*, 317-324.

[10] Escalona, A., Nadel, J. Field, T., & Lundy, L. (in press). Imitation effects on children with autism. *Journal of Autism and Developmental Disorders.*

[11] Nadel, j. (2002). Imitation and imitation recognition: their functional use in preverbal infants and nonverbal children with autism. In A. Meltzoff & W. Prinz (Eds), The imitative mind:Development, Evolution and Brain Bases. Cambridge: Cambridge University Press.

[12] Nadel, J., & Decety, J. (2002). Imiter et comprendre l'humain. Paris: PUF.

[13] Streri, A. (1993). Seeing, Reaching, Touching. The relations between vision and touch in infancy. Halverster Wheatsheaf (Simon & Schuster International Group).

[14] Hatwell, Y., Streri, A., & E. Gentaz (2000). Toucher pour connaître. Psychologie cognitive de la perception tactile manuelle. Paris: P.U.F.

[15] Lhote, M. & Streri, A. (1998) Haptic memory, handedness and hemispheric asymmetry in 2-month-old infants, Laterality, 3, 173-192.

[16] Streri, A., Lhote, M., & Dutilleul, S. (2000). Haptic perception in newborns. Developmental Science, 3, 319-327.

[17] Streri, A., Spelke, E.S., Rameix, E. (1993). Specific and amodal mechanisms of object perception and exploration in infancy: the case of active touch. Cognition, 47, 251-279.

[18] Streri, A. & Spelke, E.S. (1988). Haptic perception of objects. Cognitive Psychology, 20, 1-23.

References

1. Stein, B.E. and M.A. Meredith, *The merging of the senses*. Bradford Book. 1993: MIT-Press.
2. Pfeifer, R. and C. Scheier. *Representation in Natural and Artificial Agents: an Embodied Cognitive Science Perspective*. in *Natural Organisms, Artificial Organisms, and Their Brains*. 1998. Bielefeld, Germany: Verlag.
3. Manzotti, R., G. Metta, and G. Sandini. *Intentionalizing nature*. in *Tucson 2000*. 2000. Tucson, Arizona.
4. Zlatev, J., *The Epigenesis of Meaning in Human Beings, and Possibly in Robots.* Mind and Machines, 2001. **11**: p. 155-195.
5. Pfeifer, R. and C. Scheier, *Understanding intelligence*. 1999, Cambridge (Mass.): MIT Press.
6. Pfeifer, R. and C. Scheier, *Sensory-motor coordination: The metaphor and beyond.* Robotics and Autonomous Systems, 1997. **20**: p. 157-178.
7. Scheier, C., R. Pfeifer, and Y. Kuniyoschi, *Embedded neural networks: exploiting constraints.* Neural Networks, 1998(11): p. 1551-1569.
8. Sandini, G., G. Metta, and F. Panerai. *Modeling neural sensori - motor development in a humanoid robot*. in *X Conference on Developmental Psychology*. 2001. Uppsala (Sweden).
9. Pfeifer, R. *On the role of morphology and materials in adaptive behavior.* in *6th International Conference on the Simulation of Adaptive Behavior.* 2000: MIT Press.
10. Pfeifer, R. *Morpho-functional machines: Basics and research issues.* in *International Workshop on Morpho-Functional Machines.* 2001: Springer-Verlag.
11. Sandini, G., et al. *A Retina-like CMOS Sensor and its Applications*. in *SAM-2000*. 2000. Cambridge, USA: IEEE.
12. Sandini, G., G. Metta, and J. Konczak. *Human Sensori-motor Development and Artificial Systems*. in *International Symposium on Artificial Intelligence, Robotics and Intellectual Human Activity Support(AIR&IHAS '97)*. 1997. RIKEN - Japan.
13. Metta, G., G. Sandini, and J. Konczak, *A Developmental Approach to Visually-Guided Reaching in Artificial Systems.* Neural Networks, 1999. **12**(10): p. 1413-1427.
14. Metta, G., et al. *Development and artificial systems: modeling sensori-motor behaviors in a humanoid robot*. in *Fifth International Conference on Cognitive and Neural Systems - CNS*. 2001. Boston (USA).
15. Panerai, F., G. Metta, and G. Sandini, *Visuo-inertial Stabilization in Space-variant Binocular Systems.* Robotics and Autonomous Systems, 2000. **30**(1-2): p. 195-214.
16. Sandini, G., et al. *Computational Model of the Retino-Cortical Transformation of the Peripheral Visual Field*. in *4th European Conference on Visual Perception*. 1981. Gouvieux (France).
17. Manzotti, R. and V. Tagliasco, *Coscienza e Realtà. Una teoria della coscienza per costruttori e studiosi di menti e cervelli*. 2001, Bologna: Il Mulino.
18. Edelman, G.M. and G. Tononi, *A Universe of Consciousness. How Matter Becomes Imagination*. 2000, London: Allen Lane.
19. Togawa, T. and K. Otsuka, *A model for Cortical Neural Network Structure.* Biocybernetics and Biomedical Engineering, 2000. **20**(3): p. 5-20.

20. Martinoli, A., O. Holland, and R. Goodman, *Internal representations and Artificial Conscious Architectures*. 2000, California Institute of Technology.

21. Streri, A., M. Lhote, and S. Dutilleul, *Haptic perception in newborns.* Developmental Science, 2000(3): p. 319-327.

22. Lederman, S.J. and R.L. Klatsky, *Hand movements: a window into haptic object recognition.* Cognitive Psychology, 1987(19): p. 342-368.

23. Streri, A., *Seeing, Reaching, Touching - The Relations between Vision and Touch in Infancy*. 1993: MIT Press.

24. Nadel, J. and G. Butterworth, *Imitation in Infancy*. Cambridge Studies in Cognitive Perceptual Development, ed. G. Butterworth, G. Hatano, and K.W. Fisher. 1999: Cambridge University Press.

25. Ernst, M.O. and M.S. Banks, *Humans integrate visual and haptic information in a statistically optimal fashion.* Nature, 2002(415): p. 429-433.

26. Buttazzo, G., *Artificial Consciousness: Utopia or Real Possibility.* Spectrum IEEE Computer, 2001. **18**: p. 24-30.

27. Tononi, G., G. Edelman, and O. Sporns, *Complexity and coherency: integrating information in the brain.* Trends in Cognitive Sciences, 1998(2): p. 474-484.

28. Koch, C. and F. Crick, *The zombie within.* Nature, 2001(411): p. 893-893.

29. Zeki, S. and A. Bartels, *The asynchrony of consciousness.* Proc R Soc Lond B Biol Sci, 1998. **265**: p. 1583-5.

30. Uexküll, J.v., *A Stroll through the Worlds on Animals and Men: A Picture Book of Invisible Worlds*. 1934, New York: International University Press.