European Commission

INFORMATION SOCIETY TECHNOLOGIES
(IST)
PROGRAMME

Contract for:

**Shared-cost RTD**

Annex 1 - "Description of Work"

| | |
|---|---|
| Project acronym: | **BIBA** |
| Project full title: | **Bayesian Inspired Brain and Artefacts: Using probabilistic logic to understand brain function and implement life-like behavioural co-ordination** |
| Proposal/Contract no.: | *IST-2001-32115* |
| Related to other Contract no.: | n/a |

Date of preparation of Annex 1: July 2001

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

# Content

## 1. Project summary

### Objectives

The twin scientific objectives of the BIBA project are:

- To reconsider in the light of Bayesian probabilistic reasoning our methodology, models, algorithms and techniques for building artefacts for the "real world", gaining inspiration from the way living beings have evolved and adapted to the properties of their natural environments, and constructing artefacts that use these principles.
- To provide a firm Bayesian basis for understanding how biological systems use probabilistic logic to exploit the statistical properties of their environments, both at the level of neural mechanisms, and at the level of strategy, and to use artefacts to test the validity of these ideas.

### Description of work

The project is organised along 3 axes of research and development:

- Neural basis of probabilistic inference.

We shall construct well defined models of how probabilities may be represented and manipulated, and test predictions with psychophysical performance measures and studies of regional brain activation. We expect to improve our understanding of neural mechanisms and derive new ideas for the implementation of probabilistic inference in engineering systems.

- New probabilistic models and algorithms for perception and action.

The main goal is to illustrate how probabilistic computation, and more specifically, Bayesian programming, may account for global behaviours of organisms in interaction with their environment. We will focus on specific questions concerning multi-sensory perception and motion control. We plan to develop new probabilistic models that explain the observed behaviours in human or animals and to implement them on autonomous artefacts.

- New probabilistic methodology and techniques for artefact conception and development.

We will use the Bayesian and learning paradigm to develop an artefact that acquires repertoires of reactive probabilistic behaviours (synergies), builds combinations, hierarchies and temporal sequences of these behaviours (strategies) and can be trained for different tasks. We shall imitate biology by reducing the amount of pre-specified knowledge of the environment built in by the designer, departing radically from classic robot design, and will explore the possibility for the artefact to "discover" part of its preliminary knowledge using evolutionary techniques. We will evaluate the consequences of contraction theory.
The result will be an artefact embodying efficient probabilistic algorithms for sensory interpretation and control, with more life-like behaviour and the means to test and develop further ideas.

### Milestones and expected results

The project is organised in clear stages, with a logical progression of designs for the artefacts that will be used to test algorithms, and with the theoretical and experimental biological research planned to coordinate with the engineering implementations, and also to tackle the problems in a logical sequence. The final result should be significant progress in our understanding of the interaction between the real world and artificial or biological systems.

# 2. Project objectives

## *2.1 Goals*

The twin technological and scientific goals of the BIBA project are:

- To reconsider in the light of Bayesian probabilistic reasoning our **methodology, models, algorithms and techniques for building artefacts for the "real world"**, gaining inspiration from the way living beings have evolved and adapted to the properties of their natural environments, and **constructing artefacts** that use these principles.
- To provide a firm Bayesian basis for **understanding how biological systems use probabilistic logic to exploit the statistical properties of their environments**, both at the level of neural mechanisms, and at the level of strategy, and to **use artefacts to test the validity of these ideas**.

Bayesian probabilistic logic, an alternative to classical logic, offers a new point of view which could entirely change our conception of intelligence over the coming years. The BIBA (Bayesian Inspired Brains and Artefacts) project will bring together a group of scientists from different fields who are already applying the Bayesian approach. We shall work together on the theory, on how biological mechanisms implement Bayesian computations, and on applying the principles in making revolutionary new artefacts. We believe we can help to bring about the paradigm shift that will establish probabilistic logic firmly as one of the bases of intelligent life-like behaviour. Though several research groups do already incorporate Bayesian theory into much of their thinking, we believe that the cross-fertilisation of ideas and lateral thinking that will result from our broad-based approach will be the best way to advance our understanding in a coherent and practical manner.

## *2.2 Objectives*

The scientific and technological objectives are addressed along 3 axes of research and development:

- **Neural basis of probabilistic inference** (see WP 1)
- **New probabilistic models and algorithms for perception and action** (see WP 2)
- **New probabilistic methodology and techniques for artefact conception and development** (see WP 3)

**Neural basis of probabilistic inference**: The objective of this first axe of research is to identify how the nervous system does (or at least may) implement probabilistic inference. We shall construct well-defined models of how probabilities may be represented and manipulated, and test predictions with psychophysical performance measures and studies of regional brain activation. We expect to improve our understanding of neural mechanisms and derive new ideas for the implementation of probabilistic inference in engineering systems.

**New probabilistic models and algorithms for perception and action**: The main goal of WP2 is to illustrate how probabilistic computation, and more specifically, Bayesian programming, may account for global behaviours of organisms in interaction with their environment. We will focus on specific questions concerning multi-sensory perception and motion control. We plan to develop new probabilistic models that explain the observed behaviours in human or animals and to implement them on autonomous artefacts.

**New probabilistic methodology and techniques for artefact conception and development**: The objectives of this workpackage is to develop new methodologies for control of artefacts in the "real world" inspired by the way animals cope with uncertainty and probabilistic inference, through evolution, development, adaptation and learning. The results will be both a tool box to program and "trained" autonomous robots and a demonstrator of this new methodology.

### *2.3 Operational goals and measure of success*

These global objectives may be refined as more operational goals and associated measure of success.

| Operational goals | Measure of success |
|---|---|
| **Neural basis of probabilistic inference** | |
| Various neural information coding hypothesis as possible support for probabilistic computation | • Scientific publications |
| Strategies for representing and manipulating probability | • Scientific publications |
| Bayesian model of some human cognitive tasks | • Psychophysics experiments<br>• fMRI investigations |
| **New probabilistic models and algorithms for perception and action** | |
| Visual-vestibular interactions in self motion perception and gaze stabilization | • Demonstration of a mobile robot using a visual-vestibular system for complicated sensory-motor tasks<br>• Comparison with animal and human performances and pathologies |
| Perception of the depth structure of a complex visual scene | • Bayesian model of perception of the depth structure<br>• Psychophysics experiments testing this model |
| Action-based versus sensory-based space representation | • Demonstration of a mobile robot using an action-based representation of its environment to navigate efficiently. |
| Decision making in visual-vestibular conflict during navigation | • Bayesian model of sensorial conflicts resolution<br>• Psychophysics experiments testing this model |

| **New probabilistic methodology and techniques for artefact conception and development** | |
|---|---|
| Bayesian *programming* tool box for autonomous robots and artefacts | • Delivery of a software package<br>• Demonstration of a mobile robots *programmed* with this Bayesian package to accomplish complex animal like behaviours |
| Bayesian *training* of autonomous robots and artefacts | • Demonstration of a mobile robots *trained* to accomplish complex animal like behaviours |
| Bayesian *evolution* of autonomous robots and artefacts | • Demonstration of a mobile robots having part of its knowledge resulting of evolution processes |
| Study of mobile robots having contracting subcomponents for sensing and actuation | • Demonstration of a mobile robot with contracting subcomponents |

The number and *quality* of scientific publications resulting from the BIBA project will be also an obvious and very important measure of its success.

# 3. Participant list

## List of Participants

| Partic. Role* | Partic. no. | Participant name | Participant short name | Country | Date enter project ** | Date exit project ** |
|---|---|---|---|---|---|---|
| C | 1 | Institut National de Recherche en Informatique et Automatisme - GRAVIR | INRIA-UMR-GRAVIR | France | start | end |
| P | 2 | Centre National de la Recherche Scientifique - GRAVIR | CNRS-UMR-GRAVIR | France | start | end |
| P | 3 | University College of London - ARGM | UCL - ARGM | U.K. | start | end |
| P | 4 | University of Cambridge - DPOL | UCAM - DPOL | U.K. | start | end |
| P | 5 | Centre National de la Recherche Scientifique – Laboratoire de Physiologie de la Preception et de l'Action | CNRS-UMR-LPPA | France | start | end |
| P | 6 | Collège de France – Laboratoire de Physiologie de la Preception et de l'Action | CDF-UMR-LPPA | France | start | end |
| P | 7 | Ecole Polytechnique fédérale de Lausanne | EPFL | Suisse | start | end |
| P | 8 | Massachusetts Institute of Technology - NSL | MIT - NSL | U.S.A. | start | end |

*C = Coordinator (or use C-F and C-S if financial and scientific coordinator roles are separate)
P - Principal contractor
A - Assistant contractor

** Normally insert "Start of project" and "End of project". These columns are need for possible later contract revisions caused by joining/leaving participants

Note that Partners 1 and 2 are the 2 legal organisations corresponding to the same laboratory GRAVIR which has a UMR status (Unité Mixte de Recherche).
Note also that Partners 7 and 8 are the 2 legal organisations corresponding to the same laboratory LPPA which has a UMR status (Unité Mixte de Recherche).

## 4. Contribution to programme/key action objectives

The BIBA project is part of the Future and Emerging Technologies (FET) theme of the programme for Information Society Technologies (IST). We think that over the next decade or so the improved understanding and applications of probabilistic reasoning could entirely change our conception of intelligent behaviour, in relation to both neural systems and the man-made artefacts and information systems that people have to interact with.

We are working with fundamental issues of how best to represent and manipulate the uncertainties in the environment that information systems have to handle, so we are not as yet directly concerned with "*systems and services for the citizen*", the overarching theme of the IST programme. But in the long term we see this as a major area of benefit. We are all familiar with the problems of present-day computers and automatic devices that tend to require rigidly correct actions on our part. Intelligent behaviour - which is not restricted to humans within the animal kingdom, and which should ultimately extend also to the information devices that we handle - we regard largely as the ability to handle appropriately the uncertainties within incoming information, not just the unambiguous signals. This is exactly our domain.

We expect to make progress on the following important questions:

- How to face the incredible complexity of the real world with limited physical and intellectual resources?
- How to overcome the apparent incompleteness, uncertainty and inconsistency of the flow of information resulting from physical interactions?
- How to constantly adapt, learn and reorganise memory and knowledge structures to deal with a fluctuating environment?

Working with a bold new conception of intelligence, backed by clear mathematical formalisms, with the example of clear success stories in even simple neural systems of animals, and with the expertise to develop and test ideas with artefacts, we are confident that within four years we can make radical advances.

# 5. Innovation

The innovative focus of the BIBA project is the coordinated application of probabilistic (Bayesian) inference and learning to the problems of behavioural control in animals and artefacts. The real world - especially in the aspects that animals excel at handling - is characterised by uncertainty, unpredictability and noise. There are few if any problems of control and behaviour that should not be looked at with this in mind, yet the current state of the art does not give this the overriding importance it deserves. Bayesian inference is the necessary extension of logic in these circumstances, when there is insufficient information to perceive, infer, decide and act on rigorous principles. Though many other groups do include probabilistic reasoning in their thinking, we see the BIBA project - with committed experts from different backgrounds, focussed on this issue - as an opportunity to make a synthesis of ideas in biology and engineering, with each inspiring the other by exposure to novel aspects of the problems and novel approaches, thus helping to consolidate a genuine paradigm shift.

Ever since the initial work of Laplace and Bayes, probability theory has been regarded as a natural way to deal with incomplete models of natural phenomenon. Recently, the Bayesian approach has been taken forward strongly by the late Edward T. Jaynes, with a rigorous synthetic formulation of probabilistic reasoning, sometimes encapsulated by the phrase "Probability as Logic". Any model of a complex phenomenon is bound to be irremediably incomplete. There are always some "hidden" variables not taken into account. Consequently, the phenomenon and the model never behave exactly alike. The purpose of Bayesian inference and learning is to optimise reasoning in such a context. The BIBA project will transform this formal approach to a set of tools and practices, which could be shared by scientists coming from two communities: life science and engineering.

## *5.1 Probabilistic reasoning in artificial intelligence*

In information science and artificial intelligence, the importance of reasoning with uncertain and incomplete knowledge has been recognised for a long time. However, the Bayesian approach has emerged clearly as one of the important trends only since the introduction of Bayesian nets and graphical models[1]. Some technical progress has been achieved lately and the first prototype applications have appeared in computer vision[2], robotics [3 4 5], CAD and tolerancing systems[6 7], process control, text and speech processing, malfunction diagnosis, and game programming. A few small innovative companies have been in the Bayesian business for the last few years, with promising success (for instance Hugin[8] or Autonomy, a spin-off of Neurodynamics[9]). Microsoft[10] has considered Bayesian inference as a possible

[1] http://www.cs.berkeley.edu/~murphyk/Bayes/bayes.html
[2] http://www.cis.ohio-state.edu/~szhu/workshop/SCTV99.html
[3] S. Thrun, D. Fox, and W. Burgard (1998) A probabilistic Approach to Concurrent Mapping and Localization for Mobile Robots. Machine Learning 31, 29-53
[4] Olivier Lebeltel (1999) ; *Programmation bayésienne des robots*; Thèse de doctorat INPG (Institut National Polytechnique de Grenoble)
[5] Pierre Bessière, Olivier Lebeltel, Julien Diard & Emmanuel Mazer (2000) ; *Bayesian Robots Programming* ; Les Cahiers du Laboratoire LEIBNIZ, n°1, Mai 2000; Grenoble, France
[6] Kamel Mekhnacha (1999) ; *Méthodes probabilistes baysiennes pour la prise en compte des incertitudes géométriques : Application à la CAO-robotique* ; Thèse de doctorat INPG (Institut National Polytechnique de Grenoble
[7] Mekhnacha, K., Mazer, E. & Bessière, P. (2001) ; The design and implementation of a Bayesian CAD modeler for robotic applications ; *Advanced Robotics*, Vol. 15, N. 1 (in press)
[8] http://www.hugin.dk/
[9] http://www.neurodynamics.com/
[10] http://www.research.microsoft.com/dtas/msbn/default.htm

strategic option for near future technical development. In addition to this trend toward a wider use of Bayesian reasoning in the industry, the BIBA project will provide new biologically inspired designs for implementing and using Bayesian reasoning, and learning. For example it is not inconceivable to imagine the BIBA project will, through prompting the search for biological representations of probability distributions, lead to new ways of representing them electronically. There are many possible approaches, and the opportunities for progress through a multi-disciplinary approach with ideas inspired through biology are considerable.

### *5.2 Probabilistic reasoning in perception*

To see what innovations in understanding sensory processes may arise out of this project, consider how Bayesian thinking may produce almost literally a revolution - a reversal of the perspective from which neural processing is viewed. It is an ancient idea going back to Helmholtz[1] and advocated by others since then[2] that what we perceive corresponds, not to the physical scene before us, but to the hypothesis in our minds that best fits the sensory data currently being received from that scene. This may require that the nervous system operates in a series of distinct modes in which alternative hypotheses are assessed sequentially for the strength of support from current data, though we must emphasise that this is only one possible conclusion that our research might support. Phenomena suggestive of this are observed in familiar situations with ambiguous visual information, for instance binocular rivalry or the Neckar cube, where interpretation flips between incompatible states in which the same information is perceived as quite different things. These situations are often regarded as interesting oddities, but with Bayesian thinking they become extreme examples of what may go on all the time in perception, through the weighing of different possible interpretations.

These ideas about perception have a strong Bayesian flavour, but strangely they have never been formulated rigorously in probabilistic terms. If this were done during the BIBA project, we might begin to see how the hypotheses that are thought to populate our minds must be formed from the statistical properties of past experience, and perhaps from inborn prototypes with a Jungian flavour. And if this is how biological perception works, an engineering instantiation of the principles will almost certainly be useful.

### *5.3 Probabilistic reasoning in Gestalt theory*

Up to the middle of the last century the Gestalt movement in psychology was one of the most powerful influences on the subject, yet though it sometimes claimed to be a theory, no theoretical basis for the principles it enunciated has ever been widely accepted. This may change if the problem is viewed in a Bayesian context. It is generally accepted that Gestalt principles are useful because they lead to the segregation of "object" from "ground", and in so far as they do so successfully, there must be a principle involved. Brunswik[3] probably came close to the answer with an argument based on statistical relations between parts of an image within a single object being different from statistical relations between parts within and outside an object. That there are such differences has been confirmed for luminance[4], but needs looking at for the other qualities where "similarity" causes segregation. If it holds up, then segregation is justified on Bayesian grounds, for given the statistics of natural images,

[1] Helmholtz, H.v. (1925). Physiological Optics. Volume III. The Theory of the Perceptions of vision (Translated from 3rd German Edition, 1910). Washington: Optical Society of America.

[2] Gregory, R.L. (1970). The intelligent eye. London: Wiedenfeld; Rock, I. (1983). The Logic of Perception. Cambridge, Mass: MIT Press.

[3] Brunswik, E. & Kamiya, J. (1953) Ecological cue-valididty of "proximity" and of other Gestalt factors. American Journal of Psychology, 66 20-32.

[4] Ruderman, D.L. (1997) Origins of scaling in natural images. Vision Research, 37 3385-3398.

similarity in the qualities defined by Gestaltists is a valid cue to those parts of the image that belong to the same object. Once this is understood, the Gestaltists may have useful tips with regard to the qualities useful for segmentation.

### *5.4 Designing machines that adapt and evolve*

Today designing machines that can develop new characteristics remains quite a challenge. While some impressive demonstrations have been made recently[1], the first elements of a solid theory still have limited scope. By looking at some theoretical aspects of maturation and growth at the level of motion control, the BIBA project will lead to a better understanding of the maturation process. It will provide theories that will help engineers to design machines and artefacts capable of smoothly adapting control schemes to new conditions, without any major redesign.

### *5.5 Understanding sensor use and selection*

Living organisms have developed a set of mechanisms for constantly measuring their own motion. In addition several other sensors are used to build the knowledge necessary to control movement and to correctly interpret information flow. For example the vestibular system or the joint and force sensors are solely dedicated to this task. Others like vision or the sense of touch have mutliple functions which can be set by selecting appropriate circuits. How does the selection of information take place? What process selects the fusion or the segmentation of information flow? What happens when these mechanisms are disturbed by environmental or pathological causes? These questions are state of the art questions. The BIBA project will provide new models to better answer them and provide the means to test them thoroughly on an artificially designed creature.

### *5.6 Probabilistic judgements in education, communication and human-computer interaction*

In an uncertain and substantially unpredictable world, Bayesian principles are needed to address the concepts of knowledge, communication and evidence in a rigorous and quantitative manner[2]. Thus, even the assessment of simple factual knowledge (say, that Haydn was born before Mozart) involves the communication of a subjective probabiity - everybody agrees that a lucky guess does not deserve as much credit as a confident correct answer, and that a confident error is far worse than acknowledged ignorance. A member of the BIBA group has introduced confidence assessment as an educational initiative, recognising that the ability to make reliable confidence judgements and handle them correctly is an important student skill[3]. In animals also, it can be evident from body language how confident the animal is in the outcome of an action - from speed of response, absence of hesitation, erectness of ears, and so forth. There is no reason not to extend this to robotic artefacts, once probabilistic logic is at the heart of behavioural control, endowing them with artificial "body language" to indicate confidence. This is an innovation that we believe will be taken immediately to confer life-like qualities on even simple artefacts, including the interfaces for day-to-day computer interactions, making it possible to interact with them and predict behaviour in a more satisfactory manner.

[1] Hod Lipson & Jordan B. Pollack (2000) Nature 40, 974-978
[2] Good IJ Probability and the weighing of evidence. Griffin, London. 1950.
[3] Gardner-Medwin AR (1995) ; Confidence assessment in the teaching of basic science ; Assoc. Learning Technol. J. 3:80-85

## 6. Community added value and contribution to EU policies

The probabilistic approach to perception, inference, learning and action is an emerging research area. Its application to artefact development and construction is even more recent. Consequently, the qualified research groups are sparse. **It is only at a European scale that a multidisciplinary consortium on this subject can be gathered**.

Cross fertilisation of different disciplines and transgression of academic frontiers are required conditions for important scientific and technological breakthrough. Consequently, EC policy is to encourage this kind of project especially in the FET program**. The BIBA's consortium is a model of interdisciplinarity**. It has been designed in order to use neurosciences and life sciences as the inspiration for information sciences and technology.

Another main objective of EC is the **improvement of human potential**. The project B IBA plans to hire 6 young PhD or post-doctorate students. Coming from different scientific fields, they will have to work together and with senior researchers as a trans-disciplinary team**. BIBA will be a unique experience for these 6 young interdisciplinary scientists**.

One of the deliverable of BIBA (WP5) is a flexible experimental mobile platform where a large variety of sensor and motor devices can be plugged to fit the needs of different experiments and to be capable of easy adaptation in different versions. We hope that others could use this platform for their own researches, experiments and developments either in life science or in information science. We also hope that this platform could be an encouragement for groups to repeat the work of others; reproducibility and falsification are two major requirement of sound scientific and technological progress. Finally, we hope that **this experimental platform will stimulate exchange between European researchers**.

# 7. Contribution to Community social objectives

The BIBA project will contribute to the social objectives of the Community with possible improvements concerning health, safety and work conditions.

Health:

- Helping the design of new methods, and also new theoretical ideas **of functional exploration of cognitive function deficits in neurological patients** and, more generally, of how the brain deals with multi-sensory information and space representation.
- Building **new sensory prosthesis** based on probabilistic reconstruction of sensory coherence.
- Development of **new adaptive tools for the disabled** as for instance:
  - Mobile chair control in either known or unknown environment.
  - Devices to help blind persons in navigating or grasping.

Safety:

- Improvement of models to be used for **predicting sensory disorientation** on car or plane simulators and in general improving the design of multi-sensory simulators.
- Development of new interactive systems in cars and trucks for **improving driving safety** (navigation aids, adaptive cruise control, driving alarms...).
- Development of new methods and algorithms to **detect and react to unexpected or dangerous situations**.

Work conditions:

- Providing models for simulation of **multi-sensory channel information processing in industrial devices involving man machines interaction**.
- Conceive **new types of robotic devices** both for navigation and for manipulation (for instance in hazardous environments).
- **Education and training programs for risk evaluation in working conditions**.

## 8. Economic development and S&T prospects

The essence of the BIBA project is to propose and evaluate a new paradigm for intelligence and cognition of sensory-motor systems either natural or artificial. It is clearly a very ambitious and very long-term project. It is very difficult to foresee the economic development and scientific prospects of this kind of project. However, it should be clear that in case of success we expect some major breakthrough on both the potential industrial applications and the scientific questions.

Bayesian computing may be applied to any problem where:
- All the needed information is not at hand;
- Part of the available information is uncertain;
- Only a partial comprehension of the problem has been reached;
- Some experiments or databases are available for "learning" about the considered problem.

These characteristics correspond to a potential huge market! Nowadays prototype Bayesian applications emerge all around the world in numerous fields: image, video, text and speech processing, sensor fusion, user and client profiling, CAD and tolerancing systems, process control, malfunction diagnosis, robotics, game programming, medical diagnosis and monitoring, data mining, financial decision, etc.

GRAVIR has some experiences in applying probabilistic reasoning in several of these fields: robotics (O. Lebeltel's PhD - 1999), CAD systems (K. Makhnacha's PhD - 1999), sensor fusion and integration (CarSense European project - pending), leg and knee prosthesis design (Research project with the German company Aesculap - pending) and game programming (Research project with the French company GETRIS - pending). A spin-off company will start in the coming month.

A few small innovative companies have been in the Bayesian business for the last few years, most with little success. Things started to change very lately as Bayesian applications began to spread around. Some of the forerunners suddenly turn out to be commercial and financial success stories (for instance Autonomy, a spin-off of Neurodynamics). Some big companies (for instance, Microsoft) posit Bayesian inference as one strategic option for future technical development.

We think that it could be only the very beginning of a new major evolution of computing: **probabilistic reasoning instead of logic and Bayesian computer instead of Turing machine**. The BIBA project and its partners hope to take an important part in these changes.

# 9. Workplan

## *9.1 General description*

The project is organised in workpackages. Each workpackage is divided in several tasks. For each task[1] there is one deliverable: a report, hardware prototype or working software, due at the end of the corresponding task.

The BIBA project has 6 workpackages:

- Workpackages 1,2,3 fulfil scientific objectives, along 3 axes of research and development:
    - WP 1: Neural basis of probabilistic inference.
    - WP 2: New probabilistic models and algorithms for perception and action.
    - WP 3: New probabilistic methodology for artefact conception and development.
- Workpackage 4 is technical, generating hardware devices, software tools and support.
- Workpackage 5 establishes and implements evaluation methodologies for the project.
- Workpackage 6 consists of the project management, dissemination and exploitation procedures.

Five milestones have been identified after 3 month, 6 month, 12 month, 30 month, and 48 month. Each of these milestones is the occasion to control the progression of the project, to furnish the deliverables and to discuss the next steps. These milestones are also the contractual points to insure the exchanges between the workpackages.

Workpackages 1, 2 and 3 are scientifically very inter-dependent, and it is a major objective to benefit from the cross-fertilisation and exchange of results and ideas from different approaches, with the common thread of probabilistic inference. Milestones 1 and 2 are specially dedicated to interdisciplinary mutual training and exchange and to the further detailed specification of the work to be done. Furthermore, we plan adequate funding for frequent interchange of personnel (up to a total of 12 person-months), workshop seminars and continuous e-mail consultation.

Workpackage 4 will provide three successive versions of an experimental control platform to the partners. The first (at T0+3) will be based on an existing mobile platform already available from EPFL. The others will be available at the 12 and 30 month milestones. Maintaining this schedule will clearly be important as workpackages 1, 2 and 3 will depend on this provision. The details of the timing of the different workpackages and tasks and their interdependencies are presented in the sequel.

[1] Except a few operational ones that correspond to services and do not require deliverables: tasks T21 -> T25

### *9.2 Workpackage list*

## Workpackage list

| Work-package No[1] | Workpackage title | Lead contractor No[2] | Person-months[3] | Start month[4] | End month[5] | | Deliverable No[6] |
|---|---|---|---|---|---|---|---|
| WP 1 | Neural basis of probabilistic inference | UCL | 105 | 0 | 48 | | 6, 14, 19, 20 |
| WP 2 | New probabilistic models and algorithms for perception and action | LPPA | 109 | 0 | 48 | | 7, 15, 21 |
| WP 3 | New probabilistic methodology and techniques for artefact conception and development | GRAVIR | 81 | 0 | 48 | | 8, 16, 22 |
| WP 4 | Technical support | EPFL | 92 | 0 | 48 | | 0, 2, 9, 12, 17 |
| WP 5 | Evaluation Methodology | LPPA | 11 | 0 | 48 | | 10, 23 |
| WP 6 | Management, dissemination and exploitation | GRAVIR | 48 | 0 | 48 | | 1, 3, 4, 5, 11, 13, 18, 24 |
| | | | | | | | |
| | | | | | | | |
| | TOTAL | | 446 | | | | |

Note: A difference may be observed between the workload in person-month appearing here and the one appearing in the CPF. This difference is due to non chargeable permanent personnel cost of the partners with an additional cost funding.

[1] Workpackage number: WP 1 – WP n.
[2] Number of the contractor leading the work in this workpackage.
[3] The total number of person-months allocated to each workpackage.
[4] Relative start date for the work in the specific workpackages, month 0 marking the start of the project, and all other start dates being relative to this start date.
[5] Relative end date, month 0 marking the start of the project, and all ends dates being relative to this start date.
[6] Deliverable number: Number for the deliverable(s)/result(s) mentioned in the workpackage: D1 - Dn.

Workpackage descriptions

### 9.2.1 Workpackage 1: **Neural basis of probabilistic inference**

Responsible: University College of London (UCL)

| **Workpackage number :** | 1 | **Start date or starting event:** | | | T0 | |
|---|---|---|---|---|---|---|
| **Participant name:** | GRAV | UCL | UCAM | LPPA | EPFL | MIT |
| **Person-months per participant:** | 8 | 60 | 3 | 16 | 2 | 16 |

**Objectives**

The objective of this line of the research is to identify ways in which nervous systems may (and indeed do) implement probabilistic inference. We shall construct well-defined models of how probabilities may be represented and manipulated at both cellular and systems levels, and test predictions about the underlying strategies with psychophysical measures and studies of regional brain activation.. We expect to improve our understanding of neural mechanisms and derive new ideas for the implementation of probabilistic inference in engineering systems.

**Description of work**

After a review stage, the work is structured in three parts:

1. Explore neural strategies for representing and manipulating probability & confidence.
2. Models, quantitative simulation, and comparison with robotics.
3. Psychophysical and fMRI investigation of human strategies

**Deliverables**

- D6 (Report – T0+12): State of the art on probabilistic models of neural computation and inference
- D14 (Report – T0+30): Theoretical analysis of strategies for neural manipulation of probabilities
- D19 (Report – T0+48): Results on neural models: application, development and testing
- D20 (Report – T0+48): Results of psychophysical and fMRI experiments

**Milestones[1] and expected result**

M1 (T0+3): 2 weeks mutual training school
M2 (T0+6): 1 week precise specification brain storming
M3 (T0+12): Deliverable 6
M4 (T0+30): Deliverable 14
M5 (T0+48): Deliverable 19 and deliverable 20

[1] Milestones are control points at which decisions are needed; for example concerning which of several technologies will be adopted as the basis for the next phase of the project.

### 9.2.2 Workpackage 2: **New probabilistic models and algorithms for perception and action**

Responsible: Laboratoire de la Physiologie de la Perception et de l'Action (LPPA)

| **Workpackage number :** | 2 | **Start date or starting event:** | | | T0 | |
|---|---|---|---|---|---|---|
| **Participant name:** | GRAV | UCL | UCAM | LPPA | EPFL | MIT |
| **Person-months per participant:** | 12 | 10 | 2 | 64 | 5 | 16 |

**Objectives**

The main goal of WP2 is to illustrate how probabilistic computation, and more specifically, Bayesian programming, may account for global behaviours of organisms in interaction with their environment. We will focus on specific questions concerning multi-sensory perception and motion control. We plan to develop new probabilistic models that explain the observed behaviours in human or animals and to implement them on autonomous artefacts.

**Description of work**

The work to be done is structured in four parts:

1. Studying visual-vestibular interactions in self motion perception and gaze stabilization
2. Studying perception of the depth structure of a complex visual scene
3. Exploring action-based versus sensory-based space representation
4. Proposing decision making strategies in visual-vestibular conflict during navigation

**Deliverables**

- D7 (Report – T0+12): State of the art on probabilistic models and algorithms for perception and action
- D15 (Report – T0+30): Quantitative simulations on sensor selection and integration and space representation and navigation
- D21 (Demonstrator – T0+48): Artefact implementation of sensor selection and integration and of space representation and navigation

**Milestones[1] and expected result**

M1 (T0+3): 2 weeks mutual training school
M2 (T0+6): 1 week precise specification brain storming
M3 (T0+12): Deliverable 7
M4 (T0+30): Deliverable 15
M5 (T0+48): Deliverable 21

[1] Milestones are control points at which decisions are needed; for example concerning which of several technologies will be adopted as the basis for the next phase of the project.

### 9.2.3 Workpackage 3: **New probabilistic methodology and techniques for artefact conception and development**

Responsible: GRAVIR (GRAV)

| **Workpackage number :** | 3 | **Start date or starting event:** | T0 | | | |
|---|---|---|---|---|---|---|
| **Participant name:** | GRAV | UCL | UCAM | LPPA | EPFL | MIT | |
| **Person-months per participant:** | 28 | 22 | 1 | 8 | 6 | 16 | |

**Objectives**

The objectives of this workpackage is to develop new methodologies for control of artefacts in the "real world" inspired by the way animals cope with uncertainty and probabilistic inference, through evolution, development, adaptation and learning. The results will be both a tool box to program and "trained" autonomous robots and a demonstrator of this new methodology.

**Description of work**

The work to be done is structured in four parts:

1. Bayesian *programming* tool box for autonomous robots and artefacts
2. Bayesian *training* of autonomous robots and artefacts
3. Bayesian *evolution* of autonomous robots and artefacts
4. Contraction theory as a guideline to develop complex robots and artefacts

**Deliverables**

- D8 (Report – T0+12): State of the art on probabilistic methodology and techniques for artefact conception and development
- D16 (Demonstrator – T0+30): First demonstrator of artefact development and experimentation
- D22 (Demonstrator – T0+48): Second demonstrator of artefact development and experimentation

**Milestones[1] and expected result**

M1 (T0+3): 2 weeks mutual training school
M2 (T0+6): 1 week precise specification brain storming
M3 (T0+12): Deliverable 8
M4 (T0+30): Deliverable 16
M5 (T0+48): Deliverable 22

[1] Milestones are control points at which decisions are needed; for example concerning which of several technologies will be adopted as the basis for the next phase of the project.

### 9.2.4 Workpackage 4: **Technical support**

Responsible: Ecole Polytechnique Fédérale de Lausanne (EPFL)

| **Workpackage number :** | 4 | **Start date or starting event:** | T0 | | | |
|---|---|---|---|---|---|---|
| **Participant name:** | GRAV | UCL | UCAM | LPPA | EPFL | MIT |
| **Person-months per participant:** | 48 | 0 | 0 | 0 | 44 | 0 |

**Objectives**

The objective of this workpackage is to provide the partners with the hardware devices, software tools and technical support necessary for their experiments

**Description of work**

We will build a mobile device that includes both its own energetic source and computer capabilities. It will hold a platform where a large variety of sensor and motor devices can be plugged to fit the needs of different experiments and to be capable of easy adaptation in different versions. The sensors of interest to the consortium are analogous to the visual, auditory, vestibular, proprioceptive, tactile and olfactory senses. Consequently, the platform will be equipped with light sensors, at least one orientable video camera, microphones, inertial devices, proximeters, odometers, pressure sensors, whiskers, and a simple chemical sensor. Effector devices will include motors for locomotion, orientation and adjustment of sensors, vocalisation for auditory warning and for indicating the device's intended actions to observers, and panels for indicating degrees of confidence (subjective probability) in the device's interpretation of its environment and for the appropriateness of its objectives.

Three different versions (V0, V1 & V2) of the experimental platform will be build.

**Deliverables**

- D0 (Prototype – T0+3): Available version of the robotic platform (V0)
- D2 (Report – T0+6): Specification of V1 - experimental platform
- D9 (Prototype – T0+12): Delivery of V1 - experimental platform
- D12 (Report – T0+18): Specification of V2 - experimental platform
- D17 (Prototype – T0+30): Delivery of V2 - experimental platform

**Milestones[1] and expected result**

M1 (T0+3): 2 weeks mutual training school + Deliverable 0
M2 (T0+6): 1 week precise specification brain storming + Deliverable 2
M3 (T0+12): Deliverable 9
(T0+18): Deliverable 12
M4 (T0+30): Deliverable 17

[1] Milestones are control points at which decisions are needed; for example concerning which of several technologies will be adopted as the basis for the next phase of the project.

### 9.2.5 Workpackage 5: **Evaluation Methodology**

Responsible: Laboratoire de la Physiologie de la Perception et de l'Action (LPPA)

| **Workpackage number :** | 5 | **Start date or starting event:** | | | T0 | |
|---|---|---|---|---|---|---|
| **Participant name:** | GRAV | UCL | UCAM | LPPA | EPFL | MIT |
| **Person-months per participant:** | 1 | 1 | 1 | 6 | 1 | 1 |

**Objectives**

This workpackage will define sound evaluation criteria and methodology, under 3 headings:

- Validity of the biological models and probabilistic interpretations of biological phenomena.
- Validity of the algorithms for implementation of probabilistic inference in artefact control.
- Impact of the project in generating qualitatively new life-like features in artefact behaviour.

Evaluation of the success of the cross-fertilisation of ideas about Bayesian thinking amongst our wide spread of backgrounds will largely stand or fall by the criteria set out above.

**Description of work**

The work is organised in 2 phases:

1. Specification and criticism of evaluation methodology
2. Implementation of the selected methodology and internal challenges

**Deliverables**

- D10 (Report – T0+12): Specification of an evaluation methodology
- D23 (Report – T0+48): Critics of the selected evaluation methodology and propositions to improve it

**Milestones[1] and expected result**

M1 (T0+3): 2 weeks mutual training school
M2 (T0+6): 1 week precise specification brain storming
M3 (T0+12): Deliverable 10
M4 (T0+30): none
M5 (T0+48): Deliverable 23

[1] Milestones are control points at which decisions are needed; for example concerning which of several technologies will be adopted as the basis for the next phase of the project.

### 9.2.6 Workpackage 6: **Management, dissemination and exploitation**

Responsible: GRAVIR (GRAV)

| **Workpackage number :** | 6 | **Start date or starting event:** | | | T0 | |
|---|---|---|---|---|---|---|
| **Participant name:** | GRAV | UCL | UCAM | LPPA | EPFL | MIT |
| **Person-months per participant:** | 36 | 3 | 1 | 3 | 3 | 2 |

**Objectives**

The objective of this workpackage is to ensure good management of the project and efficient dissemination and exploitation of results.

**Description of work**

The workpackage is organised in 4 tasks:

- Administrative and scientific management and relation with EC
- Information circulation and scientific exchange inside the consortium
- Information dissemination outside the consortium
- Experimental platform availability outside the consortium

**Deliverables**

- D1 (Report – T0+4): Short proceedings of the 2 weeks starting school
- D3 (Multimedia Material – T0+6): BIBA Multimedia Presentation Package (Web site – PowerPoint Presentations – CDROM – Commented bibliographical database - Version 1)
- D4 (Report – T0+6): Dissemination and use plan
- D5 (Report – T0+7): Short proceedings of the 1 week specification brain storming meeting
- D11 (Multimedia Material – T0+12): BIBA Multimedia Presentation Package (Web site – PowerPoint Presentations – CDROM – Commented bibliographical database - Version 2)
- D13 (Multimedia Material – T0+24): BIBA Multimedia Presentation Package (Web site – PowerPoint Presentations – CDROM - Version 3)
- D18 (Multimedia Material – T0+36): BIBA Multimedia Presentation Package (Web site – PowerPoint Presentations – CDROM - Version 4)
- D24 (Report – T0+48) Exploitation plans

**Milestones[1] and expected result**

M1 (T0+3): Organisation
(T0+4): Deliverable 1
M2 (T0+6): Organisation + Deliverable 3 and 4
(T0+7): Deliverable 5
M3 (T0+12): Organisation + Deliverable 11
(T0+24): Deliverable 13
M4 (T0+30): Organisation
(T0+36): Deliverable 18
M5 (T0+48): Organisation + Deliverable 24

[1] Milestones are control points at which decisions are needed; for example concerning which of several technologies will be adopted as the basis for the next phase of the project.

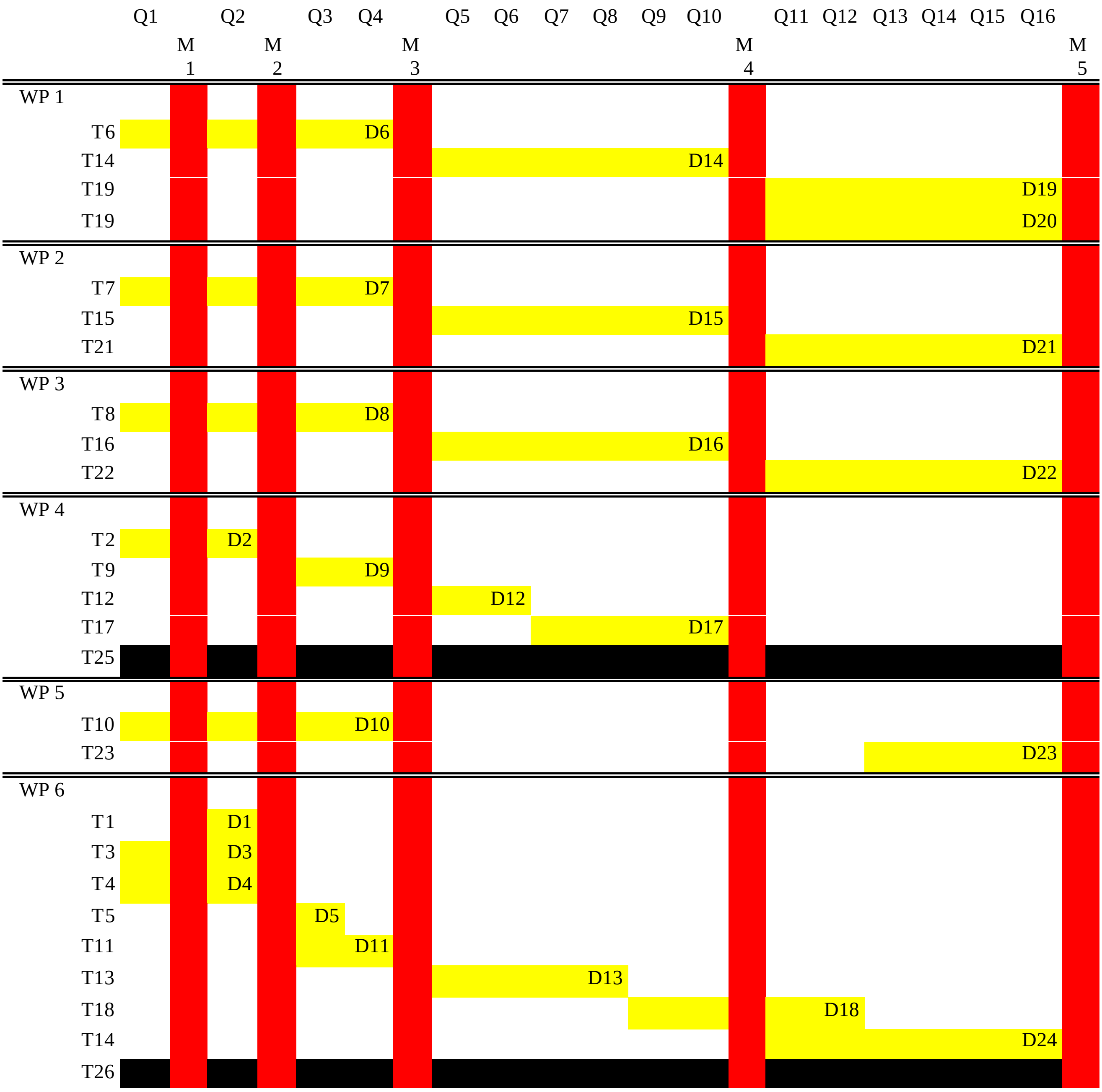
### *9.3 Deliverables list*

## Deliverables list

| Del. no. | Deliverable name | WP no. | Lead part. | Estimated person-months | Del. type* | Sec ur. | Month Due |
|---|---|---|---|---|---|---|---|
| 0 | Available version of the robotic platform (V0) | 4 | EPFL | 0 | Prototype | Pu | 3 |
| 1 | Short proceedings of the 2 weeks starting school | 6 | GRAV | 0,5 | Proceedings | Pu | 4 |
| 2 | Specification of V1 - experimental platform | 4 | EPFL | 16 | Report | Pu | 6 |
| 3 | BIBA Multimedia Presentation Package (Web site – PowerPoint Presentations – CDROM – Commented bibliographical database - Version 1) | 6 | GRAV | 4,5 | Multimedia Material | Pu | 6 |
| 4 | Dissemination and use plan | 6 | GRAV | 1 | Report | Pu | 6 |
| 5 | Short proceedings of the 1 week specification brain storming meeting | 6 | GRAV | 0,5 | Proceedings | Pu | 7 |
| 6 | State of the art on probabilistic models of neural computation and inference | 1 | UCL | 12 | Report | Pu | 12 |
| 7 | State of the art on probabilistic models and algorithms for perception and action | 2 | LPPA | 21 | Report | Pu | 12 |
| 8 | State of the art on probabilistic methodology and techniques for artefact conception and development | 3 | GRAV | 12 | Report | Pu | 12 |
| 9 | Delivery of V1 - experimental platform | 4 | EPFL | 16 | Prototype | Pu | 12 |
| 10 | Specification of an evaluation methodology | 5 | LPPA | 5,5 | Report | Pu | 12 |
| 11 | BIBA Multimedia Presentation Package (Web site – PowerPoint Presentations – CDROM - Commented bibliographical database - Version 2) | 6 | GRAV | 3,5 | Multimedia Material | Pu | 12 |
| 12 | Specification of V2 - experimental platform | 4 | EPFL | 16 | Report | Pu | 18 |
| 13 | BIBA Multimedia Presentation Package (Web site – PowerPoint Presentations – CDROM - Version 3) | 6 | GRAV | 4 | Multimedia Material | Pu | 24 |
| 14 | Theoretical analysis of strategies for neural manipulation of probabilities | 1 | UCL | 26 | Report | Pu | 30 |

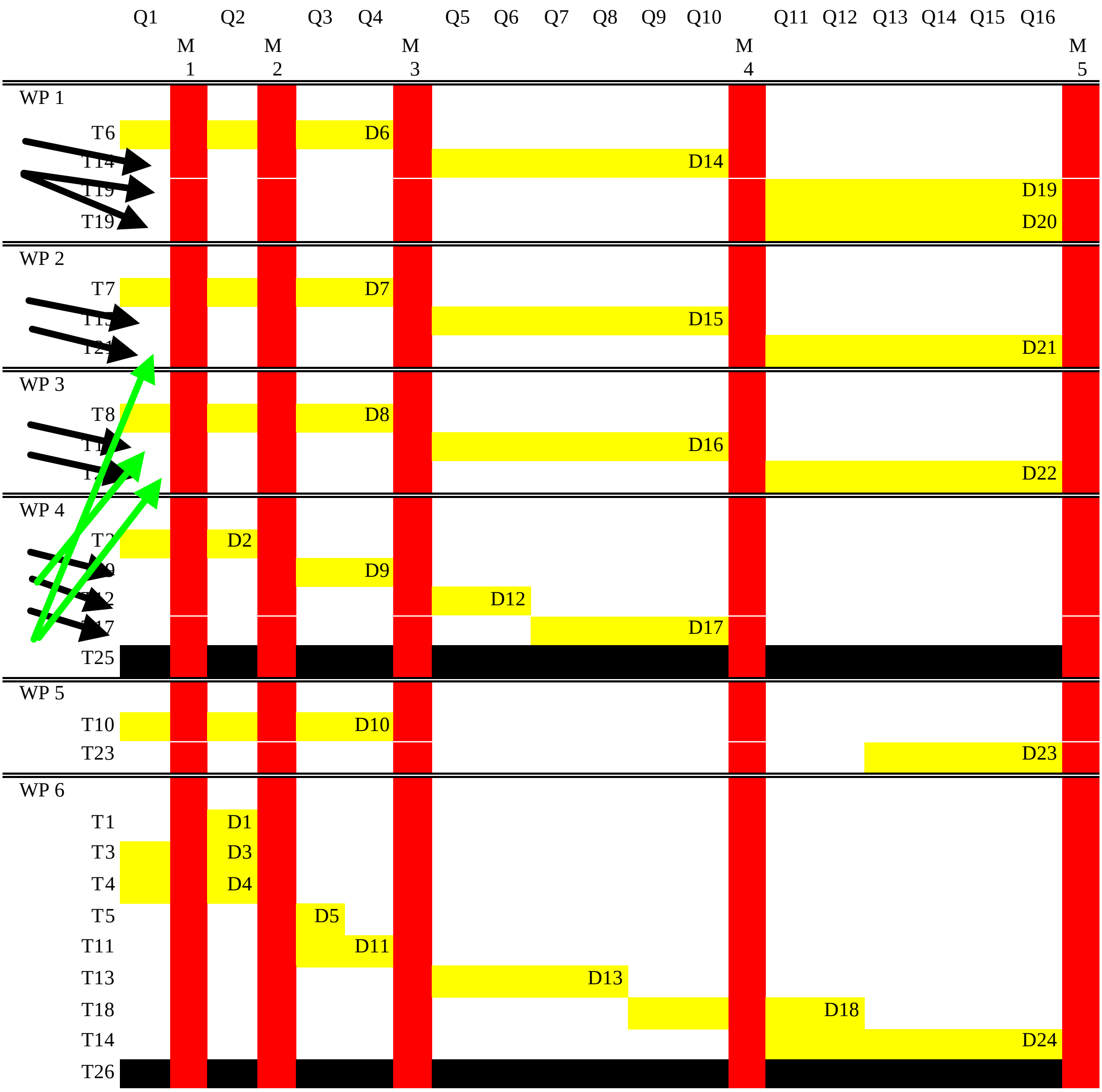
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 15 | Quantitative simulations on sensor selection and integration and space representation and navigation | 2 | LPPA | 40 | Report | Pu | 30 |
| 16 | Result of artefact development and experimentation | 3 | GRAV | 34 | Demonstrator | Pu | 30 |
| 17 | Delivery of V2 - experimental platform | 4 | EPFL | 44 | Prototype | Pu | 30 |
| 18 | BIBA Multimedia Presentation Package (Web site – PowerPoint Presentations – CDROM - Version 4) | 6 | GRAV | 4 | Multimedia Material | Pu | 36 |
| 19 | Results on neural models: application, development and testing | 1 | UCL | 40 | Report | Pu | 48 |
| 20 | Results of psychophysical and fMRI experiments | 1 | UCL | 27 | Report | Pu | 48 |
| 21 | Artefact implementation of sensor selection and integration and of space representation and navigation | 2 | LPPA | 48 | Demonstrator | Pu | 48 |
| 22 | Result of artefact development and experimentation | 3 | GRAV | 35 | Demonstrator | Pu | 48 |
| 23 | Critics of the selected evaluation methodology and propositions to improve it | 5 | LPPA | 5,5 | Report | Pu | 48 |
| 24 | Exploitation plans | 6 | GRAV | 3 | Report | Pu | 48 |

## *9.4 Project planning and timetable*




Qi stands for "Quarter i". For instance, Q3 is the third quarter or the period from T0+6 to T0+9.

### *9.5 Graphical presentation of projects components*



## *9.6 Project management*

### 9.6.1 Organization and management structure

The joint responsibility for all project activities and for the overall project strategy will be held by a **Project Management Committee** (PMC), composed of one voting representative from each partner. The representatives will be responsible for overseeing and allocating the resources of the project at each site, or their nominated deputies. The PMC member from each site will be responsible for the provision of cost and administrative information to the PMC. The main function of the PMC is to reach consensus decisions on both the strategic and the technical aspects of the project.

The PMC will be in charge of:

- Establishing the consortium agreement;
- Managing the project, in the sense of deciding on ranging options and reviewing or amending the program of work;
- Reviewing or amending the terms of the contract with the EC;
- Laying down procedures for project publications and press releases;
- Any particular action following unexpected difficulty with any of the participating partners.

An **Executive Manager** will be appointed by the coordinating partner for the daily management of the project. He will be responsible for:

- Organizing the PMC meetings and diffusing the minutes to all partners;
- Maintaining contact with EC and with the partners project leaders;
- Monitoring the interaction and the relative progress of the program among the partners, controlling this progress against the planned schedule and proposing to the PMC any actions and replannings necessary to reach the objectives of the project;
- Collecting, editing and sending to EC all the project deliverables and progress reports;
- Organizing the review meetings;
- Preparing cost statements and transmitting them to EC;
- Handling any financial matters with EC and the partners;
- Organizing information circulation and scientific exchange inside the consortium and specially for organizing the workshops, the bibliographical database and the electronic exchange.
- Organizing information dissemination outside the consortium and especially for the creation and maintenance of the BIBA Web site, for the production of the videos of the demonstrations, for the edition of the CD-ROM, for the organization of the tutorials and workshops and for the redaction of the exploitation plans.
- Promoting the use of the experimental robotics platform outside the consortium

For each work package one of the partner has been designated as **work package leader**. The workpackage leader will supervise and coordinate the work activities and will interact closely with the partners involved in the package. Each task has one **task leader** in charge of its advancement and of the issue of the deliverables. Each task has also one **task assessor** in charge of giving the consortium *imprimatur* to the deliverables.

### 9.6.2 Communication strategy and progress monitoring

The management structure reflects the work organization and the communications infra-structure is mainly based on scheduled meetings with a well structured agenda. The management board has given emphasis and attention to the problem of diffusion of all the project results within the individual partners' organizations.

### 9.6.3 Meetings

In order to establish a common information base and a cooperative effort on the project activities, both task level and general meetings have been planned.

Task level meetings will be held mostly among members of each work package and/or task according to a detailed pre-agreed work plan. The work package leader will chair them. The project executive manager who will be responsible for preparing and distributing the agenda and the minutes will organize them.

General meetings of the PMC will be held every six months or when necessary. The project executive manager who will be responsible for preparing and distributing the agenda and the minutes will organize them. Both technical and administrative issues will be discussed. If necessary, additional PMC meetings may be called by any partner. In order to reduce cost and save time simple decisions will be made by E-mail exchange or telephone meetings.

### 9.6.4 Progress reports

Periodic progress reports will be issued every twelve months. They will contain contributions from the administrative leader of each partner and from the work package leaders. They will describe the work done during the previous twelve month period by each partner and compare results with the scheduled program. They will also describe the work to be done during the next twelve month. These reports, together with an executive summary prepared by the project executive manager will form the basis of the yearly report to the EC.

## 10. Clustering

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

# 11. Other contractual conditions

### *11.1 Travel outside Europe*

The different partners budgeted different travel outside Europe. This travels will be used either to assist international conference or to visit our American partner in Boston.

The details of these travels are:
GRAVIR: 4 travels, 3000 Euros each
UCL: 2 travels, 2000 Euros each
UCAM: None
LPPA: 4 travels, 3050 Euros each
EPFL: n/a
MIT: n/a

### *11.2 Subcontractor*

BlueBotics is a swiss company appearing as a subcontractor of partner 7 for an amount of 52290 Euros.

BlueBotics is a spin-off company of EPFL (Swiss Federal Institute of Technology, Lausanne). Created early 2001 with the mission to develop and market service robotic solutions, this company produces both hardware and software for industrial and research applications. The core of the mission is not so much production of robots, but rather to provide complete hardware and software solutions.

Current developments concern a new platform of tour-guiding robot as well as a full set of robotics sensors and control modules that allow rapid prototyping of new robots as well as building mechatronics set-up for education purposes.

### *11.3 Other specific cost*

UCL (Partner 3) will have to pay subjects for fMRI experiments. This appears in the "Other significant project costs" table for an amount of 4 000 Euros.

EPFL (Partner 7) need a standard robotic platform appearing in the table "Other significant project costs" for an amount of 24 974 Euros.

## A. Consortium description

# The consortium

The consortium of the BIBA project is a unique gathering of expertise in very different scientific fields: **neuro-physiology, neuro-anatomy, neuro-psychology, mathematics, computer science, control, software and hardware engineering**.

Neurosciences and life sciences are represented by three outstanding institutions in the field:

- Department of physiology of **University College of London** (UCL-ARGM - A. Gardner-Medwin)
- Laboratory of physiology of **Cambridge University** (UCAM-DPOL - H. Barlow)
- Laboratoire de Physiologie de la Perception et de l'Action of **Collège de France** (LPPA - A. Berthoz and J. Droulez).

Information sciences and technologies are represented by three well-known institutions:

- Laboratoire GRAVIR of **INRIA** (Institut National de Recherche en Informatique et Automatique - E. Mazer and P. Bessière)
- **EPFL** (Ecole Polytechnique Fédérale de Lausane).
- Nonlinear Systems Laboratory of the **Massachusetts Institute of Technology** (MIT - J-J. Slotine)

Even if each of the partners has its own speciality, we all have in common two scientific concerns on one hand animal and "animat" cognition and, on the other hand, the probabilistic inference and learning paradigm. These shared scientific questions warrant the synergy of the work in the BIBA project. Furthermore, the partners have already a long experience of interdisciplinary research that is essential for this project.

Even if there are very strong and overlapped interactions between all the partners the role and responsibilities of every one has been clearly specified:

- UCL-ARGM is the leader of work package 1 on neural basis of probabilistic inference and collaborates closely with UCAM-DPOL on neural computation and with both UCAM-DPOL and LPPA on psychophysics.
- UCAM-DPOL collaborates with UCL-ARGM, LPPA, MIT and INRIA on several subjects. Horace Barlow will be a scientific advisor and inspirer for these tasks.
- LPPA is the leader of work package 2 on models and algorithms for perception and action. Concerning sensor selection and integration it collaborates mainly with UCL-ARGM and concerning space representation and navigation with MIT and INRIA.
- INRIA is the project leader. It is also the leader of work package 3 on new methodology and techniques for artefacts conception and development. This work package will integrate the results of all the other tasks in a robotics realization. Consequently all the partners collaborate with INRIA for this part of the work.
- EPFL is the leader of work package 4. It is in charge of the conception and realization of the hardware of the experimental mobile robotics platform. It collaborates very closely with INRIA who is in charge of the conception and realization of the Bayesian inference and learning software that will operate these robots.
- Due to the distance, MIT is not directly in charge of any tasks. MIT collaborates with UCAM-DPOL and UCL-ARGM on probabilistic models of the nervous systems, with LPPA on space representation and navigation and with INRIA on contraction theory.

# Description of the participants

Partner 1 and 2: INRIA - GRAVIR

*Description of the partner*

**INRIA** (National Institute for Research in Computer Science and Control) is a French public-sector scientific and technological institute operating under the dual authority of the Ministry of Research and the Ministry of Industry. INRIA's missions are "to undertake basic and applied research, to design experimental systems, to ensure technology and knowledge transfer, to organize international scientific exchanges, to carry out scientific assessments, and to contribute to standardization".

The research carried out at INRIA brings together experts from the fields of computer science and applied mathematics covering the following areas: Networks and Systems; Software Engineering and Symbolic Computing; Man-Machine Interaction; Image Processing, Data Management, Knowledge Systems; Simulation and Optimization of Complex Systems.

INRIA gathers in its premises around 2 100 persons including 1 600 scientists, many of which belong to partner organizations (CNRS, industrial labs, universities) and are assigned to work in common "projects". On INRIA's budget, around 500 full-time equivalent R&D positions can be accounted for.
A large number of INRIA senior researchers are involved in teaching and their PhD students (about 550) prepare their thesis within the different INRIA *research projects* (currently 74).

Its budget is roughly 90 MEuro, 20% of which comes from research and development contracts, royalties and sales. Industrial relations are strategic for INRIA:
*Industrial contracts and European Projects*

Numerous industrial partners contract with the Institute for collaborative research. They are French or foreign companies, of all sizes. 400 such contracts are presently active. Roughly 40% of these contracts are European funded ones. Since 1984, 250 European Framework-Programme (FP) projects have been executed.

*Technology companies*

as the ultimate step in technology transfer, researchers are party to the setting up of companies in order to implement their technology on the market. Thirty seven spin-off companies have been created since 1984. In 1999, INRIA has launched two subsidiaries to promote high-tech start-up companies: INRIA-TRANSFERT deals with early accompaniment of the future companies, whereas I-SOURCE GESTION provides for "seed-money".

INRIA is a member of ERCIM EEIG, European Research Consortium for Computer Science and Mathematics. Outside Europe, INRIA also has a significant activity: it has created joint research laboratories (Russia and China), signed cooperation agreements (NSF, India, Brazil, etc.) and promotes intensive scientific exchanges.

The LAPLACE research group works on two different scientific subject:

- **Probabilistic reasoning for perception, inference and action**
  - Basis of a probabilistic theory of sensori-motor cognitive systems (Bayesian models, Probabilistic inference, Maximum entropy principle).
  - Probabilistic inference engine.

  - Experiments with Khépéra mobile robot.
  - Specification of a programming environment for autonomous robots based on the probabilistic inference engine.
  - Methodological reflexion about the concepts of contingency, opportunism, unexpected and novelty.
- **Evolutionary algorithms for perception, inference and action**
  - A massively parallel genetic algorithm implemented on a 128 Transputers machine.
  - A genetic algorithm to place the processes of a parallel program on the processors of a massively parallel architecture.
  - The "Ariadne's clew" algorithm to search trajectories in high dimensional dynamic environments.
  - The control of a six degrees of freedom robotic arm with the Ariadne's clew algorithm in an environment where another six degrees of freedom arm is used as a moovingobstacle.
  - Several applications of genetic algorithms.
  - Evolutionary approach of the emergence of phonetic structures in languages.

*Key persons*

**Dr Emmanuel Mazer** (Born in 1953) is a senior researcher at CNRS since1982. He took a master in mathematics and his Phd (1989) in computer science from Grenoble University. He did a Post-Doctorate at the department of Artificial Intelligence of the University of Edinburgh. He is a co-founder of two industrial companies in Europe and one in the USA. He worked as a research fellow at the MIT AI lab for three years and he is a co-author of a book on automatic robot programming (Handey MIT press). Currently he leads with Pierre Bessiere the LAPLACE research group and works on the design of Bayesian inference engines and machines.

**Dr Pierre Bessière** (Born in 1958) is a senior researcher at CNRS (Centre National de la Recherche Scientifique) since 1992. He took his engineering degrees (1981) and his PhD (1983) in computer science from INPG (Institut National Polytechnique de Grenoble). He did a Post-Doctorate at SRI International (Stanford Research Institute) working on a project for NASA (National Aeronautics and Space Agency). He then worked for five years in an industrial company as the leader of different artificial intelligence projects. Since he came back to research in 1989, his main research concerns have been evolutionary algorithms and probabilistic reasoning for perception, inference and action. He leads with E. Mazer the LAPLACE research group (http://www-leibniz.imag.fr/LAPLACE) on these two subjects. Nine PhD and numerous international publications follow from the activity of this group during the last 8 years.

For this project INRIA - GRAVIR plans to hire:
- 1 PhD student or PostDoc research fellow with skills in robotics and cognitive science to work mainly on workpackage 3. He will be co-advised by LPPA.
- 1 engineer in computer science experienced in robotics and artificial intelligence to do the software development of work package 4.
- 1 executive manager for the project.

Partner 3: UCL - ARGM

*Description of the partner*

**University College London** is one of the top rated and highest income research universities in Britain. Particular relevant strengths in relation to this project are in:

- Cognitive Neuroscience (Institute of Cognitive Neuroscience, Director T. Shallice)
- Computational Neuroscience (Gatsby Unit, Director G. Hinton)
- Functional Imaging Laboratory (Chairman: R. Turner)
- Inst. Neurology & National Hospital for Neurology and Neurosurgery (Queen Square)
- Depts. Psychology (O. Braddick), Anatomy (C.Stern), Physiology (P.Mobbs), Pharmacology (D.Brown) all headed by neuroscientists.
- Statistics, Computer Science: strong expertise in Bayesian theory & neural network applications.

Strong seminar programmes, a wealth of visitors, and an active Graduate School promote efficient research interaction, and opportunities for discussion and consultation are close and easy. It is an ideal environment for this inter-disciplinary project. Educational research is also strong, including support for Dr. Gardner-Medwin's innovative, widely used and acclaimed introduction of Bayesian confidence judgements into student self-assessment (LAPT: www.ucl.ac.uk/~cusplap) & (2) below.

*Key person:*

GARDNER-MEDWIN, Anthony Robert

**Reader in Neurobiology,** Dept. Physiology, University College London (UCL), UK
**Born:** 27.6.1944, **Degrees:** BA (Physics) 1964, PhD (Physiology) 1968
**Appointments:** Univ. Demonstrator (Cambridge) '66, Lecturer in Physiology UCL '69 (Sen. Lect '85, Reader '91); RS European Exchange Fellow '71, Nuffield Foundation Research Fellow 1980
**Awards:** Prize Fellow (Trinity, Cambridge) '68-'71; Outstanding Teacher Award UCL '98
**Principal Experimental Research:** Visual pathway in the cat during sleep, Synaptic plasticity (hippocampal LTP), Cerebellar parallel fibre conduction, Potassium homeostasis in brain, Leão's Spreading Depression (SD) related to migraine, Magneto-encephalography, Magnetic resonance imaging (MRI) of SD and cell volume changes.
**Principal Theoretical Research:** Modifiable synapses, Auto-associative memory, Diffusion & tortuosity, Information processing in sleep, Efficient representation of events.
**Principal Recent Publications relevant to the Proposal.**

1. Gardner-Medwin AR & Kaul S '95 Possible mechanisms for reducing memory confusion during sleep. Behav. Brain Res. 69, 167-175

2. Gardner-Medwin AR '95 Confidence assessment in the teaching of basic science. Assoc. Learning Technol. J. 3:80-85

3. J.O'Shea, S.R.Williams, N.van Bruggen and A.R.Gardner-Medwin (2000) Apparent diffusion coefficient and MR relaxation during osmotic manipulation in isolated superfused turtle cerebellum. Magnetic Resonance in Medicine 44:427-432

4. Barlow H. & Gardner-Medwin A. '00 Localist representation can improve efficiency for detection and counting. *Behav.& Brain Sciences* 23:467-8

5. Gardner-Medwin, A.R. & Barlow, H.B. '01 The limits of counting accuracy in distributed neural representations. *Neural Computation 13:477-504*

6. Gardner-Medwin & Wren K Measurement of a lack of knowledge. In preparation.

UCL-ARGM plans to hire for the BIBA project a Research Fellow age 26-28 with PhD and research skills in some or all of: mathematics, neural computation, cognitive science. Mature enough scientific background to cope with diverse experimental and theoretical approaches, and working abroad.

Partner 4: UCAM - DPOL

*Description of the partner*

The **University of Cambridge** is one of the oldest in the world and is ranked first for science in the UK. Research Grants are among the highest, and its members have won over 60 Nobel Prizes.

The Physiology Department has a distinguished history in Neuroscience going back to Keith Lucas (all-or-none law in nerve and muscle), E D Adrian (recording from single sensory nerve fibres etc), Alan Hodgkin and Andrew Huxley (ionic theory of conduction in nerves etc). Current research in the department covers a wide range of topics including visual transduction (T Lamb), adaptation in photoreceptors (H R Matthews), cochlear transduction (A C Crawford), oculomotor physiology and motor control (R H S Carpenter), the visual system (D J Tolhurst) and hearing (I Winter).

Other groups and departments relevant for this project include the Inference Group at the Cavendish Laboratory (S Gull, J Skilling, D MacKay), the Computer Vision Group (R Cipolla) and Signal Processing Group (N G Kingsbury) in Engineering, and the Computer Laboratory (J Daugman).

*Key persons*

**HORACE BARLOW BA, MD, FRS**: Retired Royal Society Research Professor of Physiology at the University of Cambridge who has worked in Vision and Perception for 50 years. Contributed to the experimental discovery of bug-detectors and lateral inhibition in the frog retina, motion detection in the rabbit retina, and selectivity for stereo disparity in the cat cortex. As a theoretician, argued that exploiting the redundancy of natural stimuli is important for effective perception and cognition, and that measuring absolute statistical efficiencies is useful for defining the work involved. Recent work has been the experimental determination of the statistical efficiency of human observers detecting coherent motion in random dot kinematograms, and on the theoretical limits of counting accuracy in distributed neural representations.

UCAM-DPOL plans to hire for the BIBA project a Research Fellow skilled in both neuro-anatomy and Bayesian probabilistic models to work essentially on work package 1. He will be co-advised by INRIA.

Parnter 5 and 6: LPPA

*Description of the partner*

The Laboratory of Physiology of Perception (UMR9950 of **CNRS** and **College de France**) has about 10 staff researchers, 15 technicians, 20 post docs and PHD students and action is a multidisciplinary center devoted to one particular aspect of Cognitive Neurosciences: the study of the neural basis of perception and action in human and animals.
7 groups study this question at various levels of analysis and complexity

The main themes of the laboratory are the following:
- Brain mechanisms for the visual perception of 3 dimensional properties of objects and the role of motion cues in the perception of curvature, depths etc.. . These questions are studied by a group of psychophysicists, mathematicians using visual displays. But the group is also interested in the contribution of multisensory cues and active vision in 3D vision and has built movements systems. It also has studies on brain imaging for identification of the brain areas involved in 3D perception. The combination of mathematical models with psychophysics and a long lasting cooperation with robotic groups allows this group to be prepared to the cooperative effort of the project with excellent expertise.
- Brain mechanisms of navigation and multisensory integration for the perception of movement. This group uses virtual reality techniques and mobile robots to study the contribution of the vestibular system, vision and proprioceptive cues to the perception and memory of travelled paths in pace. It is composed of physiologists, psychophysicits, Mathematicians and Enginneers. Its expertise will be essential in the parts of the project involved in multisensory cue. It also has a long lasting cooperation with robotics groups and has participated in brain imaging studies.
- Brain mechanisms for the control of gaze. Several groups in the laboratory study the control of gaze either in humans or in animals (cat, monkey). The themes vary from a group of electrophysiologists studying the neural basis of orienting mechanisms and particularly the colliculus, to a group working on the contribution of the parietal cortex in the monkey to the control of gaze. Very sophisticated techniques of electrophysiology (such as intracellular recording in the alert animal) together with mathematical modelling of the neuronal networks involved are used by this group.
- Mechanisms of anticipation and prediction in motor tasks such as catching a ball, jumping, locomotion. These studies using video tracking methods associated with mathematical modelling and biomechanical studies are conducted both in the laboratory and in microgravity.

The laboratory has many cooperations with robotics groups and has already published with Pr Slotine in MIT on composite variables.
The Laboratory is also engaged in a EUROPEAN LAB with a group in the University of Rome. It has a strong link with several industrial groups involved in virtual reality or vision. It has a long record of European cooperation. Pr Berthoz has been the coordinator of an ESPRIT II consortium on multisenory control of movement and a BIOMED project on vestibular contribution to motion perception. It also has obtained Human Frontier projects on navigation, motor control, and multisensory fusion. It has therefore a great experience in International cooperation. It was recently evaluated by an International comittee whith a judgment of excellence. It has a large training experience of young people. Its publication record is of 122

papers in International Journals including 3 papers in Nature or Nature Neuroscience and 1 paper in Science in the last 4 years.

*Key persons:*

**Pr Alain Berthoz**, (born in 1939) is Professor at the College de France in Paris. He holds the chair of Physiology of Perception and Action. Trained as an Engineer in one of the Grandes Ecoles in France. He graduated in Psychology and Neurophysiology. Full time researcher in the Centre National de la Recherche Scientifique for twenty years he created the Laboratory of Physiology of Perception and Action specialised in the study of the neuronal mechanisms of multisensory integration, gaze control, posture and equilibrium and locomotion. In recent years his work has focussed on the neural basis of spatial memory and navigation in humans and rats. He has co-directed thesis on this topic with roboticians and has therefore experience in cooperation with roboticians.
He has more than 200 publications in International journals (recently one in Science and one in Nature Neuroscience on visual vestibular integration and sensory conflicts). He has extensive experience in cooperative work in European consortium (Coordinator of an ESPRIT project with 7 countries, of a BIOMED project). He is the co-Director of a European laboratory with Italy. Corresponding member of the French Academy of Sciences, and of the Belgium Royal Academy of Medicine he has recently received the Grand Prix of the French Academy of Sciences for his work on multisensory integration. He is author of a book published in 2000 by Harvard University Press (The brain's sense of movement).

**Jacques DROULEZ** (born in 1950) received an engineer training (Ecole Polytechnique, Paris), a medical training (Lariboisière - St Louis, Paris) and an Habilitation to supervise research. He has got a fellowship from the Centre National d'Etudes Spatiales (1978-1982). He is now Director of Research at the Centre National de la Recherche Scientifique. He is in charge of medical supervision for all experiments on Human Subjects at LPPA (Collège de France) and head of the research team « vision and motion ». His main research themes are the perception of 3D motion and objects, the theoretical study of models for multi-sensory interactions and adaptive motor control.

For this project LPPA plans to hire 2 young researchers with high-level mathematical background, good competence in computer programming, experienced or trained in either psychophysics or neurocomputation. One will be co-advised with UCL-ARGM and the other with INRIA.

Partner 7: EPFL

*Description of the partner*

The Swiss Federal Institute of Technology Lausanne (EPFL) is one of the two federal technical Universities in Switzerland. With its 200 Professors, 2000 researchers and over 4700 students it is the second largest research center for engineering sciences of Switzerland.

The 'Institut de Systèmes Robotiques' (ISR) at EPFL is part of the Department of Microengineering at EPFL. Its research focus is on autonomous robots, parallel robots and micro-robots that find their applications in industry, space, medicine, service, education and micro-manufacturing.
The Institute (ISR) has a staff of 3 professors, 1 assistant professor, around 5 post-doctoral researchers, 5 technicians, 20 project engineers and around 25 PhD students.
The 'Institut de Systèmes Robotiques' has a lot of *industrial collaborations* and links. Currently around 20 projects with industrial partners are running e.g. in the field of micro-manufacturing, high precision robotics, mobile robots for inspection and teleoperation. Partners are ABB (parallel robots), NOVARTIS (micro-robots), SEGATE (hard disc drives), Astrium (space rovers), LEICA (optical assembly), ESEC (chip assembly), AGIE (micro-robotics), SYSMELEC (micro-robotics), K-TEAM (mobile robots) and other smaller companies. The Institute is also involved in various space rover projects with ESA. Recently three spin-off companies where founded to commercialize the research results.
The Autonomous Systems Lab[1] led by Professor Roland Siegwart is part of the ISR and focuses on mobile robotics and human-robot interaction. Important contributions have recently been made in the following main fields:
Probabilistic mobile robot localization and map-building by fusing different sensor signals: We are combining feature-based metric navigation (Kalman filter) with topological navigation using a Bayesian approach. This results in very compact maps with reliable global localization and map-building. Due to the compactness of our environment representation we reach update rates for the position estimation of over 10 Hz.
New mobile robot locomotion concepts for rough terrain: In the context of different ESA projects we developed very innovative wheeled locomotion concepts that allow robots to overcome obstacles as high as twice the wheel diameter. The innovative robots are currently used for research in outdoor navigation based on stereo vision.
Human-robot interaction with mobile robots: Just recently we started a large research project in the field of personal robotics. Different tools and hardware for human-robot interaction like face detection and tracking, speech communication and gesture generation have already been established. In a next step, enhanced human-robot interaction will be developed with the help of Hidden Markov Models. The benchmark of this project is to install around 10 mobile personal robots at an exhibition in 2002.
Highly integrated mobile micro robots weighting only a couple grams: Through a consequent application of scaling laws and new technologies a series of mobile robots sizing less than 2x2x2 cm have been developed. These fully autonomous mobile robots are equipped with basic behaviors (obstacle avoidance, follow wall ..) and are used for experiment in collective robotics and map-building. The acquired competence enabled us also to realize and deliver a first prototype of a micro rover for planetary exploration to ESA. The robot weighs only 50 g including an on-board CCD camera.

[1] http://dmtwww.epfl.ch/isr/asl

Robots for research and education: Mobile robots are an excellent tool for hands-on engineering education. We therefore developed various mobile robot platforms and plug-and-play sensor and actuator modules for education. They are used for robot competitions but also within our research projects.
Throughout the large variety of research project in the field of mobile robotics the lab has established a high competence in design and navigation of mobile platforms. Over 20 different types of mobile robots have been developed and realized in the last years. Most of our robots are used on a daily base in research and education. The acquired competence in mobile robot design and navigation motivated us to found the spin-off company BlueBotics[1]. The primary objective of this newly founded company is to commercialize our existing and future mobile robot platforms and to open the market for mobile robot applications.

*Key Persons*

**Roland Siegwart** (born in 1959) is a full professor at EPFL. He received his M.Sc. ME in 1983 and his Doctoral degree in 1989 at the Swiss Federal Institute of Technology (ETH) Zurich. After his Ph.D. studies he spent one year as a postdoc at Stanford University where he was involved in micro-robots and tactile gripping. From 1991 to 1996 he worked part time as R&D director at MECOS Traxler AG and as a lecturer and deputy head at the Institute of Robotics, ETH. During this time he was mainly involved in magnetic bearings, mechatronics and micro-robotics. In 1997 he became a full professor at the Swiss Federal Institute of Technology, Lausanne (EPFL) where he establish a research lab for Autonomous Systems and Robots. His current research interests are robotics and mechatronics, namely high precision navigation, network base robotics (Internet, space exploration), human-robot interaction, all terrain locomotion and micro-robotics. He lectures various courses in robotics, mechatronics and smart product design at the two Swiss Federal Institutes of Technology and is cofounder of several spin-off companies. Roland Siegwart published more than 60 papers and is member of various scientific committees. He is the Swiss delegate for the International Federation of Robotics (IFR), member of the Advisory board for the European Robotics Network (EURON), Swiss representative for Automation and Robotics (AGAR) at ESA and general chair of the 2002 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS'2002).

**Francesco Mondada** (born in 1967) has a MSc in Microengineering and a PhD from the Swiss Federal Institute of Technology (EPFL). Co-funder of K-Team, he is one of the three main developers of the Khepera robot and associated tools, considered as a standard in evolutionary robotics and used by more than 400 universities and research centers worldwide. He participated in the development of several mobile robot platforms as mobile robotics group leader at EPFL and as director of K-Team. Through his collaboration with several researchers abroad, he has developed a solid experience in mobile robotics system design and biologically-inspired control.

[1] http://www.bluebotics.com

Partner 8: MIT - NSL

*Description of the partner*

The **Massachusetts Institute of Technology** is generally considered as the premier Technological University in the world. It counts more than 80 Nobel laureates among its current or former faculty and alumni.

The Nonlinear Systems Laboratory studies general mathematical principles of nonlinear system stability, adaptation, and learning, and how they apply to robots and to models of biological control. The lab is particularly interested in how stability and performance constraints shape system architecture, representation, and algorithms in robots, and in whether similar constraints may in some cases lead to similar mechanisms in biological systems. Tools from nonlinear control such as sliding variables, wave variables, and contraction theory also suggest a number of simple models of physiological motor control, which may help understand the specific roles of hierarchies, motor primitives, and nerve transmission delays. Current projects include:

- Fast motion-vision coordination in robots; robotic catching of free-flying objects.
- Models of the cerebellum and stability of biological feedback loops under nerve transmission delays.
- Adaptive multiresolution approximation networks for real-time control and prediction.
- Stable control using motion primitives; performance of combinations of local and centralized control mechanisms.
- Entrainment models in mechanical and biological systems.
- Nonlinear observer design techniques for real-time brain imaging.

*Key persons*

**Jean-Jacques E. Slotine** was born in Paris, France in 1959. He received his Ph.D. from the Massachusetts Institute of Technology in 1983. He is currently Professor of Mechanical Engineering and Information Science, Professor of Brain and Cognitive Sciences, and Director of the Nonlinear Systems Laboratory at M.I.T. His research interests include applied nonlinear control, robotics, learning systems, and applied nonlinear control. He is the co-author of the textbooks "Robot Analysis and Control" (Wiley, 1986) and "Applied Nonlinear Control" (Prentice-Hall, 1991), and an Associate Editor of several professional journals. He has held Visiting Professor Positions at Ecole polytechnique and College de France, and is a member of the French National Science Council.