Robot Companions for Citizens

more than machines

The Robot Companions for Citizens MANIFESTO

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The Robot Companions for Citizens consortium **robotcompanions.eu** July 2012

EUROPE NEEDS NEW HELP

There is little doubt that Europe is one of the best places to live.

Democracy, advanced economies, social inclusion and quality of life are ingredients of a welfare much of the rest of the world looks up to.

However, the future of our welfare is far from ensured.

Just look around, listen to conversations, watch television, read newspapers: it is not difficult to see Europe's most pressing problems. We have big sovereign debts, weak economic growth, low competitiveness, outsourcing of production, low job creation, and little in the way of natural resources.
Above all, we face a significant demographic shift: the next 50 years, those 65 or over will increase their share in the EU-27 population from 17.4 % to 30.0%.

Understanding what are our most widespread aspirations is just as easy.

We want more economic opportunities, especially for the young, an independent and fulfilling life, especially for older people, and greater respect of our shared environment.

We call this mismatch between our problems and our aspirations the challenge of sustainable welfare.

One of the key factors of Europe's success – together with institutions, values, human capital, and political and economic freedom – is science-based technology.

Indeed, Europe has historically founded its wealth and social progress on its pre-eminence in a wide range of technologies, especially machines.

However, the current challenge of sustainable welfare mirrors the limitations of today's machines.

We envision they could help where very cheap labour is needed, hence reversing the massive outsourcing of industrial productions, including the many good jobs that go with them.

We envision they could help make significant productivity gains in sectors such as personal and health care, infrastructure construction and maintenance, and services, hence decreasing debts, and boosting economic growth.

We envision they could help older or disabled people in their everyday lives, and help those, in health care.

We envision they could consume small amounts of energy and other natural resources.

We envision they could help start new, disruptive industries, the ones that grow rapidly, bring wealth and good jobs, and provide a competitive advantage in the long run.

With sustainable growth, our aspirations would no longer be at risk.

Therefore we envision of a whole new class of machines to overcome the limitations of today's machines, new machines based on a whole new science.

A NEW ROBOTICS IS THE ANSWER

Robotics is one of the few strategic technologies that can both restore and maintain the competitiveness of key European industries and provide solutions for many of Europe's societal challenges.

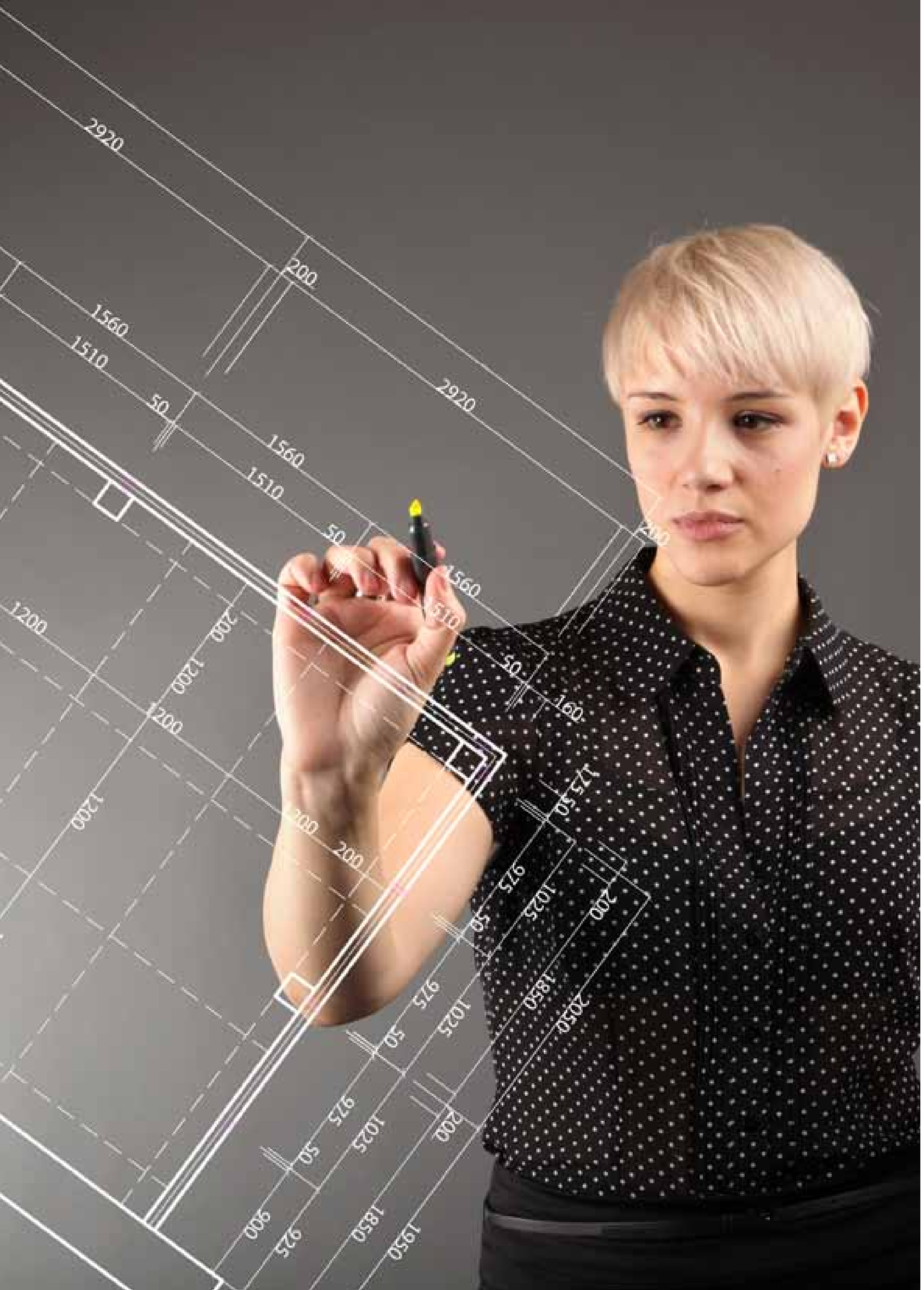
Indeed, the large-scale introduction of robots in society is already happening. Lawn-mowing and vacuum-cleaning robots are in our homes. Industrial robots manufacture our cars. Surgical robots operate in our hospitals. Un-manned submarines repair our oil rigs.

However, incremental innovation in today's robotics, though important in the short and medium term, is unlikely to address Europe's long term concerns. There are a number of reasons for this, but two stand out as fundamental, intrinsic limitations.

The first one is that current robots are unable to operate in real world conditions. Today we can find self-driving metros or trains, but their rails are a striking symbol of the limitations of current robotic systems – no existing robot or autonomous system is capable of operating without sharp boundaries that delimit its role and protect it from harming humans, the environment or itself.

The second is that for a traditionally engineered system, operating in complex real world conditions would result in high demands for energy, computation and storage. At the same time, controlling it would become almost impossible. The reason is that today's robots are mechatronic modular systems, that is, sums of components. Advances in functionality imply an insurmountable increase in system complexity in terms of its degrees of freedom, joints, sensors, computation, communication, energy, human-machine interfaces, etc. Thus small functional advances will incrementally contribute to a gradual loss of controllability and robustness, and this will ultimately lead to a substantial cost in efficiency and safety.

We call this the "robotics bottleneck".



The mission of RCC is to address Europe's challenges by laying the scientific and technological foundations of a new future robotics. What RCC envisions is a new class of machines and embodied information technologies that are affordable, sustainable and dependable.

This requires a fundamental rethinking of how we conceptualize and construct robots and introduce them into society.

Major technological revolutions are driven by the discovery and mastery of natural phenomena. In order to build machines that can overcome the robotics bottleneck we need a radically new robotics paradigm. RCC's unique paradigm to reach this goal is based on a fundamental reorientation grounded in our understanding of the most versatile "machines" we know—living beings. This new approach sees the construction of advanced machines as RCs as a direct extension of basic science, closing an understanding–generation loop that has so far been relatively unexplored in our science and engineering. The mission of the Robot Companions for Citizens initiative is to address Europe's challenges by laying the scientific and technological foundations of this new science-grounded future robotics discipline that will develop and deploy RCs.

A SCIENCE-GROUNDED ROBOTICS

RCC proposes that in order to answer the challenge of sustainable welfare and overcome the robotics bottleneck, we need to endow robots with new technologies provided by reverse engineering fundamental design principles underlying natural bodies and brains. On the basis of this fundamental insight the RCC proposes to realize a revolutionary new generation of robots based on a cross-domain grand scientific challenge:

"To unveil the natural principles of simplexity, morphological computation and sentience and to translate the resultant scientific knowledge into design principles and fabrication technologies for Robot Companions that effectively and safely act, interact and adapt to their physical and social environment."

NATURAL DESIGN PRINCIPLES UNDERLYING BODIES AND BRAINS

Conservation of core principles is a fundamental law of evolution. Indeed, our human body plan inherits many common principles from our early ancestors. Through evolution, nature has generated principles that together have given rise to all single-celled and multi-cellular organisms including the basic body plans for all extant animal phyla that emerged during the Cambrian explosion over 500 million years ago. In seeking to identify fundamental biological design principles of bodies and brains and to exploit these to engineer new robot technologies, RCC is proposing something novel that is far removed from the naïve use of biological metaphors. By investigating suitable biological examples, and "reverse engineering" their core principles, RCC will create robots that share with animals the ability to deal with complex tasks in a versatile and robust manner based on the same set of underlying principles.

RCC AS A NEW ENGINE FOR SCIENCE AND TECHNOLOGY CHANGE

To answer its grand challenge and achieve its ambitious scientific and technological goals, RCC will mobilize a densely federated interdisciplinary effort that combines a unique amalgamation of concepts, methods and technologies creating a new science and engineering of sentient machines. This RCC Science and Technology programme is radically novel in proposing an integrated and plausible paradigm for focused large-scale multi-disciplinary interaction and is structured around **five Pillars** following a biologically grounded "unity of science" heuristics: **Matter (Multifunctional Nanomaterials and Energy), Body (Morphological Computation), Brain (Simplexity), Mind (Sentience)** and **Society Society (Impacts and Ethics)**. RCC will therefore create a powerful and constructive dialogue between material scientists, engineers, mathematicians, roboticists, physicists, biologists, neuroscientists, psychologists, social scientists, philosophers and ethicists.

This will amount to a contemporary Renaissance aimed at understanding ourselves and, in doing so, creating embodied ICT solutions and tools enabling sustainable welfare. This RCC programme will have a significant impact on the scientific understanding of living systems and the engineering of artificial ones because it both facilitates coherent interaction across domains and creates a new and extremely powerful **"discovery engine"**. This force for scientific advancement is formed through a positive feedback loop between basic science and engineering, where understanding something becomes the basis for modelling it, and these models bring about a better capacity to understand that very same phenomenon. Conversely this unique paradigm is simultaneously a powerful **"technology development engine"** that inevitably leads to disruptive innovations as our understanding of the natural principles underlying sentience are advanced.

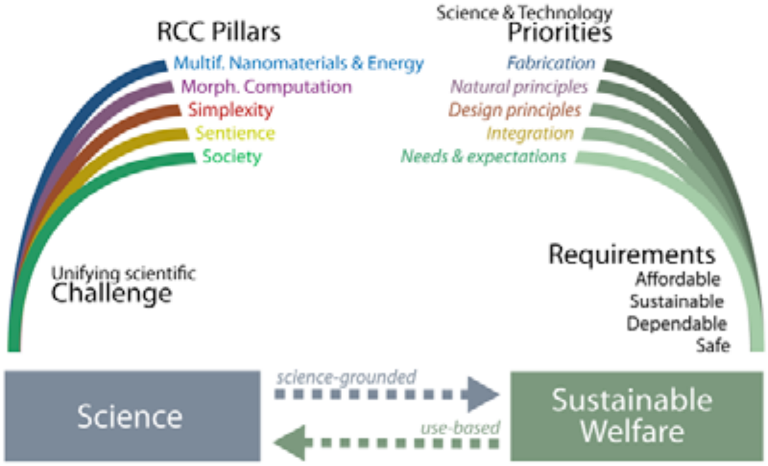
The five RCC pillars span the study of matter, body and brain, to mind and society. They provide an integrated framework to drive interaction between all disciplines required to answer the overarching RCC challenge. Within each pillar a specific focus will drive the science and technology of RCC: Multifunctional Nanomaterials and Energy, Morphological Computation, Simplexity, Sentience, and Society.

THE RCC CONVERGENT SCIENCE PARADIGM

In its design, RCC exploits the synergy resulting from the convergence of past and future advances in life science, in particular neuroscience, and engineering, in particular robotics. These are both domains in which Europe has made important investments and has gained pre-eminence, but that have never met before at a scale sufficient to boost both fields and give rise to a discipline concerned with the science and engineering of a new generation of robots.

FROM A NEW SCIENCE TO A NEW TECHNOLOGY

RCC is a science-grounded but use-based project. It combines a well defined quest for fundamental understanding with a clear vision on how this quest will in turn create novel and transformative technologies and how these technologies will be of benefit to society.
This fulfils the definition of "use-inspired basic research" that is exemplified by the work of Louis Pasteur and is the defining characteristic of the FET programme. But, more importantly, by defining a clear bridge between basic science, technology and society, a unique goal-oriented synergy can be realized that warrants a flagship-scale ambition and investment by Europe (see figure below).
RCC has a clear objective and an innovative research methodology to match, based on a constant interplay between society and basic science and engineering along with their associated fields.
The structured-yet-open research methodology that RCC follows facilitates the creation and assimilation of surprises resulting from breakthroughs in the research programme where science and technology advance in synchrony in the service of society.



The RCC bridge maps the scientific vision and its implementation into concrete innovation and engineering objectives that will be driven by societal requirements.

THE FIVE PILLARS UNDERLYING THE RCC S&T PROGAMME

The RCC programme is structured around five science and technology pillars:

- **Multifunctional Nanomaterials & Energy**
- **Morphological Computation**
- **Simplexity**
- **Sentience**
- **Society**

The pillars determine which scientific and technological milestones the project will pursue, and provide a conceptual and organisational framework. The pillars also shape all of the project activities, including the design and implementation of the RC platforms and demonstrators.

MULTIFUNCTIONAL NANOMATERIALS & ENERGY: LEARNING HOW TO BUILD A NEW CLASS OF MACHINES

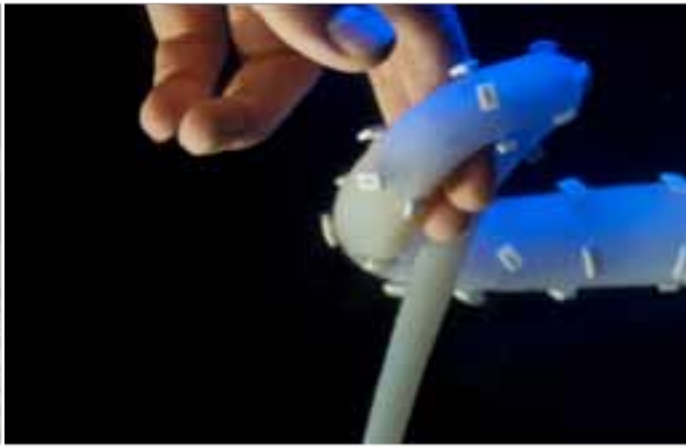
Evolution has optimized the bodies of organisms and their control strategies to the point where animals can perform complex tasks with minimum energy use whilst being highly versatile and robust. Artificial systems will need to be based on a new family of dedicated hardware and materials in order to reach a similar level of efficiency.

RCC will explore a new biologically-based paradigm based on design simplification, functional integration and sentience that will require new multi-functional micro- and nano-fabricated materials for sensing, actuation, computation, communication, energy, exo- and endoskeletons and power storage and more. The goal is to building RCs with less components, higher robustness, higher compliance, lower computational load, higher energy efficiency, higher adaptability, higher dependability and ultimately a lower cost.

The revolutionary integrated knowledge base offered by the Simplexity, Morphological Computation and Sentience pillars, defined below, will both drive and capitalize on the new class of materials and fabrication technologies that will be realized through the Multifunctional Nanomaterials & Energy pillar. This will lead to an unprecedented wide and parallel development program that will generate the interlinked biomimetic technologies required to realize RCs.

MORPHOLOGICAL COMPUTATION: OUTSOURCING COMPUTATION TO THE BODY AND THE ENVIRONMENT

Natural systems rely on **morphological computation**, a concept that has emerged from the study of the role of the body in regulating behaviour. Multidisciplinary research spanning biology and engineering increasingly demonstrates that **the clear separation between control (the brain) and the to-be-controlled (the body)** - a separation that has been the foundation of mechatronics, robotics and artificial intelligence - can no longer be maintained.

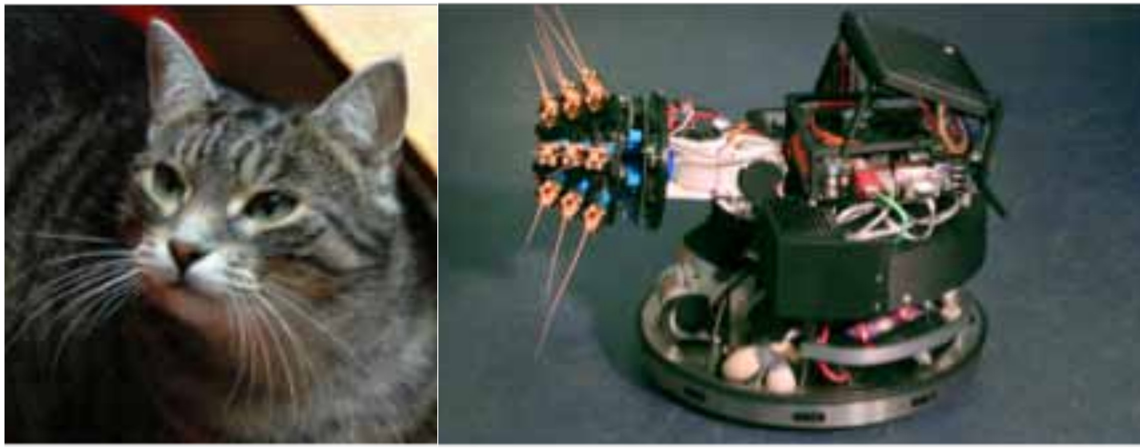


The emerging paradigm of morphological computation and softness help the animal solve most of its control problems. It also relies of radically different principles for control.

In living organisms, brain and bodies co-evolved with the environment and as a result there is a distribution of labour between the brain, the body and the environment itself, which constantly interact and influence each other. When applied to robotics, morphological computation is a genuine paradigm shift. It implies exploiting morphological and material characteristics such as a material deformability or elasticity in order to "outsource" computational tasks. This strategy will bring about a dramatic reduction of control complexity, a simplification of construction, and an overall gain in efficiency, thus overcoming the robotics bottleneck. This is also called soft robotics. In a similar fashion the morphology of the nervous system itself provides a substrate for computation as does the morphology of the environment. Thus the notion of Morphological Computation promises to have spectacular consequences for our understanding of living systems and the design of RCs endowing them with robust, smooth and energy-efficient behaviour. Moreover, it directly illustrates how fundamental sciences such as biology and neuroscience can have transformative impacts on engineering.

SIMPLEXITY: THE SEARCH FOR ELEGANT SOLUTIONS IN A COMPLEX WORLD

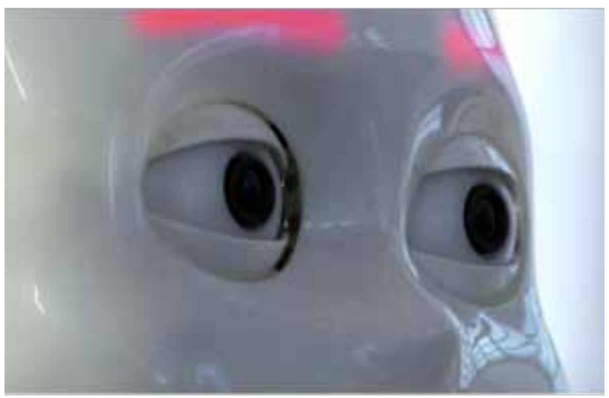
Evolution has found solutions that allow organisms to rapidly and efficiently perform complex tasks in a complex world. These simplifying principles are not trivial or even simple: they are simplex. **Simplexity is what enables living organisms to deal with complex information and situations relying on redundancy, anticipation, emotion, prediction and action.** These solutions are found in the brain and have been conserved in evolutionary history. The Simplexity Pillar of RCC will explore the natural principles of simplexity through experimental and mathematical means and use them to define the control principles that will drive the artificial brains of RCs. In particular, it will investigate simplexity along 5 axes: Simplexity and Brain, Simplexity and Geometry, Simplexity and Sensory-Motor Synergies, Simplexity and Action Modeling, Simplexity and Probabilities.
Simplexity implies a multi-scale approach to understanding adaptive behaviour in complex systems that will build on existing methodologies in the behavioural and brain sciences and that recognises that simplifying principles can be discovered at many different levels of abstraction.
The RCC approach thus contrasts strongly with reductionist views that favour, in the case of biological intelligence, the primacy of explanations at the level of brain micro-circuitry or lower. It is notable that such approaches have not so far generated any truly scalable or transferable (to AI systems) theories of brain architecture. In contrast, RCC proposes an approach that, in common with modern systems biology, recognises the importance of interactions between elements in a complex system in generating higher-level system properties that can form a useful basis for causative explanatory theories. The principle of Simplexity, as it will be applied in RCC, is that by reproducing these high-level properties in the control systems of robots, we can discover the simplifying strategies for adaptive behaviour that have evolved in biological organisms, and that can feasibly be transferred to synthetic systems faced with similar challenges.



Simplexity explores the natural principles of bodies and brains through experimental and mathematical means in order to define the control principles that will be driving the artificial brains of RCs.

SENTIENCE: INTEGRATING PERCEPTION, COGNITION AND ACTION

In order to assist humans, and to interact, physically, socially and safely with them, Robot Companions need to be sentient.
Sentience is a property of natural systems that allows them to effectively interact with their physical and social environments.
Sentience is the ability to integrate perception, cognition and action in one coherent scene and context in which action can be interpreted, planned, generated and communicated. The Sentience pillar thus integrates the conceptual and technical components provided by the Simplexity and Morphological Computation pillars and transforms them into a functional whole that can be physically realized in RCs. Its goal is two-fold—to create a natural science of Sentience, and to deliver a Sentience architecture.
Just as the overall RCC programme is designed to drive a revolutionary paradigm shift overcoming the robotics bottleneck, the integrative approach to sentience is intended to drive neuroscience and associated fields beyond their modular tendencies, thuspromoting a radically new investigation of mind, brain and behaviour.
Through developing sentience, RCs will have increased awareness of themselves, their environments, and of others. In particular, sentience will enable RCs to be cognizant of, reason about, and respond appropriately to, the needs of people.

In order to effectively assist humans and interact, physically, socially and safely with them, Robot Companions need to be sentient.

SOCIETY: INVOLVING ALL STAKEHOLDERS IN AN OPEN SCIENCE MODEL

A 21st century view of science and technology must recognise that they are not isolated from society and politics. RCC will significantly impact upon society, thus we have to consider its technological, psychological, social, ethical and legal implications. Whilst engaging with a diverse range of experts and stakeholders, the project will implement an open science strategy involving a continuous dialogue with the European public that will allow both an ongoing critical evaluation of the social and cultural impacts of RCC and a preparation of European society for the sustainable welfare that RCC is realizing.

This pillar will elaborate ethical, legal and societal frameworks for the RCC research programme, without limiting its scope. The benefits and costs of new technologies can be unpredictable and the risk is to get distracted by problems that remain hypothetical whilst missing out on the real challenges that society faces. Hence the need for a deep social and ethical examination of emerging RCC science and technology that is embedded in our core RTD strategy (rather than making pronouncements in advance or adding it as a social veneer after the fact). The Society pillar will investigate societal needs in order to identify solutions based on a human-centred design approach. RCC will also follow a controlled experimental approach were we will closely monitor how RCC technology is introduced and adopted, ready to act swiftly and effectively when problems arise and to consider all possible solutions including rethinking whether specific technology forms are needed or useful.

The Society Pillar is also the umbrella for introducing substantial innovations in education and training, including new undergraduate and graduate academic programmes that will create a new generation of RC scientists and engineers who are steeped in the broad range of disciplines and skills addressed by the RCC programme. This pillar will also create and maintain strategic links with industry enabling the development of new ICT-based markets and labour opportunities. There are significant legal issues that need to be addressed if RCs are to be deployed in European society including in our personal and public spaces.

The Society pillar will investigate societal needs in order to identify solutions based on a human-centred design approach and embed a deep social and ethical examination of emerging RCC science and technology within our research methodology.

The RCC Flagship will take a proactive approach to ensure that scenario regulatory frameworks are elaborated together with deployable RCC platforms and their use cases. Indeed, in the past, it has often been the lack of regulation that has prevented the deployment of potentially relevant technologies and services. The Society pillar will thus maintain a constant dialogue with policy makers and other stakeholders, to create the proper frameworks for RCs' safe action and integration into European public and private environments.

RCC AS A NEW ENGINE FOR SCIENCE AND TECHNOLOGY CHANGE

To test our scientific hypotheses and to demonstrate the effectiveness of our technologies, RCC will develop experimental platforms of Robot Companions at multiple scales of morphology, simplexity and sentience.

These in turn will drive the delivery of a selective set of deployment platforms, tuned to the needs of identified user groups, that will be delivered during the ten years of the project and beyond. These deployment platforms will include:

- **HealthCompanion**
- **ExploreCompanion**
- **WearableCompanion**
- **WorkCompanion**

They will range from assistive systems for our homes—useful to all but of particular benefit to older or disabled citizens, to robust platforms for operation in harsh and dangerous environments that can perform tasks such as search-and-rescue and disaster recovery.
In the long term, the new technologies underlying these platforms will be combined into the full-scaled RCC demonstrator, the **Universal Companion**, which will embody, integrate, and exemplify all the major breakthroughs incorporated in the use-case specific platforms.

At the end of the initial phase of the project, an assessment based on the preliminary results from the Simplexity, Morphological computation, Multifunctional Nanomaterials and Sentience pillars will be matched with the stakeholders' expectations from the Society pillar in order to identify appropriate metrics against which to measure the project progress.
We envisage the following scenarios:

- **Robot rescuer: the robot hero that can search for and rescue people in debris or other natural or man-made disaster areas;**

- **Robot housekeeper: a home cleaner that relieves human beings by taking care of many home chores;**
- **Robot co-worker: robot tools helping workers in industrial plants , construction, etc.;**
- **Microrobots for scarless surgery: a class of intracorporeal robots for medical intervention, medical diagnosis or organ repair, substitution and functional regeneration, completely deployed inside the body;**
- **Robot suit: a wearable robot providing support to movements and daily activities.**

The process of developing RCC experimental and deployment platforms will give rise to a plethora of novel methods and technologies grounded in an innovative multi-disciplinary basic research program. These RCC technologies have a large potential social and economic transformative power comparable to the introduction of the steam engine, the telephone, the automobile, the radio, the personal computer, or more recently, the Internet and the mobile phone. This disruptive impact will promote new industries and opportunities for worldwide commercial exploitation. Most importantly it will provide Europe with leadership in a range of fields focused around, but not limited to, automation and robotics. Further, this will facilitate the exploitation of other opportunities for new forms of advanced ICT technology, through science, technology and industrial communities actively linked to RCC.

Unlike robots of the past, which tended to be autonomous machines relying on their own computational capabilities, RCs will be immersed and integrated in the new ICT environment (the “Cloud”) that becoming a ubiquitous common interface for all kinds of technologies and applications.

IMPACT

The potential impacts of the RCC Flagship are extremely broad. We envisage impacts in many spheres of human existence—private, social, economic, urban and physical. RCCs will have a major impact in personal and social spheres as our assistants. This development of RCs will be focused towards general categories of social needs in the wider population and in particular the key social need of an ageing society and sustainable welfare. In the commercial sphere, the economies of Europe are challenged due to the high cost of manufacturing. Across the world, industrialised countries – especially in Asia – are investing in next generation robot technologies to make factories more efficient. Europe needs to be proactive in its science and technology development in order to maintain a position as a leader in this area. RCC technologies will have transformative impacts in a range of settings that are currently inaccessible to robots. For instance, we expect increased efficiency in our agriculture increased productivity in sectors such as personal health care, or infrastructure construction and maintenance, that are fast becoming too costly relative to manufacturing or information services improvements in resource harvesting and conservation of the natural world and changes to our emergency services that will make them safer, faster, and more effective.

By investing in RCC, Europe will therefore enables a serial disruption in a number of industries that will allow it to leapfrog competition in Asia and America, thus helping ensure a new sustainable welfare for European society *in the long run*. RCC thus fits perfectly with Horizon 2020’s objectives for an “Innovation Union”—excellent science, competitive industries, and a better society.

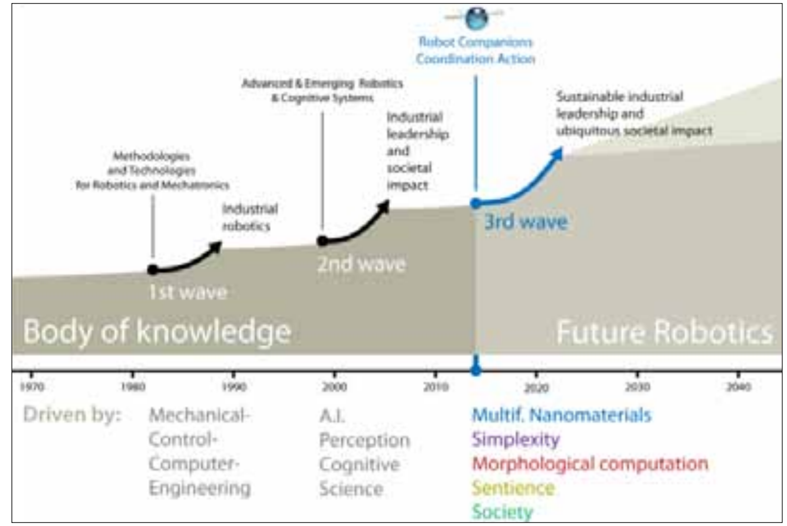
PROJECT GOVERNANCE

Driven by its vision of sustainable welfare through sentient machines, RCC will involve pertinent stakeholders in science and technology, society, finance, politics and industry. To realize its goal, and in order to place Europe at the forefront of future robotics, RCC envisions a Flagship as an incubator of advanced science and engineering involving thousands of researchers. RCC will have the structure of an international holding where resources will be allocated in a competitive fashion to the best ideas, that is, to the ones that can contribute most to answering the RCC grand challenge.

This distributed research effort will require an equally exceptional effort in project governance. A fundamental question for projects on this scale concerns the incentives for the communities involved to collectively delivery on their promises. Governance in the RCC project will therefore be built on four solid cornerstones:

- **science-driven governance grounded on the unifying scientific challenge;**
- **our explicit science and technology pillars;**
- **an uncompromising commitment to scientific excellence;**
- **an insistence that, in order to attain ambitious goals, nobody can be above scrutiny.**

RCC WILL PUT EUROPE IN A WORLD LEADING POSITION



The three waves of robotics science and innovation.

To summarise, robotic technologies provide an important component for answering societal challenges. Europe is in an excellent position to capitalize on the knowledge and skills resulting from investments made, as well as extrapolating from that base towards the future. Indeed, today's European leadership builds on a scientific foundation established in the past. Robotics **first wave**, developed in the 1970s and 1980s, emerged from computer science, control engineering and mechanical engineering, and has given us the methods and technologies of mechatronics. The **second wave**, which is giving us advanced, future and emerging robotics for industrial leadership, is based on biomimetics, perception, cognitive science and artificial intelligence.

The next wave, that will start around 2020, will be based on RCCs five scientific pillars and will deliver sustainable welfare, industrial leadership and ubiquitous scientific impact through a new generation of robots, Robot Companions for Citizens, that will be grounded in our understanding of nature and ourselves.

RCC COORDINATOR
Paolo Dario

PRINCIPAL INVESTIGATORS:

SIMPLEXITY
Jean-Paul Laumond, Tamar Flash, Henry Kennedy, Antonio Bicchi

MORPHOLOGICAL COMPUTATION
Rolf Pfeifer, Cecilia Laschi, Dario Floreano

SENTIENCE
Paul Verschure, Anil Seth, Giulio Tononi

MULTIFUNCTIONAL NANOMATERIALS AND ENERGY
Roberto Cingolani, Constantinos Soutis, Pietro Perlo, Xenophon Verikyos

SOCIETY
Paolo Dario, Eugenio Guglielmelli, Jon Agirre Ibarbia

BODYWARE AND ACTUATION
AlinAlbu-Schaeffer, Nikos Tsagarakis, Carlos Balaguer, Danilo De Rossi

SENSING
Vincent Hayward, Janwei Zhang, José Santos-Victor

SYSTEM AND CONTROL FUNDAMENTALS OF BIOMECHANICS AND ROBOTICS
Stefano Stramigioli, Jean-Pierre Merlet

SENSORI-MOTOR COORDINATION
Tony Prescott, Maria Chiara Carrozza, Etienne Burdet

ADAPTATION
Angelo Cangelosi, Cyriel Pennartz, Pierre Yves Oudeyer

PHYSICAL INSTANTIATION OF THE RC NERVOUS SYSTEM
Andreas Andreou, Tim Pearce

NEURONAL BASIS OF SIMPLEXITY, MORPHOLOGICAL COMPUTATION AND SENTIENCE
Pieter Roelfsema, Giacomo Rizzolatti, Ehud Ahissar

PSYCHOLOGICAL CORE PROCESSES
Andreas Engel, Hector Geffner, Kevin O'Regan

INTERACTION AND COMMUNICATION
Chris Melhuish, Giulio Sandini, Peter Dominey, Stephen C. Levinson

HUMAN RC CO-EXISTENCE, ETHICS, LAW
Vanessa Evers, Madeleine De Cock Buning

HEALTHCOMPANION
Arianna Menciassi, Brad Nelson, Moshe Shoham, Philippe Cinquin

EXPLORECOMPANION
Auke Ijspeert, Maarja Kruusma, Barbara Mazzolai, Annibal Ollero

WEARABLECOMPANION
Tamim Asfour, Yann Perrot

WORKCOMPANION
Gordon Cheng, Rachid Alami, Alberto Sanfeliu, Norbert Krüger

UNIVERSALCOMPANION
Giorgio Metta, Christoph Borst

Website
www.robotcompanions.eu

Contact
secretariat@robotcompanions.eu