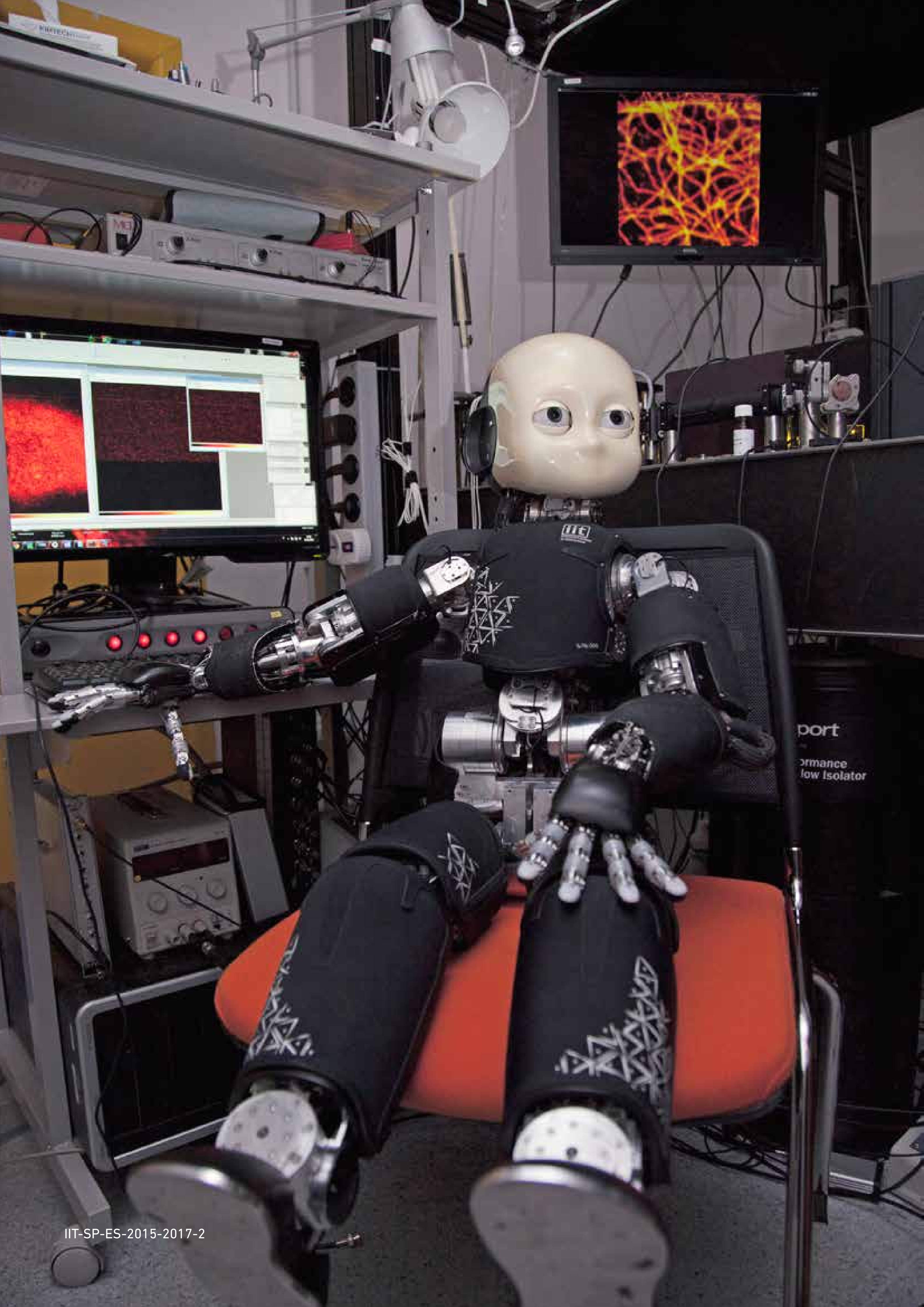
ISTITUTO ITALIANO DI TECNOLOGIA

2015-2017 STRATEGIC PLAN

EXECUTIVE SUMMARY



IIT-SP-ES-2015-2017-2

THE STRATEGIC PLAN 2015-2017

EXECUTIVE SUMMARY

ACRONYMS

DEPARTMENTS OF THE CENTRAL RESEARCH LABORATORIES, GENOVA-MOREGO:

- ADVR: Advanced Robotics
- D3: Drug Discovery and Development, including:
- D3-Compunet: Computational/Modelling lab of D3
- D3-Validation: Validation lab of D3
- D3-PharmaChemistry: Transversal facility of D3
- iCub Facility: facility for the R&D of ICub
- NACH: Nanochemistry
- NAPH: Nanophysics
- NBT: Neuroscience and Brain Technologies
  - NBT-NTECH: Neuro Technologies Labs of NBT
  - NBT-NSYN: Synaptic Neuroscience Labs of NBT
- PAVIS: Pattern Analysis & Computer Vision
- RBCS: Robotics, Brain and Cognitive Sciences

CENTERS OF THE NETWORK:

- CNCS@UniTn: Center for Neuroscience and Cognitive Sciences, University of Trento, TRENTO
- CGS@SEMM: Center for Genomic Science, IFOM-IEO Campus, MILAN
- CNST@PoliMi: Center for Nano Science and Technology, Milan Polytechnic, MILAN
- CSHR@PoliTo: Center for Space Human Robotics, Turin Polytechnic, TURIN
- BCMSC@UniPr: Brain Center for Motor and Social Cognition, University of Parma, PARMA
- CMBR@SSSA: Center for MicroBioRobotics, Scuola Superiore Sant'Anna, PONTEDERA-PISA
- CNI@NEST: Center for Nanotechnology Innovation, Scuola Normale Superiore, PISA
- CLNS@LASAPIENZA: Center for Life Nano Science, University of Rome La Sapienza, ROME
- CABHC@CRIB: Center for Advanced Biomaterials for Health Care, University of Naples Federico II, NAPLES
- CBN@UniLe: Center for Biomolecular Nanotechnologies, University of Salento, LECCE
- IIT@MIT: outstation of IIT at MIT, Boston, on Machine Learning
- IIT@Harvard: outstation of IIT at Harvard University, Neurobiology Department, on novel nanotech probes for brain study

THE PILLARS OF THE STRATEGIC PLAN 2015-2017

The IIT strategy for the forthcoming years has the twofold target of consolidating the international reputation of the Institute in its specific cross-disciplinary research areas, and accelerating the production and transfer of technology and intellectual property to industries, within Italy and worldwide. To this aim the research activity will be focused on 11 key programs, which include consolidation of the work done so far, exploration of a few new high-risk/high-return initiatives, technology transfer and creation of new enterprises. The organization of the Institute, following the recent launch of the Tenure Track program, which creates independent research teams within all Departments and Centers, will evolve toward a matrix organization.

The description of the strategic plan will start with a brief summary of the present situation, followed by a discussion of scientific strategy - specifically, of the 11 key programs - and of the key actions needed in recruiting, logistics and technology transfer, to further enhance the IIT international standing as a leading research and technology institution worldwide.

The detailed description of the scientific programs is provided in the Technical Annex 1

THE BACKGROUND: OVERVIEW OF IIT IN 2014

IIT is a research Institute with the twofold mission of performing cutting edge research and transferring technology to the industrial system.

The Governance of the Institute is that of a Private Foundation funded by the State. The decision-making structure is similar to that of a holding, and it consists of an Executive Committee, in charge of the operative management, a Board of Trustees, constituted by managers and intellectuals, and a Technical and Scientific Committee constituted by internationally acknowledged scientists.

The activity of IIT started at the end of 2005, with the construction of the central research laboratories in Morego-Genova. The start-up phase was planned to last 36 months, to set up the 30,000 sqm facility and to hire approximately 450 staff (including scientists, administrators and technicians). In 2009, with the central research lab up and running, IIT launched the network of IIT laboratories in Italy and abroad.

In 2014, IIT has more than 1250 people, 11 laboratories in Italy (with more than 45,000 sqm) and 2 small outstations in the USA (see Figure 1). 44% of the staff comes from abroad, with more than 50 different nationalities (one-third of the staff coming from abroad are Italians returning to Italy and two-thirds are foreigners). The average age of the IIT staff is less than 34 years, with a gender distribution of 41% women and 59% men. The staff is strongly cross-disciplinary, with 17 different PhD specializations.

The scientific activity developed in the frame of the previous strategic plans (2009-2011) and (2012-2014) was organized in 7 broad research platforms: Robotics, Energy, Materials, Environment Health and Safety, Brain and Cognition, Drug Discovery Development and Diagnostics, Computation. The 10 centers of the IIT network in Italy, the 2 USA outstations and the 8 Departments operating at the Central Research Laboratory contributed to the development of the research platforms in a collaborative way, under the supervision of the Department and Center Directors. This generated more than 4000 publications in the international data bases, 250 patents and 8 new companies (start up) up to the first semester of 2014, with a global portfolio of external grants (since 2006) of approximately 100 millions Euros.

Fig.1 IIT Departments, Centers and Labs in the world

In the second half of 2013 IIT launched its Tenure Track program for the recruiting of new independent principal investigators according to best international standards. In view of the launch of the new strategic plan 2015-2017, several new laboratories led by new tenure-track researchers or by internationally acknowledged senior leaders were started with independent budgets at the central research Lab in Genova and in some centers:

NANOPHYSICS DEPARTMENT

- Graphene Lab, connected to the EU-FET Flagship on Graphene (1 new tenure track and 1 new technologist recruited)
- NanoCarbon Materials Lab (1 new tenure track recruited)
- Nanostructure Lab (ERC consolidator grant on Nanoplasmonics, 1 new tenure track recruited)

NANOCHEMISTRY DEPARTMENT

- Li-Batteries lab (1 senior scientist recruited)
- Nanoparticles Transformation Lab (ERC consolidator grant)

D3 DEPARTMENT

- Intelligent Drug Delivery Lab (ERC Consolidator grant on Intelligent Drug Delivery, 1 new tenure track recruited)
- ComputationNetwork (several new senior scientists involved from Italy, France and Switzerland)

NBT DEPARTMENT

- Molecular Biology Lab (1 new senior scientist recruited)

These new laboratories bring new junior and senior forces into the IIT leadership, giving strong impulse to the growth of IIT.
In addition, some new joint initiatives have been launched with national and international industries and public institutions:

NANOPHYSICS DEPARTMENT

- IIT-Nikon Imaging center (NIC@IIT), ajoint lab with Nikon
- IIT-Directa Plus SpA, a joint lab for new Graphene-based ink jet printing

D3 DEPARTMENT

- Pharma-Chemistry Facility (matching fund by a medical foundation)

NBT DEPARTMENT

- Neurophisiology lab (NSYN@Unige), a new lab of neuroscience in the University Hospital of Genova

ALL ROBOTICS DEPARTMENTS

- INAIL-IIT joint Robotic Rehabilitation Lab (26 new scientists/engineers recruited)

THE NEW PROGRAMS OF IIT AND THE MATRIX ORGANIZATION

The unique interdisciplinary character of IIT, as well as the concerted effort to merge curiosity-driven research, applied research, and technology transfer has led to exceptional growth of IIT in the short period since its commissioning, both in size and in international reputation. Consolidating the best research areas, increasing the international standing, and boosting technology transfer are the grand challenges of IIT for the next years. To this aim, the strategic plan 2015-2017 proposes a number of important actions:

- The scientific activity of the Institute will be focused on 11 main programs synergistically developed by the different Departments and Centers of IIT. The programs derive from the previous 7 broad research platforms, and make clear priorities about highly strategic topics with strong societal and industrial impact and very high scientific relevance and novelty. Each program consists of several mainstream research lines to be developed by different cross-disciplinary teams.
- The introduction of the tenure-track system results in the constitution of research teams operating in different departments and centers coordinated by independent principal investigators (P.I.s). This results in a matrix organization, in which each program is developed by teams belonging to different departments/centers, led by PIs with strong complementary knowhow. The future strategy of IIT therefore relies on the high quality international recruiting program of outstanding new P.I.s. from all over the world.
- Each program has a steering committee in charge of monitoring the scientific progress, and of communicating with the department and center coordinators to ensure maximum efficiency and cross-disciplinarity. The global evolution of the strategic plan will be carefully monitored by periodic meetings of the steering committees of the different programs, grouping them according to specific tasks and objectives (e.g., power sources for robots, in vivo experiments for intelligent drug delivery, design of new material properties, etc.).
- Three strategic areas of development are specifically identified: Logistic expansion (to support the fast growth of IIT), Technology Transfer (to boost the start-up program and the valorization of the intellectual property of IIT) , and International Visiting Scientist/Joint Chairs programs to attract talented scientists to IIT, in collaboration with universities and other research centers.

As depicted in Fig.2, the 11 programs of the plan can be classified into three categories

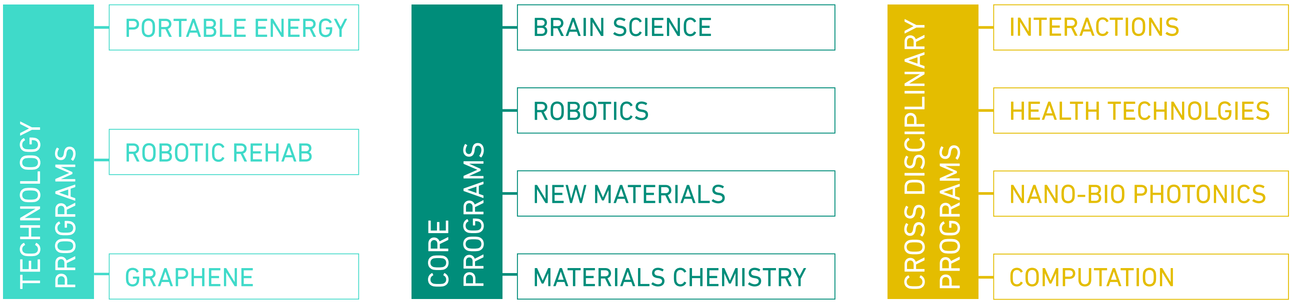
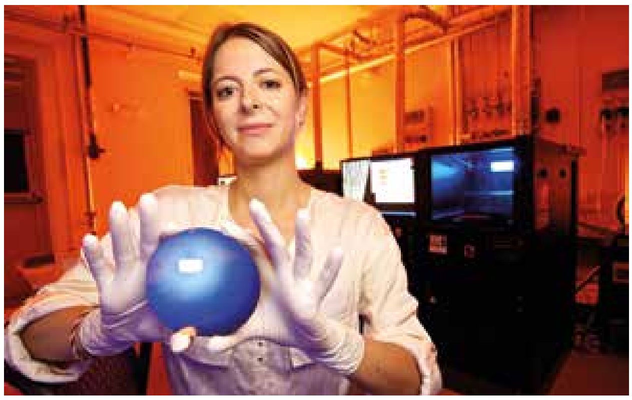


Fig.2 Graphic representation of the three classes of programs constituting the strategic plan 2015-2017

CORE PROGRAMS

Materials Chemistry, New Materials, Robotics and Brain Science trace back to the initial research platforms of IIT and ensure continuity with the previous plan (2012-2014). The core programs rely on the internationally acknowledged expertise of IIT in the fields of nanotechnology, robotics and brain science and maintain a strong curiosity-driven character. The Materials Chemistry program is dedicated to the development of new nanoparticles of atomically controlled shape, size and composition, to be used almost universally in new nanocomposite materials, catalysis, diagnostics, medicine and optoelectronics. Notably, a new ERC consolidator grant started in 2014 is dedicated to colloidal nanocrystals. The New Materials program deals with the synthesis and functionalization of multi-responsive materials, with special focus on green and natural materials. With applications in responsive polymers, environmental protection and biocompatible materials, this program is highly strategic for society and industry. The Robotics program deals with the development of a state-of-the-art robotic eco-system including plantoids, animaloids and humanoids, merging biomechanics, mechatronics, material science, cognition and artificial intelligence in a unique blend. The Brain Science program deals with the study of brain, either at molecular level to understand biological mechanisms, or at the system level to understand how the entire brain operates. Great efforts will be dedicated to learning, behavior and cognition, which are fundamental issues for developing intelligent robots. The four core programs are strictly interconnected and have benefited from mutual interaction and collaboration since the very beginning of IIT. Nanocomponents produced by the Chemistry platform enable the development of new responsive polymers which can be used in flexible robots, whose cognitive and intelligent behavior is inspired by the human brain. The robot thus becomes the technology arena where other disciplines converge to better imitate natural behaviors and functions.

NEW TECHNOLOGY-ORIENTED PROGRAMS



Graphene, Portable Energy and Robotic Rehabilitation spin off directly from the technology transfer activity of the robotics and smart material platforms of the previous strategic plan (2012-2014). These programs have a strong applied component and they are substantially supported by external partners to accelerate the transfer of technology. Program Graphene deals with the development of both ink-jet printing of graphene and highly crystalline graphene materials, for application to flexible electronic/photonic devices, biocompatible systems and basic material science. This program will be developed in the framework of the European Future Emerging Technology program, through the Flagship Graphene, a competitive 10-year long project funded with approximately 1 billion euros by the European Community, of which IIT is one of the leading institutions at the European level. A new Graphene Lab was launched in the second half of 2013 within the nanophysics department for this purpose. Portable Energy is a program dedicated to the development of novel sub-kW power sources based on energy harvesting, novel photovoltaic materials, biological fuel cells and graphene-based lithium-polymer batteries. The basic aim is to provide conformable, ultralight energy sources to power robots. A new lithium-battery laboratory was set up in 2014 in the IIT center in Rome and in the Nanochemistry department in Genova. Robotic Rehabilitation is a program dedicated to the development of assistive exoskeletons, prosthetic hand and novel rehabilitation tools, and is strongly funded by external investors. In this frame the joint IIT-INAIL Robotic Rehab lab was launched in Genova in 2014, substantially supported by the extramural funds provided by INAIL. This is the most promising technology-transfer initiative of IIT robotics, with a strong expected impact in the short term on the health system.

NEW EXPLORATORY PROGRAMS

Computation, NanoBioPhotonics, Health Technologies and Interactions all represent new, high-risk/high return, interdisciplinary research programs merging different know-how present at IIT. These programs are either oriented to basic research or to innovative technology applications, but they all share a strong cross-disciplinary content and target high-risk/high return, exploratory goals. The new Computation (Computational Network for Multiscale Computational Methods) program is the evolution of the previous Computation platform launched in the strategic plan 2012-2014. Computation deals with the development of an international network of computational scientists to set up a multiscale molecular computational tool of transversal interest for IIT, spanning material science to pharmacology. The IIT computational-network has grown impressively, and represents one of the main areas of development of the Institute in the near future. Today it involves more than 40 researchers from all over Europe, including some of the best computational scientists in the continent, with the objective to create a Multiscale Modelling facility going from atomistic to continuum simulation in a unified framework. The program NanoBioPhotonics deals with the development of novel technologies and instruments for advanced diagnostics, including imaging, super resolution microscopy for single bio-event observation, plasmonic sensors, and functional MRI. The program combines advanced basic research with a strong instrument-development activity. In this framework Nikon Industries launched the new NIKON-IIT imaging Center (NIC@IIT) incorporating a R&D lab for the development of new generation super-resolution microscopes at IIT's Genova headquarters. This program targets new high-resolution non-invasive diagnostics in humans. The program Health Technologies deals with the development of nanotech tools for intelligent drug delivery and theranostics (therapy + diagnostics integrated in a single carrier). Clinical applications are the natural outcome of these two programs. The unique combination of nanotech, biochemistry, medicine and pharmacology at IIT is a fundamental asset for the success of these programs. In 2014 two new consolidator ERC grants were started in these fields in IIT, resulting in the creation of two new laboratories for Nanoplasmonic applications to Neuro-diagnostics and Intelligent Drug Delivery by Polymeric Nanoconstructs for Brain Tumors. Finally, Interactions is a cross-disciplinary program dealing with robotics, cognition, learning and behavior, intended to study human social behavior and how it can be translated to human-machine interaction, for a range of applicative fields such as robotic applications, for the understanding of behavior pathologies and other cognitive and sensorimotor impairments, and intelligent "socially-sensitive" video surveillance.

Concerning the expected impact, the New Technology programs will be most attractive for private industries and investors. A considerable body of basic research will be developed by these programs but their main outcome will be new intellectual property, applied science, interaction with industries, start-up and fund-raising. The Core programs have a more basic science character, primarily to create new knowledge needed for technological advancement in the core fields of IIT. These programs will primarily produce high-quality scientific publications and competitive grants, and to a lesser extent new IP and applied research. The new cross-disciplinary programs are based on the unique organization of IIT, which merges expertise in hard science and life science in the same environment. These programs can be oriented either toward very fundamental issues, such as the multi-scale computational methods, or toward very applied issues, such as the human-machine interaction or intelligent drug delivery. But in all cases they will retain a profoundly exploratory and high-risk character. The majority of the ERC programs at IIT belong to this cross-disciplinary category, as do most of our imaging and nanotech-health applications.

The synergy among these programs will impact key societal and industrial challenges of our time:

- Sustainability and resources (new environmentally friendly materials and nanocomposites, multiresponsive polymers for food packaging, water purification etc.; colloidal nanoparticles for material science and catalysis, new light and efficient portable energy devices in the sub-kW range, flexible and biocompatible conductive materials, artificial tissues and scaffolds)
- Ageing society and companion for citizens (assistive robotics, rehabilitation, augmented performances, prostheses, robotic surgery, robot companions, cognition and learning, behavior analysis for the elderly, human-machine interaction, robots for disaster recovery and hostile environment operations).
- Welfare and advanced medicine (advanced diagnostics, new theranostic medical devices, point-of-care medical devices, intelligent drug delivery, brain diseases and neurodegeneration, development of new drugs)
- Development of advanced instruments and tools (metrology, diagnostics, health, automation, manufacturing, etc.)

The implementation of the plan relies on the collaboration of different research units and departments. From the organizational point of view, management of the equipment facilities, technical services and administration will remain in charge of the departments and centers. However, research teams led by their principal investigators (tenure-track and tenured scientists, directors and center coordinators, etc.) will contribute autonomously and independently to the development of the programs. Each department/center will contribute to two or more programs, increasing cross-fertilization within IIT.

Table 1 table summarizes the contributions of the different departments and centers at the beginning of the strategic plan. Clearly, IIT can face the next 3-year plan with a robust organization and considerable skills in all 11 programs. Future job openings and creation of new laboratories at IIT will be decided based on the international acknowledgment and scientific relevance of the results of the programs and/or on their technology-transfer potential (see section 4). This will be driven by expansion of the tenure-track program, and the consequent constitution of independent laboratories within the Departments and the Centers of the network.

Dep/Center/ Lab	Mat Chemistry	New Materials	Robotics	Brain Science	Graphene	Energy	Robot Rehab	Computation	NanoBio Photonics	Health	Interactions
RBCS (G. Sandini)			■	■			■				■
ADVR (Caldwell)			■				■			■	
Soft Hand (A. Bicchi)			■				■				
Humanoids & Human Centered Mechatronics (N. Tsagarakis)			■			■	■				
iCub (G. Metta)			■			■	■				
Humanoid Sensing and Perception (L. Natale)			■	■							■
PAVIS (V. Murino)			■	■					■		■
Visual Geometry and Modelling (A. Del Bue)			■						■		■
NBT-NTECH (J. Assad)				■	■						
Microtechnology for neuroelectronics (L. Berdondini)		■		■	■				■		
Neurobiology of miRNA (D. De Pietri Tonelli)				■						■	
Genetics and epigenetics of behavior (V. Tucci)				■							
Optical approaches to brain function (T. Fellin)				■							
Genetics of cognition (F. Papaleo)				■							
Non-coding RNAs and RNA-based therapeutics (S. Gustincich)				■						■	
NBT-NSYN (F. Benfenati)				■	■						
Local micro-environment and brain development (L. Cancedda)				■							
Synaptic plasticity of inhibitory networks (A. Barberis)				■							
Neuromodulation of cortical and subcortical circuits (R. Tonini)				■							
D3 PharmaChemistry (T. Bandiera)	■	■			■					■	
Nanomaterials for Biomedicals (T. Pellegrino)	■	■		■						■	
Nanotechnology for Precision Medicine (P. Decuzzi)	■			■						■	
D3 Compunet (A. Cavalli)								■		■	
Computational Modelling of NanosCalE and bioPhysical systems (W. Rocchia)								■			
Molecular Modeling and Drug Discovery (M. De Vivo)								■		■	
D3 Validation (D. Piomelli)				■						■	
NAPH – NIC@IIT (A. Diaspro)				■	■				■		
Graphene (V. Pellegrini)	■	■		■	■	■			■		
Smart Materials (A. Athanassiou)	■	■									
Nano Carbon Materials (S. Giordani)	■	■		■	■					■	
Plasmon Nanotechnologies (F. De Angelis)				■				■	■		
NACH (L. Manna)	■	■			■	■		■			
Lithium Batteries (B. Scrosati)	■		■		■	■					
Optoelectronics (R. Krahne)	■				■	■					
Nanocrystal Photonics (I. Moreels)	■										
Rehab Technologies - INAIL-IIT Lab (S. Ungaro)			■				■			■	
CNST@PoliMi (G. Lanzani)		■			■	■					
Advanced Materials for Optoelectronics (A. M. Petrozza)		■			■	■					
Printed and Molecular Electronics (M. Caironi)		■	■			■					
CGS@SEMM (B. Amati)								■		■	
SHR@PoliTo (F. Pirri)			■		■	■	■				
CNCS@UniTn (A. Bifone)				■					■		■
Neural Computation (S. Panzeri)				■			■		■		■
CMBR@SSSA (B. Mazzolai)		■	■			■					
Artificial touch in soft biorobotics (L. Beccai)		■	■			■					
CTNSC@UniFe (L. Fadiga)				■			■				
BCMSC@UniPr (Rizzolatti)				■			■				
CNI@NEST (V. Piazza)					■			■	■	■	
CLNS@Sapienza (G. Ruocco)						■		■	■	■	
CABHC@CRIB (P. A. Netti)		■								■	
CBN@UNILE (M. De Vittorio)	■					■		■		■	
Nanobiointeractions & Nanodiagnostics (P. Pompa)		■								■	
IIT@MIT			■								■
IIT@Harvard				■							

Tab.1 Matrix organization of the strategic plan 2015-2017 (as of Jan 2015), indicating the contribution of all independent teams belonging to different departments and centers to the research programs.

HUMAN RESOURCES

TENURE TRACK PROGRAM

In 2014 IIT completed the initial phase focused on the peer evaluation of the internal scientific staff (team leaders and higher) for promotion to the tenure track, resulting in about 25 scientists promoted (in a few cases fully tenured) out of approximately 160 team leaders. A critical long-term strategic goal of IIT is to increase the number of tenure-track scientists from <30 now to ~160 in about 10 years (i.e., a maximum of approximately 15% of the total staff at regime). These 160 tenure-track scientists, including fully tenured scientists as well as earlier-stage tenure-track scientists, will gradually replace current non-tenure-track scientists holding fixed-length contracts. This growth of the number of tenure-track scientists presents a unique opportunity for IIT to become even more an elite international institution. This plan requires careful planning and decisive actions in the recruiting.

At regime, the vast majority of IIT P.I.s will be tenure-track or tenured scientists, recruited by open external searches, following international best practices (as described in detail in the approved IIT hiring procedures). The paramount goal of the tenure-track recruitment process is to obtain world-class scientists, based solely on scientific merit. To ensure the highest quality recruits, members of IIT's Standing Committees of External Evaluators (about 150 international experts) will serve on our search committees along with IIT scientists, to provide diverse perspectives in evaluating candidates. At regime we expect that each tenure-track P.I. will lead "middle size labs" (with an overall ratio of ~10 PhD students and postdocs per principle investigator) that tend to provide the highest productivity in terms of the scientific impact over expense ratio (for example, see the 2010 "Nature News" piece, Nature 468, 356-357), and will keep the average age of the IIT scientific staff below 38 years. Note that this is a reference average size, which must be adapted to the needs of some specific areas (e.g., humanoid robotics or selected nanomaterial/nanotech domains), for which system integration requires the coexistence of an overall supervisor (a program director responsible for the global target) with several independent tenure track scientists contributing with their specific skill to the success of the overall program.

There are several key aspects and challenges with regard to the expansion of the IIT tenure track:

STRATEGY FOR GROWTH OF THE TENURE TRACK

In order to ensure top quality tenure-track recruits, the number of tenure-track scientists should not grow too quickly. A realistic goal would be to recruit ~10 new tenure-track scientists per year, across all research areas, over the full ten-year build-up period. New tenure track positions will be opened only in the most strategic areas of the scientific plan, under the supervision of the Technical Scientific Committee. Given the rapid changes in scientific fields, it will be crucial to continuously monitor the state-of-the-art as well as developments and emerging areas.

By the end of the next 3-year plan, the number of tenure-track scientists will approximately double. Ten recruits per year offer enormous advantages in terms of visibility for our searches; for example, all ten positions could be advertised together in high-profile international journals at the beginning of each recruiting season. IIT would gain immediate attention as an institution that is rapidly growing in cutting-edge areas, and IIT would be "on the radar" as an attractive employer for top international candidates in subsequent years. Ten new tenure-track hires per year also offer tremendous synergy in recruiting: top candidates would be especially attracted to IIT if they knew that they would be part of a strong cohort of scientists starting their labs in the same year.

The plan includes the possibility of ERC winners to be directly granted tenure-track positions, according to existing IIT policy.

ADVERTISEMENT OF THE NEW CALLS

For the actual searches, IIT must be aggressive in publicizing its searches and in pursuing the best candidates. We will advertise open tenure-track positions in high-profile journals, but also take advantage of the network of international institutions and colleagues (e.g., IIT's Standing Committee of External Evaluators) to help spread the word and attract top candidates. In addition, we will offer to sponsor and support new recruits for prestigious start-up grants, such as junior ERC grants and Armenise Foundation awards. In addition to the internal funding from IIT, these grants will allow the new recruits to have a tremendous running start at IIT.

RESOURCES FOR TENURE-TRACK RECRUITS

Resources for the new tenure-track positions must be identified and budgeted before the searches are initiated. These resources include 1) salary for the tenure-track position, 2) PhD and postdoc slots allocated for the new position over the initial 3-year period, 3) space for the new tenure-track scientist's laboratory, 4) consumables budget, 5) a reasonable start-up equipment budget, and 6) access to ancillary shared facilities, such as animal housing, large shared equipment such as electron microscopes, clean-room, etc., as well as technical and administrative support. The size of tenure-track packages could vary considerably depending on the type of research and the candidate experience and international standing. It is important to mention that new Tenure Track scientists will exploit global resources (running costs, equipment, team and space) made available by the turnover of non-tenure-track scientists, post docs and PhD students. Therefore the entire Tenure-Track recruiting program in the next year will be developed by suitably planning the yearly budget of the Institute, with no need of additional resources.

INTERNATIONAL ATTRACTIVENESS

It is essential that IIT attracts outstanding foreign scientists in addition to top Italian scientists from Italy and abroad. The Institute must increase the effort to attract foreign scientific talent. Ideally, ~1/3 of IIT tenure-track scientists should be foreigners. IIT must also make a special efforts to facilitate the relocation of foreign scientists to Italy, providing help in finding housing and schooling for children (see Section 3), dealing with Italian bureaucracy, etc. In addition, during recruitment, special attention should be paid to the gender balance among the tenure-track scientific staff: the present overall ratio at IIT of 41:59 women:men decreases to 28:72 if one considers only tenure-track scientists. This ratio must increase steadily in the next years, with a 40:60 target in 2017.

NEW PROGRAM FOR HUMAN CAPITAL: CREATION OF A SMALL NUMBER OF JUNIOR HONOR POSITIONS FOR YOUNG TALENTS AND JOINT PROFESSORSHIP PROGRAM WITH ITALIAN UNIVERSITIES

We plan to set up a special Endowed Chairs Program in cooperation with a few selected Universities (Politecnico di Torino, Politecnico di Milano and Università degli Studi di Genova, initially). The program will apply to foreigners and to young researchers wishing to return to Italy after at least a 3-year stay abroad. These will be selected by an international call according to the IIT Tenure Track procedures, while the cooperating university shall assign the winning candidate an IIT chair on an "outstanding reputation basis" as stated by the Italian law no. 382/80.

During the first 5 years, the young researchers will teach on a part-time basis at the university and carry on their research work in the assigned IIT Center/Department with an IIT start-up package. The salary cost (construed on the basis of IIT's salary tables) will be shared by IIT and the partner university. At the end of the first period, researchers can continue to teach on a part-time basis or shift to the university full time while continuing to work for IIT for a further period of 5 years by means of an external collaborator contract. In the first 5 year period the intellectual property will belong to IIT, whereas the scientific affiliation in publications shall be jointly shared between IIT and University. In the second period, both will be joint.

Under this initiative ~40 top-level IIT Endowed Chairs can be assigned in 10 years, thus creating a generation of young professors (with their graduate and PhD students) closely linked to IIT. The initiative is in synergy with the existing university network structure, because it allows endowed chairs to be hosted also in subsidiary poles of associate universities. Moreover, the creation of an IIT "Alumni Club" can be foreseen in a few years, which would strongly impact the sectors of interest for IIT within the Italian academic society. Extension of this initiative to foreign Universities is also considered.

It is important to note that this program can be developed only if extra resources, additional to the yearly budget of IIT, are made available. Donations, matching funds from the collaborating Universities and contribution form the IIT endowment should be exploited for such an action.

STRENGTHENING THE VISITING SCIENTIST PROGRAM

The second initiative of the strategic plan 2015-2017 deals with launching an international sabbatical/visiting professor program for foreign researchers of world-class reputation. The program will allow them to spend a 3 months to 1 year period in any IIT structure (a 6-month average stay is foreseen). Post-doc/fellowship positions could also be associated to some of these sabbatical/visiting professors, so that the collaborations could be extended in time. The selection of visiting professors will be approved by the Technical Scientific Committee. The objective is to increase the IIT visibility by creating a network of top-level international scientists associated with the institute. This will provide our PhD students a competitive edge when applying for top international postdoctoral positions, and it will enhance the training of young scientists within IIT sites, including the potential addition of highly specialized short-courses. The short-courses could also be uploaded on international web teaching platforms (e.g., Coursera, EDX etc..).

It is important to note that this program can be developed only if extra resources, additional to the yearly budget of IIT, are made available. Donations and contribution from the IIT endowment should be exploited for this program.

NEW POSSIBLE FIELDS UNDER CONSIDERATION

As discussed above, the Tenure Track program is a key asset of the future IIT strategy, both for consolidating its successful research programs and for opening new research fields. New tenure track positions will be opened only in the most challenging and strategic research areas or in the most successful programs of the strategic plan (described in section 2 and in Technical Annex TA1), to reinforce the best and most promising activities, or to initiate novel high-risk, exploratory fields where IIT aims at becoming a leading Institution worldwide. In the next three years, we plan approximately 30 new tenure track positions. It would be highly desirable to simultaneously open about 10 position every year in the different research areas covered by the programs, to maximize impact and visibility .

FOR THE FIRST YEAR

there are already several important activities which could deserve reinforcement in the form of new laboratories and tenure track positions. Several fields to be covered in the different research programs of the strategic plan are listed below (the list is non-exclusive and will require continuous analysis and update):

- Computation Multiscale Modelling
- Graphene: Biocompatible surfaces/devices
- Energy: Bacterial fuel cells; Harvesting (both mechanical and/or thermal)
- Brain: Bioinformatics/transcriptomics, Molecular Biology
- Interactions: Speech; Cloud intelligence for robotics (wireless ICT, etc.)
- Health: Human skin engineering; microRNA and connection to nanotech (delivery, etc.)
- Robotics: Control systems for robotics; Plastic robotics platform
- New Materials: Biodegradable plastics; Responsive and multifunctional materials
- Robotic Rehab.: Neuroprostheses; Robotic-assisted surgery
- Materials Chemistry: Materials beyond graphene
- NanoBiophotonics: Super-resolution microscopes

SIMILARLY IN THE SHORT- TO MID-TERM, (~2017)

Several other topics could be considered as potential fields for expansion to be pursued autonomously by IIT, through recruiting of new Tenure Track scientists and by a dedicated fund raising activity, namely :

- Technologies for cultural heritage (advanced nanodiagnostics for materials and pigments, polymer and nanocomposites for materials restoration and treatment, robots and micro-robots for underground exploration, image analysis and 3D digitalization of large databases, automatic artifact analysis, optical diagnostics etc.)
- Materials under extreme conditions (ultra high pressure conditions for new synthesis methods and ultra high resolution electron-microscopy analyses)
- Computational methods for climatic changes, disaster forecast, earthquakes (primarily development of state-of-the-art computational methods for global climate changes, large scale environmental monitoring, climatology, etc.)

These ideas expand the on going programs (eg the computational methods and the nanotechnologies for cultural heritages) or they are complementary to the existing activities (eg materials under extreme conditions)

Budget-wise, any expansion mentioned above, the recruiting of the new Tenure Track scientists and the construction of their teams in the next years will be planned following the internal turn over, within the institutional yearly budget of IIT.

MID-TO-LONG-TERM

The opening of totally new research fields in the mid- to long-term requires a broader analysis. The possibility of a global growth of IIT will depend not only on its own strategic choices but also on future government decisions. IIT was indeed launched as a pilot experiment by the Italian government to test a public research model that was an alternative to the existing ones, the main differences being:

- Governance (Fondazione di Diritto Privato) which allows open international recruiting and company-like management;
- Cross-disciplinary approach to research, with a strong "basic to applied" pipeline and great attention to technology transfer;
- Peer evaluation of people and activities, for the highest standard of research quality.

In less than 8 years, IIT reached a competitive position at the international level compared to high-level benchmarking institutions, but still with room for improvement. This result, together with the increasing attractiveness towards industrial partners, the growth of the IP portfolio and the launch of several start-ups, clearly indicate that the model works well for Italy.

Therefore, the future growth of IIT can change substantially depending on whether it will remain as it is now, or will be extended to other research areas/systems. In the former case IIT will keep its present size (i.e., approximately 1% of the public Italian R&D investment per year), making the maximum effort to optimize its scientific performance and impact on society and industry. In the latter case, IIT could grow substantially, eg by creating new IIT-like institutes in fields of strategic interest for the country (similar to the German Gesellschafts - Max Planck, Fraunhofer, Helmotz etc-).

Budget-wise this scenario would require a corresponding growth, which cannot be foreseen now.

Concerning international initiatives, IIT is presently developing transnational cooperative research agreements with the National University of Singapore (for nanotechnology and material science), with the Skoltech Foundation-Moscow (for robotics, computer vision and energy), with the European Molecular Biology Laboratory (Germany/France) for life science, and with the Methodist Hospital (Houston-Texas, USA) for Nanomedicine. These could lead to more structured collaborative agreements and possibly, joint laboratories. Similarly, high level contacts (global CTO and CEO) are in progress with the multinational companies Bayer-Germany (for materials, diagnostics and life science applications) and with 3M (USA) for plastics and harvesting materials. In both cases IIT is exploring the possibility to initiate with these companies joint laboratories/initiatives similar to the IIT-Nikon Center.

SHORT SUMMARY OF THE PROGRAMS AND THEIR SYNOPSIS

THE FOUNDATIONS OF THE STRATEGIC PLAN 2015-2017: "TRANSLATING EVOLUTION INTO TECHNOLOGY"

Although complex and multifaceted, the plan stands on a small set of unifying principles: first, IIT must target sustainable solutions for problems of fundamental importance to the future of mankind ("human-centric research"). Second, such solutions require a progressive convergence of technological disciplines towards a cross-disciplinary approach. Third, human-centric research must be bio-inspired, mimicking the architectures of natural evolution. Thus, the IIT strategy should be inspired by the principles that govern evolution.

Most living things are constituted by no more than a dozen types of atoms (primarily C, H, O, N and few metals). Despite the fact that nature makes available more than 100 atoms to build our world, evolution selected only those few atomic species, and optimized their organization to create living organisms and organic systems constrained by requirements for minimal energy, stability and adaptability. Biodiversity, expressed by macroscopic differences among species and organic materials, relies primarily on the way those few atoms are arranged together - i.e., by their collective architecture - rather than by the atoms themselves. Therefore, any living system is characterized by the type and number of atoms of which is composed, with its complexity defined by the architecture of its atomic ensemble, a product of the optimization accomplished by evolution. This is exemplified in the left column of Figure 3, which shows the increasingly complex systems built by evolution over three billions years. Small atomic ensembles, such as antibodies, proteins etc., are primarily capable of biochemical interactions. With increasing size and complexity nature introduced biomechanical capabilities, in the form of ciliae, tails, legs, arms etc., so that mechanical work could be produced by larger systems. This is true not only for micro-organisms and animals, but also for plants, whose roots move and grow, following chemical and physical gradients. Biomechanics and production of mechanical work thus become more and more important with increasing size and complexity. Coherent movement implies integrated higher-level control and interactions, so that cognition comes into play for most complex organisms like animals and humans. Biochemistry, biomechanics and cognition thus follow an arc of complexity in terms of the size and the architectural design of the different species, as schematically depicted in the left column of Figure 3.

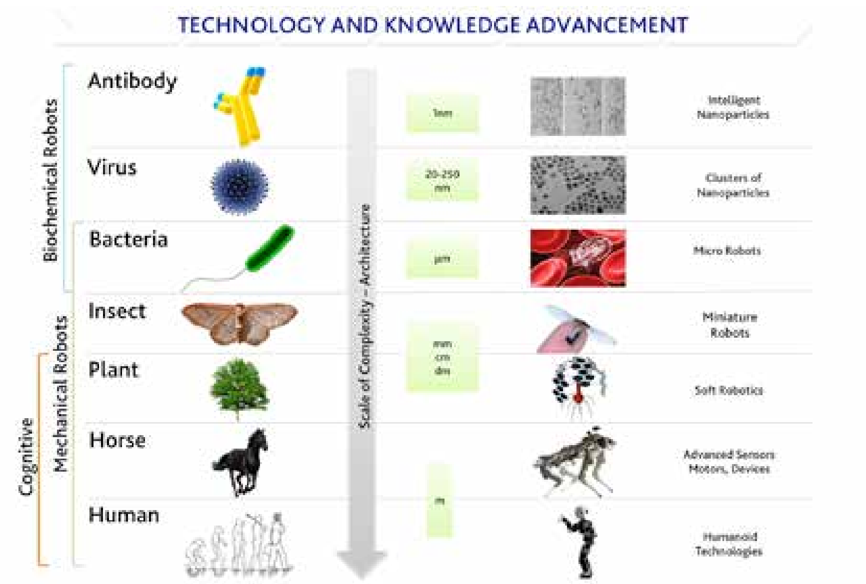


Fig.3 Transferring evolution into technology.

Such an architectural vision of nature inspires the unification of different disciplines to address the formation and differentiation of complex systems in a bottom-up fashion, from molecules to humans. This is the principle of nanoscience, which provides a common background among disciplines (from biology to robotics) to study living systems, and also provides a way to create their artificial counterparts -- nanoparticles, materials, sensors and increasingly complex robots -- that mimic the designs and functionalities emerged from natural evolution (right column of Figure 3).

In this view, the boundaries between the traditionally separated disciplines of physics, chemistry, biology, medicine and engineering fade away. This separation is essentially an artifact, created by mankind to order and classify apparently different phenomena and systems. Physics, chemistry and biology explain most of the interactions and processes that rule the formation of complex systems at the microscopic level, and in turn provide the basic knowledge for medicine and engineering to describe macroscopic properties of both living and nonliving systems. This is exemplified in Fig. 4, where conventional disciplines are mapped onto the same evolutionary pathway of Fig.3. Note that most modern disciplines intersect and parallel the evolutionary pathway.

Most importantly, Fig. 4 gives a clear indication about the development that science and technology must pursue in the next years in order to produce sustainable solutions to key mankind problems: (i) technological disciplines must become convergent, i.e., more and more cross-disciplinary, and (ii) bio-inspired approaches dictated by natural evolution need to be adopted by technology, to develop efficient and sustainable tools.

This is the fundamental approach of IIT for the development of the strategic plan 2015-2017, namely: translating evolution into technologies, a "humano-centric" approach generating technologies to find solutions to the problems of our future generations.

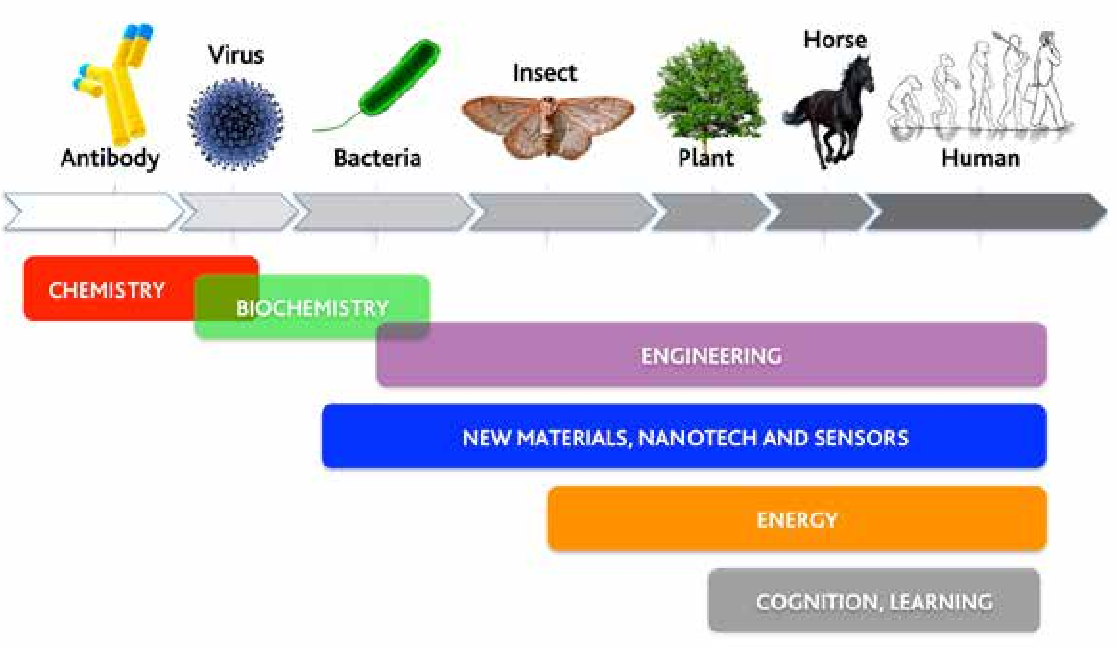


Fig.4 Convergence of traditional disciplines into the evolutionary scheme of the strategic plan

THE VISION AND THE CHALLENGES OF THE STRATEGIC PLAN

At present, our planet is strongly imbalanced with respect to resource distribution. Approximately 20% of the world's population uses about 80% of the total energy produced, despite the fact that "energy intensity" (the total energy consumption per unit GDP) is much higher in emerging countries than in Europe and the US. Water usage follows approximately the same distribution, because water and energy production are intimately related. Countries with efficient availability of water and energy have developed advanced economies, welfare, education and health systems, resulting in an ever-increasing life expectancy. Today in advanced countries life expectancy is growing by approximately 3 months per year, with a concomitant higher incidence of degenerative and oncologic diseases, whereas in poor countries life expectancy is staying constant or growing much more slowly. Such a situation will very likely become less sustainable, primarily because the planet's population is steadily increasing - forecast at 9 billion people in about 30 years - and some large countries with emerging markets are growing faster than countries with already consolidated economies. This means that natural global resources will be increasingly limited, but also that the distribution of natural resources among consolidated and emerging economies will become more problematic.

Such an unbalanced situation has important consequences for future technological requirements and sustainability. For instance, in advanced countries it will be necessary to develop technologies (i) to improve diagnostic and therapy for diseases of older populations, including cancer, heart disease and degenerative diseases; (ii) to facilitate sustainable ageing in longer-living populations; (iii) to improve resource utilization, raw materials exploitation and material recycling; (iv) to make materials and infrastructures environmentally sustainable; and (v) to develop new renewable energy sources. In developing countries, it will be a priority to develop technologies (i) to improve food and water quality; (ii) to improve health, disease-prevention and diagnostics; (iii) to increase resource availability and reduce cost and environmental impact of industrial products; and (iv) to build sustainable infrastructures.

The grand challenge is therefore to develop science and technology that reduce the disparities among people while improving the quality of life for all.

To accomplish such an ambitious task, we must stimulate the sharing of innovation and knowledge between scientific and technological fields that traditionally do not communicate well with one another. Given that most of the problems listed above are related to natural systems and resources, science could take a lesson from nature, to translate evolution into new sustainable, bioinspired technologies. The 2015-2017 Strategic Plan is based on such a developmental scenario (Fig. 3). We propose a new class of bio-inspired artificial devices, including diagnostic and therapeutic microdevices, nanoscale engineered multifunctional materials, and robots inspired by living organisms, to face diverse problems ranging from personalized therapy to assistance for elderly people. These technologies can only be developed by a synergistic approach of different disciplines, including material science, nanotechnology, biology, medicine, engineering and brain science. Ultimately, the target is to develop materials and systems that resemble natural entities, and operate inside or outside the body to help humans in their daily life. With this vision in mind, the Strategic Plan 2015-2017 will be developed along the 11 high priority programs depicted in Fig. 2 and introduced in the next section.

SYNTHETIC DESCRIPTION OF THE PROGRAMS

This section provides a synthetic description of the 11 programs at the hearth of the 2015-2017 strategic plan, their interactions and synergies, and the main contributors in the organizational matrix of Tab. 1. The full description of the programs, with a detailed presentation of the mainstream research lines, the expected impact and the developmental road map, is given in the technical annex A1.

P1: MATERIALS CHEMISTRY

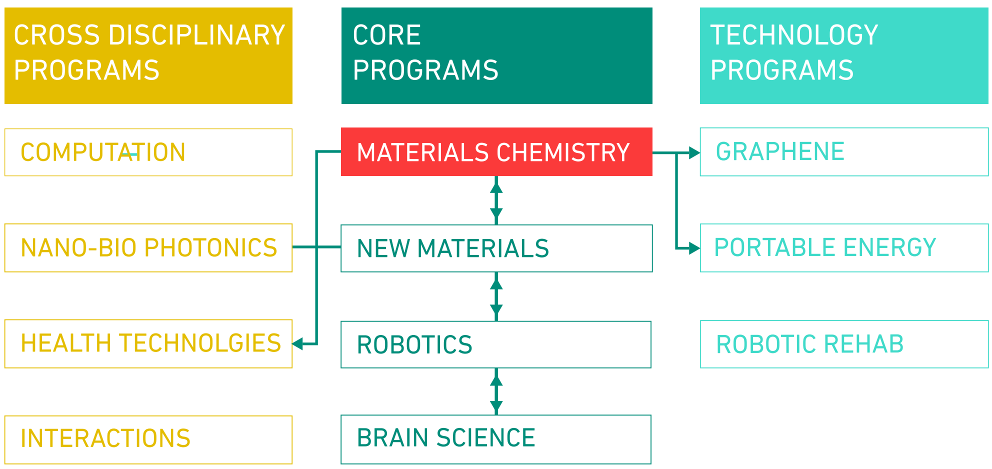


Fig.5 Correlations of the Materials Chemistry Program

Most novel applications/technologies strongly emphasize the development of new materials as the key ingredient to achieve novel capabilities. Materials development is thus transversal to almost all areas of science and technology. Nanomaterials in particular hold great promise because they offer broad range of unique properties. Among the different approaches to materials/nanomaterials fabrication, chemical synthesis has become very popular over recent decades because of its immense potential for scalability, tunability of processing parameters and material properties, low energy cost, and (in most cases) environmental compatibility. Inorganic nanocrystals (NCs) prepared by colloidal chemistry are among the most widely investigated nanomaterials. They are made of an inorganic core coated with a passivating monolayer shell of organic ligands to ensure their solubility in a variety of solvents. Research on NCs advanced considerably in the past fifteen years, especially in regard to synthesis, assembly and the control of surface passivation. This made NCs attractive low-cost alternatives for many new technologies in photovoltaics, optics and electronics. NCs also have an enormous potential impact on biology and medicine in which IIT provided key NC-related technologies. However, the most commonly used NCs either have toxic metals in their formulation, or suffer from poor optical/electronic performance due to uncertainty regarding their preparation, surface chemistry, structure, etc. In addition, in recent years other materials have become the focus of research worldwide, such as 2-dimensional layered materials and hybrid organic/inorganic perovskites.

The Nanochemistry Department at IIT, with its consolidated expertise on the fabrication and characterization of materials of various compositions and dimensionalities, will play a key role in defining new strategies for the development and implementation of new nanoscale materials. On one hand, we will continue our tradition of developing new synthesis strategies for colloidal NCs with unique optical/electronic/magnetic features, with such precise control of geometry and composition that the resulting materials will be considered as "standards" worldwide. On the other hand, our Departments and Centers will target different applications of these novel nanomaterials in diverse fields, such as optoelectronics, photovoltaics, medicine, and catalysis. We will develop unconventional assembly strategies and peculiar particle compositions/shapes, to uncover new fascinating types of artificial solids in the future.

Other important materials have also emerged in nanoscience, such as graphene, other layered materials, and hybrid perovskites, which hold great promise in photovoltaics, for example. We envision that these materials could be fabricated by exploiting chemical transformation on starting templates, in addition to the more traditional methods that are already available. We will also study of the behaviour of nanoscale materials under extreme conditions (e.g., irradiation or heating), which is poorly understood at present, yet important in many applications.

SYNERGIES AND INTERACTIONS

As shown in Fig. 5, the Materials Chemistry program will be linked to the activity in Graphene, primarily for the investigation of alternative two-dimensional quasi-crystal structures. Strong synergy will occur with the New Materials program, primarily for the investigation of novel nanocomposites employing different nanofillers in polymeric matrices. The interaction with the Portable Energy program will address novel nanostructured electrodes for storage and batteries. Finally, the interaction with the Health program will be connected to the development of super-paramagnetic nanoparticles and other multiresponsive nanoparticle carriers for intelligent drug delivery and theranostic application.

DEPARTMENTS AND LABS

The main contributors to the program will be the Nanochemistry Department, D3 and the Nanophysics Department, the Graphene Lab and the Li- Batteries Lab. Further activity will be carried out at the CBN@UniLe and the CNST@PoliMi.

P2: NEW MATERIALS

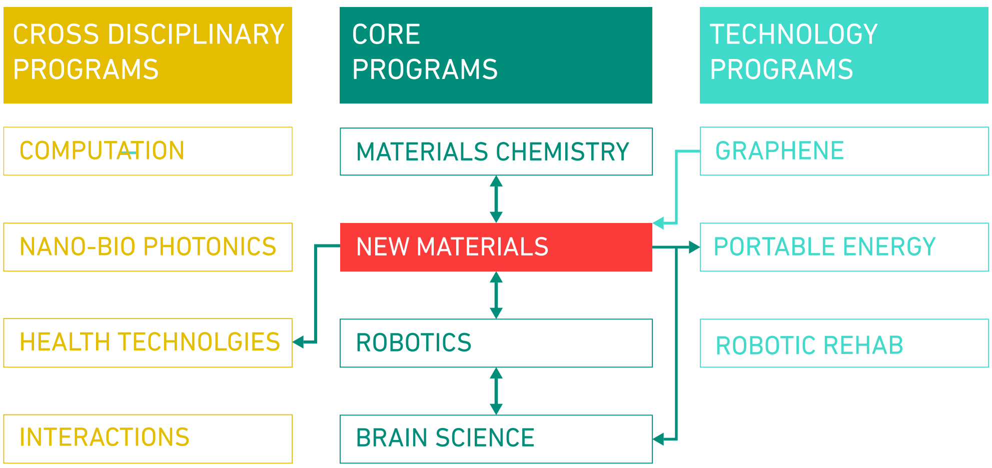


Fig. 6 Correlations of the Smart Materials Program

New Materials program deals with the development of novel classes of materials combining Nanotechnology, Materials Chemistry and Materials Engineering, to target the multiple aspects of the Strategic Plan. The developed materials should be functional, responsive or adaptive to their environment. An enhanced effort will also be devoted to their sustainability. The engineered properties of such materials will give them the unique capability of resolving challenges in multiple different fields. The program is divided into three distinct categories of materials according to their "smart" functionality:

1. MULTIFUNCTIONAL NEW MATERIALS

The engineered structure and chemistry of these materials will endow them with multiple properties and functionalities, tuned on the target applications:

Nanocomposites: i) Polymeric nanocomposite materials can attain multi-functionality by the appropriate combination of polymer matrix with a variety of inorganic nanofillers, added directly into the matrix or before their blending with the polymer; ii) Existing fibrous materials, like textiles and paper can be properly tailored in order to obtain additional functionalities that, preserving at the same time their structural characteristics; iii) Plant-derived natural nanocomposites: Natural composite plastics or elastomers will be developed directly from edible plant wastes. These natural composites will maintain together different components of the plants, endowing them with valuable multi-characteristics such as antibacterial or antifungal properties, controlled mechanical properties, water resistance, entrapment of heavy metal ions, etc.

Functional Interfaces: Different strategies will be followed to modify the material surfaces to tune their interaction with other materials, biological entities, liquids and gases. The strategies include controlling the structure, chemistry or the mechanical properties of the interface, with the specific goals of developing self-cleaning or antifogging materials, solid lubricants or adhesives, and sensors of molecules for biomedical and environmental applications.

Hierarchical Architectures: the aim of the activity is to investigate the dynamic synthesis of novel materials, which would enable on-demand growth, re-configurability and restoration. This will allow the conversion of large quantities of nanomaterials into programmable self-assembly materials. A key element of the research line is graphene: functionalized graphene layers will be cross-linked by rigid aromatic linkers, forming layers of graphene with desired porosity by tuning the length of the organic linker.

Conformable electronics: Semiconducting polymers and hybrid organic materials will be studied to develop devices and circuits fabricated by printing and direct-writing that operate at high frequencies, and that are semi-transparent, bendable, stretchable and ultra-conformable.

2. RESPONSIVE NEW MATERIALS

These materials will be designed to respond to external stimuli, such as heat, light, chemical environment, moisture, mechanical forces, or electric/magnetic fields.

Magnetically Responsive Materials: polymers or monomers will be combined with magnetic nanoparticles (NPs) whose composition, shape and assembly define the overall magnetic properties. The NPs can assemble under an external magnetic field, forming nano/microwires in polymer matrices or self-standing magnetic microwires covered by a polymer shell.

Materials Responsive to their Chemical Environment: Natural polysaccharide NPs, nanocapsules with controlled shell thickness, carbon nanomaterials and polymeric nanofibers will be loaded with active molecules. Such smart nano-vehicles will be applied for drug delivery, food-quality improvement, cosmetic stability and penetration, enhancement of medical imagining signals, smart textiles, filters, or active packaging. A similar principle will be used to develop intelligent materials for tissue engineering that facilitate the formation and growth of neo-tissues. The materials will be composite multi-nanostructures mimicking the 3D architecture of the native extracellular matrix, and will include organic nanofibers, nanobeads, "liquid marbles", and micro-nanostructured surfaces. Finally, cellular and fibrous materials properly functionalized with organic molecules or NPs will be employed for removing oil contaminants, dyes or heavy metals from water, or for emulsions separation.

Materials Responsive to External Electric Fields: Ionic electroactive polymers (EAP) support ions/molecule transport under external electric field, and will be applied to develop artificial muscles. We will develop EAP-actuator-based artificial muscles using various polymers as electrolyte and electrodes, with geometries adapted for applications such as prosthetics for rehabilitation purposes and for robotic human-assisting devices.

Multiresponsive Materials: Switchable molecules responsive to external stimuli, such as light, heat and redox potential, will be synthetized (spiropyrans and azobenzenes) and used to functionalize solid or structured polymers, biomacromolecules, and NPs. The composite materials can selectively bind metal ions and subsequently release them using light irradiation, envisioning applications in environmental pollution sensing, and drug delivery.

3. SELF-GROWING MATERIALS

This totally novel class of materials include all the hybrid materials that incorporate biological entities, and can grow taking advantage of the ability of the latter to reproduce, self-grow, and develop.

Mycelium Based Materials: the synergetic action of living organisms with materials engineering and nanotechnology will be studied to grow fully engineered self-assembling materials. The basic biological component that will be used is the fungal body, the mycelium. The mycelium grows due to its symbiotic relationship with the materials it feeds upon, forming large-scale entangled networks of branching threads. In the same way, the proposed self-growing materials will be composed of organic substrates or biological organisms (diatoms: unicellular microalgae contained into microsilica shells) merged together with mycelium fibrous network, forming strong unified structures. The envisioned self-growing materials will be hybrid solid, cellular, or fibrous structures, of any length scale; they will be lightweight and have superior mechanical and thermal properties.

In Vitro Growth of Biological Materials: Biological tissues are able to grow, react and adapt to their environment, repair themselves, and communicate with one another. Starting from in vitro 3D, thick, fully functional, heterotypic epidermis-dermis human-tissue equivalents already developed by IIT, the next stage of research envisions in vitro generation of viable, functional complex tissues like intestine, trachea, endometrium, cornea and also tumor tissues. These tissues can be used in regenerative medicine, or integrated on a chip with microfluidic devices and imaging tools for rapid, reliable and cost-effective assessment of the effects of potential toxins or drugs.

SYNERGIES AND INTERACTIONS

The New Materials program will be strongly interconnected with the Graphene program, particularly for the development of flexible plastic conductive devices to be used in prosthetic, robotic and optoelectronic systems. A second important link will be with the Portable Energy program, with special emphasis on flexoelectric materials for plastic-harvesting devices. The connection with program Brain will focus primarily on the development on novel in-vivo probes to study brain functions, including nanostructured optical devices for optogenetics. Finally, materials developed by the New Materials program will be integral to the development of the Health program, such as polymeric materials for wound healing, artificial tissues, antibacterial materials for food/water purification, and materials for separating heavy ions and oils from water.

DEPARTMENTS AND LABS

The departments and team involved in the New Materials program will be Nanophysics, D3, Nanochemistry, NBT and the Centers CNST@PoliMi, CSHR@PoliTo, CABHC@CRIB and CMBR@SSSA.

P3: ROBOTICS

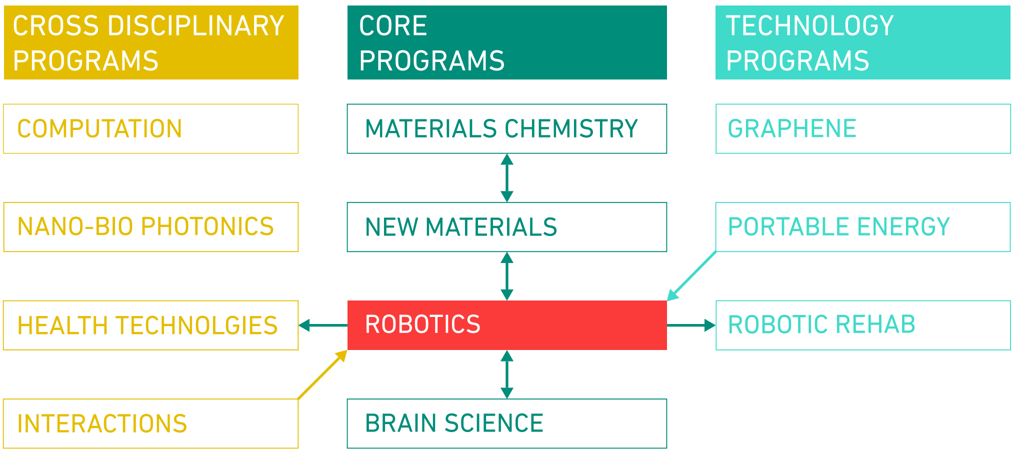


Fig.7: Correlations of the Robotics Program

The program ROBOTICS includes the development of different robotic platforms -- plantoids, animaloids and humanoids -- sharing a similar roadmap that includes hardware redesign devoted to achieve more compliance and robustness, the inclusion of new materials (e.g., additive manufacturing techniques), and more widespread sensing (e.g. tactile). These projects represent an evolution/combination of the IIT current state-of-the-art robotic platforms: the Plantoid, HyQ, COMAN, and iCub. A second important component of this roadmap is related to the control of the robots. Here we envision different approaches, such as distributed/decentralized computation for the plant-inspired robots, and novel centralized adaptive-control hardware (e.g., embedded

electronics) for animal-like robots.
The rationale for such a huge investment in robotics is that, while digital technologies have revolutionized our way to communicate and handle large datasets, to act in the real world, we need devices that can produce real actions. Such devices currently exist (e.g., milling machines and 3D printers to produce parts; industrial manipulators that assemble objects from smaller parts; service robots that move goods in large automated warehouses, etc.), but they typically rely on expensive, inflexible automation, they require continuous maintenance, and they are limited due to their overall power requirements and their reliance on external power sources.

IIT's plan is to change this situation radically by developing a new breed of robots for everyday use. These will first require developing several key enabling technologies spanning the world of material science, neuroscience and engineering, and integrating them into a number of integrated research platforms which will eventually become the building blocks of the applications described in Program Robotic Rehab.

Fig.8: Robotics systems developed at IIT

- The tangible result of this program is represented by a number of robotic platforms that include (Fig.8):
- Plant-inspired robots that rely heavily on new materials and special fabrication technologies, and that utilize distributed computation. These robots could be deployed in the domain of disaster recovery or environmental monitoring/protection.
- Animal-like robots with legs for all-terrain deployment. These include robots that can be used in harsh environments and for disaster recovery, and also for applications in farming/agriculture and land management.
- Large humanoids. Robots with physical interaction skills and embedded safety to work side-by-side with humans in factories and in disaster-relief scenarios.
- Small humanoids. Machines designed with embedded intelligence and cognitive interaction capabilities (speech, vision, touch) to be usable in the household or for precise assembly tasks.
- Some of the solutions invented for the research platforms are transferred (partly or entirely) to the Assistive and Rehabilitation Robotics Program. The Rehabilitation Program uses a variety of technologies to implement solutions to advance physical rehabilitation programs in human patients and provide assistive devices to people who suffered limb amputation or other motor and/or neural impairments.

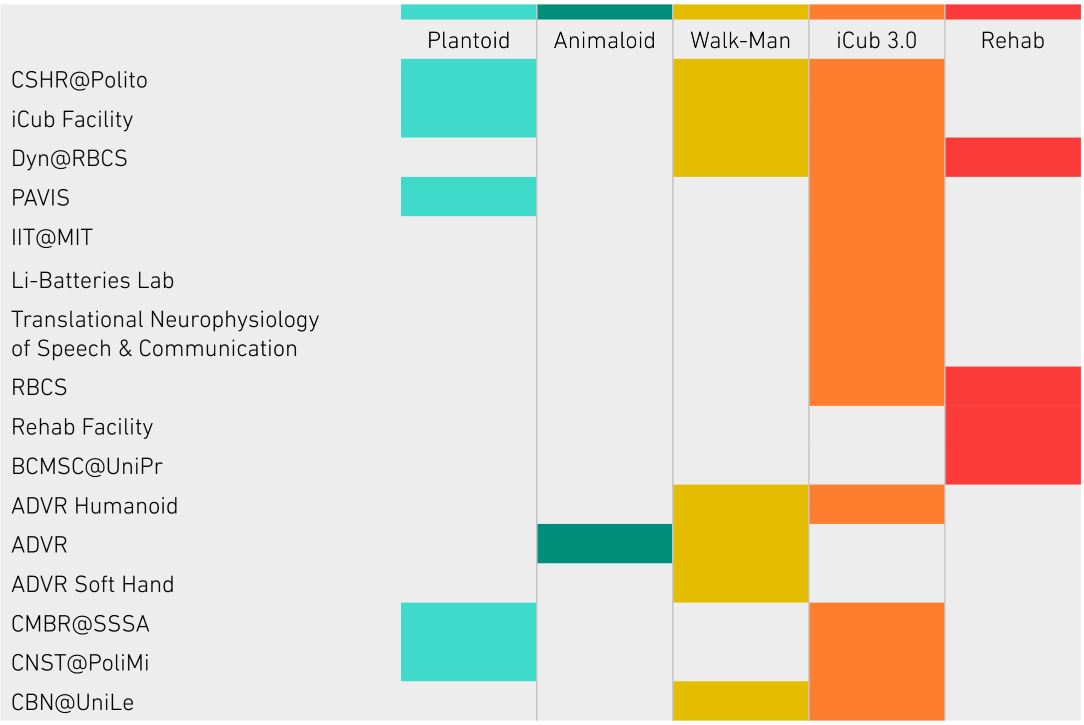
The following tables summarize the contribution (only major contributions/collaborations are indicated) of the various research teams into the overall picture.

SYNERGIES AND INTERACTIONS

Besides the long traditional interaction with the other core programs (Fig. 7) (for materials and cognition), the Robotics Program will have strong interaction with the Energy Program for the development of portable power sources to be integrated in the robots. Transfer of robotic solutions to the Rehabilitation Program will be another fundamental asset of the strategic plan. The recent development of a novel surgical robot with user-friendly human-machine interface will be consolidated in collaboration with the Health Program. Finally, cognition and robot interactions will be studied in collaboration with the Interactions Program.

DEPARTMENTS AND LABS

The Program Robotics involves many departments and laboratories of IIT, as outlined in Table 2. The most relevant contributions will come from the Advanced Robotics Department (COMAN/WALKMAN and the Hydraulic Quadruped, HyQ), the iCub facility (iCub), the Robotic Brain and Cognitive Science and the INAIL-IIT Rehab Laboratory, PAVIS Department (vision) and the CMBR@SSSA (Plantoid). Several technologies will be developed and transferred to different robots by the Nanophysics (Li-Batteries Lab), and by the centres in CSHR@PoliTo, CNST@PoliMi, CBN@Lecce, Parma. Links with IIT@MIT are also planned.



Tab.2 Overview of the laboratories contributing to the program Robotics

P4: BRAIN SCIENCE

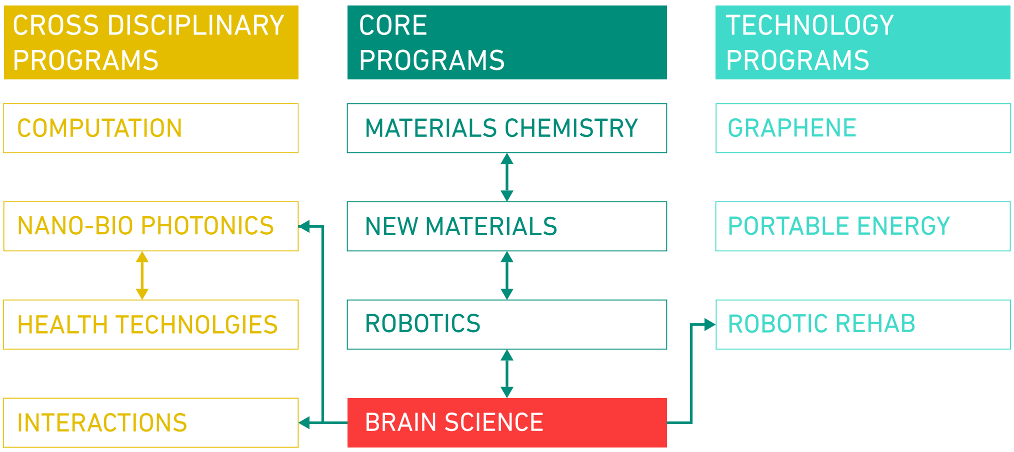


Fig.9 Correlations of the Brain Science Program

A deep understanding of "how the brain works" requires innovative new ideas and new experimental tools to reveal neuronal function at multiple spatial scales. Models of large-scale brain function have been hampered by the lack of neuronal data at appropriate spatiotemporal scales; new approaches that allow "zooming in" or "zooming out" on brain function are urgently needed to provide detailed measurements on the scale of thousands of neurons simultaneously, as well as approaches for manipulating the activity of specific neuronal populations. At the same time remarkable recent discoveries in molecular biology are upending traditional views of the regulation of genes and protein networks in the nervous system. We urgently need to understand the implications of non-coding RNAs, epigenetics and other non-classical molecular effects on brain development, function and disorders.

While there is an immense worldwide effort in neuroscience, IIT neuroscientists are in a particularly favorable position because of the fundamental technological and interdisciplinary strengths of IIT. For example, the use of optical methods for neuroscience research has exploded In recent years, but few neuroscience institutes world-wide enjoy ready access to world-class facilities and expertise in optical methods like those present at IIT. Even fewer neuroscience departments have advanced in-house capabilities in microelectronics and nano-technology for developing innovative new methods of monitoring and manipulating neural circuits. While most IIT neuroscientists carry out curiosity-driven basic research, that research is propelled in innovative directions by the development of these new research tools.

The Brain Science program will focus on the following areas:

1. UNDERSTANDING OF THE FUNCTION OF LARGE-SCALE NEURONAL POPULATIONS

This part of the program will tackle the study of large-scale neural networks, including development of innovative active multielectrode probes for simultaneous electrophysiological recording from thousands of single neurons in multiple brain regions. These technical developments will be paralleled by the development of advanced computational methods to understand how neurons interact in networks to underlie brain function at multiple spatiotemporal scales, and to interpret causal manipulations of neuronal activity. IIT's combined experimental and computational approach to study large-scale networks is well placed to leverage major European funding, including established programs (e.g., Future and Emerging Technologies) and emerging programs (e.g., Human Brain Project - HBP - Flagship). IIT scientists already have strong ties with these funding programs (including collaborative projects and publications). In particular, IIT's strength in "top-down" approaches, combining experimental systems-level data acquisition and data-driven analytical methods, is complementary to the "bottom-up" modelling approach of HBP.

Neurophysiological and computational approaches will be complemented by a sophisticated new platform for structural and functional magnetic resonance imaging from the brain of small laboratory animals, which leverages the power of genetic model organisms like the mouse, including combination of opto- and pharmacogenetics with fMRI for "connectomic" analysis in healthy and diseased brains.

2. UNDERSTANDING LOCAL NEURONAL CIRCUITS AND INTERACTIONS

This part of the program will investigate detailed interactions and development of neural circuit in cortical and subcortical structures. These approaches will involve sophisticated technical developments, including structured light microscopy for in vivo optical imaging and optogenetics, as well as spatially directed delivery of exogenous genes in utero. These technical developments will facilitate unprecedented studies on how information is encoded in precise patters of electrical activity in neural networks, and how local cellular environments affect neural network development. Sophisticated optical approaches and probes will also be developed and used to understand molecular events underlying synaptic function, modulation and plasticity, as well to control expression of specific neural genes in vivo. Innovative new opto-electrically active materials will also be used to interact with neural tissues, and to potentially serve as neural prosthetics, for example in the retina. Additional technical developments will include advanced optical techniques for in vivo optogenetics and exploratory applications of plasmonics for multimodal monitoring of neuronal function and environment.

3. UNDERSTANDING BRAIN MOLECULAR NETWORKS

The domain will target cutting-edge molecular biology as a centerpiece of IIT neuroscience in the next three years. A critical goal is to decipher the role played by microRNA and other noncoding RNA species in brain function, development, and disease. We envision a new class of RNA-based therapies for brain disease, diagnosis and repair, which will require close interactions with IIT colleagues with expertise in chemistry and macromolecular delivery. Approaches for reprogramming of neurons will be investigated for potential transplantation therapies in the diseased of damaged brain. Other areas of intense interest at the molecular level include investigating the role of retro-transposition and epigenetics in brain function, neurogenesis and plasticity, as well as understanding genetic networks involved in cognitive disorders.

SYNERGIES AND INTERACTIONS

Strong interactions between the scientists involved in the Brain program and those involved in the Rehabilitation program and Interaction project is expected, since both require strong expertise in neuroscience. Interactions with the NanoBioPhotonics program will be crucial to develop new tools and methods to monitor and manipulate the brain in vivo. Finally, efforts in molecular neuroscience will mesh strongly with the Health program.

DEPARTMENTS AND LABS

Neuroscience is most effectively carried out by smaller, nimble independent labs. The departments involved in the Brain program are Neuroscience and Brain Technology, PAVIS and several teams working in the Nikon center for SuperMicroscopy, as well as in the Nanophysics department. Strong collaboration is expected also with the teams of the D3 and Nanochemistry departments within the Health Program. The centers involved in the project will be CNCS@UniTn, CBN@UniLe, CNI@NEST, CGS@SEMM, NSYN@UniGe, CNST@PoliMi, IIT@ Harvard and BCMSC@UniPr.

P5: GRAPHENE

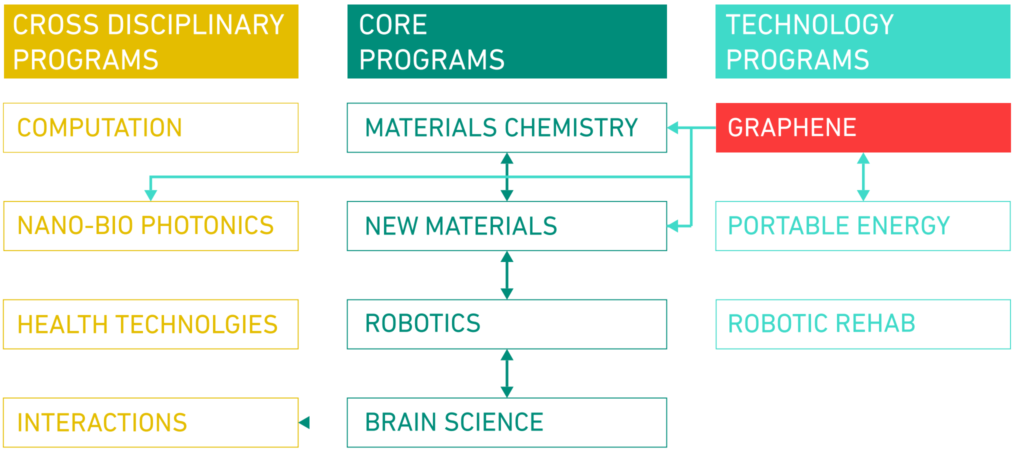


Fig.10 Correlations of the Graphene Program

The goal of the program is to develop a new class of materials based on graphene and on other two-dimensional (2D) layered systems. The target is for IIT to become one of the few recognized graphene centers worldwide, to contribute to the global effort to take graphene and other 2D materials from a state of raw potential to a point where they can revolutionize multiple industries. For this reason the program will have a strong fundamental activity aiming at producing state-of-the-art graphene monolayers of high crystalline quality on different substrates (metals, SiC etc) as well as inks employing solutions of graphene nano-flakes in different solvents. The materials-science effort will be supported by intensive physical, chemical and structural characterizations and by advanced computational simulations, to optimize material properties. Another main challenge of the Graphene Program is to develop, in cooperation with relevant industries, key prototypes ready for commercialization. In parallel, we also want to develop our own technology-transfer strategy.

The production methods that we will address range from wafer-scale 2D layers obtained by CVD and SiC sublimation methods, to production of 2D inks by liquid exfoliation. We want also to establish procedures for the printing/deposition of the inks on flexible substrates. The Graphene Program will be developed within the European Graphene Flagship effort (2013-2023) (http://www.graphene-flagship.eu). To further emphasize the European and global character of our activity we will set up specific agreements for exchange of students and staff on common research goals with two major graphene research centers in the world, the Graphene Engineering Center at Cambridge (UK) (http://www.graphene.cam.ac.uk/) and the Graphene center at the National University of Singapore (http://graphene.nus.edu.sg). Additional agreements with other centers will be explored (see Figure 11).

Figure 11. Main Graphene centers worldwide. The blue circle corresponds to the IIT Graphene Lab in Genova.

The mainstream lines of the program are listed below:

- Materials: primarily devoted to material fabrication by different methods, coatings based on graphene and new two-dimensional systems.
- Nanobiotechnology: dedicated to the study of graphene as biocompatible material at the interface with cells and to graphene-based hybrid interfaces and devices, such as lab on chips.
- Optoelectronics: devoted to the study and fabrication of novel graphene-based detectors and sensors with very high sensitivity.
- Energy: dealing with the study of novel contacts for batteries, photovoltaic devices and fuel cells.

SYNERGIES AND INTERACTIONS

Through the development of key prototypes, Program Graphene aims to establish a new set of potential applications for flexible, wearable and transparent nano-opto-electronic components, in collaboration with programs Materials Chemistry and New Materials. On the more technological side Program Graphene will develop graphene-based rechargeable batteries and organic photovoltaic modules, in collaboration with the Energy Program. Finally, the plan includes a significant effort to apply 2D layered materials in nanobiotechnology. In particular the use of graphene sheets as tumoral cells attractors to reduce metastatic processes will be explored, as well as the use of graphene layers for new smart supports for nanobiomaging, in collaboration with program NanoBio Photonics.

DEPARTMENT AND LABS

The program Graphene will be carried out primarily by the NanoPhysics Department (Graphene Lab and NIKON-IIT lab), NanoChemistry Department, with the contribution of the Neuroscience and Brain Technology Dept, the D3 PharmaChemistry, and the centers CNI@NEST, CNST@PoliMi, CBN@UniLe and CSHR@PoliTo.

P6: PORTABLE ENERGY

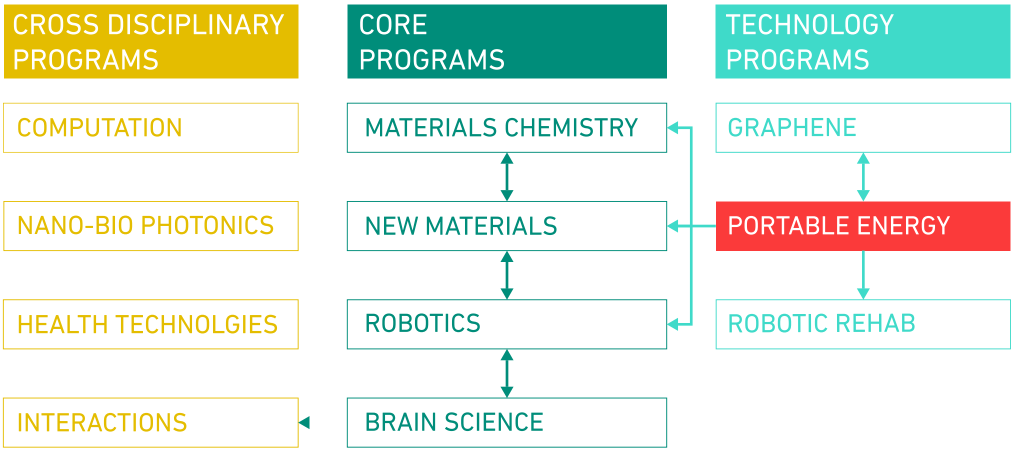


Fig.12 Correlations of the Portable Energy Program

Research and development of new renewable energy sources is a major effort worldwide. In its Horizon 2020 roadmap, the European Commission lists "Energy" among the most important societal challenges to be faced in coming years. There is an urgent need for high-performance carbon-free technologies to reach the 2020 and 2050 targets for CO_2 emissions, as set by EU policy. In addition to the need for sustainable energy sources, there is an increasing demand of energy, which will grow by 56% between 2010 and 2040, according to US EIA's recently released international energy outlook. This energy demand can be only faced by new approaches and technologies for efficient harvesting, conversion, and storage of the huge amount of renewable energy available in the environment. While the overall investments in the field are orders of magnitude larger than that of the entire IIT, we will nevertheless make an impact by adopting a very selective strategy. To best utilize IIT's strengths, we have chosen to pursue a niche of technologies and devices which are specifically conceived for portability, in the power range below 1 KW. The target is twofold. First, we intend to develop integrable, lightweight energy sources to endow robots with power levels comparable to those of humans, ~1000 W. Second, the 100-1000 W range is the typical power range of domestic and consumer electronics (refrigerators, TV, microwave ovens, interior lighting, etc.), which account for approximately 20% of the global power consumption in advanced countries. However, surprisingly, the 100-1000 W range is poorly covered by existing technologies, which instead privilege small batteries (below 10W) and high-power batteries for automotive application. Thus the development of novel sub-kW portable energy sources could have a strong commercial impact, beyond the application to robotics.

This Portable Energy program will target the development of conformable, lightweight portable materials and devices for harvesting, converting, and storing energy. We envision applications such as autonomous robots, small vehicles and energy-self-sufficient buildings, operating indoor, outdoor or embedded in humans and robots. This technology could dramatically improve the autonomy of portable electronics or robotics, enabling wireless remote sensors and human-implanted biosensors, and it could facilitate new paradigms for large-scale renewable energy production from sun, air, and water. In addition, we will explore approaches to mimic natural metabolic pathways to exploit organic fuels as energy sources (e.g., glucose, ethanol, organic waste).

The program will be based on four mainstream lines:

ENERGY CONVERSION

- Piezoelectric energy harvester
- Triboelectric and electrostatic energy harvester
- Electromagnetic energy harvester
- Thermoelectric devices

PHOTOVOLTAICS

- Flexible, portable photovoltaics
- Perovskite based devices
- Multifunctional photovoltaic devices

FUEL CELL TECHNOLOGIES

- Electrochemical fuel cells (polymer-electrolite fuel cells)
- Bio-electrochemical fuel cells (enzymatic and microbial fuel cells)

ENERGY STORAGE

- Hydrogen storage by graphene
- Novel approaches to Li batteries

SYNERGIES AND INTERACTIONS

The synopsis of the Portable energy program is displayed in Fig.12. The materials and technology solutions developed by the Graphene, New Materials and Materials Chemistry programs will be tested and optimized in a continuous collaborative effort. The Portable Energy program will provide the new energy sources primarily to the Robotics and Robotic Rehab programs to make all IIT-developed machines self-powered.

DEPARTMENTS AND LABS

The Departments involved in the Portable Energy program are Nanochemistry (Li-batteries Lab), Nanophysics-(Graphene Lab), ADVR and iCub Facility. The Centers are CLNS@Sapienza (Li-batteries Lab), CSHR@PoliTo (fuel cells), CNST@PoliMi (printed photovoltaics, perovskite and thermoelectrics), CMBR@SSSA, and CBN@UniLe (new materials for energy harvesting).

P7: ASSISTIVE AND REHABILITATION ROBOTICS

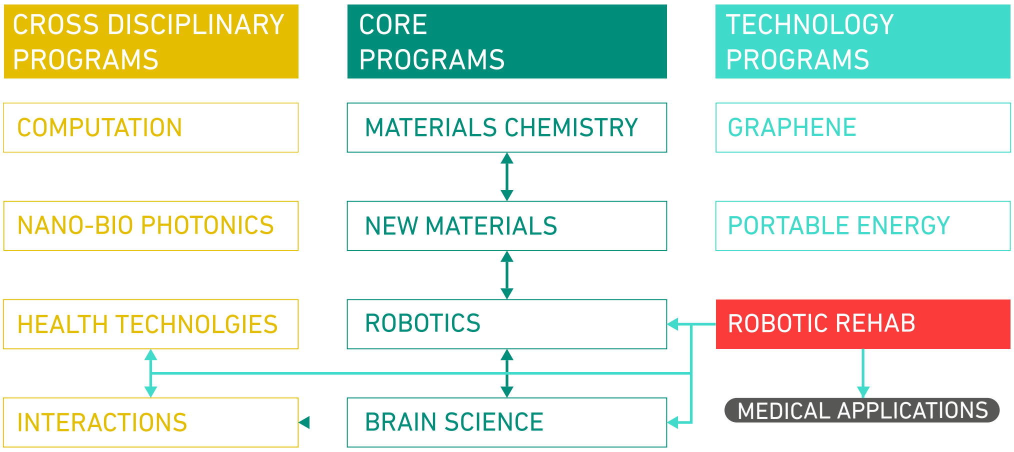


Fig.13 Correlations of the Assistive and Rehabilitation Robotics Program

The Assistive and Rehabilitation Robotics program addresses the needs for the deployment of robotics to help people recover from severe physical trauma or assist them in Activities of Daily Living (ADL). Building on the know-how provided by the ROBOTICS program, the Assistive and Rehabilitation Robotics Program will develop a number of specialized platforms, such as robots that assist humans with reduced mobility (exoskeletons), rehabilitation (therapy), as well as substitutes for missing limbs (prosthetics devices). All these specialized platforms share the common feature of soft robotics technology, for enhanced safety, compliance, adaptation, etc.. Due to its unique expertise in soft robotics, IIT is in a leading position to create a new generation of robots for human assistance, orthopaedic rehabilitation and prostheses.

With increasing life expectancy in Europe, it is predicted that by 2050 the ratio of persons over 65 to those between 15 and 64 will be less than 1:2. This shift in demographics presents one of the most daunting social and economic challenges for Europe in the next 30 years. Robots that can assist humans could enable elderly or infirm persons to live more independently, reducing health care costs. The ageing of our population and the increasing expense of healthcare necessitate the development of innovative and cost-effective rehabilitation solutions, to improve quality-of-life and maintain independence. Robotics technologies could drastically enhance traditional rehabilitation techniques and devices, providing rehabilitation instrumentation, assistive exoskeletons, and prosthetic systems. Robotic approaches will also provide a rich stream of objective data to assist in patient diagnosis, prognosis, customization of therapy, assurance of patient compliance with treatment regimens, and maintenance of patient records.

Existing robotic technologies are still inadequate. Current state-of-the-art robots for these purposes have been designed following the traditional paradigm of rigid, heavy industrial manipulators that execute mostly pre-programmed motion trajectories related to a well-defined tasks. This paradigm does not allow the ability to compliantly adapt and to promptly - yet safely - interact physically with humans. Thus one of the major challenges in robotics is to move beyond traditional mechatronic solutions toward robots that are softer and safer, that are adaptable to direct physical contacts with humans (e.g., wearable exoskeletons), and that can be operated to assist humans in domestic, industrial or hostile environments. Surgical robots share similar requirements and provide another possible deployment of soft robotics applications.

Soft actuation and control technologies will not only provide safer robots, but will also facilitate higher performance in terms of efficiency, smoothness, and naturalness of motion. Mechanisms with adjustable mechanical impedance are essential to swiftly adapt to varying conditions and to store and release energy in different phases of dynamic motion, allowing more natural motion while consuming less energy. This basic approach will be applied to different body parts and different modalities of human-robot interaction, namely:

- Exoskeleton: balance, soft human-robot interaction, usability and advanced force control
- Prosthetics: low-cost, flexibility, weight and versatility for human-like grasping
- Rehabilitation robotics: assistive technologies, advanced interaction control techniques, sensing and biomechanical modelling
- Surgical robotics: advanced accurate control, specialized robot shapes, support to the surgeon's sensorimotor coordination during operation.

SYNERGIES AND INTERACTIONS

The Program Robotics Rehab will be strongly connected to the Robotics program (see Fig. 13). Most of the deliverables will be geared toward the external society, including the rehabilitation and clinical worlds, as well as high-tech manufacturing industries. Important connections are also envisaged with the Interaction program (primarily for the human-machine interaction point-of-view), with the Health program (for neuro-prostheses and related issues) and with the program Brain (for neuro-rehabilitation).

DEPARTMENTS AND LABORATORIES

The program Assistive and Rehabilitation Robotics involves the ADVR and the RBCS Departments, the iCub Facility, and the INAIL-IIT joint laboratory. Contributions to the R&D program will also come from the CSHR@PoliTo.

P8: COMPUTATION

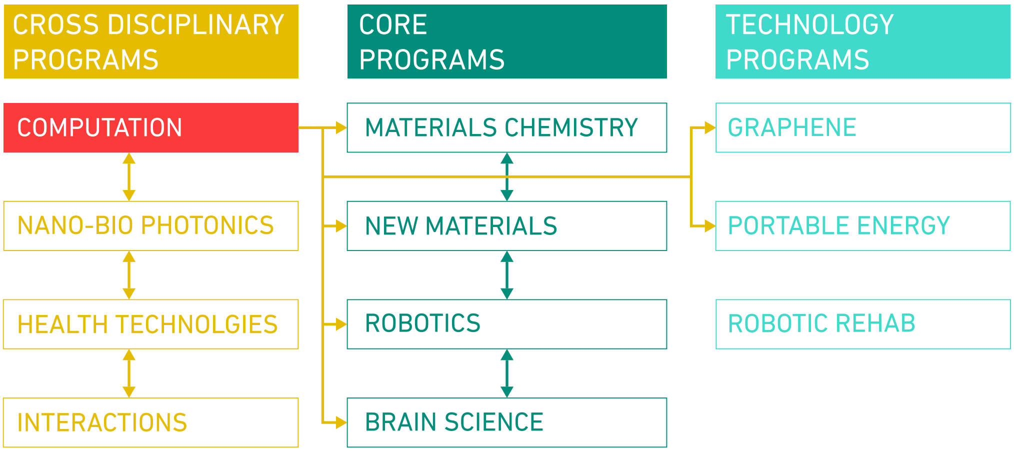


Fig.14 Correlations of the Computation Program

Computation is a national and international network of computational scientists with diverse and complementary backgrounds ranging from quantum chemistry to statistical mechanics and coarse-grained models. The main mission of Computation is to develop innovative multiscale methods and algorithms to tackle a wide range of scientific challenges. This strategy is built on the traditional strong position of Italy in computational-modelling science: it was one of the birthplaces of this key scientific discipline, giving rise to the school that educated many of the current scientific leaders in computation. Multiscale modelling has proven to be powerful in many theoretical and applied fields, including biology, chemistry, physics, mathematics, and engineering. The approach allows detailed investigations of complex phenomena by combining highly accurate methods to study the system at the level of the detailed physical process with less costly methods to treat the remaining model system. With this dual-pronged approaches, the models can reach huge dimensions, up to millions of particles. Multiscale approaches and methods are an important frontier in computational science, and are at the heart of Computation.

Computation is inherently inter-disciplinary: Computation theoreticians collaborate with experimental scientists to address challenging open questions in life sciences and material sciences. In the next 3 (to 5) years, Computation members will provide theoretical solutions and simulation tools for many IIT activities. One major objective of Computation is to develop new multiscale approaches combining quantum chemistry and statistical mechanics, to develop more realistic model systems of catalysis (biological or inorganic).

Computation is currently composed of 11 different centers located in Italy, France (École Nationale Supérieure de Chimie de Paris), and Switzerland (EPFL). Concerning the computational resources, Computation has a collaborative research agreement with a supercomputer center , which provides more than 1.5 million CPU hours per year to IIT. In addition, each center is equipped with small-to-medium-sized internal computer centers for pilot calculations and initial production runs.

Computation aims to become one of the main drivers of IIT development. The possibility to simulate and model complex system from the nanoscale to the macroscopic scale, in the wide variety of fields spanning pharmacology to material science, makes Computation one of the most ambitious programs at IIT. We plan to progressively enlarge the network by including other teams at the national and international level, to cover all the areas of the strategic plan. The ultimate target of Computation is to develop and integrate new codes for fully multiscale modelling and simulation. The long-term perspective is to provide open-source simulation software worldwide, and/or to commercialize the software through new IIT start-up. A pioneering test is presently underway through the start-up BIKI technology. BIKI was created by researchers of the D3 Department to bring to market new molecular dynamics-based computational and simulation tools for drug discovery.

SYNERGIES AND INTERACTIONS

The synopsis of the Computation, shown in Fig. 14, reveals the global impact of Computation on almost all the activity of the Institute. In the following table we summarize the currently participating team and the topics addressed so far by Computation.

DEPT./CENTER OR EXTERNAL SITE	R&D AREA
D3 NACH NAPH	Development in statistical mechanics for free energy and kinetics estimation in biomolecular systems; continuum media approaches; applications to drug discovery and material sciences; applications to quantum enzymology; computational nanotoxicology
CLNS@Sapienza	Development and applications in statistical mechanics
CNI@NEST	Development and applications of coarse-grained potentials for multiscale applications
CBN@UniLe	Development in density functional theory; applications in material sciences and computational plasmonics
CGS@SEMM	Genomic modelling
Pisa	Development in quantum chemistry (density functional theory); development and applications in computational spectroscopy
Perugia	Quantum chemical applications in material sciences
Cagliari	Quantum chemical applications in material sciences
Modena	Quantum and classical studies of hybrid organic/inorganic systems
Bologna	Development and applications in quantum chemistry and statistical mechanics
Trieste	Methodological advanced of enhanced sampling techniques; applications to nucleic acids functional and structural characterization; development of QM/MM interfaces for multiscale codes
Paris	Development in quantum chemistry, mainly in density functional theory; applications to study graphene properties
Lausanne	Development and applications in the field of surface chemistry

P9: NANOBIO PHOTONICS

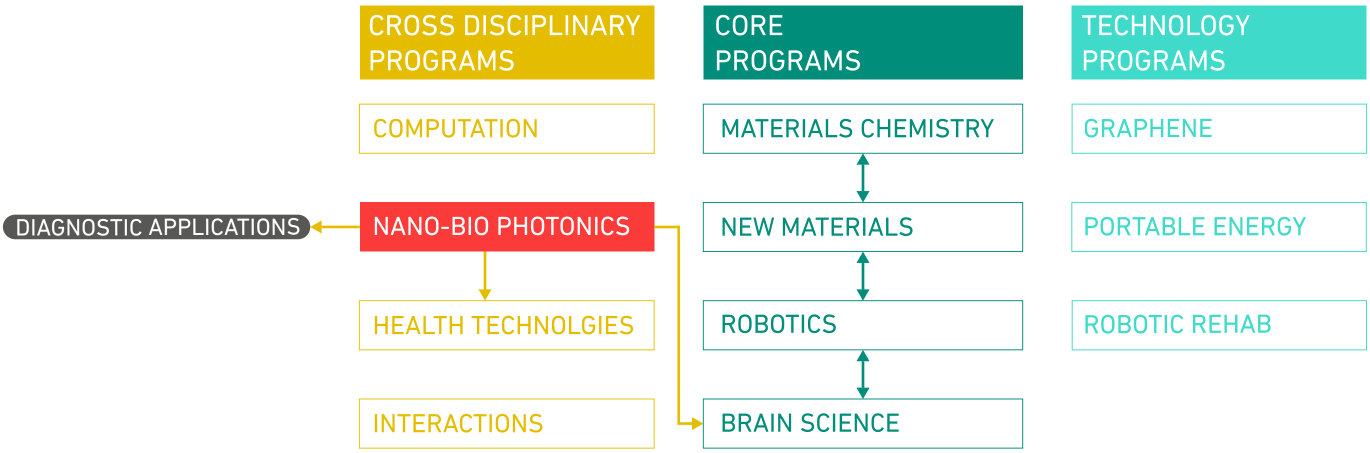


Fig.15 Correlations of the NanoBioPhotonic Program

The program NanoBioPhotonics deals with research and development in the field of imaging biological matter at nanoscale, with high spatial and temporal resolution, in three dimensions, both in the linear and nonlinear regime, and in the presence of localized perturbations (localized emitting centers, magnetic fields, plasmons, etc.). The program develops along two mainstream lines:

- development of new instruments, in the frame of the new NIKON-IIT Imaging center established in Genova in 2014,
- fundamental studies of the electromagnetic interactions in biological systems.

The first research line deals with the development of multi-scale and multimodal correlative nanoscopy for versatile modular optical microscopes. This will allow us to develop different image contrast mechanisms, from fluorescence to label free signatures, able to push resolution to the nanoscale level (1-5 nm in materials science - 20-50 nm in life sciences) on a variety of samples, including three-dimensional, thick (>50 um) biological systems. The applications of those instruments include the study and characterization of oncological and neurodegenerative diseases, of tissue engineering processes and of new materials.
The development of new instruments will be based on Multiphoton/NIR in vivo nanoscopy, as well as on High Temporal and Spatial Resolution Microscopy. Super resolution in tissues and organs will be implemented combining in vivo tomography and single molecule tracking and super-resolution imaging.

A by-product will be novel laser-based direct-writing methods for the fabrication of micro and nanofluidic systems for lab-on-a-chip applications.
The second research line is based on the ability to control and handle the electromagnetic interaction at the nanoscale - interconnecting plasmonic nanodevices and/or suitably designed nano-antennas to neuronal networks (or any other living cell network) to study by enhanced Raman spectroscopy or other optical methods the network operation with unprecedentedly high spatiotemporal resolution. The research activity will be oriented to the exploitation of 3D nanofabrication techniques to design novel plasmonic 3D nanomaterials that can probe the intrinsic organization and operation of cells and tissues.
Plasmonics will allow to perform enhanced spectroscopy on thermo-porated neural cells, as well as to understand the dynamics of neurotransmitter and second-messenger systems in the brain. Moreover, the proposed combination of plasmon-based devices and NMR can open new perspectives for in-vivo sub-cellular tracking, restricted diffusion imaging and functional NMR at the micro/sub-micro level.
The experimental neuro-plasmonic research program will be supported by extensive data analysis in collaboration with the Computation Program.

SYNERGIES AND INTERACTIONS

Internally, the NanoBioPhotonics program will interact mainly with the Health and Brain Programs, for the development of innovative micro devices as diagnostic tools (e.g., super-resolution microscopes). A significant effort will be directed towards instrument development for external markets, such as the diagnostics market (e.g., hospitals, pharmaceutical companies, etc.), ranging from implantable devices to high-throughput diagnostic platforms. Further applications are expected for characterization of new materials.

DEPARTMENTS AND LABS

The program will be developed primarily by the IIT-NIKON joint lab, by the Plasmon Nanotechnologies Lab teams of the Nanophysics department, and by PAVIS. Contributions will be provided by the Graphene Lab, the NBT department (Microtechnology for Neuroelectronics), and by the centers: CNST@UniTn, CLNS@Sapienza, and CNI@NEST.

P10: HEALTH TECHNOLOGIES

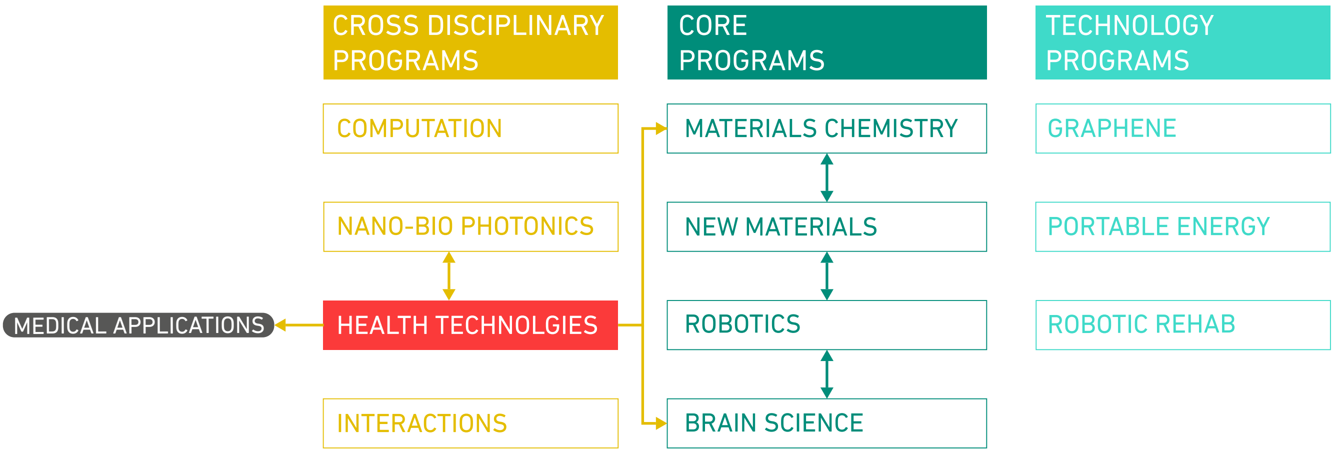


Fig.16 Correlations of the Health Program

The goal of this program is to develop a new generation of therapeutic approaches that will improve the treatment of a disease, address the underlying causes and biological mechanisms, and modulate its progression. The main focus of the activities will be on cancer, but the flexibility of the modular strategy allows straightforward extensions to other pathologies by simply selecting the right module combination.

NANOPARTICLES BASED THERAPY: INTELLIGENT DRUG DELIVERY.

Nanotechnology is developing promising new materials for fighting cancer, cardiovascular and neurodegenerative diseases. Progress with respect to the current state-of-the-art will arise by engineering intelligent drug delivery systems (IDDSs) able to extravasate and accumulate at much higher concentrations onto the tumor. This will be achieved through different strategies: at the microscale size, shape and stiffness will be key parameters, whereas at the nanoscale colloidal stability, stealth properties, targeting and overall size will play an important role. Magnetic, semiconductors and metal nanocrystals can be exploited as nano-heating probes for hyperthermia by triggering with an external excitation source. This offers the great advantage of generating a heat in the proximity of the nanoparticles, to specifically kill cells only near where the particles accumulate (for instance a tumor mass). The same types of nanoparticles can also be functionalized with thermo-responsive polymers to induce controlled release of drug molecules associated with the nanoparticles (e.g., chemotherapeutic agents or short oligonucleotides). Polymeric/organic carriers will also be developed to promote direct targeted cytosolic delivery or targeted receptor-mediated endocytosis.

NANODIAGNOSTICS

The team will develop hybrid nanosensors for genes, enzymes, bacteria, small analytes and cells, based on nano-plasmonics. The basic idea is to develop low-cost, disposable sensors in solution that change color when they detect the targeted species. The basic principle relies in the hybridization of the target molecules with small (<20 nm radius) metallic nanoparticles acting as plasmonic antennas. Upon hybridization/recognition, the plasmonic frequency of the nanoparticle changes, resulting in a global change of the optical absorption, i.e., the color of the solution. The sensitivity of such devices is orders of magnitude higher than corresponding lab analyses, due to the strong enhancement of the optical response induced by the plasmonic effect. Devices of this kind have applications in the fields of diagnostics, safety, and food control, and open new directions for point-of-care technology.

NANOTOXICOLOGY

Approximately 30% of current manufacturing exploits artificial nanocomponents of size well below 100 nm. These include oxide, metallic and semiconductor nanoparticles of various size, shape and composition, that are used in cosmetics, coatings, home goods, plastics, mechanical parts, etc. The interaction of these nanocomponents with the human body over the course of a lifetime is not fully known, because it depends on many different parameters, such as the nature of the particles, the route of uptake (dermal contact, ingestion, respiration, etc), and the dose. There is thus a strong need for basic research to clarify the interaction of nanoparticles with living systems, including metrological assessment of the particles, uptake control, pharmacokinetics and in vivo tests in suitable animal models, with the goal of producing a body of data that can inform the establishment of regulatory guidelines. The IIT Nanotoxicology line is a pioneering systematic attempt to create such a pipeline of activity, through the unique combination of nanotechnology groups fabricating metrologically controlled prototype nanoparticles, biochemistry groups investigating biological reactions in vitro, and pharmacology teams studying pharmacokinetics and toxicity in vivo.

MOLECULAR-BASED THERAPIES

This research line deals with the development of molecular therapies for specific diseases. The activity traces back to the longstanding drug-discovery efforts of the D3 department, and will deal primarily with three lines: (i) New approaches for cancer therapy, (ii) Structure of membrane proteins, and (iii) Search of new drugs for the treatment of cystic fibrosis.
These activities will exploit the support of the experimental and computational genetic research programs of the IIT center CGS@SEMM.

SYNERGIES AND INTERACTIONS

Program Health will be linked to NanoBioPhotonics, Materials Chemistry and to Brain Programs, and very likely most of the deliverables are geared toward clinical applications.

DEPARTMENT AND LABORATORIES

The program will be developed by teams operating in D3, Nanochemistry, Nanophysics, NBT, and at the centers CGS@SEMM, CLNS@Sapienza, CNI@NEST, and CBN@UniLe. Collaborations with external hospitals will also be established.

P11: INTERACTIONS

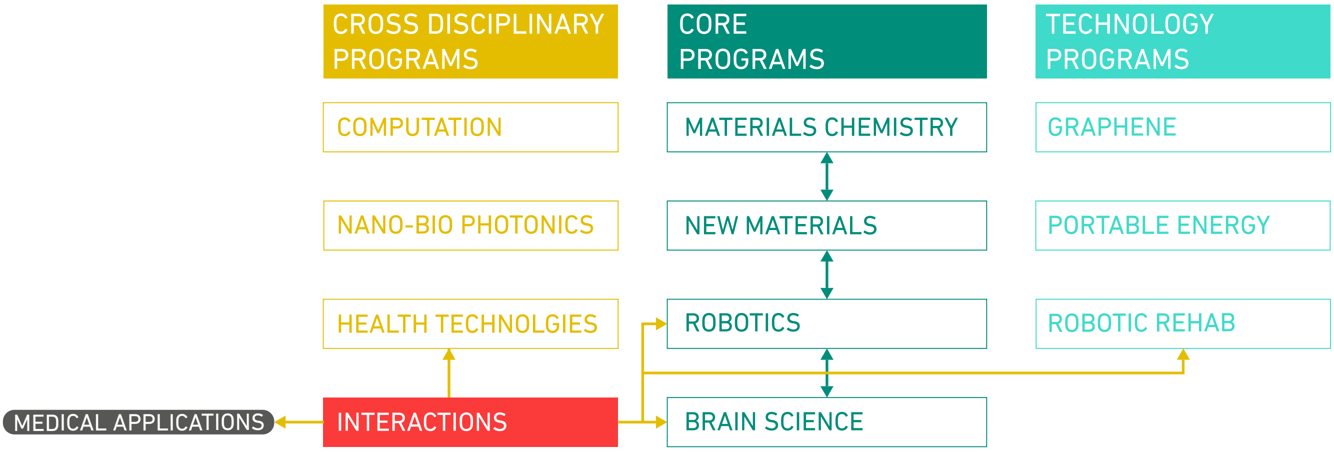


Fig.17 Correlations of the Interactions Program

Human perception, action and cognition are geared to enable coordination and communication with others. Consequently deficits of cognitive, sensorial and/or motor abilities impacts on the social life of humans, leading to marginalization. In this light, the three main objectives of the Interactions program are:

- To study the sensory, motor and cognitive abilities in supporting and guiding human-human interaction, by actions, gestures, speech and language;
- To implement artificial systems with human-like interaction/communication and cognitive abilities;
- To investigate how "defective" sensorimotor systems could be substituted/enhanced through the use of assistive technologies to help affected individuals to orient and move in space and to access everyday information, and to restore, even by direct brain interfaces, lost interactive/communicative capabilities.

The Interactions program is characterized by two distinctive ingredients: the first is the prominent role of "communication" (explicit and implicit, verbal and non-verbal), and the second is the role of sensorimotor and cognitive development as an essential guide to understand human-human interaction. We propose to go beyond reactive interactions to investigate the role of prediction in collaboration between agents. The knowledge in this area of research must be multifaceted, to establish links between the factors involved in interaction rather than concentrating on specific facets.

From the scientific perspective, the project will investigate sensory, motor and cognitive aspects of verbal and nonverbal interactive behaviours and communication in humans, including their neurophysiological correlates, as well as the implementation of computational and robotics models of collaborative behaviours. From the technological perspective, we intend to develop technologies and rehabilitation procedures to substitute debilitated functions by enhancing/exploiting intact functions. Restoring sensorimotor abilities needed to orient and move in space, to communicate and access information are essential for social interactions.

The program will be articulated in three main streams of research.

1. MOTOR COGNITION, INTERACTION AND SOCIAL INCLUSION

- The development of multimodal integration and social inclusion
- Understanding human interaction with the physical world through touch
- Sensory enhancement and inclusive technologies for spatial awareness
- Action reading and social behavior in human-human and human-robot interaction
- Intentions in interaction
- Actions, syntax and sensorimotor interaction

2. SPEECH AND COMMUNICATION

- Neurophysiological study of speech communication
- Motor mirroring and automatic speech recognition
- Neuroprosthetics for speech and rehabilitation

3. MULTIMODAL BEHAVIOR ANALYSIS: STUDIES ON HUMAN AND MACHINE INTELLIGENCE

- Human Nonverbal Behavior Understanding and Social Interactions
- Neural Bases of Human Behavior
- 3D Man-Machine Interaction

These research activities have clear and strong potential links with groups working on cognitive aspects of human behavior and perception, cognitive robotics, human and robot motor control and biomechanics. In addition, technologies to facilitate social inclusion described here could be linked to robotic rehabilitation. The two fields have strong technological overlap even if with different research goals., e.g., haptic interfaces. Other important potential links are with new materials, such as for the design of tactile displays and touch-sensitive surfaces.

SYNERGIES AND INTERACTIONS

Program Interactions will be complementary to the Robotics rehabilitation Program. Whereas the latter will primarily focus on physical interactions (orthopaedic rehabilitation, prostheses, etc.) the former will focus primarily on neuro-rehabilitation and cognitive interactions. The program will have strong links with Program Robotics and Program Brain Science. Ultimately we expect program Interaction to produce important outcome towards the clinics, especially for the rehabilitation of patients with sensory deficits.

DEPARTMENTS AND LABS

Program Interactions will be carried out primarily by the RBCS and PAVIS Departments. Contributions will also come from the iCub Facility, and by the center CNCS@UniTn.

In conclusion, the IIT Strategic Plan 2015-2017 is largely based, as outlined above, on a unified development of traditionally independent technologies. Material science and nanotechnology provide multifunctional materials and molecular scale engines of transformation to create complex entities, to be used both in living and artificial systems. Electronic and engineering add mechanical and computational capability to these entities, which in turn provide intelligence and enable interaction between humans and machines. Cognition, social behaviour and other higher level capabilities can be accomplished by imitating human brain processes. These facts explain why the fantastic nexus between molecules, body, and brain that evolution has developed over billions of years is the inspiring model for science at IIT.

LOGISTICS: EXTENSION AND OPTIMIZATION OF EXISTING INFRASTRUCTURES

Space has become a main limiting factor for the growth of IIT: (i) the expansion of the scientific activity,(ii) the increased attractiveness of foreign scientists (e.g., ERC, Armenise, etc.), (iii) the need to update and upgrade the existing laboratories to keep competitiveness with respect to other international institutions, (iv) the increasing number of new projects, industrial collaborations and start-up activities, require the extension of the existing infrastructure. In the past 3 years IIT created 160 new positions on external grants and some 45 new jobs connected to the new start-up companies. This means that approximately 1/6 of the total headcount is funded externally and could not have been be accurately forecast when the original infrastructure was designed. It is thus mandatory to have an expansion plan for the next 3 years. In addition, the infrastructure of the Morego center needs a substantial improvement to maintain peak international competitiveness. IIT made a tremendous capital investment in the last 3 years, including a 250-seat cafeteria for the staff, a 400-seat auditorium and a new parking area. The completion of the Morego Hill campus also urgently requires a nursery school, due to the low average age of the staff and the commitment to create equal gender opportunities at IIT. In addition, it would be extremely useful to have a guest house for visiting scientists and for newly hired extra-European scientists at the very beginning of their contracts.

In view of these requirements, a concerted effort should be made in the next three years to complete the Infrastructure on Morego Hill, including new building of up to 5000 sqm, primarily funded by donations received by IIT in 2014. The construction could proceed in a modular basis. The campus will stretch along the west side of the hill adjacent to the current perimeter wall, so as to contain 2-3 building blocks hosting the nursery school, guest house, faculty club, light laboratories and offices. Such an extension would also include operating the most up-to-date co-generation energy systems capable of producing up to 1 Megawatt donated by ENEL (National Energy Company).

Fig.18 Rendering of the new building on the west side of the Morego headquarter.

At the moment negotiations on land transfer are underway with the Municipality of Genova and with both the Municipality and Regione Liguria to ensure stability of the land assets (be it either donated land or land leased for a very long period of time).

Fig. 18 shows a preliminary working scheme, subject to further analysis.

The total logistic expansion would increase the global size of the Morego Facility up to approximately 40,000 sqm, which is the intrinsic limit of the available area.
The completion of the Morego Hill campus cannot be delayed, since it is crucial to effectively accommodate (i) the research activities and projects already launched (compliant with safety rules and operational requirements for the laboratories) and , (ii) the start up phase of the new research activities foreseen in the short to mid term (2017), as discussed in section 1.4.

TECHNOLOGY TRANSFER: CREATION OF A PRIVATELY OWNED BODY TO EXPLOIT IIT INTELLECTUAL PROPERTY

A critical issue faced by IIT in the transfer of technologies from lab to market is the scarcity of capital dedicated to funding seed companies (in Italy and, to a less serious extent, in Europe). Investors in seed and venture funding are often confined to narrow timeframes for their investments. On the other hand, IIT research is focused on the "hard sciences", disciplines that require heavy investments in equipment, laboratories and certifications (robotics, neuroscience, material science, etc.). Therefore, while IIT can supply start-up companies with the needed infrastructure and cultural environment, these business venture will normally require an incubation period of about 4-5 years before finding their way on the market. Such trajectory requires adequate funds, often in the range of a few million to tens of millions of euros, and long-term perspective, before they can significantly impact global markets.

Such a situation has a two main consequences:

- the pipeline for growth-capital investors, who normally provide larger amount of funds to start-up with established business models, is weak. A poor offer of start-up will not attract large venture capital investors; these players will then invest less, making it difficult for start-up companies to grow their liquidity beyond seed investments to reinvest in new deals. Augmenting the seed capital investments will allow start-up companies to break out of this negative loop .
- the most promising technologies and teams leave the country to find their way in more dynamic economies. A new investment tool in Italy could help these teams to retain their ventures in Italy, creating a start-up culture in our country.

In this context, the strategic plan 2015-2017 proposes to set up a mixed private/public-owned investment vehicle to boost IIT Technology Transfer. The vehicle shall have either the form of an investment company or an investment fund, and will be dedicated to IIT technologies, therefore adopting adequate policies in terms of seed-investment amounts and timeframes for exits. IIT's participation in such a project will be crucial not only for its scientific contribution, but also to provide an anchor investor to attract co-investments from the private sector, which ultimately will provide the majority of the collected resources. The investment vehicle (in the following referred to as "IIT Solutions"), should accelerate the birth of start-up companies and increase the value of IIT's intellectual property. "IIT Solutions" could solve two problems: i) it could reduce potential conflicts-of-interest by separating the role of the IIT researchers from that of the IIT "developer/entrepreneur" after the start up phase, and ii) it could avoid the ongoing and time-consuming search for external investors for the different IIT activity areas. IIT Solutions would provide the two major tools necessary to develop a new high-tech company:

- Immediate capital availability to launch and develop high-tech start-ups financed by means of share capital.
- The availability of the IIT facilities as part of the support in the early phase of the start up.

Considering duration, mission and average size of the recipients, the Fund may hypothetically have a duration of 10-15 years and a volume of around 20 million Euros, less than 50% of which under IIT's control, to maintain a predominantly private character. The public part of the Fund could come from the IIT endowment, whereas the private part should come from fundraising action by the Technology Transfer Office of IIT.From an organizational point of view, one option could be to have IIT involved in setting up a "Società di Gestione del Risparmio" (savings management company or SGR) tasked with the promotion and management of a joint investment fund while acting as business incubator in the initial phase (see Italian Legislative Decree n. 58/98). As to the attraction of risk capital, the SGR is considered the most transparent and consolidated company model by financial operators (both investors and supervisory bodies) active in this sector. "IIT Solutions" may hypothetically finance experimental/embryonic activities in different ways, namely:

- Seed capital: financing the first development of a technology (pre-engineering phasetypically corresponding to the incubation phase)
- Start up: financing the initial production phase of the company Expansion (subsequent enlargement and development phases).

The IIT participation in the Fund has the following advantages:

- the initial fixed costs connected to high-level infrastructure investments on behalf of incubated companies would be replaced by variable costs in the form of fees;
- the structure will be operative at the national level thanks to the presence of the IIT network. This will foster the development of start-up companies born out of research poles, and promote interactions with other local business incubators which can provide experience and ideas (e.g., I3P Incubator from Politecnico di Torino and other similar initiatives);
- IIT could host ad hoc joint-lab initiatives as well as manage industrial projects.

The Fund exit strategies may be expressed by:

- trade sale to sector-related companies or other investors (including the entrepreneurial team holding the remaining share volume);
- initial public offering (IPO) (to be checked against the reference financial scenario).

To date, the "IIT Solutions" technological interests revolve around the following areas:

ROBOTICS

- actuators and new generation sensor technology;
- humanoids (initial sale of platforms to research centres and the R&D units of major industrial groups);
- robotics for rehabilitation and neuroprosthesis;
- microrobotics for diagnostic technology.

LIFE TECHNOLOGY

- New in vivo and in vitro highly sensitive diagnostic techniques;

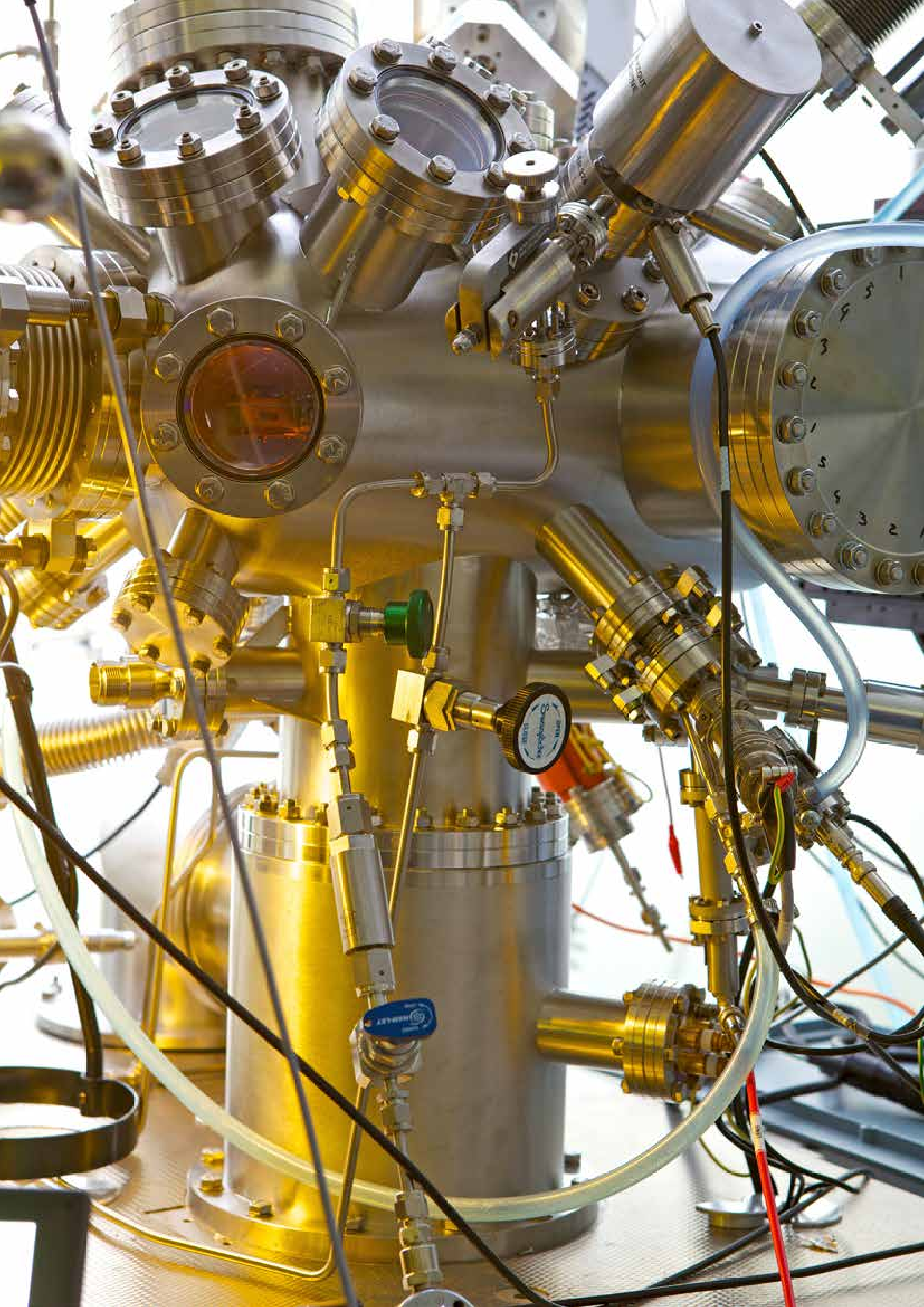
NANOTECNOLOGIES AND MATERIALS

- Nanomaterials for drugs release and diagnostics;
- Nanocomposites: ultra-light, fibrous, reinforced materials, cultural heritage etc ...;
- Nanotech surfaces: hydrophobic, self-cleaning, oleophobic surfaces etc ...;
- Chemistry of nanofillers enabling modification of the properties of any material;
- Development of instrumentation and metrology;
- Nanotoxicity for food and environment;
- Low-cost plastic photovoltaics (PV).

ICT

- Numerical models and computational methods for miscellaneous applications;
- Image analysis for the biomedical and safety field.

These technologies can potentially impact a wide and transverse spectrum of industrial sectors: automotive, automation, health care, energy and environment, textile industry and, more generally, all industrial sectors where the focus is on high tech materials, services and processes. In essence, these industrial sectors represent a key strategic asset for the development and competitiveness of the national economy.



15
-
17

ISTITUTO
ITALIANO DI
TECNOLOGIA

Via Morego, 30,
16163 Genova, Italy
T: +39 010 71781
F: +39 010 720 321
www.iit.it