INFORMATION AND COMMUNICATIONS TECHNOLOGIES

ICT PORTUGAL: AN ENTREPRENEURIAL RESEARCH INITIATIVE

A ROADMAP FOR THE SECOND PHASE OF THE CARNEGIE MELLON PORTUGAL PARTNERSHIP

2012-2017

May 19, 2012[1]

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[1] This is the Final Version of the Roadmap for the Phase 2 of the Carnegie Mellon|Portugal Program and replaces the draft dated March 31, 2012.

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EXECUTIVE SUMMARY

By connecting major universities, research institutions and high-tech companies in Portugal, with schools, research centers and institutes at Carnegie Mellon University, and focusing on **key strategic areas** of **information and communications technologies** (ICT) where **Portugal can gain competitive advantages**, the Carnegie Mellon | Portugal Program has had a **tangible impact** on the scientific culture, the research output, and the entrepreneurship capability of the ICT sector in Portugal. This was recognized as a first overall conclusion by the recent "Independent Assessment" carried out by the Academy of Finland[2] that recognized its "great potential in promoting R&D&I, and cultural change, [with its] ambitious agenda for taking Portugal to the next level in innovation activity."

Since the initial kick-off in October 2006, partners in Portugal and at Carnegie Mellon have succeeded in establishing nine **dual degree PhD programs**, launching five dual **Professional Master's programs**, developing **high quality research** that has led to **hundreds of publications** in the best venues, **recruiting high quality faculty, researchers, and students** in Portugal and internationally, and establishing a number of collaborative research, development and innovation efforts, in which **industry and academia join forces** to create new scientific knowledge, solve real-world engineering problems, and deliver products and services that can be exported worldwide. Again, the Academy of Finland's report in its overall conclusions recognized that "internationalization…," "through positive international attention and visibility gained through the program," "increased collaboration within Portugal, and cultural change have all been positively influenced."

After five years of intense collaboration (*Phase I),* the Program is expected to enter a new period (*Phase 2*), aimed at **consolidating**, **extending**, and **reaping the full benefit** of the investment made in Phase 1 and **leveraging the innovation capacity** of the **Carnegie Mellon Portugal knowledge network** for Portugal to affirm and increase its competitive advantages internationally. The purpose of this document is thus to identify the challenges and opportunities that are before us and set an ambitious roadmap for the period of 2012 to 2017.

In the aftermath of the financial crisis, Portugal now faces a number of challenges that threaten its desired trajectory towards greater prosperity and quality of life for its citizens. Building on the solid foundation and achievements of Phase 1 of the Program, Phase 2 is focused on the **core goal of a strong impact on the innovation potential and the economic development of Portugal** through **cutting edge research**, **world-class graduate education**, and **successful entrepreneurship and knowledge exchange** from academia to industry and back. The Program should serve as a vehicle to foster even stronger ties between Portuguese Universities and Carnegie Mellon and among Portuguese partner institutions and companies, while connecting them to key global networks and creating new opportunities for the **Portuguese export sector to expand internationally**. Ultimately, its activities and outcomes should contribute to help Portugal regain steady growth leading to greater prosperity and quality of life for all its citizens.

It is extremely important to recognize that the **successful entrepreneurship and knowledge exchange** between academia and industry does not occur in a vacuum. **Successful entrepreneurship and knowledge exchange** requires a long term view and emerges from high quality educational and research

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[2] *Independent Assessment of Portuguese Collaboration with US Universities in Research and Education.* International programmes between Portuguese universities and Carnegie-Mellon, Massachusetts Institute of Technology (MIT), and University of Texas at Austin,* Academy of Finland, Working Paper, January 2012.

programs that contribute to an ecosystem that fosters creativity and entrepreneurship at the same time. Technology transfer is a *"contact sport"* and the CMU|Portugal Program nurtured from the very beginning its endeavors, academic programs and research projects, to partner University faculty and students with company researchers. Our dual degree Professional Masters, our dual degree PhD Programs, and our research projects were intimately connected to companies: companies supported their employees as students recruited by these programs; companies helped define projects and research activities pursued by students; companies recruited our graduates; research projects *had to* include companies' researchers as partners; and companies were integral participants in the entrepreneurship and technology transfer activities of the Program. The Academy of Finland report emphasized that "the overall Programme approach and model [were] well thought-out and the focus areas (education and training, collaborative projects, innovation and entrepreneurship) complement[ed] each other very well." Phase 2 is structured to strengthen and emphasize these goals by reinforcing a ecosystem where high quality academic and research programs carried out in dual degree Professional Masters and dual degree PhD Programs are immersed in a culture of partnership between universities and companies researchers.

From a thematic viewpoint, the Program presents a **new roadmap** with an academic and research agenda that, while evolving some of the original strategic areas, introduces new ones, where Portugal is believed to have the potential to develop comparative advantages. This emphasis conforms to the directives and goals of the *Guidelines* as developed and presented by the Secretary of State for Science (SEC) and by the President of the Fundação para a Ciência e a Tecnologia (FCT).

Beyond the traditional funding mechanisms of FCT, Phase 2 introduces a **core integrated program** that supports a **core of high quality dual degree academic and research programs** with **new instruments**, most notably **Entrepreneurial Research Initiatives (ERI)** that target important social-economic challenges and will serve as innovation platforms for collaboration among academics and industry professionals. This core will assure the minimal level of research activity and talent needed to guarantee that Phase 2 will meet the recommendations of the Academy of Finland and of the Guidelines of the SEC and FCT by crafting the three major ingredients for successful technology transfer: **World class research**, **World class talent**, with **World class partners**.

The Phase 2 **core will be supplemented by complementary instruments** that will expand its education and research activities, by augmenting the levels of research funding and number of students and faculty involved.

We believe that the Carnegie Mellon Portugal program will continue to serve as an important vehicle for attaining world-class excellence in **graduate education**, **science**, **technology**, and **entrepreneurship** for the benefit of Portuguese society.

01 GOALS OF THE CARNEGIE MELLON PORTUGAL PARTNERSHIP

The Carnegie Mellon | Portugal program is an **educational**, **research**, and **innovation** platform aimed at developing an **ecosystem of high quality (dual degree) graduate academic and research programs** that foster the emergence of new concepts in information and communication technologies, with an **orientation towards new products and services for markets worldwide**, while leveraging a vibrant and young research community as well as the unique positioning of Portugal to serve as a platform to deploy, test and demonstrate advanced technologies and systems in unique large scale testbeds. The

core program has two major goals: **Talent development**, through dual degree PhD and Professional masters and faculty exchange programs; and **research in potentially commerciable technologies** by fostering interdisciplinary projects where integrated teams from universities and companies work and play together in defining and pursuing commonly defined goals and meeting commonly accepted milestones. The emphasis of these two goals is placed on key focused areas of ICT, continuously under discussion in the scientific and industrial communities.

This joint venture was launched in 2006 and is achieving its goals through an open, broad and deep collaboration. Phase 2 will build upon a multi-level partnership among Portuguese research institutions, universities and companies in cooperation with Carnegie Mellon University. **Key to the success** of Phase 2 is the **strong and intimate partnership** between **faculty** at Portuguese Universities and at Carnegie Mellon. This intimate collaboration will be achieved through the **shared goals** and **common responsibility** of developing **dual degree academic programs**, educating and **coadvising** dual degree students, and **engaging** with **industrial partners** in **high quality research** projects. For the period 2012-2017, Phase 2 will strengthen and foster strong consortia specialized in academic and research programs in the ICT areas with potential impact in international markets, while facilitating a new generation of leaders with a global perspective and unique research and entrepreneurial capabilities.

02 ACHIEVEMENTS OF PHASE 1

After five years of intense activity, the Carnegie Mellon Portugal program has reached a successful steady state, featuring innovative research projects with strong industrial participation, stable educational programs that foster collaboration across multiple Portuguese universities, and a constant flow of people and knowledge between Portugal and the United States. Through these constituents, domestic institutional change, international visibility and economic impact are becoming increasingly palpable.

Numerous examples, projects and success stories demonstrate how the Program is creating new knowledge and contributing to the development of unique capabilities for Portugal in key focused areas of information and communication technologies (ICT). Signs of a positive change of culture towards greater entrepreneurship in several Portuguese universities and their departments become visible, induced by the exchange of faculty, students and best practices both with Carnegie Mellon and among the Portuguese participating institutions.

The success of the first phase of the Program is evident in the achievements in the following two major areas.

TALENT DEVELOPMENT

- **Establishing nine dual degree PhD Programs**: The Program established nine dual degree PhD Programs between several Departments at Carnegie Mellon and nine Universities in Portugal. These have recruited over 80 PhD students that are coadvised by at least one faculty member from Carnegie Mellon and one faculty member from a Portuguese University. These students (and their advisors) have carried out their research and fulfilled their dual degree Program requirements seamlessly, bridging the activities of the two groups across the ocean, and acting as catalysts for change and adoption of best practices. They have produced high quality research archived in several hundred publications and recognized by their peers through awards at the best venues in their fields.

- **Advanced Professional Training:** Professional Master's programs in Human-Computer Interaction, Information Networks, Information Security, Software Engineering and Entertainment Technology led to new forms of professional education in Portuguese universities and have been key to strengthening the ties among industry and academia. More than 150 professionals were recruited for training. Their companies of origin recognize the value of these Programs and support students

either by providing fellowships or supporting their employees for the full 16-month duration. Teams of 3 to 5 Professional Master students involving faculty and companies completed about 15 projects. The Professional Masters Programs witness close to 100% employment of their graduates and are provide them with a competitive edge that is recognized both by the companies and by the students themselves.

- **Dynamic Faculty Exchange:** The Carnegie Mellon|Portugal Program established a nationwide faculty exchange program that supports a semester long visit of a Portugal faculty member at Carnegie Mellon where this faculty member is a visiting professor and belongs both to a team teaching a course and the research team of their Carnegie Mellon host. Currently, around 30 faculty members (mostly young assistant professors) have participated in this faculty exchange program. They return to their institutions in Portugal as energized contributors to change, often leading the implementation of new processes to bring them closer to best international practices.

FOSTERING JOINT RESEARCH AND COMMERCIALIZATION

- **New Knowledge in Information and Communication Technologies:** The growing Carnegie Mellon Portugal research community is producing world-class research with 84 Phd Students co-supervised by more than 150 faculty members and senior researchers. There are currently 25 collaborative research projects selected through two competitive research Calls (Call I in 2008 and Call II in 2009). Each of these projects involves teams from at least two Institutions in Portugal, one company, and one research team at Carnegie Mellon. More than 330 papers have been published in peer-reviewed journals and international conferences. The number and quality of joint publications with authors from one or more Portuguese universities and Carnegie Mellon is increasing steadily. Several papers received "best paper" awards in the international conferences in which they were presented. Research highlights with real-world impact include a vehicular ad-hoc network of 465 taxi cabs that is currently being deployed in the city of Porto with GPS manufacturer NDRIVE (to the best of our knowledge the largest in the world), wearable technologies by company BioDevices and sensor network support undergoing tests with two corporations of firemen, prototypes for automatic speech translation and reading practice exploiting databases of publisher Porto Editora, web technology platforms developed with software house OutSystems, a comprehensive study of the impact of smart grid technologies using Electricity of Azores in two islands of Azores in the Green Island Project, analyses of public policies for broadband deployment in Portuguese schools and one stop shop for the establishment of entrepreneurial ventures, among many other examples.

- **Stronger Collaboration among Portuguese Universities:** Nine Portuguese Universities, namely Universidade de Aveiro, Universidade Católica Portuguesa, Universidade de Coimbra, Universidade de Lisboa, Universidade Nova de Lisboa, Universidade da Madeira, Universidade do Minho, Universidade do Porto, and Universidade Técnica de Lisboa (Instituto Superior Técnico), have succeeded in establishing advanced training programs with dual degrees awarded by at least one of the Portuguese partner institutions and by Carnegie Mellon. Several of these programs involve partnerships and knowledge sharing among multiple Portuguese Universities and Carnegie Mellon in the general areas of Computer Science (CS), Electrical and Computer Engineering (ECE), Applied Mathematics (Math), Technological Change and Entrepreneurship (TCE), and Engineering and Public Policy (EPP). Courses are shared among partners and taught through video conferencing facilities either from Carnegie Mellon to Portuguese campuses, or among Portugal campuses, and, at in some instances, from Portuguese Universities to Carnegie Mellon.

- **Visible Institutional Development:** The Carnegie Mellon|Portugal Program is having considerable impact at the institutional level – with research focus emerging and giving rise to new institutional forms. Examples include: i) the Madeira–Interactive Technologies Institute (M-ITI); ii) the Instituto de Engenharia de Software at Universidade de Coimbra, the PT-Security Lab, a Portugal Telecom research center, and several new thematic networks that were launched in early 2010 and congregate faculty from several campuses as well as experts from high-tech companies working in

cross-cutting areas of the Program. These networks include: Future Internet Services and Technologies (NET-FIT), Security and Critical Infrastructure Protection (NET-SCIP), Services and Technologies for Interactive Media (NET-STIM), and Software Engineering (NET-SE). Their focus areas are deliberately aligned with the Digital Agenda of the European Commission in an effort to mobilize the research community and firms to increase the Portuguese participation in the 7th Framework Program. Deans and Department heads are also reporting important changes in aspects such as PhD admission policies, faculty recruitment, or external outlook of their schools as the result of the collaboration. Similarly, firms report how involvement in the CMU – Portugal has been changing perspectives and paradigms in the establishment and valuation of academic collaboration.

- **Successful Independent Evaluation:** The progress of the Program has been evaluated independently on a yearly basis by the External Review Committee (ERC), which includes world-leading experts in information and communication technologies. The ERC is chaired by Sir John O'Reilly, Vice-Chancelor of Cranfield University UK, and includes Profs. Luigia Aiello, President of the College of Information Engineering, Informatics, and Statistics, at University of Rome La Sapienza, Joel Moses, former Provost from MIT, and Tariq Durrani, former Deputy Principle of the University of Strathclyde, Scotland. In addition, specific international panels were asked to review the master's programs and the progress of the funded research projects. In its most recent evaluation the ERC made the following statement: *We congratulate all involved on the excellent way in which the activities in the programme have been progressed. In our view the Carnegie Mellon|Portugal Program is making an important contribution to transformational further development of university research and postgraduate education in Portugal, ensuring that the very highest international standards of excellence are attained. As this exemplary international collaboration enters the fifth year of its initial phase it is greatly to be hoped that the momentum can be maintained by a continuation in the activity.*

- **Initial Economic Impact:** The economic impact of the Program is becoming noticeable. A large number of highly educated and trained graduates are making a difference in the companies employing them. Universities are developing technology transfer offices and the Carnegie Mellon|Portugal Program is an active participant in the UTEN initiative (see below.). Partner firms are introducing new products and improving processes or services as a result of their involvement in the partnership (e.g. new features in the MEO video-on-demand system of Portugal Telecom or in the web development platform of OutSystems). The first spin-offs of the Carnegie Mellon|Portugal Program, Feedzai and GeoLink, entered the market recently. The number of companies actively involved in the Carnegie Mellon|Portugal Program has reached more than eighty – a testimony that companies are finding value in partnering in the several educational and research initiatives of the Carnegie Mellon|Portugal Program. The program has also deepened our understanding of the processes and mechanisms by which IT contributes to development and economic growth, either through existing firms or as a source of opportunities for entrepreneurs to exploit through new business ventures.

- **Numerous Dissemination Activities:** There have been many technical meetings either organized or sponsored by the Carnegie Mellon|Portugal Program. These include three Carnegie Mellon|Portugal Conferences 2009-2011, with 130 to 180 participants; several workshops on topics such as Future Internet, Smart Grids, Cyber-Security, Electrical Mobility, Interactive Technologies, and Technology Based Entrepreneurship (with 40 to 90 participants, including both academy and industry) and a strong involvement in several sessions organized by the Carnegie Mellon|Portugal Program in the Encontro Nacional de Ciência sponsored by the Ministério de Ciência, Tecnologia, e Ensino Superior. The Carnegie Mellon|Portugal Program and its related activities are reaching out to the general public in Portugal. Practically on a daily basis, small or extensive coverage of Carnegie Mellon|Portugal Program related events are object of articles in newspapers and segments on TV and radio stations in Portugal. Research outcomes of the partnership have been highlighted in news programs and science programs on television and radio with demos and interviews with the leading scientists, PhD students and company professionals.

03 GOALS FOR PHASE 2

To push further the original goals of the Carnegie Mellon Portugal program, Phase II shall pursue in full depth the two main objectives: Talent development and research in commerciable technologies.

TALENT DEVELOPMENT

- **Advanced Training through Dual Degree Professional Masters and PhD Programs:** Reinforce the existing dual degree Professional Masters and PhD Programs by continuing to recruit the best and brightest in Portugal and abroad, by promoting increased partnership in the educational programs, dual supervision of students, sharing academic initiatives across Portuguese Universities and with Carnegie Mellon, and strengthening the research activities and their coupling to industry.

  These dual degree educational programs will create a growing number of courses (disciplines) to be offered distance learning – from Carnegie Mellon to several sites in Portugal and from a University in Portugal to Carnegie Mellon and other sites in Portugal. This will endogenize new teaching methods and share valuable experiences and resources, while increasing the level of partnership among Portuguese Universities. We will seek to expand the impact of these joint educational activities to include graduate students who are enrolled in the regular MS and PhD programs of Portuguese partner universities. We believe this broader interaction will accelerate impact and induce further institutional change across Portuguese graduate programs.

- **Self-sustaining Professional Masters Programs:** Already in the context of Phase 2, we have the first experience of a self-sustained partnership between Carnegie Mellon's Department of Electrical and Computer Engineering and the University of Porto's Business School (EGP-UPBS). These two Institutions partnered to offer a new dual-degree graduate Masters program in engineering and business this fall. The two-year program will give participants the opportunity to study one year in Portugal at the University of Porto and another year in the U.S. at Carnegie Mellon. Students will meet academic requirements from both universities to receive a master's degree in electrical and computer engineering from Carnegie Mellon and an MBA ("The Magellan MBA") from Universidade do Porto EGP-UPBS. This program builds on the long-term partnership established by the ECE departments at CMU and the University of Porto through Phase 1 of the Carnegie Mellon|Portugal Program sharing technical course offerings at Carnegie Mellon and Universidade do Porto through Porto's ECE department. Ten fully self-supported international students have already been recruited and will enter the Program in January 2013.

  While this format cannot be extended to all Phase 2 Professional Masters, it will serve as a model to develop other dual degree Professional Master Programs that can leverage the extremely high number of high quality applications to some of the Carnegie Mellon Professional Masters programs.

- **Mentoring of High-Potential Scientific Leaders:** Capitalizing on the success of the faculty exchange program, we aim to extend the opportunities for young researchers and academics.

  In particular, we aim to connect them to experienced leaders of their fields, who can provide them with advice and guidance in the initial stages of their careers. This form of mentorship shall take place in the context of mutual visits, collaborative research and joint supervision of post-docs and PhD students.

- **Foster Stronger Mobility and Knowledge Exchange among Industry and Academia:** Beyond promoting the organization of regular workshops and conferences, the Program shall actively promote a constant flow of people between industry and academia.

This will be achieved by means of an industrial internship program for PhD Students and an industry exchange program for faculty members. Specific routines shall also be set in place to allow for industry professionals to spend some time working at university labs and for researchers and academics to engage in short-term visits and internships in the participating companies.

- **International Branding of Portuguese Universities:** We will explore new ways for individual institutions of higher education in Portugal to leverage the special relationship they have with Carnegie Mellon to raise their international profile and further extend the cooperation with other partners in Europe and elsewhere in the world.

  The outcomes should be measureable in the form of new joint degree programs, as well as increases in the hiring of foreign students, researchers and faculty members.

FOSTERING JOINT RESEARCH AND COMMERCIALIZATION

- **Promote Entrepreneurial Activities with Strong Impact on the Economic Development of Portugal:** Small, medium and large companies operating in Portugal are among the main stakeholders and contributed actively to the success of the first phase of the Program.

  Through a carefully tailored industrial affiliates program, the Program will strive to complete the innovation chain by consolidating the ongoing research efforts with the existing industrial partners and expanding the list of industrial affiliates with new companies not only from the ICT industry sector but also from other areas in which ICT plays an important role, such as energy, retail, tourism and manufacturing. The growing critical mass of firms allows the organization of thematic workshops and other efforts to develop activities above and beyond the program in Portugal. This will promote the formation of strong university industry consortia that can compete successfully in the Horizon 2020 R&D program of the European Commission, among other international funding schemes. It will also create conditions to accelerate the process of spinning off technologies through new entrepreneurial ventures with high impact in the national economy and a strong international outlook by developing a structured entrepreneurial startup program to help CMU-Portugal researchers mature business models and successfully launch new initiatives.

- **Enable the Fast Launching of New High-Risk Ideas:** To ensure that high-risk high-impact ideas can be launched without unnecessary delay, the Program shall award a small fraction of the total research budget in the form of seed funding by means of a fast, competitive process.

  This will allow a team to start working immediately on a great idea, while preparing a deeper and more structured proposal for the next call for large-scale research projects. These short-term awards will allow the development of a quick understanding of how successful these risky ideas might be if they are to be expanded to full fledge projects.

- **Develop Expertise in Large-Scale System Integration:** Realizing that the competitiveness of Portugal in key areas in ICT depends on its ability to design, construct and manage large-scale systems rather than a simple technology, the Program is committed to support targeted efforts involving the development and deployment of test beds and living labs that can be used by national and international consortia to develop new knowledge, products and services.

  Such living labs shall promote and provide platforms for experimentation and learning fostering a tight relationship between research programs and market and industry needs. Specific examples can be found in the technical annex.

- **Support the Strategic Integration of Research Programs, Advanced Training and Entrepreneurship Activities:** World-class graduate education and entrepreneurship is only possible in connection with strong research programs. Conversely, high-impact research programs that can lead to competitive businesses must rely on the work and creativity of all graduate students.

  We aim to integrate further the research and education components of the Program by ensuring that course offerings, master theses and class projects are well aligned with the needs of the industrial partners and the focus areas in which the Program funds research initiatives. We are also committed to increase the opportunities for undergraduate research training and entrepreneurship.

- **Promote the Integration of Engineering and Technology with Policy Analysis and Assessment:** Technical innovation is essential, but it is of limited value when one fails to enact and to pursue the right market and regulatory conditions that foster both the adoption and dissemination of new technologies as well as a more efficient and general deployment of existing technologies. CMU's culture of interdisciplinary work, together with multi-disciplinary teams of Portuguese researchers from several research institutions, will build and strengthen the capability to integrate technical and economic as well as social perspectives in leading Portuguese schools, aiming to foster both innovation and entrepreneurship.

04 GENERAL STRATEGY

High-impact **graduate education**, **research**, and **innovation** will continue to be at the heart of all initiatives within the Carnegie Mellon | Portugal Program. A major goal of the partnership is to identify the key focused areas in ICT that offer opportunities for high-impact **collaborative education and research** in cooperation with Carnegie Mellon, while ensuring that Portugal's **competitive advantage** is leveraged through the formation of **industrial and academic consortia** capable of meeting the challenges of international competition. The key challenge is to define targeted **academic and research endeavors**, where the partnership with Carnegie Mellon can be leveraged to achieve **higher international impact**, **wider academic and research recognition**, and **industrial applicability** and **greater value creation**.

To boost relevant research and provide opportunities for world-class graduate education, the Program supports dual degree PhD programs designed to train the most talented young researchers in the context of thriving research collaborations between faculty at Carnegie Mellon and in Portugal. It also offers post-doctoral positions to attract bright minds for a scientific career in Portugal. We aim to foster cooperation among Portuguese universities to further promote the excellence, international visibility and attractiveness of research and graduate education in our country. Professional master programs aim at qualifying skilled personnel in ICT. Dual degree programs are part of an internationalization strategy that builds on Carnegie Mellon's excellent reputation and explores Portugal's location in Europe and the special relations with Africa, Brazil and Macau.

To strengthen the involvement and impact on private companies, the Program will continue to foster the establishment of dual degree professional master programs and set them on a path to become financially self-sustainable.

Since scientists and entrepreneurs alike usually have more ideas at hand than they can reasonably address with the time and the resources available to them, the Carnegie Mellon | Portugal Program will focus efforts around common objectives, thus aggregating the critical mass and providing incentives for

emerging thrusts to focus on problems that have strategic value towards higher comparative advantage for all partners.

The thematic orientation of the Program in the various focus areas is described in the technical annex.

05 INSTRUMENTS FOR THE CORE PROGRAM

Successful entrepreneurship activities in the form of startup creation and technology transfer do not occur in a vacuum or by dictum. It is the **result of an ecosystem of excellence** in an ebullient **academic and research environment** and are best catalyzed by the combination of advanced training programs for graduate students, medium-sized collaborative research initiatives, intensive exposure to Carnegie Mellon's innovation environment and strong networking with the industry. This basic philosophy leads to the funding instruments described in the following.

WHAT WE LEAVE OUT FROM PHASE I TO PHASE II

Before describing the funding instruments to be implemented in Phase II, it is important to give account on what is left out:
- *Institutional funding:* In Phase II, the program will not provide institutional funding aimed at supporting the administrative costs of the dual degree programs.
- *Individual research projects:* The program will not fund individual research projects by small consortia as in Phase I.
- *Hiring of new faculty:* The program will not provide separate funding for hiring new faculty at participating institutions.

TALENT DEVELOPMENT

DUAL DEGREE PHD | PROFESSIONAL MASTER | ACCREDITED COURSES

Consortia of Portuguese universities cooperate with Carnegie Mellon to offer **world-class graduate dual degree programs**, where **PhD students and professionals from the industry are trained** partly in Portugal and partly in the United States, **develop research projects** under **co-supervision** by faculty on both sides of the Atlantic, and receive a degree both from a Portuguese institution and from Carnegie Mellon. In addition, students in other graduate programs of participating institutions have the opportunity to spend time at Carnegie Mellon's labs and departments, where they are exposed to the best practices of a vibrant interdisciplinary research environment. The **core Program will guarantee** the recruiting of **a minimum number of PhD students** and the **engagement of a significant number of faculty** from Portuguese Universities and Carnegie Mellon to foster a **significant level of activity** in well-chosen areas. This in *the* **essential component and** *raison-d'être* of the Program; it engages faculty and students from both sides to create a **critical mass of research activity** around which all other Phase 2 goals and activities can be built, expand, and be successful.

FACULTY EXCHANGE PROGRAM

As one of the most successful components of Phase 1, the Carnegie Mellon|Portugal Partnership supports faculty exchange programs, in which Portuguese academics can spend at least one term working in research and education at Carnegie Mellon to experience the culture of a top university in the United States. Carnegie Mellon professors are also given the opportunity to spend time in Portugal to engage in teaching and research activities with local institutions of higher education and research labs.

The goal of the faculty exchange program is to accelerate the adoption of best practices through cultural immersion giving the opportunity to adopt, adapt, propagate, and consolidate the best practices of top Universities in the United States. This unique opportunity is offered by the Carnegie Mellon|Portugal Partnership to promote a positive exchange of culture and faculty experiences.

During their time at Carnegie Mellon, a faculty member from Portugal is exposed to the same environment and working conditions as a colleague at Carnegie Mellon University. The visitor receives a formal appointment as a visiting faculty member, is hosted by a research group, joins the teaching team of a course (undergraduate or graduate level) in a specific area of interest, and is invited to participate in various activities.

FOSTERING JOINT RESEARCH AND COMMERCIALIZATION

ENTREPRENEURIAL RESEARCH INITIATIVES

It is by now well understood that research carried out by faculty and PhD students in university labs and research institutes can be a critical source of entrepreneurship activities and startup creation. A dynamic ecosystem of companies and research units can greatly accelerate and enhance the transfer of knowledge resulting from this research to products and services that can be commercialized by private companies. The key to building and nurturing such an ecosystem is to provide many well-structured opportunities for faculty, researchers, students and industry experts to engage in joint research and training activities. It is this step that allows for the establishment of strong personal and professional relationships that are indispensable ingredients for successful business ventures.

The Carnegie Mellon Portugal Program, through the Portuguese Foundation for Science and Technology (FCT), shall support Entrepreneurial Research Initiatives (ERIs) that target key focus areas of information and communication technologies. The research programs to be funded shall be selected on a competitive basis through open calls and international peer review. Each proposal must be submitted by a consortium of 3 to 5 research groups with a total of 8 to 16 PhD researchers from at least three different fields of research, including basic sciences, engineering, humanities, arts and/or social sciences. Preference will be given to consortia that include up to three different universities, multiple research units and strong industry participation in the form of direct financial support through matching funds in Portugal and in the United States. Each funded research Initiative shall be formally based at and led by the home institution of the Principal Investigator, who will take responsibility for its successful implementation.

Entrepreneurial Research Initiatives (ERI) are expected to be substantially different from standard research projects because, instead of a specific research problem, they address a specific set of challenges driven towards a new market or solution that must be met through research developments across several areas. They differ from Associate Laboratories, research units, and thematic networks in that they are smaller, more focused and required to be multidisciplinary in the boldest possible way, cutting across existing schools, research units and disciplinary boundaries. They must each have an aggressive research agenda and a strategic plan that demonstrates clearly how the proposed research program will leverage the collaboration with Carnegie Mellon and industry partners to contribute to science and technology, the advanced training of graduate students, the mentoring of young researchers, as well as the international profile of the participating institutions vis-a-vis a stronger involvement in the European Research Area. RIs are also expected to aggregate the scientific and industrial communities by means of thematic workshops, conferences, dissemination and networking activities, summer academies and technical publications. In addition, and of critical importance, ERIs will include as part of the proposal the explanation of the envisaged market and solution space that will be

targeted and, as part of the output, a plan and business model aiming towards the commercialization of the results in the context of intrapreneurial or entrepreneurial ventures.

In the spirit of the Ciência 2007 and Ciência 2008 programs, which successfully attracted more than one thousand researchers with PhD to the Portuguese scientific community, the Carnegie Mellon | Portugal program will enable participating institutions to recruit and hire experienced international researchers, who will strengthen the existing critical mass in the areas of the program. These positions shall be awarded in connection with the Research Initiatives by means of open calls for applications that are announced internationally.

ENTREPRENEURSHIP IN RESIDENCE

The Program will build on the very successful collaboration with the UTEN network, which is fostering a professional, globally competitive and sustainable technology transfer and commercialization network in Portugal. This network, which is oriented toward international markets, can continue to count on the Carnegie Mellon Portugal program to assist in developing the following main actions:

International internships – This action primarily envisions internships for Portuguese professionals and researchers to work on ongoing projects at CMU, but it also permits foreign individuals to be interns in Portuguese institutions.

Networking – The goal is to organize thematic workshops, training weeks, in-situ training, leader roundtables, initiation brainstorms with students, an annual conference, and other events in close collaboration with universities, research centers and associated laboratories and with the involvement of companies that will be hosting activities.

International Business Development – We will pursue the pilot project held in 2011 in assisting a limited number of university-based startups and technology ventures establish successful business relationships in international markets.

The Entrepreneurship In Residence (EIR) would be a Pilot Program developed and implemented by CMU, which is organized with the support of the Carnegie Mellon Portugal Program in coordination with the UTEN Portugal Program. The goal is to expose Portuguese companies to business practices of American startups and help them enter the U.S. market. The EIR consists of three Phases, spread over a seven month period with one-on-one workshops, training and consultation sessions with various business and academic mentors from Carnegie Mellon and Portuguese schools. Phase I and II prepare the companies to develop pitches to potential investors and customers, providing information on topics such as knowing your market and competition, university relationships, differentiation and segmentation, and partnerships for development and distribution. On Phase II Portuguese companies travel to Pittsburgh, PA to participate in a "Business Week" with more focused training and information sessions, individual meetings and public presentations. These take place in an International showcase event and in "Innovation Happens", where a group of entrepreneurs and corporate executives can connect and see demonstrations by entrepreneurs and innovative tech startups.

EARLY BIRD PROJECTS

To foster the timely pursuit of high-risk high-impact ideas, the Carnegie Mellon | Portugal Program shall also award small exploratory grants of 30k to 90k EUR, which allow a small team of researchers from Portuguese institutions, Carnegie Mellon and industry partners to jump start their collaboration in a topic of strategic relevance to the program. The corresponding call for short proposals will remain continuously open with several cut-off dates per year and a quick review cycle by the scientific

leadership of the Program and their advisors. The quality and impact of the projects shall be monitored on a regular basis by the Board of Directors and the External Review Committee.

06 COMPLEMENTARY INSTRUMENTS

TALENT DEVELOPMENT

PHD AND POST-DOC FELLOWSHIPS

To increase the talent pool provided by the core financing, the Carnegie Mellon|Portugal Program will also apply to other funding instruments, including FCT new programs that will foster international partnerships for dual degree programs. Through these, Phase 2 will afford the opportunity on a yearly basis for an additional number of high-potential young researchers to apply to PhD and Post-Doc fellowships, which are awarded by FCT and by the funded multi-disciplinary Initiatives in the various key focused areas of the Carnegie Mellon|Portugal Program. PhD Students will be enrolled in the Carnegie Mellon|Portugal dual degree programs. A number of PhD fellowships will also be allocated to the research initiatives and projects funded by the Program.

DISTINGUISHED VISITOR CHAIRS

The Program shall give Portuguese institutions the opportunity to host a faculty member from Carnegie Mellon for at least one term, during which he or she will engage with the host local scientific community in research, teaching and institutional development activities. This shall be achieved by means of adequately funded distinguished visitor chairs, which shall be awarded on a competitive basis taking into consideration the merit of the candidate and the strategic value of the proposed work plan for the candidate institution and the Portuguese scientific and technological system. Preference shall be given to proposals that are co-sponsored by the industry.

FOSTERING JOINT RESEARCH AND COMMERCIALIZATION

RESEARCH PROJECTS FUNDED BY OTHER SOURCES

Although not awarding project grants in Phase II, the Carnegie Mellon Portugal Program shall encourage its community to apply for funding in Portugal and in the US to support collaborative research projects, which are selected by means of open calls and independent evaluation, as is the standard practice of FCT, the US National Science Foundation and other institutions. Typical budgets shall lie between 200k and 500k EUR over three years. Ideally, each proposal should include at least two research institutions in Portugal, one research group at Carnegie Mellon and one Portuguese company. A financial commitment from the industrial partner is expected, which can take many forms from direct funding to human resources, prototyping or data sources. Research projects typically involve faculty members, researchers, and PhD students. It is desired that they also result in research opportunities for undergraduates, both as a tool for recruiting talent and as a means for promoting the scientific culture of our society.

07 TRAINING THE BEST

Attracting and training the most talented young researchers and professionals is a necessary condition for Portugal to be successfully involved in the global networks that develop breakthrough science and

technology. As in Phase I, consortia of Portuguese universities will cooperate with Carnegie Mellon to offer world-class graduate programs, where PhD students and professionals from the industry are trained partly in Portugal and partly in the United States, develop research projects under co-supervision by faculty on both sides of the Atlantic, and receive a degree both from a Portuguese institution and from Carnegie Mellon. In addition, students in other graduate programs of participating institutions have the opportunity to spend time at Carnegie Mellon's labs and departments, where they are exposed to the best practices of a vibrant interdisciplinary research environment.

DUAL DEGREE PHD PROGRAMS

As described before, the core program in Phase 2 will support a minimum number of students in dual degree PhD programs in the general areas shown below. Portuguese universities and Carnegie Mellon have worked on cooperation agreements by which students are co-supervised by a faculty member at a Portuguese institution and another faculty member at Carnegie Mellon, thus enabling close research collaborations. Moreover, each graduate who satisfies the requirements of both universities obtains a PhD degree from Portugal and the PhD degree from Carnegie Mellon.

Students typically spend 40% of their time at Carnegie Mellon, where they are immersed in the vibrant culture of a top American university. When returning to their labs in Portugal, these students bring with them a powerful set of experiences, skills and working habits, which makes them ideal leaders for a renewed culture of change.

Dual Degree PhD Programs	
CS	**Computer Science** - **Software Engineering** - **Language Technologies** - **Robotics** - **Computer Science** - **Human-Computer Interaction**
ECE	**Electrical and Computer Engineering**
EPP	**Engineering, Public Policy and Entrepreneurship** - **Engineering and Public Policy** - **Technological Change & Entrepreneurship**

PROFESSIONAL MASTER PROGRAMS / TECHNOLOGY MBAS

Professional MS programs and Technology MBAs play an important role in establishing a close connection with the Portuguese industry, as they provide top training for the engineering leaders of the industry. These leaders are well poised to become key enablers in bringing new ideas from academia to their companies. In Phase II, we will work towards self-sustained dual degree professional master's programs, which, in the long run, shall be supported primarily through industry sources. The Program shall provide resources for researchers with PhDs to be involved in such programs as course instructors. Industry representatives must also engage in the design of these programs from the outset, as well as in teaching some courses and in actively co-supervising applied MS theses.

08 INDUSTRIAL INVOLVEMENT

The goal of the industrial affiliates program is to promote a closer interaction between the participating universities and the industry, thereby increasing the financial contribution of the private sector to the overall effort of the Program and ensuring measurable benefits to the level of technological capability and export capacity of companies operating in Portugal.

09 ROADMAP

At the kick-off of the second phase of the Carnegie Mellon Portugal program, July 1st, 2012, the directors will submit a detailed operational plan for the partnership as a whole. Below, we provide a preliminary roadmap with particular emphasis on the launching of the main activities.

4th Quarter of 2012	Recruiting the Fall 2103 new class of PhD dual degree students
	Recruiting the Fall 2013 new class of dual degree Professional Master Programs
	Launching of a Call for Entrepreneurial Research Initiatives
	Continuous Call for Applications to the Faculty Exchange Program
1st Quarter of 2013	Launching of the Entrepreneurial Research Initiatives
	Continuous Call for Early Bird Projects
	Continuous Call for Applications to the Faculty Exchange Program
3rd Quarter of 2013	Fifth Annual Carnegie Mellon Portugal Conference
	Continuous Call for Applications to the Faculty Exchange Program
	Continuous Call for Early Bird Projects
4th Quarter of 2013	Kick-off of Large-Scale Research Projects
	Continuous Call for Applications to the Faculty Exchange Program
	Continuous Call for Early Bird Projects
	External Review
2013-2016	Continuous recruiting of PhD and Professional Master dual degree program students
	Continuous Call for Applications to the Faculty Exchange Program
	Continuous Call for Early Bird Projects
	Research and Entrepreneurship Activities, Periodic Evaluations, Conferences and Workshops
2017	Final Evaluation (Pipeline of dual degree PhD students empties in Summer 2021)

10 GOVERNANCE, EVALUATION AND ACCOUNTABILITY

The Carnegie Mellon | Portugal Program shall continue to adhere to the most rigorous evaluation practices and accountability standards. External reviews by international peers are a key element in guaranteeing the success and the sustainability of the Program.

The directors of the Program shall be responsible for the implementation of reporting mechanisms that allow for continuous assessment of the quality and the impact of every funded activity. Beyond traditional measures of success, such as scientific and technological significance of results, quality and number of publications, patents, degrees conferred, and number of students, post-doctoral and other young researchers, the impact of projects will be measured also by the effective deployment of research prototypes, the adoption of new services by leading companies and the existence of partnerships between industry and academia.

The principal investigators of each research project and multi-disciplinary Initiative must submit detailed descriptions of the proposed work and a clear execution plan with verifiable milestones and success metrics by which progress can be measured. The directors shall be assisted by internationally recognized experts, who will carry out independent evaluations of every project and initiative on a regular basis.

The External Review Committee (ERC) shall be responsible for evaluating the progress of the Program as a whole, providing feedback on the performance of the directors, the quality and impact of the research, the degree of excellence of the educational programs and the active participation of industrial partners. Every year the ERC shall make detailed recommendations on how to improve the Program and converge towards the stated goals.

Particular attention shall be devoted to the institutional development of partner universities in Portugal and how they can leverage the collaboration with Carnegie Mellon to increase their international visibility and participation in European funding schemes for research, as well as in the establishment of new double degree programs with other reputed institutions in Europe and beyond.

10 BUDGET

Based on the instruments described in Section 5, we propose the core program annual budget summarized in Table 1 (in Euros).

Instruments	Portugal	CMU	Rationale
Entrepreneurial Research Initiatives	TBD	TBD	TBD
PhD Fellowships and PhD Program	TBD	TBD	TBD
Master Programs	TBD	TBD	TBD
Early Bird Projects	TBD	TBD	TBD
Workshops / Conferences	TBD	TBD	TBD
Management	TBD	TBD	TBD

	TBD	TBD	TBD
Faculty Exchange Program			
TOTAL	TBD	TBD	TBD

Table 1 Annual Budget for Core Integrated Program

TECHNICAL ANNEX – KEY STRATEGIC AREAS

Since its inception the Carnegie Mellon|Portugal partnership has strived to identify key focused areas of ICT where Portuguese universities and companies can become worldwide leaders by jointly developing high-impact research and innovative products and services. In collaboration with colleagues at Carnegie Mellon and partners from the local industry, the scientific community has been engaged in a broad discussion, which allowed a number of relevant topics to emerge in a bottom-up fashion into a clear sense of focus and direction for Phase II of this partnership.

The technical challenges described below are transversal to the various disciplines, touching various fields in electrical and computer engineering, computer science, engineering and public policy, technological change and entrepreneurship, among others.

FUTURE INTERNET ARCHITECTURES AND BUSINESS MODELS

As many of the world's communication and computation infrastructures expand, connect and evolve into one pervasive mesh of heterogeneous devices, we witness large investments to bring fiber directly to the home and the fast convergence of large-scale data processing facilities, ultra-portable computers, intelligent transportation systems, safety and health-care systems, energy-aware technologies and peer-to-peer architectures. Network operators, equipment manufacturers and regulators are now confronted with ever changing system architectures, traffic demands, and costumer expectations with respect to quality of experience, brought now to new levels, for example, by high-definition television over IP. Overall, the telecommunications industry is changing at an unprecedented pace in order to benefit from this myriad of new technologies and opportunities. Regulation also adapts to dynamically balance competition and incentives for investment in this new world. Most of today's users want to go beyond simply acquiring information from centralized servers, many of them want to upload their own content and share it with others in their social networks and in the world. Likewise, businesses are becoming increasingly global with teams collaborating across continents and time zones, which requires massive data transfers and high-speed Internet connectivity for real time multimedia communication. Businesses are also increasingly monitoring real time data feeds and social media to tap into conversations and collective discussions among consumers. The high-performance networks of the future must provide their customers with safe and secure unhindered access to the world wide web of people, information and things, which must be available at all places and in all moments, automatically and without delays, irrespective of the underlying telecommunications infrastructure, yet automatically adapting to and taking optimal advantage of the available features of access devices. An important benefit that such network-based platforms will provide is the capacity to store and analyze the cross-platform and cross-network behaviors of people in a privacy-preserving manner. Such data and analysis will enable a new generation of applications informed by hitherto inaccessible data detailed on human behavior. Collecting, synthesizing and understanding these data will enhance the users' experience in new and clever ways. These dramatic technology and social developments are changing the way research and

technology commercialization is conducted, opening opportunities to both existing and new firms. Open and more distributed innovative efforts are emerging as growing paradigms and a variety of entrepreneurial initiatives will challenge incumbents through new business models.

MAIN CHALLENGES:

- **Design and Integration of Future Internet Technologies:** Seamless communication and service continuity over the emergent global network requires innovative technologies, which can be integrated, optimized and operated with ease over multiple domains, from the physical communications channel up to the services and applications as seen by the user. This includes an all fiber infrastructure capable of carrying massive traffic across the network to individual homes and businesses, as well as an array of wireless gateways that enable mobile services and reliable connectivity in dense and volatile environments. Limited wireless spectrum requires dynamic resource allocation, based on new hardware and software for flexible radio, as well as secondary markets for efficient spectrum allocation. It is important to investigate how novel lower layer techniques ranging from cognitive radio to multiple-antenna systems and cooperative communications (e.g. relaying, beam forming, and network coding) can be leveraged by the communications protocols at higher layers of the system architecture to provide the necessary throughput and robustness guarantees. Mesh networks, home networks and vehicular networks will complement the cellular infrastructure in ways that are yet to be explored, with users roaming from one network to another seamlessly or even tuning simultaneously to multiple access points for higher rates and efficiency. Decisions on the best radio access technology selection may be based on context awareness and localization. The selfishness of users and devices that compete for common network resources must also be taken into account (e.g. game-theoretic models are appropriate to find stable network equilibria). Increasingly the network will interact more and more with the physical world through wireless enabled objects, also known as the Internet of Things, which are likely to change traffic patterns and alter services and applications thus justifying the development of new reliable and secure architectures and protocols.
- **User-Driven Innovation:** The use of advanced ICTs and networks for delivering services is forcing us to revisit many of our assumptions behind service management. In addition, there is great interest in understanding how innovation in ICT-enabled services can be used to differentiate and enhance commercial relationships. One of such dimensions is to explore the role of 'users' be sources for new offerings in the service sector. In particular, it is important to understand the operational antecedents that influence new service development, including software and processes support, as well as the extent to which service innovation influences business performance. The extent to which users can be the sources of new services and the managerial and policy implications thereof are also relevant topics for future research.
- **Scalable Query Processing:** The large number of sensing devices produces an enormous amount of sensor readings and clearly this generates an enormous amount of traffic. Fortunately, application designers are not interested in obtaining every sensor reading but designers are rather interested in answering high-level queries such as "What is the maximum temperature in this area?" or "Is there a person in this room?". It is therefore typically not necessary to communicate all sensor readings since it is possible to compute answers to such queries inside the network. Novel approaches have been recently proposed that excel one of the main features of cyber-physical systems: tight coupling of computing and communications with the physical environment and dynamics.
- **Middleware for Large-Scale Deployments:** The design of massively distributed applications poses great challenges to the programmer and to developers of programming languages. A top-down design would allow for the system designer to specify the functionalities of the system as

a whole, which could then be translated semi-automatically to code that runs on each individual node. These micro-programs and their updates and configurations then have to be spread over the network, which from an operational point of view also requires dedicated middleware and adequate interfaces for the system administrator. Embedded nodes are becoming more and more powerful, but complex to specify and develop. In one hand, new multiprocessor and multi-core technologies are being used for small devices, which allows building more powerful applications, but that imposes new requirements in terms of resource management (CPU, memory, power, etc). On the other hand, applications become more complex to specify, imposing the need for advanced, but more and more reliable, operating systems and programming languages.

- **Security, Privacy and Trust:** The growth of the ICT sector is strongly dependent on the level of confidence with which the average costumer is willing to carry out electronic transactions over the network However, it is not sufficient for the infrastructure, protocols and services to be secure. Rather, their level of security must be obvious to anyone willing to use them. This includes the correct usage of enabling technologies for security like cryptography, protection against spoofing attacks on wireless and cable links, active measures against identity theft by means of phishing, virtual machines to isolate malware, trust primitives for software updates, traitor tracing for peer-to-peer content, intrusion detection, and other defense mechanisms capable of adapting to the constant surge of new attacks and vulnerabilities. Electronic IDs can be included in the effort towards implementing reliable identity management. Security should not be an add-on to existing communication protocols and services, but rather be a primary concern in the design of new information and communication technologies.

- **Applied Machine Learning for Traffic analysis and Efficient Network Management:** Peer-to-peer communication and social networking are only two examples of recent developments that are fundamentally changing how information and data packets flow within a large-scale communications network. By collecting and compressing massive quantities of data on network traffic and employing tailored machine learning and data mining techniques, it should be possible to characterize, at least partially, the resulting patterns of network usage. A natural step could be to investigate how root-cause analysis can predict demands, anticipate problems, reduce congestion and combat failures. The key is to understand how the decisions made by a myriad of devices based on local rules and partial information impacts the emergent behavior of large-scale networks as a whole. Peer-to-peer communication and social networking are only two examples of recent developments that are fundamentally changing how information and data packets flow within a large-scale communications network. By collecting and compressing massive quantities of data on network traffic and employing tailored machine learning and data mining techniques, allows for characterizing the resulting patterns of network usage. A natural is to investigate how root-cause analysis can predict demand, anticipate problems and network bottlenecks, reduce congestion and combat failures. The key is to understand how the decisions made by a myriad of devices based on local rules and partial information impacts the emergent behavior of large-scale networks as a whole. This idea extends naturally to selectively sharing information among vehicles in intelligent transportation systems to improve overall performance.

- **Socio-economic analysis of human behaviors on the network:** User behavior on networks and devices provide rich streams of real time data. Examples of such data include calling behavior on cellular telephone networks, purchase behavior using mobile devices, micro-blogging (e.g., tweeting), and TV channel viewing behavior (set top box data). Instrumenting networks and devices will permit this detailed and granular data to be available for analysis. Much of these data rests on the underlying latent network structure among the people who generate them. As a consequence, its analysis requires new types of statistical techniques and algorithmic

methods. Furthermore, these data is revealing of private behavior, hence new techniques are required to protect the privacy of this network data.

- **Network Assessment and Evaluation:** How customers value the services provided by high-performance networks is ultimately determined by the levels of satisfaction they reach during their interaction with the various systems. Standard metrics such as packet loss rates or transmission delay are clearly insufficient to capture the end user's satisfaction, which is closely tied to human perception and our ability to process intelligible speech or tolerate certain classes of visual artifacts. Consequently there is need for research on testing methodologies and measurable criteria by which networks can be assessed and compared. More adequate metrics should be incorporated into the optimization and planning that governs the interaction between different operators and user terminals. The objective must be to maximize network efficiency whilst minimizing the effort of each network entity and guaranteeing a prescribed level of quality of experience. Multimedia services should be context-aware and adapt to the conditions of the network and the terminal of the user. Network virtualization, with large pools of networked physical machines that can host tens of thousands of virtual machines and services, emerges as a possible tool to provide differentiated services requiring specific methods for management and assessment.

- **Regulating, Charging and Billing:** With the paradigm shifting from connection oriented traffic to distributed systems with constant roaming among multiple service providers, it is not yet clear how governments should regulate the telecommunications sector to best promote reliable cost-effective service and how businesses can charge for their services in a fair and effective manner without incurring excessive management overhead. Recent economic trends point towards fragmented markets, in which communication services are offered by autonomous service providers, who are independent of access network provision and core network management entities. Load balancing techniques must also be revisited to account for new modes of communication in which users are as much service providers as service recipients. Ultimately, we must seek ways for the network infrastructure and its protocol stack to provide the means to track individual users without compromising their privacy, measure their contributions and their benefits, and produce a billing scheme that ensures the economic viability of successful services. Integrating such a fragmented supply chain to provide high quality services to end users rests also on ensuring proper pricing schemes at interconnection points, which raises issues akin to the network neutrality debate.

- **Economic Impact and Regulation of Future Internet Technologies and Services:** The ICT sector is highly dynamic with new technologies emerging at increasing rates and conflicting interests of operators, manufacturers and costumers affecting the level of competition among different infrastructures, products and services. Regulation is likely to have a decisive role in determining whether and what services emerge and which competitors ultimately survive and succeed. Without a thorough understanding of how regulation shapes the trajectory of the ICTs industry, regulation can stifle innovation rather than promote an environment where both individual and societal needs are attained. The socio-economic impact of future Internet technologies, services and applications must be analyzed and understood in advance in order to provide adequate recommendations for public policy in a timely fashion.

- **User-Driven Innovation:** The use of advanced ICTs and networks for delivering services is forcing us to revisit many of our assumptions behind service management. In addition, there is great interest in understanding how innovation in ICT-enabled services can be used to differentiate and enhance commercial relationships. One of such dimensions is to explore the role of 'users' as sources for new offerings in the service sector. In particular, it is important to understand the operational antecedents that influence new service development, including software and processes support, as well as the extent to which service innovation influences

business performance. In today's intricate world it is paramount to understand the extent to which users can be the sources of new services. This is particularly important in the ICTs industry where open platforms for the development of new applications (e.g. iphone and ipad) allow individuals to quickly disseminate their inventions possibly attaining success both faster and more often. This, in turn, leads to new managerial and policy considerations that must be tackled in a systemic way. Idea Management Systems (IMS) in ICT companies raise similar challenges. Businesses need to know better how to screen IMS for successful ideas and adapt their processes to benefit from them at reasonable cost.

SECURE AND DEPENDABLE SOFTWARE-INTENSIVE SYSTEMS

Software is a key enabler of economic development as it provides the means to store, process and exchange information as varied as catalogs of products, items in a warehouse, positioning of vehicles, market transactions, and energy measurements. To meet the challenges of globalized software development, where thousands of components must be combined to provide the customer with an adequate application or information system, program modules and software services must be engineered to operate in a seamless, secure and reliable way with each other, adapting to unpredictable scenarios, recovering from unexpected breakdowns and providing simple means to maintain or extend their features and configurations. To satisfy these requirements, software cannot be developed in an ad-hoc fashion. Thus, better software engineering methodologies and tools offering agility and fast delivery emerge as an indispensable tool for developing the information systems and software based services of the future. Along with the tools, businesses are also changing practices and structures in fundamental ways to be able to work with and leverage these new software systems. A variety of new firms are also emerging to explore a wealth of opportunities created with these developments.

MAIN CHALLENGES:

- **Dependable Software Systems:** The development of industrial strength software requires new ways to certify the integrity, the correctness and the inter-operability of different modules and systems, even when such subsystems must operate across large-scale networks, and subject to continuous updates and extensions. This objective can be attained by means of formal methods from computational logic and type theory, which can be used to develop new high-level design and implementation idioms that are intrinsically reliable and extensible, as well as verification tools. Some intervention by human operators is likely to be necessary even in the presence of self-healing, self-adaptive software. Therefore, research should be devoted to identifying critical scenarios in which human oversight and actions are indispensable, leading to novel methodologies for dealing with highly complex software systems.

- **Collaborative Workflow Software:** Many software packages from business applications to multi-player games are now being developed by large teams that are spread out in various parts of the globe. This is possible because workflow software and online collaboration tools allow for a project to be divided into multiple chunks that are sent out to different developers, whose work is then assembled to produce the final product. New infrastructures for distributed software development will provide the fertile ground over which global innovation networks are likely to grow. As the development process becomes disaggregated into multiple stages, each component can be located where it can be undertaken at maximum efficiency. This means that new regions and players at a global scale can be part of a process so far concentrated in the advanced world. Understanding how this emerging global division of development can be organized and what are the implications for existing and new organizations is therefore critical.

- **High Growth Entrepreneurship in IT and beyond:** Entrepreneurship is now seen as a critical driver of innovation and economic development. As a response, many countries, including Portugal, have enacted policies to foster entrepreneurial activity. However, only a small number of fast-growing new firms, typically with a strong knowledge base, account for the majority of job creation, while most are born small and remain small during their life spans. IT and software in particular have been major drivers of the entrepreneurial effort and are among some of the most successful cases. It is therefore vital to improve our understanding of the critical factors that lead an entrepreneurial venture to have the desired high growth path, including the origin and experience of the founders and other leading employees, the access and characteristics of the capital structure and the expansion paths.
- **Software Modules for Global Supply Chains:** Inventory tracking, automatic transactions and consistent distributed databases are some of the key ingredients of modern supply chain management. Software systems for multinational enterprises must enable reliable real-time monitoring of goods and processes, thus ensuring that vital data is freshly available to all key partners and decision makers at all stages of the global supply chain. Research in this direction must rely on the real-world data collected by internationally operating companies. Challenges also include dealing with shared data-sets where parties with conflicting interests recognize the benefits of collaboration, but impose strong bounds on the admissible information flows.
- **Multi-core and Parallel Systems:** The multi-core processor is today a standard building block. It is commonly used in the edge (servers, proxies) and in the core (routers switches using network processors) and it is an appropriate computational substrate for telecommunication workloads because this class of workloads tends to exhibit large amounts of parallelism. Sharing of the computational capacity of multi-cores contributes heavily to the end-to-end delay that users experience. A comprehensive theory with algorithms for sharing resources and for proving upper bounds on the delay experienced by an individual program does exist, however this theory is arguably not yet well developed for multi-cores. Moreover, it does not take into account the effects of contention for internal buses and switched interconnection networks inside a multi-core. It is now clear that future massive parallel processing will bring concurrency to the center of software engineering concerns. Harvesting the benefits of parallelization will require new programming abstractions and tools for expressing parallel programs at a high level, verifying correctness properties of concurrent code, and efficiently executing code on modern multi-core platforms.

INTELLIGENT ELECTRIC POWER AND SMART TRANSPORTATION SYSTEMS FOR SUSTAINABLE MOBILITY

As Europe and the world move to decarbonize their electric power systems, several challenges arise. Methods must be found to reliably and economically integrate large amounts of variable and intermittent supply generated by wind and other renewable sources. More efficient and economical methods to store energy must be developed and disseminated. Strategies to increase the capacity and reliability of existing high voltage transmission systems must be developed and deployed. "Smart grid" technologies must be able to monitor and control these systems at the level of generation, transmission, distribution, and end use in ways that are both economic and reliable. Strategies, such as real time "prices to devices," combined heat and power (CHP) systems, and micro grids must be refined. Regulatory and market environments must be developed that make the dissemination of new technologies and strategies attractive to private parties and to utilizes.

As small devices with navigation capability become ubiquitous and wireless communication and sensing technologies pave their way into the main components of today's transportation systems, information

gathering and sharing among vehicles, drivers, service providers and travelers can be supported at very low cost leading to safer, more comfortable and more sustainable mobility. Digital maps can be updated by overlaying "social information sharing networks" over physical devices and vehicular networks. This real-time information sharing about traffic conditions, allow for the computation of low-carbon or energy-efficient routes, as well as realistic estimates for travel duration and the expected arrival time. Citizens will be able to use this information to choose among or even combine different modes of transportation, navigating through cars, taxis, buses and trains with the assistance of their smart phones and specific software applications. At the same, companies can manage their transportation systems and fleets in a more efficient way, while providing customers with greater quality of service.

Intelligent transportation systems are also at the heart of electro-mobility solutions in that they allow for the integration of fully electrical vehicles in the existing power grid in a balanced and manageable way. Electro-mobility has been considered one of the most relevant paradigm shifts in the way people move within and interact with the urban eco-system, which shall have profound implications on energy efficiency and environmental performance. The electric vehicle, both green and intelligent, is expected to function as a fundamental source of stimulus for economic development in a wide range of technology sectors, with ICT likely to become one of the most important fields. Electro-mobility goes well beyond individual transport in that it offers the opportunity for systems integration of private and public transportation, which must be matched with public policies addressing the generation of electricity from clean, renewable sources, efficient land management and rational use of energy.

MAIN CHALLENGES

- **Smart Grid:** While the catch-phrase "smart grid" has become popular, there is still much to be done to develop the information and communication technologies, and the control strategies to assess and control the high voltage transmission system to: assure maximum capacity and security; monitor and reconfigure distribution circuits in real time to supply reliable service in the face of varying loads and distributed supply; and, assess energy demands in real time and manage the power supply network in the most efficient and sustainable way. At the moment the greatest vulnerabilities of the electricity system are physical. As more and more sensing and control is added to the system, it will be essential to assure that adequate safeguards are included to prevent intentional or accidental disruptions.
- **Integrating Variable and Intermittent Renewables:** Unlike traditional sources of electric power wind and solar are variable and intermittent. In power systems with excess capacity, with hydro or with fast response gas turbines intermittency can be managed. But as the fraction of renewable power grows, issue of forecasting, storage and grid operation become ever more important. Smart grid technology can help, but only within limits. New approaches to system operation, direct and price-based load control, and storage must all be developed and demonstrated if the future electricity system is to be clean, sustainable and reliable. In the future electric vehicles could also play a role in vehicle-to-grid support. However, for that to become significant, battery costs will have to be substantially lowered and cycle-lifetimes will have to dramatically increased.
- **Vehicle-to-Grid Communication:** Large numbers of electric vehicles (EV) that require substantial charging times and impose varying demands on the electrical power gird offer numerous challenges both to users and utilities. A key element in ensuring that the grid can cope with these demands is the ability to establish reliable communication links between each electrical vehicle and the charging infrastructure, to allow for timely and accurate predictions of mobility patterns and related energy requirements. This task, which is even more critical with a high percentage of renewable sources in the overall energy mix, can be ensured by means of an

advanced vehicle-to-grid communications infrastructure capable of gathering all the necessary data on vehicle and grid states and coordinating the various charging periods.

- **Charging Platforms for Electric Vehicles:** How the EV charging management platform must evolve to support future needs is one of the key questions that would determine the ability to deploy electro-mobility solutions on a wider scale. Problems related to faults, configuration, accounting, performance and security need to be addressed. Grid management is also crucial, since electric vehicles fleets will demand localized load and low voltage production. Also important are questions related with standardization, openness, and technology independence.

- **Vehicular Networks:** The large-scale behavior of networks with thousands of vehicles is far from understood. On the communications side it is important to characterize how the wireless spectrum can best be used to support these networks, while ensuring that networking protocols are well tailored to a scenarios in which communicating nodes are aware of their location and likely to be constantly moving. Opportunities for new applications and services that leverage inter-vehicle communication must be explored to their full potential in order to guarantee sustainable mobility. The role of the infrastructure as a potential backbone and gateway to the Internet must also be clarified.

- **Platforms for Mobile Sensing:** Vehicles and smart phones alike typically possess a significant number of sensors whose readings can be accessed through the communication bus or the operating system. Thus, every entity in the transportation system can be viewed as a mobile sensor node providing potentially useful information about the context and state of the urban fabric. The information thus gathered must be selected, processed and filtered by an adequate platform that can meet the information needs of various mobility applications.

- **Real-Time Traffic Management and Safety:** Vehicle-to-vehicle communication allows for cars, trucks and buses to share information about traffic in real time. Moreover, vehicles become aware of each other as soon as they are within wireless range, which often happens before visual contact is even made. This feature can be used to increase road safety and organize traffic in a more efficient way. Instead of relying on centralized systems such as traffic lights, the transportation system can function in a distributed way, allowing vehicles to warn each other of potential hazards or collaborate in finding the most efficient routes thus utilizing the road network in the most sustainable way. Specific security mechanisms and policies must be in place to ensure the highest safety levels.

- **Efficient Electricity Use:** Electricity is the most flexible, and potentially the cleanest and most sustainable source of energy. We will always need it. However comparative studies across nations shows that even today, how much is needed to assure a high quality of life varies dramatically. Some of the differences are of course due to climate, but many more are due to the way electricity is used. While finding new, cleaner and more sustainable sources of supply are important, equally if not more important is developing the most efficient means possible to provide social services that depend on energy. Work is need both to develop more efficient end-use products and processes and also to find strategies that can accelerate their rapid and wide adoption.

- **Public Policies for Clean, Sustainable and intelligent Electric Power and Smart Mobility:** The socio-economic benefits of different policies related to electric power and intelligent transportation system must be quantified, particularly with respect to the reduction of carbon emissions, the overall energy consumption and the well being of users. Another important aspect to consider is the transition from existing modes of power-system operation and transportation to an information-driven paradigm. Selective sharing of information across drivers may prove efficient to dynamically adjust traffic patterns to road conditions, congestion and other unexpected events. The integration of public policies and new traffic management

practices must be revisited so that the clever analysis and use of pervasive information on the transportation system can lead to a new level of efficient transportation.

A MULTI-INSTITUTIONAL LABORATORY IN TECHNOLOGY POLICY AND ENTREPRENEURSHIP

Economic, social, and legal impediments often prevent a new technology from yielding the industrial expansion, job creation, and productivity enhancement that the Carnegie Mellon Portugal collaboration aspires to. Thus, it is critical to learn how to promote market and regulatory conditions that foster the adoption and dissemination of new technologies. This is important when considering existing firms and is especially relevant for new entrepreneurial ventures, which are more fragile and thus greatly affected by their environment. The distributed "laboratory" for research and education in Technology Policy and Entrepreneurship (LTPE) will strengthen the capabilities of Portuguese schools to engage in integrated analysis and assessment that combines deep technical understanding with modern methods of policy analysis. It will foster interdisciplinary research at the intersection of policy, information systems and the social sciences. This multi-institutional LTP will promote collaboration across schools in Portugal and at CMU (including the EPP Department, the Heinz College and the Department of Social and Decision Sciences) in ways that provide grounds for a truly international learning environment for policy making, particularly in areas relevant to ICTs and energy systems.

BIG DATA: A MULTI-INSTITUTIONAL LABORATORY IN LARGE DATA ANALYSIS FOR NETWORK SCIENCE, NETWORK ENGINEERING, AND CONSUMER ANALYTICS

- Information networks are everywhere. The number of devices and sensors they connected, the number of distinct connections and the bandwidth required per connection are also growing rapidly, propelled in part by the availability and the ease of use of new information-based services, such as streaming media, social networking and online education. The distributed laboratory in Large Data Analysis (LDA) will take advantage of the large datasets that information networks make available. LDA will promote research and education using such datasets, which can be used in two complementary perspectives. On the one hand, they allow for developing a new generation of consumer and social analytics for the network centric world. This requires the development of new concepts, methods, and tools that are experiment-driven, closed-loop, increasingly real-time, and practical at the societal scale in ways that transform and expand computational social science and lead to the development of new applications that benefit individual consumers, private organizations, and the public sector. LDA will also promote research on data confidentiality, privacy and security to address the challenges associated with protecting the individuals whose data are part of our studies. This requires developing new methods that maximize data utility subject to confidentiality constraints. On the other hand, large datasets on traffic flows are key to inform the design of future Internet architectures, services and applications that increasingly support interactive media. LDA will promote ways in which network science can guide network design, engineering and management. LDA will be developed jointly by Portuguese schools and research centers and Carnegie Mellon University as a distributed center that will pull together skills from Computer Science, Electrical and Computer Engineering, Machine Learning, Social and Behavioral Sciences, Management of Information Systems and Management Science. LDA¹s objective is to provide the appropriate common ground for interdisciplinary research across all areas in the CMU-Portugal Program. This will elevate collaboration across Portuguese research units and CMU to a new level.

HUMAN-COMPUTER INTERACTION

In the last few decades, advances in computer-based technologies have irrevocably changed the way people work and live across the globe. Although these changes have been fueled by fundamental technical advancements at the infrastructure level, it is how technology enables people to interact with their physical, human and social environment that has ultimately transfigured and transformed the world we live in. Work on this topic falls under the domain of Human-Computer Interaction (HCI), a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them. HCI has been a critical component of many important computing developments including such fundamental and ubiquitous systems as the mouse and the desktop graphical user interface as well as more recent developments such as advanced multi-touch enabled mobile UIs, ubiquitous computing devices and context-aware applications. With the impact of technology in our cultural milieu (music, video and film, TV, radio, performing arts, etc.) HCI is playing an increasingly important role understating how new forms of multimedia content shape our society and can be used to produce innovation in many application domains. The research in the interactive digital media application domain for HCI ranges from multimedia processing and analysis, new media formats, content creation, searching, integration, adaptation, delivery and presentation of new media. They also tackle other emergent areas like robotic technologies, end-to-end immersion that could play an important role in developing markets for artificial forms of entertainment, caregiving and human assistance. By combining scientific, technological and artistic methodologies, this type of research aims on the one hand at understanding, modeling, and producing digital media using computational approaches; and on the other hand at understanding how artificial agents and robots can effectively interact with humans in real-life environments.

MAIN CHALLENGES:

- **Tangible and Embodied Interaction:** Increasingly, things think. Computation is inexorably moving beyond the desktop and into everyday objects and environments, into physical and social contexts. As the very fabric of our lives gains computational behavior, mundane objects are becoming reprogrammable, customizable, repurposable, and interoperable in rich ecologies and diverse contexts. The cost of such novel abilities is complexity and intense design efforts are currently required in order to ensure that physical artifacts imbued with computational power remain functional, usable, and enjoyable. Designing, developing and researching such systems encompasses contributions from software, electronics, and mechanics as well as a detailed consideration and comprehension of the role of physical form and behavior and the milieu in which an object is placed. This requires completely new approaches, tools and design methods that incorporate and emphasize the tangible and embodied aspects of this new interaction paradigm. Specific challenges in this topic include: technological development of hardware and software systems that lower the barriers to embedding computation in objects; detailed exploration of the benefits that tangible interaction can bring particular key application domains (such as education); broadening and deepening design knowledge, tools and know-how suited to the construction of mixed physical-digital systems; improving the audio and visual behaviors of the artificial audiovisual objects that surround us to enhance the affective and emotional character of these objects and consequently our quality of life; and the construction and validation of evaluation methods that can be use to effectively study tangible systems.
- **Human Assistance:** Human-assistance encompasses the long-held vision of helping people with everyday tasks through robots, agents, and devices. This is an area expanding from helping people with disabilities to helping those with functional limitations (e.g. busy parents). The focus in human assistance is to appropriately design technology for people, not just addressing

traditional usability aspects of HCI, but moving beyond to help people construct their identities and help them become the people they want to be. This involves developing fundamental technologies all the way to the deployment and evaluation of human assistance systems, including the development of adequate sensors and processing algorithms in order to make computer systems 'understand' all types of inputs as meaningfully as possible, like low cost multi-sensor systems that detect human-behavior, machine learning systems that can classify and act on sensed data such as detecting routines in people's behaviors and software infrastructures for enabling the collection, inference on, and distribution of sensed data. An example of the deployment of new interactive media solutions that can serve as a basis for motor behavior rehabilitation is the combination of virtual reality, motion capture and videogame techniques, to define a new interface layer between the participants and the system.

- **Sustainability and societal concerns:** Environmental sustainability is an increasingly important global issue. Quite simply, human beings, and particularly those in the western world, use resources far faster than they can be reproduced. This behavior is arguably a consequence of the seductive vision of "wellbeing" afforded, enabled and encouraged by industrialization; a vision based on personal ownership and mass consumption. As a result personal choice can have a huge impact on energy consumption and waste production. Thus, a solution to global warming depends on change at the individual level. The impact of individual choice can be seen in the increasing popularity of organic foods, hybrid cars, and other environmentally friendly consumption choices. HCI research can play an important role by understanding people behaviors and inducing sustainable consumption choices. It can contribute to understanding the material effects of particular interaction designs in terms of how they promote acts of use, reuse, and disposal. It can also contribute to the broader definition of sustainable interaction design as a perspective of sustainability, in which design is defined as an act of choosing among (or informing choices of) future ways of being. Finally, HCI research can help addressing social and ethical concerns. Indeed, while globalization and connectivity have the tendency to establish a rather uniform technological culture, it is of utmost importance that this research should aim towards maintaining, promoting and respecting cultural diversity. Furthermore, as HCI and associated technologies are at the heart of inter-personal relations, research in this domain must remain aware and potentiate ethical concerns, the ultimate goal being to empower individual users in their choice and consumption of technology.

- **Technologies for education and researcher training**: Knowledge plays a central role in today's world. The more knowledgeable the society is, the more potential for a successful and sustained development it has. Although not the only source of knowledge, education plays a central role in the accomplishment of this great objective. Most developed countries now offer around 12 years of public teaching. But the educational system must keep pace with the paradigm change in the way children search for knowledge. Today's children are "digital natives" meaning they were born and raised in a completely different environment than previous generations regarding access to information and knowledge. As an example, nearly 90% of Portuguese children aged 10-15 already had contact with the Internet, and virtually every child aged 6-10 already owns a notebook. Therefore, educational systems must adapt quickly to cope with this brand new way of knowledge creation and sharing, so that school-based learning can catch up with the kinds of knowledge creating and sharing that children do on their own time. HCI plays a major role in this matter by exploring cognitive tutors, the use of new devices and natural language technologies, applying models of learning processes to complex performance, digital storytelling environments, and the use of games and other entertainment technology to foster learning. For instance, intelligent, smart environments allow creating rich environments where students can interact with digital objects, tools and simulated experiences. Moreover, they provide the means for students to collaborate among them and share opinions, results and experiences. Considering

researcher training, HCI research is highly multidisciplinary, however, the boundaries of academic disciplines involved are quite sharp. The increasing need for specialists in this domain will require a decisive growth in the size and quality of existing relevant educational programmes and the creation of new ones with a particular focus on a broad integration of Human and "hard" Sciences.

- **Crowdsourcing and Computational Sensemaking:** There is growing evidence that collaborative user data will change the future of both work and entertainment. From games with a purpose, to movie ratings and opinions, to creative uses of Mechanical Turk, to massive volunteer projects like Wikipedia, crowdsourcing has become a powerful form of collective intelligence changing the way we accomplishing work online. HCI research on this topic will involve gaining a deeper understanding of the implications and uses of this new work paradigm. Specific challenges in this domain include: studying and understanding how to integrate the contributions of crowds in systems that power human computation; engineering next-generation platforms that enable work to be accomplished online; researching data mining methods to handle such large-scale volumes of user generated data; using Web 2.0 and 3.0 technologies and approaches to create advanced and appealing services while blurring the distinction between content producer and consumer, Recommending and adapting content to users preferences and constraints; understanding micro-task markets in which employers can tap into a global population of workers for a fraction of the time and cost of more traditional methods; in understanding the wider implications of crowdsourcing as a new organizational model for companies, marketplaces and even government.

- **Design Research:** It is widely recognized that as technology matures and adoption evolves, key differentiators between products and services move from those based on technology and features to those based on marketing and design – in later stages consumers are driven by convenience and delight rather than enhanced functionality. Computing technology is not an exception. Successful products and services are currently the result of either radical design-driven innovation or solid, incremental human-centric design. These phenomena are challenging HCI research and academia to understand the role of design and integrate design practice in research and education. A new model for design research is required to allow design researchers to collaborate on an equal footing with HCI engineering and behavioral science researchers. Integration of "design thinking" and other forms of creative problem solving in current development practice is an important challenge that could also benefit from close collaboration with industry.

- **Digital Art and Interactive Entertainment:** Art and design stimulate creativity and imagination. They provide visual, tactile and sensory experiences and a unique way of understanding and responding to the world. Through art and design activities, we learn to make informed value judgments and aesthetic and practical decisions, becoming actively involved in shaping our context and environment. Today many design schools are looking at the input of artists and their non-linear and innovative processes by including digital arts as an area of applied research through new media and technologies to anticipate their important role in innovation for industry and education. Furthermore, It is widely recognized that the industry of interactive entertainment is rapidly evolving to become the most important cultural industry in the world, surpassing traditional media as television or film. Also the Portuguese industry has manifested the goal to pursuit investing and developing new methods and works not only in the domains of videogames; but also in content production for social networks; shopping malls, shopping windows, street installations; and technologies development as public displays, multi-touch displays and new interactive materials. This shows the relevance to invest in a domain that will during the near future become more and more pervasive. It is not only the cultural and artistic aspects like games, interactive films, museums, or applications of interactive music in

entertainment, but also the advertising sector searching for new ways to communicate with an audience, which is not anymore a mass but a distributed set of groups of people. Furthermore the entire publishing area (e.g. newspapers and magazines) being transported into the new multimedia platforms (e.g. iPad), which are craving for interactive solutions, with the power to entertain and engage customers such as the development of efficient distribution of HD and 3D immersive content to these mobile multimedia platforms. In the end this interactive entertainment is one of the most creative and innovative dimensions of HCI, which means it can represent an important asset for an economy looking to make the difference in the world.

- **Human factors in interactivity with virtual environments:** Understanding human behavior and emotions in order to improve our interaction with virtual environments is certainly a challenging and stimulating topic in the field of HCI. It can help make the interaction with virtual environments more seamless and intuitive, thus contributing to the topics of Human Assistance and Technologies for education as described above. For example, developing emotion-driven 3D avatars to increase immersion with virtual environments opens a new dimension of research that leads to the synthesis in real time of 3D avatars with cinematographic quality that can modify their physical appearance according to a specific context and situation. Another great potential exists for interactive computers to perform in live music and audio-visual productions, but this will require new problems to be solved. Computers must be able to perceive and synchronize to conventional music. They must also be able to sense, model and mimic in real-time high-level aspects of human emotional behavior. Computers must also sense human gestures to control, shape, and cue music, much the way musicians use gesture to coordinate in a live performance. Finally, computers must communicate with human musicians to give feedback, confirmation, or even to direct them. Solving these problems will lead to a better understanding of collaborative interaction in general and enable many new artistic applications of computing.

APPLIED MATHEMATICS

Carnegie Mellon University and the participating Portuguese Institutions have strong groups in Applied Mathematics, and a long history of scientific collaboration. With this partnership we will continue to explore these existing connections, we will encourage the emergence of new synergies, and we will enhance the training of a new generation of young researchers well positioned to respond to contemporary scientific and technological challenges that require new fundamental and applied research in Mathematics. The key areas of this program are: Applied Analysis and Stochastic Analysis:

Applied Analysis: This is a broad area of research which includes calculus of variations, partial differential equations, mathematical modeling and its applications. Particularly active research areas are imaging and the study of properties of advanced materials.

Stochastic Analysis: Many of the current research topics in this area, ranging from mathematical finance, stochastic control theory, to viscosity solutions of Hamilton-Jacobi equations, have wide real-world applications.

These areas address cutting-edge mathematical questions in science and engineering, including materials science, biotechnology, and computational finance, to highlight emerging areas in mathematics deriving from applications, and to develop new applications of mathematical sciences. In what follows we present some of the main challenges that are being studied in collaboration in the framework of the joint research projects.

Main Challenges:

Advanced materials: This is a very broad area ranging from composites, micro and nano-structures to biological structures with a clear impact in real world applications . In this area, new techniques in calculus of variations, partial differential equations, homogenization and numerical methods have been developed both by CMU and Portuguese faculty. The experience form the first phase of the program shows that this a area where cooperation between Portuguese and CMU faculty is extremely fruitful. Among the topics that are being studied in collaboration we single out the following:

- Thin structures: dimension reduction and eigenvalue problems; bending, nonlocality and linear growth asymptotics;mathematical models for thin structures in a BV setting;
- Homogenization and multi-phase problems: relaxation of first and second order problems with linear growth; relaxation and homogenization of functionals in image segmentation models; variational problems with volume constraints; homogenization in multi-phase and multi-component systems;homogenization in multi-phase and multi-component systems;
- Interfaces, front propagation and image processing.

A large and important class of nonlinear PDEs is that of singular and degenerate equations, that range from flows by mean curvature to Monge-Ampère equations to the infinity-Laplacian. Despite having a common structure, singular and degenerate PDEs are connected to many different applications, such as front and interface propagation, image processing, motion of multi-phase fluids in porous media, melting of crushed ice (and phase transitions in general), optimal transportation, Aubry-Mather theory, deterministic and stochastic optimal control, behavior of composite materials, diffusion in highly non-homogeneous and anisotropic media, or pricing of assets in financial markets. This is also an area where there is a great potential of interaction between Portuguese and CMU faculty. The following are some examples of concrete applications:

- Stefan-like parabolic equations with measurable coefficients model physical phenomena like transitions of phase and/or the flow of immiscible fluids in a porous medium. Singular equations modeling the dynamics of thin films can be viewed, at least formally, as a limiting case of the porous medium equation and thus several properties of the latter are expected to hold for the former. A crucial issue is to understand if solutions are continuous or, on the contrary, if they develop singularities corresponding to the film rupture. In this case, understanding the local behavior of solutions close to the discontinuity is not only a challenging analytical question but also one with a true impact in terms of the applications.

- Populations of individuals of many different species aggregate into large groups such as ungulate herds, bird flocks, fish schools, and locust swarms. An important problem is to explain how decisions of individuals lead to formation of groups and determine their properties. A related area of research are mean field games, which study the behavior of a large population of rational agents in competition. Several mathematical challenges from modeling to existence, uniqueness and regularity issues are still open and are topics of active research.

Mathematical finance and stochastic models: A clear lesson from the present financial crisis is the need of robust stochastic finance methods for risk analysis and management. These challenges are of different types, and concern not only the need of new mathematical approaches, as well as computational applications . In a recent article from the "Financial Times", its editor states the need of more – and better – mathematical methods to underpin individual banks and the enhanced regulatory regime thatwill oversee them.In this area some of the most pressing questions concern the three following topics:

- Efficient and robust numerical algorithms: present and future applications of Computational Finance require powerful and efficient resources. High efficiency of numerical methods is

essential mainly because models are often re-built and re-calibrated, as new data from the real is available

- Investment decisions under uncertainty: a typical example concerns real options, where the impact of uncertainty is extremely important in terms of optimal decisions, as it can speed up or postpone investment decisions. Moreover, the irreversibility of investment costs is also a key factor in the decision process.

- Interest rate models. It is clear that the high volatility and uncertainty in the evolution of interest rates is a reason of concern for companies and governments. Better modeling and hedging techniques are essential and are a current topic of research.

LIST OF CONTRIBUTORS

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A number of individuals contributred to the first draft of this document (dated March 31, 2012). This draft was subject to public discussion among numerous other faculty and interested parties that identified a number of important issues and provided clarification and helped inform this final document. At the risk of missing many of the contributors (apologies presented in advance), we list below some of the main contributors.

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