EXPRESSION OF INTEREST

FOUNDATIONS OF GLOBAL COMPUTING

NETWORK OF EXCELLENCE

University of Aarhus (DK)
Università di Bologna (I)
University of Cambridge (UK)
Trinity College, University of Dublin (IRL)
École Normale Supérieure, Paris (F)
University of Edinburgh (UK)
Università di Firenze (I)
Università di Genova (I)
Imperial College, University of London (UK)
INRIA – Grenoble (F)
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École Polytechnique Fédérale de Lausanne (CH)
Universidade de Lisboa (P)
Université de Provence, Marseille (F)
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Università di Pisa (I)
University of Sussex (UK)
Università di Torino (I)
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PREPARED IN RESPONSE TO CALL **EOI.FP6.2002**

JUNE 7TH, 2002

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1 Relevance of the Network

Ambient intelligence (AmI) envisions four scenarios where people interact with ubiquitous networks of various dimensions (Personal and Vehicle Area Networks) via (wearable) digital devices (Digital-Me, Personal-Com) sensitive to the 'intelligent' enclosing ambient (e.g. automatic debiting systems). Technical requirements for AmI are at the hardware level (miniaturised components, network devices far beyond the current plug-and-play capabilities) as well as at the network level. *Global computing* (GC) refers to computation over seamless, massively distributed networks with swiftly changing topologies, where a multitude of digital, possibly embedded devices use distributed, not centrally-owned resources. GC is thus one of the fundamental components of AmI and, consequently, a key target for Europe and its IST and eEurope programme.

The aim of this proposal is to establish Europe as the international scientific leader in Foundations of Global Computing. Several research projects focusing on GC are currently active in Europe, some of which funded under the European Commission's Framework V programme, including a dedicated FET proactive initiative. The variety of aspects of GC, however, make it a very difficult research topic, one that demands much higher integration and joint efforts at European level for Europe to be successful. And Europe needs to be successful to support its future economic strategies (currently IST represents 10% or more in European market economies). The recent rise of GC as a focal research topic makes the current moment particularly suitable to found a network of excellence on the theme. Five years ago it would have not been possible to put together the needed critical mass of researchers, five years from now it would be too late for Europe to gain leadership in the field and, consequently, retain it in related areas.

The proposed Network of Excellence *"Foundations of Global Computing"* (FOG) aims at gathering together the strongest European researchers in the field with a joint programme of scientific activities, involving research, integration, and dissemination. The Consortium's overall strategic objectives are:

Research: to develop programming language abstractions and software developer's level construction and analysis tools for GC;

Integration: to initiate a lasting integration of the partners to work together at a supranational level for research, experimentation and education;

Dissemination: to spread excellence in science and technology, with particular attention to the needs and activities of small/medium enterprises (SME).

The partners have been selected among the European research groups involved in GC research of the highest quality and willing to commit to integrate their activities with the network's. The synergy will deliver results much beyond the sum of the individual efforts: as we will document shortly, the complexity of the field is such that no partner is likely to succeed without strict, continuous, programmed contact with the other partners' knowledge, insights, activities and results.

Contribution to the FP6 priority thematic areas. Central to FP6 is the Information Society Technologies Advisory Group's (ISTAG) AmI vision. AmI is introduced by four near future scenarios (Maria, or personal ambient communicator; Dimitrios, or digital me; Carmen, or traffic optimisation; Annette and Solomon, or social learning), and ISTAG extracts from them five key technological factors for AmI to deliver. Three of these are directly addressed at the foundational level by FOG's research, namely 'Seamless mobile/fixed web-based communication infrastracture,' 'Dynamic and massively distributed device networks,' and 'Dependability and security.' Similarly, FOG targets exactly not less than three of the six fundamental technologies pinned down by the Commission after the recent round of consultation meetings on FP6 as the major enablers for the IST applications envisioned for the years 2010–2020, and pinpointed as the pillars of FP6.

In terms of the FP6 Priority Thematic Research areas, FOG is central to 1.2.2 'Communication, computing, software technologies,' and in particular to its subtheme 'Software technologies, embedded and distributed systems,' which aims at the realisation of the AmI landscape. Of clearly related interest is the subtheme of 1.2.1 'Technologies for trust and security.'

Contribution to the European Research Area. The Commission identifies the main problems of the European research in the fragmentation of its base, the brain drain to the United States, and its weakness in converting RTD into useful social economical benefits. FOG has the excellence to address in its application area all of these problems. GC is unique in that it has emerged very recently as one of the most relevant areas for the future of the information technology industry. Europe *is* at the moment the worldwide leader on basic research in GC; yet, the complexity of the issues involved is overwhelming, and it is recognised that major breakthroughs will need a substantially greater commitment to foundational research.

Based on this state of the art, FOG offers the opportunity to bring together the leading European research teams in GC, in a network of excellence with a coherent and targeted strategy of strengthening Europe's worldwide leadership in the research on Global Computing with a new and elaborate scheme of ensuring a close collaboration with European SMEs.

2 Excellence of the Network

GC has many aspects to it, ranging from network and domain mobility, to security and trust, to software interoperability and adaptability to multi-linguistic platforms. In order to tackle it in a comprehensive manner, a successful network should need be knowledgeable at least in the following technologies:

> concurrency and mobility; distributed, real-time algorithms and systems; computer security and trust; components and middleware; web programming and semi-structured data; distributed (OO) modelling; programming language design;

and in the following theories and techniques:

> semantics of programming languages; type systems and static analysis; verification techniques; specification logics.

Although this is manifestly beyond the expertise of any single site, it transpires clearly from Table 1 that the joint expertise of the core sites of our proposed network cover all these aspects. The critical mass we bring together is remarkable, in that it is very homogeneous for research focus and interests, whilst being very heterogeneous for techniques and approaches to GC research, and will trigger common activity and results. The forthcoming project proposal will detail the initial activity making clear synergies and connections.

Table 1 shows the quality of the research groups involved and, in turn, the excellence of their universities. The figures therein refer to the number of full-time researcher (with at least four years experience) dedicated to FOG, the groups' research income (in KEuro) in the last 12 months, the number of international refereed publications, and number of FOG's partners with whom the site has an active institutional cooperation. Table 2 argues for the quality of the network's individual members. They include the top European scientists in the field (with the noticeable omission of the people at MSR Cambridge).

3 Activities of the Network

The scientific activities of the network can be classified into research, integration and dissemination activities. We outline the main point of each of these below.

Research Activities. FOG's research activity aims at establishing solid foundations for the software technology of the future, dealing with the complexity of the essential aspects of GC. To gain a leading edge in the field will be crucial for the success of European industry, and one of the challenges FOG will be facing throughout its lifetime is to enhance its ability to impact industry. More immediately, the purpose of foundational theories is to provide a formal understanding of the difficulties of GC, as well as new specification formalisms to cope with them and to develop the corresponding verification techniques.

Before discussing some of the gaps theory needs to address, it is worth remarking that foundations will be directly useful for a series of programmer level abstractions that FOG will positively develop, prototype, and experiment with. A programming paradigm for GC requires a blend of features not present in current programming languages. These include, network-awareness and mobility (ambient-based technology), encapsulation and controlled access to resources (object-based technology), security (static type-based and dynamic execution-monitoring), searching for services (enhanced tuple-space and pattern matching), reusability and customisation to user needs and local environment (generative components, dynamic assembly, mixin modules), reconfiguration and adaptability to environment changes. Object technology itself needs to be improved to support the evolution of code and interfaces at run-time, as well as the deployment of service-oriented software architectures. FOG will engage in experimental distributed implementation of programming languages and libraries that integrate and reinforce mainstream programming practice for GC, including mechanisms for mobility, security, coordination, service-orientation, and fault-tolerance. It will also focus on critical large-scale distributed execution platforms, such as distributed operating systems and middleware architectures.

Programming abstractions which will be considered, both for design and for implementation, include the following.

- ▷ Network-aware programming languages, and their experimentation on non-trivial applications.
- ▷ Programming languages for space-restricted computation to be used in e.g. smart cards, wearable computers and mobile phones.
- ▷ Programming languages and component infrastructures well suited for the construction of web services. Generative programming, mixin modules and types here will have to be compatible with the multilingual nature of the programming environment. Such languages will interoperate smoothly with mainstream languages and attempt to unify major programming paradigms, e.g. such us the object-oriented and the functional.
- ▷ Programming languages for handling, transforming and querying XML documents, and in general semi-structured data. Their characteristic features

will be powerful pattern matching, very rich type systems and precise type inference.

Such a body of experimental activity needs theoretical support. Often, the relevant theory does not exist and will have to be developed. FOG will provide for that by focusing on *models*, *semantics*, *specifications*, and *types*. A fundamental activity will be to design new expressive foundational calculi in which a wide variety of phenomena (mobility, security, uncertainty, trust) can be described. Such calculi will require a semantic theory to support new reasoning principles, and new logics for expressing network and agent behaviours, as well as specification and verification techniques. The coordination aspects of mobile code will be studied by defining new models under the hypothesis of open environments with dynamically reconfigurable topologies supporting both physical and logical mobility. Further along this avenue, FOG will develop a formal model for the separation of the three main concerns involved in service-oriented architectures: computation, coordination, and distribution.

A parallel research stream will address the development of process calculi for mobile object-oriented programs, by relying on a mixin-based approach and, in general, on integrated formal models of concurrency, mobility and object-oriented programming.

Following an established trend, types will provide a fundamental vehicle for the analysis and enforcement of security. Among the issues of major interest is the study of mixed static/dynamic techniques, including the design of type systems supporting run-time type checking of (part of) programs and dynamic change of the capabilities assigned to them.

From the specification point of view, FOG will extend the standard modelling language UML for GC, and integrate it with formal validation and verification methods. Due to its inherent complexity, GC requires new software engineering techniques; to be applicable in practice these need to be compatible with UML, the standard of semiformal engineering methods. The integration with UML will be a major factor to import the new technology into the typical SME's development process, as software engineers will easily adapt to it.

Semi-structured data play an important role in the exchange of information between globally distributed applications. A key example is XML, the universally agreed standard for describing and exchanging data on the Web. FOG's work on languages for XML processing and querying will be supported by the study of their formal foundations and their relationships to logical formalisms, issues that are poorly understood at present. In particular, FOG will focus on spatial logics for semi-structured data and their application to query languages. The power of spatial logics is that they can reason locally about a property's truth value, and hence integrate well with models of distributed data. FOG's ambition is to achieve a level of understanding of query languages for semi-structured data which rivals that of languages associated with the relational model.

Among the most challenging requirements of the GC infrastructure is security. FOG will be concerned with the design and semantics study of processes with cryptographic primitives, as well as the development of tools for their analysis. Validation of cryptographic protocols will be one of the main applications of the theory. A challenging goal will be to develop decision methods (exact or approximated) for fragments of first-order logic suitable to express the specifications of such protocols, and to evaluate them on real examples.

Further on verification, we plan to advance the state of the art on formal modelling and automated checking and testing of (realtime) systems with a dynamic process and linking structure, and develop the corresponding tools. We will work on semi-automatic verification for globally distributed systems, such as entire phone networks and 'the grid.'

Integration Activities. FOG's work-programme will make provisions for the integration of its partners to last beyond the natural end of the Commission's financial support. The programme will include the creation of joint research infrastructure, including common programmes to provide education by training and research. The consortium will commit to exchange of PhD students and research fellows. An exchange programme will be set up that enhances quality and timeliness of research, whilst maximising the opportunity for young researcher to receive training on GC at the highest level in the best suitable European institution.

The consortium will keep a positively open-ended attitude, trying to tighten links with new emerging groups, as well as to attract top researchers from all over the world to visit or even be recruited by the participating sites. In addition FOG will issue open calls for SMEs to join the consortium on specific experimental tasks or for the selection of case studies of real interest. In this way, we will set up small collaborative projects with potential users.

FOG will organise scientific meetings and internal workshops at regular intervals, so as to guarantee that partners are fully aware of advances obtained at the various sites. The leadership of such meetings will be circulated among the core sites. It is envisaged that the links between partners will tighten along the duration of the project, so as to become 'hardwired' into their future GC activities.

Dissemination Activities. Besides the classical dissemination channels associated with research activities (publications, seminars, conferences), FOG's partners

are committed to spreading excellence by novel means devised specifically for this project's purposes. These include organising scientific meetings and workshops on the subject of GC with active industrial participation. Excellence will be pursued also by initiating joint programmes for training of young researcher, both at master and doctoral level. FOG will also organise training activities for the dissemination of GC literacy to small and medium enterprises (SME). The preferred method will be to package results into course material and teach courses at various levels, including summer schools for PhD students and mini courses for potential users. Following such a strategy, FOG will reach researchers, users groups, as well as industries, contributing to international standards and feeding input to EU and national policy makers.

FOG will found a yearly scientific meeting on GC and make of it the worldwide meeting point for the international GC community. The success of such a meeting, both in terms of participants and number and variety of scientific works submitted, will be an objective measure of the consortium's success in upholding FOG's aims.

FOG's dissemination strategy will include the release of research software, such as experimental programming languages, libraries, distributed systems, real case studies, and more, to demonstrate the ideas arising from its approach to GC.

4 Effects of the Network

The network's success will have the effect to advance the foundational theories underpinning the development of programming languages and paradigms for GC, as well as the corresponding specification and verification techniques. Primary effects are also a tight, permanent integration between partners and the dissemination of knowledge to young researchers and SMEs. A schematic view of the long term effects and results expected of FOG is illustrated in Table 3.

The joint programme of activities is carefully designed to boost integration and multiply occasions of common scientific development. In particular, we expect to advance the state of the art of several key enabling technologies for the FP6's IST vision by addressing them by the joint strengths of the network members.

The partners are committed to integration of research and educational programmes, by actively pursuing the adaptation of nationally funded (research) activities to the network's activities. Among these, the design and realisation of common research and dissemination infrastructures, viz. joint programmes of studies and a detailed institutional plan for short/middle-term exchanges of research personnel: young researchers moving to complete their formation, and senior ones bringing new knowledge to partner institutions.

The role of SMEs. By the year 2010 an estimated 30% of SMEs will be using IST, in particular eBusiness, to carry out their business profitably. FOG's workprogramme will thus address central needs of SMEs, and impact them both indirectly, as our research topics underly the deployment of eBusiness applications, and directly, by means of open calls to participate in the network's activities and to inform the consortium by presenting major problems and challenges. SMEs will also be called to attend FOG's dissemination activity.

The structuring effect. FOG has the potential for triggering a very long term institutional collaboration between its partners. As shown in Table 1 (column 'Links to Partners', that counts the institutional, official relationship of each site with the others), the partners have already a long history and a solid pattern of collaboration. This witnesses the extent, quality, and duration of the integration FOG proposes. The network will work to establish a permanent structuring and integrating effect on the European research in the field. In particular, it will reduce the level of fragmentation of the research and facilitate a united European strategy on GC, both by providing the context for constant dialogue among the main researchers in the field. As a matter of fact, due to its pervasive presence in future applications, GC could very well be a suitable topic for a major European scheme of training young researchers based on a dedicated grant from EU. It is envisaged that the network's dissemination and training programme (mini courses, summer schools, PhD courses, etc) will have the effect of giving rise to a European school of GC.

5 Management of the Network

The network will have a Coordinator (for the Commission to interact with) whose role will be as indicated in the Commission's documents. Furthermore, there will be a Governing Council formed by senior representatives of the core partners. Assistant partners will be selected as the need arises, mainly to incorporate emerging groups and isolated researchers into the network, and for selecting SMEs willing to propose interesting, real case studies and engage into experimental activity in the network. FOG will have an Industrial Board formed by people from industry. An initial list of potential candidates is given in Table 4 who will be contacted in due time. Senior researchers among those in Table 2 will be responsible for units of FOG's activity and will act as site leaders.

The partners will sign a consortium agreement binding them to common rules concerning the protection of intellectual property and the exploitation of the project's results.

Partner	**Staff in Group**	**Recent Research Grants**	**Publ. 1999-2002**	**Links to Partners**	**Area of Excellence and Role in the Network**
AARHUS	10	1000	90	16	Concurrency; Security; Verification; Web programming
BOLOGNA	12	160	60	5	Distributed programming languages; Coordination languages; Verification
CAMBRIDGE	13	768	69	11	Design of middleware and distributed systems; Security; Complexity and expressive power of languages; Denotational and operational semantics of computation; Concurrency and mobility: calculi, models, logics; Type systems
DUBLIN	5	500	20	5	Sentient computing; Adaptable systems; Secure collaboration; Formal methods
ENS, PARIS	2	240	19	4	Type theory; Formal models for concurrent mobile systems; Object-oriented languages; Language-level security; Languages for XML documents.
EDINBURGH	9	2150	40	8	Semantics; Logics; Theorem proving; Type theory; Concurrency
FIRENZE	6	400	30	6	Network-aware programming languages and technologies; concurrency and mobility
GENOVA	6	330	50	8	Module systems: foundations and design; Semantics and extensions of OO programming languages; Metamodelling and UML; Development techniques for component-based and distributed systems; Meta-programming and staging; Monadic metalanguages
IMPERIAL	11	638	62	12	Semantics of OO programming languages; Dynamic program evolution; Foundations of distributed systems; Querying data on the web; Type systems
INRIA GRENOBLE	3	900	30	5	Distributed software infrastructures; Operating systems and middleware; Concurrency; Mobility
INRIA ROQUENC.	5	152	8	7	Programming languages: Semantics and Implementation; Concurrency; Mobility
INRIA SOPHIA	5	181	21	8	Concurrency; Mobility; Reactive and functional programming
LAUSANNE	4	600	13	4	Programming languages; Distributed algorithms; Middleware; Concurrency; Mobility
LISBOA	7	100	35	6	Algebraic and logic semantics; Software architectures; Service-oriented software development; Coordination; Concurrency and mobility; Types systems
MARSEILLE	8	130	60	9	Security and mobility; Verification of Crypto Protocols; Temporized systems
MÜNCHEN	11	500	70	7	Semantics of specification and programming languages; Type systems; Logics for concurrency and distributed systems; OO modelling; Software engineering; Multimedia applications
PISA	9	100	80	8	Graph rewriting systems; Verification of mobile systems; Constraint programming; Coordination models; Algebraic models for concurrency; Models and languages for secure, open distributed systems; Network aware programming
SUSSEX	8	750	43	7	Semantic foundations of concurrency; Semantics of programming languages
TORINO	6	350	35	8	Denotational and logical semantics; Type theories
UPPSALA	9	1000	63	6	Distributed and embedded systems; Concurrency; Validation; Verification; Realtime systems
VENEZIA	10	270	90	6	Program analysis and verification; Formal models for concurrent mobile and distributed systems; Formal methods for security; Type systems; XML

Table 1: THE CONSORTIUM

Partner	**Key Researchers**
AARHUS	Ivan Damgaard, Oliver Danvy, Kim G. Larsen, Peter Mosses, Mogens Nielsen, Michael Schwartzbach
BOLOGNA	Nadia Busi, Paolo Ciancarini, Cosimo Laneve, Maurizio Gabbrielli, Gianluigi Zavattaro
CAMBRIDGE	Jean Bacon, Gavin Bierman, Anuj Dawar, Marcelo Fiore, Robin Milner, Ken Moody, Andrew Pitts, Peter Sewell, Glynn Winskel
DUBLIN	Andrew Butterfield, Vinny Cahill
ENS, PARIS	Giuseppe Castagna
EDINBURGH	David Aspinall, Peter Buneman, Stephen Gilmore, Don Sannella, Ian Stark
FIRENZE	Michele Boreale, Rocco De Nicola, Rosario Pugliese, Betti Venneri
GENOVA	Egidio Astesiano, Eugenio Moggi, Elena Zucca
IMPERIAL	Sophia Drossopoulou, Susan Eisenbach, Philippa Gardner, Iain Phillips, Nobuko Yoshida
INRIA	GRENOBLE: Jean-Bernard Stefani ROQUENCOURT: Georges Gonthier, Jean-Jacques Levy, James Leifer, Luc Maranget, Didier Remy SOPHIA: Gerard Boudol, Frederic Boussinot, Ilaria Castellani, Davide Sangiorgi, Manuel Serrano
LAUSANNE	Rachid Guerraoui, Uwe Nestmann, Martin Odersky, Christine Roeckl
LISBOA	José-Luis Fiadeiro, Vasco T. Vasconcelos
MARSEILLE	Roberto Amadio, Silvano Dal Zilio, Denis Lugiez
MÜNCHEN	Martin Hofmann, Martin Wirsing
PISA	Andrea Corradini, Gianluigi Ferrari, Fabio Gadducci, Ugo Montanari
SUSSEX	Guy McCusker, Matthew Hennessy, Julian Rathke, Bernhard Reus, Vladimiro Sassone
TORINO	Viviana Bono, Mariangiola Dezani, Paola Giannini, Simona Ronchi
UPPSALA	Parosh Abdulla, Bengt Jonsson, Joachim Parrow, Wang Yi
VENEZIA	Annalisa Bossi, Michele Bugliesi, Agostino Cortesi, Riccardo Focardi, Massimo Marchiori

Table 2: KEY RESEARCH PERSONNEL

Expected Result	**Users / Effects of the Results**
Programming languages and paradigms for GC	Sofware designers, developers, and engineers; Software companies; Application service providers; Manufacturers of embedded devices; Web site developers.
Specification and verification techniques for GC.	Security policy designers, engineers, and administrators; Computing center administrators; Protocol designers; Academic researchers.
Calculi, models and types for GC.	Programming language designers; Protocol designers; Academic researchers.
Integration of the partners; Spreading of excellence; The creation of a European school of GC; A structuring effect on the field and a consequent defragmentation of research base.	Achieved by means of adaptation of national research and teaching schemes and by packaging research material into courses of various levels, this will reach: PhD students, young researchers, SMEs, and the European Research Area (ERA) in general.

Table 3: THE EFFECTS OF THE NETWORK

Company	**Contact Person**	**Company**	**Contact Person**
ALTRAN (I)	Renato Bellavita	ATX Software (P)	Luis Andrade
Cryptomatic (DK/UK)	Peter Landrock	Microsoft Research (UK)	Luca Cardelli, Andrew D. Gordon
EDS (UK)	Sharman Walker	FAST GmBH (D)	Rudolf Haggenmüller
France Telecom R&D (F)	Pierre Cregut	Marconi (UK)	Derek Macaulay
Protos Software (D)	Klaus Birken	Softlab GmBH (D)	Günther Merbeth
Telecom Italia Lab	Corrado Moiso		
OTHER INTERESTED PARTIES: ASTEC (SE); British Telecom (UK); BMW (D); Cryo Networks (F); DataCall Systeme (D); Ericsson (SE); Fluxmedia (F); Gemplus (DK/F); Infineon (D); MediaOnAir Technologies (D); Telecom Italia Mobile (I); TXT E-Solutions (I)			

Table 4: THE INDUSTRIAL LIAISON