MEMORANDUM OF UNDERSTANDING

Subject: Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action TD1307: European Model Reduction Network (EU-MORNET)

Delegations will find attached the Memorandum of Understanding for COST Action TD1307 as approved by the COST Committee of Senior Officials (CSO) at its 188th meeting on 14 November 2013.
MEMORANDUM OF UNDERSTANDING
For the implementation of a European Concerted Research Action designated as
COST Action TD1307
EUROPEAN MODEL REDUCTION NETWORK (EU-MORNET)

The Parties to this Memorandum of Understanding, declaring their common intention to participate in the concerted Action referred to above and described in the technical Annex to the Memorandum, have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of document COST 4114/13 “COST Action Management” and document COST 4112/13 “Rules for Participation in and Implementation of COST Activities”, or in any new document amending or replacing them, the contents of which the Parties are fully aware of.

2. The main objective of the Action is to significantly bringing down computation times for realistic simulations and co-simulations of industrial, scientific, economic and societal models by developing appropriate ‘model reduction’ methods.

3. The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 60 million in 2013 prices.

4. The Memorandum of Understanding will take effect on being accepted by at least five Parties.

5. The Memorandum of Understanding will remain in force for a period of 4 years, calculated from the date of the first meeting of the Management Committee, unless the duration of the Action is modified according to the provisions of section 2. Changes to a COST Action in the document COST 4114/13.
GENERAL FEATURES

Initial Idea:
This Action will bring together all major groups in Europe working on a range of model reduction strategies with applications in many domains of science and technology. The increasing complexity of mathematical models used to predict real-world systems, such as climate or the human cardiovascular system, has led to a need for model reduction, which means developing systematic algorithms for replacing complex models with far simpler ones, that still accurately capture the most important aspects of the phenomena being modelled. The Action will emphasize model reduction topics in several themes: 1. design, optimization, and control theory in real-time with applications in engineering; 2. data assimilation, geometry registration, and parameter estimation with a special attention to real-time computing in biomedical engineering and computational physics; 3. real-time visualization of physics-based simulations in computer science; 4. the treatment of high-dimensional problems in state space, physical space, or parameter space; 5. the interactions between different model reduction and dimensionality reduction approaches. The focus of the Action is methodological; however, a wide range of both scientific and industrial problems of high complexity is anticipated to motivate, stimulate, and ultimately demonstrate the meaningfulness and efficiency of the Action.

Keywords: model reduction, numerical mathematics, systems and control, stochastics, parameterization, tensor analysis, reduced basis methods, Krylov methods, balanced truncation

STRATEGY

Objective 1 (A.5) - Type: Development of knowledge needing international coordination: new or improved theory / model / scenario / projection / simulation / narrative / methodology / technology / technique
1. Science and Technology Coordination, Application for Framework Programme Funding.
2. Science and Technology Output, Education and/or Training Material.
3. Science and Technology Coordination, Short-Term Scientific Missions (STSM).
4. Science and Technology Event or Meeting, Action Workshop.
Objective 2 (B.11) - Type: Around a topic of scientific and/or socio-economic relevance, allowing for knowledge exchange and the development of a joint research agenda beyond objectives 1 to 10.

1. Science and Technology Event or Meeting, Action Conference.
2. Science and Technology Coordination, Short-Term Scientific Missions (STSM).
4. Science and Technology Coordination, Application for Framework Programme Funding.
5. Internal and External Communication, Production of dissemination material for distribution.

Objective 3 (A.10) - Type: Dissemination of research results to stakeholders (excluding specific input in view of knowledge application, as per objective 7)

1. Documents to be Used as Input to Stakeholders, to users/practitioners.
3. Science and Technology Coordination, Application for Framework Programme Funding.
4. Science and Technology Coordination, Short-Term Scientific Missions (STSM).
5. Science and Technology Event or Meeting, Action Conference.

Objective 4 (A.9) - Type: Dissemination of research results to the general public

2. Science and Technology Output, Education and/or Training Material.
3. Internal and External Communication, Website.

A. CHALLENGE

A.1 Features of the Challenge

A.1.1 Background and Motivation

The mathematical sciences play a vital part in all aspects of modern society. Without research and training in mathematics, there would be no engineering, economics or computer science; no smartphones, MRI scanners, bank accounts or PIN numbers. Mathematics is playing a key role in tackling the modern-day challenge of cyber security and in predicting the consequences of climate change, whereas in manufacturing sectors such as automotive and aerospace industries benefit from superior virtual design processes. Likewise the life sciences sector, with significant potential for
economic growth, would not be in such a strong position without mathematics research and training, providing the expertise integral to the development of areas such as personalised healthcare and pharmaceuticals, and underpinning development of many medical technologies. The emergence of truly massive datasets across most fields of science and engineering increases the need for new tools from the mathematical sciences.

One of the classic ways in which mathematical science research plays a role in the economy is through collecting data towards understanding it, by using tools and techniques, enabling the discovery of new relationships or models. Modelling of physical phenomena already dates back several centuries, and well-known systems of equations with the names of Maxwell, Navier-Stokes, Korteweg-de Vries and more recently the Schrödinger equation plus many others are now well established. But it was not until the advent of computers in the middle of the previous century, and the development of sophisticated computational methods (like iterative solution methods for large sparse linear systems) that this could be taken to a higher level, by performing computations using these models. Software tools with advanced computational mathematical techniques for the solution of the aforementioned systems of equations have become common place, and are heavily used by engineers and scientists.

Mirroring this activity is increased awareness by society and industry that mathematical simulation is ubiquitous to address the challenging problems of our times. Industrial processes, economic models and critical events like floods, power failures or epidemics have become so complicated that its realistic description does not require the simulation of a single model, but rather the co-simulation of various models. Better scientific understanding of the factors governing these will provide routes to greater innovation power and economic well-being across an increasingly complex, networked world with its competitive and strongly interacting agents. Industry, but also science, is highly dependent on the development of virtual environments that can handle the complex problems that we face today, and in the future.

For example, if the origins of life are to be explained, biologists and mathematicians need to work together, and most of the time spent will be on evaluating and simulating the mathematical models. Using the mathematics of evolutionary dynamics, the change from no life to life (referring to the self-replicating molecules dominating early Earth) can be explained. Another example is the electronics industry, which all of us rely on for new developments in virtually every aspect of our everyday life. Innovations in this branch of industry are impossible without the use of virtual design
environments that enable engineers to develop and test their complex designs behind a screen, without ever having to go into the time-consuming (several months) process of prototyping.

Principles of computational science and engineering rooted in modern applied mathematics are at the core of these developments, subjects that are set to undergo a renaissance in the 21st century. Indeed, no less a figure than Stephen Hawking is on record as saying that the 21st century will be the century of complexity. Another great figure, yet young, is Fields medallist Terence Tao, who was a major contributor to the recently published document entitled “The mathematical sciences in 2025”, stating: “Mathematical sciences work is becoming an increasingly integral and essential component of a growing array of areas of investigation in biology, medicine, social sciences, business, advanced design, climate, finance, advanced materials, and many more – crucial to economic growth and societal well-being”.

Growing computing power, nowadays including multicore architectures and GPU’s, does not provide the solution to the ever growing demand for more complex and more realistic simulations. In fact, it has been demonstrated that Moore’s Law, describing the advances in computing power over the last 40 years, equally holds for mathematical algorithms. Hence, it is important to develop both faster computers and faster algorithms, at the same time. This is essential if we wish to keep up with the growing demands by science and technology for more complex simulations. Traditionally, algorithmic speed-ups have come from developments in the area of linear system solution, in which iterative algorithms developed since the 1970’s have been prominent and very effective. Since the start of the new century, however, another powerful development is seen in mathematics, as well as in the systems and control area. This field, which we term ‘model reduction’ for simplicity (we will detail this further in the next section), aims at capturing essential features of models, thereby drastically reducing the size of the problem to be solved. As it holds many promises, this will be the basis for the challenge addressed in this COST Action.

A.1.2 The Challenge

Improved computational techniques and advanced computer architectures will help cope with the important industrial, technological, scientific and societal issues that our world is facing, and contribute to innovations and new insights. This depends crucially on the availability of accurate and realistic mathematical models for the multitude of phenomena we are observing, in many different fields. Fortunately, many well-established models exist, and by using combinations of
several models the necessary high level of accuracy can be achieved. However, whereas the simulation of a single model within reasonable time has been mastered in most cases (turbulent flow simulation remains rather demanding), the co-simulation of several models to obtain realistic simulations is often still out of reach, even on today’s computers and those of the near future. In many situations, this is due to the fact that the individual models lead to much superfluous detail for the combined simulation. Often, what matters are the dominant features of a model, interacting with the models describing another aspect of the problem at hand. An example is the simulation of interconnect structures in a chip, where the Maxwell equations need to be coupled to the system of electronic circuit equations. If the full system of 3-D Maxwell equations is solved, this introduces millions of extra degrees of freedom on top of the large system of circuit equations. However, it turns out that the electromagnetic problem can be greatly reduced, often to only a few hundreds of degrees of freedom, thereby still describing accurately the performance of the circuit under the influence of the metallic interconnect structure and its parasitic electromagnetic effects.

Model reduction is a field that has been rapidly growing since the beginning of this century, and is able to provide solutions to this important challenge. Using model reduction techniques, dominant features can be captured, thereby reducing computation times enormously and enabling realistic simulations to be carried out in acceptable time. However, classified in a mathematical way, the variety of problems is very large, ranging from simple linear time-varying to nonlinear and autonomous systems. Simulations are combined with experimental data, parameters may be present, problem information (such as coefficients in the models) can be uncertain. Furthermore, often specific model properties need to be preserved by the reduced order models. Last but not least, engineers are interested in optimizing their designs in such a way that prescribed specifications are met, leading to a sequence of many simulations. While for (non-parameterized) linear problems the theories are relatively well-developed, and a wealth of methods is available, this is certainly not the case for problems that contain one or more of the aforementioned aspects. Many researchers have turned their attention towards the field of model reduction, and are addressing the many aspects as well as working on many different applications. Conferences like the successful SIAM (Society for Industrial and Applied Mathematics) series on Computational Science and Engineering or the series of ICIAM (International Congress for Industrial and Applied Mathematics) conferences nowadays contain many sessions and mini-symposia devoted to model reduction. The field of ‘model reduction’ attracts researchers from tensor analysis, reduced basis methods, and other disciplines.
FORMULATION OF THE CHALLENGE

This COST Action will address the challenge of significantly bringing down computation times for realistic simulations and co-simulations of industrial, scientific, economic and societal models by developing appropriate ‘model reduction’ methods for linear and nonlinear, autonomous and non-autonomous, parameterized and non-parameterized models, with or without variability and/or additional experimental data, and enabling optimization of designs. The Action will also lead to a unified framework of ‘model reduction’ techniques to achieve this challenge.

A.1.3 Relevance and Timeliness

Improved computational model reduction techniques will help cope with the important industrial and societal challenges that are facing Europe. European businesses compete in a global market where in many regions manufacturing and labour costs are much lower. To be competitive in such an arena Europe must rely on innovation. According to the Organisation for Economic Co-operation and Development 2008 Report “Industrial innovation is increasingly based on the results and techniques of scientific research. That research, in turn, is both underpinned and driven by mathematics.” A 2012 Deloitte report commissioned by the UK Engineering and Physical Sciences Research Council (EPSRC) strongly confirms this, by concluding that up to 16 percent of Gross Value Added can be attributed to results of mathematical research. A stunning example is the numerical wind tunnel developed by Airbus in France and Germany, costing more than 1 billion Euros in development, but now enabling Airbus to design and test aircraft without using any physical wind tunnels. Virtual design environments in other areas of industry are also under development, and are highly dependent on efficient computational techniques, most prominently in the field of model reduction. These environments should be able to handle increasingly large data sets.

The challenge defined in the foregoing section is valid in several of the domains of science and technology. In the environmental sciences, any real-world simulation such as a weather- or climate prediction requires an objective synthesis between a dynamical model of the atmosphere/ocean and noisy, incomplete and heterogeneous observations of the real atmosphere/ocean. To provide this synthesis is the purpose of variational data assimilation. Data assimilation allows using a mathematical atmosphere/ocean model in order to determine uncertain variables (control variables) such as the initial condition or model parameters (e.g. mixing coefficients) from noisy measurements. From the mathematical point of view one has to deal with a very large-scale
optimization problem with PDE constraints governed by the atmosphere- and/or ocean model. The computational costs for this optimization problem increase considerably within the trend towards high-resolution simulation. To reduce these costs nonlinear model reduction techniques must be developed.

In medical research, data from EEG, MRI, or PET scans amounts to multiple mega-, giga-, or potentially even terabytes, with an associated increase in the time required to execute an individual step in NLME model fitting. Similarly, more complex models such as stochastic and partial differential equations, and Markovian and survival models, will push the limits of the current algorithms and implementations. To be able to face the challenges of the near future with the ever increasing complexity of the data and the associated models, increased performance both at the algorithmic and software/hardware levels are deemed crucial, with parameterised and nonlinear model reduction being one of the best candidates to resolve this challenge.

In the area of physics and material sciences, a systematic comparison between numerical simulations and experiments in order to validate new experimental techniques, mathematical modeling and to uncover a cleaner and more complete picture of the physics of air pollution is highly needed. Model reduction plays an important role in reducing the computation times for the complex turbulent flow simulations.

From the above it should be clear that the topic is not only of considerable interest. It is extremely timely, as the demand is high. The simulation of extremely complex models is a topic with numerous applications in areas of importance, with a high potential for innovations and breakthrough scientific results. The mathematics community is required to cross disciplinary borders, and COST Actions are ideal for facilitating such activity.

This COST Action is not only timely but with its networking tools including working group meetings, Short-Term Scientific Missions (STSMs) and training schools is the most appropriate framework to facilitate progress and enable this novel and emerging subject to truly develop and achieve maximum effectiveness.
A.1.4 Feasibility

The topic of this COST Action is model reduction, in a very broad sense. Europe is a centre for model reduction, with many renowned experts in all areas related to ‘model reduction’. Research is carried out at a very high level in these areas, with many young people being attracted and participating in workshops and conferences organized on a world wide scale. Researchers from areas that were not directly associated with model reduction are now realizing the often intimate relations and opportunities, and are also participating in scientific discussions. Vice versa, scientists working in the area of model reduction are very active in contacting other research communities to take advantage of the knowledge available in other disciplines, and apply it for model reduction. There is also a lot of attention for the application of model reduction directly to industrial and societal problems, in many different fields. The beauty of model reduction and mathematics in general, is its ability to abstract from the original application, leading to methods that are generally applicable, also to other domains. For this reason, model reduction is by definition a trans-domain activity, being able to transfer results from one application area to another. Model reduction techniques motivated by electronics problems can immediately be applied to mechanical problems. Methods developed in a domain can be abstracted, generalized, and then applied to challenges from another domain.

The network of scientists involved in the area of model reduction within Europe is large and growing, whereas the contribution from mathematical model reduction is now becoming not only recognized but also endorsed by other disciplines. This COST Action will play a seminal role in facilitating links within the various communities. The Action will gather experts from across the academic spectrum including physicists, engineers as well as experts in the private sector to share state of the art knowledge and experience. In this way the Action will support the building of a world leading community versed in developing methods enabling complex multiphysics simulations and their application to industrial and societal challenges. The network will bring new and innovative science to bear on the challenges outlined above, applying principles of complex systems to the construction of both new methodologies and building blocks for understanding development of complex models. Many of these methods are currently under active discussion and require a flexible approach for further development. This involves networking and intensive discussion between the protagonists and parties involved.
A.2 Impact

A.2.1 Risks

The field of model reduction has evolved continuously over the last 15 years, with many seminal contributions and methodologies that overcome barriers that were previously considered to be almost impossible. Initially, most of the attention has been for linear problems, where many issues have been resolved, so that the state of the art for such problems is now quite mature. Similar developments in other areas of model reduction, such as parameterized and nonlinear problems, as well as in situations coping with uncertainty, are expected. In several of these areas, researchers are currently obtaining promising results by using newly developed methods, sometimes inspired by other fields of mathematics or by developments in data science. The range of feasible mathematical technologies is vast, and researchers are exploring many of these right now. The formation of a community that interacts via a pan-European network will have a very positive effect on the development of new techniques, so that there is a high level of confidence that the Action can adequately address the challenge.

A.2.2 Scientific and societal impact

European scientists involved in model reduction and related areas are very active in their field, often being at the forefront and having cooperations with renowned experts elsewhere in the world, leading to publications in learned journals. By addressing the Action Challenge, the activity on publishing will only increase leading also to improved scientific profiles (for example the h-index) of the researchers in the network. New mathematical techniques will be developed that can be applied directly in an industrial or scientific context, leading to improved design environments in industry, and improved research tools for engineers and scientists. The developments will also have an impact on related disciplines within the mathematical sciences, but also in the systems and control area, optimization, and other fields.

Technology transfer is not a one way street: besides transferring mathematical ideas and methods to science and technology, in many cases the specific applications provide inspiration for new developments in mathematics. In this sense, the Action will lead to considerable two-way traffic between researchers in the area of model order reduction, and scientists and engineers. Universities and this COST Action will act as centres of cooperation. By means of networking, the process of finding the best partners for relevant EU projects will be simplified, as well as the provision of
mentoring support for researchers new to the process. This will result in increased participation of countries that are currently less well represented in European (and other international) projects.

Mobility within the network will provide Early-Stage Researchers (ESRs) access to hands-on mathematical modelling training workshops, with an emphasis on enhancing their communication skills. COST funding will assist researchers from the institutions that do not currently run these activities to participate in those organised by other institutions, and thereby seed new initiatives in many research centres. This will result in increased numbers of early-stage mathematics researchers highly trained to work on interdisciplinary problems.

The Action will provide financial support for ESRs to visit established industrial mathematics research centres, or take up industrial internships, for up to three months duration. Long-term benefits of this initiative will be an increased number of mathematicians realising the rewards of an industrial mathematics career in industry or academia.

**A.2.3 Economic impact**

By addressing the Action Challenge and developing novel model reduction methodologies, the network can help positively the Five Drivers of Productivity (Investment, Skills, Innovation, Entrepreneurship, and Competition) by providing insights that stimulate competition and contribute to innovation. Improved computational techniques and advanced computer architectures will help cope with the important industrial, technological, scientific and societal issues that our world is facing, and contribute to innovations and new insights. The previously mentioned 2012 Deloitte Report estimated the contribution of Mathematical science research to the UK economy in 2010 to be 2.8 million jobs (around 10 per cent of all jobs in the UK) and £208 billion in terms of Gross Value Added (GVA) contribution (around 16 per cent of total UK GVA), clearly demonstrating the importance of mathematical science research.
B. ADDED VALUE OF NETWORKING

B.1 Added Value of Networking in Relation to the Challenge

The Action Challenge provides a big challenge to the community of researchers interested – with different perspectives and tools – to investigate a multitude of aspects of model order reduction, and further develop methods and theory that is so important for practical applications in industry and science. It is in view of this long plan for the future to join the efforts, to spread knowledge, to increase the impact of the research conducted by single groups. In recent years, researchers are meeting each other more frequently than before, at workshops and at mini-symposia organized at conferences, all with the main theme of model reduction, but often distinct from workshops on related areas like reduced basis methods and tensor analysis that are vital for the new developments in the area of model reduction. By joining the Action, the community will grow into a large collaborative effort, thereby significantly increasing the chances of meeting the Action Challenge. This can already be observed in recent workshops, where advanced problems from the aerospace and automotive industry have been presented and solved using a combination of model order techniques developed in different groups.

The COST Action is particularly suited to inject fuel into this recently established, fast growing international collaboration. It will allow building a community around science and technology topics in the area of model reduction that has previously failed to gather the necessary critical mass. This is absolutely necessary in order to be successful in addressing the Action Challenge. In many domains of science and technology, problems are becoming so complex with corresponding data sets becoming so large that only combined efforts in developing combinations of model reduction with tensor algorithms, reduced basis methods and algorithms from discrete mathematics or other disciplines like data science can lead to the desired reduction of simulation times for realistic simulations. There is a high necessity for error estimations in reduced models, further building of techniques for data-driven reduction, incorporation of stochastic effects, and many more. All of this cannot be overseen by individual groups, and also for national projects it is far too much to be handled. What is needed is a coordinated effort, combining the expertise of all groups, so that the Action Challenge can be adequately dealt with.

The benefits for science will be immense: both in terms of a deep fundamental understanding of how to address complex multiphysics problems using sophisticated model reduction methods, and
of development of applicative models. Models that the Action plans to develop/validate will be immediately useful e.g. to industrial and scientific challenges. The Action’s contribution will have an immediate impact on these disciplines, and hence on meeting the Action Challenge. The Action will also share raw computational and experimental data with all the scientific community; this will allow for further breakthroughs in the field. For the first time, the European scientific community will possess the capability to combine all expertise in the field of model reduction, thanks to the integration of research results from tens of different European groups. Central websites and repositories will be extremely useful, thereby easing the communication between the various groups, and making challenges from several different domains available to all Action participants.

The Action will address the Action Challenge by gathering experts from across the academic spectrum including scientists from other disciplines as well as some experts in the private sector to share state of the art knowledge and experience. In this way the Action will support the building of a world leading community versed in the understanding of model reduction for complex systems and their application to a large variety of challenges from several scientific domains. The network will bring new and innovative science to bear on the Action Challenge outlined in Section A, constructing new and developing further existing model reduction methodologies and providing building blocks for understanding development of models and strategies that deal with simulations of multiphysics systems. Many of these methods are currently under active discussion and require a flexible approach for further development. This involves networking and intensive discussion between the protagonists and parties involved, as well as the coordination of efforts at a European level.

**B.2 Added Value of Networking in Relation to Existing Efforts**

All groups in the collaboration are equipped with their own facilities, some with large-scale computational facilities; some other nodes are more focused on theoretical / modelling aspects. So far, these efforts are not coordinated. Many groups are very successful in the development of new techniques, addressing novel applications and pursuing completely new research directions, but research programmes are often developed at a national level. Coordination at a European level reduces the risk of duplication of efforts, will maximize results and eases the exploration of new research directions related to other mathematical fields, thereby putting the European model reduction community in a much stronger situation.
The Action will require wider multidisciplinary consortia spanning not just numerical analysis and systems and control theory, but also other mathematical disciplines such as discrete mathematics (for the reduction of extremely large networks) and linear algebra (tensor analysis) and also engineering disciplines such as electronic and mechanical engineering. This is one aim of this COST Action that will provide new opportunities for participants to bid for research funds in the coming years. Unlike other frameworks, COST offers a flexible mode of operation that optimizes the ability of participants to develop and share new ideas and evolve tailored partnerships that can then be the basis for more formal research applications to, for example, the EC Framework Programme or Member State programmes covering both basic and strategic or applied aspects. A significant benefit offered by COST concerns the involvement of new groups and institutions. The ability to involve both Early-Stage Researchers and eminent experts in a flexible way is one of the most valuable aspects of the COST framework. This COST Action will act as a global umbrella for young researchers who seek to participate and benefit from being linked to these new and emerging projects. The Action will strongly support the mobility of these young researchers across Europe.

The key networking tools offered by COST (Working Group meetings, STSMs and training schools) will provide the basis for achievement of the objectives. These will be used to stimulate the community which in turn will help with the identification of key problems and routes to their solution via collaborative research programmes supported by the EU, individual Member States and other means. Challenges in the various domains of science and technology require a range of expertise that is usually not found in a single institution. Expertise for a particular project may lie within another country. The Action will enable transnational matchmaking between academic groups and international industry or science partners. Stronger communication between existing activities in model reduction and related areas will result in identification of important areas/sectors in which to focus research efforts. As stated in the previously mentioned OECD report: “The creation of national and international networks can both stimulate mathematical awareness and creativity concerning industrial problems and avoid duplication of intellectual effort.”

In addition the Action will:

- Widen understanding of and develop access to complex multiphysics systems where a multidisciplinary approach for model reduction is essential;
- Assist the evolution of new cooperation and shared understanding between mathematical and engineering disciplines;
• Provide a new, unique forum at the European level for communication not only between researchers but also those interested in developing improved model reduction methods;
• Help support the emergence of new research programme initiatives within both the European Union and Member States;
• Facilitate the mobility of ESRs into research teams for model reduction across Europe;
• Open new employment opportunities for young researchers from mathematical sciences and several related engineering disciplines;
• Provide a new route at the European level for communication between scientific researchers, companies and regulatory bodies;
• Facilitate improved competitiveness of European industry;
• Issue case study reports and publicity that will help spreading awareness of the benefits of mathematics, and in particular model reduction, for addressing industrial and societal challenges.

This initiative will facilitate the emergence of a new group of researchers engaged in research of a highly novel nature with extensive multi-disciplinary relevance. In this way the Action will play a key role in broadening the training of young researchers within participating Institutes.

B.3 Model reduction: an ICT application

The demand for reliable model reduction algorithms in ICT engineering application fields has been continuously increasing over the last few years, and is expected to grow even further in the future. In fact, precisely this area has been very inspirational for developments in model order reduction. Design flows for present and future hardware architectures are more and more based on system-level approaches that include all parasitics and second-order effects into consideration during computer-based simulation and prototyping, thereby constituting an extremely challenging problem that cannot be handled by available software. The only viable solution for the simulation of the resulting large dynamical systems is to resort to model compression and order reduction. Among the most critical aspects that need advancement with respect to the available state of the art are:
- Model reduction of systems characterized not only by a large number of states, but also a large number of inputs and outputs. As an example, verification of mixed power/signal distribution networks requires accurate characterization of systems with several hundreds of interface ports.
- Guaranteed passive macro model extraction from frequency and time-domain responses, possibly under parameter variation and uncertainties. Although passive macro modelling from measurements
is a relatively mature field, the extension to the parametric case is still not mature for routine application in system design and optimization.

- Compact dynamical modelling of both weakly and strongly nonlinear circuit blocks in digital, analog, and analog/mixed signal systems as found in portable devices of present and future generation, for which current simulation methodologies are based on extremely inefficient full transistor-level extracted netlists.

To address these problems, mathematicians and engineers need to work closely together. Automatic model reduction techniques for strongly nonlinear devices and circuit blocks are needed based on tensor approximations or on extensions of the recently developed and promising POD-DEIM method. An additional complication is the fact that designers in industry are changing the classical way of design, and making more and more use of parameterized cells. This means that the model reduction techniques need to be able to deal with parameterized models. Other groups will provide the algorithms for the stochastic aspects of the problem, for the reduction of the large networks with many ports by techniques inspired by graph theory. Important is also that the techniques are suitable for use on modern computer architectures, requiring again a different skill. Clearly, this cannot be addressed by a single team, but only by a coordinated larger scale effort. Software vendors, supplying the electronics industry with tools, are extremely interested in such methods.

C. MILESTONES AND DELIVERABLES: CONTENTS AND TIME FRAMES

C.1 Use of COST networking tools

The challenge of this COST Action is an ambitious one, and can only be met if the participants in the Action meet regularly, at various occasions, and the participating ESRs are mobile, have internships and short-term stays at other sites. Therefore, the Action will be very active in communication and collaboration, so that the Action challenge can be achieved by generating new common research results, demonstrated on a variety of problems in several application domains. Results will be shared, published on the website and a repository of publications and problem information available to all participants will be set up.

Milestones and deliverables mentioned in the following will be closely monitored by the Action Management Committee (MC).
After the Action approval, the first steps will be performed, most notably the formation of the Management Committee for the COST Action, and the definition of the Working Groups that will be responsible for a variety of tasks.

It is envisaged to have one major event per year where all Action participants have the opportunity to meet and discuss research results. This annual meeting will also be used to discuss progress, and project into the future by assigning new tasks if necessary, discuss internships, review deliverables. Summer schools will also be held on an annual basis.

STSMs: as mobility of ESRs is a key issue in the Action, the MC will make an effort to accommodate as many STSMs as possible. Short-Term Scientific Missions are an ideal tool to foster communication within the Action, by direct contact between researchers of different groups participating in the Action Network. In this way, the network is strengthened, allowing a STSM grantee to learn a new technique or gain access to specific instruments and/or methods not available in their own institution; and/or to gather and analyse data and to produce a joint publication or write a joint research proposal.

Call for STSMs, Industrial internships and themed one-day industrial mathematics workshops will be launched four times a year, in January, April, July, and October.

STSM applications will be assessed within one month; the assessment based on excellence and impact, prioritising applications from countries that have less capacity in the field of the Action. Industrial internship and STSM applications are assessed by the WG 3, while Themed one-day workshop applications are assessed by WG 1.

Deliverables:
I. One page summary report prepared by visiting researcher.
II. Joint peer-reviewed publication or funding proposal co-authored by visiting researcher.

Action Conference: the Action Conferences are scientific conferences organized by the COST Action for researchers to present, discuss and disseminate their work.
These COST Action Conferences:
- Provide an important channel for exchange of information between researchers
- Are composed of various presentations including those by keynote speakers
- Feature panel discussions, round tables or workshops.
- The work presented will be published as papers in selected journals (special issues); as conference proceedings or in a shorter form as a book of abstracts.
- Are open to the participation of any self-funded participant (i.e. any researcher or stakeholder outside the COST Action).
- Are an opportunity to network

As attendance of these conferences will be high, they will also be used to discuss new funding opportunities, and form separate teams to work on these (including finding industrial or other partners if necessary for the type of project).

Deliverables from Action conferences:
I. Technical summary of Conference.
II. Report uploaded to Maths In Industry (MIIS) repository.
III. Dissemination of research results: presentation to a wider audience (industry, general public).

Summer Schools: in order to enable ESRs to profit optimally from the acquired knowledge within the COST Action, tutorials will be given by experts during annual Summer Schools. These tutorials will start from the basics, and then build towards well established but advanced methodologies. In this way, ESRs having attended a summer school will be able to assess the latest developments presented at the Action Conferences.

Deliverables:
I. Collection of tutorials added to ‘living handbook’ on website

Industrial internships: in order to obtain hands-on experience with industrial problems from various scientific domains, industrial internships will be made available based on the large contact database possessed by the Action participants. These internships will allow, on the one hand, to get acquainted with challenging problems that need model reduction for their solution. And, on the other hand, they will allow researchers to have direct access to problems and software, so that tests can be carried out with newly developed methods, and compare with existing techniques.
Deliverables:
I. Each internship student to prepare a one page case study summarising their project.
II. Collection of case studies to be collated in a booklet under the supervision of WG 4.

Themed one-day industrial mathematics workshops: it is envisaged to organize short 1-day meetings to provide a bridge between researchers in the Action, and specialists from various application areas, so as to discuss requirements and expectations of these specialists, and disseminate the results obtained by the Action researchers.

Deliverables:
I. One page summary report prepared by local organising committee.

C.2 Measuring the success of the Action

Measuring the success of the scientific research carried out by the Action participants will be done in several ways. All scientific publications generated by participants will be stored in a database, organised in such a way that easy access is guaranteed. A repository of benchmark problems will be made available, for which all participants can contribute examples, or extract problems to run tests with newly developed algorithms. Participants are expected to provide their experimental results, so that comparisons can be made. In this way, progress of the state of the art can be monitored by the MC, providing a measure of success of addressing the Action Challenge during the course of the activities.

Every year the Action Chair, supported by the Action participants, will issue a progress report summarizing the achievements of the network. This may serve as a basis for Action evaluation.

At the end of the Action, i.e. after 4 years, a handbook will be prepared containing the advances of the Action as far as model reduction methodologies is concerned. This handbook will mirror the state of the art, and contain suggestions for future research. It will serve as the starting point for new research activities after the Action has ended.

An important measure of success of the Action will be its size, and the involvement of as many researchers working in the area of model reduction and related areas. It is our aim to involve all researchers working in the area in Europe, and involve colleagues from International Partner
Countries, thereby forming a worldwide community for model reduction that will be the natural partner for industry, society and scientists across scientific domains.

Deliverables:
I. Collection of scientific publications (living repository)
II. Collection of benchmark problems and results (living repository)
III. Annual progress report by the Action Chair (incl. Financial report)
IV. Handbook containing a description of the developed model reduction methods
V. Statistics on the size of the network and Action participants

D. ACTION STRUCTURE AND PARTICIPATION – WORKING GROUPS, MANAGEMENT, INTERNAL PROCEDURES

D.1 Overall structure

The Management Committee (MC) will consist of at least one member from participating COST countries, as nominated by those countries' COST National Coordinators. Under the supervision and coordination of the MC, four Working Groups (WGs) will be established, one in each of the following key areas of the Action:

WG1: Model reduction methods – coordination of research in the broad area of model reduction, with techniques from the fields of numerical analysis, systems-control theory, behavioural modelling and related fields.

Responsibilities: Coordinate at the European level all efforts on model reduction, set up committees for different problem types, organize workshops and conferences, possibly in connection with important events in the area.

WG2: Design optimisation techniques – applying model reduction techniques to coupled and multiphysics problems in order to significantly speed up simulations, in a setting with parameters and optimisation requirements.
Responsibilities: Bridge the gap between researchers working in academia and industry, using model reduction techniques to obtain improved and optimized designs of products, coordinate these efforts on a European scale. Joint supervision of ESRs and monitoring the entire process of STSMs.

WG3: Applications – using model reduction and design optimisation methods to solve challenging industrial and societal problems.

Responsibilities: Compiling success stories and internship projects. Take care of repository of benchmark examples. Suggest topics and venues for 1-day Industrial thematic workshops. Assess applications for industrial STSMs.

WG4: Dissemination and Outreach – dissemination of results obtained and outreach to the broad community of model reduction researchers and stake holders.

Responsibilities.
1. Disseminate the results of the Action.
2. Set up and oversee website to include members, committees, events, calls for proposals.
3. Recruit additional members, in particular to support countries within to strengthen competences in the broad area of model reduction.
4. Make contact with industries, in particular SMEs, across Europe via members.

Each WG will consist of a leader and at least three MC members, drawn from at least three different European countries. Special care will be devoted to promote gender balance and to encourage ESRs participation in each WG.

D.2 Management Committee

The MC will be responsible for processing and approving STSM and Training School applications, as well as WG member reimbursement requests for attending Action events. The named roles of the MC are as follows:

- Action Chair – responsible for leading the Action strategy, and producing an annual report of the Action's activities and outputs. At MC meetings, the Chair must ensure that the views of all present are taken into consideration.
- Vice-chair – responsible for reviewing the Action strategy, and assisting the Chair in producing the annual report.
- Working Group leaders – responsible for leading their respective Working Groups and maintaining strong channels of communication with the Management Committee.

MC meetings will be held twice a year. At one of these meetings, the planned Action activities will be reviewed on the basis on the available budget and additional events, internships and STSMs considered. A call for proposals will be sent out and the MC will decide on host locations for these events by majority vote. Countries and institutions that have not run these events before will be prioritised.