



## **Graphs in Geometry and Algorithms (EuroGIGA)**

### **EuroGIGA Review Panel**

### **Final Consensus Report**

The EuroGIGA EUROCORES programme was a combined research effort to enforce collaborations and to strengthen the European leadership in a broad scientific area that encompasses computational geometry, computational topology, geometric graph theory, and graph drawing. The final reports of the programme include a number of results of very good to excellent level, proving that joint collaborations between well-established research groups have been successful.

Besides the quality of the presented results, the greatest achievement of EuroGIGA is the consolidation of a strong community. While in the past the interactions between the European graph drawing community and the European computational geometry community had been occasional, EuroGIGA has been instrumental in bringing these communities together and strengthening a common scientific language by learning techniques and problems from each other. Many scientific breakthroughs of EuroGIGA are in fact the result of joint forces by different teams from different nations and with different backgrounds.

Europe plays a leading role in scientific areas that span from network visualization to graph drawing, graph algorithms, and computational geometry. EuroGIGA has been the first example of an inter-European programme covering these topics. Given the increasing demand for new technologies in rapidly growing areas such as data science, IoT, cybersecurity, smart environments, the results of EuroGIGA anticipate the tremendous potential that follow-up initiatives of similar nature may have on the European leadership in these key applications areas.

#### **1. Progress in the Collaborative Research Projects (CRPs)**

All CRPs made significant progress towards their goals, in terms of solutions to mathematical problems in the fields of geometry and graphs, and the combination field of geometric graphs. They have fulfilled and in, some cases, exceeded the objectives envisaged in the initial projects both in terms of scientific results and levels of cooperation. The final reports also document numerous new collaborations not only within the CRPs but also across them.

The achievements of individual CRPs ranged from very good (VORONOI, GreGAS) to outstanding (GraDR, ComPoSe). Several results obtained reached well outside the community

of the programme helping substantially to better position European-based science on the international scientific scene.

Integration and collaboration within the CRP teams was excellent. Many joint/multinational scientific events and networking activities were held and a great number of papers were co-authored by several IPs from the same CRP team. It is noteworthy that of the 42 accepted papers at the 23rd International Symposium Graph Drawing 2015 (held in Los Angeles), 23 are co-authored by researchers that have been members of GraDR. Within CRPs, there has been considerable collaboration, e.g., apart from GReGAS, between 20-25% of journal publications involved collaboration within the IPs of a CRP (GReGAS was around 6%). An example of joint output is also the *Encyclopaedia of Graphs* edited by Pisanski.

It appears that the framework of EUROCORES helped to facilitate the collaborations between individual scientists and between teams within the same CRP in a very substantial way.

#### **Scientific highlights from CRPs include:**

- A significant progress towards the solution of the Harary-Hills conjecture on the number of crossings in any drawing of a complete graph; the presented results are the first breakthrough after about 50 years of research on the question.
- New results about planarity, planarity testing, and its variants; they include a linear time algorithm to test the planarity of partially drawn graphs and new combinatorial and algorithmic insights about cluster planarity.
- The first definition of straight skeleton in 3D and the first implementation of a numerically and topologically robust algorithm to compute it; the straight-line skeleton was well understood in 2D but its extension in 3D had not been canonically defined yet.
- The study of the combinatorial properties of ray intersection graphs which implies a solution to a long-standing open problem about the computational complexity of finding a maximum clique in a segment intersection graph.

#### **2. Programme Integration**

All CRPs contributed substantially to the overall programme through cooperation and joint work. The integration of the individual CRPs within the programme was very good. Some CRPs collaborated with others more intensively, partly due to the proximity of their scientific subjects and goals (GraDR, ComPoSe, VORONOI), and partly due to geographical factors (co-location etc.). It appears that CRP GreGAS was somewhat less involved in joint projects with the other three CRPs, which can, to some extent, be explained by the subject of GreGAS.

The general scheme and framework certainly instigated cooperation between the CRPs; in particular, joint scientific events funded by the programme significantly helped to establish and foster fruitful scientific contacts and collaboration between the projects.

The EuroGIGA programme also allowed researchers from smaller teams to join common activities at the programme level. This included in particular research stays for young researchers, which would have not been possible without the EuroGIGA programme.

### 3. Networking, Training and Dissemination

The **networking** part of the programme worked very well, with many joint events and activities organized. All teams took a very active part in these activities which included special sessions/minisymposia within large meetings, but also dedicated meetings and workshops between the CRPs oriented on joint work on specific problems.

The **training** part of the programme was perhaps less successful, with relatively few events aimed explicitly at young researchers and graduate students organized. One can argue though that the best way to train research students is to involve them actively in research activities which was certainly the case. Training activities appeared to be undertaken in a more ad hoc fashion, e.g., VORONOI has organized no training meetings, ComPoSe built training into the CRP through integration with the research and GreGAS organized summer schools specifically for PhD students.

The **dissemination** of the results obtained was achieved both through networking events of the programme, and through additional activities (special sessions, etc.) organized by the programme participants at general scientific events. Noteworthy are dissemination activities organized by GreGAS.

Overall, networking and dissemination activities had a very substantial impact on the pursuit of the programme goals, as well as on publicizing the program and its achievements to the general scientific community.

### 4. General comments and other feedback

Overall, the programme was successful and has achieved most of the goals. The general scheme, instigating and funding collaboration between different collaborative research projects, between individual researchers and between different countries, worked well and fulfilled its goal. The programme remarkably strengthened existing collaborations and created new ones.

Some drawbacks of the programme were related to the fact that, due to the funding via national agencies, not all European countries were able to join the programme, and rules and timelines differed slightly in different countries (as noted by VORONOI and GraDR). For future programmes, it would be worth trying to find a way to overcome these issues.

In terms of follow-up activities, a number of longer-term and spin-off initiatives were started, such as the establishment of a new journal *Ars Mathematica Contemporanea* by GreGAS and the follow-up project VORONOI++ under the heading of the joint DACH program of the Austrian, German, and Swiss science foundations.

Some recommendations for future programmes of this type (if there will be any) are:

- More attention should be paid to synchronization and coordination of the programme between individual national science foundations;
- An effort should be made to include scientifically coherent and mutually complementing CRPs in the programme;
- More emphasis should be put on training activities and events (schools, lecture courses etc.) oriented explicitly at young participants including graduate students.