# Research and Teaching Statement

**Alper Üngör**
Department of Computer & Information Science & Engineering
University of Florida

## 1 Research Statement

My research areas are *design and analysis of algorithms*, *computational geometry*, *mesh generation*, and their applications. Geometric algorithms play a fundamental role in many areas such as *scientific computing*, *graphics*, *visualization*, *computer aided design*, *computer vision*, *structural biology*, and *geographic information systems*. The overall goal of my research is to understand the mathematical structure of problems in these areas; and to design, analyze and implement efficient algorithmic solutions with both theoretical bounds and good performance in practice. This enables me to have an inter-disciplinary impact on various scientific applications.

**Mesh Generation.** A principal component of my research is *meshes (triangulations)*, which are subdivisions of geometric domains into small and simple elements. Meshes are essential to numerical simulations. Two of their key requirements are to ensure that the shape of the mesh elements are of good quality and that the size of the mesh is small. Mesh element quality is critical in determining interpolation error in applications and hence is an important factor in the accuracy of the simulations as well as the convergence speed. Mesh size is also critical because between two meshes with the same quality bound, the one with fewer elements is generally preferred as it implies faster processing by the numerical algorithm in use. In collaboration with many researchers from various institutions[1], I made a number of significant contributions in the mesh generation area. I co-designed the first time-optimal Delaunay meshing algorithm [13]. I designed the currently best performing simplicial meshing algorithm [23, 9]. I co-developed three-dimensional meshing algorithms including the first sliver-free mesh smoothing algorithm [3], a scheme for re-meshing solid models [19], and a method for constructing sparse well-spaced point sets for quality tetrahedralizations [14].

**Dynamic Modeling.** Modeling motion and evolving geometry is a challenging problem and falls into my areas of interest. I co-developed algorithm that model geometric deformations in engineering simulations [17], parametric solid modeling [19], and protein modeling [4]. More importantly, I proposed an unconventional approach to dynamic geometric modeling, which addresses the problem directly in the space-time continuum rather than looking at a finite number of static spatial problems. My work on space-time meshing [6, 25], which has been pioneering in the area, supports efficient linear-time numerical solution strategies by novel space-time numerical methods.

**Parallel Algorithms.** Scalability of computational methods become more important as scientists study increasingly complex problems in areas such as high energy physics, molecular biology, earthquake and meteorological simulations. I developed expertise in parallelization of geometric algorithms. I co-developed the first provably-good parallel Delaunay refinement algorithm that has a poly-logarithmic time bound [20, 21, 22]. One of my ongoing research projects is to develop a parallel meshing software using the insights gained in this line of of research.

[1] For the list of my co-authors for each of the papers cited, please see the references section.

**Approximation Algorithms.** For many science problems, including the ones mentioned above, it is extremely difficult if not impossible to compute exact solutions. For such problems, I design computationally efficient approximate solutions and prove that the output of my algorithms are not much different than exact/optimum solutions. In graph-theoretic applications such as degree-constrained network flows, I study the combinatorics of the problem in-hand to establish approximation guarantees for my solutions [1]. In geometric applications, approximation analyses usually require more tools such as mathematical functions to express the distributions of geometric objects [2, 23].

**Sphere Packing, Covering, and Tiling.** A good amount of applications benefit from fundamental results established in packing, covering, and tiling theory. I do research on solving problems in these math subjects and utilizing them in applications. I co-presented the first tiling of the space, and also of slabs, with only acute tetrahedra [5]. Such constructions are related to crystallography and find use in finite element modeling [6]. I also study packing and covering of spatial domains with spheres and ellipsoids for developing geometric modeling tools [16, 15, 19].

**Robust Geometric Software.** It is not uncommon to see algorithmic research with elegant theory that does not make as much of an impact as it could. Implementation of algorithms, particularly those that deal with geometric data, involve a great deal of challenges such as robustness, handling of degeneracy, and software design. Even with a perfect implementation, practical performance of an algorithm could be significantly different than what the theory predicts (due to simplifying assumptions and hidden constants in the analysis). An important component of my work has been on robust geometric software design and algorithmic experimentation. My mesh refinement algorithm has been integrated as the default option into the popular meshing software `Triangle`, the winner of the J.H. Wilkinson Prize for Numerical Software. This new algorithm, in addition to being provably-good, works similar to the popular heuristic called advancing front; and hence improves the performance of the software. Moreover, numerical calculations within the key procedure is now unconditionally stable making the software significantly more robust. With `Triangle` reportedly having 30 downloads per day, benefits of my research are already utilized by many scientists and engineers. I am now releasing a new software called `aCute` which is superior to `Triangle` in mesh quality (providing practical bounds for smallest angles as high as 42 degree and for largest angles as low as 81 degrees) and in output size (up to an order of magnitude). See ⟨`http://www.cise.ufl.edu/~ungor/aCute`⟩ for more details and comparisons. Overall, my work on robust geometric software facilitates longer, faster, more complex and more accurate simulations in a wide range of applications and also enables the use of new numerical methods [9, 10, 23, 24]. I also continue to conduct research towards a robust and effective higher dimensional geometric meshing software.

My research has been recently funded through two grants from the *Algorithmic Foundations* program within NSF's CCF division which, as stated on their web site, supports theoretical research concerning "the time and space complexity of finding exact and approximate solutions in deterministic, randomized, sequential, parallel, and distributed models of computation". Given the practical and interdisciplinary nature of my research, I expect to receive funding also from other institutions such as DoE, DoD, NOAA, and NIH. Overall, I will continue to utilize my theoretical computer science background to formulate, study, and solve fundamental problems that contribute to real-life applications.

## 2 Teaching Statement

Teaching and mentoring are essential components of an academic career. I find the ability to impact so many young minds an important and highly motivating responsibility. I have two main goals in mind when teaching and mentoring students. First is to inform my students on the best-known computer science concepts, techniques, and tools that is key for their future studies and careers. Second is to help them develop appreciation, interest, and necessary skills to conduct research in Computer Science, particularly in Algorithms. Below, I highlight a number of principles and techniques that help me attain these main goals.

- Rather than teaching my students just the class material, I also teach them how to learn such material. This is especially important in this era in which vast amount of computer science and engineering resources are available in the libraries and on the web. I reflect from my own learning experience, elaborate on my thinking and problem-solving process, and give them tips for effective studying.
- Having a friendly and an interactive environment encourages the students be more attentive to the material. I frequently encourage students to interrupt me with their questions and comments. Classroom interactions also help me maintain the proper pace for the class.
- I think that independent, creative and critical thinking are merits of a good student as well as of a good researcher. To promote independent thinking, I give students time to come up with their own solutions, whenever I pose a problem. To stimulate critical thinking, I allow time to discuss the differences between the presented and the student solutions.
- Understanding the material is often not sufficient. A student should be able to present the material with clarity. I let my students make mistakes and then show them the right way to do it. I help them shape and express their thoughts.
- I am not shy of acknowledging it if I make a mistake or do not know the answer to a question. Indeed, I encourage my students to point out my errors, which keeps them alert in lectures.
- Keeping students' attention in math classes are often a challenge. I integrate application topics (animation applets, clips from current science news, etc.) that shows the relevance of the presented theory. My lectures compromise a good balance between the intuitive descriptions and mathematical formalism.
- I observe that students from different backgrounds especially underrepresented groups have different needs and concerns. Most of my classes are also available through UF EDGE, an on-line teaching program which makes the classes available to students with a wide range of backgrounds. I adapt my teaching and mentoring to accommodate such differences. In addition, I am actively involved in recruiting students from these groups into engineering. Indeed, my involvement in facilitating the integration of underrepresented groups in engineering is a crucial educational component of my NSF CAREER Award.
- I present the material using an effective combination of the latest classroom technology and traditional techniques. I prepare slides that include a good summary, interesting animations, and references to online resources, videos, etc. While slides provide a structure for the lectures, I present the key details of the material on the blackboard, which is highly appreciated by students as they can see how I do certain derivations.

- Teaching a topic motivates me to develop a deeper understanding of it and learn the latest developments on the topic. So, in this aspect, teaching perfectly complements my research.
- I value scientific curiosity and do my best to ignite it during my lectures and office meetings. Questions such as "why study this problem?" and "why approach it this way but not this other way?" frequent my lectures. I inform and encourage my students including undergraduates about the current open research problems. Here is a quote from my student evaluations: "I like computational geometry; some of you might not. But, Alper is a great instructor that helped make the material come to life: there were lectures he was almost shouting for joy because he was so enthusiastic about such-and-such. He gave us a choice to work on open/unsolved problems for our term project: how cool is that?!!!"

**Teaching Experience.** Before joining the University of Florida, I taught classes in two institutions at various levels. I was the instructor for two undergraduate courses at the University of Illinois. Having been nominated by my students, I received an *Excellence in Teaching Award*. I taught two graduate courses at Duke University, one of which was co-taught with Prof. Herbert Edelsbrunner. Since I joined the University of Florida in 2004, I have taught five different courses in ten semesters. I proposed two new courses in the Algorithms area. Previously, there were three courses (*Analysis of Algorithms, Formal Languages & Computation Theory,* and *Advanced Data Structures*) offered regularly in this area. Based on my proposals, *Computational Geometry* and *Approximation Algorithms* courses have been assigned the regular course numbers *COT5520* and *COT5442* respectively, and became a part of the CISE curriculum. I offered Computational Geometry first as a special topics course in Fall 2004, and then as a regular course in Fall 2006 and 2008. The class has been popular among graduate students of CISE as well as other departments such as ECE, MAE, and CCE, and some advanced undergraduate students. Based on the feedback I received, I am happy to report that this course helped students in various areas to improve their foundations to conduct research in their respective areas. Similarly *Approximation Algorithms* course is particularly useful and popular among students doing research in algorithms, networks, databases, and graphics areas. I also regularly teach three other courses: *COT5405 Analysis of Algorithms*, a core graduate course; *CAP5515 Computational Molecular Biology*, a core course in our Bio-informatics program; and *COT3100 Applications of Discrete Structures*, a core undergraduate course.

**Teaching Evaluations.** My instructor evaluations have been among the best in my department and college. In my ten semesters here, my overall scores were never below 4.0 out of 5.0 (they were above 4.75 in four of those semsters). I receive high scores and praise from students particularly on my (i) enthusiasm for the subject, (ii) communication of ideas and information, (iii) encouragement of independent, creative, and critical thinking, and (iv) knowledge of the material. I observed that being enthusiastic about the material helps the students appreciate the importance of the topic and encourages them to pursue research in this field. Indeed, many students (notably undergraduates) told me that thanks to my teaching, they now have a much better appreciation of the algorithms and theoretical computer science and consider doing research in this area.

## References

[1] E. Akcali, A. Üngör , and Reha Uzsoy. Short-term capacity allocation problem with tool and setup constraints, *Naval Research Logistics (NRL)*, 52(8): 754–764, 2005.

[2] C. Boyaci, H. Erten, and A. Üngör . Triangulations Loosing Bundles and Weight, Canadian Conference on Computational Geometry (CCCG) 2007: 201-204.

[3] H. Edelsbrunner, X.-Y. Li, G. Miller, A. Stathopoulos, D. Talmor, S.-H. Teng, A. Üngör , and N. Walkington. Smoothing cleans up slivers, *Proc. of the ACM Symp. on Theory of Computing (STOC)*, 273–277, Portland, Oregon. May 2000.

[4] H. Edelsbrunner and A. Üngör. Relaxed scheduling in dynamic skin triangulation. *Discrete and Computational Geometry, Japanese Conference, Lecture Notes in Computer Science*, 135–151, 2003. vol. 2866, Springer.

[5] D. Eppstein, J. Sullivan, and A. Üngör . Tiling space and slabs with acute tetrahedra. *Computational Geometry Theory & Applications* 27:237–255, 2004.

[6] J. Erickson, D. Guoy, J. Sullivan, and A. Üngör . Building space-time meshes over arbitrary spatial domains, *Engineering with Computers (EwC)*. 20(4): 342–353, 2005.

[7] H. Erten and A. Üngör . Triangulations with locally optimal points. *Proc. Eurographics/ACM SIGGRAPH Symposium on Geometry Processing*, 143–152, 2007.

[8] H. Erten and A. Üngör . Computing Acute and Non-obtuse Triangulations, Canadian Conference on Computational Geometry (CCCG) 2007: 205-208.

[9] H. Erten and A. Üngör . Quality Triangulations with Locally Optimal Steiner Points, *SIAM Journal of Scientfic Computing*, 31(3): 2103–2130, 2009.

[10] H. Erten and A. Üngör . Computing Triangulations with No Small No Large Angles, International Symposium on Voronoi Diagrams (ISVD) 2009.

[11] H. Erten, A. Üngör , and C. Zhao. Mesh Smoothing Algorithms for Complex Geometric Domains, *Proc. of the* 18th *Int. Meshing Roundtable (IMR)*, (to appear), 2009.

[12] R. Haber, L. Yin, A. Sheffer, A. Üngör , and B. Petracovici. Discontinuous galerkin method for elastodynamics with local balance of energy and momentum. *Symposium on Discontinuous Galerkin Methods, Sixth USNCCM*, 2001.

[13] S. Har-Peled and A. Üngör. A time optimal Delaunay refinement algorithm in two dimensions. *Proc. 20th ACM Symposium on Computational Geometry*, 300–309, 2005.

[14] R. Jampani and A. Üngör . Construction of sparse well-spaced point sets for quality tetrahedralizations. *Proc. of the* 18th *Int. Meshing Roundtable (IMR)*, 63–80, 2007.

[15] X.-Y. Li, S.-H. Teng, and A. Üngör . Point placement for meshless methods using sphere packing and advancing front methods. *Advances in Computational Sciences & Engineering. (resived papers from Int. Conf. Comp. Eng. & Sci.),* ed. by S.N. Atluri and F.W. Burst, Tech Science, 1348–1353, Los Angeles, CA, Aug 2000.

[16] X.-Y. Li, S.-H. Teng, and A. Üngör . Biting: advancing front meets sphere packing, *Int. Journal of Numerical Methods in Engineering (IJNME)*, 49:61–81, 2000,

[17] X.-Y. Li, S.-H. Teng and A. Üngör . Simultaneous refinement and coarsening for adaptive meshing, *Engineering with Computers (EwC)*, 15:280–291, 1999.

[18] A. Saifullah and A. Üngör . A Simple Algorithm For Triconnectivity of a Multigraph, Computing: The Australasian Theory Symposium (CATS) Wellington, New Zealand, 2009. (also published as a technical report at Washington University, WUCSE-2009-6).

[19] A. Sheffer and A. Üngör . Efficient adaptive meshing of parametric models, *ASME Int. J. of Computing and Information Science in Engineering (IJCISE)*, 1(4): 366–375, 2001.

[20] D. Spielman and S.-H. Teng and A. Üngör . Parallel Delaunay refinement: algorithms and analyses, *Int. J. of Comp. Geometry & Applications (IJCGA)*, (17)1: 1–31 2007.

[21] D. Spielman, S.-H. Teng, and A. Üngör . Time complexity of practical parallel steiner point insertion algorithms, *Proc. of the ACM Symposium on Parallel Algorithms and Architectures (SPAA)*, 267–268, Barcelona, Spain, 2004.

[22] D. Spielman, S.-H. Teng, and A. Üngör . Parallel Delaunay refinement with off-centers, *Proc. European Conference on Parallel Processing (EUROPAR)*, 812–819, Pisa, Italy, 2004.

[23] A. Üngör . Off-centers: A new type of Steiner points for computing size-optimal guaranteed-quality Delaunay triangulations. *Computational Geometry: Theory and Applications (CGTA)*, 42(2): 109–118, 2009.

[24] A. Üngör . Software for computing acute and non-obtuse triangulations of complex geometric domains. *European Conference on Numerical Mathematics and Advanced Applications (ENUMATH)*, Uppsala, Sweden, July 2009.

[25] A. Üngör and A. Sheffer. Pitching tents in space-time: Mesh generation for discontinuous Galerkin method. *Int. J. of Foundations of Computer Science* 201–221, 2002.