Yoav Kallus

Curriculum Vitae

Santa Fe Institute
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Research Interests

Statistical physics, soft matter, complex systems, discrete geometry.

Education

2006–2011 **Cornell University**, *Ithaca, New York*, PhD Physics, Adviser: Veit Elser.
Dissertation: *Solving Geometric Puzzles with Divide and Concur*

2004–2006 **Rice University**, *Houston, Texas*, BS Physics.

2002–2004 **University of California**, *Berkeley, California*.

Research Experience

2014–2017 **Omidyar Fellow**, *Santa Fe Institute*.

2011–2014 **Postdoctoral Fellow**, *Princeton Center for Theoretical Science*, Princeton University.

2007–2011 **Graduate Research Assistant**, *Veit Elser group, Laboratory of Atomic and Solid State Physics*, Cornell University.

Teaching Experience

2016 **MOOC Content Development**, *SFI Complexity Explorer*, Introduction to Information Theory.

2015 **Lecturer**, *Complex Systems Summer School, SFI*.

2006–2011 **Graduate Teaching Assistant**, *Department of Physics*, Cornell University.

Service

2015 **Workshop coorganizer**, *"Kinetic Networks: From Topology to Design"*, Santa Fe Institute.

2014–Present **Selection committee**, *Omidyar Fellowship*, Santa Fe Institute.

2011 **Program coorganizer**, *"Toward unifying concepts in the physics of aperiodic systems" workshop and seminar series*, Princeton Center for Theoretical Science.

2010–Present **Journal referee**, *Phys. Rev. E, Phys. Rev. Lett., Phys. Rev. X, Discrete Comput. Geom., Adv. Math., J. Math. Phys., Ann. Comb., J. Chem. Phys.*.

Publications

Discrete Comput. Geom. **44**:245 (2010) **A dense periodic packing of tetrahedra with a small repeating unit**, *YK, V. Elser, and S. Gravel.*
We reported on a surprisingly simple and dense packing of regular tetrahedra – denser than any previously reported – which we discovered using a numerical search method I developed.

Phys. Rev. E **82**:056707 (2010) **Method for dense packing discovery**, *YK, V. Elser, and S. Gravel.*
I developed a general numerical search method for discovering periodic optimal configurations. In this paper we used it for high-dimensional sphere packing and for polyhedron packing, demonstrating with original results its applicability as a general alternative to conventional methods.

Discrete Comput. Geom. **46**:799 (2011) **Upper bound on the packing density of regular tetrahedra and octahedra**, *S. Gravel, V. Elser, and YK.*
We prove the first non-trivial upper bound on the optimal packing density of regular tetrahedra. Though the bound is only marginally less than 1, it has not been surpassed to date.

Phys. Rev. E **83**:036703 (2011) **Dense-packing crystal structures of physical tetrahedra**, *YK and V. Elser.*
I generalized my previous packing discovery method to non-polyhedral particles and used it to study the packing behavior of a family of particles with tetrahedral symmetry, connecting the tetrahedron packing problem to the sphere packing problem. We reported a rich packing behavior, including four novel structures.

Phys. Rev. E **87**:063307 (2013) **Statistical mechanics of the lattice sphere packing problem**, *YK.*
Using a Monte Carlo simulation, I was able to repeatedly reproduce the densest known sphere packing lattices in up to 20 dimensions. My method not only went beyond previous methods in exploring higher dimensions, but also sheds light on the statistical mechanical properties of the lattice sphere packing problem.

Geom. Dedicata **173**:177 (2014)

Inextensible domains, *YK*.

The theory of irreducible shapes in the plane—shapes such that any proper subset can be packed at a strictly greater number density than the original shape—has been of central importance in the study of packing in the plane. I developed a similar theory for the covering problem and uncovered an unexpected link to the theory of periodic billiard orbits.

Phys. Rev. E **88**:062151 (2013)

Jammed lattice sphere packings, *YK, É. Marcotte, and S. Torquato*.

We study the ensemble of locally optimal lattice sphere packings obtained under rapid compression. These lattices display many of the same phenomena as random-close-packed spheres and can be studied at much higher dimensions.

Phys. Rev. E **90**:022114 (2014)

Marginal Stability in jammed packings: quasicontacts and weak contacts, *YK and S. Torquato*.

We studied the structural and geometric implications of the abundance of near contacts in random packings. We derived an updated estimate of the asymptotic random packing density in high dimensions, which seems to match other theoretic predictions more closely.

Adv. Math. **264**:355 (2014)

The 3-ball is a local pessimum for packing, *YK*.

I made the first significant theoretical progress in attacking a notoriously hard conjecture by Stanislaw Ulam that the ball is the worst packing convex shape. I showed that among point-symmetric shapes, the ball is a local minimum. I also show that this is not the case in higher dimensions.

Geom. Topol. **19**, 343 (2015)

Pessimal packing shapes, *YK*.

After a review of historical and recent results about shapes that are worst cases for packing in different settings, I gave new results, including a proof that the regular heptagon is a local pessimum.

Discrete Comput. Geom. **54**, 232 (2015)

When is the ball a local pessimum for covering?, *YK*.

I showed that for the covering problem too, the ball is locally worst among point-symmetric convex shapes.

Phys. Rev. E **93**, 012902 (2016)

Scaling collapse at the jamming transition, *YK*.

I studied a simple model of the jamming transition using numerical simulations. The results demonstrate a finite-size scaling collapse and yield accurate values of scaling exponents.

Discrete Comput. Geom. **56**, 449 (2016)

The local optimality of the double lattice packing, *YK and W. Kusner*.

We proved that the densest known packing of regular pentagons and heptagons cannot be improved by small rearrangements and that this result can be generalized to the double lattice packing of most convex polygons.

Soft Matter, **12**, 4123 (2016) **The random packing density of nearly spherical particles**, *YK*.
I show by an analytic calculation that particles of any nearly-spherical shape have a higher random packing fraction than do spherical particles subjected to the same protocol.

Preprints

arXiv: 1605.08678 (2016) **Free energy of singular sticky-sphere clusters**, *YK and M. Holmes-Cerfon*.
We derived a general analytic expression for the free energy of a cluster of spherical particles with short-range attractive interaction, such as colloids with DNA coating. Clusters with zero modes in the vibration spectrum exhibit an entropic advantage that diverges in the zero-range limit. We calculated the free energy for all rigid cluster up to $N = 19$ spheres.

arXiv: 1604.02096 (2016) **Dynamics of beneficial epidemics**, *Santa Fe Institute Postdocs*.
This highly collaborative 15-author paper came out of *72 Hours of Science*, an innovative experiment in interdisciplinary science, in which the postdocs of SFI sought to go from a fresh idea to a preprint in 3 days. Using ideas from population genetics, epidemiology, and social networks, we showed that contagions that confer certain benefits to their hosts can spread superexponentially.

Selected talks

Feb. 2010 **Geometry Seminar**, *Courant Institute, New York University*.

May 2010 **Optimal configurations on the sphere and other manifolds**, *Vanderbilt University*.

Jun. 2010 **Particulate matter: does dimensionality matter**, *Max Planck Institute for Physics of Complex Systems, Dresden*.

Nov. 2010 **Widely Applied Math Seminar**, *Harvard University*.

Sep. 2012 **International workshop on packing problems**, *Trinity College Dublin*.

Jun. 2013 **Physics of glassy and granular materials**, *Yukawa Institute of Theoretical Physics, Kyoto University*.

Nov. 2013 **Soft Condensed Matter Seminar**, *New York University*.

Nov. 2013 **Jorge Urrutia 60th Birthday Conference**, *Oaxaca*.

Jan. 2014 **Physics Colloquium**, *Vanderbilt University*.

Feb. 2014 **Mathematics Colloquium**, *Colorado State University*.

Mar. 2014 **Geometric tomography and harmonic analysis**, *Banff International Research Station*.

Oct. 2014 **Minimal Energy Point Sets, Lattices, and Designs**, *Erwin Schrödinger Institute, Vienna.*

Dec. 2014 **Center for Nonlinear Studies seminar**, *Los Alamos National Laboratory.*

Feb. 2015 **Unifying Concepts in Glass Physics VI (invited)**, *Aspen Center for Physics.*

Sep. 2015 **Conference on Complex Systems**, *Tempe.*

Mar. 2016 **Applied Math Seminar**, *Courant Institute, New York University.*

Jul. 2016 **International Workshop on Jamming and Granular Matter**, *Queen Mary University of London.*

Oct. 2016 **Stochastic Toplogy and Thermodynamic Limits (invited)**, *ICERM, Brown University.*

Jan. 2017 **AMS Special Session on Discrete Geometry and Convexity (invited)**, *Joint Math Meeting, Atlanta.*

Jan. 2017 **Recent Advances on the Glass and Jamming Transitions (invited)**, *CECAM, EPFL, Lausanne.*