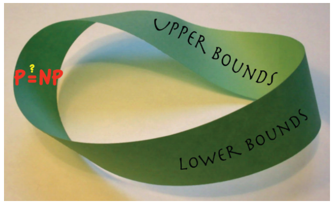


Understanding, Coping with, and Benefiting from Intractability

http://intractability.princeton.edu/

Eric Allender, Sanjeev Arora, Boaz Barak, Moses Charikar,
Bernard Chazelle, Subhash Khot, Russell Impagliazzo, Assaf Naor,
Mike Saks, Mario Szegedy, Robert Tarjan, Avi Wigderson
(since inception) Mark Braverman, Zeev Dvir, Swastik Kopparty, Shubhangi Saraf

Expeditions in Computing PI Meeting
May 14-16, 2013

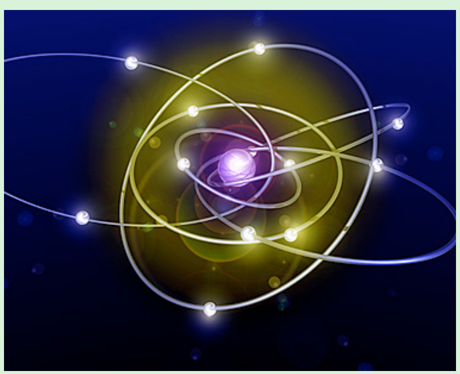
Computational Intractability is everywhere

Mathematics

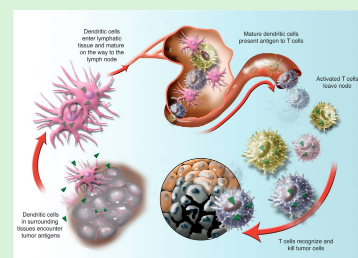
$$X^n + Y^n = Z^n$$

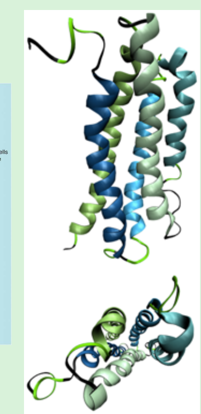
Computer Science

Computation



Physics





Biology

Computational Intractability is a fundamental notion which permeates the sciences

- limits our ability to design better computer and communication systems

- limits our ability to understand natural and social systems

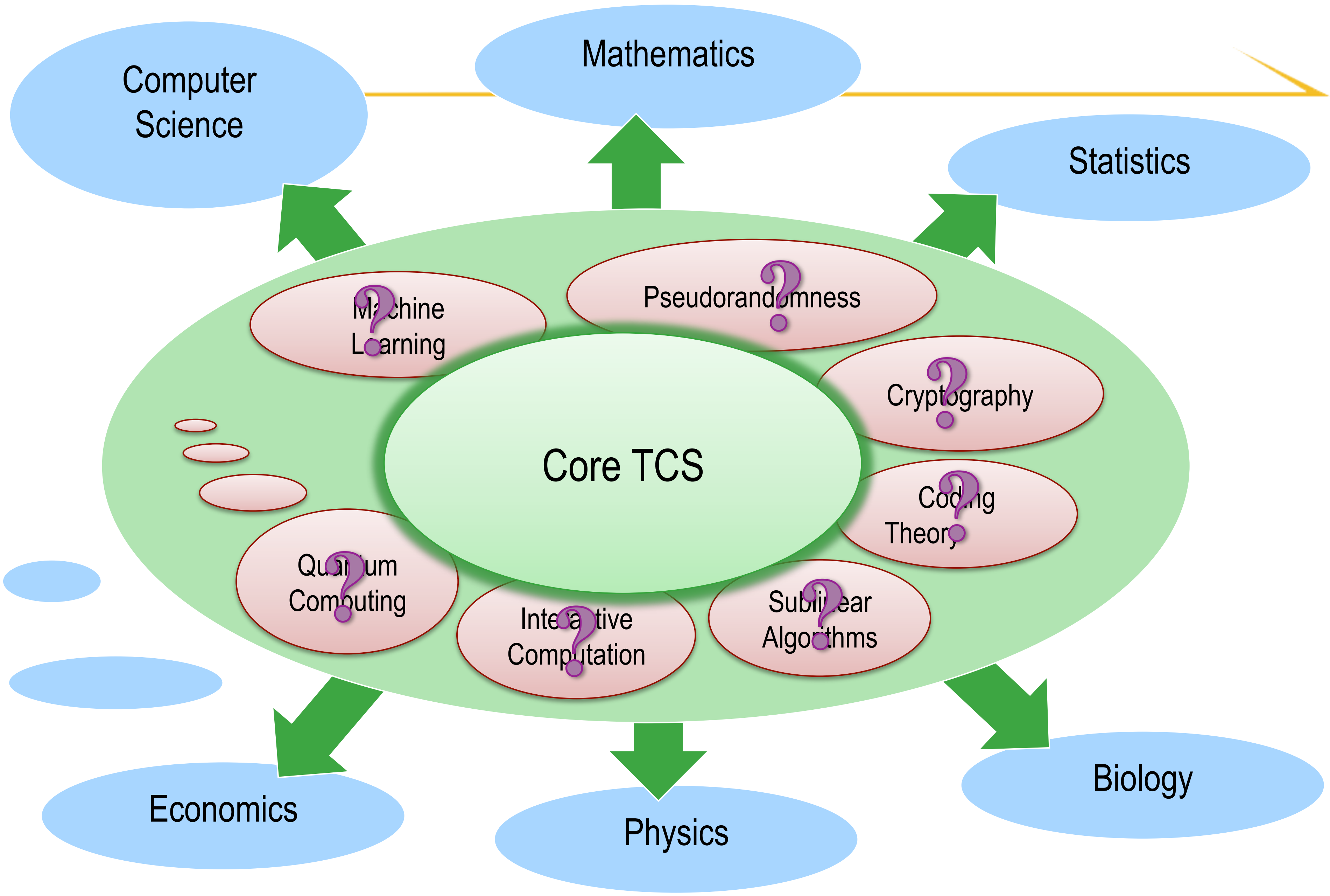
Research Goals

Three frontiers of intractability:

- **Understanding**: model natural phenomena as information processes, study their resources, prove lower bounds.

- **Coping**: Find new algorithmic paradigms and techniques to circumvent intractability (approximation, heuristics, instance-based analysis, structure in practical instances)

- **Benefiting**: Using hardness to ensure privacy, secrecy, fault-tolerance; generate randomness


Computer Science
Mathematics
Statistics
Machine Learning
Pseudorandomness
Cryptography
Core TCS
Coding Theory
Quantum Computing
Interactive Computation
Sublinear Algorithms
Economics
Physics
Biology

Why an Intractability Center?

- Solution to major open problems comes from deep and unexpected connections.

- mount large scale, focused attack on major problems by top TCS researchers with diverse interests and skills but common purpose.
  - 12 PIs (+4 -2), focused monthly meetings, constant interaction

- train next generation of top TCS researchers with broad expertise; disseminate knowledge to whole community.
  - 40+ graduate students, 30+ postdocs, 20+ workshops

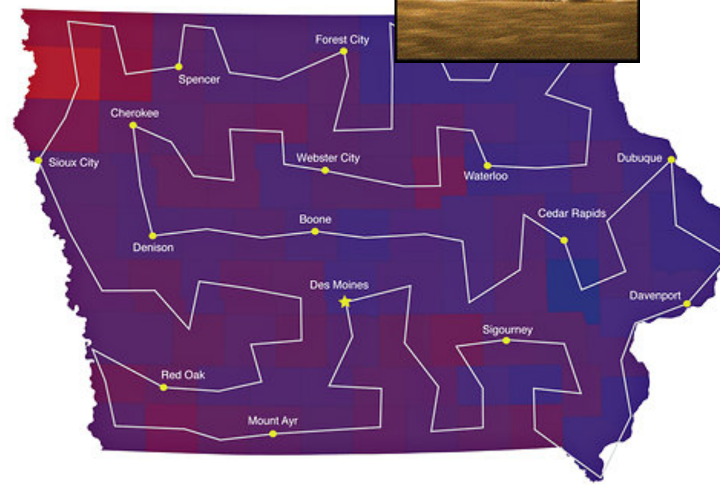
Research Highlights

- Progress on major problems.
- New surprising connections.

A brief history of optimization

- **NP-completeness** (early 70's): Many optimization problems hard to solve exactly
- approximately optimal solution?
- **PCP theorem** (early 90's): optimization problems cannot be approximated beyond threshold
- threshold of approximability?

Traveling Salesman



Arora

Szegedy

Unique Games Conjecture

- Systems of linear equations.
- How easy to satisfy?
- **What if only 99% of equations satisfiable?**

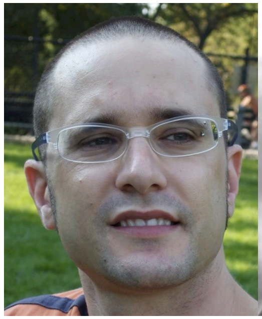
- **[Khot]**
  Conjecture: Hard to satisfy even 1%

- Far reaching implications:
  - captures power of convex programming for optimization problems
  - universal optimal algorithm

Significant Progress on UGC

- Focus area for Intractability Center

Arora

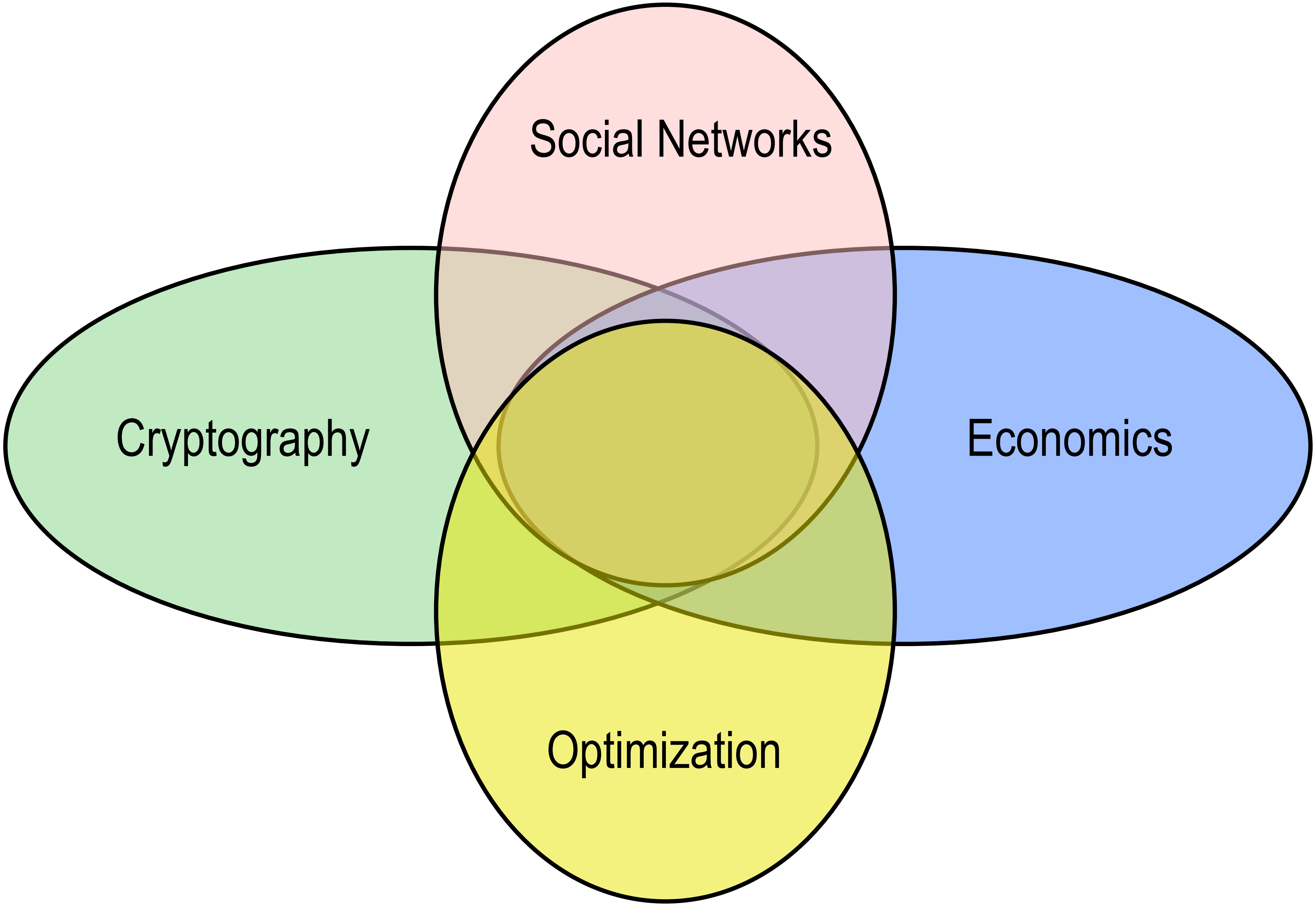


Barak

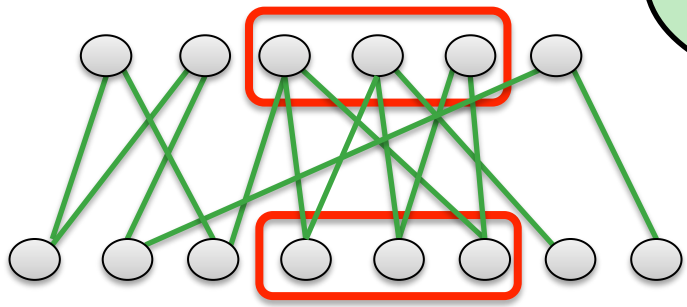
Steurer

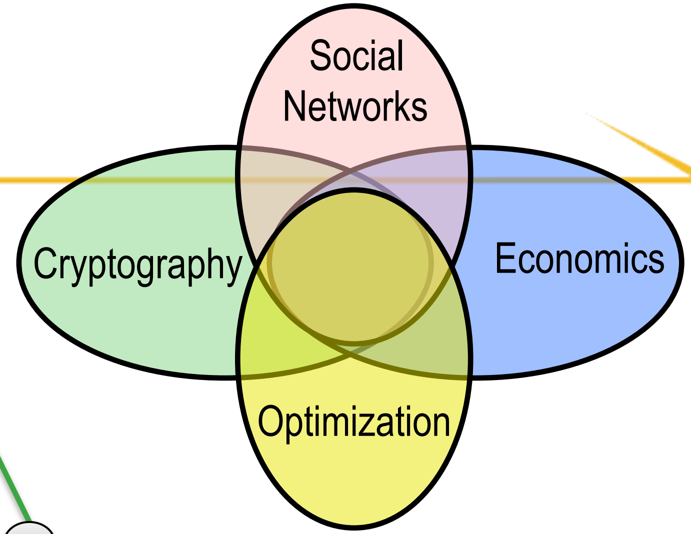
- **Surprising new algorithm for Unique Games**
  - culmination of insights (geometric, algebraic, algorithmic) from Center PIs and postdocs
  - insights into strength of convex programming
  - spectral graph partitioning

New Surprising Connections



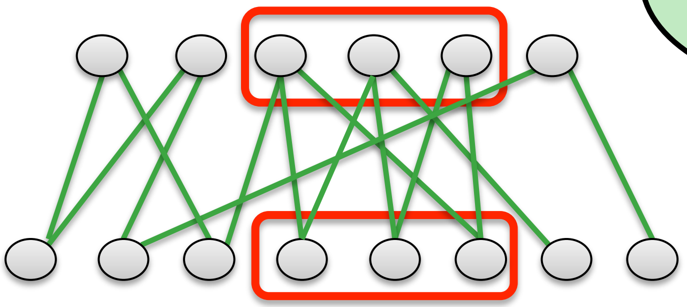
Dense Subgraph

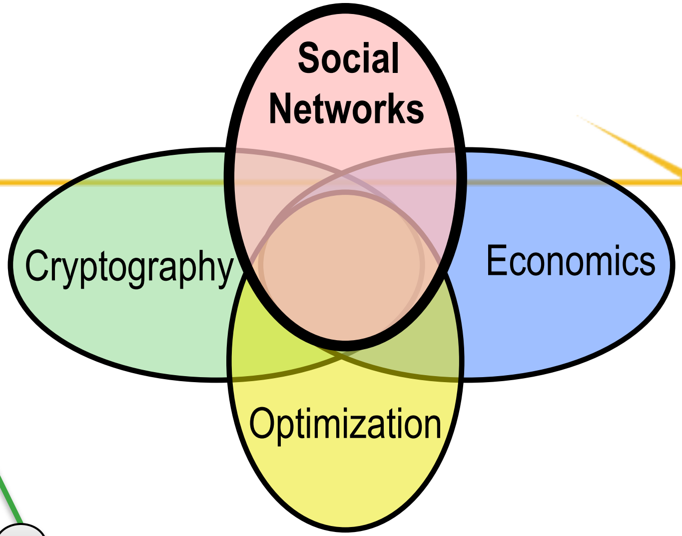




- Given graph, find subset with many edges

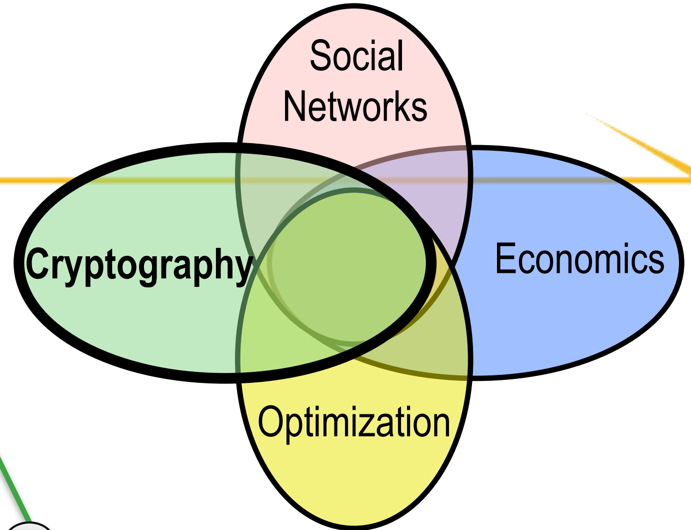
Dense Subgraph

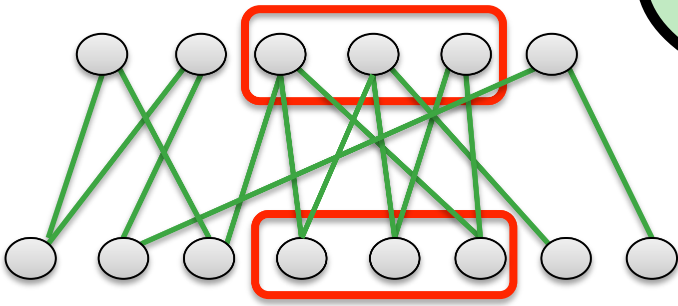




- **Social networks**: Dense subgraph = community
  - algorithms for instances in practice

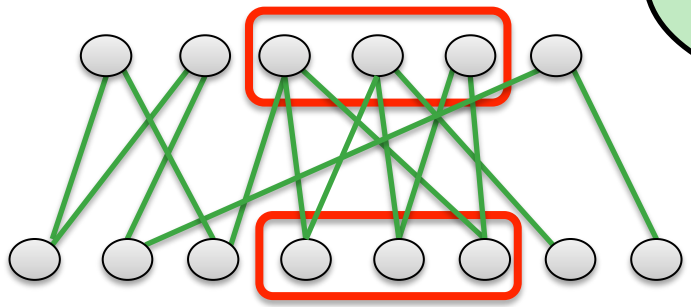
Dense Subgraph

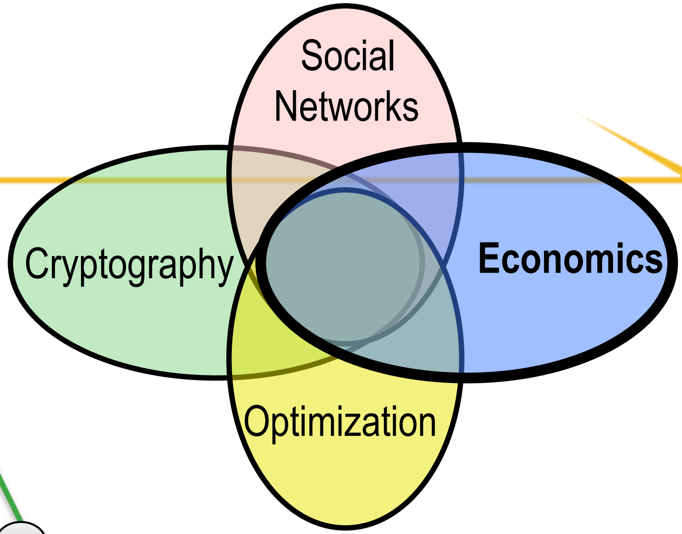




- **Cryptography**: Dense subgraph = hidden key
  - new public key cryptosystem resistant to attack

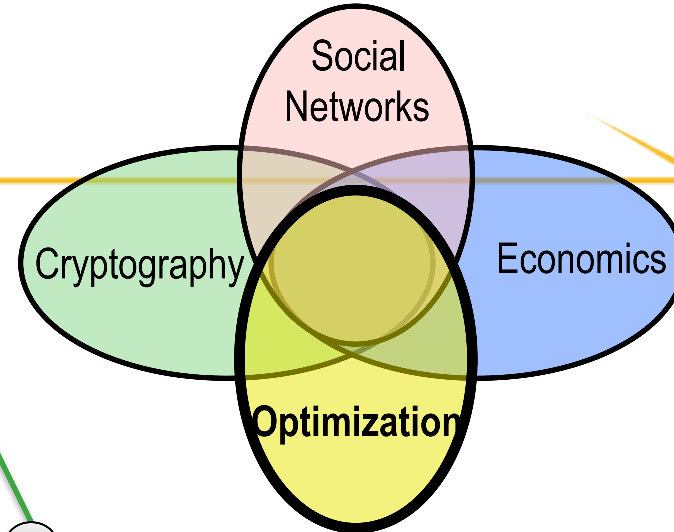
Dense Subgraph

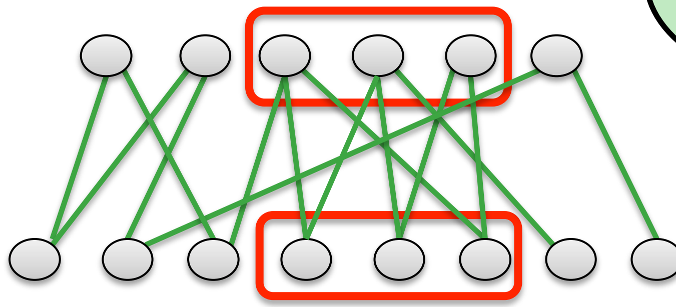




- **Economics**: Dense subgraph = evidence of tampering in creation of financial derivatives
  - pricing derivatives *computationally hard* even if full information available
  - questions conventional economics wisdom on efficient markets
  - injects computational complexity into discussion

Dense Subgraph



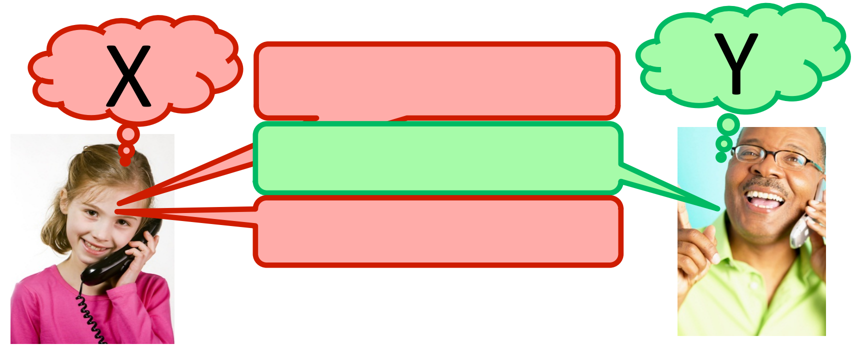


- **Optimization**: Dense subgraph = open problem
  - new algorithms
  - limitations of algorithmic techniques
  - hardness of approximation

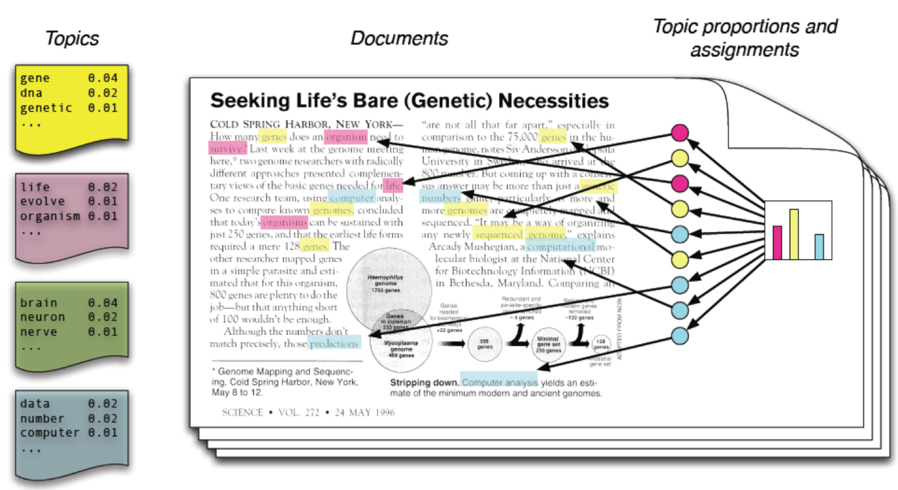
Natural Algorithms

- *How computing theory helps explain natural processes*
- *Learning algorithmic techniques from nature*
- CS theory tools and techniques solve open problems in multiagent systems
  - bird flocking
  - opinion dynamics

- ***Interactive Communication***
  - Extending Shannon theory to interactive communication



- ***Machine Learning***
  - Why are machine learning approaches successful for seemingly hard problems?
  - structural insights lead to new, practical algorithms



Women in Theory

- Biennial workshop at Princeton (2008, 2010, 2012)
- 50-70 participants (grad+undergrad)
- technical program, career advice

- Tal Rabin (chair)
- Barak, Charikar (local organizers)

Women in Theory speakers

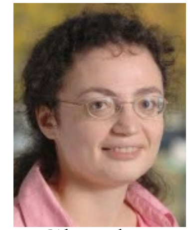

Dwork


Malkin


Chawla


Goldwasser

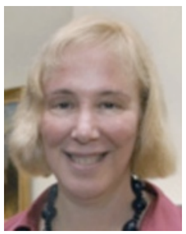

Zhang


Chuzhoy


Dinur

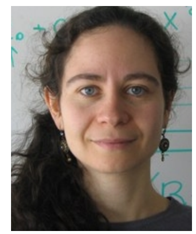

Tardos

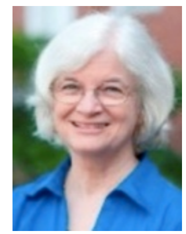

Aharonov


Feigenbaum


Kalai


Pitassi


Rashkhodnikova


Lynch


Singh


Fleischer


Randall


Moshkovitz


Lysyanskaya


Karlin


Rexford


Ramachandran


King


Wright


Immorlica


Klawe


Ron


Saraf


Rubinfeld


Borradaile


Aggarwal


Tilghman

Outreach

- **NJ Governor's School** (2009, 2010, 2011, 2012, 2013)

- **"The Math behind the Machine"**
  - 3 week course taught by center postdocs; guest lectures by PIs
  - Topics: matching, flows, markets, complexity, randomness, learning,

Troy Lee
(2009)

Ryan Williams
(2010)

Virginia Williams
(2010)

Grant Schoenebeck
(2011,2012)

Ankur Moitra
(2013)

Outreach

- **Intensive 7-week theoretical computer science course for high-schoolers (2011, 2012, 2013)**
  - **discrete math, algorithms, proof techniques**

  - 2011: 20 students (5 female)
    2012: 31 students (9 female)
    2013: 32 students (14 female), 90+ applicants
- guest lectures by PIs, postdocs, students
- biweekly meetings at Princeton through the year (2012-13)

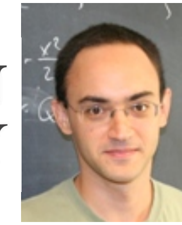
Workshops 20 workshops, 50-150 participants each

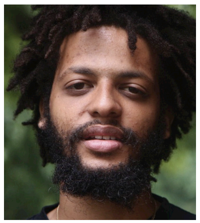
strong inter-disciplinary focus to foster interactions, knowledge transfer

Geometry in Algorithms	Oct 29-31,	2008
Impagliazzo's Worlds	June 3-5,	2009
Limits of approximation algorithms	July 20-21,	2009
Barriers in Computational Complexity	Aug 25-29,	2009
Natural Algorithms	Nov 2-3,	2009
Decentralized Mechanism Design, Distributed Computing&Cryptography	June 3-4,	2010
Pseudorandomness in Mathematics and Computer Science,	June 14-18,	2010
Geometric Complexity Theory	July 6-7,	2010
Barriers in Computational Complexity II	August 26-30,	2010
Analysis and Geometry of Boolean Threshold Functions	Oct 21-22,	2010
Approximation Algorithms – the last decade and the next	June 13-17,	2011
Quantum Computing day	Nov 1,	2011
Counting, Inference and Optimization on Graphs	Nov 2-5,	2011
Quantum Statistical Mechanics & Quantum Computing	March 22-23,	2013
Turing Centennial	May 10-12,	2012
Graph and Analysis:	June 4-8,	2012
Provable Bounds in Machine Learning	Aug 1-2,	2012
Quantum Statistical Mechanics and Quantum Computation	March 22-23,	2012
Natural Algorithms and the Sciences	May 20-21,	2013
Horizons in TCS	Aug 27-29,	2013

Mentoring: faculty placements of alumni

Massachusetts Institute of Technology


PRINCETON UNIVERSITY



HARVARD UNIVERSITY


ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK


STONY BROOK
STATE UNIVERSITY OF NEW YORK



STANFORD UNIVERSITY


Cornell University

UCSD


UNIVERSITY OF WASHINGTON



RUTGERS