Theoretical Computer Science

$$\lambda \mapsto \int e^{i\lambda x} f(x)dx$$

79 November 2029

What does it mean to compute?

- Computation means following a set of instructions.
- Originally, theoretical computer science was concerned only with (Turing / von Neumann) computers.
- The field has matured, and is beginning to export its knowledge. (Daskalakis, Arora, Childs (Quantum).)
- (Most of the field is still doing what it did ten years ago: approximation algorithms, complexity, optimization.. but I'll focus on recent fancy stuff.)

The world according to ..

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LATEST: Sarah Palin sneezes, snot sold for £2,000,000

G20 summit stretches to seventieth day

Politicians act like five-year-olds in the face of financial strains and China owning the west in every conceivable manner.

Financial crisis predicted

Bankers still treat constituents like endless coffers and wonder how many yachts they can squeeze into their private harbors.

Lady Gaga concert cancelled

Collapses prior to concert, citing fatigue and ill-adjustment to new tour schedule.

The world according to .. a CS theorist.

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LATEST: International holiday commemorating Grigori Perelmar

G20 summit stretches to seventieth day

Desired consensus is a Nash equilbrium, and therefore PPAD-hard; deliberations will last forever. (Daskalakis et al.)

Financial crisis predicted

Detecting unfairness in a set of CDOs is equivalent to the dense subgraph problem and therefore NP-hard. (Arora et al.)

Lady Gaga concert cancelled

Finding optimal chord progression is reducible to knapsack and therefore NP-hard.

Algorithmic game theory.

- To prove the existence of Nash Equilibria, the Brouwer fixed point theorem was used. Was this necessary? (in a sense of computational equivalence.)
- It turns out, YES: both are complete for the same complexity class (PPAD, a subset of FNP).
- Constantinos Daskalakis won the 2008 ACM Dissertation award for "The Complexity of Nash Equilibria".
- Papadimitriou: "If my laptop can't compute it, neither can the market".
- Lots of research into better equilibria concepts.
- Lots of internet companies hire game theorists, e.g. for their ad auctions.

UGC-hardness, the new holy grail.

- Theorists care about SDPs: 0.878-factor approximation to max-cut via SDP.
- Unique Games Conjecture (roughly): determining whether a (an exotic) graph property is fractionally satisfiable is NP-hard. (Details if time..)
- 0.878 looks ridiculous.. under UGC + $(P \neq NP)$, it is optimal.
- UGC says that for a wide variety of problems, the SDP is the optimal algorithm, and the integrality gap is thus the approximation ratio.

Smoothed analysis.

- To solve a linear program, can use an interior point method ($O(s^{3.5}\log(1/\epsilon))$) or the simplex method ($2^{\Omega(n)}$)… but simplex is fast in practice!!
- The point: for some algorithms and their typical settings, these bad instances are rare.
- Smoothed analysis: convolve optimization space with a gaussian, read off the "smoothed" worst case.
- Key results: simplex and k-means are smoothed-poly.
- Won Teng+Spielman the 2008 Gödel prize!
- Interesting aside: Vempala has a new algorithm (ICS'10) which solves strong linear programming. No one knows the running time yet, but it seems to defeat typical bad cases.

Graph partitioning.

- Classical problem: max-flow/min-cut. (Still open! Lower bound $\Omega(m)$, upper bound Spielman/Daitch $\tilde{O}(m^{1.5} \log(w_{\max}/\epsilon))$.)
- This cut may be unbalanced: divide by smaller size or inner connectivity! (“Sparsest Cut”, ”Normalized Cuts”.)
- Spectral methods: look at eigenspace of matrix representation. (first alg for normalized cuts.)
- OR: do some matrix math, write down approximating SDP. (Can solve it with boosting!)

Miscellaneous gossip.

- STOC/FOCS are the top conferences, but many felt it became a technical proving ground for grad students; ICS was started (this year) to give a place to show new ideas.
- The Arora result alluded to in the joke was presented at ICS, and also at UCSD.
- Princeton/IAS/Rutgers/Courant received a huge grant for pure complexity theory (with no concrete stated goals!).
- Privacy preserving operations.

Top theory schools.

- MIT. Optimization (Goemans), Complexity (~~Sudan~~), Crypto (Goldwasser), Quantum (Aaronson). (indyk rivest sipser daskalakis..)
- Berkeley. Quantum (U. Vazirani), Games (Papadimitriou), Crypto/Complexity (Trevisan).
- Princeton/IAS. Everything (Arora), Complexity (Widgerson).
- CMU. Boolean functions (O'Donnell), Approximation Algorithms (Gupta/other dude), being smarter than everyone (A. Blum).
- Other strong places: UWashington (James Lee), Georgia Tech (Prasad Raghavendra, Santosh Vempala), Microsoft Research Cambridge (Mark Braverman, Adam Kalai, Madhu Sudan).

Theory @ UCSD.

- ♡♡ Russell Impagliazzo ♡♡: is randomness inherently more powerful?
- Sanjoy Dasgupta: wrote algorithms textbook lots of schools use.
- Yoav Freund: Boosting → multiplicative weights.
- Mihir Bellare: fundamental results in crypto (theory people think he is awesome).
- Daniele Micciancio: applying hard problems to build crypto systems (paper with Panos on shortest vector appeared in SODA this year).
- Mohan Paturi: recent focus on social networks.
- Fan Chung Graham: spectral graph theory.

The Unique Games Conjecture

A **unique game** is a graph $G = (V, E)$, a set of admissible colors C, and a set of permutations f_e constraining $c(v_1) = f_e(c(v_2)$ where $e : v_1 \to v_2$ and $c(x)$ is the color of vertex x.

To find an exact coloring takes time $O(C(m+n))$; fix a vertex, and for each color it can take, propagate colors to other vertices in the graph. But seeing if an ϵ fraction of the constraints can be satisfied is a pain. In fact..

The **Unique Games Conjecture** is that for every small constant $\epsilon > 0$, there exists a C such that for any unique game, it is NP-hard to tell if at least $1 - \epsilon$ of the constraints can be satisfied, or if every color satisfies less than ϵ.