Interdisciplinary Teaching Grant Proposal

Applicants:

Core Faculty

Professor Ron Cytron, Department of Computer Science, School of Engineering
Professor Maggie Penn, Department of Political Science, College of Arts & Sciences

Overview of Proposed Course: "Fair Division in Theory and Practice"

The concept of fair division in a central tenet in the design of procedures aimed at generating equitable social outcomes and mitigating conflict. At the national level, such procedures include systems of apportionment, voting and legislative districting, to name a few. On a smaller scale, these procedures could govern how assets are divided in a divorce, or how to divide a cake.

While "fairness" in theory is indisputably a good thing, in practice the courts, politicians, and even mathematicians have grappled with the question of what it means for a procedure to be fair. An illustration is the 2004 case *Vieth v. Jubelirer* in which a plurality of the Supreme Court ruled that claims of political gerrymanders (the drawing of district lines to advantage on political party over another) were not capable of being decided by a court. Interestingly, the Court unanimously agreed that severe gerrymanders are unconstitutional and incompatible with democratic principles of fairness. But neither the Court nor the appellants could agree on a principle of fairness that could be applied to all such cases. Absent such a principle, Justice Scalia wrote, " 'Fairness' does not seem to us a judicially manageable standard."

This course will examine algorithms and applications of procedures that aim to divide or allocate resources fairly. Some of these procedures were developed by mathematicians looking for formulas that satisfy mathematical properties such as *envy-freeness and equi-tability*. Other procedures emerged through historical debates concerning issues like feder-alism and voting rights. All of the procedures we consider will be examined in terms of the fairness goals they aspire to achieve, the mechanisms they employ to achieve those goals, and the shortcomings of the procedures.

Course Objectives

This course spans the fields of political science and computer science. The area of computational social choice is relatively new, and this course allows us to expose students at an early level to the ideas in this new field. The course is novel in terms of content but also in the manner that it presents research from

the areas of political and computer science in a familiar pedagogical setting. Issues of fairness are central to all disputes, and this course provides normative and computational rationales for achieving and evaluating fairness of outcomes. The methods we cover have certain advantages but also shortcomings. We aim for students to understand these properties of fairness procedures, so as to understand when they can be applied and what results can be expected. This set of skills has remarkably wide applicability to students from both schools. It is also likely that students in this course will develop research interests in this area, working with either or both professors in the future, or undertaking graduate studies in this area.

Target Student Audience

We intend this course to be taken by students in Arts & Sciences and Engineering. Students from both populations would approach this course with an interest in both the social and computational aspects of fairness. These students will work together on applying the concepts studied in this course to actual problems of historical or current interest. The students should have had CSE 131, but this includes a very large population of students from both schools. Approximately 500 students take 131 each year, and over half are from outside of Engineering. While this course could attract a large number of students, I would expect its first offering would be limited to a small number, say 35 students, so that we can pilot the course and obtain feedback. The course also requires some maturity on the part of the students, as there is no text, so it should be available to students who are past their freshman year.

Assessment Plan

The course syllabus (below) shows the topics we intend to cover, and we can solicit student feedback about these topics to evaluate interest, applicability, and comprehension. Homework assignments and lab exercises will help us assess the students' progress throughout the semester. We plan to give the students a pre-course and post-course survey, designed to assess the extent to which the students understand 1) what is meant by "fair;" 2) how does one analyze a particular division algorithm in terms of fairness, complexity, and manipulability; 3) how does one evaluate the advantages and disadvantages of a particular division algorithm; 4) how does one evaluate the applicability of a given division algorithm to a particular, actual dispute?

Use of TAs

Absent a text, students will be meeting with TAs to formulate project ideas, discuss fair division problems and algorithms, and to receive help with the lab (computer) work they undertake for the course. Outside of lecture / meeting time, the TA hours can also include recitation time to expand on the ideas presented in lecture.

Teaching and Planning

Each week will be presented as a module with the first half consisting of a lecture by Professor Penn concerning the applicability of the procedure to questions in political science. The second half of the module will consist of a hands-on lab run by Professor Cytron in which students will implement the procedure themselves on data that we provide. The goal is for students to emerge with an understanding of the practical problem the procedure was meant to resolve along with the mechanics of the procedure and its strengths and shortcomings. These aspects cleanly divide between Maggie and Ron, respectively, and we plan to share the teaching in that manner. Planning will consist of ideas driven from one side or the other, with the complimentary side filling in context or algorithmic detail as needed. We plan to meet in summer and fall to organize the course an have it ready for spring.

Draft Syllabus: Fair Division in Theory and Practice

Course Description

The concept of fair division is a central tenet in the design of procedures aimed at generating equitable social outcomes and mitigating conflict. At the national level, such procedures include systems of apportionment, voting and legislative districting, to name a few. On a smaller scale, these procedures could govern how assets are divided in a divorce or how to divide a cake.

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Grading

You will be graded on regular problem sets (20%), a first exam (25%), a second exam (30%), and an independent project that you will present to the class during our "science fair" (20%). The remaining 5% of your grade will be based on your participation in class and attendance.

Readings

Readings are listed on the syllabus by week. If the material is not available on JSTOR we will provide a link to it on the course website. We also recommend the books *Fair Division: From Cake-Cutting to Dispute Resolution* by Brams & Taylor, and *The Mathematics of Voting and Elections* by Jonathan Hodge and Richard Klima.

Week 1

- Introduction to course, syllabus, schedule, programing and mathematical notation.

Week 2

- "Divide-and-chose," and its variants.
- Excerpts from *Fair Division: From Cake-Cutting to Dispute Resolution*, Brams & Taylor, 1996/

Week 3

- The Adjusted Winner procedure/
- "Fair Division, Adjusted Winner Procedure (AW), and the Israeli-Palestinian Conflict", Massoud, *Journal of Conflict Resolution*, 44(3):333-358, 2000.
- Excerpts on the Panama Canal treaty negotions, in *Fair Division: From Cake-Cutting to Dispute Resolution*, Brams & Taylor, 1996.

Week 4

- Apportionment in the U.S. House: Fair allocation of seats to states and axioms of proportionality.
- Excerpts from Fair Representation: *Meeting the Ideal of One Man, One Vote*, Balinski and Young, 1982.
- *House of Representatives Apportionment Formula: An Analysis of Proposals for Change and Their Impact on States*, Royce Crocker, Congressional Research Service Report for Congress, 2010.

Week 5

- Measures of proportionality with an application to the list systems of proportional representation.
- "Proportionality, Disproportionality and Electoral Systems," Michael Gallagher, *Electoral Studies*, 10(1):33-51, 1991.

Week 6

- Approval voting and the cumulative vote: Expressions of preference.
- "Cumulative Voting in the United States," Pildes and Donoghue, *University of Chicago Legal Forum* 241, 1995.

Week 7

- Positional and transferable vote systems: Fair division through elections.

- Chapter 10 in *Fair Division: From Cake-Cutting to Dispute Resolution*, Brams & Taylor, 1996.

Midterm Exam

Week 8

- Shapley-Shubik and Banzhaf power indices: Weighted votes for differently-sized constituencies
- "Weighted Voting in New York," Grofman and Scarrow, *Legislative Studies Quarterly* 6(2): 287-304, 1981.

Week 9

- Gerrymandering: Measuring district shape and composition
- "The Quest for Legislative Districting in the Public Interest: Elusive or Illusory," Lowenstein and Steinberg, *UCLA Law Review*, 33(1), 1985.
- "Gerrymandering and convexity," Hodge, Marshall & Patterson, *The College Mathematics Journal* 41(4): 312-324, 2010.

Week 10

- Measures of segregation: Evenness, dispersion and contact as fairness criteria
- "Sorting Out Deepening Confusion on Segregation Trends," Orfield, Siegel-Hawley & Kucsera, *The Civil Rights Project*, March 2014.

Week 11

- Arrow's Theorem and Sen's Theorem: Sensibility in procedure and outcome.
- Excerpts from *Social Choice and Legitimacy: The Possibilities of Impossibility,* Patty and Penn, 2014.

Week 12

- The Gibbard-Satterthwaite Theorem: Non-manipulability of procedures.
- "Arrow's theorem and the Gibbard-Satterthwaite theorem: a unified approach," Philip Reny, *Economics Letters*, 70(1): 99-105, 2001.
- "Almost all social choice rules are highly manipulable, but a few aren't," Jerry Kelly, *Social Choice and Welfare*, 10(2):161-175, 1993.

Week 13

- Zero-sum competition: Divide-the-dollar, “truels,” and Colonel Blotto games.
- Chapter 8 in *Fair Division: From Cake-Cutting to Dispute Resolution*, Brams & Taylor, 1996.
- “The Truel,” Kilgour & Brams, *Mathematics Magazine*, 70(5):315-326, 1997.
- “Sequential, nonzero-sum ‘Blotto’: Allocating defensive resources prior to attack,” Robert Powell, *Games and Economic Behavior*, 67(2):611-615, 2009.

Final Exam