Making the World Fairer

Spliddit.org is a not-for-profit academic endeavor with the mission to provide free access to sophisticated and provably fair methods developed in the scientific community. Spliddit has been a major driving force for novel theoretical and empirical fair division research.

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You move to a new city, and, with three friends, rent a beautiful four-bedroom apartment. You need to decide which roommate gets which room, and how to split the $2,800 monthly rent. Of course, everyone wants the master bedroom with an attached bathroom, but you *really* need it, more than others, you believe. So, you propose to pay $1,000 for it; that's $300 above what an equal split would require. One of your friends is considering paying even more for the master bedroom, while another friend gives up on the master bedroom and offers to pay $800 for the next largest room. You say, "Wait, but if I don't get the master bedroom, I'll pay $900 for that room."

After hours of messy negotiations, someone proposes to just flip coins to decide who gets which room and split the rent equally. Everyone, tired at this point, agrees. Coins are flipped. You get the worst room, while your lucky friend enjoys the master bedroom, yet you both will pay $700. Sure, the process was fair in some sense, but you are left envying your friend. You start to ponder if there was a better way to resolve this quickly that could have made everyone happy. It sounds too good to be true, but then you hear about Spliddit.

Spliddit.org is a first-of-its-kind, not-for-profit, and freely accessible website that provides provably fair solutions to a range of everyday tasks, one of them being the rent division scenario. Spliddit uses an algorithm to produce an outcome that is guaranteed to satisfy an almost magical fairness property called "envy-freeness." Given the prices, no roommate will prefer anyone else's room above their own room. In other words, everyone will be happy with what they receive. This strong fairness guarantee has incentivized people to use Spliddit's rent division application to solve more than 25,000 instances. Overall, Spliddit has attracted more than

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Figure 1. Spliddit.org offers five applications for everyday tasks requiring fair solutions.

100,000 users in less than two and a half years since it launched. This article describes Spliddit's services , its contributions to society, and its benefit to the scientific community.

THE BEGINNING

Ariel Procaccia, a computer science professor at Carnegie Mellon University (CMU), and Jonathan Goldman, a then-undergraduate student at CMU, launched Spliddit in November 2014. Two then-graduate students working with Procaccia, including me, joined shortly after. The goal of Spliddit is to provide people free access to sophisticated methods developed in decades of research in fair division theory.

Mathematically rigorous study of fair division began with the work of Hugo Steinhaus [1] during World War II, and immediately attracted significant attention among researchers in economics and political science, and later among computer scientists. The central question is to fairly divide a common pool of resources or costs among a set of people who have different preferences or entitlements. Over the past 70 years, researchers have studied what fairness means and how to achieve it in a slew of different scenarios ranging from the simple task of dividing a single dollar between a set of people with different entitlements, to the complex task of dividing computational resources in a cluster environment between computing jobs with different resource needs.

HOW IT WORKS

Spliddit offers five applications, each for a different everyday fair division task. Two of them were added six months after the initial launch based on significant public demand. Each application implements the most attractive solution with provable fairness guarantees that the literature has to offer. These applications allow fair division of rent, goods, chores, credit, and taxi fare. We describe these applications briefly; interested readers can learn more about them, the methods used, and the fairness guarantees they provide by visiting Spliddit.org.

Rent division. This application allows n roommates to divide n rooms (or potentially fewer rooms that still accommodate n individuals), and split the rent in a fair manner. Spliddit asks all roommates to divide the total rent between the different rooms according to how valuable they think the rooms are. Once all the roommates submit their preferences, Spliddit finds a rent value for each room and assigns rooms to roommates such that two properties are guaranteed.

"Envy-freeness," is one of the most desirable fairness guarantees, which demands that all roommates have at least as much net value (value minus rent) for their own room as for any other room. In other words, given the rents, all roommates should prefer their own room the most. "Pareto optimality" is an efficiency guarantee, which demands that no other solution to the problem be able to make some roommates happier without making any roommate less happy than in the current solution. A beautiful result in fair division theory guarantees the existence of a solution satisfying both properties, irrespective of the preferences of the roommates, and Spliddit uses an algorithm that efficiently computes such a solution [2].

Goods division. This application allows a group of people to fairly divide a collection of goods. It is useful for dividing an estate among heirs, splitting assets in a divorce settlement, or splitting collectively purchased items among roommates. The collection may contain divisible items such as money or land, as well as indivisible items such as artwork, jewelry, houses, and cars.

Spliddit asks all participants to divide 1,000 points between the items based on how valuable they think the items are. The value a participant assigns to an item is reflective of not just the monetary value of the item, but also its sentimental value for the participant. Once all the participants submit their preferences, Spliddit uses a fundamental fair division method called "Maximum Nash Welfare" [3] to split the items. When all the items in the pool are divisible, this solution is guaranteed to satisfy envy-freeness and Pareto optimality, but without requiring payments from the participants like in the rent division setting.

However, if the pool contains indivisible items, an envy-free split may not always exist. For example, if two people want a diamond, giving the diamond to either of them would make the other envious. In this case, Splid-

dit's algorithm is guaranteed to satisfy envy-freeness up to one good: No participant would envy the bundle of goods received by another participant if the former got to remove at most a single good from the latter's bundle.

Chores (tasks) division. This application is akin to goods division, but divides chores or tasks that participants dislike. This is useful for assigning call shifts to doctors and nurses (in fact, the application was added to Spliddit due to requests from medical practitioners), or for splitting household chores among roommates. Spliddit asks each participant to report how much they dislike one chore over another, and finds a way to split the chores that achieves Pareto optimality together with "equitability." The latter mandates that all participants must equally dislike the bundle of chores they are assigned.

Credit division. When a group of people collaborate, a key task is to divide credit for the outcome. In the absence of external information, we must ask the participants themselves to report their perception of the relative contributions. Spliddit asks each participant to divide 100 points among the rest of the participants, and uses these reports to divide 100 percent credit among the participants in a way that satisfies impartiality: Participants cannot obtain more credit by misreporting their view of the relative contributions of others. This incentivizes each participant to report truthfully, resulting in an accurate division of credit. It was envisioned that the primary use of this application would be ordering authors of a research article by their contribution, but based on user feedback, it has been equally useful to teachers for grading individual students in group projects, and to companies looking to assign performance-based bonuses to employees.

Taxi fare division. Imagine a group of friends hailing a cab after a party, and each dropping off at a different location. Clearly, splitting the total cab fare equally isn't fair. This application finds a fair split by implementing a classic concept from cooperative game theory called "the Shapley value," which is the unique solution satisfying a combination of important desiderata, and, among other contributions, led Lloyd Shapley to receive the Nobel Prize for Economics in 2012.

Spliddit has initiated the process of bridging the gap between theory and practice in fair division, which is part of the larger field of social choice theory.

CONTRIBUTIONS TO SOCIETY

Interactions among groups of people necessitate fair division of resources or costs. While extensive research in fair division theory has produced beautiful and provably fair solutions to many problems, people are unaware of them. Also, some of these solutions are hard for humans to compute by hand. Spliddit was designed to implement these solutions on an online platform and allow people free access to them.

For the past two and a half years, Spliddit has stood by its mission:

- *"To provide easy access to carefully designed fair division methods, thereby making the world a bit fairer."*
- *"To communicate to the public the beauty and value of theoretical research in computer science, mathematics, and economics, from an unusual perspective."*

During this time, it has attracted more than 100,000 users and solved more than 35,000 real-world fair division dilemmas. Spliddit's attractiveness stems from its three key attributes. First, it provides a quick and hassle-free way to settle a dispute. Figuring out individual contributions in a collaborative project can take days, while dividing an estate or settling a divorce can often take years and result in significant acrimony. In contrast, Spliddit elicits participants' inputs in a single shot and finds a solution in seconds. Second, Spliddit's solution is provably fair, which incentivizes people to not only use it, but often reveals their inputs truthfully. For instance, in the rent division application, roommates who are unaware of the preferences of the other roommates may want to reveal their preferences truthfully to ensure that Spliddit finds a solution in which they

Figure 2. RoboVote.org helps groups of users pick optimal choices through voting.

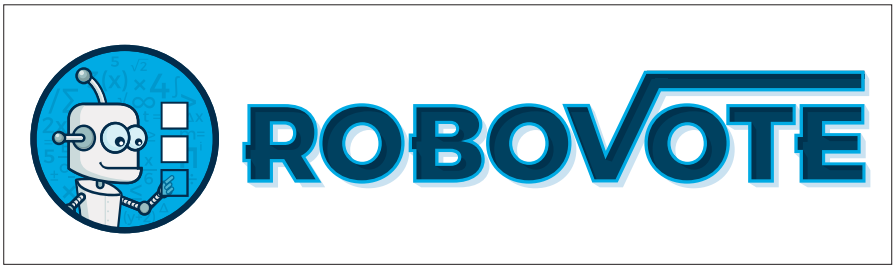
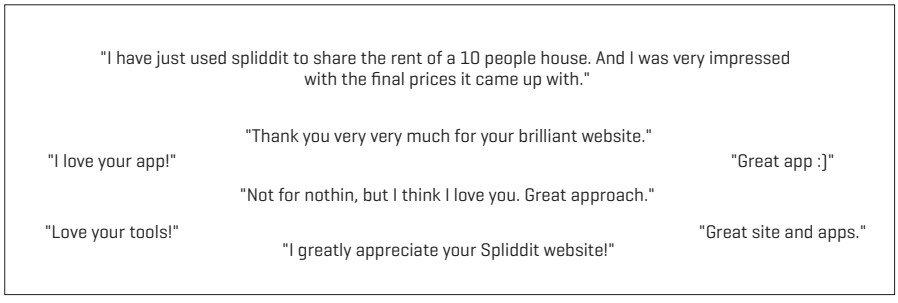


Figure 3. This shows a selection of comments from the users of Spliddit.



do not envy anyone. Third, Spliddit's automated approach is increasingly useful when the problem instances become large, as it becomes harder for humans to contemplate fairness in such instances.

Spliddit users have found Spliddit's approach, algorithms, and provable fairness guarantees very satisfactory, as reflected from their comments (see Figure 2).

CONTRIBUTIONS TO THE SCIENTIFIC COMMUNITY

In addition to being a medium through which the scientific community can help make the world a bit fairer, Spliddit has, rather surprisingly, served as a medium for the world to help the scientific community. Having been used to solve more than 35,000 real-world instances, Spliddit has become a rich dataset for empirical fair division research. Data from the goods division, chores division, and rent division applications have already been used for analyzing empirical effectiveness of existing and novel fair division mechanisms. This dataset has allowed researchers to quantify the fairness and efficiency of different mechanisms, which provides a useful contrast to the qualitative notions often used for theoretical evaluation.

Spliddit users have also helped steer research in fair division more directly through their valuable feedback. Several users identified problems with the deployed algorithms, helping us design improved algorithms. For example, while trying out Spliddit's goods division application for dividing an inheritance, one of the users encountered a simple instance for which the solution generated seemed demonstrably unfair. This spawned a research project in which an algorithm with stronger fairness guarantees was developed—the Maximum Nash Welfare algorithm, which has been a Spliddit feature since May 2016.

Other users identified a plethora of real-world problems, not covered by Spliddit's five applications, for which fair solutions are required. One such feedback initiated a collaboration with school districts in California, and led us to design a provably fair solution for allocating unused space inside public schools to local charter schools. Other examples include a school teacher approaching us with the problem of fairly assigning project ideas to groups of students; users asking us to incorporate various constraints in rent division, such as limited budgets or couples requiring to be in the same room; and medical practitioners asking for an application that allows a participant to have positive or negative value for an item (for example, a doctor may want certain call shifts, but may want to avoid others). All of these are subjects of ongoing research.

The central question is to fairly divide a common pool of resources or costs among a set of people who have different preferences or entitlements.

Spliddit also has the potential to be a platform for conducting meaningful experiments. In the past, empirical validation in fair division literature typically involved a laboratory experiment, in which participants were introduced to an artificial problem instance, shown two allegedly fair solutions, and asked to pick the one they find fairer. The problem is in an artificial setting, participants only truly care about the payments they receive, and thus concepts like envy do not play a role. In contrast, envy is commonplace in real-world problems like inheritance division. A recent study circumvented this problem by asking Spliddit users to pick the fairer solution on the actual instances that they were part of, thus eliciting more meaningful responses.

Spliddit has initiated the process of bridging the gap between theory and practice in fair division, which is part of the larger field of social choice theory, which studies how groups of individuals make collective decisions. Inspired by the success of Spliddit, some of us launched another not-for-profit website, RoboVote.org, in November 2016. RoboVote is designed for voting problems in which a collective choice, equally applicable to all participants, is to be made. This includes problems with no objectively correct answer ("Which restaurant should we go to for group lunch?") and problems that admit a correct but potentially unknown answer ("Who will win the next presidential election?"). RoboVote optimally solves such problems by using sophisticated techniques that build on decades of research in social choice theory and artificial intelligence.

Going forward, we hope to see more platforms that help people make informed decisions by using algorithms with strong theoretical foundations, and similar feedback loops through which such platforms in turn fuel additional research. We invite you, the reader, to try out Spliddit (and RoboVote). Do tell us what you like, whether you find the solutions to be fair, and what novel applications you would like to see added. Most of all, we invite you to participate in fair division research, and join us in the effort of making the world a bit fairer.

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Biography

Nisarg Shah is an assistant professor at the University of Toronto. He received his Ph.D. from Carnegie Mellon University, and was a postdoctoral fellow at the Center for Research on Computation and Society at Harvard University. He is broadly interested in algorithmic economics—theory and applications. His research has focused on topics such as computational social choice, fair division, game theory, prediction markets, and peer prediction. Shah is the winner of the 2013-2014 Hima and Jive Graduate Fellowship, the 2014-2015 Facebook Fellowship, and the 2016 IFAAMAS Victor Lesser Distinguished Dissertation Award.