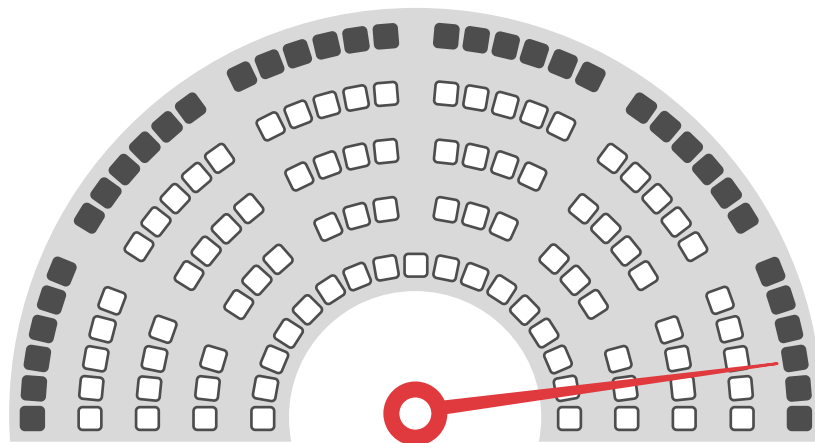




Optimized Democracy

Spring 2021 | Lecture 3

Strategic Manipulation

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REMINDER: THE VOTING MODEL

- Set of **voters** $N = \{1, \dots, n\}$ (assume that $n \geq 2$)
- Set of alternatives A ; denote $|A| = m$
- Each voter has a **ranking** $\sigma_i \in \mathcal{L}$ over the alternatives; $x \succ_{\sigma_i} y$ means that voter i prefers x to y
- A **preference profile** $\sigma \in \mathcal{L}^n$ is a collection of all voters' rankings
- A **social choice function** is a function $f: \mathcal{L}^n \rightarrow A$

MANIPULATION



So far the voters were honest!

MANIPULATION

- Using Borda count
- Top profile: b wins
- Bottom profile: a wins
- By changing their vote, voter 3 achieves a better outcome!

1	2	3
b	b	a
a	a	b
c	c	c
d	d	d

1	2	3
b	b	a
a	a	c
c	c	d
d	d	b



Jean-Charles de Borda

1733–1799

“My rule is intended for honest men!”



STRATEGYPROOFNESS

- Denote $\sigma_{-i} = (\sigma_1, \dots, \sigma_{i-1}, \sigma_{i+1}, \dots, \sigma_n)$
- A social choice function f is **strategyproof (SP)** if a voter can never benefit from lying about their preferences:

$$\forall \sigma \in \mathcal{L}^n, \forall i \in N, \forall \sigma'_i \in \mathcal{L}, f(\sigma) \succsim_{\sigma_i} f(\sigma'_i, \sigma_{-i})$$

Poll 1

Max m for which plurality is SP?

- $m = 2$
- $m = 3$
- $m = 4$
- $m = \infty$



THE G-S THEOREM

- Theorem [Gibbard 1973, Satterthwaite 1975]: Let $m \geq 3$, then a social choice function f is SP and onto A (any alternative can win) if and only if f is dictatorial
- In other words, any voting rule that is onto and nondictatorial is manipulable

Question

For $m \geq 3$, are there rules that are SP and nondictatorial? Onto and nondictatorial?



PROOF SKETCH OF G-S

- Lemmas (prove in HW1):
 - **Strong monotonicity:** If f is SP function, σ profile, $f(\sigma) = a$, then $f(\sigma') = a$ for all profiles σ' s.t. $\forall x \in A, i \in N: \left[a \succ_{\sigma_i} x \Rightarrow a \succ_{\sigma'_i} x \right]$
 - **Unanimity:** If f is SP and onto function, σ profile, then $\left[\forall i \in N, a \succ_{\sigma_i} b \right] \Rightarrow f(\sigma) \neq b$
- Let us assume that $m \geq n$, and **neutrality:**
 $f(\pi(\sigma)) = \pi(f(\sigma))$ for all $\pi: A \rightarrow A$

PROOF SKETCH OF G-S

- Say $n = 4$ and $A = \{a, b, c, d, e\}$
- Consider the following profile

$\sigma =$

1	2	3	4
a	b	c	d
b	c	d	a
c	d	a	b
d	a	b	c
e	e	e	e

- Unanimity $\Rightarrow e$ is not the winner
- Suppose $f(\sigma) = a$

PROOF SKETCH OF G-S

1	2	3	4
<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>
<i>b</i>	<i>c</i>	<i>d</i>	<i>a</i>
<i>c</i>	<i>d</i>	<i>a</i>	<i>b</i>
<i>d</i>	<i>a</i>	<i>b</i>	<i>c</i>
<i>e</i>	<i>e</i>	<i>e</i>	<i>e</i>

σ

1	2	3	4
<i>a</i>	<i>d</i>	<i>d</i>	<i>d</i>
<i>d</i>	<i>a</i>	<i>a</i>	<i>a</i>
<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>
<i>c</i>	<i>c</i>	<i>c</i>	<i>c</i>
<i>e</i>	<i>e</i>	<i>e</i>	<i>e</i>

σ^1

- Strong monotonicity $\Rightarrow f(\sigma^1) = a$

PROOF SKETCH OF G-S

1	2	3	4
<i>a</i>	<i>d</i>	<i>d</i>	<i>d</i>
<i>d</i>	<i>a</i>	<i>a</i>	<i>a</i>
<i>b</i>	<i>b</i>	<i>b</i>	<i>b</i>
<i>c</i>	<i>c</i>	<i>c</i>	<i>c</i>
<i>e</i>	<i>e</i>	<i>e</i>	<i>e</i>

σ^1

1	2	3	4
<i>a</i>	<i>d</i>	<i>d</i>	<i>d</i>
<i>d</i>	<i>b</i>	<i>a</i>	<i>a</i>
<i>b</i>	<i>c</i>	<i>b</i>	<i>b</i>
<i>c</i>	<i>e</i>	<i>c</i>	<i>c</i>
<i>e</i>	<i>a</i>	<i>e</i>	<i>e</i>

σ^2

Poll 2

How many options are there for $f(\sigma^2)$?

- 1 option
- 2 options
- 3 options
- 4 options



PROOF SKETCH OF G-S

1	2	3	4
<i>a</i>	<i>d</i>	<i>d</i>	<i>d</i>
<i>d</i>	<i>b</i>	<i>a</i>	<i>a</i>
<i>b</i>	<i>c</i>	<i>b</i>	<i>b</i>
<i>c</i>	<i>e</i>	<i>c</i>	<i>c</i>
<i>e</i>	<i>a</i>	<i>e</i>	<i>e</i>

σ^2

1	2	3	4
<i>a</i>	<i>d</i>	<i>d</i>	<i>d</i>
<i>d</i>	<i>b</i>	<i>b</i>	<i>a</i>
<i>b</i>	<i>c</i>	<i>c</i>	<i>b</i>
<i>c</i>	<i>e</i>	<i>e</i>	<i>c</i>
<i>e</i>	<i>a</i>	<i>a</i>	<i>e</i>

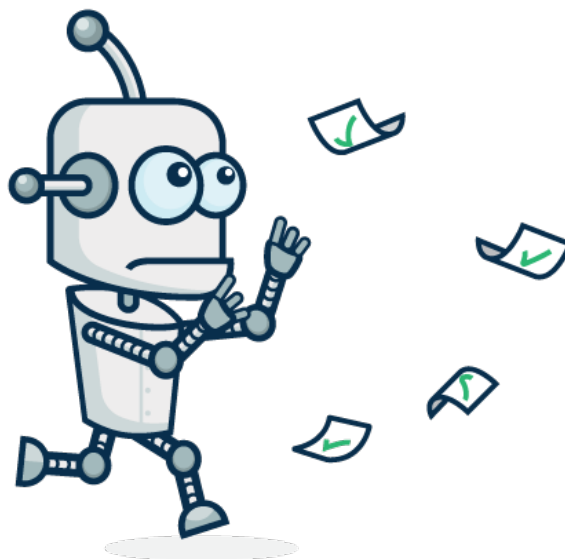
σ^3

1	2	3	4
<i>a</i>	<i>d</i>	<i>d</i>	<i>d</i>
<i>d</i>	<i>b</i>	<i>b</i>	<i>b</i>
<i>b</i>	<i>c</i>	<i>c</i>	<i>c</i>
<i>c</i>	<i>e</i>	<i>e</i>	<i>e</i>
<i>e</i>	<i>a</i>	<i>a</i>	<i>a</i>

σ^4

- Unanimity $\Rightarrow f(\sigma^j) \notin \{b, c, e\}$
- $[\text{SP} \Rightarrow f(\sigma^j) \neq d] \Rightarrow f(\sigma^j) = a$
- Strong monotonicity $\Rightarrow f(\sigma) = a$ for every σ where 1 ranks *a* first
- Neutrality $\Rightarrow$ 1 is a dictator ■

HARDNESS OF MANIPULATION



Manipulation may be unavoidable in theory, but we can we design “reasonable” voting rules where manipulation is computationally hard?

THE COMPUTATIONAL PROBLEM

- f -MANIPULATION problem:
 - Given votes of nonmanipulators and a preferred alternative p
 - Can manipulator cast vote that makes p **uniquely** win under f ?
- Example: Borda, $p = a$

1	2	3
b	b	
a	a	
c	c	
d	d	

1	2	3
b	b	a
a	a	c
c	c	d
d	d	b

A GREEDY ALGORITHM

- Rank p in first place
- While there are unranked alternatives:
 - If there is an alternative that can be placed in next spot without preventing p from winning, place this alternative
 - Otherwise return false

EXAMPLE: BORDA

1	2	3	1	2	3	1	2	3
<i>b</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>b</i>	<i>a</i>
<i>a</i>	<i>a</i>		<i>a</i>	<i>a</i>	<i>b</i>	<i>a</i>	<i>a</i>	<i>c</i>
<i>c</i>	<i>c</i>		<i>c</i>	<i>c</i>		<i>c</i>	<i>c</i>	
<i>d</i>	<i>d</i>		<i>d</i>	<i>d</i>		<i>d</i>	<i>d</i>	

1	2	3	1	2	3	1	2	3
<i>b</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>b</i>	<i>a</i>
<i>a</i>	<i>a</i>	<i>c</i>	<i>a</i>	<i>a</i>	<i>c</i>	<i>a</i>	<i>a</i>	<i>c</i>
<i>c</i>	<i>c</i>	<i>b</i>	<i>c</i>	<i>c</i>	<i>d</i>	<i>c</i>	<i>c</i>	<i>d</i>
<i>d</i>	<i>d</i>		<i>d</i>	<i>d</i>		<i>d</i>	<i>d</i>	<i>b</i>

EXAMPLE: LLULL

1	2	3	4	5
<i>a</i>	<i>b</i>	<i>e</i>	<i>e</i>	<i>a</i>
<i>b</i>	<i>a</i>	<i>c</i>	<i>c</i>	
<i>c</i>	<i>d</i>	<i>b</i>	<i>b</i>	
<i>d</i>	<i>e</i>	<i>a</i>	<i>a</i>	
<i>e</i>	<i>c</i>	<i>d</i>	<i>d</i>	

Preference profile

	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>
<i>a</i>	-	2	3	5	3
<i>b</i>	3	-	2	4	2
<i>c</i>	2	2	-	3	1
<i>d</i>	0	0	1	-	2
<i>e</i>	2	2	3	2	-

Pairwise comparisons

EXAMPLE: LLULL

1	2	3	4	5
<i>a</i>	<i>b</i>	<i>e</i>	<i>e</i>	<i>a</i>
<i>b</i>	<i>a</i>	<i>c</i>	<i>c</i>	<i>c</i>
<i>c</i>	<i>d</i>	<i>b</i>	<i>b</i>	
<i>d</i>	<i>e</i>	<i>a</i>	<i>a</i>	
<i>e</i>	<i>c</i>	<i>d</i>	<i>d</i>	

Preference profile

	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>
<i>a</i>	-	2	3	5	3
<i>b</i>	3	-	2	4	2
<i>c</i>	2	3	-	4	2
<i>d</i>	0	0	1	-	2
<i>e</i>	2	2	3	2	-

Pairwise comparisons

EXAMPLE: LLULL

1	2	3	4	5
<i>a</i>	<i>b</i>	<i>e</i>	<i>e</i>	<i>a</i>
<i>b</i>	<i>a</i>	<i>c</i>	<i>c</i>	<i>c</i>
<i>c</i>	<i>d</i>	<i>b</i>	<i>b</i>	<i>d</i>
<i>d</i>	<i>e</i>	<i>a</i>	<i>a</i>	
<i>e</i>	<i>c</i>	<i>d</i>	<i>d</i>	

Preference profile

	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>
<i>a</i>	-	2	3	5	3
<i>b</i>	3	-	2	4	2
<i>c</i>	2	3	-	4	2
<i>d</i>	0	1	1	-	3
<i>e</i>	2	2	3	2	-

Pairwise comparisons

EXAMPLE: LLULL

1	2	3	4	5
<i>a</i>	<i>b</i>	<i>e</i>	<i>e</i>	<i>a</i>
<i>b</i>	<i>a</i>	<i>c</i>	<i>c</i>	<i>c</i>
<i>c</i>	<i>d</i>	<i>b</i>	<i>b</i>	<i>d</i>
<i>d</i>	<i>e</i>	<i>a</i>	<i>a</i>	<i>e</i>
<i>e</i>	<i>c</i>	<i>d</i>	<i>d</i>	

Preference profile

	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>
<i>a</i>	-	2	3	5	3
<i>b</i>	3	-	2	4	2
<i>c</i>	2	3	-	4	2
<i>d</i>	0	1	1	-	3
<i>e</i>	2	3	3	2	-

Pairwise comparisons

EXAMPLE: LLULL

1	2	3	4	5
<i>a</i>	<i>b</i>	<i>e</i>	<i>e</i>	<i>a</i>
<i>b</i>	<i>a</i>	<i>c</i>	<i>c</i>	<i>c</i>
<i>c</i>	<i>d</i>	<i>b</i>	<i>b</i>	<i>d</i>
<i>d</i>	<i>e</i>	<i>a</i>	<i>a</i>	<i>e</i>
<i>e</i>	<i>c</i>	<i>d</i>	<i>d</i>	<i>b</i>

Preference profile

	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>
<i>a</i>	-	2	3	5	3
<i>b</i>	3	-	2	4	2
<i>c</i>	2	3	-	4	2
<i>d</i>	0	1	1	-	3
<i>e</i>	2	3	3	2	-

Pairwise comparisons

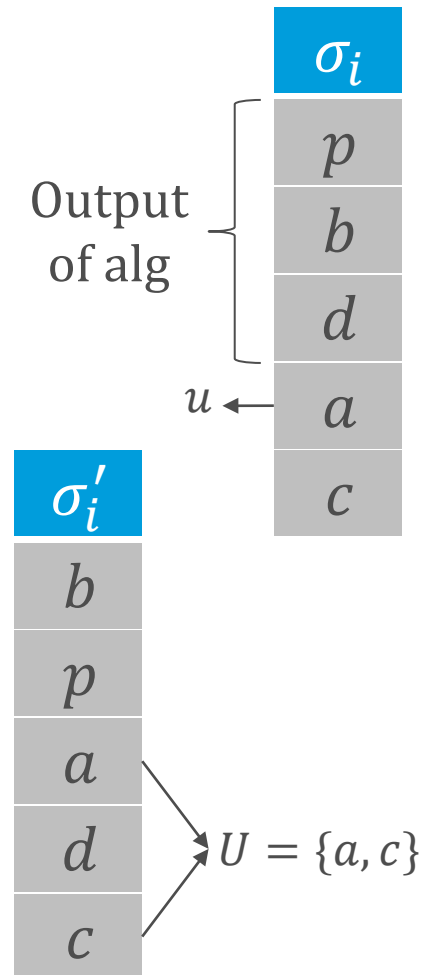
WHEN DOES THE ALG WORK?

- **Theorem:** Fix $i \in N$ and the votes of other voters. Let f be a rule s.t. $\exists$ function $s(\sigma_i, x)$ such that:
 1. For every σ_i , f chooses an alternative that **uniquely** maximizes $s(\sigma_i, x)$
 2. $\{y: y \prec_{\sigma_i} x\} \subseteq \{y: y \prec_{\sigma'_i} x\} \Rightarrow s(\sigma_i, x) \leq s(\sigma'_i, x)$

Then the greedy algorithm decides the f -MANIPULATION problem correctly

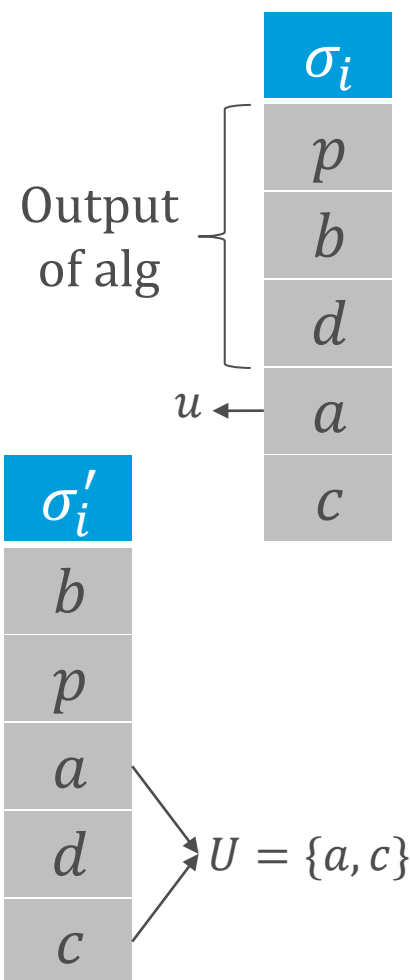
PROOF OF THEOREM

- Suppose the algorithm failed, producing a partial ranking σ_i
- Assume for contradiction σ'_i makes p win
- $U \leftarrow$ alternatives not ranked in σ_i
- $u \leftarrow$ highest ranked alternative in U according to σ'_i
- Complete σ_i by adding u first, then others arbitrarily

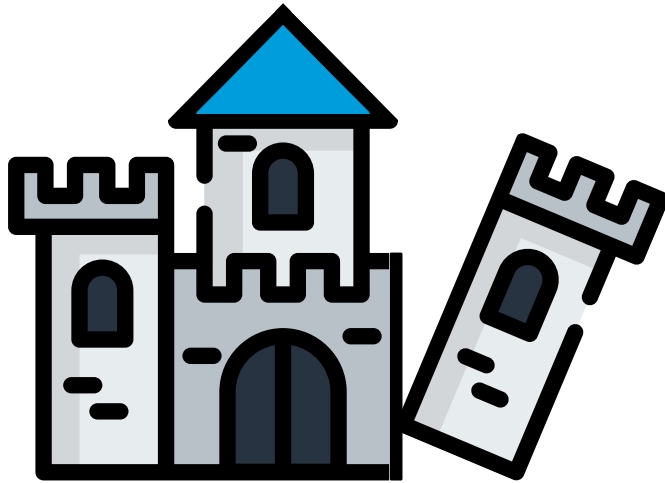


PROOF OF THEOREM

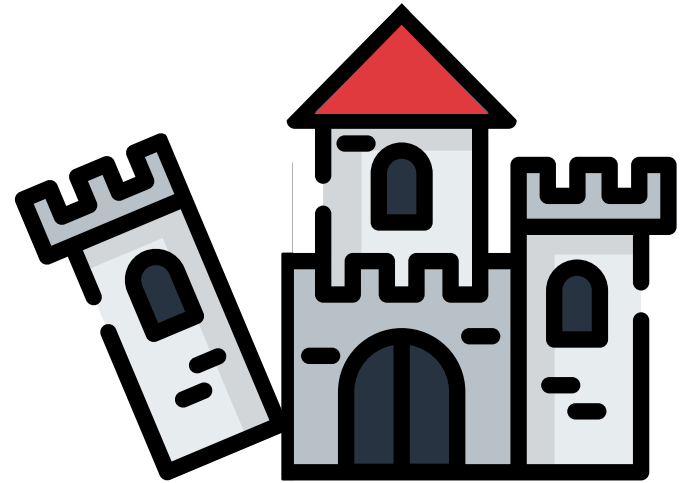
- Property 2 $\Rightarrow s(\sigma_i, p) \geq s(\sigma'_i, p)$
- Property 1 and σ'_i makes p the winner $\Rightarrow s(\sigma'_i, p) > s(\sigma'_i, u)$
- Property 2 $\Rightarrow s(\sigma'_i, u) \geq s(\sigma_i, u)$
- Conclusion: $s(\sigma_i, p) > s(\sigma_i, u)$, so the alg could have inserted u next ■



HARD-TO-MANIPULATE RULES



Single Transferable Vote



Llull (w. tie breaking)

But worst-case hardness isn't necessarily an obstacle to manipulation in the average case!

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