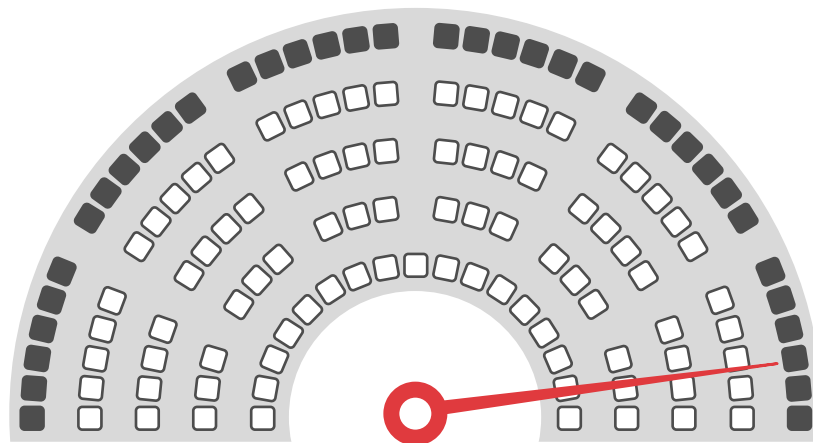




# *Optimized Democracy*

Spring 2022 | Lecture 4

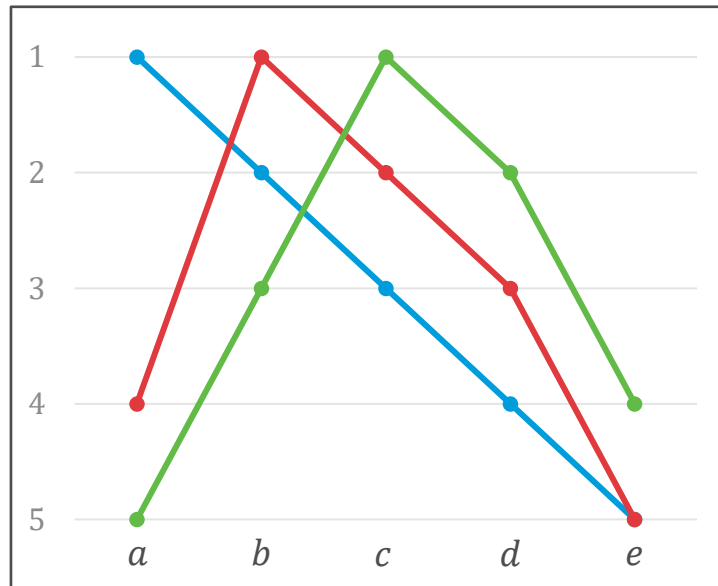
**Restricted Preferences**

Ariel Procaccia | Harvard University

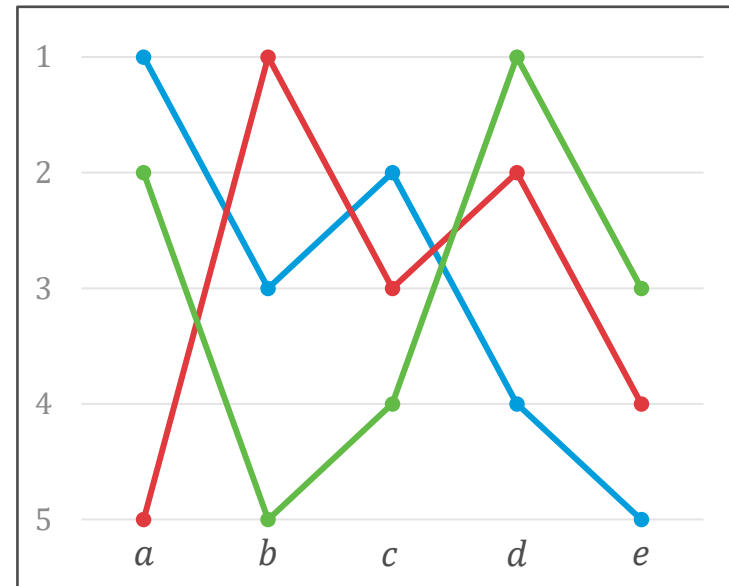
# SINGLE-PEAKED PREFERENCES

- The Gibbard-Satterthwaite Theorem requires a full preference domain, i.e., each ranking of the alternatives is possible
- Can we circumvent the theorem if we restrict the preferences in reasonable ways?
- Assume an ordering  $\leq$  over the set of alternatives  $A$
- Voter  $i$  has **single-peaked preferences** if there is a **peak**  $x^* \in A$  such that  $y < z \leq x^* \Rightarrow z \succ_{\sigma_i} y$  and  $y > z \geq x^* \Rightarrow z \succ_{\sigma_i} y$

# SINGLE-PEAKED PREFERENCES

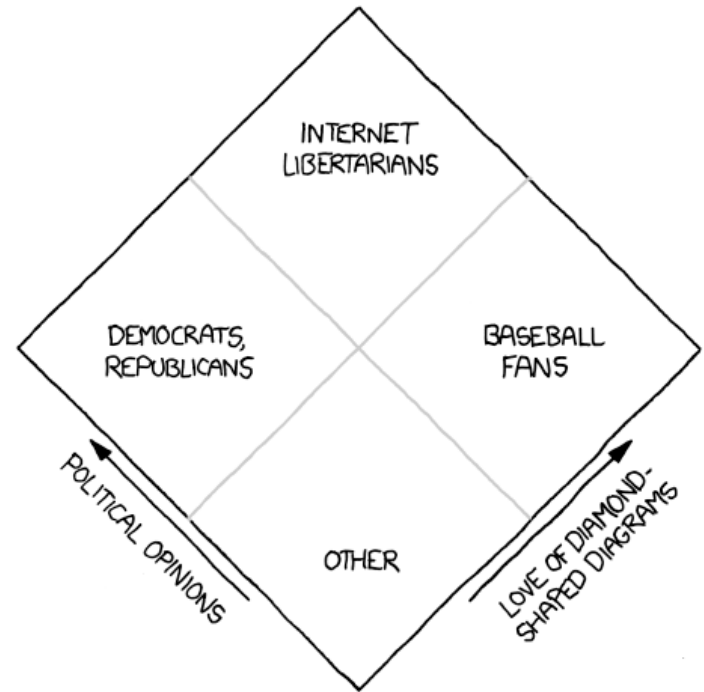
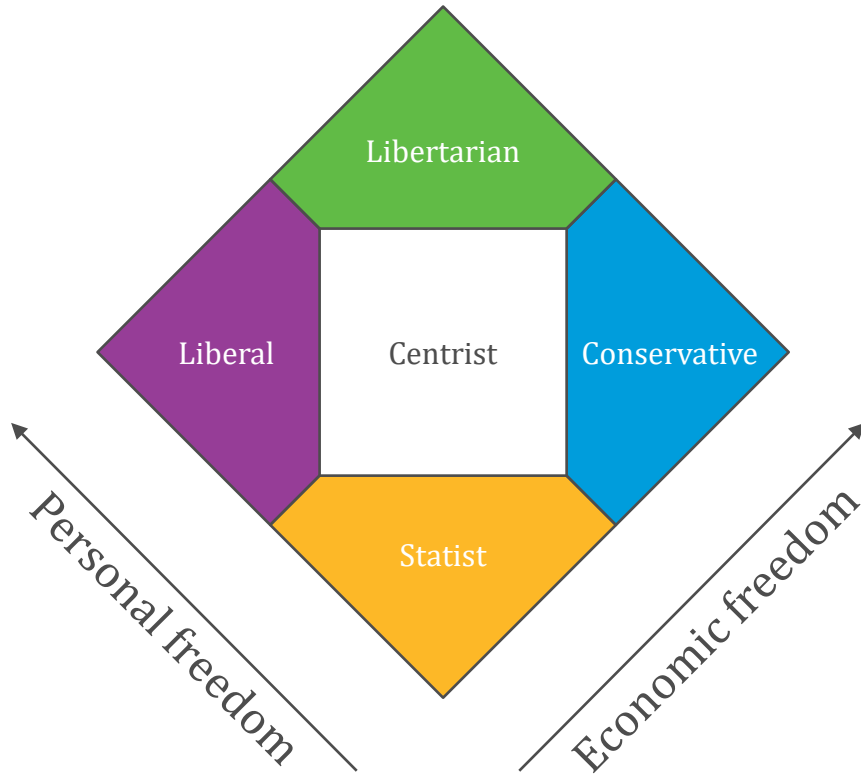


Single peaked



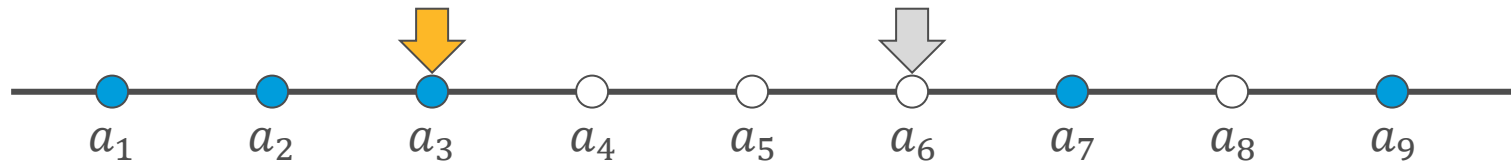
Not single peaked

# EXAMPLE: NOLAN CHART

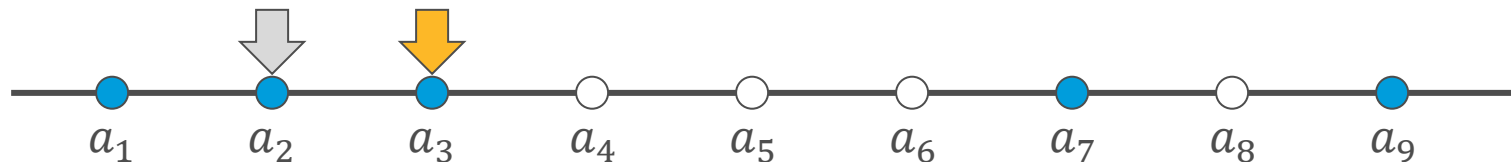


# SINGLE-PEAKED PREFERENCES

- Assume an odd number of voters with single-peaked preferences, then a Condorcet winner exists, and is given by the median peak



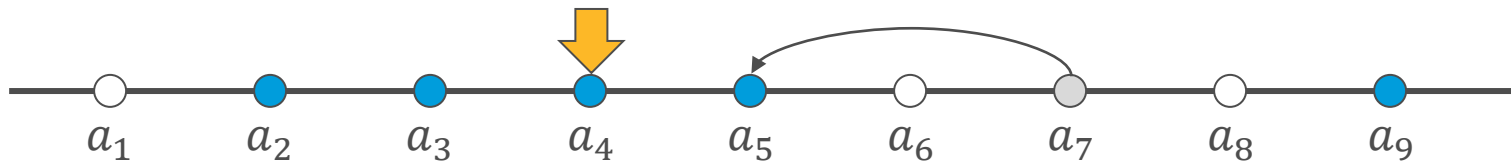
A majority of voters prefer the median to any alternative to its right



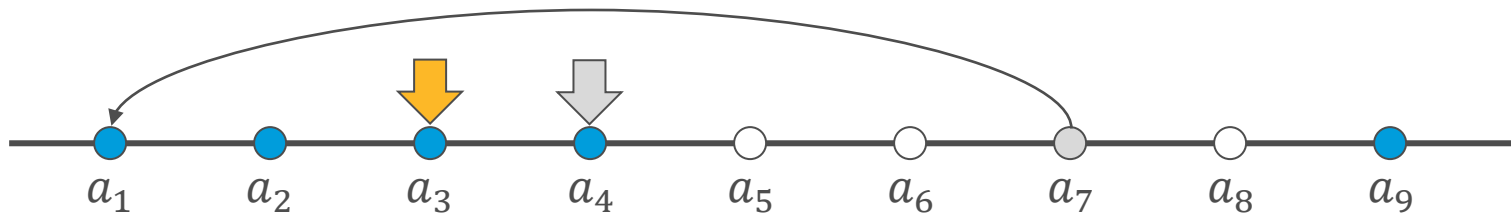
A majority of voters prefer the median to any alternative to its left

# STRATEGYPROOF RULES

- Assume voters with single-peaked preferences, then the voting rule that selects the median peak is strategyproof



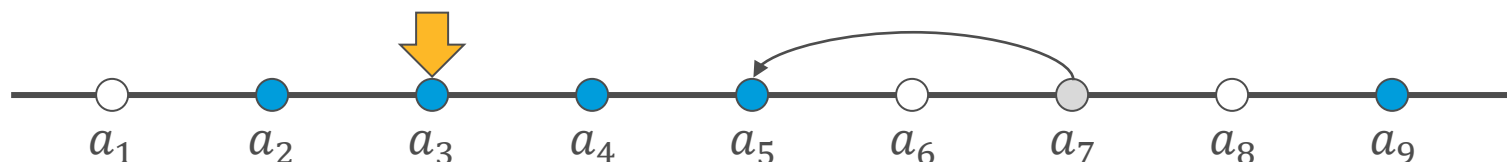
Reporting another peak on the same side of the median makes no difference



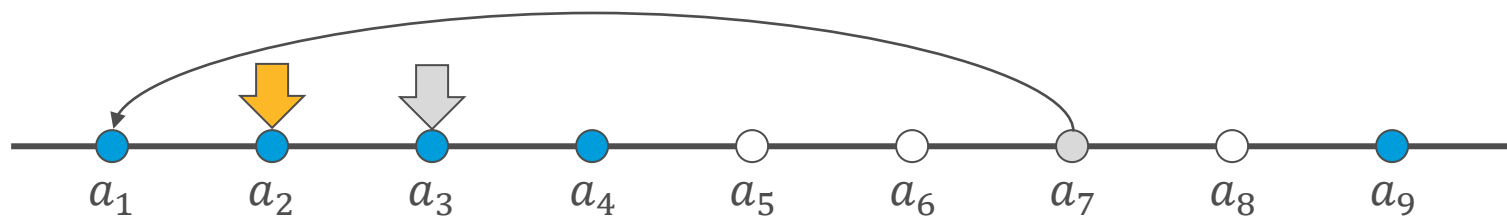
Reporting another peak on the other side of the median make things worse

# STRATEGYPROOF RULES

- Assume voters with single-peaked preferences, then the voting rule that selects the  $k$ th order statistic is strategyproof



Reporting another peak on the same side of the 2<sup>nd</sup> order statistic makes no difference



Reporting another peak on the other side of the 2<sup>nd</sup> order statistic make things worse

# STRATEGYPROOF RULES

- For single-peaked preferences  $\sigma_i$ , denote the peak by  $P(\sigma_i)$
- **Theorem [Moulin 1980]:** An anonymous voting rule on single-peaked preferences is SP if and only if there exist  $p_1, \dots, p_{n+1} \in A$  (called **phantoms**) such that, for every profile  $\sigma$ ,

$$f(\sigma) = \text{med}(p_1, \dots, p_{n+1}, P(\sigma_1), \dots, P(\sigma_n))$$

- Examples:
  - Median (odd  $n$ ):  $(n + 1)/2$  phantoms at each of  $a_1$  and  $a_m$
  - Second order statistic:  $n - 1$  phantoms at  $a_1$ , two at  $a_m$
  - $f \equiv x$  (constant function):  $n + 1$  phantoms at  $x$

# FACILITY LOCATION

- Each **player**  $i \in N$  has a **location**  $x_i \in \mathbb{R}$
- Given  $\mathbf{x} = (x_1, \dots, x_n)$ , choose a facility location  $f(\mathbf{x}) = y \in \mathbb{R}$
- $\text{cost}(y, x_i) = |y - x_i|$
- This defines (very specific) single-peaked preferences over the set of alternatives  $\mathbb{R}$ , where the peak of player  $i$  is  $x_i$

# FACILITY LOCATION

- Two objective functions
  - **Social cost:**  $sc(y, \mathbf{x}) = \sum_{i \in N} |y - x_i|$
  - **Maximum cost:**  $mc(y, \mathbf{x}) = \max_{i \in N} |y - x_i|$
- For the social cost objective, the median is optimal and SP

## Question

What is the optimal solution for the max cost objective? Is it SP?



# DETERMINISTIC RULES FOR MC

- We say that a deterministic rule  $f$  gives an  $\alpha$ -approximation to the max cost if for all  $\mathbf{x} \in \mathbb{R}^n$ ,

$$\text{mc}(f(\mathbf{x}), \mathbf{x}) \leq \alpha \cdot \min_{y \in \mathbb{R}} \text{mc}(y, \mathbf{x})$$

## Poll 1

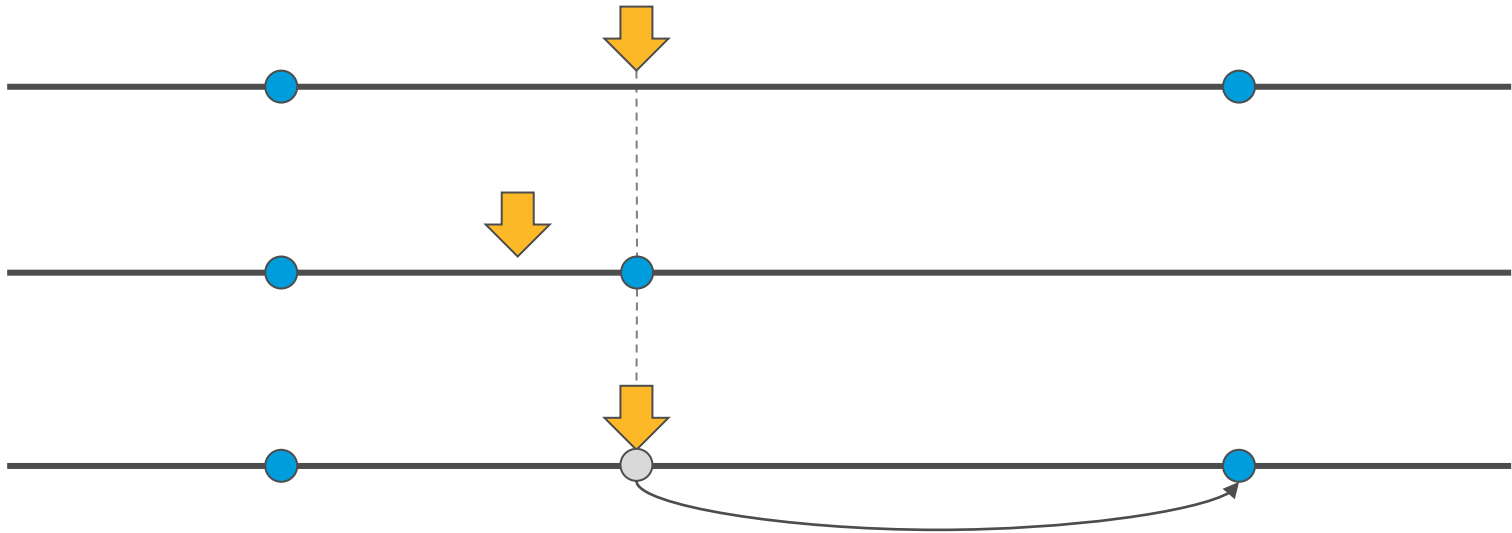
Approximation ratio of the median to max cost?

- In  $[1,2)$
- In  $[2,3)$
- In  $[3,4)$
- In  $[4, \infty)$



# DETERMINISTIC RULES FOR MC

- **Theorem:** No deterministic SP rule has an approximation ratio  $< 2$  to the max cost
- **Proof:**



# RANDOMIZED RULES FOR MC

- We say that a randomized rule  $f$  gives an  **$\alpha$ -approximation** to the max cost if for all  $\mathbf{x} \in \mathbb{R}^n$ ,  
$$\mathbb{E}[\text{mc}(f(\mathbf{x}), \mathbf{x})] \leq \alpha \cdot \min_{y \in \mathbb{R}} \text{mc}(y, \mathbf{x})$$
- **The Left-Right-Middle (LRM) rule:** Choose  $\min x_i$  with prob.  $\frac{1}{4}$ ,  $\max x_i$  with prob.  $\frac{1}{4}$ , and their average with prob.  $\frac{1}{2}$

## Poll 2

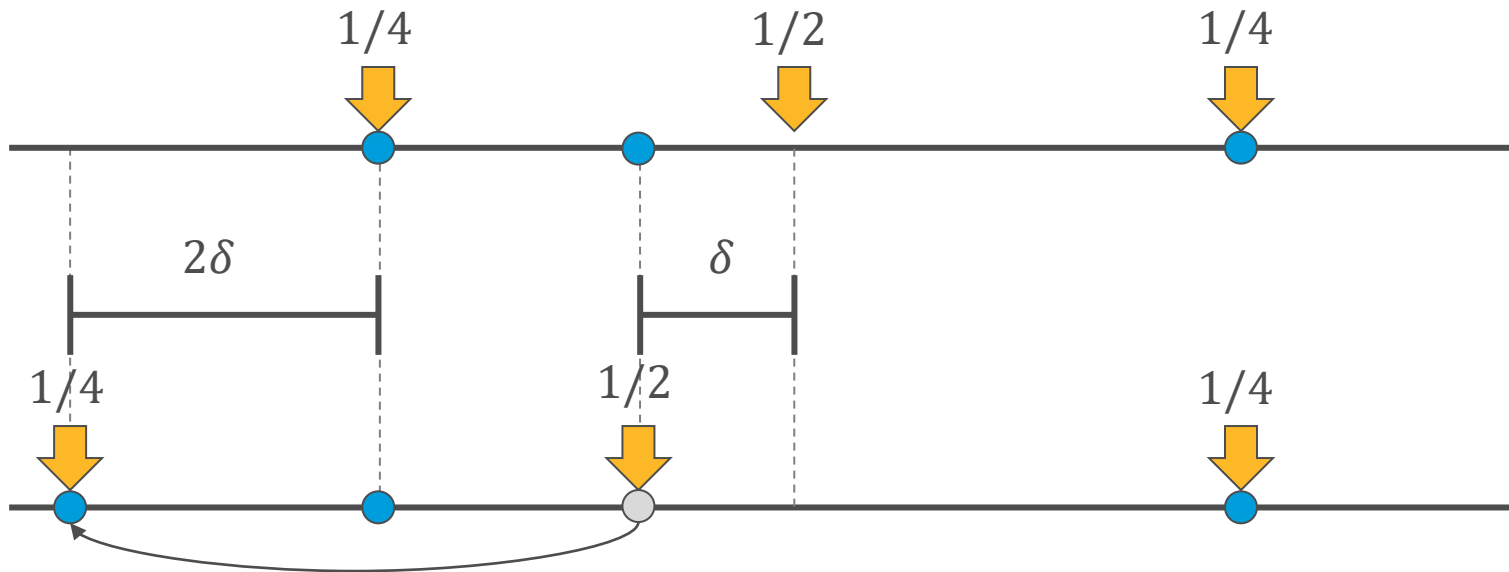
Approximation ratio of LRM to max cost?

- |         |         |
|---------|---------|
| • $5/4$ | • $7/4$ |
| • $3/2$ | • $2$   |



# RANDOMIZED RULES FOR MC

- **Theorem:** LRM is SP (in expectation)
- **Proof:**



# RANDOMIZED RULES FOR MC

- **Theorem:** No randomized SP mechanism has an approximation ratio  $< 3/2$
- **Proof:**
  - $x_1 = 0, x_2 = 1, f(\mathbf{x}) = P$
  - $\text{cost}(P, x_1) + \text{cost}(P, x_2) \geq 1$ ; w.l.o.g. assume that  $\text{cost}(P, x_2) \geq 1/2$
  - $x_1 = 0, x'_2 = 2$ ; by SP, the expected distance from  $x_2 = 1$  is at least  $1/2$
  - Expected max cost at least  $3/2$ , because for every  $y \in \mathbb{R}$ , the maximum cost is  $|y - 1| + 1$  ■

# BIBLIOGRAPHY

H. Moulin. **On Strategy-Proofness and Single-Peakedness.** Public Choice, 1980.

A. D. Procaccia and M. Tennenholtz. **Approximate Mechanism Design Without Money.** ACM Transactions on Economics and Computation, 2013.

