AI for collective decision making

Jérôme Lang
LAMSADE, CNRS, Université Paris-Dauphine, PSL

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Collective decision making

- Social choice : *designing and analysing methods for collective decision making*
  - finding a date for a meeting.
  - deciding of a set of collective projects to fund.
  - deciding how to divide a budget between projects, party lists, etc.
  - in a high school : deciding who gets which class and who teaches when.
  - in a company : finding a partition of employees in groups of people who will work together.
  - assigning students to universities (*Parcoursup* etc.).
  - deciding which Covid-19 patients should get a vaccine.
  - in crowdsourcing : aggregate labels given by different individuals.
  - aggregate ranked lists of web pages given by different search engines

Collective decision making

- Social choice : *designing and analysing methods for collective decision making*
  - finding a date for a meeting. Voting
  - deciding of a set of collective projects to fund. Multiwinner voting
  - deciding how to divide a budget between projects, party lists, etc. Portioning
  - in a high school : deciding who gets which class and who teaches when. Fair division
  - in a company : finding a partition of employees in groups of people who will work together. Coalition structure formation
  - assigning students to universities (*Parcoursup* etc.). Matching
  - deciding which Covid-19 patients should get a vaccine. Matching

  ↑ aggregating preferences

  ↓ aggregating beliefs

  - in crowdsourcing : aggregate labels given by different individuals. Belief/judgment aggregation
  - aggregate ranked lists of web pages given by different search engines

Social choice rules

- input : agents have preferences over possible alternatives
- output : an alternative

What are the alternatives ?

- in voting : candidates, or sets of candidates
- in fair division : assignments from resources to agents
- in matching : assignment of agents of class 1 (students) to agents of class 2 (universities)
- in coalition formation : agents have preferences over sets of agents, an alternative is a partition of agents into groups
- in portioning : a division of a total budget between projects, lists etc.

Social rules must be

- designed
- studied axiomatically (which properties do they satisfy ?).
- computed (communication protocols + algorithms)

Axioms give guarantee on the behaviour of the rule. They are a way of ensuring some fairness or other ethical guarantees.

A very rough history of social choice

1. end of 18th century : early stage, with Condorcet and Borda (Journées plénières du GDR IA 1789, Versailles)
2. 1951 : birth of modern social choice
   - results are mainly *axiomatic* (economics/mathematics)
     - impossibility theorems : *incompatibility of a small set of seemingly innocuous conditions*, such as Arrow's theorem :

       With at least 3 candidates, an aggregation function satisfies *unanimity* and *independence of irrelevant alternatives* if and only if it is a *dictatorship*.
   - computational issues are neglected
3. from the 90's : computer scientists come into play

   ⇒ **Computational social choice** : using computational notions and techniques (mainly from Artificial Intelligence, Operations Research, Theoretical Computer Science) for solving complex collective decision making problems.

Example 1 : Participatory budgeting

- a set of candidate projects, each of which with a cost
- a maximal budget
- voters vote on projects

$\longrightarrow$ select a set of projects

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$\longrightarrow$ **select** a set of projects **(yes but how ?)**

Participatory budgeting in Paris

(Until 2020) Each citizen can vote for :

- at most 4 projects of their district
- and at most 4 projects concerning all of Paris

(2021 : each citizen can evaluate every project on a qualitative scale, but this is irrelevant to what follows.)

Participatory budgeting in Paris

They use the **greedy method** :

- each district has its maximal budget ;
- projects are ranked by decreasing number of votes ...
- ... and are funded as long as the budget is not exhausted
- while respecting some quotas for low-income neighbourhoods

	cost	**votes**	**select ?**
Amélioration de la cour du Collège Charlemagne	350 000	1 066	yes
Rénovation de la fontaine Niki de Saint Phalle	900 000	996	yes
Aménagement du préau de l'école (...)	325 000	825	yes
Aménagement des balcons terrasses de l'école (...)	150 000	807	–
Un arbre de la laïcité dans le 4eme arrondissement	5 000	756	–
Valorisation de la rue de Venise (...)	20 000	740	–
Des vidéoprojecteurs interactifs pour l'école (...)	18 000	591	–
Création de mezzanines de stockage à l'école (...)	150 000	404	–

Fourth district, 2018. Thanks : Dominik Peters

Participatory budgeting

Greedy vs. global

	vote for
17 voters	A and B
17 voters	A and C
17 voters	A and D
17 voters	B and C
16 voters	B and D
16 voters	C and D

	cost	**votes**	**greedy**
A	50	51	yes
B	20	50	–
C	20	50	–
D	20	49	–

maximal budget : 60

Greedy algorithm :

- 49 voters see no project funded for which they voted
- dictatorship of majority, not fair, not proportional

Participatory budgeting

Greedy vs. global

	vote for
17 voters	A and B
17 voters	A and C
17 voters	A and D
17 voters	B and C
16 voters	B and D
16 voters	C and D

	cost	**votes**	**greedy.**	**global**
A	50	51	oyesui	–
B	20	50	–	yes
C	20	50	–	yes
D	20	49	–	yes

maximal budget : 60

Global algorithm :

- for each voter wo voted for a funded project : a point
- selection of projects to fund : the feasible set of projects that has the largest set of points
- select {A} : 51 points ; select {B, C, D} : 149 points
- global algorithm is more fair, more proportional (yes but ?)

(A strong form of) proportionality : if α% of the population agrees on a set of projects P representing at most α% of the total budget, then the selection should satisfy them at least as much as P.

Participatory budgeting in Paris

	cost	votes	gr.	gl.
Amélioration de la cour du Collège Charlemagne	350 000	1 066	yes	yes
Rénovation de la fontaine Niki de Saint Phalle	900 000	996	yes	–
Aménagement du préau de l'école (...)	325 000	825	yes	yes
Aménagement des balcons terrasses de l'école (...)	150 000	807	–	yes
Un arbre de la laïcité dans le 4eme arrondissement	5 000	756	–	yes
Valorisation de la rue de Venise (...)	20 000	740	–	yes
Des vidéoprojecteurs interactifs pour l'école (...)	18 000	591	–	yes
Création de mezzanines de stockage à l'école (...)	150 000	404	–	yes

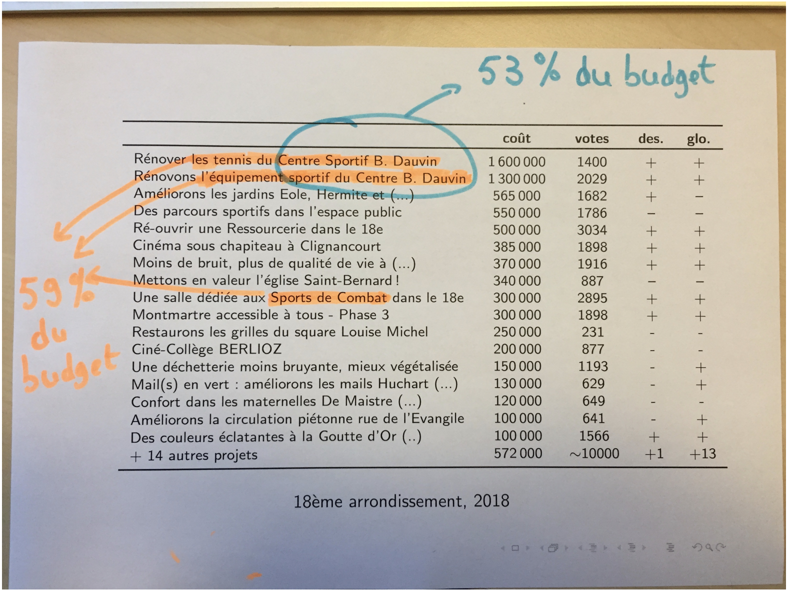
Fourth district, 2018. Thanks : Dominik Peters

Participatory budgeting in Paris

	cost	votes	gr.	gl.
Rénover les tennis du Centre Sportif Dauvin	1.6M	1400	+	+
Rénovons l'équipement sportif du Centre Dauvin	1.3M	2029	+	+
Améliorons les jardins Eole, Hermite and (...)	565 000	1682	+	−
Des parcours sportifs dans l'espace public	550 000	1786	−	−
Ré-ouvrir une Ressourcerie dans le 18e	500 000	3034	+	+
Cinéma sous chapiteau à Clignancourt	385 000	1898	+	+
Moins de bruit, plus de qualité de vie à (...)	370 000	1916	+	+
Mettons en valeur l'église Saint-Bernard !	340 000	887	−	−
Une salle dédiée aux sports de combat	300 000	2895	+	+
Montmartre accessible à tous - Phase 3	300 000	1898	+	+
Restaurons les grilles du square Louise Michel	250 000	231	-	-
Ciné-Collège BERLIOZ	200 000	877	-	-
Une déchetterie moins bruyante (...)	150 000	1193	-	+
Mail(s) en vert : améliorons les mails Huchart (...)	130 000	629	-	+
Confort dans les maternelles De Maistre (...)	120 000	649	-	-
Améliorons la circulation piétonne rue de (...)	100 000	641	-	+
Des couleurs éclatantes à la Goutte d'Or (..)	100 000	1566	+	+
+ 14 other projects	572 000	∼10000	+1	+13

18th district, 2018. Thanks : Dominik Peters

Participatory budgeting in Paris



	coût	votes	des.	glo.
Rénover les tennis du Centre Sportif B. Dauvin	1 600 000	1400	+	+
Rénovons l'équipement sportif du Centre B. Dauvin	1 300 000	2029	+	+
Améliorons les jardins Eole, Hermite et (...)	565 000	1682	+	–
Des parcours sportifs dans l'espace public	550 000	1786	–	–
Ré-ouvrir une Ressourcerie dans le 18e	500 000	3034	+	+
Cinéma sous chapiteau à Clignancourt	385 000	1898	+	+
Moins de bruit, plus de qualité de vie à (...)	370 000	1916	+	+
Mettons en valeur l'église Saint-Bernard !	340 000	887	–	–
Une salle dédiée aux Sports de Combat dans le 18e	300 000	2895	+	+
Montmartre accessible à tous - Phase 3	300 000	1898	+	+
Restaurons les grilles du square Louise Michel	250 000	231	-	-
Ciné-Collège BERLIOZ	200 000	877	-	-
Une déchetterie moins bruyante, mieux végétalisée	150 000	1193	-	+
Mail(s) en vert : améliorons les mails Huchart (...)	130 000	629	-	+
Confort dans les maternelles De Maistre (...)	120 000	649	-	-
Améliorons la circulation piétonne rue de l'Evangile	100 000	641	-	+
Des couleurs éclatantes à la Goutte d'Or (..)	100 000	1566	+	+
+ 14 autres projets	572 000	~10000	+1	+13

18ème arrondissement, 2018

Participatory budgeting and proportionality

	vote for
60 voters	A B C
30 voters	D

	cost	**votes**	**greedy**	**global**
A	20	60	yes	yes
B	20	60	yes	yes
C	20	60	yes	yes
D	20	30	–	–

budget : 60

Participatory budgeting and proportionality

	vote for
60 voters	A B C
30 voters	D

	vote for
30 voters	A B
30 voters	B C
30 voters	A C D

	cost	**votes**	**greedy**	**global**
A	20	60	yes	yes
B	20	60	yes	yes
C	20	60	yes	yes
D	20	30	–	–

budget : 60

Participatory budgeting : proportional approval voting

- for each voter i and each selection of projects S : if i votes k projects in S then S receives $1 + 1/2 + \ldots + 1/k$ points.
- the feasible subset of projects with maximal global score wins.

	vote for
60 voters	A B C
30 voters	D

	cost	greedy/global	PAV
A	20	yes	yes
B	20	yes	yes
C	20	yes	-
D	20	–	yes

budget : 60

Participatory budgeting : proportional approval voting

- for each voter i and each selection of projects S : if i votes k projects in S then S receives $1 + 1/2 + \ldots + 1/k$ points.
- the feasible subset of projects with maximal global score wins.

	vote for
60 voters	A B C
30 voters	D

	cost	greedy/global	PAV
A	20	yes	yes
B	20	yes	yes
C	20	yes	-
D	20	–	yes

budget : 60

	vote for
30 voters	A B
30 voters	B C
30 voters	A C D

	cost	greedy/global	PAV
A	20	yes	yes
B	20	yes	yes
C	20	yes	yes
D	20	–	–

budget : 60

Participatory budgeting : proportional approval voting

	vote for
60 voters	A B C
30 voters	D

	cost	greedy/global	PAV
A	20	yes	yes
B	20	yes	yes
C	20	yes	-
D	20	–	yes

budget : 60

	vote for
60 voters	A B C
30 voters	D

	cost	greedy/global	PAV
A	10	yes	yes
B	10	yes	yes
C	10	yes	-
D	40	–	yes

budget : 60

Is PAV fair ?

Participatory budgeting : the equal shares rule

Input :

- projects : $P = \{p_1, \ldots, p_m\}$; for each j, $cost(p_j) \in (0, 1]$ (maximum budget : 1)
- voters $N = \{1, \ldots, n\}$ with approval ballots $A_i \subseteq P$ for each i.

Algorithm :

- each voter i is initially given budget $b_i = 1/n$
- $W := \emptyset$
- sequentially add projects to W, and have voters pay for them :
  - if $cost(p) > \sum_{i \in N, p \in A_i} b_i$ for all $p \in P \setminus W$
  - then stop and return W
  - else find a minimum ρ such that for some $p \in P \setminus W$:

$$\sum_{i \in N, p \in A_i} \min\left(b_i, \rho\ cost(p)\right) = cost(p)$$

and for each i such that $p \in A_i$: $b_i := b_i - \min(b_i, \rho\ cost(p))$

(Peters, Pierczyński and Skowron, 2021)

Participatory budgeting rules

	vote for
60 voters	A B C
30 voters	D

	cost	greedy/global	PAV	ES
A	20	yes	yes	yes
B	20	yes	yes	yes
C	20	yes	-	-
D	20	–	yes	yes

budget : 60

	vote for
60 voters	A B C
30 voters	D

	cost	greedy/global	PAV	ES
A	10	yes	yes	yes
B	10	yes	yes	yes
C	10	yes	-	yes
D	40	–	yes	-

budget : 60

Participatory budgeting : not so simple

How to evaluate a participatory budgeting method :

- possible formats for ballots : approvals, rankings ou evaluations ? How to trade-off simplicity and expressivity ?
- how to trade-off fairness to groups (proportionality) and efficiency ?

Example 2 : Allocating scarce resources

How to allocate artificial ventilators when demand exceeds supply ? (And what about vaccines ?) Four big principles :

1. utilitarianism : maximise the sum of individual satisfactions (social welfare).
   1.1 maximise the expected number of lives saved
   1.2 maximiser the expected number of years of life saved
2. *ex ante* egalitarianism : same chances *a priori* to access resources
   2.1 first come, first serve
   2.2 random allocation with uniform probability
3. reward and merit : for instance, give priority to health care workers. Two interpretations :
   - reward for past or future actions
   - maximisation of instrumental value
4. *ex post* egalitarianism, or compensation : priority to patients who have been most disadvantaged until now (i.e., who would have the shortest lives if they are not allocated a ventilator).

Example 2 : Allocating scarce resources

How to allocate artificial ventilators when demand exceeds supply ? (And what about vaccines ?) Four big principles :

1. utilitarianism
2. *ex ante* egalitarianism
3. reward and merit
4. *ex post* egalitarianism

- how to aggregate these four principles ?
- who decides the way to aggregate them ?
  - doctors ?
  - the State ?
  - the cititizens ?
- learning societal preferences ?
  - for kidney exchange : Freedman, Schaich Borg, Sinnott-Armstrong, Dickerson, Conitzer : Adapting a kidney exchange algorithm to align with human values. *Artif. Intell.* (2020)
  - for the trolley problem (→ autonomous cars) : Awad, Dsouza, Bonnefon, Shariff, Rahwan : Crowdsourcing moral machines. *Comm. ACM* 63(3) : 48-55 (2020) `https://www.moralmachine.net/`

Example 3 : Fair division of indivisible items

	a	*b*	*c*	*d*	*e*
Ann	1	1	0	1	0
Bob	1	1	0	1	0
Charles	0	0	1	0	1

Properties of allocations :

envy-freeness: no individual prefers the share of another individual to hers

efficiency: it is not possible to do at least as well for each individual and strictly better for at least one.

	a	*b*	*c*	*d*	*e*
Ann	1	1	0	1	0
Bob	1	1	0	1	0
Charles	0	0	1	0	1

- $[a|bc|de]$: envy-free, but not efficient
- $[a|bd|ce]$ et $[ab|d|ce]$: efficient, but not envy-free,
- etc.
- here, no allocation is both efficient and envy-free

Example 3 : Fair division of indivisible items

- for each individual i, the *maximin fair share* value of i is the value she gives to the worst share of the best possible partition

$$MaxMinFS(i) := \max_{\pi} \min_{j} u_i(\pi(j))$$

	a	b	c	d
Ann	10	5	7	0
Bob	9	6	7	2

- $MaxMinFS(Ann) = 10$
- $MaxMinFS(Bob) = 11$

	a	b	c	d
Ann	10	5	7	0
Bob	9	6	7	2

- π satisfies the *maxmin fair share* property if each individual obtains at least her maxmin fair share value.
- $[bc|ad]$ is maxmin fair share and efficient (but not envy-free)
- for additives preferences, envy-freeness $\Rightarrow$ maxmin fair share

Example 4 : Voting

1. plurality : each voter votes for a single candidate.
2. plurality with runoff ("scrutin majoritaire à deux tours")
3. approval voting : each voter chooses to approve or not each of the candidates ; the candidate with the largest number of approvals wins.
4. voting by evaluation : each voter gives a score to each candidate ; the scores received by a candidate are aggregated...
   - by the sum : range voting (variant : cumulative voting)
   - by the median : majority judgment
5. Borda : each voter ranks all m candidates. Her vote gives $m-1$ points to candidate ranked top ; $m-2$ to the one ranked second, etc.
6. single transferable vote (STV) : each voter ranks all m candidates ;

   Repeat
   - x : candidate ranked top least often
   - x is eliminated from votes {votes for x are "transferred to the voter's preferred candidate among those that have not been eliminated yet }

   Until a candidate y is ranked first in $> 50\%$ of votes.
   Winner : y

7+ many others !

Example 4 : Voting

An important example : clone-proofness

- plurality with runoff is highly vulnerable to cloning :

24	abc	24	$aa'bc$
24	acb	24	$a'acb$
27	bac	27	$baa'c$
25	cab	25	$caa'b$
finalists a, c		finalists b, c	
winner a		winner b	

  But 75 voters prefer a (and a') to b...
- Borda : also vulnerable to cloning, but to a lesser extent
- single transferable vote : clone-proof !

Oneline voting : communication, simplicity, explainability

- plurality with runoff :
  - easy to understand ;
  - low communication cost : each voter sends $\log m$ bits at first round and one bit at second round
- Borda : single round, each voters sends $O(m \log m)$ bits.
- STV :
  - distributed protocol with $m - 1$ rounds : possible but a bit complex to implement
  - simple one-round protocol : each voter sends her ranking $\rightarrow O(m \log m)$ bits
  - quite reasonable
  - Australia, Ireland, many places in the US...

Social acceptability of collective decision mechanisms

- normative properties (included resistance to strategic behaviour)
- simplicity, explainability
- verifiability
- social or political justification of the mechanism.

Matching

- students to universities
- resident to hospitals
- kidney donors to patients
- etc.

Diversity in group formation

1. composing citizen assembly / a cohort of patients / a set of students
2. each group (gender, age, region, professional category etc.) should be represented in proportion of its importance in the population
3. off-line and online methods

Two nice platforms

Vote : `https://whale.imag.fr/`

Resource allocation : `http://www.spliddit.org/`