Computational Social Choice

From Arrow's impossibility to Fishburn's maximal lotteries

STACS 2015 Tutorial

Felix Brandt

DSS
Decision Sciences & Systems

Motivation

- *What is "social choice theory"?*
  - How to aggregate possibly conflicting preferences into collective choices in a fair and satisfactory way?
  - Origins: mathematics, economics, and political science
  - Essential ingredients
    - Autonomous agents (e.g., human or software agents)
    - A set of alternatives (depending on the application, alternatives can be political candidates, resource allocations, coalition structures, etc.)
    - Preferences over alternatives
    - Aggregation functions
- The axiomatic method will play a crucial role in this tutorial.
  - Which formal properties should an aggregation function satisfy?
  - Which of these properties can be satisfied simultaneously?

Handbook of Computational Social Choice

(Cambridge University Press, forthcoming in 2015)

Plurality

- Why are there different voting rules?
  - What's wrong with plurality (the most widespread voting rule) where alternatives that are ranked first by most voters win?
  - Consider a *preference profile* with 21 voters, who rank four alternatives as in the table on the right.

3	**5**	**7**	**6**
a	*a*	*b*	*c*
b	*c*	*d*	*b*
c	*b*	*c*	*d*
d	*d*	*a*	*a*

  - Alternative *a* is the unique plurality winner despite
    - a majority of voters think *a* is the worst alternative,
    - *a* loses against *b*, *c*, and *d* in pairwise majority comparisons, and
    - if the preferences of all voters are reversed, *a* still wins.
  - In July 2010, 22 experts on social choice theory met in France and voted on which voting rules should be used. Plurality received *no support* at all (among 18 rules).

5 Common Voting Rules

- Plurality
  - Used in most democratic countries, ubiquitous
  - Alternatives that are ranked first by most voters
- Borda
  - Used in Slovenia, academic institutions, Eurovision song contest
  - The most preferred alternative of each voter gets $m-1$ points, the second most-preferred $m-2$ points, etc. Alternatives with highest accumulated score win.
- Plurality with runoff
  - Used to elect the President of France
  - The two alternatives that are ranked first by most voters face off in a majority runoff.

5 Common Voting Rules (ctd.)

- Instant-runoff
  - Used in Australia, Ireland, Malta, Academy awards
  - Alternatives that are ranked first by the lowest number of voters are deleted. Repeat until no more alternatives can be deleted. The remaining alternatives win.
  - In the UK 2011 alternative vote referendum, people chose plurality over instant-runoff.
- Sequential majority comparisons
  - Used by US congress to pass laws (aka *amendment procedure*) and in many committees
  - Alternatives that win a fixed sequence of pairwise comparisons (e.g., ((a vs. b) vs. c), etc.).

A Curious Preference Profile

33%	16%	3%	8%	18%	22%
a	*b*	*c*	*c*	*d*	*e*
b	*d*	*d*	*e*	*e*	*c*
c	*c*	*b*	*b*	*c*	*b*
d	*e*	*a*	*d*	*b*	*d*
e	*a*	*e*	*a*	*a*	*a*

Example due to Michel Balinski

- Plurality: ***a* wins**
- Borda: ***b* wins**
- Sequential majority comparisons (any order): ***c* wins**
- Instant-runoff: ***d* wins**
- Plurality with runoff: ***e* wins**

Rational Choice Theory

- A prerequisite for analyzing collective choice is to understand individual choice.
- Let U be a finite universe of alternatives.
- A *choice function* f maps a feasible set $A \subseteq U$ to a choice set $f(A) \subseteq A$.
  - We require that $f(A)=\varnothing$ only if $A=\varnothing$.
- Not every choice function complies with our intuitive understanding of rationality.
  - Certain patterns of choice from varying feasible sets may be deemed inconsistent, e.g., choosing a from $\{a,b,c\}$, but b from $\{a,b\}$.

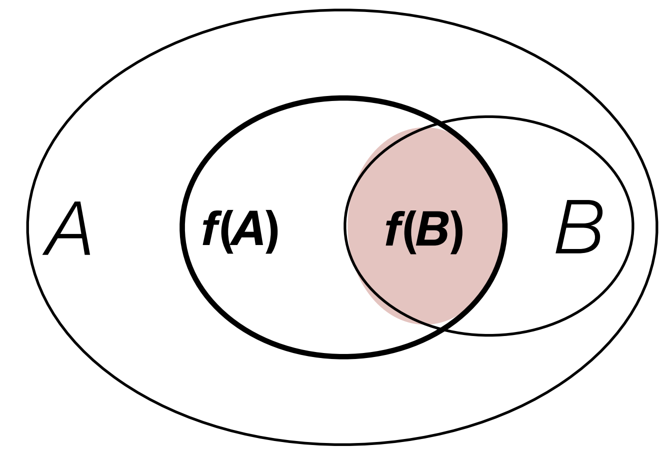
A	***f(A)***
ab	*a*
bc	*b*
ac	*a*
abc	*a*

Rationalizable Choice

- Binary preference relation $\succcurlyeq$ on U
  - $x \succcurlyeq y$ is interpreted as "*x is at least as good as y*".
  - $\succcurlyeq$ is assumed to be transitive and complete.
- Best alternatives
  - For a binary relation $\succcurlyeq$ and a feasible set A,
    $Max(\succcurlyeq,A) = \{x \in A \mid \nexists y \in A \text{ such that } y \succ x\}$
- f is rationalizable if there exists a preference relation $\succcurlyeq$ on U such that $f(A) = Max(\succcurlyeq,A)$ for all A.
  - The previously mentioned choice function f with $f(\{a,b,c\}) = \{a\}$ and $f(\{a,b\}) = \{b\}$ cannot be rationalized.

Consistent Choice

- It would be a nice if the non-existence of a rationalizing relation could be pointed out by finding inconsistencies.
- f satisfies consistency if for all A,B with $B \subseteq A$, $f(A) \cap B \neq \emptyset$ implies $f(B) = f(A) \cap B$.



  - Consequence: If x is chosen from a feasible set, then it is also chosen from all subsets that contain x.
  - Example: Plurality does not satisfy consistency (when scores are computed for each feasible set).
    - $f(\{a,b,c\}) = \{a\}$ and $f(\{a,b\}) = \{b\}$

3	2	2
a	b	c
b	c	b
c	a	a

- Theorem (Samuelson, 1938; Arrow, 1959): A choice function is rationalizable iff it satisfies consistency.

From Choice to Social Choice

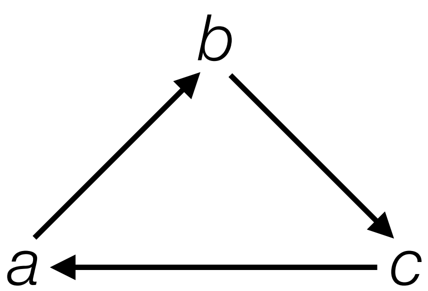
- *N* is a finite set of at least two voters.
- $R(U)$ is the set of all preference relations over U.
- Every $R=(\succcurlyeq_1, \ldots, \succcurlyeq_{|N|}) \in R(U)^{|N|}$ is called a *preference profile*.
- A *social choice function (SCF)* is a function f that assigns a choice function to each preference profile.
  - An SCF is rationalizable (consistent) if its underlying choice functions are rationalizable (consistent) for all preference profiles.
  - We will write $f(R,A)$ as a function of both R and A.
- Let $n_{xy} = |\{i \in N \mid x \succcurlyeq_i y\}|$ and define the *majority rule relation* as $(x \; R_M \; y) \Leftrightarrow n_{xy} > n_{yx}$.

Condorcet's Paradox

Marquis de Condorcet

- Social choice from feasible sets of size two is easy.
  - The *majority rule SCF* is defined as $f(R,\{x,y\}) = Max(R_M,\{x,y\})$.
  - Majority rule can easily be characterized using uncontroversial axioms (e.g., May, 1952).
- Problems arise whenever there are more than two alternatives.
  - Condorcet paradox (1785): R_M can be intransitive.
  - Alternative x is a *Condorcet winner* in A if $x \; R_M \; y$ for all $y \in A \setminus \{x\}$.
  - An SCF f is a *Condorcet extension* if $f(R,A)=\{x\}$ whenever x is a Condorcet winner in A.

1	1	1
a	*b*	*c*
b	*c*	*a*
c	*a*	*b*



Arrow's Impossibility


Kenneth J. Arrow

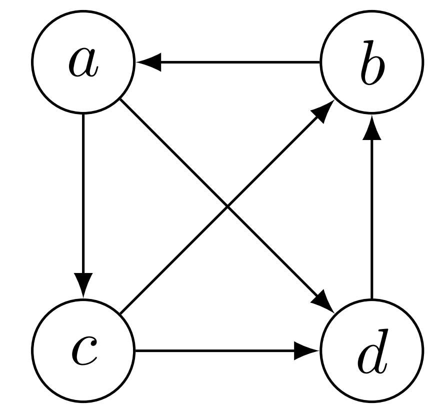
- An SCF satisfies *independence of infeasible alternatives (IIA)* if the choice set only depends on preferences over alternatives within the feasible set.
- An SCF satisfies *Pareto-optimality* if an alternative will not be chosen if there exists another alternative such that all voters prefer the latter to the former.
- An SCF is *dictatorial* if there exists a voter whose most preferred alternative is always uniquely chosen.
- Theorem (Arrow, 1951): Every rationalizable SCF that satisfies IIA and Pareto-optimality is dictatorial when $|U|\geq 3$.
  - Nipkow (2009) has verified a proof of Arrow's theorem using Isabelle.
  - Tang & Lin (2009) reduced the statement to a finite base case that was solved by a computer.

What now?

- Rationalizability (or, equivalently, consistency) is incompatible with collective choice when $|U|\geq 3$.
  - Dropping IIA offers little relief (Banks, 1995).
  - Dropping Pareto-optimality offers little relief (Wilson, 1972).
  - Dropping non-dictatorship is unacceptable.
- In this tutorial, we will consider two escape routes from Arrow's impossibility:
  - SCFs that satisfy weaker notions of consistency
    - Top cycle, uncovered set, Banks set, tournament equilibrium set
  - Randomized SCFs
    - Random dictatorship, maximal lotteries

Weakly Consistent SCFs

Tournaments



- For a given preference profile R, a feasible set A and majority rule R_M define a directed graph (A,R_M).
  - We say that b dominates a if $b\ R_M\ a$.
  - Every asymmetric directed graph is induced by some preference profile (McGarvey, 1953).
- A *majoritarian* SCF is an SCF whose output only depends on (A,R_M).
  - For simplicity, we will assume that individual preferences are anti-symmetric and that $|N|$ is odd. Hence, (A,R_M) is a tournament.
  - SCF f is said to be *finer* than SCF g if $f \subseteq g$.
  - Dominion $D(x)=\{y \in A \mid x\ R_M\ y\}$
  - Dominators $\overline{D}(x)=\{y \in A \mid y\ R_M\ x\}$

Majoritarianness

$|A|=2$

Non-dictatorship

IIA

Pareto-optimality

Rationalizability/ Consistency

Expansion

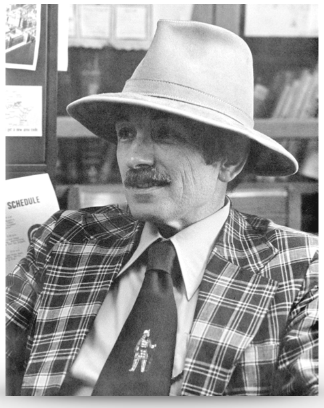
Weak expansion

Strong retentiveness

Retentiveness

Arrow's Impossibility

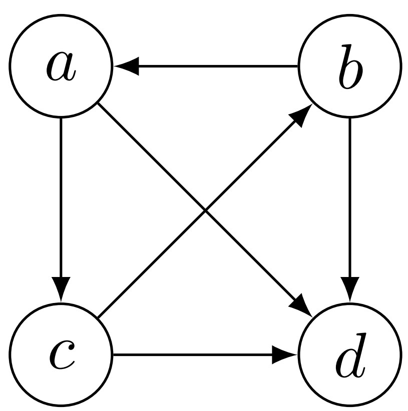
The Top Cycle



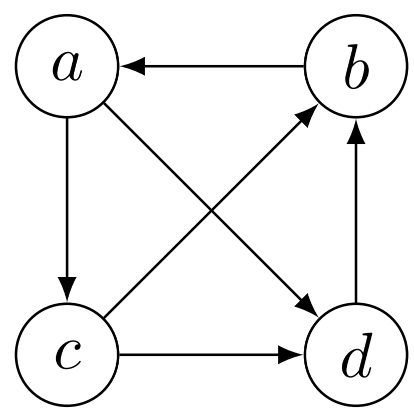
John I. Good

- Consistency can be weakened to expansion:
  $B \subseteq A$ and $f(A) \cap B \neq \emptyset$ implies $f(B) \subseteq f(A)$.
- Theorem (Bordes, 1976): There is a unique finest majoritarian SCF satisfying expansion: the top cycle.
- A *dominant set* is a nonempty set of alternatives $B \subseteq A$ such that for all $x \in B$ and $y \in A \setminus B$, $x \, R_M \, y$.
  - The set of dominant sets is totally ordered by set inclusion (Good, 1971).
  - Hence, every tournament contains a unique minimal dominant set called the top cycle (TC).
  - TC is a Condorcet extension.

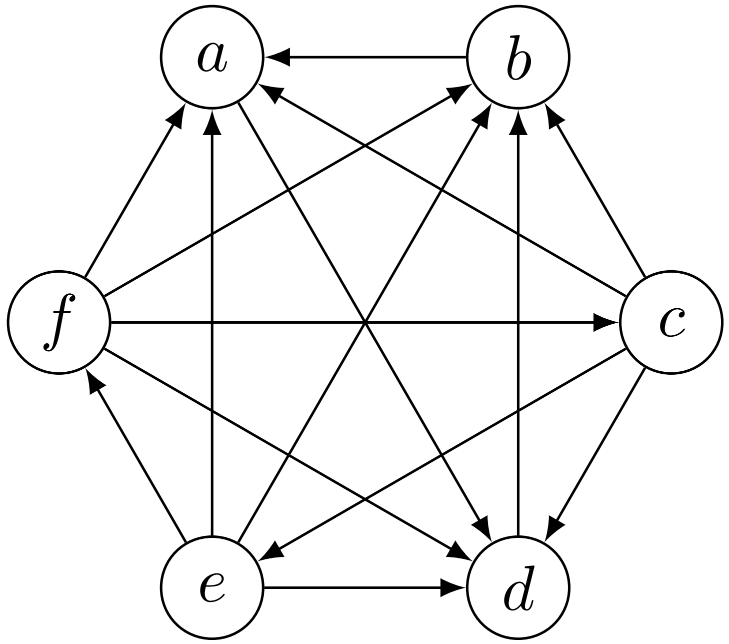
Examples



$TC(A,R_M)=\{a,b,c\}$



$TC(A,R_M)=\{a,b,c,d\}$



$TC(A,R_M)=\{c,e,f\}$

Transitive Closure

- The essence of Condorcet's paradox and Arrow's impossibility is that majority rule fails to be transitive.
  - Why not just take the transitive (reflexive) closure R_M^*?
- Theorem (Deb, 1977): $TC(A,R_M) = Max(R_M^*,A)$.
- Consequences
  - *TC* itself is a cycle. It is the source component in the DAG (directed acyclic graph) of strongly connected components.
  - Linear-time algorithms for computing *TC* using Kosaraju's or Tarjan's algorithm for finding strongly connected components
    - Alternatively, one can initialize working set *B* with all alternatives of maximal outdegree and then iteratively add all alternatives that dominate an alternative in *B* until no more such alternatives can be found.

Top Cycle and Pareto-Optimality

- The top cycle is very large.
- In fact, it is so large that it fails to be Pareto-optimal when there are more than three alternatives (Ferejohn & Grether, 1977).

1	**1**	**1**
a	*b*	*d*
b	*c*	*a*
c	*d*	*b*
d	*a*	*c*

- Since Pareto-optimality is an essential ingredient of Arrow's impossibility, this escape route is (so far) not entirely convincing.
    - Although, technically, Arrow's theorem only requires Pareto-optimality for two-element sets (which the top cycle satisfies).

Majoritarianness

$|A|=2$

Non-dictatorship

IIA

Pareto-optimality

Rationalizability/
Consistency

Expansion

Weak expansion

Arrow's Impossibility

Top Cycle (TC)

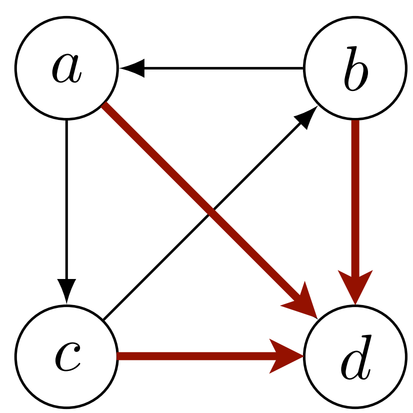

Peter C. Fishburn

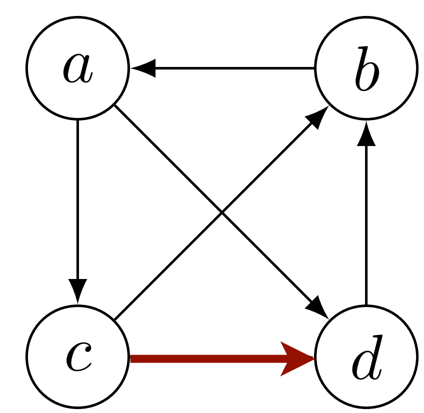
The Uncovered Set


Nicholas Miller

- Expansion can be further weakened to weak expansion: $f(A) \cap f(B) \subseteq f(A \cup B)$.
- Theorem (Moulin, 1986): There is a unique finest majoritarian SCF satisfying weak expansion: the uncovered set.
- Given a tournament (A,R_M), x covers y ($x\ C\ y$), if $D(y) \subset D(x)$.
  - Proposed independently by Fishburn (1977) and Miller (1980)
  - Transitive subrelation of majority rule
  - The uncovered set (UC) consists of all uncovered alternatives, i.e., $UC(A,P_M) = Max(C,A)$.

Examples





$UC(A,R_M)=\{a,b,c\}$

$UC(A,R_M)=\{a,b,c\}$

$TC(A,R_M)=\{a,b,c,d\}$

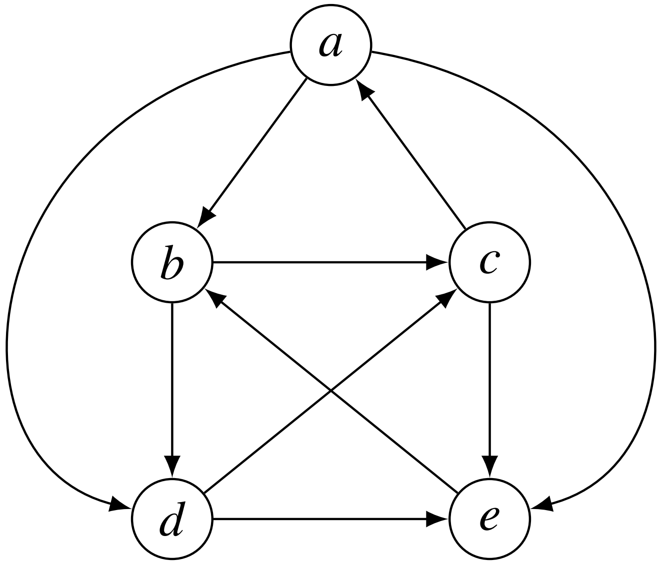
Properties of the Uncovered Set

- Since expansion ⇒ weak expansion, $UC \subseteq TC$.
  - UC is a Condorcet extension.
- UC satisfies Pareto-optimality.
  - Theorem (B. and Geist, 2014): UC is the largest majoritarian SCF satisfying Pareto-optimality.
- How can the uncovered set be efficiently computed?
  - Straightforward $O(n^3)$ algorithm that computes the covering relation for every pair of alternatives
  - Can we do better than that?

Uncovered Set Algorithm

- Equivalent characterization of *UC*
  - Theorem (Shepsle & Weingast, 1984): *UC* consists precisely of all alternatives that reach every other alternative in at most two steps.
    - Such alternatives are called kings in graph theory.
- Hence, *UC* can be computed by squaring the tournament's adjacency matrix.
  - Fastest known matrix multiplication algorithm (Le Gall, 2014): $O(n^{2.3728639})$
  - Just slightly faster than Vassilevska Williams, 2011: $O(n^{2.372873})$
  - Based on Coppersmith & Winograd (1990): $O(n^{2.376})$
  - Matrix multiplication is believed to be feasible in linear time ($O(n^2)$).

Uncovered Set Algorithm (Example)



$$\begin{pmatrix} 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \end{pmatrix}^2 + \begin{pmatrix} 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \end{pmatrix} + \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} 1 & 1 & 2 & 1 & 1 \\ 1 & 1 & 1 & 1 & 2 \\ 1 & 2 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \end{pmatrix}$$

Majoritarianness

$|A|=2$

Non-dictatorship

IIA

Pareto-optimality

Rationalizability/
Consistency

Expansion

Weak expansion

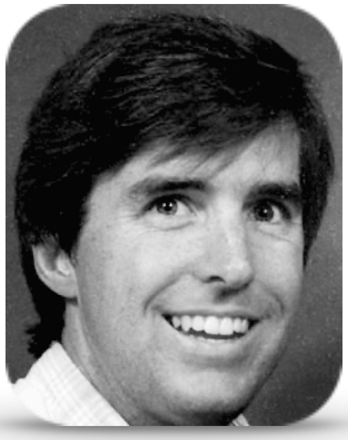
Strong retentiveness

Arrow's Impossibility

Top Cycle (TC)

Uncovered Set (UC)

Banks Set

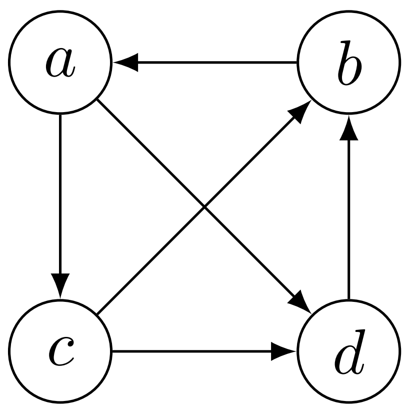


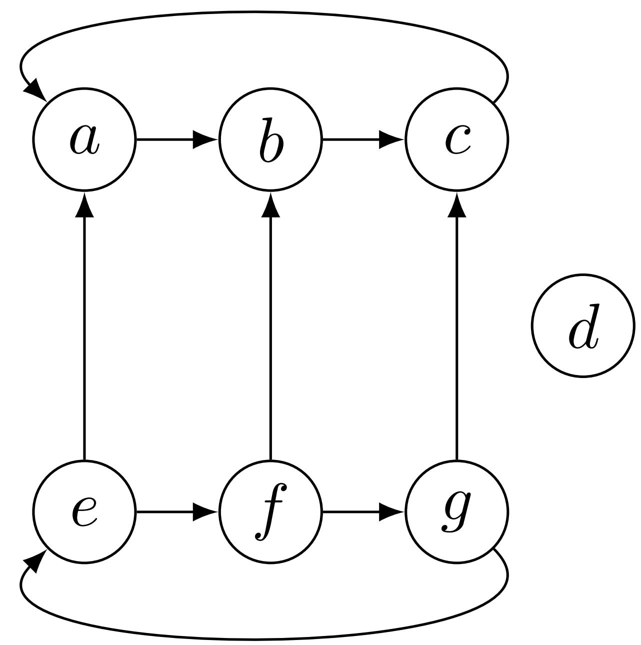
Jeffrey S. Banks

- Weak expansion can be weakened to strong retentiveness: $f(\overline{D}(x)) \subseteq f(A)$ for all $x \in A$.
- Theorem (B., 2011): There is a unique finest majoritarian SCF satisfying strong retentiveness: the Banks set.
- A *transitive subset* of a tournament (A, R_M) is a set of alternatives $B \subseteq A$ such that R_M is transitive within B.
- Let $Trans(A,R_M) = \{B \subseteq A \mid B \text{ is transitive}\}$.
- The Banks set (BA) consists of the maximal elements of all inclusion-maximal transitive subsets (Banks, 1985), i.e., $BA(A,R_M) = \{Max(R_M,B) \mid B \in Max(\supseteq, Trans(A,R_M))\}$

Examples

(All missing edges are pointing downwards.)





$UC(A,R_M)=\{a,b,c\}$

$BA(A,R_M)=\{a,b,c\}$

$TC(A,R_M)=\{a,b,c,d,e,f,g\}$

$UC(A,R_M)=\{a,b,c,d\}$

$BA(A,R_M)=\{a,b,c\}$

Properties of the Banks Set

- Since expansion ⇒ weak expansion ⇒ strong retentiveness, $BA \subseteq UC \subseteq TC$.
  - As a consequence, *BA* is a Condorcet extension and satisfies Pareto-optimality.
- Random alternatives in *BA* can be found in linear time by iteratively constructing maximal transitive sets.
- Yet, computing the Banks set is NP-hard (Woeginger, 2003) and remains NP-hard even for 5 voters (B. et al., 2013).
- Strong retentiveness can be further weakened to retentiveness:
  $f(\overline{D}(x)) \subseteq f(A)$ for all $x \in f(A)$.

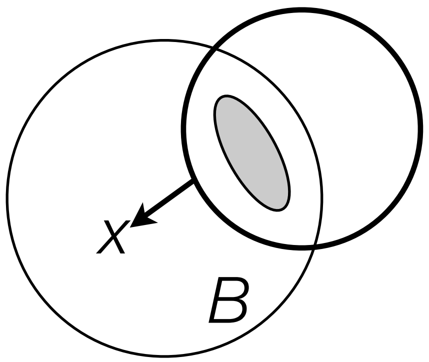
$$\begin{tikzcd} & \text{Majoritarianness} \arrow[dl] \arrow[d] \arrow[dr, "|A|=2"] & \\ \text{Non-dictatorship} & \text{IIA} & \text{Pareto-optimality} \end{tikzcd}$$

Rationalizability/ Consistency	**Arrow's Impossibility**
↓	
Expansion	**Top Cycle (TC)**
↓	
Weak expansion	**Uncovered Set (UC)**
↓	
Strong retentiveness	**Banks Set (BA)**
↓	
Retentiveness	

Tournament Equilibrium Set

Thomas Schwartz

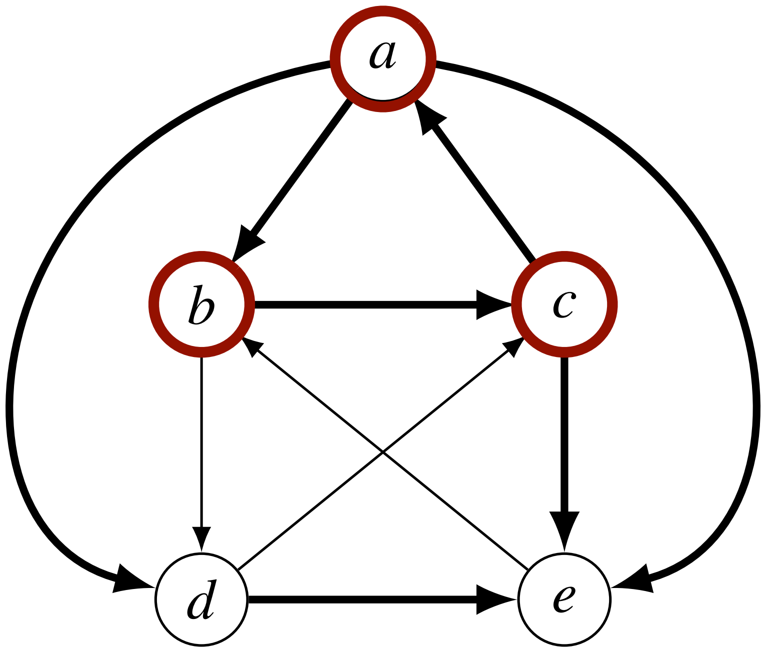
- Let f be an arbitrary choice function.
  - A non-empty set of alternatives B is *f-retentive* if $f(\overline{D}(x))\subseteq B$ for all $x\in B$.
  - Idea: No alternative in the set should be "properly" dominated by an outside alternative.

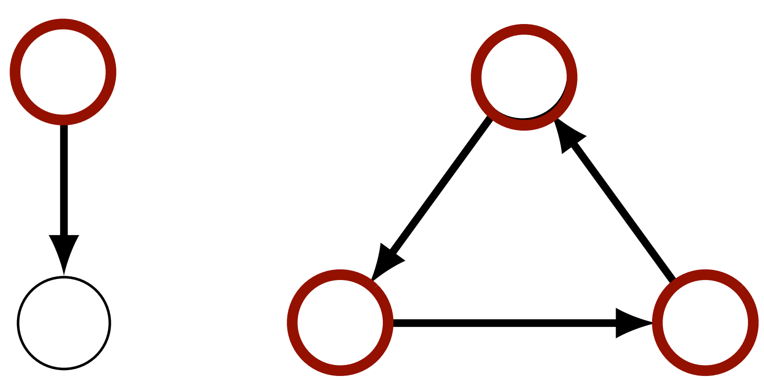


- $\mathring{f}$ is a new choice function that yields the union of all inclusion-minimal f-retentive sets.
  - $\mathring{f}$ satisfies retentiveness.
- The tournament equilibrium set (TEQ) of a tournament is defined as $TEQ=\mathring{TEQ}$.
  - Recursive definition (unique fixed point of ring-operator)
  - Theorem (Schwartz, 1990): $TEQ\subseteq BA$.

Example

- $\{a,b,c\}$ is the unique minimal *TEQ*-retentive set.
  - $TEQ(\overline{D}(a)) = TEQ(\{c\}) = \{c\}$
  - $TEQ(\overline{D}(b)) = TEQ(\{a,e\}) = \{a\}$
  - $TEQ(\overline{D}(c)) = TEQ(\{b,d\}) = \{b\}$
  - $TEQ(\overline{D}(d)) = TEQ(\{a,b\}) = \{a\}$
  - $TEQ(\overline{D}(e)) = TEQ(\{a,c,d\}) = \{a,c,d\}$



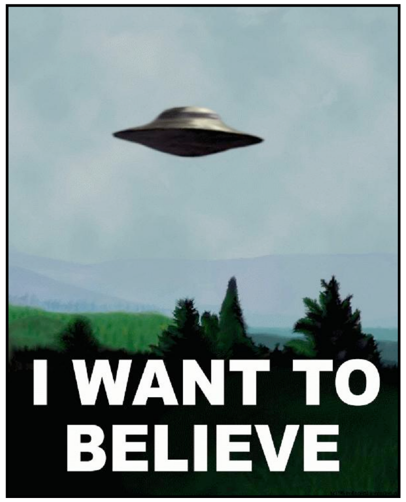


A thick edge from y to x denotes that $y \in TEQ(\overline{D}(x))$.

Properties of TEQ

- Computing *TEQ* is NP-hard (B. et al., 2010) and remains NP-hard even for 7 voters (Bachmeier et al., 2015).
  - The best known upper bound is PSPACE!
- Theorem (Laffond et al., 1993; Houy 2009; B., 2011; B. and Harrenstein, 2011): The following statements are equivalent:
  - Every tournament contains a unique minimal *TEQ*-retentive set. (Schwartz' Conjecture, 1990)
  - *TEQ* is the unique finest majoritarian SCF satisfying retentiveness.
  - *TEQ* satisfies monotonicity (and many other desirable properties).
- All or nothing:
  Either *TEQ* is a most appealing SCF or it is severely flawed.

Schwartz's Conjecture

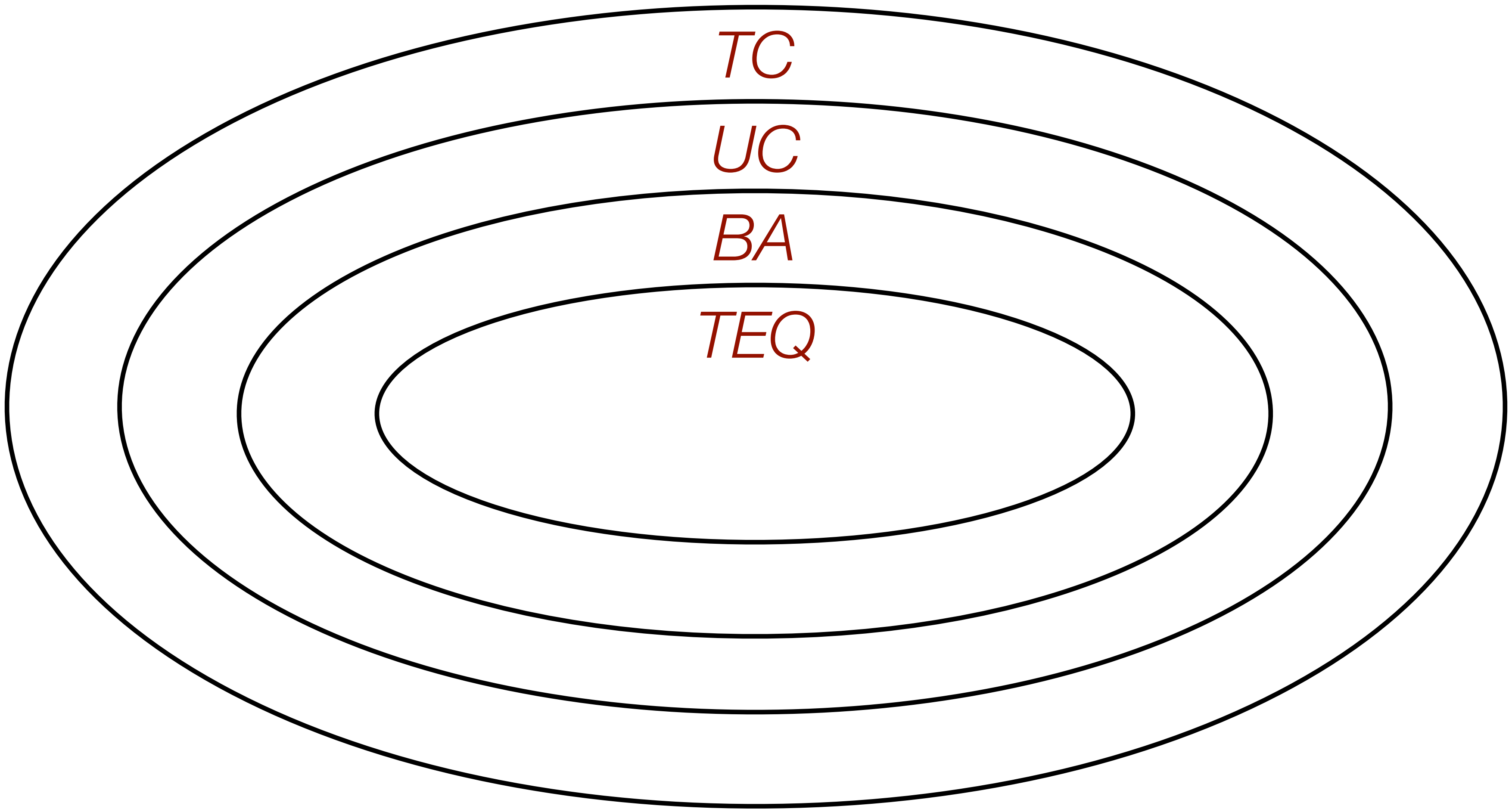


- There exists no counterexample with less than 13 alternatives (154 billion tournaments have been checked).
  - *TEQ* satisfies all nice properties if $|A|<13$.
- No counterexample was found by searching billions of random tournaments with up to 50 alternatives.
  - Checking significantly larger tournaments is intractable.
- Many non-trivial weakenings of Schwartz's conjecture are known to hold (Good, 1971; Dutta, 1988; B. et al., 2010; B., 2011).
- Theorem (B., Chudnovsky, Kim, Liu, Norin, Scott, Seymour, and Thomassé, 2012): Schwartz's conjecture is false.

Aftermath

- Non-constructive proof relying on a probabilistic argument by Erdős and Moser (1964)
  - Neither the counter-example nor its size can be deduced from proof.
  - Smallest counter-example of this type requires about 10^{136} alternatives.
- More recently, a counter-example with 24 alternatives was found with the help of a computer (B. & Seedig, 2013).
- In principle, *TEQ* is severely flawed. However, counter-examples are so extremely rare that this has no practical consequences.
  - This casts doubt on the axiomatic method.

Weakly Consistent SCFs



Top Cycle (1971)	*TC*	expansion	$O(n^2)$
Uncovered Set (1977)	*UC*	weak expansion	$O(n^{2.38})$
Banks Set (1985)	*BA*	strong retentiveness	$2^{O(n)}$
Tournament Equilibrium Set (1990)	*TEQ*	(retentiveness)	$2^{O(n)}$

Randomized SCFs

Random Dictatorship

Allan Gibbard

- A randomized SCF maps a preference profile to a lottery (probability distribution) over the alternatives.
- Perhaps the most notorious randomized SCF is random dictatorship.
  - One agent is picked uniformly at random and his most preferred alternative is implemented as the social choice.
- Random dictatorship is not as bad as it may sound.
  - It satisfies most of the axioms that are usually considered in social choice theory.
- Random dictatorship is the only Pareto-optimal randomized SCF that is strategyproof, i.e., it cannot be manipulated by lying about one's preferences (Gibbard, 1977).

Germaine Kreweras

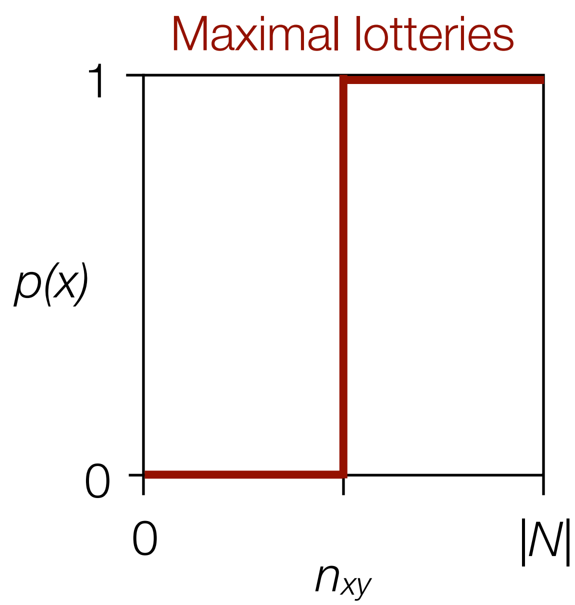
Maximal Lotteries

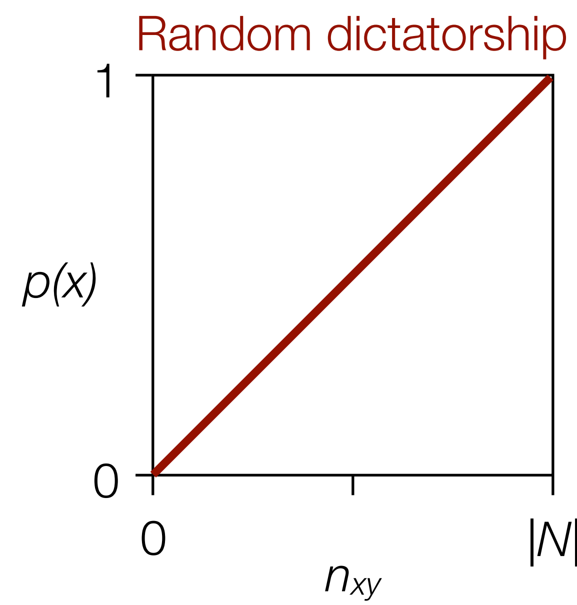
Peter C. Fishburn

- Kreweras (1965) and Fishburn (1984)
  - Rediscovered by Laffond et al. (1993), Felsenthal and Machover (1992), Fisher and Ryan (1995), Rivest and Shen (2010)
- Let $g(x,y) = n_{xy} - n_{yx}$ be the *majority margin* of x and y.
- Alternative x is a (weak) Condorcet winner if $g(x,y) \geq 0$ for all y.
- Extend g to lotteries: $g(p,q) = \sum_{x,y} p(x) \cdot q(y) \cdot g(x,y)$
  - Expected majority margin
- p is a maximal lottery if $g(p,q) \geq 0$ for all q.
  - Randomized (weak) Condorcet winner
  - Always exists due to Minimax Theorem (v. Neumann, 1928)

Examples

- Two alternatives





- *R* can be transformed into a symmetric zero-sum game.
  - Maximal lotteries are mixed minimax strategies (or Nash equilibria).

2	**2**	**1**
a	*b*	*c*
b	*c*	*a*
c	*a*	*b*

$$\begin{array}{c|ccc|} & a & b & c \\ \hline a & 0 & 1 & -1 \\ b & -1 & 0 & 3 \\ c & 1 & -3 & 0 \\ \hline \end{array}$$

  - The unique maximal lottery is $3/5\ a + 1/5\ b + 1/5\ c$.

Properties of Maximal Lotteries (*ML*)

- Maximal lotteries are almost always unique.
  - Always unique for odd number of voters (Laffond et al., 1997)
- *ML* does not require asymmetry, completeness, or even transitivity of preferences.
  - Random dictatorship requires unique maximum.
  - Canonical generalization (*RSD*) requires at least one maximum.
- *ML* can be efficiently computed via linear programming.
  - Computing *RSD* probabilities, on the other hand, is #P-complete (Aziz et al., 2013).
- In the assignment domain, maximal lotteries are known as popular mixed matchings (Kavitha et al., 2011).

Properties of Maximal Lotteries (ctd.)

- Pareto-dominated alternatives always get zero probability in every maximal lottery.
  - In fact, *ML* is even efficient with respect to stochastic dominance.
  - No lottery gives more expected utility for any utility representation consistent with the voters' preferences (Aziz et al., 2012).
  - Violated by *RSD* (Bogomolnaia and Moulin, 2001).
- *ML* is weakly strategyproof in a well-defined sense (Aziz et al., 2013).
- *ML* can be <u>uniquely characterized</u> using a version of consistency for randomized SCFs (Brandl et al., 2015).

Recommended Literature

- Books
  - Allingham: *Choice Theory - A very short introduction*. Oxford University Press, 2002
  - Austen-Smith and Banks: *Positive Political Theory I*, University of Michigan Press, 1999
  - Gärtner: *A Primer in Social Choice Theory*, Oxford University Press, 2009
  - Moulin: *Axioms of Cooperative Decision Making*. Cambridge University Press, 1988
  - Nitzan: *Collective Choice and Preference*. Cambridge University Press, 2010
- Introductory book chapter
  - B., Conitzer, and Endriss. *Computational Social Choice*. In "*Multiagent Systems*" (G. Weiss, ed.), MIT Press, 2013.