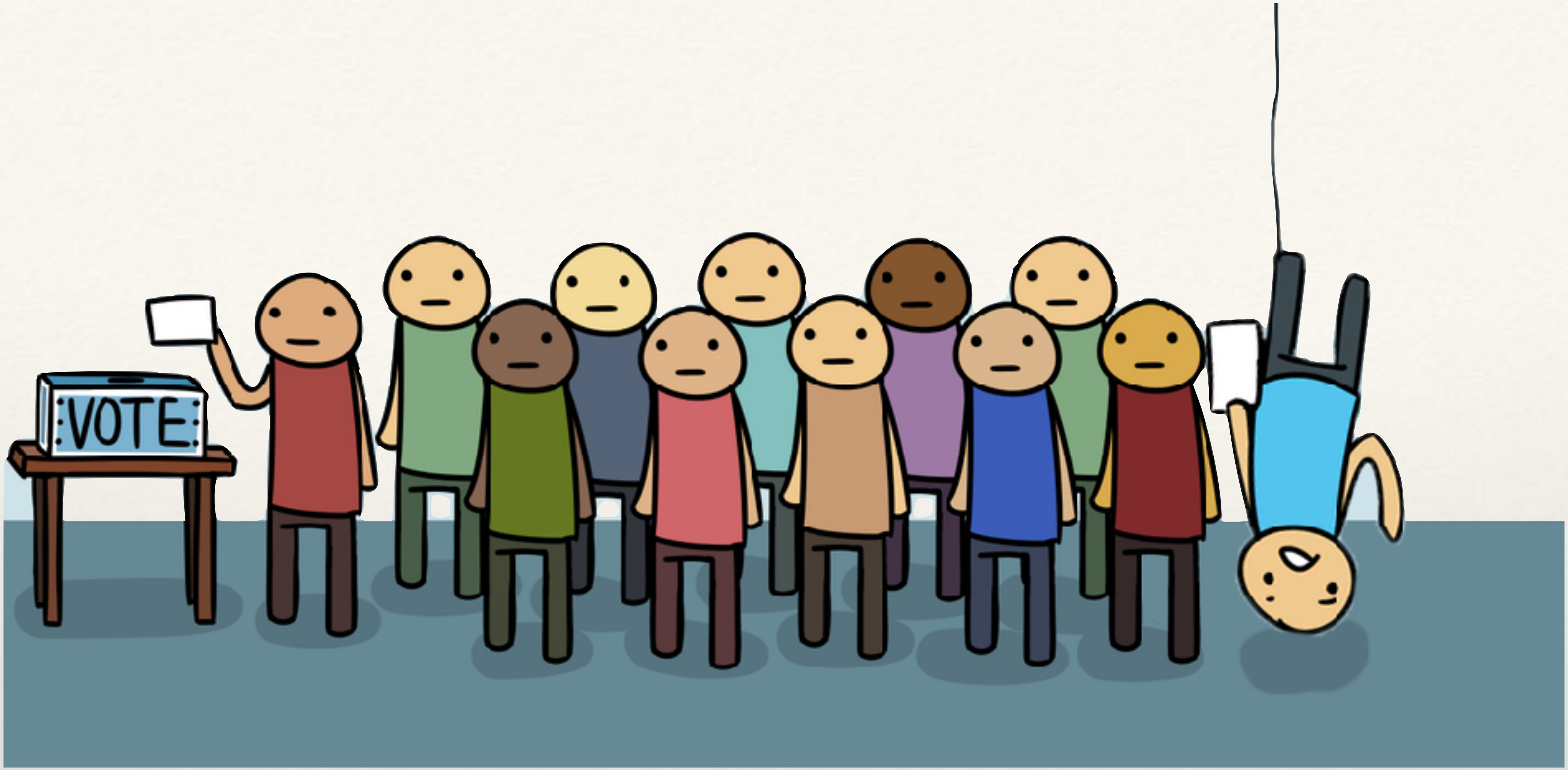

Condorcet's Principle and the Preference Reversal Paradox

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The Paradox

- Under many voting rules, it is sometimes better to report the *exact opposite* of your true preference ordering.

3	3	4	2	3
a	b	c	d	d
b	d	a	c	c
d	c	b	a	b
c	a	d	b	a

d is Kemeny winner

The Paradox

- Under many voting rules, it is sometimes better to report the *exact opposite* of your true preference ordering.

3	3	4	2	3
a	b	c	d	d
b	d	a	c	c
d	c	b	a	b
c	a	d	b	a

d is Kemeny winner

$\longrightarrow$

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

The Paradox

- Under many voting rules, it is sometimes better to report the *exact opposite* of your true preference ordering.

3	3	4	2	3
a	b	c	d	d
b	d	a	c	c
d	c	b	a	b
c	a	d	b	a

d is Kemeny winner

$\longrightarrow$

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

b is Kemeny winner

The Paradox

- Under many voting rules, it is sometimes better to report the *exact opposite* of your true preference ordering.

3	3	4	2	3
a	b	c	d	d
b	d	a	c	c
d	c	b	a	b
c	a	d	b	a

d is Kemeny winner

$\rightleftarrows$

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

b is Kemeny winner

Half-way monotonicity

- A voting rule satisfies **half-way monotonicity** if it avoids the paradox.
- => always weakly better to report truth rather than reverse.
- Introduced by Sanver and Zwicker (IJGT 2009).

Good rules:

- Borda
- Plurality
- Scoring rules

Bad rules:

- STV / Baldwin / Coombs
- Kemeny / maximin / Copeland / Schulze / Ranked Pairs
- Condorcet extensions i.e. rules that select the Condorcet winner if it exists

Impossibility Theorem

- Sanver and Zwicker (2009): **No Condorcet extension satisfies half-way monotonicity if there are $m \geq 4$ alternatives and sufficiently many voters.**
- Proof needs $n = 702 + \Omega(m!)$ voters, and n even.
- Unfortunately, their proof contains an arithmetical mistake, non-trivial to fix.
- Is the paradox a problem in small electorates?
- **We show the result holds for $n = 15$.**

Proof.

P_0

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

$P_0 \xrightarrow{\text{reverse } 1\ dcba} P_1$

$P_0 \xrightarrow{\text{reverse } 1\ abcd} P_4$

$P_1 \xrightarrow{\text{reverse } 1\ dcab} \bullet \xrightarrow{\text{reverse } 2\ cabd} P_3$

$P_1 \xrightarrow{\text{reverse } 2\ bdca} P_2$

$P_4 \xrightarrow{\text{reverse } 2\ cabd} P_5$

$P_4 \xrightarrow{\text{reverse } 3\ abdc} P_6$

P_3

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

P_2

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

P_5

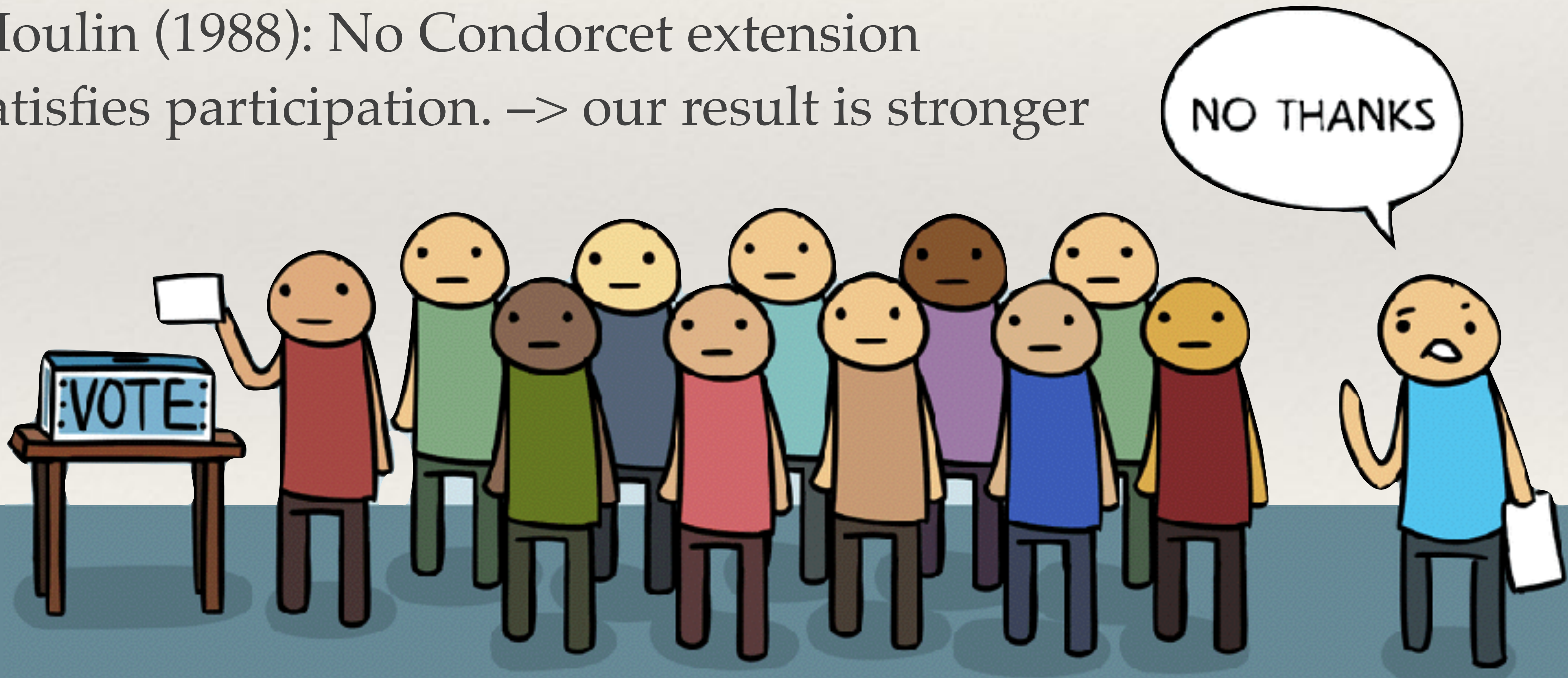
3	3	2	2	2	3
a	b	c	d	d	d
b	d	a	b	c	c
d	c	b	a	a	b
c	a	d	c	b	a

P_6

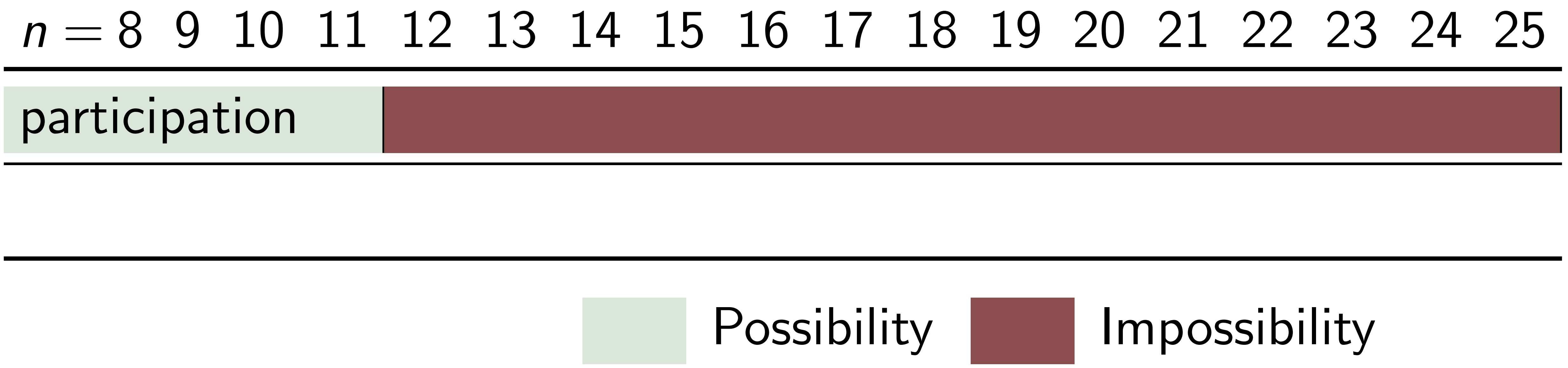
3	4	3	2	3
b	c	c	d	d
d	a	d	c	c
c	b	b	a	b
a	d	a	b	a

Comparison to Participation

- Voting rule satisfies **participation** if it is always weakly better to participate than to abstain (–> avoid **no-show paradox**).
- participation => half-way monotonicity
- Moulin (1988): No Condorcet extension satisfies participation. –> our result is stronger

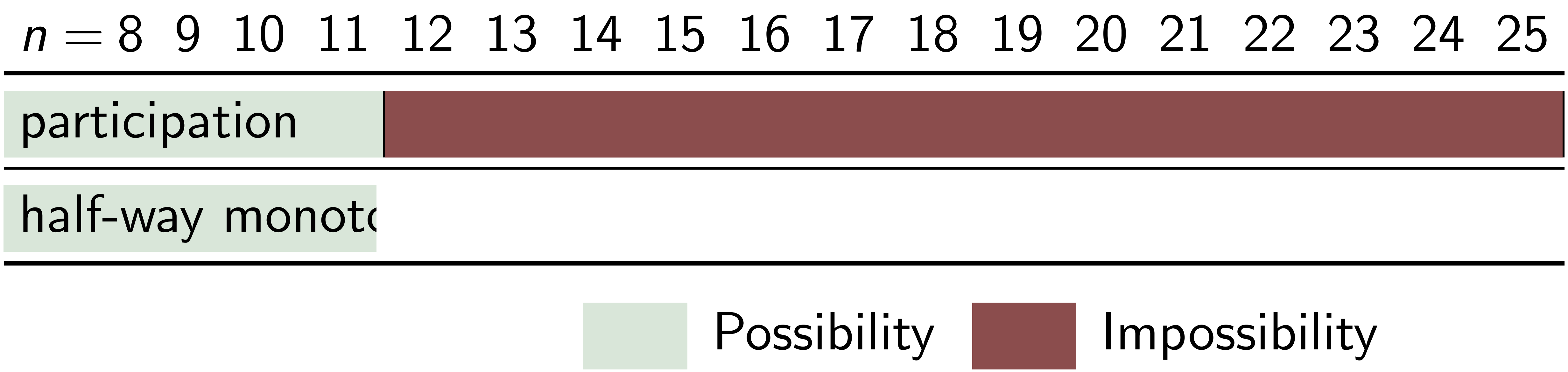


Number of Voters Required



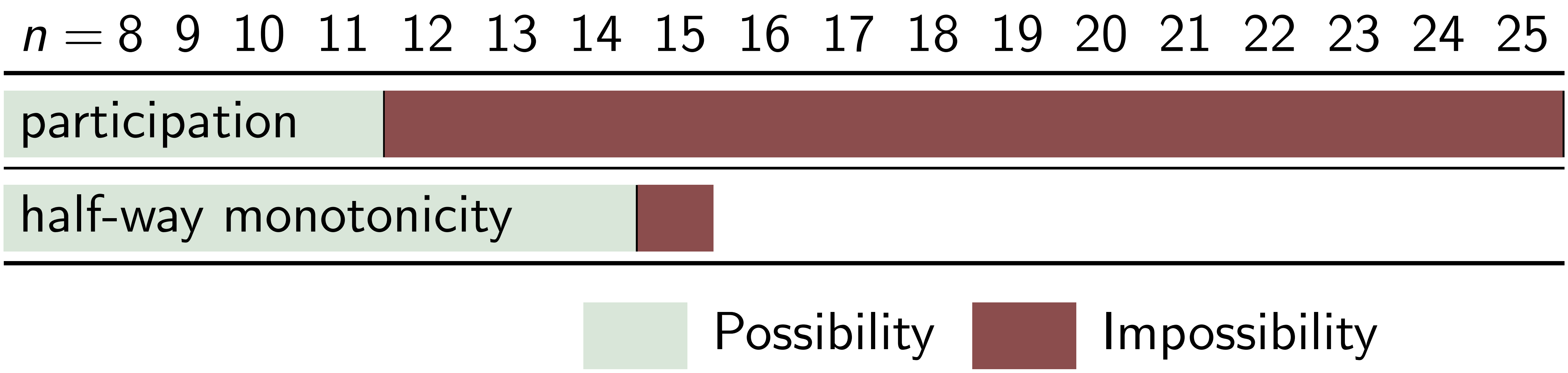
Brandt, Geist, P. (AAMAS 2016): For $m = 4$, participation is compatible with Condorcet consistency for $n = 11$, but incompatible for $n \geq 12$.

Number of Voters Required



Brandt, Geist, P. (AAMAS 2016): For $m = 4$, participation is compatible with Condorcet consistency for $n = 11$, but incompatible for $n \geq 12$.

Number of Voters Required



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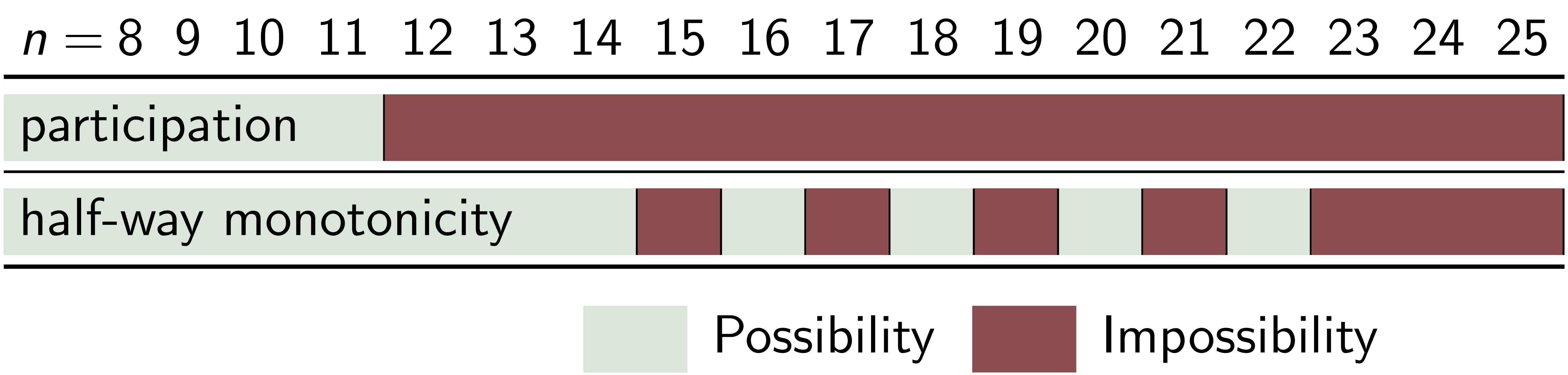
Number of Voters Required



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Method: Impossibility Theorems via SAT Solving

- For fixed n and m, write a formula of propositional logic whose models correspond to good voting rules.
- Give to state-of-the-art SAT solver (e.g., lingeling, glucose)
- SAT => good rule given by a look-up table
- UNSAT => impossibility result
- Induction steps on n and m

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- More info in book chapter: Geist and P., Computer-aided Methods for Social Choice Theory. In Ulle Endriss (ed.), *Trends in Computational Social Choice* (forthcoming).

Encoding

- *functionality* of f, i.e., that $f(P) = a$ for exactly one alternative, which means that there is *at least* one and *at most* one such alternative:

$$\varphi_{\text{functionality}} \equiv \bigwedge_{P \in A!^N} \left(\left(\bigvee_{a \in A} x_{P,a} \right) \wedge \bigwedge_{a \neq b \in A} (\neg x_{P,a} \vee \neg x_{P,b}) \right)$$

- *Condorcet-consistency*: for $a \in A$, let $C_a \subseteq A!^N$ be the set of profiles in which a is the Condorcet winner.

$$\varphi_{\text{Condorcet}} \equiv \bigwedge_{a \in A} \bigwedge_{P \in C_a} x_{P,a}$$

- *half-way monotonicity*: if $a, b \in A$ are such that $a \succ_i b$ for voter i in profile $P \in A!^N$, and $f(P) = b$, then $f(P_{-i}, \succ_i^{\text{rev}}) \neq a$.

$$\varphi_{\text{half-way monotonicity}} \equiv \bigwedge_{i \in N} \bigwedge_{P \in A!^N} \bigwedge_{\substack{a,b \in A \\ a \succ_i b}} (\neg v_{P,b} \vee \neg v_{(P_{-i}, \succ_i^{\text{rev}}),a}).$$

Satisfiability –> Lookup-Table

A,#1,(1,1,1,1,1,1)
A,#1,(1,1,1,1,1,-1)
A,#1,(1,1,1,-1,1,1)
A,#1,(1,1,1,-1,-1,1)
A,#1,(1,1,1,1,-1,-1)
A,#1,(1,1,1,-1,-1,-1)
B,#1,(-1,1,1,1,1,1)
B,#1,(-1,1,1,1,1,-1)
B,#1,(-1,-1,1,1,1,1)
B,#1,(-1,-1,-1,1,1,1)
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C,#1,(-1,-1,1,-1,1,1)
C,#1,(-1,-1,-1,-1,1,1)
C,#1,(1,-1,-1,-1,-1,1)
C,#1,(-1,-1,-1,-1,-1,1)
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D,#1,(1,1,-1,-1,-1,-1)
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D,#1,(-1,-1,-1,1,-1,-1)
D,#1,(1,-1,-1,-1,-1,-1)
D,#1,(-1,-1,-1,-1,-1,-1)
A,#2,(2,2,2,2,2,2)
A,#2,(2,2,2,2,2,0)
A,#2,(2,2,2,0,2,2)
A,#2,(2,2,2,0,0,2)
A,#2,(2,2,2,2,0,0)
A,#2,(2,2,2,0,0,0)
A,#2,(0,2,2,2,2,2)
A,#2,(0,2,2,2,2,0)
B,#2,(0,0,2,2,2,2)
B,#2,(0,0,0,2,2,2)
B,#2,(0,2,0,2,2,0)
B,#2,(0,0,0,2,2,0)
A,#2,(2,0,2,0,2,2)
A,#2,(2,0,2,0,0,2)
C,#2,(0,0,2,0,2,2)
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C,#2,(0,0,0,0,0,2)

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A,#2,(2,2,0,0,0,0)
B,#2,(0,2,0,2,0,0)
B,#2,(0,0,0,2,0,0)
A,#2,(2,0,0,0,0,0)
D,#2,(0,0,0,0,0,0)
A,#2,(2,2,2,2,2,-2)
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A,#2,(0,2,2,2,2,-2)
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B,#2,(0,2,0,2,2,-2)
B,#2,(0,0,0,2,2,-2)
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A,#2,(0,0,2,0,2,0)
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B,#2,(-2,0,0,2,0,0)
B,#2,(-2,0,0,0,0,0)
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B,#2,(-2,0,2,2,2,0)
B,#2,(-2,2,0,2,2,-2)
B,#2,(-2,0,0,2,2,-2)
B,#2,(-2,0,2,0,2,0)
B,#2,(-2,0,0,0,2,0)
B,#2,(-2,2,0,2,0,-2)
B,#2,(-2,0,0,2,0,-2)
D,#2,(-2,0,0,0,0,-2)
B,#2,(-2,-2,2,2,2,2)
B,#2,(-2,-2,0,2,2,2)
B,#2,(-2,-2,0,2,2,0)
C,#2,(0,-2,2,0,2,2)
C,#2,(0,-2,2,0,0,2)
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B,#2,(-2,-2,0,0,2,2)
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C,#2,(-2,-2,0,0,0,2)
B,#2,(-2,-2,0,2,0,0)
C,#2,(0,-2,0,0,0,0)
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C,#3,(1,-1,3,-1,3,1)
C,#3,(1,-1,3,-3,3,3)
C,#3,(1,-1,3,-3,1,3)
C,#3,(1,-1,3,-1,1,1)
C,#3,(1,-1,3,-3,1,1)
C,#3,(-1,-1,3,-1,3,3)

Unsatisfiability – Proof?

sat-solving — -bash — 67×15

```
c reading input file majority-resolute.cnf
c no embedded options
c found 'p cnf 648 12048' header
c read 648 variables, 12048 clauses, 24144 literals in 0.00 seconds
s UNSATISFIABLE
c
c    0.000  38% simplifying
c    0.000   0% search
c ----------------------------------
c    0.000 100% all
c
c 0 decisions, 0.0 decisions/sec
c 0 conflicts, 0.0 conflicts/sec
c 241 propagations, 1.2 megaprops/sec
c 0.0 seconds, 0.1 MB
```

Unsatisfiability – Proof?

- Use Minimal Unsatisfiable Sets (MUS)
- Subselection of the clauses, already unsatisfiable
- Removing any clause yields satisfiability
- => every clause in MUS is “necessary proof step”
- Fast tools to find an MUS (e.g. MUSer2, MARCO)
- If small, can obtain a **human-readable proof**

Proof.

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

P_0

reverse 1 $dcba$

P_1

reverse 1 $dcab$

reverse 2 $cabd$

P_3

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

reverse 2 $bdca$

P_2

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

reverse 1 $abcd$

P_4

reverse 2 $cabd$

P_5

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

reverse 3 $abdc$

P_6

3	4	3	2	3
b	c	c	d	d
d	a	d	c	c
c	b	b	a	b
a	d	a	b	a

Other Examples of the Method

- No Pareto-optimal **tournament solution** is strategyproof (Brandt and Geist, JAIR 2016) nor satisfies participation (Brandl et al, IJCAI 2015)
- No **probabilistic voting rule** is efficient and strategyproof (Brandl, Brandt, Eberl, Geist, JACM 2017)
- Impossibilities for **set extensions** (Geist and Endriss, JAIR 2011).
- Proofs of **Arrow's** and **Gibbard–Satterthwaite** Theorem (Tang and Lin, AIJ 2009)
- No strategyproof and proportional **multiwinner rules** (P., working paper)
- *many other possible applications..*

Results in the Paper

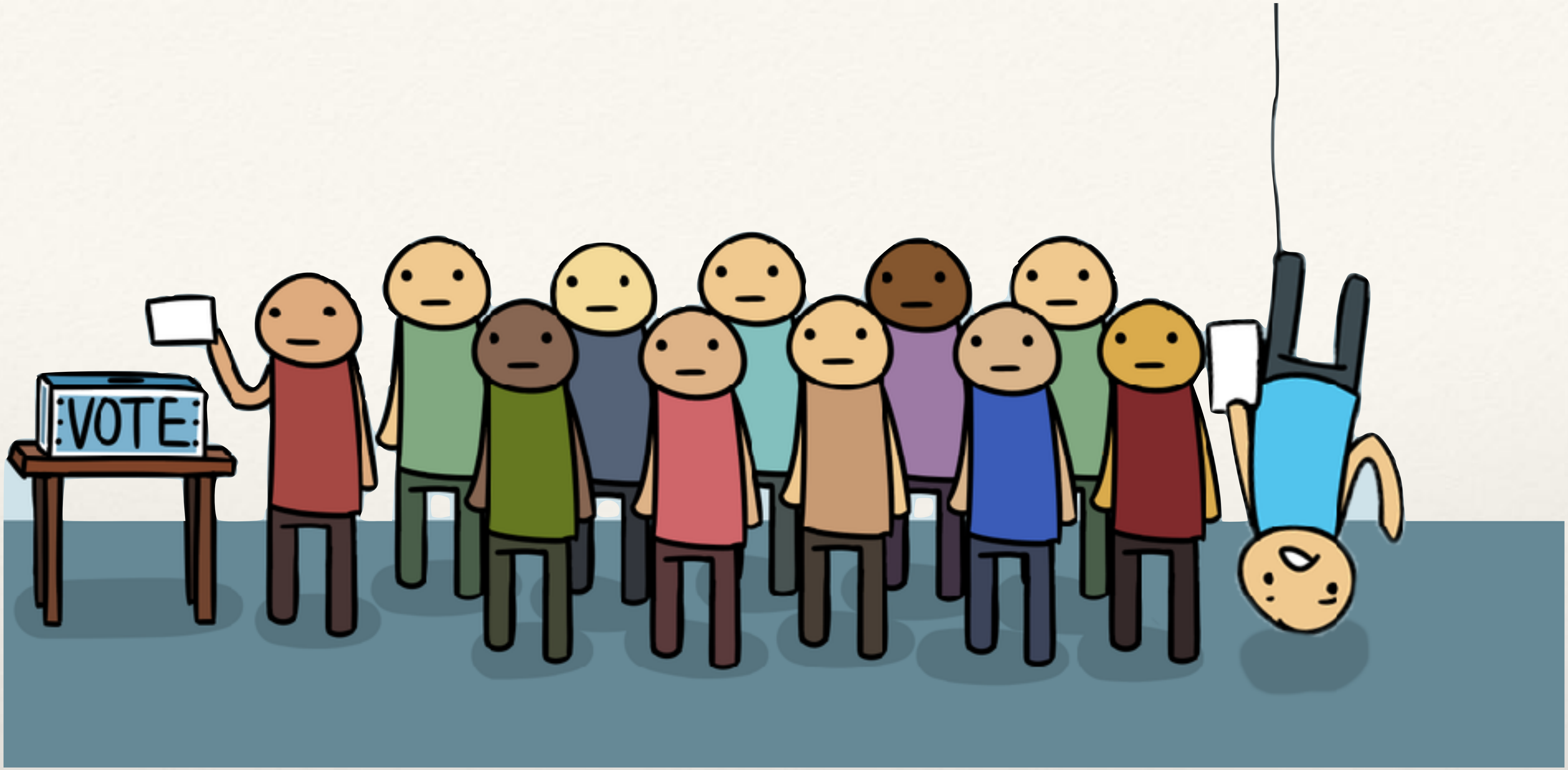
- Incompatibility for $n = 15$ and 24
- Induction steps for $m + 1$ and $n + 2$
- Set-valued voting rules (optimists and pessimists)
- Strong preference reversal paradox (which most Condorcet extensions except maximin exhibit)
- A version of the Gibbard–Satterthwaite Theorem

Disjunctive Gibbard–Satterthwaite

- **Every anonymous, unanimous voting rule is either *needlessly* or *egregiously* manipulable.** ($n \geq 15$ odd, $m \geq 4$)
- Idea for this type of result appears in Zwicker (2016, Handbook of COMSOC)
- Proof:
  - If the voting rule is a Condorcet extension, then it is manipulable by preference reversal.
  - If the voting rule is *not* a Condorcet extension, then by the Campbell–Kelly Theorem (2003, Econ Theory), the rule is manipulable between two profiles with a Condorcet winner, since the Condorcet rule is the only (non-trivial) strategyproof rule on Condorcet profiles.

Future Work

- Find other versions of G–S with restricted manipulations
  - e.g., known that G–S holds even if manipulators only perform a single swap (Caragiannis et al, EC 2012; Sato, JET 2013)
- Analogue of G–S result for Duggan–Schwartz
- Find concise description of positive examples
- What happens for $m \geq 5$?



Condorcet's Principle and the Preference Reversal Paradox

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