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Tiny Systematic Vote Manipulations Can Swing Elections[1]

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[1]The authors are undergraduates at Yale University. We thank the Faculty of Engineering and the Office of New Haven and State Affairs for hosting the *Voting in an e-Democracy* symposium and the *Yale Undergraduate Debates on Technology and Society* which prompted us to prepare this analysis.

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Abstract

We examine the effects of a type of electoral fraud easily perpetrated by someone with access to the system software for a direct-recording electronic voting system. The hypothetical attacker modifies the software to arbitrarily change a small number of votes on each voting machine. We determine the effect of this manipulation on the electoral college results of the 2000 United States Presidential election.

We conclude that changing only a single vote per electronic voting machine can change the outcome of the election.

Introduction

Under the mandate of the Help America Vote Act, precincts across the country are upgrading their polling processes. Some precincts are choosing to purchase electronic voting machines. The use of direct-recording electronic voting machines[1] raises concerns, which we illustrate with a case study based on data from the 2000 United States Presidential election.

We determine the influence a hypothetical adversary might have had on the outcome of the election. Our adversary is able to select and change a small fixed number of votes per machine. This represents the effect of subtly modifying the voting software to fraudulently alter the results. In programming the system to perform a simple, seemingly insignificant action on every voting machine, the attacker obtains a result magnified by the sheer number of machines. We calculate the number of states and electoral votes such an adversary might change, and conclude that the outcome of the election can be changed by manipulating one vote per voting machine.

Method

The total votes and winning margins of the the 2000 Presidential election are given in Table 4. The states are listed in order of increasing winning margin as a percentage of the votes cast.

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[1] An electronic voting machine is a computer-controlled device with which the voter interacts in producing and casting his or her ballot.

m will be the number of ballots chosen and altered by the adversary. For instance, the adversary might choose to select from each voting machine m ballots containing votes for candidate A and change them to votes for candidate B.

In our hypothetical electronically-balloted version of the 2000 election, we assume 90% of the total votes are cast by means of electronic voting machines. The ten percent remaining are cast in some other way (early, absentee, etc.) and do not contribute to the number of voting machines required. We then assume one electronic voting machine is required for every v votes to be cast cast by machine. The number of voting machines required is thus $(90\% \times \text{total votes cast})/v$.

We use $v = 150$ in our calculations. We believe this is reasonable given the recent electronic voting machine purchases of the states of Georgia and Maryland.[2] Also, 150 voters is all a machine can handle on election day if the polls are open for 14 hours and each voter requires 5.6 minutes on average to vote. In any case, our results are not particularly sensitive to the exact value of v. As can be deduced from Table 5, the adversary remains effective even if the number of electronic voting machines used is reduced such that each machine serves, say, twice $150 = 300$ voters. Even then, it could swing not just Florida but also New Mexico and Wisconsin.

We consider changing votes for Bush into votes for Gore, and vice-versa. We then determine the number of electoral votes that can be changed given the adversary's manipulation of size m in favor of the chosen candidate.

Results

The data given in Table 1 show statistics for the five closest margin 2000 presidential election states. These states were all decided by margins of less than half of one percent of votes cast.

Figure 1 shows the number of electoral votes changed versus the percent of the popular vote changed in favor of each candidate. Note that less than a small fraction of one percent of votes needed to be modified to change the winner to Gore, due to the very small margin in Florida, though changing about two percent of popular votes would give either candidate a large margin in the electoral college.

Tables 2 and 3 show the capacity of the adversary to direct the manipulation to the benefit of a particular candidate. In particular, Table 2 shows that an adversary capable of changing one vote per voting machine could have swung 25 electoral votes from Bush to Gore. This would have made the final electoral college totals 246 votes for Bush versus 291 votes for Gore, rather than the actual 271 votes for Bush versus 266 votes for Gore. Thus, an adversary with the ability to manipulate one vote per machine could have changed the outcome of the 2000 United States Presidential election.

[2] Georgia purchased 19,015[4] voting machines to serve the entire state. If these machines had been used to collect the 2,596,804 votes cast in Georgia in the 2000 Presidential election, then 136 votes would have been cast per machine. Georgia does not have absentee voting.

Maryland recently purchased 11,000[6] machines. In the 2000 Presidential election, there were 2,025,480[1] votes cast in Maryland. If those 11,000 machines had been used to collect the votes cast in 2000, 186 votes would have been cast per machine.

Table 1: Closest margin 2000 presidential election states [1, 2].

State	Electoral votes	Vote count			Winning Margin	
		Bush	Gore	Total	Absolute	Percent of total
FL	25	**2,912,790**	2,912,253	5,963,110	537	0.009%
NM	5	286,417	**286,783**	598,605	366	0.061%
WI	11	1,237,279	**1,242,987**	2,598,607	5,708	0.220%
IA	7	624,373	**638,517**	1,315,563	4,144	0.315%
OR	7	713,577	**720,342**	1,533,968	6,765	0.441%

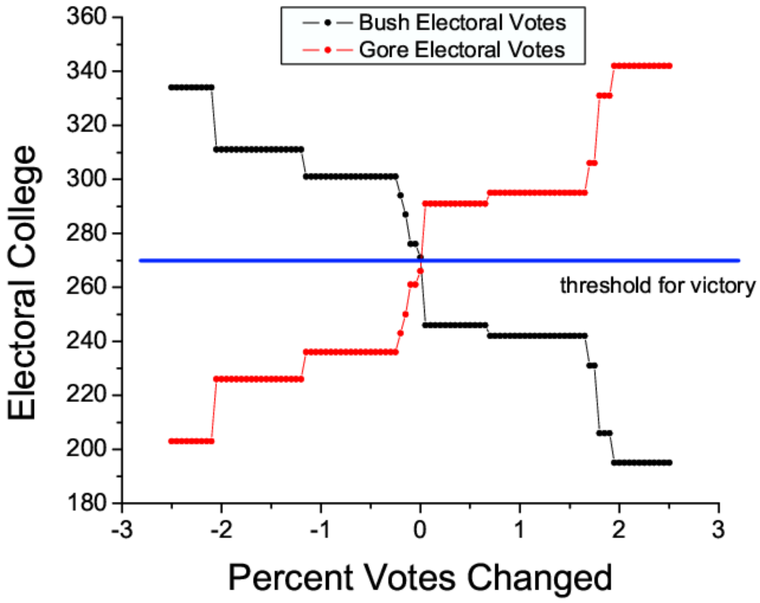

Figure 1: Electoral college votes changed versus percent popular vote changed.

Table 2: States swung from Bush to Gore by manipulating m votes per machine.

m votes manipulated per machine	States swung		
	Count	Electoral votes	Percentage of total electoral votes
1	1	25	4.6%
4	2	29	5.3%
8	6	76	14.1%
16	12	125	23.2%
20	13	138	25.6%

Table 3: States swung from Gore to Bush by manipulating m votes per machine.

m votes manipulated per machine	States swung		
	Count	Electoral votes	Percentage of total electoral votes
1	4	30	5.6%
4	4	30	5.6%
8	6	63	11.6%
16	9	96	16.7%
20	11	153	28.4%

Conclusion

Electronic voting machines present an opportunity for fraud in the form of widespread subtle manipulations. The master copy of the voting machine software can be programmed to misrecord or misreport one or a few chosen ballots. Where an election saboteur formerly needed to individually alter thousands of ballots, he or she now only need introduce a small change in the master copy of the voting software, which will be deployed on all of the electronic voting machines. As Mercuri noted, "Whereas earlier technologies required that election fraud be perpetrated at one polling place or machine at a time, the proliferation of similarly programmed e-voting systems invites opportunities for large-scale manipulation of elections."[5] Our analysis demonstrates that even a trivial example of this kind of fraud can be effective.

We have shown that changing just one vote per voting machine may well be enough to allow an adversary to control the result of this election. Moreover, an adversary willing to change a few more votes can swing states with much wider margins, which may be effective in changing the outcome of an election with wider margins overall than those of the 2000 election, or in establishing wider margins for other purposes, such as avoiding key close election recounts or establishing a "mandate" beyond merely winning the election.

Such slight manipulations, despite significantly changing the outcome of the election, are small enough that they might plausibly evade detection entirely, be dismissed as random noise if detected, be obscured by noise inherent in the voting and auditing process, or fail to prompt a recount if they are detected but their significance underestimated or misunderstood.

Acknowledgements

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References

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[5] Rebecca Mercuri. "A Better Ballot Box?", *IEEE Spectrum*, Volume 39, Number 10, October 2002. http://www.spectrum.ieee.org/WEBONLY/publicfeature/oct02/evot.html.

[6] Tadayoshi Kohno, Adam Stubblefield, Aviel D. Rubin, and Dan S. Wallach, *Analysis of an Electronic Voting System*, May, 2004, Proc. IEEE Symposium on Security and Privacy, http://avirubin.com/vote.pdf.

Appendix

Table 4 shows the true 2000 election statistics. Note the small margins by which some of the states were won.

Table 5 shows the number of electronic voting machines that would have been required for the 2000 election according to our estimates and the number of manipulations per machine required by the adversary in order to swing the state.

Table 4: Winning margins by state in 2000 election.

State	Electoral votes	Votes cast			Winner margin	
		Bush	Gore	Total	Absolute	As % of votes cast
FL	25	**2912790**	2912253	5963110	537	0.009%
NM	5	286417	**286783**	598605	366	0.061%
WI	11	1237279	**1242987**	2598607	5708	0.220%
IA	7	634373	**638517**	1315563	4144	0.315%
OR	7	713577	**720342**	1533968	6765	0.441%
NH	4	**273559**	266348	569081	7211	1.267%
MN	10	1109659	**1168266**	2438685	58607	2.403%
MO	11	**1189924**	1111138	2359892	78786	3.339%
OH	21	**2351209**	2186190	4705457	165019	3.507%
NV	4	**301575**	279978	608970	21597	3.546%
TN	11	**1061949**	981720	2076181	80229	3.864%
PA	23	2281127	**2485967**	4913119	204840	4.169%
ME	4	286616	**319951**	651817	33335	5.114%
MI	18	1953139	**2170418**	4232501	217279	5.134%
AR	6	**472940**	422768	921781	50172	5.443%
WA	11	1108864	**1247652**	2487433	138788	5.580%
AZ	8	**781652**	685341	1532016	96311	6.287%
WV	5	**336475**	295497	648124	40978	6.323%
LA	9	**927871**	792344	1765656	135527	7.676%
VA	13	**1437490**	1217290	2739447	220200	8.038%
CO	8	**883748**	738227	1741368	145521	8.357%
VT	3	119775	**149022**	294308	29247	9.938%
GA	13	**1419720**	1116230	2596804	303490	11.687%
CA	54	4567429	**5861203**	10965856	1293774	11.798%
IL	22	2019421	**2589026**	4742123	569605	12.012%
NC	14	**1631163**	1257692	2911262	373471	12.828%
DE	3	137288	**180068**	327622	42780	13.058%
AL	9	**941173**	692611	1666272	248562	14.917%
KY	8	**872492**	638898	1544187	233594	15.127%
IN	12	**1245836**	901980	2199302	343856	15.635%
NJ	15	1284173	**1788850**	3187226	504677	15.834%
SC	8	**785937**	565561	1382717	220376	15.938%
MD	10	813797	**1145782**	2025480	331985	16.390%
MS	7	**572844**	404614	994184	168230	16.921%
CT	8	561094	**816015**	1459525	254921	17.466%
HI	4	137845	**205286**	367951	67441	18.329%
KS	6	**622332**	399276	1072218	223056	20.803%
TX	32	**3799639**	2433746	6407637	1365893	21.317%
OK	8	**744337**	474276	1234229	270061	21.881%
SD	3	**190700**	118804	316269	71896	22.733%
NY	33	2403374	**4107697**	6821999	1704323	24.983%
MT	3	**240178**	137126	410997	103052	25.074%
MA	12	878502	**1616487**	2702984	737985	27.303%
ND	3	**174852**	95284	288256	79568	27.603%
NE	5	433862	**231780**	697019	202082	28.992%
RI	4	130555	**249508**	409112	118953	29.076%
AK	3	**167398**	79004	285560	88394	30.955%
ID	4	**336937**	138637	501621	198300	39.532%
WY	3	**147947**	60481	218351	87466	40.058%
UT	5	**515096**	203053	770754	312043	40.485%
DC	3	18073	**171923**	201894	153850	76.203%

Table 5: Estimated number of voting machines required to hold election and consequent number of manipulations per machine required to swing state.

State	Electoral votes	Winning margin	Voting machines required	Manipulations per machine to swing state
FL	25	537	35779	0.02
NM	5	366	3592	0.10
WI	11	5708	15592	0.37
IA	7	4144	7893	0.53
OR	7	6765	9204	0.74
NH	4	7211	3414	2.11
MN	10	58607	14632	4.01
MO	11	78786	14159	5.56
OH	21	165019	28233	5.84
NV	4	21597	3654	5.91
TN	11	80229	12457	6.44
PA	23	204840	29479	6.95
ME	4	33335	3911	8.52
MI	18	217279	25395	8.56
AR	6	50172	5531	9.07
WA	11	138788	14925	9.30
AZ	8	96311	9192	10.48
WV	5	40978	3889	10.54
LA	9	135527	10594	12.79
VA	13	220200	16437	13.40
CO	8	145521	10448	13.93
VT	3	29247	1766	16.56
GA	13	303490	15581	19.48
CA	54	1293774	65795	19.66
IL	22	569605	28453	20.02
NC	14	373471	17468	21.38
DE	3	42780	1966	21.76
AL	9	248562	9998	24.86
KY	8	233594	9265	25.21
IN	12	343856	13196	26.06
NJ	15	504677	19123	26.39
SC	8	220376	8296	26.56
MD	10	331985	12153	27.32
MS	7	168230	5965	28.20
CT	8	254921	8757	29.11
HI	4	67441	2208	30.54
KS	6	223056	6433	34.67
TX	32	1365893	38446	35.53
OK	8	270061	7405	36.47
SD	3	71896	1898	37.88
NY	33	1704323	40932	41.64
MT	3	103052	2466	41.79
MA	12	737985	16218	45.50
ND	3	79568	1730	45.99
NE	5	202082	4182	48.32
RI	4	118953	2455	48.45
AK	3	88394	1713	51.60
ID	4	198300	3010	65.88
WY	3	87466	1310	66.77
UT	5	312043	4625	67.47
DC	3	153850	1211	127.04