Recount 2016

A cybersecurity audit of the U.S. presidential election

J. Alex Halderman
University of Michigan
2016 U.S. Presidential Election

Donald Trump
Republican

Hillary Clinton
Democrat

November 8, 2016
Predictions were for a Clinton Win

FiveThirtyEight

Who will win the presidency?

Chance of winning

Hillary Clinton 71.4%

Donald Trump 28.6%
Predictions were for a Clinton Win

The New York Times

Hillary Clinton has an 85% chance to win.

Last updated Tuesday, November 8 at 10:20 PM ET

CHANCE OF WINNING

85%
Hillary Clinton

15%
Donald J. Trump
Predictions were for a Clinton Win

Princeton Election Consortium
A first draft of electoral history. Since 2004

As of November 7, 9:06PM EST:  
Snapshot (212 state polls): Clinton 312, Trump 226 EV  
Meta-margin: Clinton +2.7%  
Clinton Nov. win probability: random drift >99%, Bayesian >99%

Sam Wang
@SamWangPhD

It is totally over. If Trump wins more than 240 electoral votes, I will eat a bug.
Nearly everyone predicted victory for Clinton...

<table>
<thead>
<tr>
<th>Source</th>
<th>Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>NYT</td>
<td>85% Dem.</td>
</tr>
<tr>
<td>538</td>
<td>71% Dem.</td>
</tr>
<tr>
<td>HuffPost</td>
<td>98% Dem.</td>
</tr>
<tr>
<td>PW</td>
<td>89% Dem.</td>
</tr>
<tr>
<td>PEC</td>
<td>&gt;99% Dem.</td>
</tr>
<tr>
<td>DK</td>
<td>92% Dem.</td>
</tr>
<tr>
<td>Cook</td>
<td>Lean Dem.</td>
</tr>
<tr>
<td>Roth.¹</td>
<td>Lean Dem.</td>
</tr>
<tr>
<td>Sabato</td>
<td>Lean Dem.</td>
</tr>
</tbody>
</table>
POLL EXPERT EATS BUG AS PROMISED
Election Results

Donald Trump

Hillary Clinton


electoral vote 304
popular vote 62,979,879
percentage 45.95%

Electoral vote 227
Popular vote 65,844,954
Percentage 48.04%

In addition to winning the Electoral College in a landslide, I won the popular vote if you add the millions of people who didn’t vote for Hillary!

Not Really...

Presidential Election Winners, Ranked by Percentage of Electoral Vote

<table>
<thead>
<tr>
<th>Rank</th>
<th>Year</th>
<th>President</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1789</td>
<td>George Washing.</td>
<td>106</td>
</tr>
<tr>
<td>2</td>
<td>1792</td>
<td>George Washing.</td>
<td>106</td>
</tr>
<tr>
<td>3</td>
<td>1800</td>
<td>James Monroe</td>
<td>99.97</td>
</tr>
<tr>
<td>4</td>
<td>1804</td>
<td>Franklin D. Roosevelt</td>
<td>90.49</td>
</tr>
<tr>
<td>5</td>
<td>1844</td>
<td>Ronald Reagan</td>
<td>97.08</td>
</tr>
<tr>
<td>6</td>
<td>1877</td>
<td>Richard Nixon</td>
<td>66.05</td>
</tr>
<tr>
<td>7</td>
<td>1884</td>
<td>Thomas Jefferson</td>
<td>52.05</td>
</tr>
<tr>
<td>8</td>
<td>1884</td>
<td>Abraham Lincoln</td>
<td>50.79</td>
</tr>
<tr>
<td>9</td>
<td>1884</td>
<td>James A. Garfield</td>
<td>53.00</td>
</tr>
<tr>
<td>10</td>
<td>1884</td>
<td>Chester A. Arthur</td>
<td>56.00</td>
</tr>
<tr>
<td>11</td>
<td>1892</td>
<td>Benjamin Harrison</td>
<td>57.89</td>
</tr>
<tr>
<td>12</td>
<td>1892</td>
<td>Grover Cleveland</td>
<td>58.04</td>
</tr>
<tr>
<td>13</td>
<td>1892</td>
<td>William McKinley</td>
<td>58.04</td>
</tr>
<tr>
<td>14</td>
<td>1892</td>
<td>William H. Taft</td>
<td>58.04</td>
</tr>
<tr>
<td>15</td>
<td>1892</td>
<td>Theodore Roosevelt</td>
<td>59.24</td>
</tr>
<tr>
<td>16</td>
<td>1912</td>
<td>Woodrow Wilson</td>
<td>59.86</td>
</tr>
<tr>
<td>17</td>
<td>1912</td>
<td>Woodrow Wilson</td>
<td>60.34</td>
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<tr>
<td>18</td>
<td>1912</td>
<td>Woodrow Wilson</td>
<td>61.72</td>
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<tr>
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<td>1912</td>
<td>Woodrow Wilson</td>
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<tr>
<td>20</td>
<td>1912</td>
<td>Woodrow Wilson</td>
<td>63.46</td>
</tr>
<tr>
<td>21</td>
<td>1912</td>
<td>Woodrow Wilson</td>
<td>65.00</td>
</tr>
</tbody>
</table>

Source: John Pitney of Claremont McKenna College

Donald J. Trump
@realDonaldTrump
What Happened?

Explanation A: Systematically Wrong Polls

Explanation B: Results Were Rigged

Is rigging actually **feasible**?

How can we **find out** which explanation is true?
American Elections
Election Technology by County: State of Arkansas
U.S. Voting Machines

2 Styles, 52 Models

Optical Scan
Computer counts paper ballots as they’re placed in ballot box

DRE (Direct Recording Electronic)
Votes cast on-screen, recorded in memory; sometimes prints paper audit records (VVPATs)
Every U.S. voting machine subjected to rigorous independent security review suffered vulnerabilities that allow the spread of vote-stealing malware.

<table>
<thead>
<tr>
<th>Voting Machine</th>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hart InterCivic eSlate</td>
<td>2007</td>
<td>Cards spread malware</td>
</tr>
<tr>
<td>AVC Advantage</td>
<td>2009</td>
<td>Cards spread malware</td>
</tr>
<tr>
<td>Sequoia AVC Edge</td>
<td>2007</td>
<td>Cards spread malware</td>
</tr>
<tr>
<td>Optech Insight</td>
<td>2007</td>
<td>Cards spread malware</td>
</tr>
<tr>
<td>ES&amp;S iVotronic</td>
<td>2007</td>
<td>Cards spread malware</td>
</tr>
<tr>
<td>Diebold AccuVote TSX</td>
<td>2007</td>
<td>Cards spread malware</td>
</tr>
<tr>
<td>Diebold AccuVote OS</td>
<td>2007</td>
<td>Cards spread malware</td>
</tr>
<tr>
<td>ES&amp;S Model 100</td>
<td>2007</td>
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</tr>
</tbody>
</table>
Hacking an Election?
Election Hacking

Alter election-night results
Undermines credibility, even if detected

Denial of service
Selectively cause long lines, etc.

Political interference
Selectively discredit candidates
Election Hacking

Visible Attacks

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Political interference
Selectively discredit candidates

Ukraine election narrowly avoided 'wanton destruction' from hackers

A brazen three-pronged cyber-attack against last month’s Ukrainian presidential elections has set the world on notice – and bears Russian fingerprints, some say.

By Mark Clayton, Staff writer | JUNE 17, 2014

A three-pronged wave of cyber-attacks aimed at wrecking Ukraine’s presidential vote – including an attempt to fake computer vote totals – was narrowly defeated by government cyber experts, Ukrainian officials say.

The still little-known hacks, which surfaced May 22-26, appear to be among the most dangerous cyber-attacks yet deployed to sabotage a national election – and a warning shot for future elections in the US and abroad, political scientists and cyber experts say.
Election Hacking

**Alter election-night results**
Undermines credibility, even if detected

**Denial of service**
Selectively cause long lines, etc.

**Political interference**
Selectively discredit candidates

*Visible Attacks*

**July:** Democratic National Committee emails hacked; leaked to press

**August:** Voter registration systems in Illinois and Arizona hacked; other states probed

**October:** John Podesta (Clinton’s campaign manager) email hacked; leaked to press


**Politics**

**U.S. Says Russia Directed Hacks to Influence Elections**

By DAVID E. SANGER and CHARLIE SAVAGE  OCT. 7, 2016

WASHINGTON — The Obama administration on Friday formally accused the Russian government of stealing and disclosing emails from the Democratic National Committee and a range of other institutions and prominent individuals, immediately raising the issue of whether President Obama would seek sanctions or other retaliation.
How hard would it be to invisibly change the outcome, by tampering with the voting machines?

**Challenge 1**
Diverse, decentralized voting technology

**Challenge 2**
Machines aren’t connected to the Internet

**Challenge 3**
70% of U.S. votes have a paper record
How hard would it be to invisibly change the outcome, by tampering with the voting machines?

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Centralized **election management** computer programs ballot design to memory cards before each election. If infected, can spread malware to all machines across one or more counties.
How hard would it be to attack an election management computer?

Many jurisdictions outsource their ballot programming to small, outside businesses.

75% of Michigan counties use just two ~20 person companies.
Election Hacking

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Invisible Attacks

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Paper as a Defense

Slow/expensive to tally
Verified by voter

Fast/cheap to tally
Unverified
Use of Paper has Increased

Over 70% of votes cast in 2016 were recorded on paper.
How hard would it be to invisibly change the outcome, by tampering with the voting machines?

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Most states rarely or never look at paper!
How hard would it be to invisibly change the outcome, by tampering with the voting machines?

**Easier than you thought!**

**Step 1**
Use pre-election polls to identify likely close states.

**Step 2**
Target large counties or service providers, and compromise election management computers.

**Step 3**
Infected memory cards exploit vulnerable voting machines to run malware, swap, e.g., 10% of votes.

**Step 4**
Most states just throw away the paper ballots.
An Uninvited Security Audit
Hacking Was Plausible

After Election Day (Nov. 8), we knew:

Presidential results were extremely close, defied polling.
U.S. alleged Russian political cyberattacks during campaign.
Feasible to attack enough machines to have changed outcome.

Shockingly, even under these circumstances, no state would examine enough evidence to expose such an attack.

Five weeks until results are locked in on Dec. 13.
Will we ever be able to confirm outcome was correct?
We and other election integrity advocates wonder what to do?
Would Clinton Demand a Recount?

Where’s **evidence** of fraud? (!!!)
How to pay for recounts?
Backpedalling her concession?
In third presidential debate, Trump refused to say he would accept the election results.

“He said something truly horrifying… A direct threat to our democracy.”
New Idea: Any Candidate can Demand a Recount!

Where's evidence of fraud? (!!)

How to pay for recounts?

Backpedalling her concession?

Jill Stein
2016 Green Party Presidential Candidate

On ballot in most states
Won 1.06% of the vote
Willing to lead recounts!
“they’ve found persuasive evidence that the results … may have been hacked.”

“The only way to know whether a cyberattack changed the result is to examine the physical evidence: paper ballots and voting equipment.”
How to Pay?

Crowdfunding!

In two days, raised $5M

After two weeks, $7M

Over 160,000 donors!
All three projected for Clinton, won by Trump

Combined 46 electoral votes

All three had margins <0.8%, in total decided by fewer than 78,000 votes

MI and WI allow candidates to petition for a recount, PA requires court order
Why Not Other States?

Donald J. Trump
@realDonaldTrump

Serious voter fraud in Virginia, New Hampshire and California - so why isn't the media reporting on this? Serious bias - big problem!

New Hampshire . . . . . . . deadline passed 6 days after election
Virginia . . . . . . . . . . illegal to recount unless margin of victory is under 1% (Clinton won by 4.9%)
California . . . . . . . . margin of victory in California was 30%

Trump could have initiated his own recounts, but did not.
First recount petition filed, in Wisconsin, Nov. 25
President-elect Trump not a fan
He and his lawyers would oppose efforts in all three states

Let the Recounting Begin!

Donald J. Trump
@realDonaldTrump

The Green Party scam to fill up their coffers by asking for impossible recounts is now being joined by the badly defeated & demoralized Dems
IN THE COURT OF COMMON PLEAS OF ALLEGHENY COUNTY, PENNSYLVANIA

IN RE: RECOUNT AND/OR RECANVASS OF THE VOTE FOR PRESIDENT OF THE UNITED STATES AND FOR UNITED STATES SENATE IN NOVEMBER 8, 2016 GENERAL ELECTION

) CIVIL DIVISION
) No. GD 16-22954

PETITION FOR INTERVENTION IN OPPOSITION TO APPEAL AND IN SUPPORT OF VOTER-INITIATED RECOUNTS AND RECANVASSES UNDER ELECTION CODE SECTION 1404

Pursuant to Pa. R.C.P. 2326-30, Jill Stein for President and Jill Stein (collectively, “Dr. Stein”) hereby petition this Court for leave to intervene in this appeal to assert their interests in a voter-initiated recount and recanvass under Section 1404 of the Pennsylvania Election Code, and for an order (s) affirming the decision of the Allegheny County Board of Elections to conduct a
What Does a Recount Look Like?  ...and also like this

Lansing, Michigan
What Does a Recount Look Like?  ...and also like this

Philadelphia, Pennsylvania
What Does a Recount Look Like?  ...and also like this

Philadelphia, Pennsylvania
What Does a Recount Look Like? ...and also like this
The Election is Decided
Donald Trump Completes Final Lap, Electoral College, to White House

By THE NEW YORK TIMES  DEC. 19, 2016
Completed Wisconsin recount widens Donald Trump's lead by 131 votes

Michigan Halts Election Recount, Effectively Ending Bid
Recount Outcome … no state completed a full hand recount

Wisconsin . . . . Recounted statewide, though not all by hand
51 counties counted by hand, 9 by re-scanning, 12 by a combination
11,883 vote corrections (over half the margin of victory!)
Net change: 397 votes. No evidence of an attack.

Michigan . . . . Halted after three days under opposition from state and Trump
10 counties finished, 12 started but did not finish (out of 83)
2,099,578 ballots recounted (43% of total cast); still waiting for full data.
Net change: 1651 votes. No evidence of an attack.

Pennsylvania . . Defeated in federal court under opposition from state and Trump
One county (out of 67) recounted by hand, and only 143 of its 228 precincts
No published results. Presumably no evidence of an attack?
Lesson: It is really difficult to audit the votes in Pennsylvania!
Records: Too many votes in 37% of Detroit’s precincts

Half of Detroit votes may be ineligible for recount
What we really want:

Statistical Risk-Limiting Audit

Hand count randomly sampled precincts until you establish, with high statistical confidence, that hand-counting all of the paper records would yield the same winner.

Much cheaper than a full recount and yields the same confidence.

What we actually have:

Incomplete, non-random county-level samples.

What to do?
Recounts let us rule out some attack scenarios (e.g., statewide fraud). What about other scenarios?

Still waiting for full data to do complete analysis, but here’s the idea: Test likelihood of probable attack scenarios being caught.

One attack model:

Attacker compromises entire counties at random until enough to change election winner. Can swap up to 10% of county’s votes without suspicion.

If the randomly selected counties were recounted by hand, then this attempt to throw the election is considered detected.
Under this scenario, how much confidence do the recounts provide?

<table>
<thead>
<tr>
<th>State</th>
<th>Average number of counties needed for attack</th>
<th>Chance of attack being detected during recount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wisconsin</td>
<td>7</td>
<td>95%</td>
</tr>
<tr>
<td>Michigan</td>
<td>4</td>
<td>82%</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>13</td>
<td>9%</td>
</tr>
</tbody>
</table>
What did we learn from the recount results?

Evidence **supports the integrity of the election outcome**, but is **not strong enough to definitively rule out a cyberattack** on the voting machines, due to the recounts being incomplete.
Lessons & Conclusion
Hacking a U.S. presidential election **even easier** than we thought!

- **Vulnerable machines** and **central points of attack** can be exploited to steal votes in jurisdictions across multiple swing states.

- **States unlikely to look at paper**, even in a close election with surprising results and known cyberattacks by a foreign power.

- Even if candidates try to force a recount, many opportunities for apparent winner to put up **legal roadblocks**, as they inevitably will, whoever wins.
This election probably wasn’t hacked ... what about next time?

**U.S. badly needs to reform its voting system**

- Make attacks more difficult: **Harden voting technology**
- Ensure attacks detectable: **Implement 100% paper ballots**
  States that need to act: PA, IN, TX, NJ, DE, SC, GA, MS, TN, NC, VA, LA, AR, KS, KY
- Use the physical evidence: **Conduct routine risk-limiting audits**
  Much cheaper than full recounts; should be done in every national election

Reforms could be in place by 2018 if states and federal government act now.
Recount 2016

A cybersecurity audit of the U.S. presidential election

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