QCon, San Francisco
11/11/2013

A/B tests and Online Controlled Experiments: Introduction, Insights, Scaling, and Humbling Statistics

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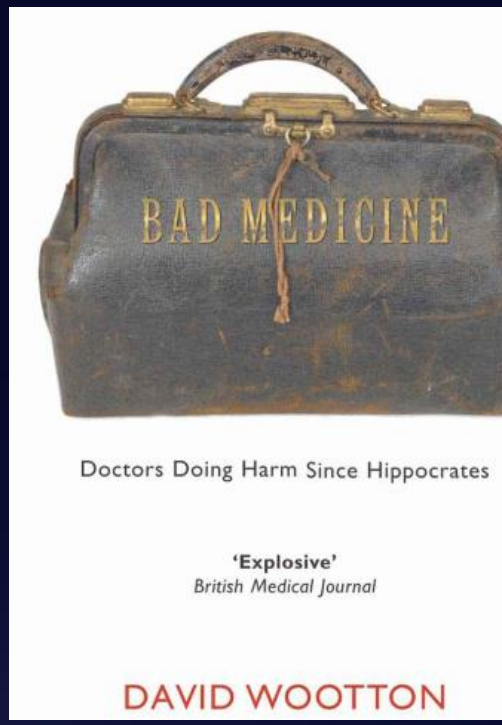
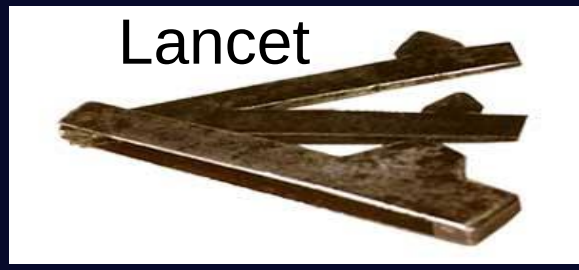
Assessing Ideas is Hard



- Doctors take the Hippocratic Oath associated with "Do no harm," yet David Wootton writes
  - For 2,400 years patients have believed that doctors were doing them good; for 2,300 years they were wrong
- For centuries, an illness was thought to be a toxin
  - Opening a vein and letting the sickness run out was the best solution –bloodletting
  - A British medical text recommended bloodletting for acne, asthma, cancer, cholera, coma, convulsions, diabetes, epilepsy, gangrene, gout, herpes, indigestion, insanity, jaundice, leprosy, ophthalmia, plague, pneumonia, scurvy, smallpox, stroke, tetanus, tuberculosis, and for some one hundred other diseases
  - Physicians often reported the simultaneous use of fifty or more leeches on a given patient
  - Through the 1830s the French imported about forty million leeches a year for medical purposes

Assessing Ideas is Hard (2)



- President George Washington had a sore throat
  - Doctors extracted 82 ounces of blood over 10 hours (35% of his total blood), causing anemia and hypotension.
  - He died that night
- Pierre Louis did an experiment in 1836
  - One of the first randomized controlled experiments (clinical trials). He treated people with pneumonia either with
    - early, aggressive bloodletting, or
    - less aggressive measures
  - At the end of the experiment, Dr. Louis counted the bodies; they were stacked higher over by the bloodletting sink

Most software changes are believed to be positive to the user experience, but are often flat or negative!

Once you objectively evaluate changes, you're often humbled

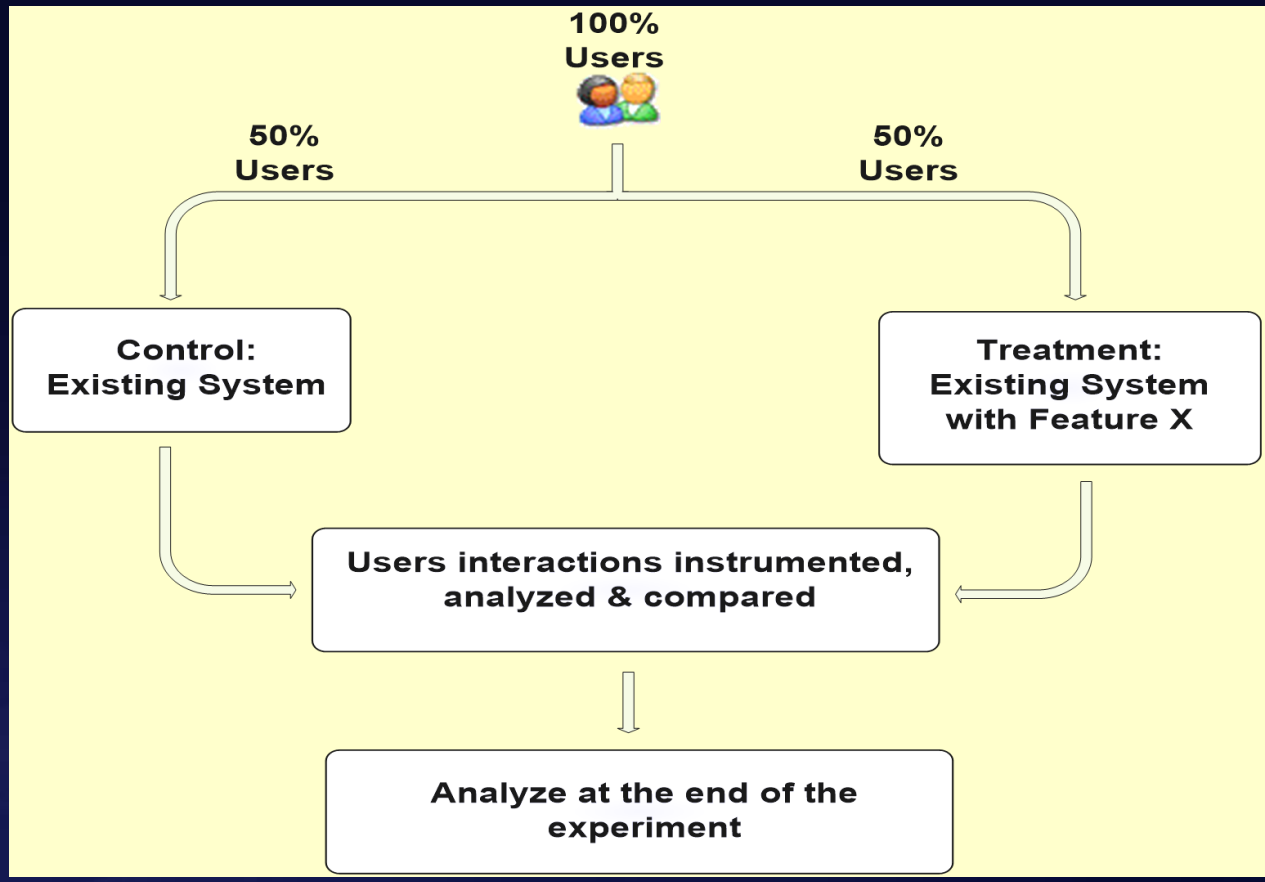
Agenda

- Controlled experiments and observational studies
- Examples: you’re the decision maker
- Running experiments at scale and best practices
- The cultural challenge

- Two key messages to remember
  - It is hard to assess the value of ideas.
    Get the data by experimenting because data trumps intuition
  - Make sure the org agrees **what** you are optimizing

Controlled Experiments in One Slide

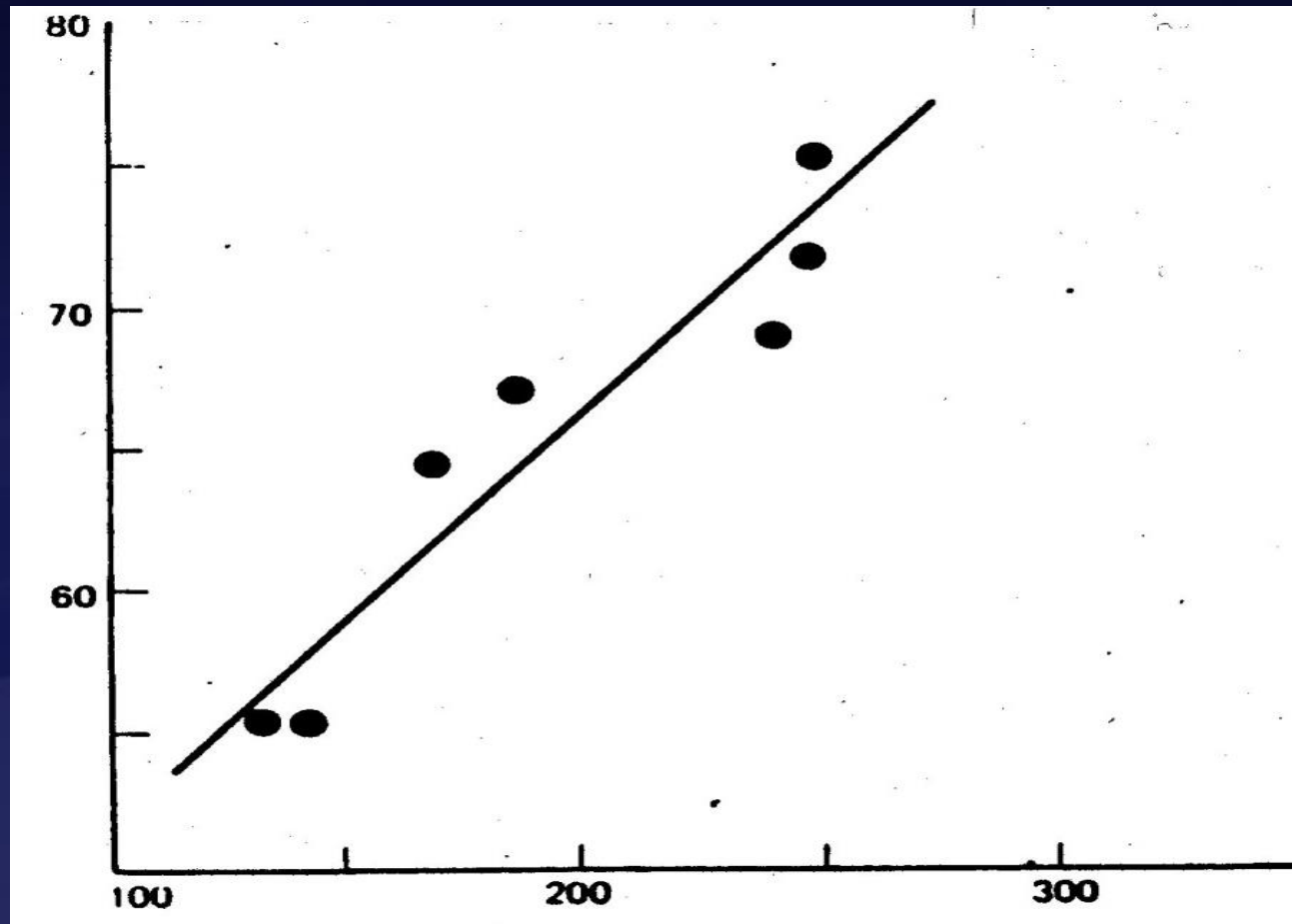
- Concept is trivial
  - Randomly split traffic between two (or more) versions
    - A (Control)
    - B (Treatment)
  - Collect metrics of interest
  - Analyze



- Must run statistical tests to confirm differences are not due to chance
- Best scientific way to prove causality, i.e., the changes in metrics are caused by changes introduced in the treatment(s)

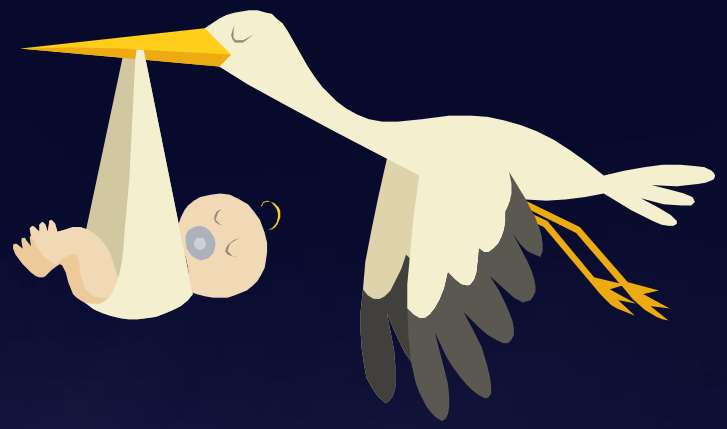
Typical Discovery

- With data mining, we find patterns, but most are correlational, providing hypotheses for possible causes
- Here is one a real example of two highly correlated variables



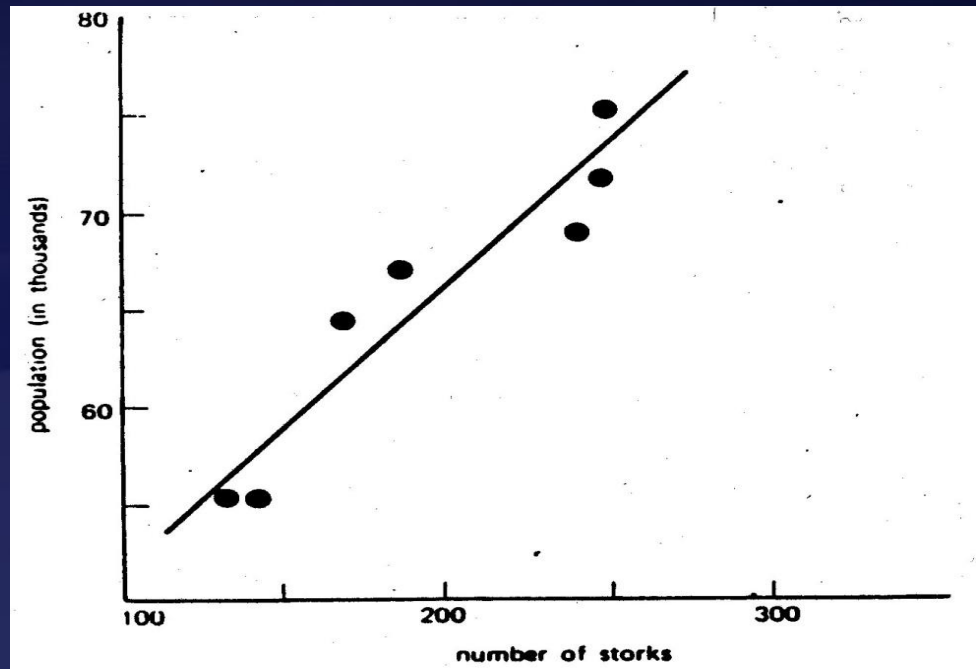
Correlations are not Necessarily Causal

- Real Data for the city of Oldenburg, Germany
  - X-axis: stork population
  - Y-axis: human population



- What your mother told you about babies and storks when you were three is not correct, despite the strong correlational "evidence"

- Killing the storks won't solve population growth problems



Ornitholigische Monatsberichte 1936;44(2)

Personalized Correlated Recommendations

- Actual personalized recommendations from Amazon.
  (I was director of data mining and personalization at Amazon back in 2003, so I can ridicule my work.)
- Buy a 30” monitor because you bought a DisplayPort cable

- Buy Atonement movie DVD because you bought a Maglite flashlight

- Buy Organic Virgin Olive Oil because you bought Toilet Paper

Even the "Best" Observational Studies are Wrong

"[Ioannidis] evaluated the reliability of forty-nine influential studies (each cited more than 1,000 times) published in major journals …

- 90 percent of large randomized experiments produced results that stood up to replication, as compared to only
- 20 percent of nonrandomized studies."

-- Jim Manzi, Uncontrolled

Advantage of Controlled Experiments

- Controlled experiments test for causal relationships, not simply correlations
- When the variants run concurrently, only two things could explain a change in metrics:
  1. The “feature(s)” (A vs. B)
  2. Random chance

  Everything else happening affects both the variants

  For #2, we conduct statistical tests for significance (“Student’s t-test”)
- The gold standard in science and the only way to prove efficacy of drugs in FDA drug tests
- Controlled experiments are not the panacea for everything. Issues discussed in the journal survey paper

Examples

- Three experiments that ran at Microsoft
- Each helps share interesting lessons
- All had enough users for statistical validity
- Game: see how many you get right
  - Everyone please stand up
  - Three choices are:
    - A wins (the difference is statistically significant)
    - A and B are approximately the same (no stat sig diff, < 2% delta)
    - B wins

MSN Home Page Search Box

OEC: Clickthrough rate for Search box and popular searches

A

B

Differences: A has taller search box (overall size is the same), has magnifying glass icon, "popular searches"
B has big search button

- Raise your left hand if you think A Wins
- Raise your right hand if you think B Wins
- Don't raise your hand if they are the about the same

Search Box

- <deleted>
- Insights
  - Stop debating, it's easier to get the data
  - Most people are overly confident that their idea will work.
    How confident were you?
    Reality: most ideas fail to deliver (statistics in later slides)
  - To get insights try OFAT: One Factor At a Time.
    Don't tweak too many things at once.
    (But be careful not to fall into Incrementalism)

MSN US Home Page: Search Box

- A later test showed that changing the magnifying glass to an actionable word (search, go, explore) was highly beneficial.
- This:

is better than

In line with Steve Krug's great book: Don't Make Me Think

Bing Ads with Site Links

- Should Bing add “site links” to ads, which allow advertisers to offer several destinations on ads?
- OEC: Revenue, ads constraint to same vertical pixels on avg

A B

- Pro: richer ads, users better informed where they land
- Cons: Constraint means on average 4 “A” ads vs. 3 “B” ads
  Variant B is 5msc slower (compute + higher page weight)

- Raise your Left hand if you think A Wins
- Raise your Right hand if you think B Wins
- Don’t raise your hand if you think they’re about the same

Bing Ads

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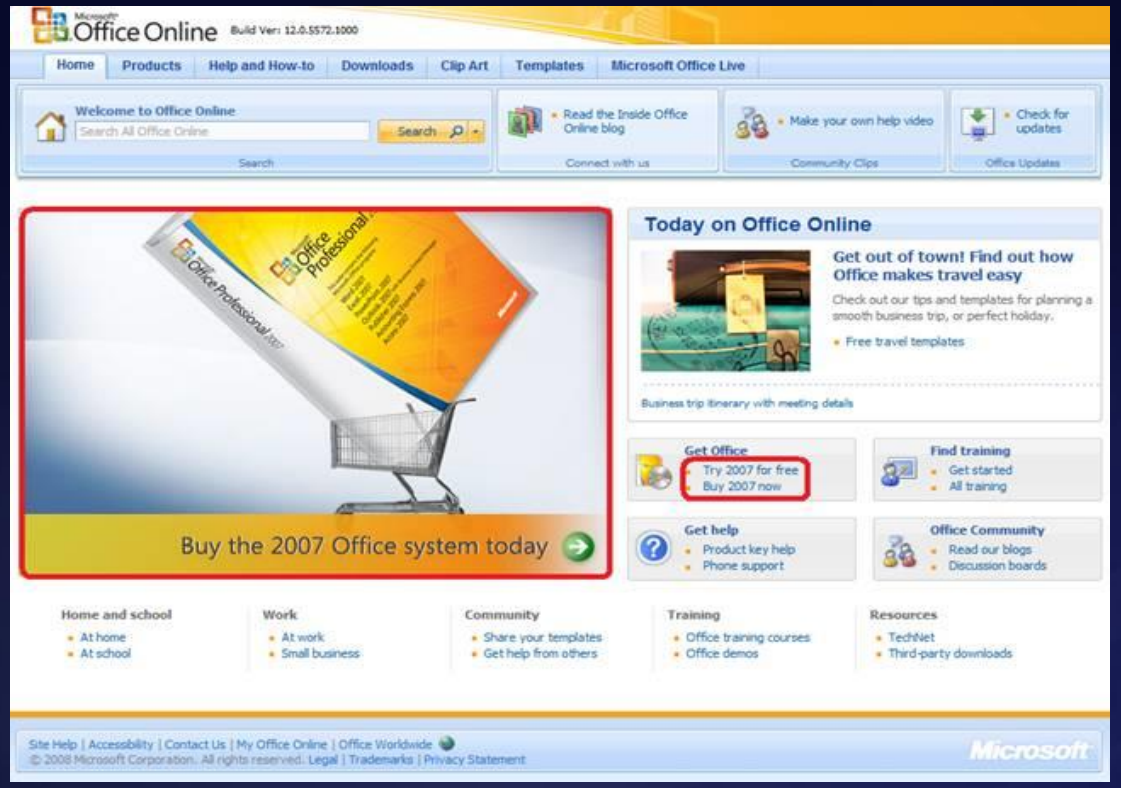
Office Online

OEC: Clicks on revenue generating links (red below)

A



B

- Raise your left hand if you think A Wins
- Raise your right hand if you think B Wins
- Don’t raise your hand if they are the about the same

Office Online

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- What % of the audience is still standing? Humbling!
- Remember: random guesses = 1/3^3 = 1/27

Twyman's Law

Any figure that looks interesting or different is usually wrong

- If something is "amazing," find the flaw!
- Examples
  - If you have a mandatory birth date field and people think it's unnecessary, you'll find lots of 11/11/11 or 01/01/01
  - If you have an optional drop down, do not default to the first alphabetical entry, or you'll have lots of: jobs = Astronaut
  - For most web sites, traffic will be lower 2AM-3AM March 9, 2014, relative to the same hour a week prior. Why?
- Previous Office Example
- More at http://bitly.com/twymanLaw

Hard to Assess the Value of Ideas: Data Trumps Intuition

- Features are built because teams believe they are useful. But most experiments show that features fail to move the metrics they were designed to improve
- We joke that our job is to tell clients that their new baby is ugly
- In *Uncontrolled,* Jim Manzi writes
  - Google ran …randomized experiments… with [only] about 10 percent of these leading to business changes.
- In an Experimentation and Testing Primer by Avinash Kaushik, authors of *Web Analytics: An Hour a Day,* he wrote
  - 80% of the time you/we are wrong about what a customer wants

Hard to Assess the Value of Ideas: Data Trumps Intuition

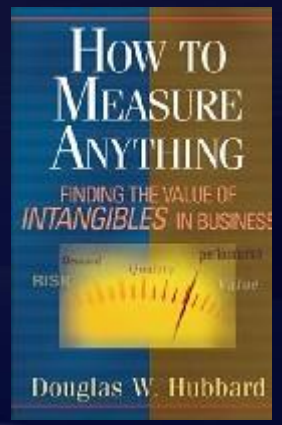
- Based on experiments at Microsoft (paper)
  - 1/3 of ideas were positive ideas and statistically significant
  - 1/3 of ideas were flat: no statistically significant difference
  - 1/3 of ideas were negative and statistically significant
- Our intuition is poor: 60-90% of ideas do not improve the metric(s) they were designed to improve (domain dependent). Humbling!

Key Lessons

- Avoid the temptation to try and build optimal features through extensive planning without early testing of ideas
- Experiment often
  - *To have a great idea, have a lot of them* -- Thomas Edison
  - *If you have to kiss a lot of frogs to find a prince, find more frogs and kiss them faster and faster*
    -- Mike Moran, Do it Wrong Quickly
- Try radical ideas. You may be surprised
  - Doubly true if it's cheap to implement (e.g., shopping cart recommendations)
  - *If you're not prepared to be wrong, you'll never come up with anything original* – Sir Ken Robinson, TED 2006 (#1 TED talk)

The OEC

- If you remember one thing from this talk, remember this point
- OEC = Overall Evaluation Criterion
  - Agree early on what you are optimizing
  - Getting agreement on the OEC in the org is a huge step forward
  - Suggestion: optimize for **customer lifetime value**, not immediate short-term revenue
  - Criterion could be weighted sum of factors, such as
    - Time on site (per time period, say week or month)
    - Visit frequency
  - Report many other metrics for diagnostics, i.e., to understand the why the OEC changed and raise new hypotheses



OEC for Search

- KDD 2012 paper (*)
- Search engines (Bing, Google) are evaluated on query share (distinct queries) and revenue as long-term goals
- Puzzle
  - A ranking bug in an experiment resulted in very poor search results
  - Distinct queries went up over 10%, and revenue went up over 30%
  - What metrics should be in the OEC for a search engine?
- Degraded (algorithmic) search results cause users to search more to complete their task, and ads appear more relevant

(*) KDD 2012 paper with Alex Deng, Brian Frasca, Roger Longbotham, Toby Walker, Ya XU

Puzzle Explained

- Analyzing queries per month, we have

$$\frac{Queries}{Month} = \frac{Queries}{Session} \times \frac{Sessions}{User} \times \frac{Users}{Month}$$

where a session begins with a query and ends with 30-minutes of inactivity. (Ideally, we would look at tasks, not sessions).

- Key observation: we want users to find answers and complete tasks quickly, so queries/session should be smaller
- In a controlled experiment, the variants get (approximately) the same number of users by design, so the last term is about equal
- The OEC should therefore include the middle term: sessions/user

Agenda

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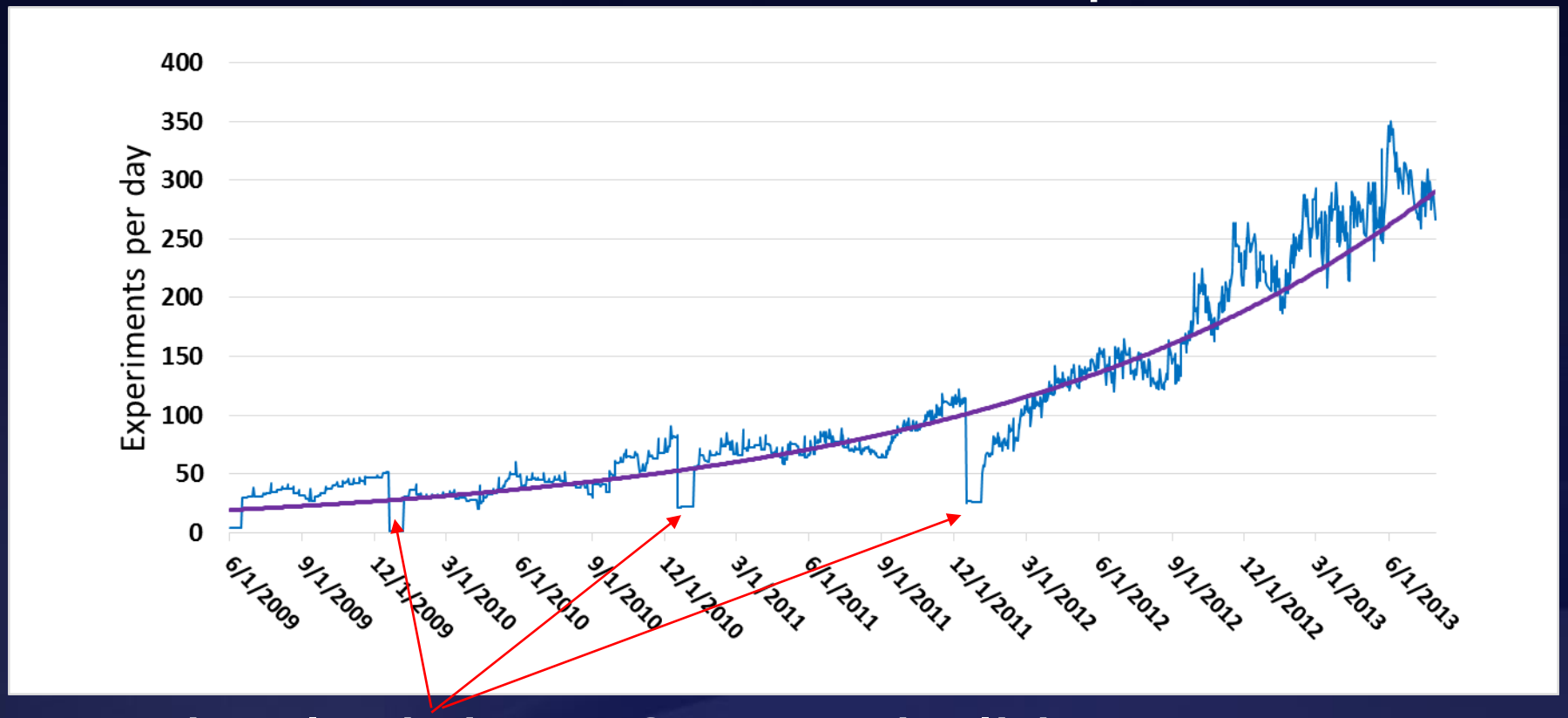
Scaling Experiments at Bing

- KDD 2013 paper to appear: http://bit.ly/ExPScale
- We now run over 250 concurrent experiments at Bing



- We used to lockdown for Dec holidays. No more

No Single Version of “Production”

It is usually a safe assumption that you only have one version of your software in production at a time
-- Jez Humble and David Farley from Continuous Delivery

Running Controlled Experiments at Scale (1)

- In a visit, you're in about 15 experiments
  - There is no single Bing.
    There are 30B variants (5^15)
  - 90% of users are in experiments.
    10% are kept as holdout
- Sensitivity: we need to detect small effects
  - 0.1% change in the revenue/user metric > $1M/year
  - Not uncommon to see unintended revenue impact of +/-1% (>$10M)
  - Sessions/UU, a key component of our OEC, is hard to move, so we're looking for small effects
  - Important experiments run on 10-20% of users

UI	Ex	Ex p 2	Ex P 3	Exp 4	Exp 5
Ads	Ex P 1	Ex P 2	Ex P 3	ExP 4	Exp 5
Rele vance	…				
…					
Feature area					

Running Controlled Experiments at Scale (2)

- Challenges
  - QA. You can't QA all combinations, of course.
    What are the equivalence classes?
    For UI change, no need to QA combinations of relevance exps
  - Alarming on anomalies is critical: notify experiment owners that there's a big delta on metric M (100 metrics) for browser B
  - Interactions (optimistic experimentation): everyone experiments.
    Run statistical tests for pairwise interactions, and notify owners.
  - Carryover effects: reuse of "bucket of users" from one experiment to the next is problematic

Important Lesson: Performance

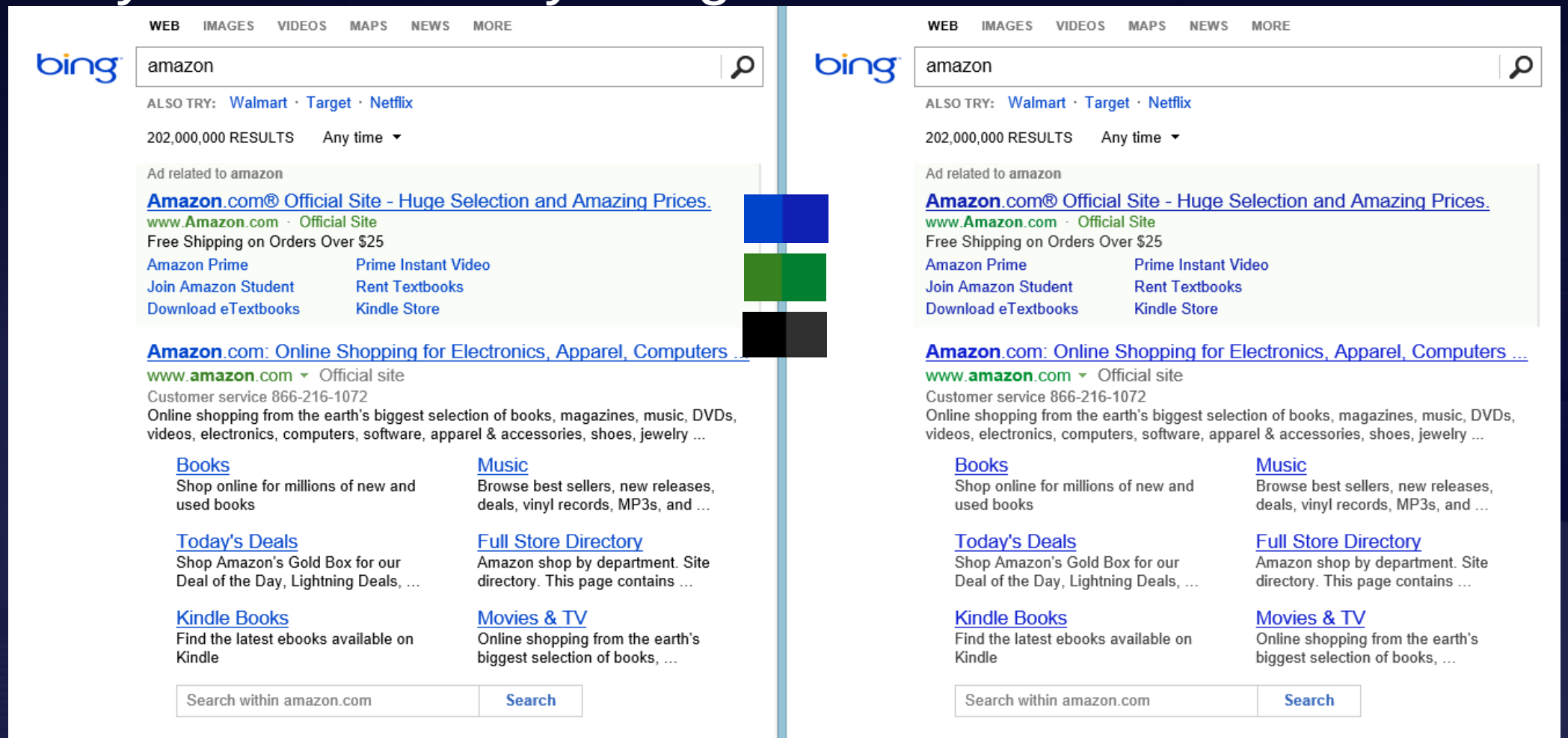
- Bing server time is under one second at the 95th percentile
- Is it worth improving?
- We ran slowdown experiments to see the impact: we introduce an artificial server delay
- Performance matters a LOT. Here's the summary:

An engineer that improves server performance by 10msec (that's 1/30 of the speed that our eyes blink) more than pays for his fully-loaded annual costs

- Every millisecond counts

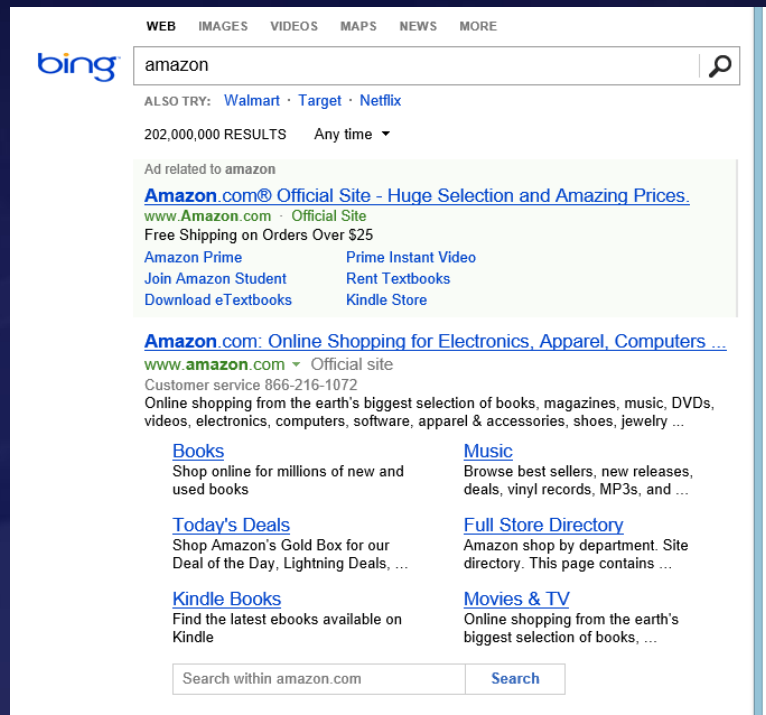
Lesson: Small Changes can have High ROI

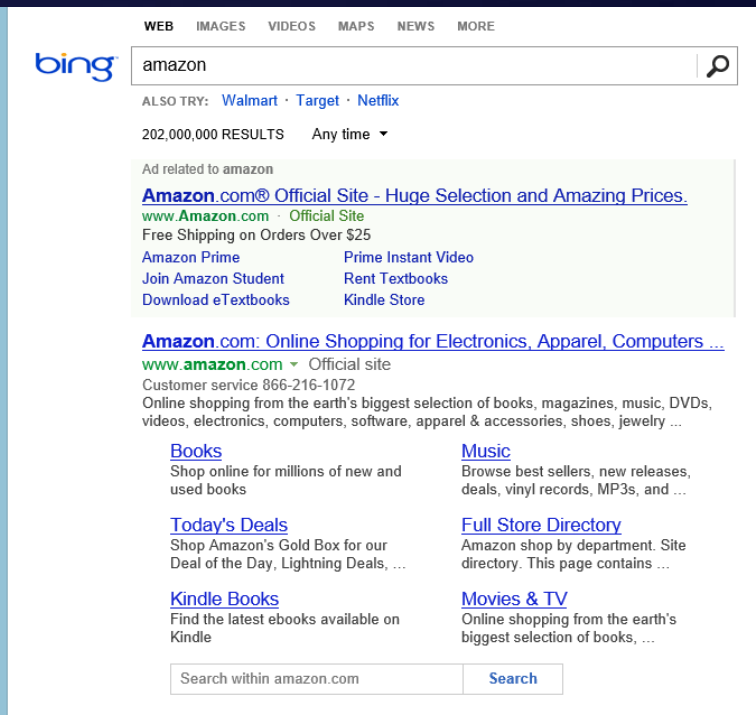
- We made small changes to font colors in August 2013
- Can you see? Can you figure out which is better?



Lesson: Small Changes (2)

- The change was from the left version to the right version
- Users were more successful in their tasks (SSR)
- Users completed tasks faster (time-to-success)
- We made more money (over $10M annually)
- Companies set standard company color/fonts without appreciating the impact it can have





Best Practice: A/A Test

- Run A/A tests – simple, but highly effective
  - Run an experiment where the Treatment and Control variants are coded identically and validate the following:
    1. Are users split according to the planned percentages?
    2. Is the data collected matching the system of record?
    3. Are the results showing non-significant results 95% of the time?
  - This is a powerful technique for finding problems
  - Generating some numbers is easy
  - Getting correct numbers you trust is much harder!

Remove Bots for Analysis

- Bots are lucrative business, but they skew the statistics
- At Bing, >50% of traffic comes from bots

Actual picture I took

Best Practice: Ramp-up

- Ramp-up
  - Start an experiment at 0.1%
  - Do some simple analyses to make sure no egregious problems can be detected
  - Ramp-up to a larger percentage, and repeat until 50%
- Big differences are easy to detect because the min sample size is quadratic in the effect we want to detect
  - Detecting 10% difference requires a small sample and serious problems can be detected during ramp-up
  - Detecting 0.1% requires a population 100^2 = 10,000 times bigger
- Abort the experiment if treatment is significantly worse on key metrics

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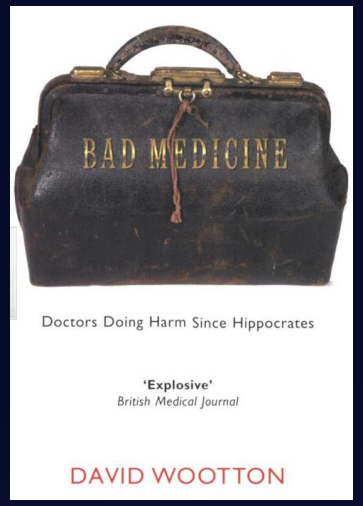
The Cultural Challenge

It is difficult to get a man to understand something when his salary depends upon his not understanding it.
-- Upton Sinclair

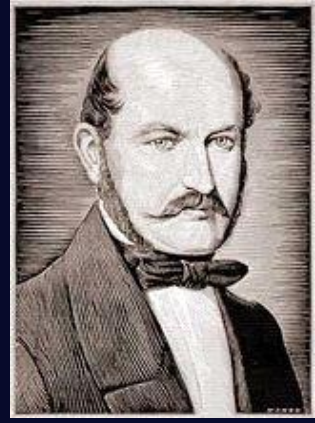
- Why people/orgs avoid controlled experiments
  - Some believe it threatens their job as decision makers
  - At Microsoft, program managers select the next set of features to develop. Proposing several alternatives and admitting you don't know which is best is hard
  - Editors and designers get paid to select a great design
  - Failures of ideas may hurt image and professional standing. It's easier to declare success when the feature launches
  - We've heard: "we know what to do. It's in our DNA," and "why don't we just do the right thing?"

Cultural Stage 1: Hubris

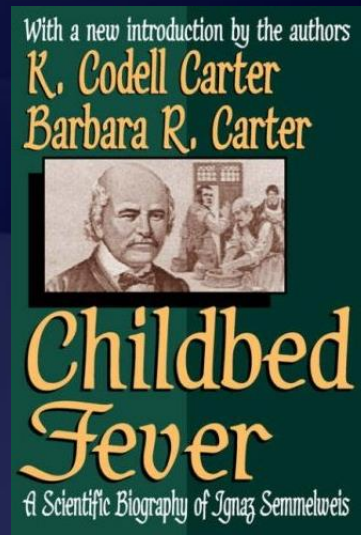


- The org goes through stages in its cultural evolution
- Stage 1: we know what to do and we're sure of it
  - True story from 1849
  - John Snow claimed that Cholera was caused by polluted water
  - A landlord dismissed his tenants' complaints that their water stank
    - Even when Cholera was frequent among the tenants
  - One day he drank a glass of his tenants' water to show there was nothing wrong with it
- He died three days later
- That's hubris. Even if we're sure of our ideas, evaluate them
- Controlled experiments are a powerful tool to evaluate ideas

Cultural Stage 2: Insight through Measurement and Control



- Semmelweis worked at Vienna's General Hospital, an important teaching/research hospital, in the 1830s-40s
- In 19th-century Europe, childbed fever killed more than a million women
- Measurement: the mortality rate for women giving birth was
  - 15% in his ward, staffed by doctors and students
  - 2% in the ward at the hospital, attended by midwives



Cultural Stage 2: Insight through Measurement and Control

- He tries to control all differences
  - Birthing positions, ventilation, diet, even the way laundry was done
- He was away for 4 months and death rate fell significantly when he was away. Could it be related to him?
- Insight:
  - Doctors were performing autopsies each morning on cadavers
  - Conjecture: particles (called germs today) were being transmitted to healthy patients *on the hands of the physicians*
- He experiments with cleansing agents
  - Chlorine and lime was effective: death rate fell from 18% to 1%

Cultural Stage 3: Semmelweis Reflex

- Success? No! Disbelief. Where/what are these particles?
  - Semmelweis was dropped from his post at the hospital
  - He goes to Hungary and reduced mortality rate in obstetrics to 0.85%
  - His student published a paper about the success. The editor wrote

    We believe that this chlorine-washing theory has long outlived its usefulness… It is time we are no longer to be deceived by this theory
- In 1865, he suffered a nervous breakdown and was beaten at a mental hospital, where he died
- Semmelweis Reflex is a reflex-like rejection of new knowledge because it contradicts entrenched norms, beliefs or paradigms
- Only in 1800s? No! A 2005 study: inadequate hand washing is one of the prime contributors to the 2 million health-care-associated infections and 90,000 related deaths annually in the United States

Cultural Stage 4: Fundamental Understanding

- In 1879, Louis Pasteur showed the presence of Streptococcus in the blood of women with child fever
- 2008, 143 years after he died, there is a 50 Euro coin commemorating Semmelweis

True Story – Scurvy and Vitamin C

- Without fundamental understanding, you make mistakes
- Scurvy is a disease that results from vitamin C deficiency
- It killed over 100,000 people in the 16th-18th centuries, mostly sailors
- First known controlled experiment in 1747
  - Dr. James Lind noticed lack of scurvy in Mediterranean ships
  - Gave some sailors limes (treatment), others ate regular diet (control)
  - Experiment was so successful, British sailors are still called limeys
- But Lind didn't understand the reason
  - At the Royal Naval Hospital in England, he treated Scurvy patients with concentrated lemon juice called "rob."
  - He concentrated the lemon juice by heating it, thus destroying the vitamin C
  - He lost faith in the remedy and became increasingly reliant on bloodletting
- In 1793, a formal trial was done and lemon juice became part of the daily rations throughout the navy; Scurvy was quickly eliminated

Summary: Evolve the Culture

- In many areas we're in the 1800s in terms of our understanding, so controlled experiments can help
  - First in doing the right thing, even if we don't understand the fundamentals
  - Then developing the underlying fundamental theories

Summary

The less data, the stronger the opinions

1. Empower the HiPPO with data-driven decisions
   - HiPPO = Highest Paid-Person in Org, or Highest Paid-Person's Opinion
   - Hippos kill more humans than any other (non-human) mammal (really)
   - OEC: make sure the org agrees **what** you are optimizing (long term lifetime value)
2. It is hard to assess the value of ideas
   - Listen to your customers – Get the data
   - Prepare to be humbled: data trumps intuition
3. Compute the statistics carefully
   - Getting a number is easy. Getting a number you should trust is harder
4. Experiment often to accelerate innovation
   - Triple your experiment rate and you triple your success (and failure) rate. Fail fast & often in order to succeed

Resources and Q&A

- This talk: http://bit.ly/expQCon
- http://exp-platform.com has papers, talks including
  - Controlled Experiments on the Web: Survey and Practical Guide (Data Mining and Knowledge Discovery journal)
  - Online experiments at Microsoft (Third Workshop on Data Mining Case Studies and Practice Prize)
  - Trustworthy Online Controlled Experiments: Five Puzzling Outcomes Explained (KDD 2012)
  - Online Controlled Experiments at Large Scale (KDD 2013)
- Nice Etsy talk: http://www.slideshare.net/danmckinley/design-for-continuous-experimentation