

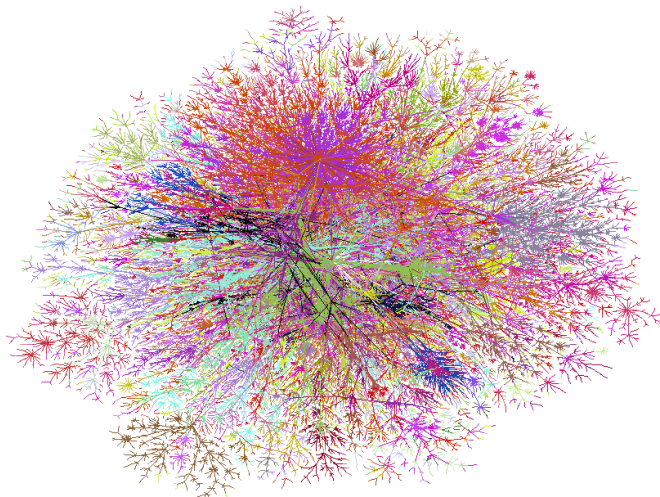
Internet Measurement and Data Analysis (1)

Kenjiro Cho

2016-04-11

introduction

how does the entire Internet look like?



lumeta internet mapping <http://www.lumeta.com>

<http://www.cheswick.com/ches/map/>

introduction (cont'd)

how does the entire Internet look like?

- ▶ no one knows
- ▶ but, everyone is interested

the theme of the class

- ▶ looking at the Internet from different views
 - ▶ how to measure what is difficult to measure
 - ▶ how to extract useful information from huge data sets

this kind of approach will be increasingly important in the future
information society

Internet measurement and data analysis

- ▶ Faculty: Kenjiro Cho <kjc@sfc.keio.ac.jp>
- ▶ TA: Yusaku Sawai <sawai@sfc.wide.ad.jp>
- ▶ SA: Yuma Kurogome <gomachan@sfc.wide.ad.jp>
- ▶ URL: <http://web.sfc.keio.ac.jp/~kjc/classes/sfc2016s-measurement/>
- ▶ support email (faculty, TA, SA): <imda2016s@sfc.wide.ad.jp>
- ▶ textbooks, references: the lecture slide materials will be provided online.
- ▶ programming: data processing exercises by Ruby
- ▶ evaluation: 2 assignments (20% each) and a final report (60%)

what you will learn in the class

- ▶ how to understand statistical aspects of data, and how to process and visualize data
 - ▶ which should be useful for writing thesis and other reports
- ▶ programming skills to process a large amount of data
 - ▶ beyond what the existing package software provides
- ▶ ability to suspect statistical results
 - ▶ the world is full of dubious statistical results and information manipulations
 - ▶ (improving literacy on online privacy)
- ▶ programming and hands-on data analysis
 - ▶ just reading textbooks isn't enough
 - ▶ certain skills can be learned only through first hand experiences

Big Data everywhere

the WHITE HOUSE PRESIDENT BARACK OBAMA

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Big Data is a Big Deal

Posted by Tom Kalil on March 29, 2012 at 09:23 AM EDT

E-Mail | Tweet |

Editor's Note: Watch <http://five.science.360>

Today, the Obama Admin promises to help accelerate transform teaching and

To launch the initiative, 1 commitments that, together address the challenges:

We also want to challenge President calls an "all ha

Some companies are all research. Universities a generation of "data scolar bono data collection, an forum to highlight new p

Tom Kalil is Deputy Dir

The Economist

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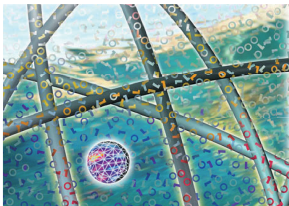
Special report: Managing Information ▾

Data, data everywhere

Information has gone from scarce to superabundant. That benefits, says Kenneth Cukier (interviewed here)—but also

Feb 25th 2010 | from the print edition

Like 30



The New York Times Sunday Review | The Opinion Pages

WORLD U.S. N.Y./REGION BUSINESS TECHNOLOGY SCIENCE HEALTH

NEWS ANALYSIS

The Age of Big Data

By STEVE LOH

Published: February 11, 2012

GOOD with numbers? Fascinated by data? The sound you hear is opportunity knocking.



Enlarge This Image

Mo Zhou was snapped up by I.B.M. last summer, as a freshly minted Yale M.B.A., to join the technology company's fast-growing ranks of data consultants. They help businesses make sense of an explosion of data — Web traffic and social network comments, as well as software and sensors that monitor shipments, suppliers and customers — to guide decisions, trim costs and lift sales. "I've always had a love of numbers."

McKinsey Global Institute

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Report

Big data: The next frontier for innovation, competition, and productivity

May, 2011 | by James Manyika, Michael Chui, Brad Brown, Jacquesughin, Richard Dobbs, Charles Roxburgh

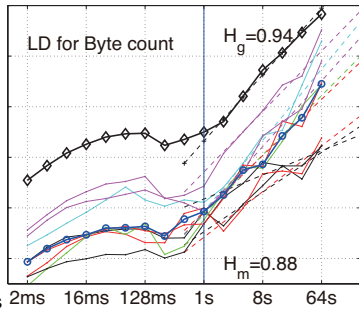
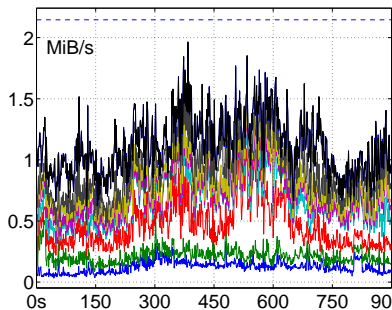
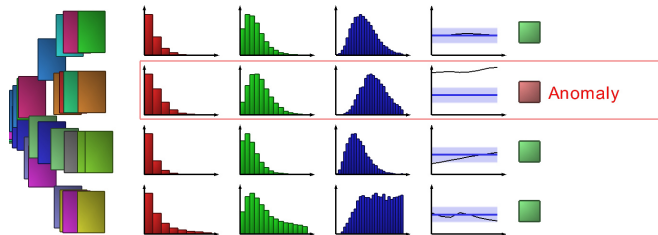
Download Executive Summary PDF-822KB Full Report PDF-5MB Kindle MOBI-5MB eBook EPUB-3MB

The amount of data in our world has been exploding, and analyzing large data sets—so-called big data—will become a key basis of competition, underpinning new waves of productivity growth, innovation, and consumer surplus, according to research by MGI and McKinsey's Business Technology Office. Leaders in every sector will have to grapple with the implications of big data, not just a few data-oriented managers. The increasing volume and detail of information captured by enterprises, the rise of multimedia, social media, and the Internet of Things will fuel exponential growth in data for the foreseeable future.

big data and Internet measurement

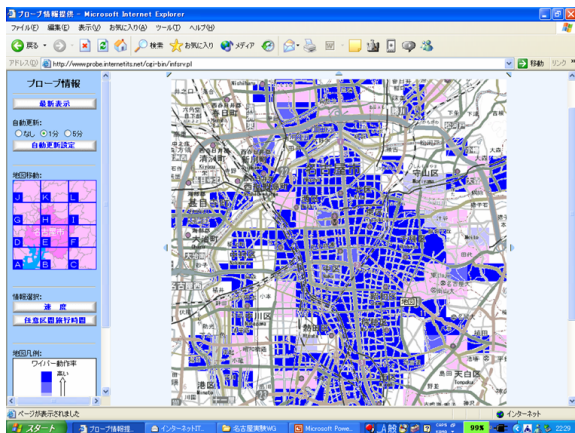
- ▶ big data: broadly, technologies for extracting valuable information hidden in a large volume of unstructured data
 - ▶ often aiming at constructing new service or business models
- ▶ most technologies have been around
 - ▶ search ranking, online recommender systems, etc.
- ▶ Internet measurement: efforts to understand the Internet from huge but incomplete data
 - ▶ need to use inferences by statistical methods

example: anomaly detection by sketch and statistical feature comparison



example: Internet vehicle experiments

- ▶ by WIDE Project In Nagoya in 2001
 - ▶ location, speed and wiper usage data from 1,570 taxis
 - ▶ blue areas indicate high ratio of wiper usage, showing rainfall in detail

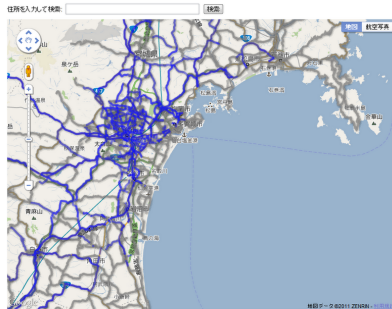


Japan Earthquake

- ▶ the system is now part of ITS
- ▶ usable roads info released 3 days after the quake
 - ▶ data provided by HONDA (TOYOTA, NISSAN)

Google Crisis Response 自動車・通行実績情報マップ

下記マップ中に青色で表示されている道路は、前日の0時~24時の間に通行実績のあった道路を、灰色は同期間に通行実績のなかった道路を示しています。
(データ提供: 本田技研工業株式会社)



この「自動車・通行実績情報マップ」は、被災地内での移動の参考となる情報を提供することを目指しています。ただし、個人が現地に向かうことには、承認済みの経路・交通規制を必ずご確認ください。

このマップは、Googleが、本田技研工業株式会社(Honda)から提供を受けた、Hondaが運営する「インターネット・ナビゲーション」サービスが運営する「スマートルート」が作成した「通行実績情報」を参照して作成されています。Hondaは、24時間限りに通行実績情報を更新する予定であり、Googleは更新後の情報更新が完了後、可能な速やかに情報更新を予定しています。

なお、通行実績がある道路でも、現在通行できなくなっている可能性があります。実際の道路状況は、このマップと異なる場合があります。緊急交通路に指定される等、通行が規制されている可能性もあります。事前に、国土交通省、警察、東日本高速道路株式会社等の情報をご確認ください。

the age of data

- ▶ big data is not just for marketing
- ▶ technological innovations known as the data revolution are occurring in every field
- ▶ previously difficult applications become possible
 - ▶ access to huge amount of data, analysis of data constantly being updated, and applications to non-linear models
- ▶ big data analysis becomes an indispensable research method in all areas of science and technology

example: impact to science

e-science: paradigma shift?

- ▶ theory
- ▶ experiment
- ▶ simulations (enabled by computer)
- ▶ data-driven discovery (enabled by big data)



Google's Chief Economist Hal Varian on Statistics

The McKinsey Quarterly, January 2009

"I keep saying the sexy job in the next ten years will be statisticians. People think I'm joking, but who would've guessed that computer engineers would've been the sexy job of the 1990s? The ability to take data — to be able to understand it, to process it, to extract value from it, to visualize it, to communicate it — that's going to be a hugely important skill in the next decades, not only at the professional level but even at the educational level for elementary school kids, for high school kids, for college kids. Because now we really do have essentially free and ubiquitous data. So the complimentary scarce factor is the ability to understand that data and extract value from it."



data analysis is merely a tool

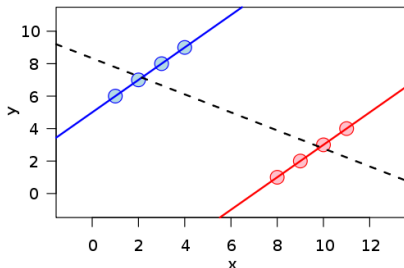
- ▶ recent big data trends focus too much on tools and methods but data analysis is merely a tool
- ▶ data analysis is an iterative process
 - ▶ forming a hypothesis, verifying it with data
 - ▶ if the results are unexpected, you find new questions
 - ▶ repeating the process will uncover interesting facts
- ▶ analysis without purpose ends up with useless numbers
- ▶ if you identify what to get from data, you will see a path forward

fundamental change to creative thinking process?

- ▶ data-driven decision making has been always important
- ▶ but, ICT pushes it to a completely different level (in quality, quantity, expressions)
- ▶ now, we can literally interact with data (data-human interaction)

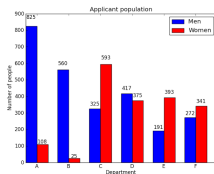
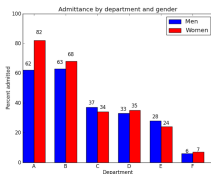
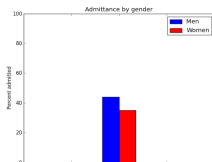
Simpson's paradox

- ▶ one of paradoxes in statistics
 - ▶ a trend observed for aggregated groups is different from that observed for each groups



example: UC Berkeley gender bias case in 1973

- ▶ the university was sued for bias against women as acceptance ratio to graduate school is lower for women
- ▶ investigation revealed that most departments had statistically significant bias in favor of women
- ▶ the reason: women tend to apply to competitive departments with low acceptance ratio



self-introduction

Kenjiro Cho

- ▶ positions
 - ▶ Research Director, IJ Research Lab
 - ▶ Guest Professor, Keio SFC
 - ▶ Board member, WIDE Project
- ▶ bio
 - ▶ BE in electronics from Kobe University in 1984.
 - ▶ started as a hardware engineer at Canon, Inc, then became interested in operating systems
 - ▶ M.Eng in computer science from Cornell University in 1993
 - ▶ studied computer science and distributed systems
 - ▶ Researcher at Sony Computer Science Labs from 1996
 - ▶ research on the Internet
 - ▶ Ph.D. (Media and Governance) from Keio University in 2001
 - ▶ Researcher at IJ from 2004
- ▶ research topics
 - ▶ Internet measurement and data analysis
 - ▶ large-scale content distribution
 - ▶ datacenter management and cloud services

class overview

It becomes possible to access a huge amount of diverse data through the Internet. It allows us to obtain new knowledge and create new services, leading to an innovation called "Big Data" or "Collective Intelligence". In order to understand such data and use it as a tool, one needs to have a good understanding of the technical background in statistics, machine learning, and computer network systems.

In this class, you will learn about the overview of large-scale data analysis on the Internet, and basic skills to obtain new knowledge from massive information for the forthcoming information society.

class overview (cont'd)

Theme, Goals, Methods

In this class, you will learn about data collection and data analysis methods on the Internet, to obtain knowledge and understanding of networking technologies and large-scale data analysis.

Each class will provide specific topics where you will learn the technologies and the theories behind the technologies. In addition to the lectures, each class includes programming exercises to obtain data analysis skills through the exercises.

Prerequisites

The prerequisites for the class are basic programming skills and basic knowledge about statistics.

In the exercises and assignments, you will need to write programs to process large data sets, using the Ruby scripting language and the Gnuplot plotting tool. To understand the theoretical aspects, you will need basic knowledge about algebra and statistics. However, the focus of the class is to understand how mathematics is used for engineering applications.

class schedule (1/4)

- ▶ Class 1 Introduction (4/11)
 - ▶ Big Data and Collective Intelligence
 - ▶ Internet measurement
 - ▶ Large-scale data analysis
 - ▶ exercise: introduction of Ruby scripting language
- ▶ Class 2 Data and variability (4/18)
 - ▶ Summary statistics
 - ▶ Sampling
 - ▶ How to make good graphs
 - ▶ exercise: graph plotting by Gnuplot
- ▶ Class 3 Data recording and log analysis (4/25)
 - ▶ Network management tools
 - ▶ Data format
 - ▶ Log analysis methods
 - ▶ exercise: log data and regular expression

class schedule (2/4)

- ▶ Class 4 Distribution and confidence intervals (5/2)
 - ▶ Normal distribution
 - ▶ Confidence intervals and statistical tests
 - ▶ Distribution generation
 - ▶ exercise: confidence intervals
 - ▶ **assignment 1**
- ▶ Class 5 Diversity and complexity (5/9)
 - ▶ Long tail
 - ▶ Web access and content distribution
 - ▶ Power-law and complex systems
 - ▶ exercise: power-law analysis
- ▶ Class 6 Correlation (5/16)
 - ▶ Online recommendation systems
 - ▶ Distance
 - ▶ Correlation coefficient
 - ▶ exercise: correlation analysis

class schedule (3/4)

- ▶ Class 7 Multivariate analysis (5/23)
 - ▶ Data sensing and GeoLocation
 - ▶ Linear regression
 - ▶ Principal Component Analysis
 - ▶ exercise: linear regression
- ▶ Class 8 Time-series analysis (5/30)
 - ▶ Internet and time
 - ▶ Network Time Protocol
 - ▶ Time series analysis
 - ▶ exercise: time-series analysis
 - ▶ **assignment 2**
- ▶ Class 9 Topology and graph (6/6)
 - ▶ Routing protocols
 - ▶ Graph theory
 - ▶ exercise: shortest-path algorithm
- ▶ Class 10 Anomaly detection and machine learning (6/13)
 - ▶ Anomaly detection
 - ▶ Machine Learning
 - ▶ SPAM filtering and Bayes theorem
 - ▶ exercise: naive Bayesian filter

class schedule (4/4)

- ▶ Class 11 Data Mining (6/20)
 - ▶ Pattern extraction
 - ▶ Classification
 - ▶ Clustering
 - ▶ exercise: clustering
- ▶ Class 12 Search and Ranking (6/27)
 - ▶ Search systems
 - ▶ PageRank
 - ▶ exercise: PageRank algorithm
- ▶ Class 13 Scalable measurement and analysis (7/4)
 - ▶ Distributed parallel processing
 - ▶ Cloud computing technology
 - ▶ MapReduce
 - ▶ exercise: MapReduce algorithm
- ▶ Class 14 Privacy Issues (7/11)
 - ▶ Cybersecurity
 - ▶ Internet data analysis and privacy issues
 - ▶ Summary of the class

Internet measurement

- ▶ network measurement (engineering)
 - ▶ measurement in limited environment
 - ▶ snapshot at a time
- ▶ Internet measurement
 - ▶ measurement of the Internet as a large-scale open system
 - ▶ open system (keep changing with undefined inputs)
 - ▶ behaviors of people on the Internet (social science)

Internet measurement – measuring unmeasurable Internet

- ▶ need for generic measurement data for the Internet
 - ▶ example: typical traffic usage of Internet users
- ▶ the Internet is an open system continuously changing, evolving, and expanding
 - ▶ no central point, representative locations, different behaviors are observed depending on observing location and time
 - ▶ seeking for generality of the Internet: measuring unmeasurables
- ▶ for operation of the Internet, for development of protocols, equipment and services
 - ▶ seeking for the best estimates, predicting the future, and revisiting the existing knowledge
- ▶ user behavior: need to consider not only from technical aspects but also from social, political and economical aspects

characteristics of network data and behavior

- ▶ skewed distributions with large variance
 - ▶ inherent mechanism to make burst transfer
 - ▶ skewed utilization: e.g., a handful users generate most traffic
- ▶ anomalies everywhere
 - ▶ bugs, mis-configurations, spec mismatches, accidents, maintenance's
- ▶ interferences among various mechanisms
- ▶ aggregation
 - ▶ complex behavior as a whole (more than the sum of the individual components)

why measurement of Internet is so hard?

- ▶ traditional measurement is mainly to improve measurement accuracy according to some engineeringly defined metrics
- ▶ Internet measurement is to explore Internet from massive and noisy data, using statistical methods
 - ▶ massive, diverse, skewed, dynamic data
 - ▶ complex behavior of open distributed systems
 - ▶ resilient and fault-tolerant mechanisms
 - ▶ anomalies are the norm

massive volume

- ▶ unprecedented scale with unprecedented growth
- ▶ far more data than we can analyze
 - ▶ techniques needed to reduce data size
 - ▶ filtering: e.g., record only TCP SYN packets
 - ▶ aggregation: e.g., flow-based accounting
 - ▶ sampling: e.g., record 1 in n packets
 - ▶ also, techniques needed to reduce dimensionality
- ▶ still, details matter
 - ▶ a big impact often comes from a small and minor fraction
 - ▶ look at the whole while paying attention to details

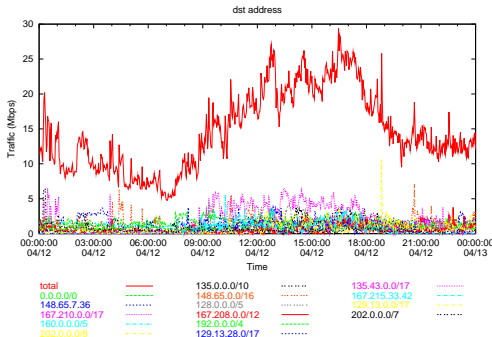
diverse data

- ▶ different behaviors are observed from different locations and time
 - ▶ country, region, time
 - ▶ industry/university/home, backbone/access networks
- ▶ different services use different technologies and have different users

typical data doesn't exist!

constant change

- ▶ daily, weekly traffic pattern
- ▶ trend changes over time
 - ▶ web in 90s and p2p/video in 2000s completely changed traffic pattern
- ▶ hard to predict future!



limitations of Internet measurement

- ▶ problems often occur at boundaries of different networks
 - ▶ cooperation needed but not easy
- ▶ need understanding and help from operators
- ▶ cost: measurement doesn't come free
 - ▶ limitations to measure high-end routers with a PC
- ▶ privacy and confidential information in data
 - ▶ barriers for researchers to access commercial data

measurement targets

- ▶ network infrastructure
 - ▶ traffic, CDN, packet loss, delay, jitter, topology, routes, DNS
- ▶ applications
 - ▶ Web, email, messaging, P2P, gaming, SNS, videos
- ▶ security and anomaly detection
 - ▶ anomalies, attacks, flash crowd

broader targets

- ▶ connections among SNS users, popular keyword extraction, online privacy
- ▶ SPAM/virus, MapReduce, GeoLocation services, Web server log analysis
- ▶ search ranking (PageRank), online recommender systems (collaborative filtering)

possible topics to be studied in the class

- ▶ online recommender systems(collaborative filtering)
- ▶ search ranking (PageRank)
- ▶ SPAM filtering (Naive Bayesian filter)
- ▶ Web server log analysis
- ▶ MapReduce and other big data technologies
- ▶ deep learning and neural networks
- ▶ Internet topology and packet routing
- ▶ how users are connected in social network services
- ▶ GeoLocation services
- ▶ packet analysis
- ▶ Internet traffic analysis

summary

Internet measurement and data analysis

- ▶ measurement is basis for all technologies
- ▶ for networking, it is an attempt to observe invisible networks
- ▶ need to consider not only from technical aspects but also from social, political and economical aspects

theme of the class

- ▶ Internet measurement and data analysis as case studies
- ▶ learn how to measure what is difficult to measure
- ▶ learn how to extract useful information from huge data sets

Introduction to Ruby

Preparation

terminal

- ▶ terminal window for command line interface
 - ▶ Mac: Applications ⇒ Utilities ⇒ Terminal
 - ▶ Windows: Accessories ⇒ "Command Prompt"
- ▶ command line: text commands to manipulate the computer
 - ▶ Mac: UNIX commands are available
 - ▶ Windows: recommend to install "Gow (Gnu On Windows)"
- ▶ shell: a program for command line
 - ▶ e.g., bash, csh

text editor (for editing plain text files)

- ▶ use your favorite one (e.g., vim, emacs, nano)

Ruby

- ▶ a scripting language for object-oriented programming
- ▶ supports wide range of functions for text processing and system management
- ▶ free software started in 1993
- ▶ original author: Yukihiro Matsumoto
- ▶ became popular for Ruby on Rails (a web application framework)
- ▶ installation
 - ▶ Mac: ruby is available by default
 - ▶ Windows: use "RubyInstaller" or other installers

Ruby information

Ruby official site: <http://www.ruby-lang.org/>

Ruby reference manual: <http://www.ruby-lang.org/en/documentation/>

Ruby の歩き方: <http://jp.rubyist.net/magazine/?FirstStepRuby>

Ruby characteristics

- ▶ interpreter language: no need to compile for execution
- ▶ highly portable: runs on most platforms
- ▶ simple syntax
 - ▶ no predefined data type for variables, variables can store any data and are dynamically typed
 - ▶ no need to declare variables, variable types (local variables, global variables, instance variables) can be inferred from variable names
- ▶ garbage collection: users do not need to manage memory
- ▶ object-oriented
 - ▶ everything is an object
 - ▶ class, inheritance, methods
 - ▶ iterator and closure
 - ▶ control structures and procedures can be written in object-oriented manner
- ▶ powerful string operations/regular expressions
- ▶ built-in support for large integers
- ▶ Ruby's shortcomings: a bit slower than its competitors

Ruby commands

- ▶ irb: Ruby's interactive interface

```
$ irb --simple-prompt  
>> puts "Hello"  
Hello
```

- ▶ ruby: Ruby main program

```
$ ruby test.rb
```

or,

```
$ ruby -e 'puts "Hello".reverse'  
olleH
```

exercise: a program to count text lines

count the number of text lines in a file given by the argument

```
filename = ARGV[0]      # filename is passed as an argument
count = 0              # initialize 'count' variable
file = open(filename)  # open the specified file
while text = file.gets # loop reading next line to 'text'
  count += 1           # increment 'count'
end
file.close             # close the file
puts count             # print the content of 'count'
```

write to “count.rb” and then run it

```
$ ruby count.rb foo.txt
```

rewrite it in a more rubyish way

- ▶ ARGF: open the file(s) passed as argument(s)
- ▶ each_line: enumerator method of the IO class

```
#!/usr/bin/env ruby
count = 0
ARGF.each_line do |line|
  count += 1
end
puts count
```

next class

Class 2 Data and variability (4/18)

- ▶ Summary statistics
- ▶ Sampling
- ▶ How to make good graphs
- ▶ exercise: graph plotting by Gnuplot

references

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