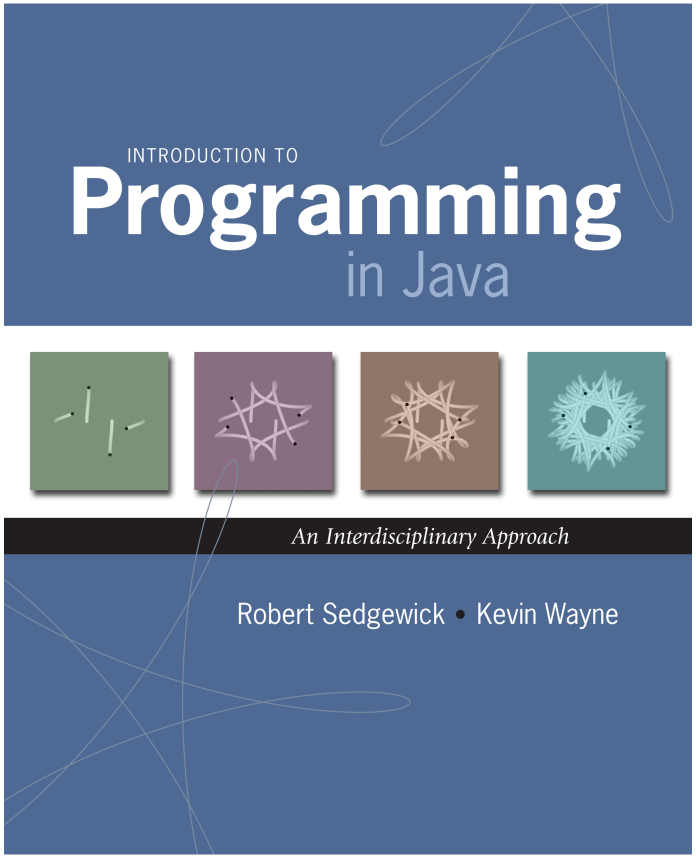
3.3 Designing Data Types



Object Oriented Programming

Procedural programming. [verb-oriented]

- Tell the computer to do this.
- Tell the computer to do that.

OOP philosophy. Software is a simulation of the real world.

- We know (approximately) how the real world works.
- Design software to model the real world.

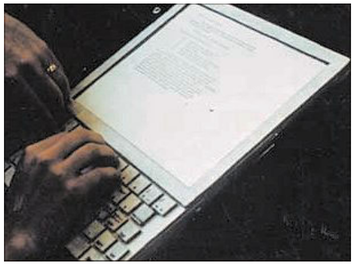
Objected oriented programming (OOP). [noun-oriented]

- Programming paradigm based on data types.
- Identify objects that are part of the problem domain or solution.
- Identity: objects are distinguished from other objects (references).
- State: objects in the world know things (instance variables).
- Behavior: objects do things (methods).

Alan Kay

Alan Kay. [Xerox PARC 1970s]

- Invented Smalltalk programming language.
- Conceived Dynabook portable computer.
- Ideas led to: laptop, modern GUI, OOP.



> *" The computer revolution hasn't started yet. "*
>
> *" The best way to predict the future is to invent it. "*
>
> *" If you don't fail at least 90 per cent of the time,*
> *you're not aiming high enough. "*
>
> *— Alan Kay*

Alan Kay
2003 Turing Award

Encapsulation

Bond. What's your escape route?
Saunders. Sorry old man. Section 26 paragraph 5, that information is on a need-to-know basis only. I'm sure you'll understand.

Encapsulation

Data type. Set of values and operations on those values.

Ex. `int`, `String`, `Complex`, `Vector`, `Document`, `GuitarString`, …

Encapsulated data type. Hide internal representation of data type.

Separate implementation from design specification.

- Class provides data representation and code for operations.
- Client uses data type as black box.
- API specifies contract between client and class.

Bottom line. You don't need to know how a data type is implemented in order to use it.

Intuition

Client

API
- volume
- change channel
- adjust picture
- decode NTSC signal

Implementation
- cathode ray tube
- electron gun
- Sony Wega 36XBR250
- 241 pounds

client needs to know how to use API

implementation needs to know what API to implement

Implementation and client need to agree on API ahead of time.

Intuition

Client

API
- volume
- change channel
- adjust picture
- decode NTSC signal

Implementation
- gas plasma monitor
- Samsung FPT-6374
- wall mountable
- 4 inches deep

client needs to know
how to use API

implementation needs to know
what API to implement

Can substitute better implementation
without changing the client.

Counter Data Type

Counter. Data type to count electronic votes.

```
public class Counter {
   public int count;
   public final String name;

   public Counter(String id)  { name = id;     }
   public void increment()    { count++;       }
   public int value()         { return count;  }

}
```

Legal Java client.

```
Counter c = new Counter("Volusia County");
c.count = -16022;
```

Oops. Al Gore receives -16,022 votes in Volusia County, Florida.

Counter Data Type

Counter. Encapsulated data type to count electronic votes.

```
public class Counter {
   private int count;
   private final String name;

   public Counter(String id) { name = id;     }
   public void increment()   { count++;       }
   public int value()        { return count;  }

}
```

Does not compile.

```
Counter c = new Counter("Volusia County");
c.count = -16022;
```

Benefit. Can guarantee that each data type value remains in a consistent state.

Changing Internal Representation

Encapsulation.

- Keep data representation hidden with `private` access modifier.
- Expose API to clients using `public` access modifier.

```
public class Complex {
   private final double re, im;

   public Complex(double re, double im)  { … }
   public double abs()                    { … }
   public Complex plus(Complex b)         { … }
   public Complex times(Complex b)        { … }
   public String toString()               { … }
}
```

e.g., to polar coordinates

Advantage. Can switch internal representation without changing client.

Note. All our data types are already encapsulated!

Time Bombs

Internal representation changes.

- [Y2K] Two digit years: January 1, 2000.
- [Y2038] 32-bit seconds since 1970: January 19, 2038.
- [VIN numbers] We'll run out by 2010.

HI-TECH SUPPLIES
DIGITAL-COMPATIBLE & YEAR 2000-COMPLIANT SYSTEMS IN STOCK NOW

www.cartoonstock.com/directory/m/millenium_time-bomb.asp

Lesson. By exposing data representation to client, might need to sift through millions of lines of code in client to update.

Ask, Don't Touch

Encapsulated data types.

- Don't touch data and do whatever you want.
- Instead, ask object to manipulate its data.

"Ask, don't touch."

Adele Goldberg
Former president of ACM
Co-developed Smalltalk

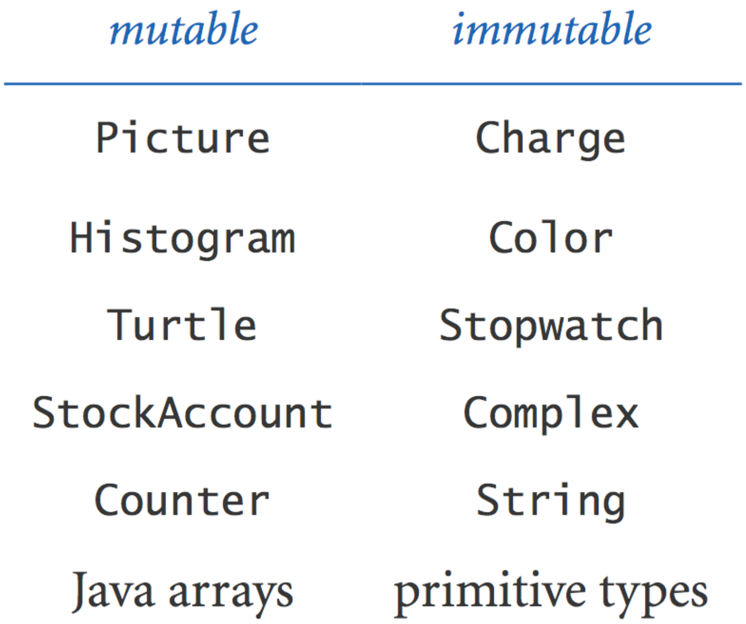
Lesson. Limiting scope makes programs easier to maintain and understand.

"principle of least privilege"

Immutability

Immutability

Immutable data type. Object's value cannot change once constructed.



mutable	*immutable*
Picture	Charge
Histogram	Color
Turtle	Stopwatch
StockAccount	Complex
Counter	String
Java arrays	primitive types

Immutability: Advantages and Disadvantages

Immutable data type. Object's value cannot change once constructed.

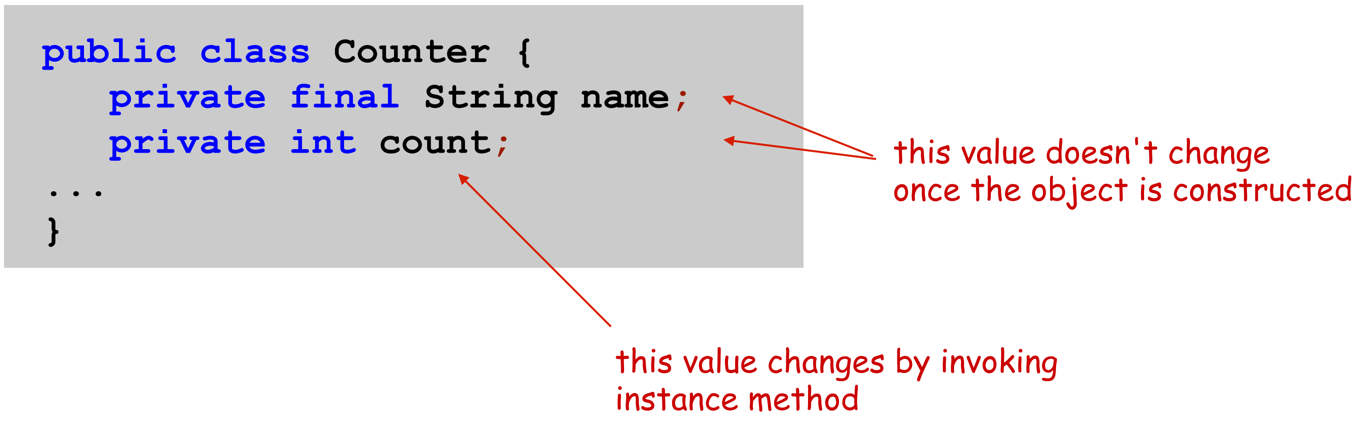
Advantages.

- Avoid aliasing bugs.
- Makes program easier to debug.
- Limits scope of code that can change values.
- Pass objects around without worrying about modification.

Disadvantage. New object must be created for every value.

Final Access Modifier

Final. Declaring an instance variable to be **final** means that you can assign it a value only once, in initializer or constructor.



```
public class Counter {
   private final String name;
   private int count;
...
}
```

this value doesn't change once the object is constructed

this value changes by invoking instance method

Advantages.

- Helps enforce immutability.
- Prevents accidental changes.
- Makes program easier to debug.
- Documents that the value cannot not change.

Spatial Vectors

Vector Data Type

Set of values. Sequence of real numbers. [Cartesian coordinates]

API.

`public class Vector`		
	`Vector(double[] a)`	*create a vector with the given Cartesian coordinates*
`Vector`	`plus(Vector b)`	*sum of this vector and* `b`
`Vector`	`minus(Vector b)`	*difference of this vector and* `b`
`Vector`	`times(double t)`	*scalar product of this vector and* `t`
`double`	`dot(Vector b)`	*dot product of this vector and* `b`
`double`	`magnitude()`	*magnitude of this vector*
`Vector`	`direction()`	*unit vector with same direction as this vector*

$$x = (0, 3, 4, 0), \quad y = (0, -3, 1, -4)$$

$$x + y = (0, 0, 5, -4)$$

$$3x = (0, 9, 12, 0)$$

$$x \cdot y = (0 \cdot 0) + (3 \cdot -3) + (4 \cdot 1) + (0 \cdot -4) = -5$$

$$|\, x \,| = (0^2 + 3^2 + 4^2 + 0^2)^{1/2} = 5$$

$$\vec{x} = x \,/\, |\, x \,| = (0, 0.6, 0.8, 0)$$

Vector Data Type Applications

Relevance. A quintessential mathematical abstraction.

Applications.

- Statistics.
- Linear algebra.
- Clustering and similarity search.
- Force, velocity, acceleration, momentum, torque.
- …

Vector Data Type: Implementation

```
public class Vector {
   private int N;
   private double[] coords;
```

instance variables

```
   public Vector(double[] a) {
      N = a.length;
      coords = new double[N];
      for (int i = 0; i < N; i++)
         coords[i] = a[i];
   }
```

constructor

```
   public double dot(Vector b) {
      double sum = 0.0;
      for (int i = 0; i < N; i++)
         sum += (coords[i] * b.coords[i]);
      return sum;
   }

   public Vector plus(Vector b) {
      double[] c = new double[N];
      for (int i = 0; i < N; i++)
         c[i] = coords[i] + b.coords[i];
      return new Vector(c);
   }
```

methods

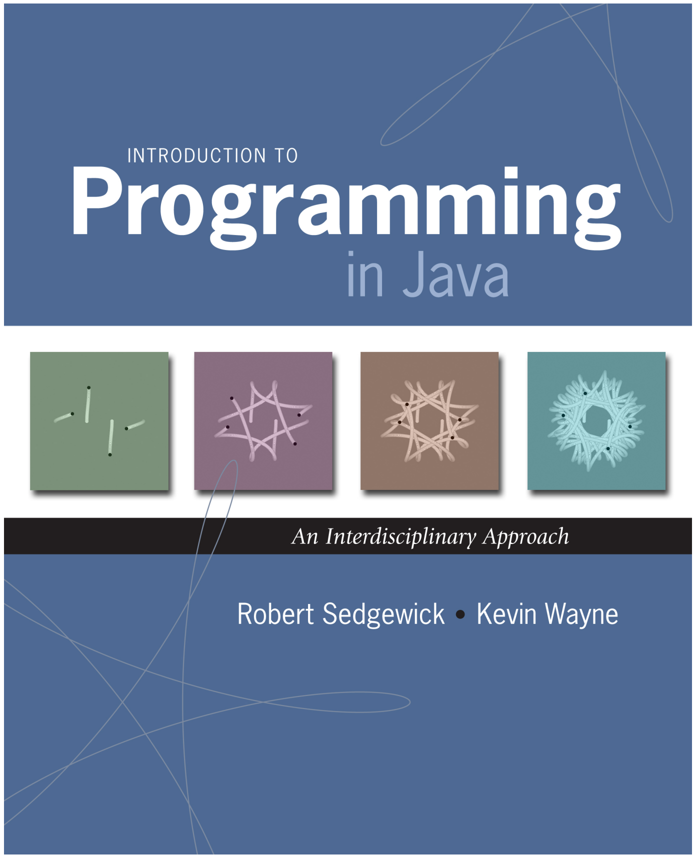
Vector Data Type: Implementation

```
public Vector times(double t) {
   double[] c = new double[N];
   for (int i = 0; i < N; i++)
      c[i] = t * coords[i];
   return new Vector(c);
}

public double magnitude() {
   return Math.sqrt(this.dot(this));
}

public Vector direction() {
   return this.times(1.0 / this.magnitude());
}
...
```

This. The keyword `this` is a reference to the invoking object.

Ex. When you invoke `a.magnitude()`, `this` is an alias for `a`.

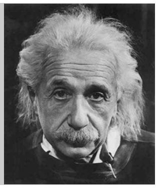
3.5 Case Study: Purple America

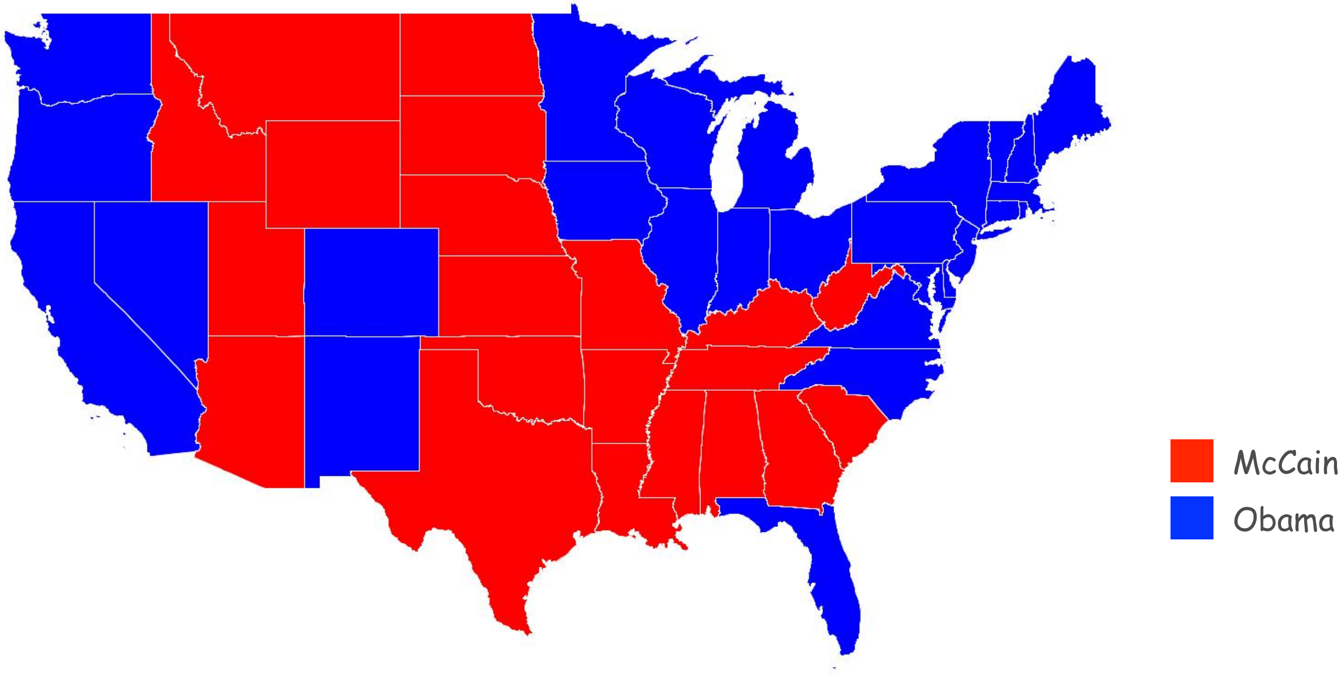


Data Visualization

Challenge. Visualize election results.

> *" If I can't picture it, I can't understand it. "*
> *— Albert Einstein*



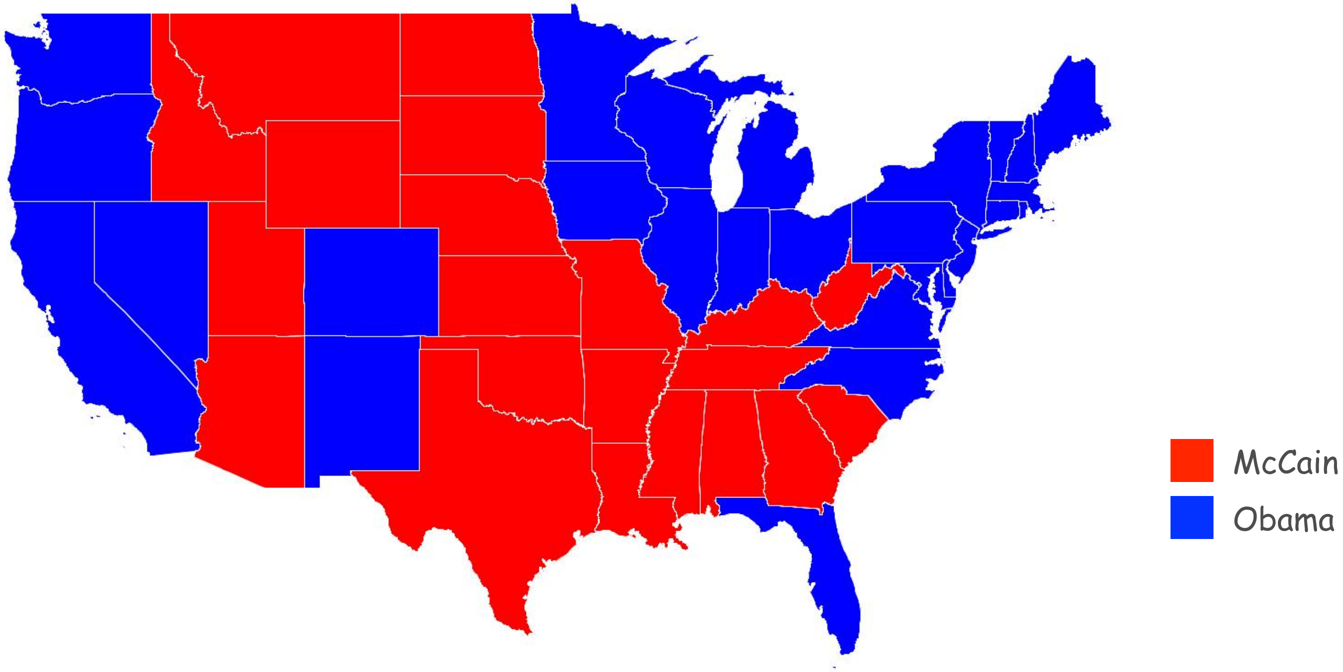


2008 Presidential election

Data Visualization

Approach.

- Gather data from data sources on the web; save in local files.
- Build a modular program that reads files and draws maps.



2008 Presidential election

Data Sources

If I'd known they wanted me to use all this info– I would never have asked for it!
Julie ©

Locate the Data Sources

Geometric data.

- `www.census.gov/tiger/boundary`
- Text files have boundaries of every state and county.
  (format useful for programmers)

Election returns.

- `www.uselectionatlas.org`
- Web site displays election results.
  (need to screen scrape to extract raw data)

Emerging standard.

- Publish data in text format on the web (like geometric data).
- Write mashup program to produce visuals (like we're doing)!

Geometric Data: States within the Continental US

USA data file. State names and boundary points.

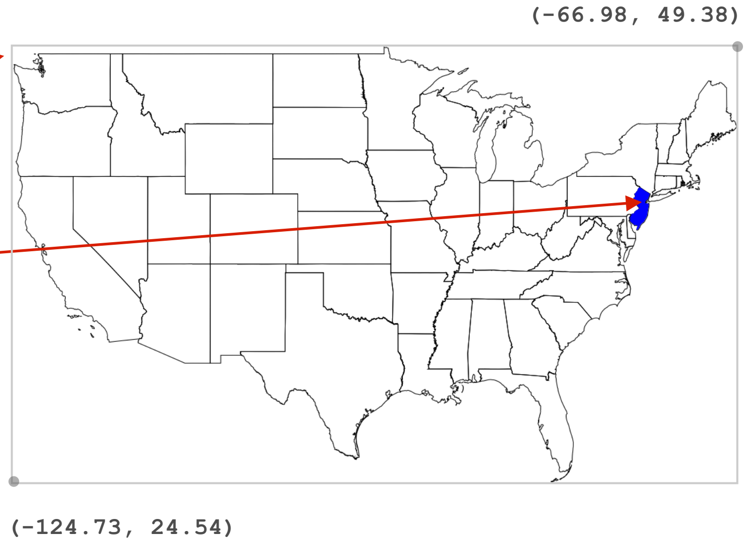
```
% more USA.txt
-124.731216 24.544102 -66.980385 49.384365
104
Alabama
498
 -88.200027   34.995548
 -88.202919   35.007942
…

New Jersey
368
 -74.695305   41.357330
 -74.461754   41.250000
 -74.366302   41.202801
…
 -74.721313   41.347294

…
```

number of regions

bounding box

region

368 points
(longitude, latitude)



Geometric Data: Counties within a State

State data files. County names and boundary points.

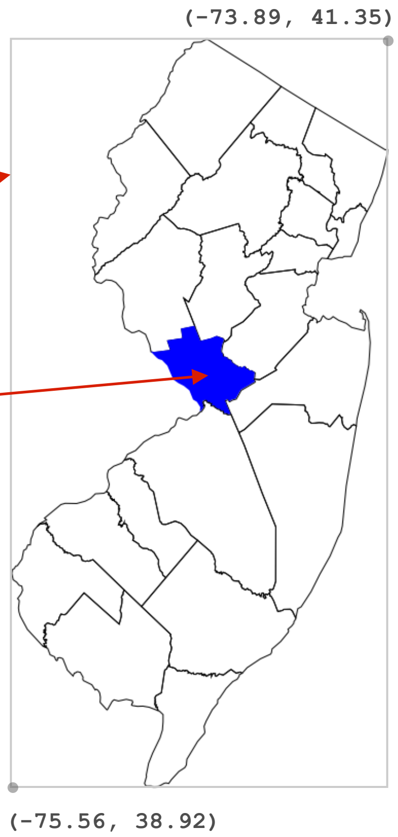
```
% more NJ.txt
-75.560143 38.928589 -73.894402 41.35733
21
Atlantic
127
 -74.877563   39.608414
 -74.736694   39.729721
…

Mercer
88
 -74.748825   40.424248
 -74.722702   40.375301
 -74.674507   40.384399
…
 -74.808403   40.415401

…
```

number of regions

bounding box

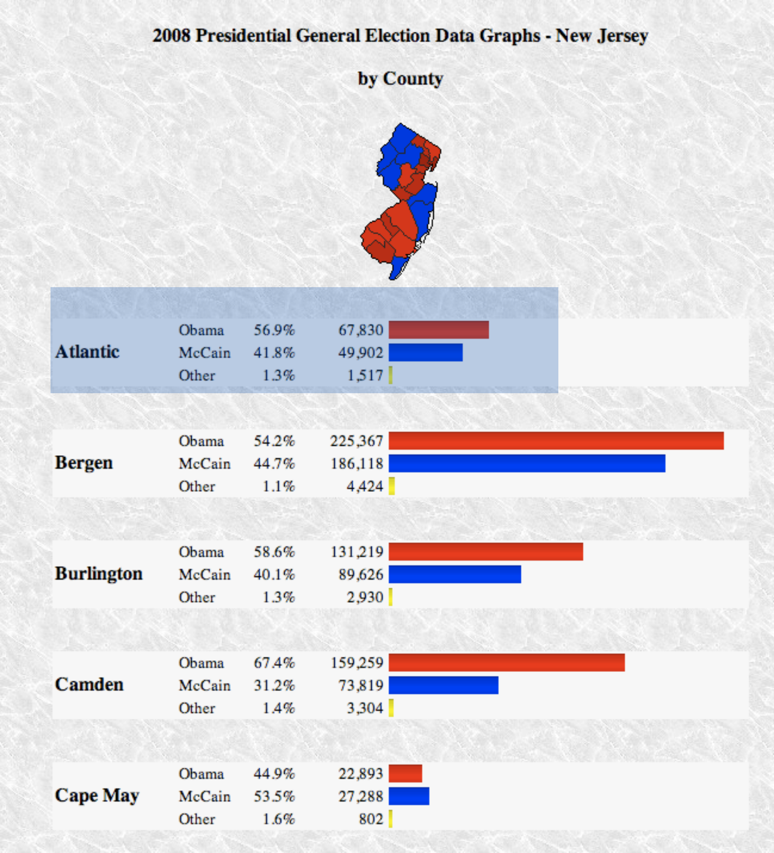
region

88 points
(longitude, latitude)



Screen Scraping the Election Returns

Screen scraping. Download html from web and parse.



2008 Presidential General Election Data Graphs - New Jersey

by County

Atlantic	Obama	56.9%	67,830
	McCain	41.8%	49,902
	Other	1.3%	1,517
Bergen	Obama	54.2%	225,367
	McCain	44.7%	186,118
	Other	1.1%	4,424
Burlington	Obama	58.6%	131,219
	McCain	40.1%	89,626
	Other	1.3%	2,930
Camden	Obama	67.4%	159,259
	McCain	31.2%	73,819
	Other	1.4%	3,304
Cape May	Obama	44.9%	22,893
	McCain	53.5%	27,288
	Other	1.6%	802

region name is text between `<b>` and `</b>` tags that occurs after `width:100px`

```
<div>
<br /><b>2008 Presidential General Election Data Graphs - New Jersey<br /><br />by
County</b><br /><br /><img src="img.php?
year=2008&amp;st=NJ&amp;type=map&amp;off=0&amp;fips=34&amp;elect=0" alt="Map" /><br
/><br /><div class="info"><table cellpadding="2"><tr><td style="width:100px"
rowspan="3"><b>Atlantic</b></td><td class="cnd">Obama</td><td
class="per">56.9&#37;</td><td class="dat">67,830</td><td class="bar"><div
class="bardem" style="width:28.2%">&nbsp;</div></td></tr><tr><td>McCain</td><td
class="per">41.8&#37;</td><td class="dat">49,902</td><td><div class="barrep"
style="width:20.8%">&nbsp;</div></td></tr><tr><td>Other</td><td
class="per">1.3&#37;</td><td class="dat">1,517</td><td><div class="baroth"
style="width:1.0%">&nbsp;</div></td></tr></table><br /><br /><table
cellpadding="2"><tr><td style="width:100px" rowspan="3"><b>Bergen</b></td><td
class="cnd">Obama</td><td class="per">54.2&#37;</td><td class="dat">225,367</td><td
class="bar"><div class="bardem"
style="width:93.8%">&nbsp;</div></td></tr><tr><td>McCain</td><td
class="per">44.7&#37;</td><td class="dat">186,118</td><td><div class="barrep"
style="width:77.5%">&nbsp;</div></td></tr><tr><td>Other</td><td
class="per">1.1&#37;</td><td class="dat">4,424</td><td><div class="baroth"
style="width:1.8%">&nbsp;</div></td></tr></table><br /><br /><table
cellpadding="2"><tr><td style="width:100px" rowspan="3"><b>Burlington</b></td><td
class="cnd">Obama</td><td class="per">58.6&#37;</td><td class="dat">131,219</td><td
class="bar"><div class="bardem"
style="width:54.6%">&nbsp;</div></td></tr><tr><td>McCain</td><td
class="per">40.1&#37;</td><td class="dat">89,626</td><td><div class="barrep"
style="width:37.3%">&nbsp;</div></td></tr><tr><td>Other</td><td
class="per">1.3&#37;</td><td class="dat">2,930</td><td><div class="baroth"
style="width:1.2%">&nbsp;</div></td></tr></table><br /><br /><table
cellpadding="2"><tr><td style="width:100px" rowspan="3"><b>Camden</b></td><td
class="cnd">Obama</td><td class="per">67.4&#37;</td><td class="dat">159,259</td><td
class="bar"><div class="bardem"
```

...

`http://uselectionatlas.org/RESULTS/datagraph.php?year=2008&fips=34`

NJ = FIPS 34

Screen Scraping the Election Returns (Java sketch)

```java
int year     = 2008;  // election year
String whole = "NJ";  // region name for New Jersey
int fips     = 34;    // FIPS code for New Jersey

String url   = "http://uselectionatlas.org/RESULTS/datagraph.php";
In in        = new In(url + "?year=" + year + "&fips=" fips);
Out file     = new Out(whole + year + ".txt");
String input = in.readAll();

while (true) {

  // screen scrape region name
  int p = input.indexOf("width:100px", p);
  if (p == -1) break;
  int from = input.indexOf("<b>", p);
  int to   = input.indexOf("</b>", from);
  String region = input.substring(from + 3, to);

  // screen scrape vote totals for each candidate

  // save results to file
  file.println(region + "," + mccain + "," + obama + "," + other + ",");
}
```

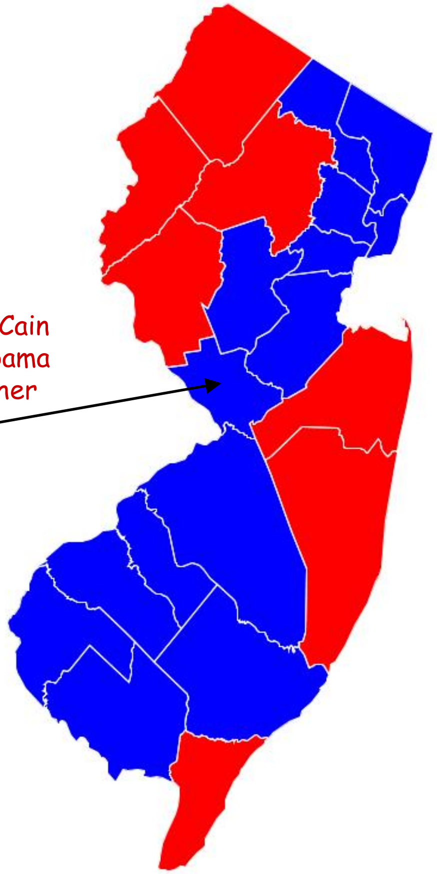
NJ2008.txt

extract text between <b> and </b> tags, that occurs after width:100px

Election Returns: By County

Screen-scraped results. Votes for McCain, Obama, Other by region.

```
% more NJ2008.txt
Atlantic,49902,67830,1517,
Bergen,186118,225367,4424,
Burlington,89626,131219,2930,
Camden,73819,159259,3304,
Cape May,27288,22893,802,
Cumberland,22360,34919,915,
Essex,74063,240306,2181,
Gloucester,60315,77267,1848,
Hudson,55360,154140,2116,
Hunterdon,39092,29776,1147,
Mercer,50223,107926,2229,
Middlesex,123695,193812,4283,
Monmouth,160433,148737,4244,
Morris,132331,112275,2913,
Ocean,160677,110189,4111,
Passaic,72552,113257,1904,
Salem,14816,16044,672,
Somerset,70085,79321,1672,
Sussex,44184,28840,1393,
Union,78768,141417,2241,
Warren,27500,20628,980,
```

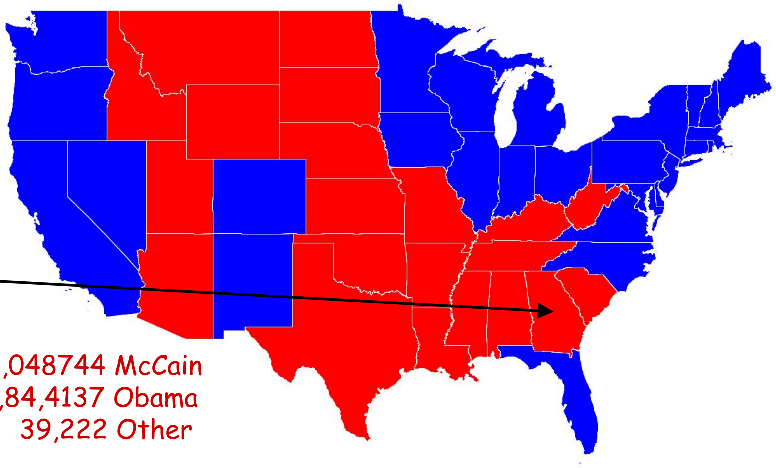


50,223 McCain
107,926 Obama
2,229 Other

Election Returns: By State

Screen-scraped results. Votes for McCain, Obama, Other by region.

```
% more USA2008.txt
Alabama,1266546,813479,19773,
Alaska,193841,123594,8762,
Arizona,1230111,1034707,39020,
Arkansas,638017,422310,26290,
California,5011781,8274473,289260,
Colorado,1073584,1288568,39197,
Connecticut,629428,997772,19592,
Delaware,152374,255459,4579,
District of Columbia,17367,245800,2686,
Florida,4045624,4282074,82621,
Georgia,2048744,1844137,39222,
Hawaii,120566,325871,7131,
Idaho,403012,236440,17978,
Illinois,2031527,3419673,71851,
…
Virginia,1725005,1959532,38723,
Washington,1229216,1750848,68820,
West Virginia,398061,304127,12550,
Wisconsin,1262393,1677211,43813,
Wyoming,164958,82868,6832,
```



2,048744 McCain
1,84,4137 Obama
39,222 Other

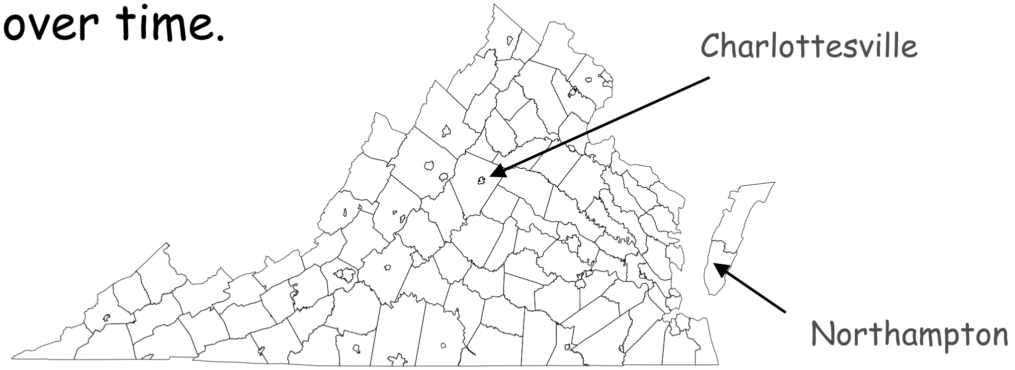
Real Data are Messy

Different data sources have different conventions.

- State names: NJ vs. New Jersey vs. FIPS 34.
- County names: LaSalle vs. La Salle, Kings County vs. Brooklyn.

Other annoyances.

- A state can be comprised of several disjoint polygons.
- A county can be entirely inside another county.
- County boundaries change over time.
- Write-in candidates.
- Unreported results.
- Alaska and Hawaii.

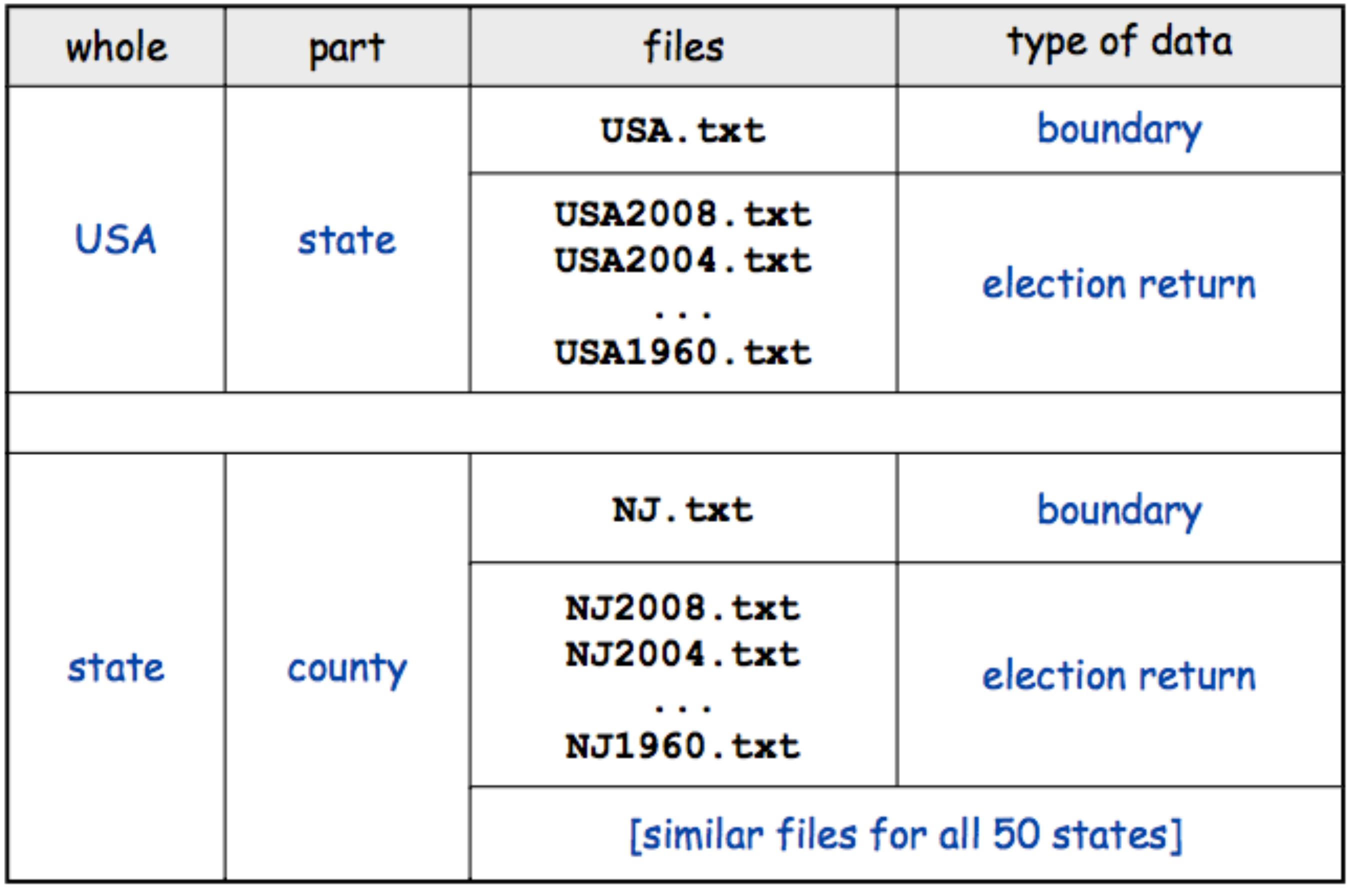


Bottom line. Must clean the data (but write a program to do most of it!)

Summary of Data Files

714 data files. [(13 + 1) × (50 + 1)]

- Each file represents a "whole" divided into regions.
- One entry per region.



whole	part	files	type of data
USA	state	USA.txt	boundary
		USA2008.txt USA2004.txt ... USA1960.txt	election return
state	county	NJ.txt	boundary
		NJ2008.txt NJ2004.txt ... NJ1960.txt	election return
		[similar files for all 50 states]	

Modular Programming

Modular Programming

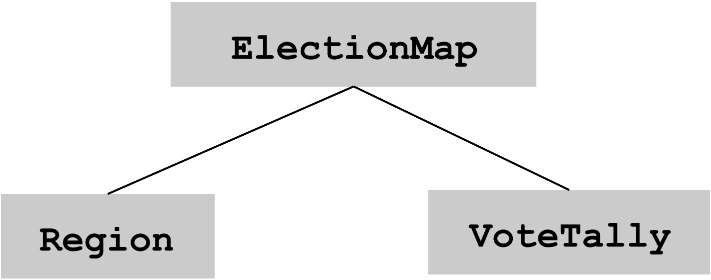
Modular programming.

- Model problem by decomposing into components.
- Develop data type for each component.

Region. State or county.

Vote tally. Number of votes for each candidate in a region.

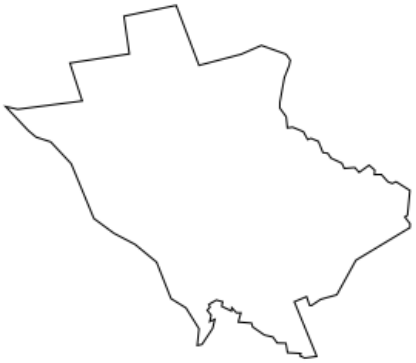
Election map. Map of votes by region in a given election.



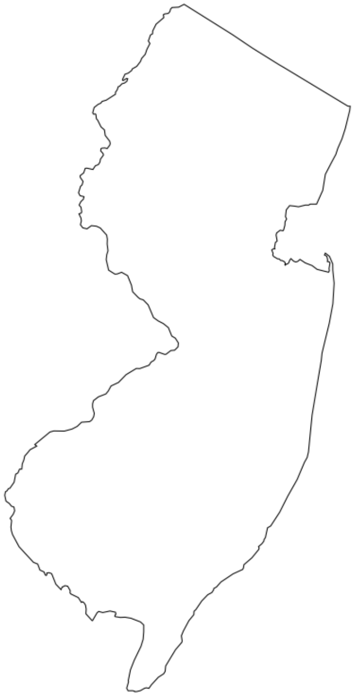
dependency graph

Region Data Type

Region. A state or county.



Mercer
88 point polygon



New Jersey
368 point polygon

Set of values. Sequence of boundary points, name.

Operations. Create and draw.

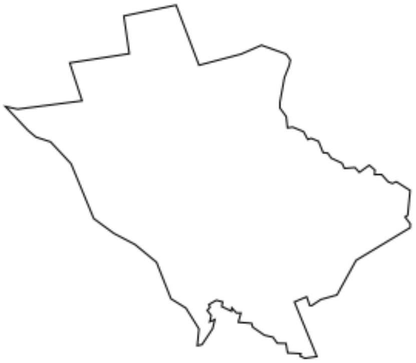
Region Data Type: Java Implementation

```
public class Region {
   private final String name;     // name of region
   private final int N;           // number of boundary points
   private final double[] x, y;   // the points (x[i], y[i])

   public Region(String name, double[] x, double[] y) {
      this.name = name;
      this.N = x.length;
      this.x = new double[N];
      this.y = new double[N];
      for (int i = 0; i < N; i++) {
         this.x[i] = x[i];
         this.y[i] = y[i];
      }
   }

   public void draw()   { StdDraw.filledPolygon(x, y); }
   public String name() { return name;                 }

}
```

← defensive copy (stay tuned)

Vote Tally Data Type

Vote tally. Election returns for one region.



Mercer, NJ

McCain:	50,223
Obama:	107,926
Other:	2,229

Set of values. Number of votes for each candidate.

needed to locate the data

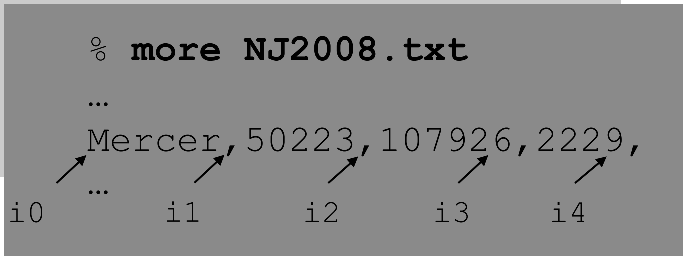
Operations.

- Create (whole, region, year).
- Number of votes for Republican, Democrat, and Independent candidates.

```
% more NJ2008.txt
…
Hunterdon,39092,29776,1147,
Mercer,50223,107926,2229,
Middlesex,123695,193812,4283,
Monmouth,160433,148737,4244,
…
```

Vote Tally Data Type: Java Implementation

```
public class VoteTally {
   private final int rep, dem, ind;

   public VoteTally(String region, String whole, int year) {
      In in = new In(whole + year + ".txt");
      String input = in.readAll();
      int i0 = input.indexOf(region);
      int i1 = input.indexOf(",", i0+1);
      int i2 = input.indexOf(",", i1+1);
      int i3 = input.indexOf(",", i2+1);
      int i4 = input.indexOf(",", i3+1);
      rep = Integer.parseInt(input.substring(i1+1, i2));
      dem = Integer.parseInt(input.substring(i2+1, i3));
      ind = Integer.parseInt(input.substring(i3+1, i4));
   }

   public int rep() { return rep; }
   public int dem() { return dem; }
   public int ind() { return ind; }
}
```



```
% more NJ2008.txt
…
Mercer,50223,107926,2229,
…
```

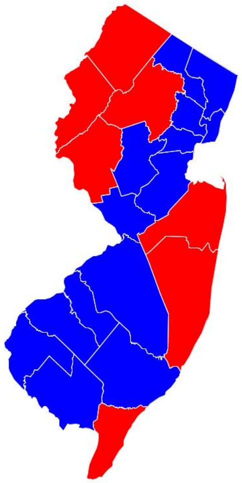
Election Map Data Type

Election map. Map of votes by region in a given election.

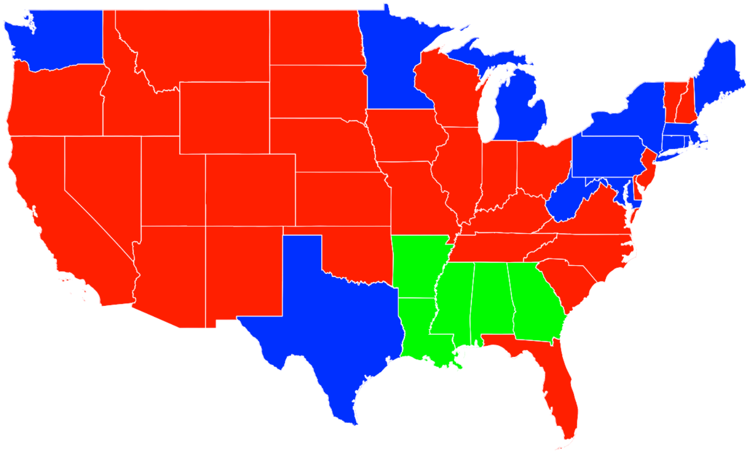
client

```
public static void main(String[] args) {
   String whole = args[0];
   int year = Integer.parseInt(args[1]);
   ElectionMap election = new ElectionMap(whole, year);
   election.show();
}
```

```
% java ElectionMap NJ 2008
```



```
% java ElectionMap USA 1968
```



Election Map Data Type: Java Implementation

```
public class ElectionMap {
   private final int REIGONS          // number of regions
   private final Region[] regions;    // regions[j] = jth region
   private final VoteTally[] votes;   // votes[j]   = jth vote tallies

   public ElectionMap(String whole, int year) {
      // see next slide
   }

   private Color getColor(VoteTally tally) {
      if      (tally.rep() > tally.dem()) return StdDraw.RED;
      else if (tally.dem() > tally.rep()) return StdDraw.BLUE;
      else                                return StdDraw.BLACK;
   }

   public void show() {
      for (int j = 0; j < REGIONS; j++) {
         StdDraw.setPenColor(getColor(votes[j]));
         regions[j].draw();
      }
   }

}
```

for each region, set the pen color according to
the vote tallies and draw the region

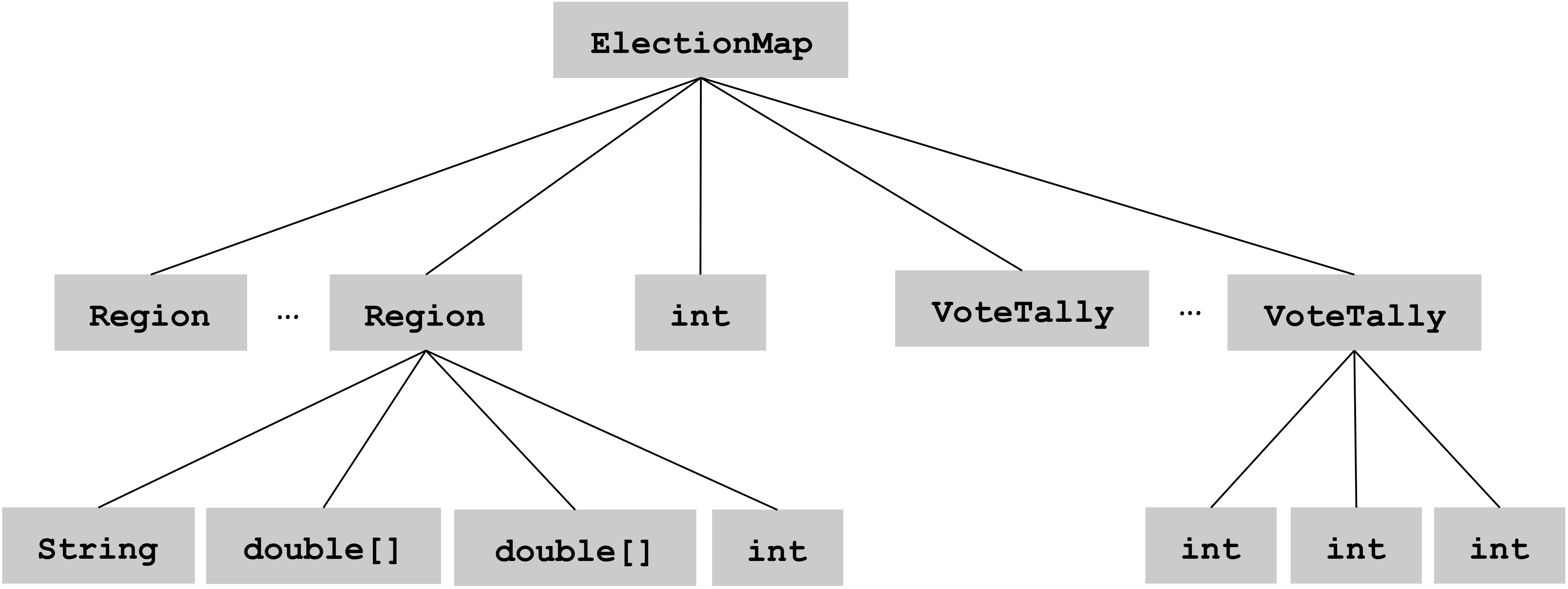
Election Map Data Type: Java Implementation

```java
public ElectionMap(String whole, int year) {
   In in = new In(whole + ".txt");
   // read in bounding box and rescale coordinates
   REGIONS  = in.readInt();

   regions = new Region[REGIONS];
   votes   = new VoteTally[REGIONS];
   for (int j = 0; j < REGIONS; j++) {
      String region = in.readLine();
      int N = in.readInt();
      double[] x = new double[N];
      double[] y = new double[N];
      for (int i = 0; i < N; i++) {
         x[i] = in.readDouble();
         y[i] = in.readDouble();
      }

      regions[j] = new Region(part, x, y);
      votes[j]   = new VoteTally(region, whole, year);
   }
}
```

```
% more NJ.txt
-75.560143 38.928589
-73.894402 41.35733
21

Atlantic
127
 -74.877563   39.608414
 -74.736694   39.729721
…

Mercer
88
 -74.748825   40.424248
 -74.722702   40.375301
 -74.674507   40.384399
…
 -74.808403   40.415401

…
```

Modular Programming

Modular program. Collection of interacting data types.

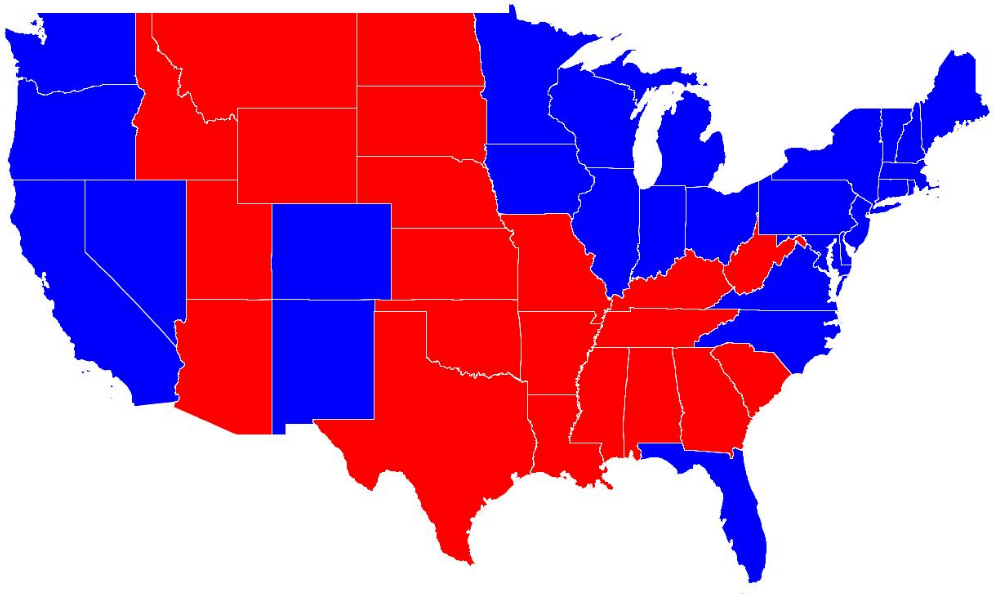


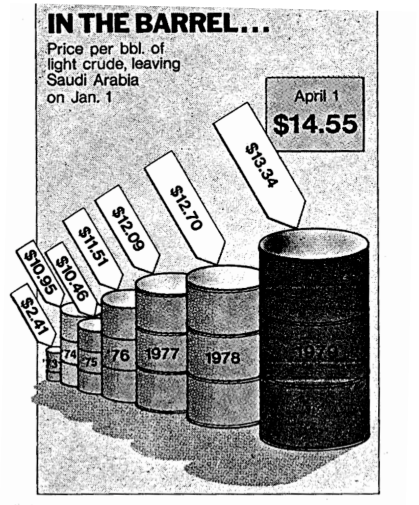
hierarchy of instance variables

Data Visualization

Visual Display of Quantitative Information

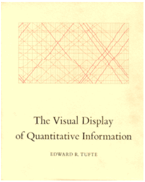
Red states, blue states. Nice, but a misleading and polarizing picture.

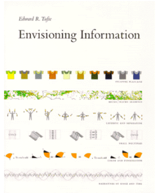


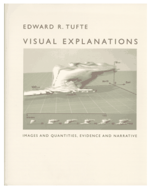


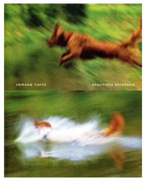
Time, April 9, 1979, p. 57.

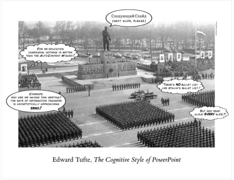
Edward Tufte. Create charts with high data density that tell the truth.

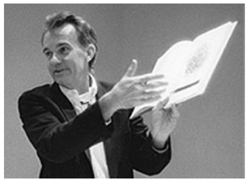












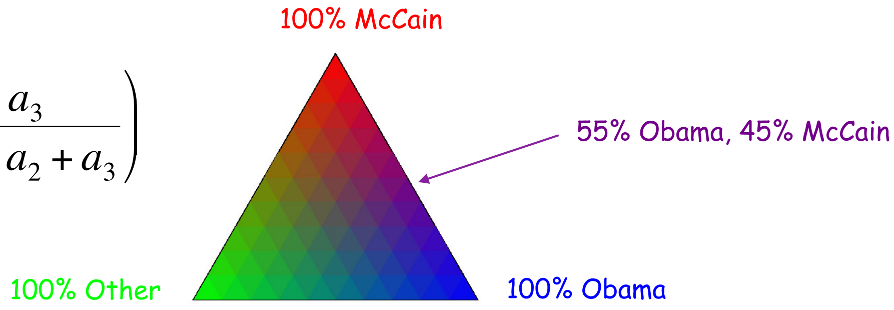
Purple America

Idea. [Robert J. Vanderbei] Assign color based on number of votes.

- a_1 = McCain votes.
- a_2 = Other votes.
- a_3 = Obama votes.

http://www.princeton.edu/~rvdb/JAVA/election2004

$$(R,\ G,\ B) \ = \left(\frac{a_1}{a_1 + a_2 + a_3},\ \frac{a_2}{a_1 + a_2 + a_3},\ \frac{a_3}{a_1 + a_2 + a_3} \right)$$

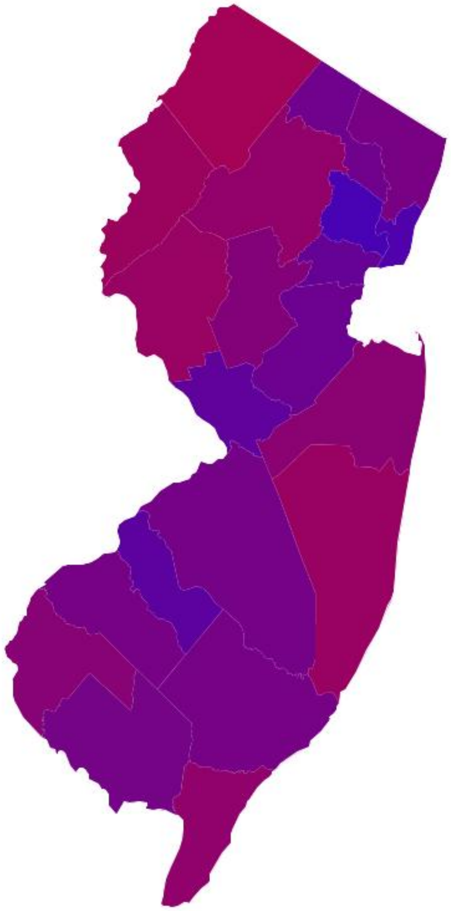


Implementation. Change only one method in **`ElectionMap.java`**.

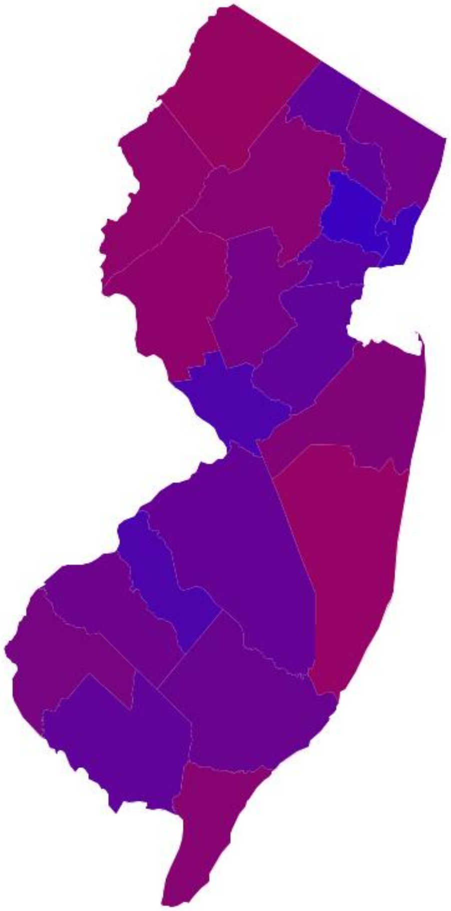
```
public Color getColor() {
   int dem = tally.dem(), rep = tally.rep(), ind = tally.ind();
   int tot = tally.dem + tally.rep + tally.ind;
   return new Color((float) rep/tot, (float) ind/tot, (float) dem/tot);
}
```

Purple New Jersey

```
% java ElectionMap NJ 2004
```

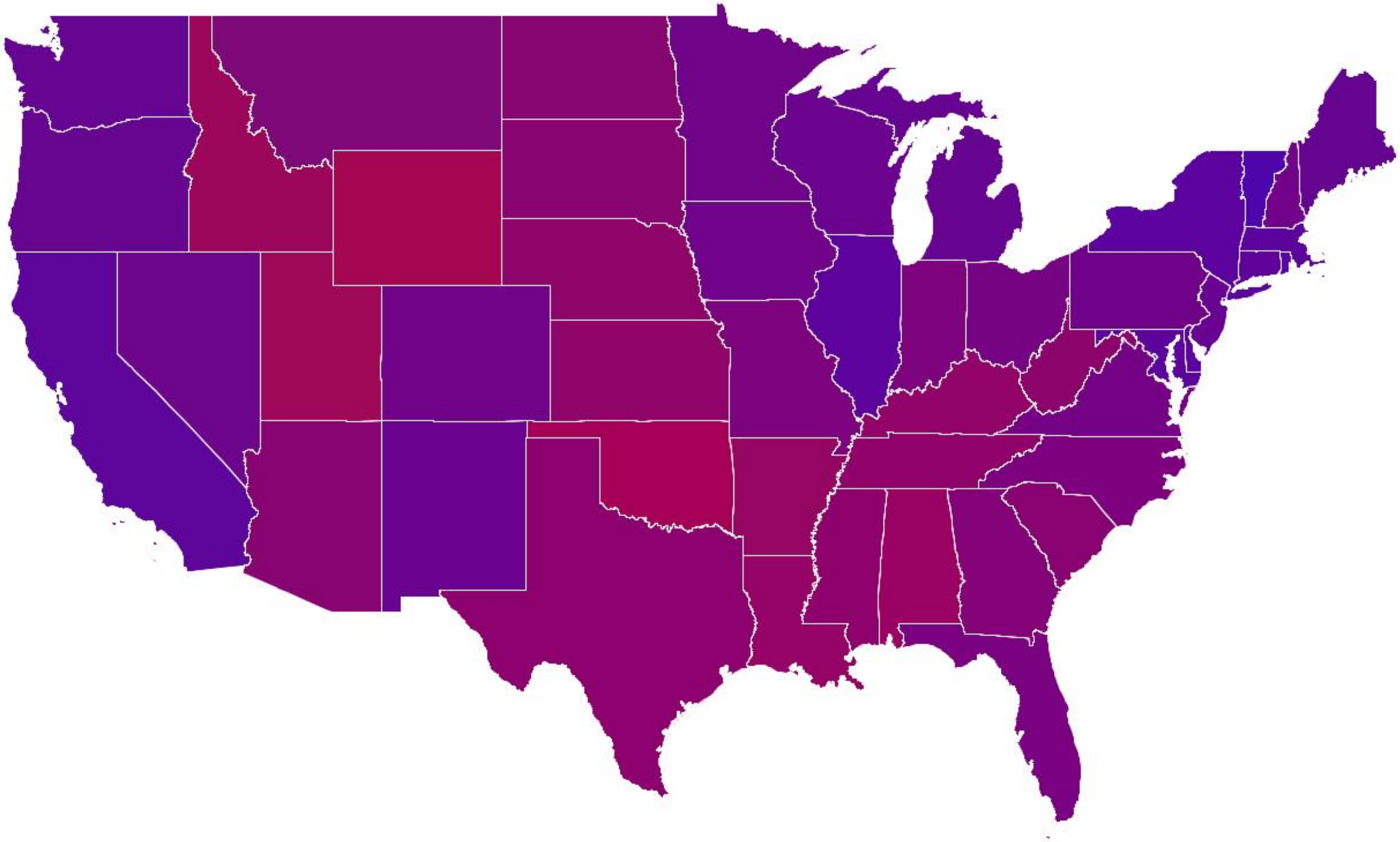


```
% java ElectionMap NJ 2008
```



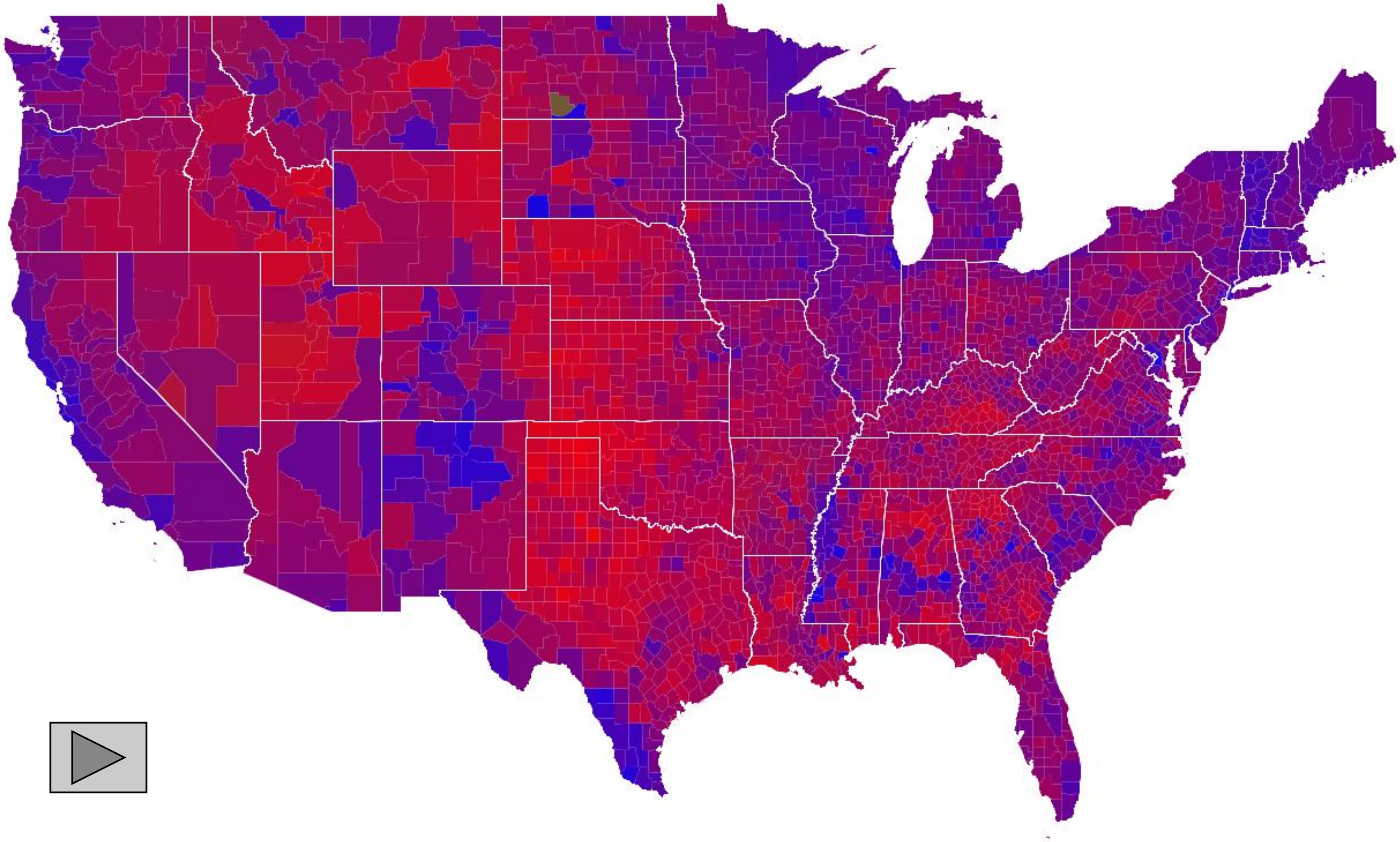
Purple America

```
% java ElectionMap USA 2008
```



Purple America

```
% java ElectionMap USA-county 2008
```



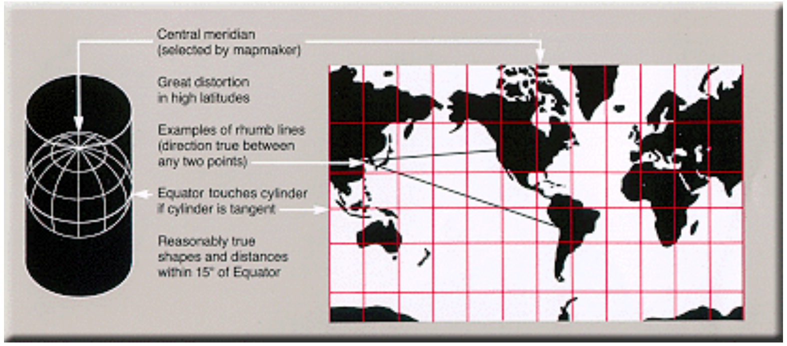
▷

Data Visualization: Design Issues

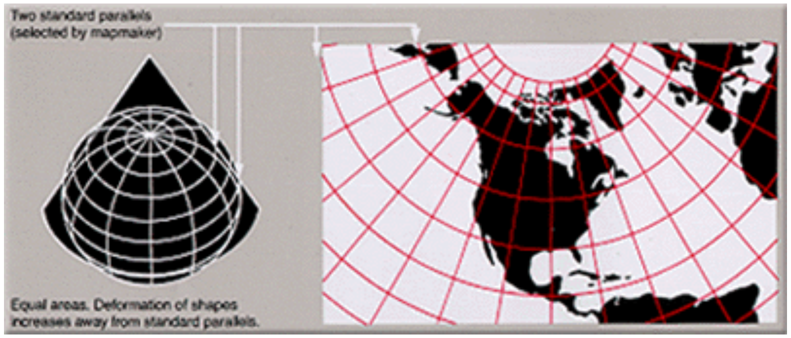
Remark. Humans perceive red more strongly than blue.

Remark. Amount of color should be proportional to number of votes, not geographic boundary.

Remark. Project latitude + longitude coordinates to 2d plane.



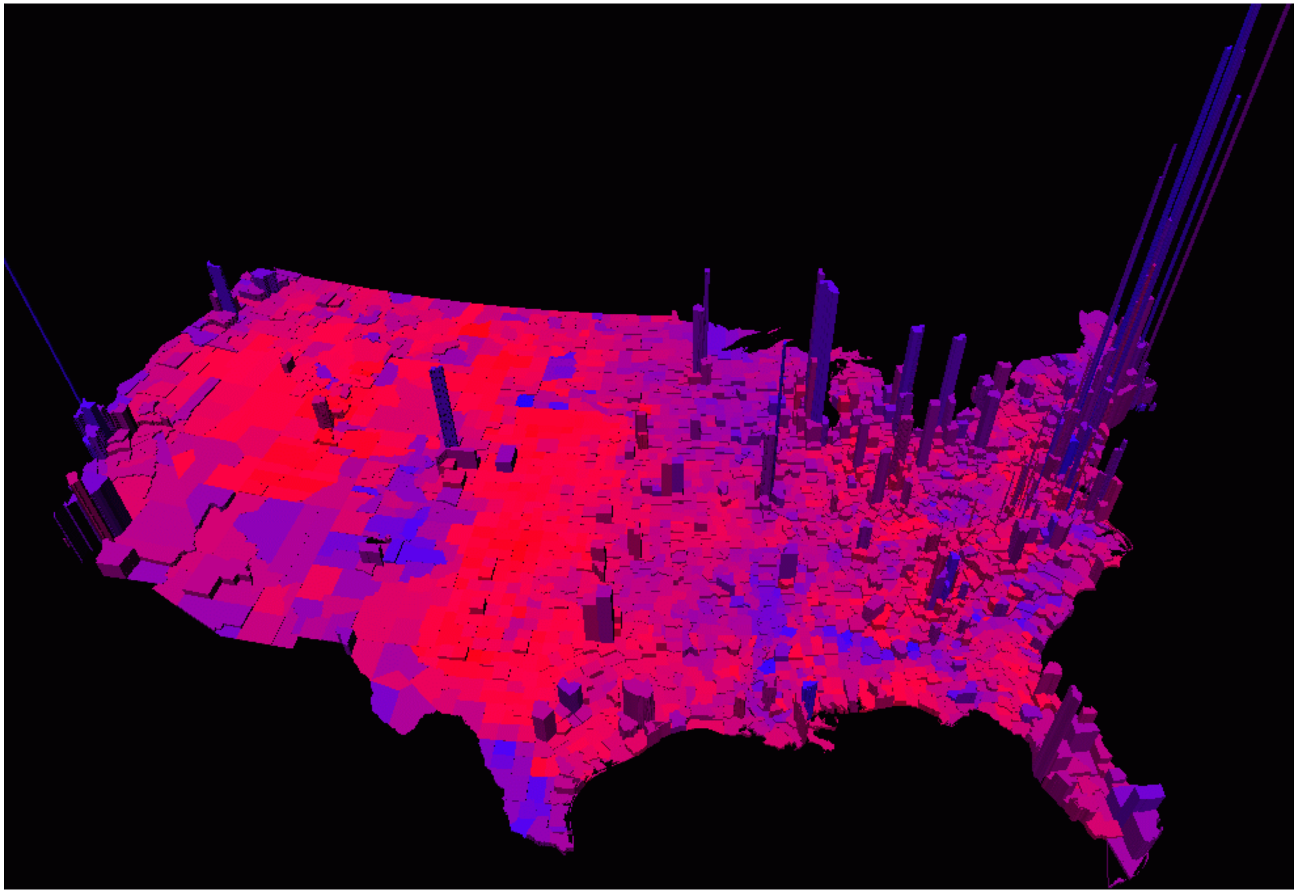
Mercator projection


Two standard parallels
(selected by mapmaker)
Equal areas. Deformation of shapes
increases away from standard parallels.

Albers projection

3D Visualization

3D visualization. Volume proportional to votes; azimuthal projection.



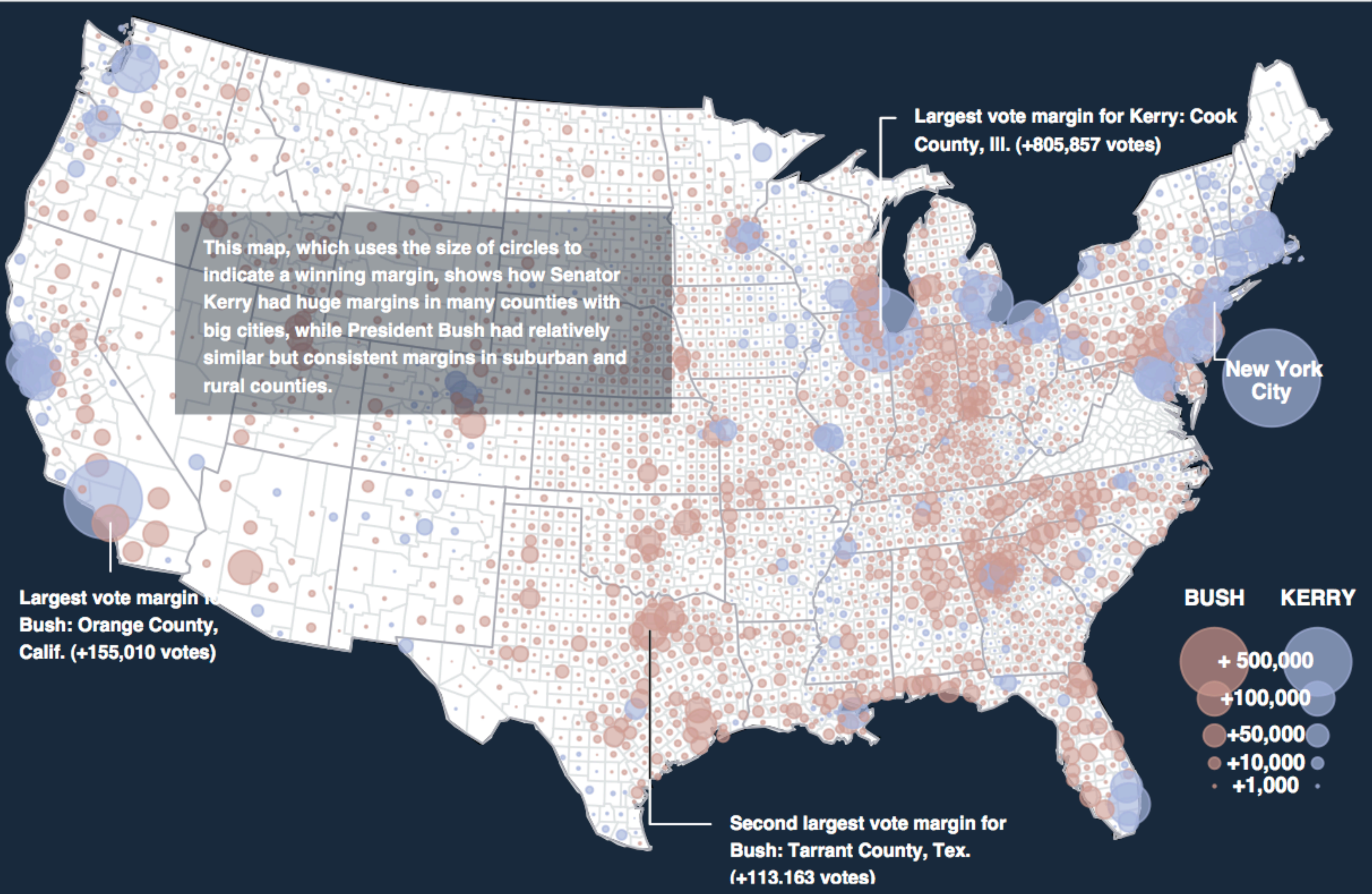
Robert J. Vanderbei
www.princeton.edu/~rvdb/JAVA/election2004

ELECTION 2004 THE FINAL TALLY

How Much Each County Counted

Popular Vote, By County

Popular Vote, By Population



This map, which uses the size of circles to indicate a winning margin, shows how Senator Kerry had huge margins in many counties with big cities, while President Bush had relatively similar but consistent margins in suburban and rural counties.

Largest vote margin for Kerry: Cook County, Ill. (+805,857 votes)

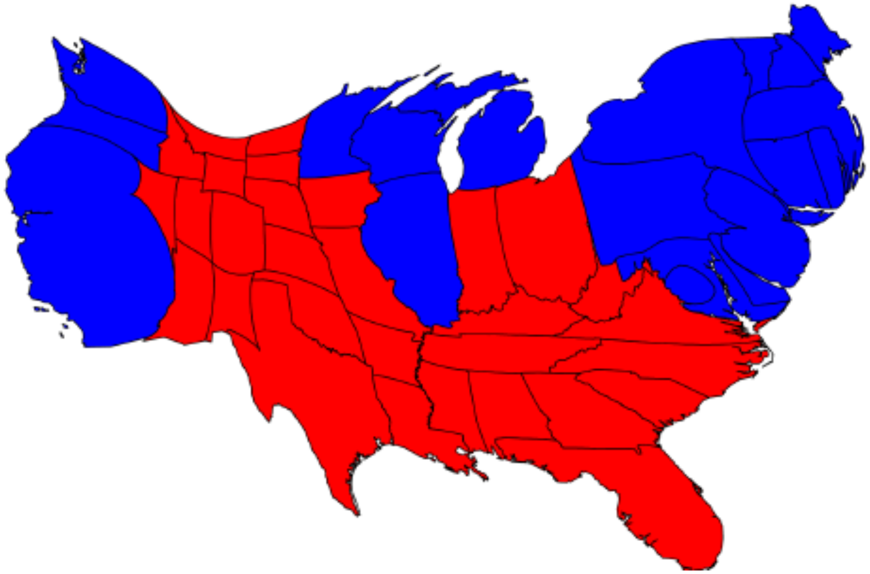
Largest vote margin for Bush: Orange County, Calif. (+155,010 votes)

Second largest vote margin for Bush: Tarrant County, Tex. (+113.163 votes)

Eugene Pyatigorsky (based on New York Times visualization)
www.ocf.berkeley.edu/~gene/media/docs/Election.pdf

Cartograms

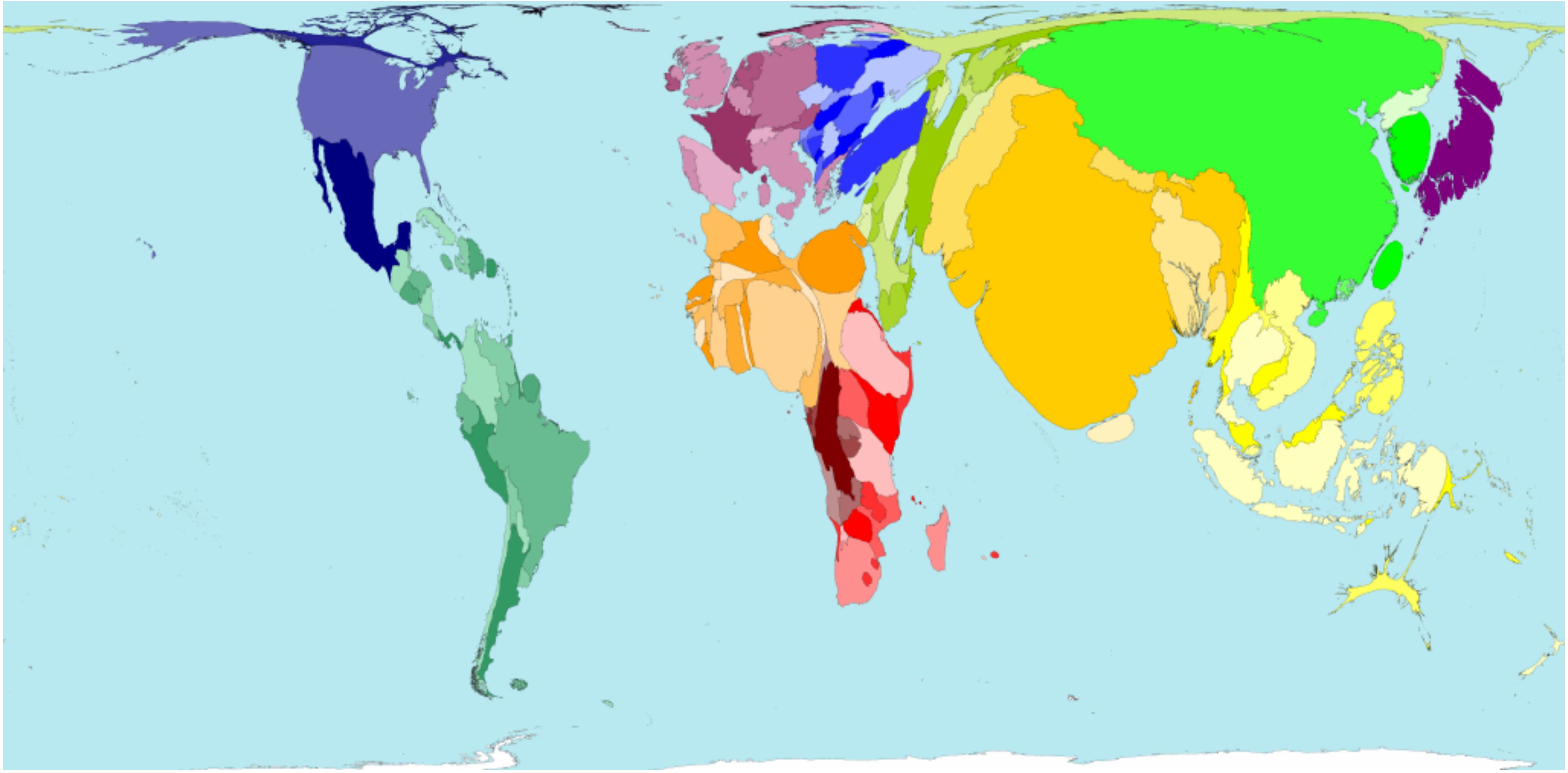
Cartogram. Area of state proportional to number of electoral votes.



Michael Gastner, Cosma Shalizi, and Mark Newman
www-personal.umich.edu/~mejn/election

Cartograms

Cartogram. Area of country proportional to population.



Summary

Modular programming.

- Break a large program into smaller independent components.
- Develop a data type for each component.
- Ex: `Region`, `VoteTally`, `ElectionMap`, `In`, `Out`.

Ex 1. Build large software project.

- Software architect specifies API.
- Each programmer implements one module.
- Debug and test each piece independently. [unit testing]

Ex 2. Build reusable libraries.

- Language designer extends language with new data types.
- Programmers share extensive libraries.

Data visualization. You can do it! [worthwhile to learn from Tufte]