3.3 Designing Data Types
Object Oriented Programming

Procedural programming. [verb-oriented]
- Tell the computer to do this.
- Tell the computer to do that.

Alan Kay's 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 things that are part of the problem domain or solution.
- Things in the world know things: instance variables.
- Things in the world do things: methods.
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
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, Tour, ...

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

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client needs to know how to use API

implementation needs to know what API to implement

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Can substitute better implementation without changing the client.
Counter Data Type

Counter. Data type to count electronic votes.

```java
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.

```java
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.

```java
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.

```java
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.

```java
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.
- [VIN numbers] We'll run out by 2010.

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

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

"Ask, don't touch."

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

"principle of least privilege"

Adele Goldberg
Former president of ACM
Co-developed Smalltalk
Immutability
Immutability

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

<table>
<thead>
<tr>
<th>mutable</th>
<th>immutable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picture</td>
<td>Charge</td>
</tr>
<tr>
<td>Histogram</td>
<td>Color</td>
</tr>
<tr>
<td>Turtle</td>
<td>Stopwatch</td>
</tr>
<tr>
<td>StockAccount</td>
<td>Complex</td>
</tr>
<tr>
<td>Counter</td>
<td>String</td>
</tr>
<tr>
<td>Java arrays</td>
<td>primitive types</td>
</tr>
</tbody>
</table>
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.

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

**Advantages.**
- Helps enforce immutability.
- Prevents accidental changes.
- Makes program easier to debug.
- Documents that the value cannot change.
Spatial Vectors
Vector Data Type

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

API.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vector(double[] a)</td>
<td>create a vector with the given Cartesian coordinates</td>
</tr>
<tr>
<td>Vector plus(Vector b)</td>
<td>sum of this vector and b</td>
</tr>
<tr>
<td>Vector minus(Vector b)</td>
<td>difference of this vector and b</td>
</tr>
<tr>
<td>Vector times(double t)</td>
<td>scalar product of this vector and t</td>
</tr>
<tr>
<td>double dot(Vector b)</td>
<td>dot product of this vector and b</td>
</tr>
<tr>
<td>double magnitude()</td>
<td>magnitude of this vector</td>
</tr>
<tr>
<td>Vector direction()</td>
<td>unit vector with same direction as this vector</td>
</tr>
</tbody>
</table>

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

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

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

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

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

$x = x / \|x\| = (0, 0.6, 0.8, 0)$
Vector Data Type Applications

**Relevance.** A quintessential mathematical abstraction.

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

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

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

    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);
    }
}
This. The keyword \texttt{this} is a reference to the invoking object.

Ex. When you invoke \texttt{a.magnitude()}, \texttt{this} is an alias for \texttt{a}. 

```java
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());
}
...