Designing Programs --- Understanding Data

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Introduction

Student Expectations: The Four Problems

- Understanding Data
- Designing Computations
- Designing Abstractions
- Conclusion and Acknowledgements
Student Expectations

Students want to know what computers can do

- How do the programs work
- How to design their own programs

I have this neat idea to make computer do ...

- Where do I start?
- How do I proceed?
TeachScheme! --- ReachJava

An Introduction to Programming and Computing

The team:
- Matthias Felleisen, Robert Bruce Findler, Matthew Flatt
- Kathryn E. Gray, Shriram Krishnamurthi, Viera K. Proulx

Part 1: TeachScheme! curriculum
- programming environment: DrScheme/HtDP
- textbook: How to Design Programs, MIT Press 2001

Part 2: ReachJava! curriculum
- programming environment: DrScheme/ProfessorJ
- textbook: How to Design Classes, MIT Press 2007
Sample Problems

A Rat Race

- A rat in a cage looks for food, dies if not fed in time, or if food is poisoned.

Geometric Shapes

- Circles, squares, combinations of them: within bounds?, contains a point?, distance to the top, closer to the top?, ...

A College Registrar System

- Students, Instructors, Courses, Transcripts, Rosters, Schedules: e.g. Have all students in a course completed a prerequisite?

The Boston Marathon

- Runners, Timing: produce results in various forms
Goals

Teach students to think through the problems:

- Analyze the information available
- Learn to represent the information as data
- Analyze the problem statement that requires a programmatic solution
- Design the programming solution systematically
Introduction

Understanding Data

  Information vs. Data

Designing Computations

Designing Abstractions

Conclusion and Acknowledgements
Understanding Data

Information:

○ A hungry rat in the middle of a cage 20 wide and 40 tall with 5 days to live

○ A red circle of radius 10 with center at (30, 50) on top of blue square of size 20 with NW corner at (40, 20)

○ Student John Dunne, id 2345, math major ... + the current schedule and a transcript

○ Bill Rogers, 52 years old, male, bib number 7733 ... + the timing info: start and end times
Understanding Data

Data:

- rat-location, rat-lifespan, cage-width, cage-height
- circle-location, circle-radius, circle-color
- location-x, location-y
- square-location, square-size, square-color
- student-name, student-id, student-major, student-schedule...
- runner-name, runner-age, runner-gender, runner-bib, ...
Design Recipe for Data Definition

Does the information consists of several parts?

- Design a class of data, one field per part
- Identify the type of data needed to represent each field

If the field itself has parts, design a new class of data

... containment

- **Rat**: location, lifespan
- **Location**: x-coordinate, y-coordinate

- **Student**: name, id, major, schedule, transcript
- **Schedule**: list of current-courses
Design Recipe for Data Definition

Data Definition in Scheme:

;;; to represent a rat ...

;;; A Rat is given by Posn Number
(define-struct rat (location lifespan))

(define a-rat make-rat (make-posn 10 20) 5))

(rat? a-rat) ⇒ true

(rat-location a-rat) ⇒ (make-posn 10 20)

(rat-lifespan a-rat) ⇒ 5
Design Recipe for Data Definition

Data Definition in Java:

// to represent a rat ...

class Rat {
    Point location;
    int lifespan;
    ... constructor, methods ...
}

Rat aRat = new Rat(new Point(10 20), 5);
aRat.location ➔ new Point(10 20)
aRat.lifespan ➔ 5
Design Recipe for Data Definition

Does the information consists of several variants?
  ◦ Design a union class of data, one subclass per variant
  ◦ **Shape**: Circle, Square, Combo

Does one of the fields represent data in another class?
  ◦ containment (reference)
  ◦ ... possibly a self-reference (recursive definition)
Design Recipe for Data Definition

;; to represent a shape

;; A Shape is one of:

;; -- Circle: given by a center Point and the radius

;; -- Square: given by the NW Point the size

;; -- Combo: given by the top Shape and the bottom Shape

Data Definition - in (key)words:
Design Recipe for Data Definition

;; to represent a shape

;; A Shape is one of:

;; -- Circle: given by a center Point and the radius

;; -- Square: given by the NW Point the size

;; -- Combo: given by the top Shape and the bottom Shape

Data Definition - in (key)words:

- is given by ➔ class,
- reference to other class ➔ containment,
- is one of ➔ union
- reference to itself ➔ self-reference
Design Recipe for Data Definition

`; to represent a shape
`; A Shape is one of:
`; -- Circle
`; -- Square
`; -- Combo

`; to represent a circle
`; A Circle is given by Posn Number
(define-struct circle (center radius))

`; to represent a combination of two shapes
`; A Combo is given by Shape Shape
(define-struct combo (top bottom))

... and include examples of data as well ...
Design Recipe for Data Definition

Class diagram for the IShape class hierarchy:

Corresponds exactly to the narrative data definition

Students use the diagrams to represent the data definition
Design Recipe for Data Definition

// to represent geometric shapes
interface IShape {
}

// to represent a circle
class Circle implements IShape {
    Point center;
    int radius;

    Circle(Point center, int radius){
        this.center = center;
        this.radius = radius;
    }
}

Code can be generated automatically
Design Recipe for Data Definition

Examples of \texttt{IShape} objects

// Examples of geometric shapes - in the Client class

Point center = new Point(100, 100);
Point nw = new Point(120, 100);

\texttt{IShape} c = new \texttt{Circle} (this.center, 50);
\texttt{IShape} s = new \texttt{Square} (this.nw, 150);

\texttt{IShape} sc = new \texttt{Combo} (this.s, this.c);

Translation of data into information:

\begin{itemize}
  \item \texttt{s} is a square with the nw corner at coordinates \texttt{(120, 100)},
  \texttt{size 150}
\end{itemize}
Understanding Data

Information vs. Data:

- A hungry rat in the middle of a cage 20 wide and 40 tall with 5 days to live

- `(make-rat (make-posn 10 20) 5)`

- A red circle of radius 10 with center at (30, 50) on top of a blue square of size 20 with NW corner at (40, 20)

- `new Shape(new Circle(new Point(30, 50), 10, Color.red), new Square(new Point(40, 20), 20, Color.blue))`
Understanding Data

Information vs. Data:

- Student John Dunne, id 2345, math major ... + the current schedule and a transcript

- (make-student "John Dunne" 2345 "math" ...)

- Bill Rogers, 52 years old, male, bib number 7733 ... + the timing info: start and end times

- new Runner("Bill Rogers", 52, true, 7733, ...)

Understanding Data

Program design depends on the data we use

Increase the complexity of both gradually

Design systematically --- student in the driver seat

Understanding data is essential regardless of the language
Introduction

Understanding Data

Designing Computations

The Design Recipe

Designing Abstractions

Conclusion and Acknowledgements
Designing Computations

Functions vs. Procedures:
Start by focusing on programs (functions/methods) that consume data and produce a new value

- no accessors, mutators, change of state is needed
- no input, no output, just test cases
- user interaction through DrScheme and interactive graphics

**Design Recipe**: the steps in the design process

- Clear set of questions to answer for each step
- Outcomes that can be checked for correctness and completeness
Designing Computations

Design recipe for methods: method contains-- Part 1

Step 1: Problem analysis and data definition

a shape is the object that invokes the method
the user supplies the desired point

Step 2: Purpose statement and the header

○ // is the given point within this shape
  boolean contains(Point p);

Step 3: Examples

○ this.c.contains(new Point(90, 110)) ---> true
  this.s.contains(new Point(90, 110)) ---> false
  this.sc.contains(new Point(130, 110)) ---> true
Designing Computations

Design recipe for methods: method contains -- Part 2

Step 4: Template -- an inventory of available data

○ // in the class Circle
  ... this.center ...   -- Point
  ... this.center.distTo(p) ...  -- int
  ... this.radius ...   -- int
  ... p ...             -- Point
  ... p.distTo(Point ...) ...  -- int

○ // in the class Combo
  ... this.top ...        -- IShape
  ... this.bottom ...     -- IShape
  ... this.top.contains(p) ...  -- boolean
  ... this.bottom.contains(p) ...  -- boolean
  ... p ...               -- Point
Designing Computations

Design recipe for methods: method contains -- Part 3

Step 5: Body

○ // in the class Circle
  boolean contains(Point p) {
    return this.center.distTo(p) <= this.radius;
  }

○ // in the class Combo
  boolean contains(Point p) {
    return this.top.contains(p)
    || this.bottom.contains(p);
  }

Step 6: Tests

○ turn the examples into tests in the Client class and evaluate them
Designing Computations

Design Recipe: the steps in the design process:

• Problem Analysis and Data Definition  -- understand
• Purpose & Header  -- interface and documentation
• Examples  -- show the use in context: design tests
• Template  -- make the inventory of all available data
• Body  -- only design the code after tests/examples
• Test  -- convert the examples from before into tests

Clear set of questions to answer for each step
Outcomes that can be checked for correctness and completeness
Opportunity for pedagogical intervention
Designing Computations

**Design Recipe**: the steps in the design process:

- Problem Analysis and Data Definition  -- **understand**
- Purpose & Header  -- **interface and documentation**
- Examples  -- **show the use in context: design tests**
- Template  -- **make the inventory of all available data**
- Body  -- **only design the code after tests/examples**
- Test  -- **convert the examples from before into tests**

**Design foundation:**

- Required documentation from the beginning
- Test-driven design from the beginning
- Focus on the structure of data and the structure of programs
➤ Introduction
➤ Understanding Data
➤ Designing Computations
➤ Designing Abstractions
  Reusable Software Components
➤ Conclusion and Acknowledgements
Designing and Understanding Abstractions

Abstractions --- both in Scheme and in Java

- motivated by observing repeated code patterns
- students are taught to design abstractions
Designing and Understanding Abstractions

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Design Recipe for Abstractions:

- Identify the differences between similar solutions
- Replace the differences with parameters and rewrite the solution
- Rewrite the original examples and test them again
Designing and Understanding Abstractions

Abstracting over similarities:

- Classes with similar data ➔ super classes

Person: name, id

Student: name, id, major, transcript, schedule

Instructor: name, id, title, schedule

- (define-struct person (name id))
- (define-struct student (p-data major transcript schedule))
- (define-struct instructor (p-data title schedule))
Designing and Understanding Abstractions

Abstracting over similarities:

- Classes with similar data ➔ super classes

Person: name, id

Student: name, id, major, transcript, schedule

Instructor: name, id, title, schedule

- class Person{ String name; int id; ...
- class Student extends Person{ String major; ...
- class Instructor extends Person{ String dept; ...}
Designing and Understanding Abstractions

Abstracting over similarities: abstract - if methods are all different

abstract int distToTop();

In the class Circle:

int distToTop() {return this.location.y - this.radius;}

In the class Square:

int distToTop() {return this.location.y;}

In the class Combo:

int distToTop() {
    return min(this.top.distToTop(),
               this.bottom.distToTop());}
Designing and Understanding Abstractions

Abstracting over similarities: concrete - if methods are the same.

In the class Circle:
boolean closerToTop(IShape that){
    return this.distToTop() < that.distToTop();}

In the class Square:
boolean closerToTop(IShape that){
    return this.distToTop() < that.distToTop();}

In the class Combo:
boolean closerToTop(IShape that){
    return this.distToTop() < that.distToTop();}
Designing and Understanding Abstractions

Abstracting over similarities:

- Classes with the same methods ➔ methods in abstract classes

```java
boolean closerToTop(IShape that) {
    return this.distToTop() < that.distToTop();
}
```

Same method in all subclasses of IShape

➔ lift as concrete method in the abstract class
Designing and Understanding Abstractions

Abstracting over similarities:

- Lists of different data ➔ list of \(<T>\) ➔ generics
Designing and Understanding Abstractions

Abstracting over similarities:

- Lists of different data ➔ list of `<T>` ➔ generics
Designing and Understanding Abstractions

Abstracting over similarities:

- Classes with similar structure and methods ➔ ADTs

Methods for a sorted list SList:

- SList insert (Data data), Data getFirst ()
- SList removeFirst (), boolean isEmpty ()

Methods for a binary search tree BST:

- BST insert (Data data), Data getFirst ()
- BST removeFirst (), boolean isEmpty ()
Designing and Understanding Abstractions

Abstracting over similarities:

- Classes with similar structure and methods ➔ ADTs

Interface for a sorted list *SortedData*:

```java
interface SortedData {
    SortedData insert(Data data);
    Data getFirst();
    SortedData removeFirst();
    boolean isEmpty();
}
```

abstract class SList implements SortedData{...}

abstract class BST implements SortedData{...}
Designing and Understanding Abstractions

Abstracting over similarities:

- Functions used as parameters ➔ function objects in Java

In the Boston Marathon Problem:

- make a list of all male runners under 50 years old
- make a list of all female runners under 40 years old
- make a list of all female runners over 50 years old
- make a list of all runners who finished under 2 hrs and 30 minutes
Designing and Understanding Abstractions

Abstracting over similarities: functions as parameters

In the Boston Marathon Problem:

\begin{verbatim}
AList selectSuch(Alist allRunners){
    AList result = new Alist();
    while (!allRunners.isEmpty()){
        if ( allRunners.getFirst() ??? )
            result = result.add(allRunners.getFirst());
        allRunners.getRest();
    }
    return result;
}
\end{verbatim}
Designing and Understanding Abstractions

In Scheme:

;; to produce a list of all runners such that ... from the given list
;; [Listof X] (X -> Boolean) -> [Listof X]

(define (filter alist predicate?)
  (cond
   [(empty? alist) empty]
   [(cons? alist)
    (cond
     [(predicate? (first alist))
      (cons (first alist)
        (filter (rest alist) predicate?))]
     [else (filter (rest alist) predicate?)])])
Designing and Understanding Abstractions

In Java:

// to produce a list of all runners such that ... from the given list
AList selectSuch(AList allRunners, ISelect choice){
    AList result = new AList();
    while (!allRunners.isEmpty()){
        if (choice.select(allRunners.getFirst()))
            result = result.add(allRunners.getFirst());
        allRunners.getRest();
    }
    return result;
}
Designing and Understanding Abstractions

Abstracting over similarities: functions as parameters

interface ISelect{
    boolean select(); }

class QualifyingTime implements ISelect{
    boolean select(Runner r){
        return r.runningTime() < 150; }

AListRunners qualified =
    allRunners.filter(new QualifyingTime());
Designing and Understanding Abstractions

Abstracting over similarities: functions as parameters

Sort all marathon runners by their names
Sort all marathon runners by their running times
Sort all marathon runners by their bib numbers

interface Comparator...
Designing and Understanding Abstractions

Abstracting over similarities:

- Traversal of a container ➔ iterator

Methods:

- boolean isEmpty()
- Data getFirst()
- Traversal getRest()

Reason: provide the container class as a library -- no more changes
Designing and Understanding Abstractions

Abstracting over similarities:

- Classes with similar data or methods ➔ abstract classes
- Classes with same concrete methods ➔ abstract classes
- Lists of different data ➔ list of <T> ➔ generics
- Classes with common functional representation of structures ➔ ADTs
- Comparisons ➔ interfaces that represent a function object
- Traversal of a container ➔ iterator
Designing and Understanding Abstractions

Abstractions --- integrated throughout the course
  ◦ motivated by observing repeated code patterns
  ◦ students are taught to design abstractions
Designing and Understanding Abstractions

Abstractions --- integrated throughout the course

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**Designing abstractions:** Design Recipe for Abstractions

- Identify the differences between similar solutions
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Introduction
Understanding Data
Designing Computations
Designing Abstractions
Conclusion and Acknowledgements
Other Work; Our Plans
Conclusion

Solid understanding of principles
Student is the designer
Language features motivated by need
Language weaknesses exposed
Abstractions are made concrete
Exposure to alternate ways of solving problems
Understanding Mutation

When is mutation needed
What are the dangers of using mutation
Designing tests in the presence of mutation

• The need for mutation:
  ◦ First used to support the definition of circularly referential data
  ◦ ArrayList - the need for mutating a structure
  ◦ GUIs - the need to record the current state - apart from the current view
  ◦ Efficiency - mutating sort and other algorithms
Understanding the Big Picture

The foundations are there for understanding full Java

• Study of the Java Collections Framework
• Understanding the meaning of Javadoc
• Foundations for reasoning about complexity
• Foundations for understanding the data structure tradeoffs
  ◦ HashMap, Set, TreeMap, Linked structures
• Motivation for and using the JUnit
Our Experiences

TeachScheme! --- over 500 high schools - great results
ReachJava! --- four years at Northeastern University, many others

Instructors in follow-up courses feel students are much better prepared

Students are much more confident in their understanding of program design

Two very successful summer workshops for secondary school and university teachers

Workshops planned for summer 2007, 2008, 2009
A growing number of followers despite the 'work in progress'
Web sites:

http://teach-scheme.org

http://www.ccs.neu.edu/home/vkp/HtDCH.html
Understanding Data --- Designing Programs

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