Introductory Computing:
The Design Discipline

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Informatics: The Science of Design

- **Introduction:** Design in the context of information systems
- **Didactics:** Systematic problem solving
- **Didactics:** Information and data: the connection
- **Didactics:** Design of abstractions = libraries
- **Didactics:** Libraries for the beginners

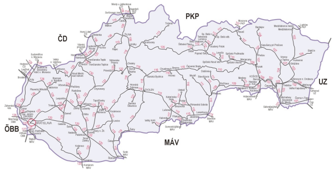
Informatics: The Science of Design

Before computers: concrete complex systems

- Automobiles

- Skyscrapers

- Slovak railroad system



Informatics: The Science of Design

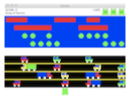
Complex web pages

Systems for the weather forecasts

Medical information systems

Wikipedia

Computer games



Social computing

Program by Design:
Design-Based Introductory Curriculum

Simple language context

Systematic didactics for program design

Connection between information and data

Test-first design with appropriate support

Computer games - via libraries - focus on the model

Managing complexity through abstractions

Program by Design: Design-Based Introductory Curriculum

Bootstrap

grades 6 - 8, very detailed curriculum, clear goals

software support

TeachScheme!

secondary schools, introductory college

textbook, DrRacket student languages, libraries

ReachJava

second semester, class-based, object-oriented

libraries for game design, testing, textbook (draft)

Die Macht der Abstraktion

Herbert Klaeren, Michael Sperber, Tübingen,
Germany (Dein Program in DrScheme)

Program by Design: Design-Based Introductory Curriculum

Bootstrap

“I program my own video games” (and learn algebra)

TeachScheme!

Interactive games with timer, key and mouse

Client-server games over internet

ReachJava

Interactive games with timer, key, mouse, sound

Systematic design and use of abstractions

Transition to full language, libraries, trade-offs

Program by Design: Design-Based Introductory Curriculum

Bootstrap

“I program my own video games” (and learn algebra)

Focus on understanding the concepts:

coordinate system

evaluation of expressions

substitution of values for variables

conditionals, logical expressions

functions with one or two variables

Pythagorian theorem - to detect collisions

Program by Design: Design-Based Introductory Curriculum

Bootstrap

show the web site
run the Ninja Game

TeachScheme!

show the first program (train)

ReachJava

run the musical frogger

Didactics for Program Design

Functions with the given (input) data and output data

Design Recipe for a function (a procedure)

1. Think what are the inputs and outputs

2. Write down the purpose statement and the header (contract)

3. Make examples of use with expected outcomes

4. Inventory: make a list of all data parts and functions/methods/procedures that you can use

5. Design the body of the function/procedure

6. Use the examples from step three as test cases

Didactics for Program Design (Step 1)

- Find the largest prime in a list of numbers
- Sort a list of names by alphabet
- Where is the given letter in the given String?

Functions with the given (input) data and output data

Didactics for Program Design (Step 1)

- **Find the largest prime in a list of numbers**

  inputs: a list of numbers output: number

- **Sort a list of names by alphabet**

  inputs: list of String-s output: list of String-s

- **Where is the given letter in the given String?**

  inputs: character, String output: int

Analyze the problem, the types of inputs, outputs

Didactics for Program Design (Step 2)

- **Find the largest prime in a list of numbers**

```
// find the largest prime in the given list of numbers
int largestPrime(List mylist)
```

- **Sort a list of names by alphabet**

```
// produce a sorted list from the given list of names
ListofString sort(ListofString mylist)
```

- **Find the position of the given letter in the given String**
- **... produce -1 if not found**

```
// produce the location of a letter in the given String
int whereIs(char c, String text)
```

Purpose statement, the header of the function/procedure

Didactics for Program Design (Step 3)

- **Find the largest prime in a list of numbers**

```
largestPrime(12 17 5 24 6) -> 17

largestPrime(4 9 6) -> ??
```

- **Sort a list of names by alphabet**

```
sort(“hi” “ciao” “bye”)->(“bye” “ciao” “hi”)
```

- **Find the position of the given letter in the given String**

```
whereIs(“b”, “mama”) -> -1

whereIs(“a”, “mama”) -> 1
```

Examples of use with the expected outcomes

Didactics for Program Design (Step 4)

- **Find the largest prime in a list of numbers**

inventory:

empty(mylist) --- boolean

if not:

... first(mylist) -- int

... rest(mylist) -- List of numbers

... largestPrime(rest(mylist))

... needed: isPrime(int) -- boolean

    to use as ... isPrime(first(mylist))...

-structure -- select fields, record their types
-variants -- process every variant separately
-list all functions/procedures/methods that can be used with the available data

Didactics for Program Design (Step 5)

- **Find the largest prime in a list of numbers**

body:

```
if (empty(mylist))
  return ??noPrimes??
else
  if (isPrime(first(mylist))
    return max(first(mylist), largestPrime(rest(mylist)))
  else
    return largestPrime(rest(mylist))
```

Only now work out the body of the function/procedure

Didactics for Program Design (Step 4)

- **Sort a list of names by alphabet**

inventory:

empty(mylist) --- boolean

if not:

... first(mylist) -- String

... rest(mylist) -- ListofString

... sort(rest(mylist)) -- ListofString (sorted)

... needed: insert(String, ListofString) -- ListofString (sorted)

-structure -- select fields, record their types
-variants -- process every variant separately
-list all functions/procedures/methods that can be used with the available data

Didactics for Program Design (Step 5)

- **Find the largest prime in a list of numbers**

body:

```
if (empty(mylist))
  return mylist
else
  insert(first(mylist), (sort(rest(mylist)))
```

```
wish list:
// insert the given name into the sorted list of names
ListofString insert(String, Listof String)
```

Only now work out the body of the function/procedure

Didactics for Program Design (Step 4)

- **Find the position of the given letter in the given String**

inventory:

char c

String text

functions for Strings:

// produce a substring of String s starting at the location i until location j

// produce empty of cut off String if the given String is not long enough

String substring(int i, int j, String s)

-structure -- select fields, record their types
-variants -- process every variant separately
-list all functions/procedures/methods that can be used with the available data

Didactics for Program Design (Step 5)

- **Find the position of the given letter in the given String**

body:

```
[for (int i = 0; i < length(text); i++)
   if (substring(text, i, i+1) == c)
   return i;
return -1;]
```

Only now work out the body of the function/procedure

Didactics for Program Design (Step 6)

- **Find the largest prime in a list of numbers**

  ```
  largestPrime(12 17 5 24 6) -> 17
  largestPrime(4 9 6) -> ??
  ```

- **Sort a list of names by alphabet**

  ```
  sort(“hi” “ciao” “bye”)->(“bye” “ciao” “hi”)
  ```

- **Find the position of the given letter in the given String**

  ```
  whereIs(“b”, “mama”) -> -1
  whereIs(“a”, “mama”) -> 1
  ```

Verify the correctness - the tests are defined in the third step

Information and data: the connection

Design Recipe for a Data Definition

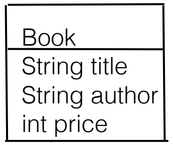
- **primitive/basic types:** numbers, Strings, images, bool
- **clases/structures:** several pieces of data are needed to describe the information
- **references:** a piece of data in one class/structure is an instance of another class/structure
- **variants:** several variants of data share common properties
- **combinations** of these possibilities

Analyze the problem (according to the above criteria), produce data definitions; make several examples of data

Information and data: the connection

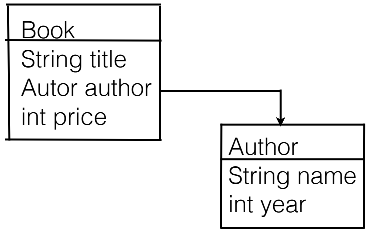
- **primitive/basic types:** int, String, boolean, image

- **classes/structures:**



Book
String title
String author
int price

- **references:**

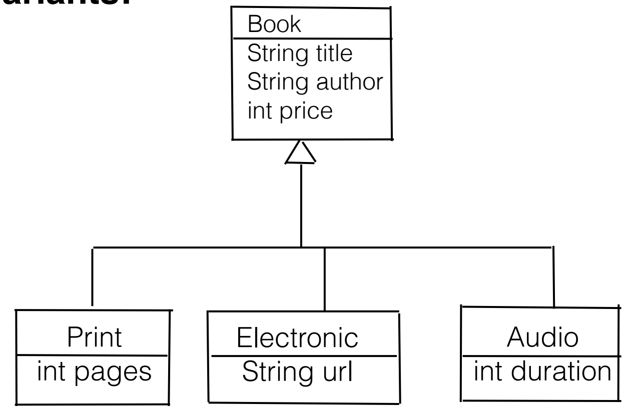


Book
String title
Autor author
int price

Author
String name
int year

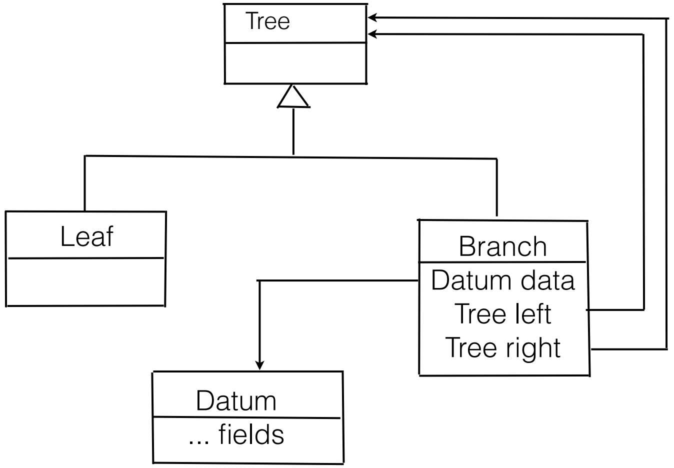
Information and data: the connection

- **variants:**

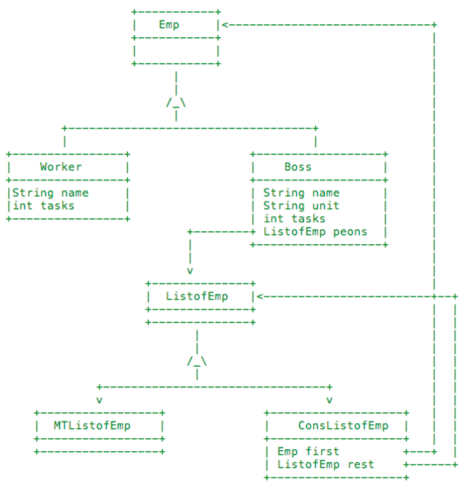


Information and data: the connection

- **combinations:**



Information and data: the connection



```
                  +-----------+
                  |   Emp     |<-----------------------------+
                  +-----------+                              |
                  |           |                              |
                  +-----------+                              |
                        |                                    |
                        |                                    |
                       /_\                                   |
                        |                                    |
        +-----------------------------------+                |
        |                                   |                |
+----------------+                 +------------------+      |
|    Worker      |                 |    Boss          |      |
+----------------+                 +------------------+      |
|String name     |                 | String name      |      |
|int tasks       |                 | String unit      |      |
+----------------+                 | int tasks        |      |
                          +--------+ ListofEmp peons  |      |
                          |        +------------------+      |
                          |                                  |
                          v                                  |
                    +--------------+                         |
                    |  ListofEmp   |<------------------------+--+
                    +--------------+                         |  |
                    +--------------+                         |  |
                           |                                 |  |
                           |                                 |  |
                          /_\                                |  |
                           |                                 |  |
             +--------------------------------+              |  |
             v                                v              |  |
    +-----------------+              +-------------------+   |  |
    |  MTListofEmp    |              |    ConsListofEmp  |   |  |
    +-----------------+              +-------------------+   |  |
    +-----------------+              | Emp first         +---+  |
                                     | ListofEmp rest    +------+
                                     +-------------------+
```

Information and data: the connection

```
                             +---------+
                             |  Marta  |
                             | CEO 100 |
                             +----+----+
                                  |
                +-----------------+-----------------------------+
                |                                               |
        +-------+-----+                                     +---+---------+
        | Danko       |                                     | Anka        |
        | Operacie 70 |                                     | Financie 20 |
        +------+------+                                     +------+------+
               |                                                   |
   +-----------+-------------------+------------+               +--+------+
   |                               |            |               |         |
+-------------+            +-------+-----+ +----+--------+   +-----+ +----+--------+
| Jurko       |            | Janka       | | Palko       |   | A 3 | | Peter       |
| Sekcia-A 25 |            | Sekcia-B 15 | | Sekcia-C 20 |   +-----+ | Sekcia-D 10 |
+----+--------+            +-----------+-+ +----------+---+           +----+--------+
     |                                 |              |                    |
  +--+-------------+-------+         +-+-----+      +-+---+             +--+---+
  |                |       |         |       |      | H 6 |             | B  5 |
+-+------------+ +-+---+ +-+---+   +-+---+ +-+---+  +-----+             +------+
| Milan        | | D 4 | | E 2 |   | F 8 | | G 6 |
| Skupina-A 10 | +-----+ +-----+   +-----+ +-----+
+--+-----------+
   |
+--+--+
| C 6 |
+-----+
```

Information and data: the connection

```
                             +---------+
                             |  Marta  |
                             | CEO 100 |
                             +----+----+
                                  |
                +-----------------+-----------------------------+
                |                                               |
        +-------+-----+                                     +---+---------+
        | Danko       |                                     | Anka        |
        | Operacie 70 |                                     | Financie 20 |
        +------+------+                                     +------+------+
               |                                                   |
   +-----------+-------------------+------------+               +--+------+
   |                               |            |               |         |
+-------------+            +-------+-----+ +----+--------+   +-----+ +----+--------+
| Jurko       |            | Janka       | | Palko       |   | A 3 | | Peter       |
| Sekcia-A 25 |            | Sekcia-B 15 | | Sekcia-C 20 |   +-----+ | Sekcia-D 10 |
+----+--------+            +-----------+-+ +----------+---+           +----+--------+
     |                                 |              |                    |
  +--+-------------+-------+         +-+-----+      +-+---+             +--+---+
  |                |       |         |       |      | H 6 |             | B  5 |
+-+------------+ +-+---+ +-+---+   +-+---+ +-+---+  +-----+             +------+
| Milan        | | D 4 | | E 2 |   | F 8 | | G 6 |
| Skupina-A 10 | +-----+ +-----+   +-----+ +-----+
+--+-----------+
   |
+--+--+
| C 6 |
+-----+
```

How many people work in the unit with the given name?

What is important:

- There are many types of data, we can combine them if the information consists of several types or variants
- The goal of a program is to produce from the given data some new data that represents new information
- Every function or procedure should handle just one task: use helper functions/methods when needed
- Input-output is not important on its own: processing of the inputs and preparation of data for output are tasks to be programmed as well

What is important:

- It is important to know how to represent information as data and how to interpret data as the information it represents
- Every function/procedure should be designed systematically, test-first approach...
- Build larger programs by designing abstractions

    if code is repeated (with only small differences), produce a program where the differences are represented by parameters and the common part appears only once

Design of abstractions = libraries

Design Recipe for Abstractions

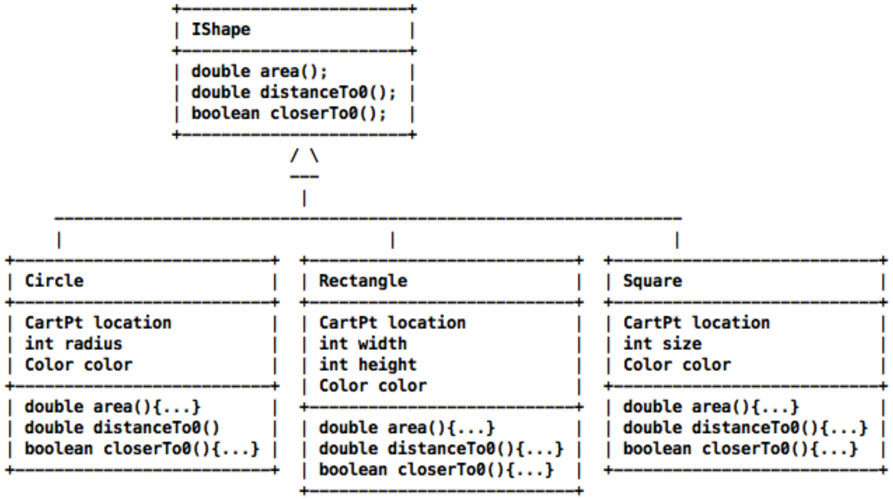
- Mark all places where the similar code segments differ.
- Replace them with parameters and rewrite the solution using them as arguments.
- Rewrite the original solutions to your problems by invoking the generalized solution with the appropriate arguments.
- Make sure that the tests for the original solution still pass.

Design of abstractions = libraries

- interfaces -- abstract classes
- function objects
- parametrized types
- iterators
- abstract data types

The keys to understanding how to build/use reusable code

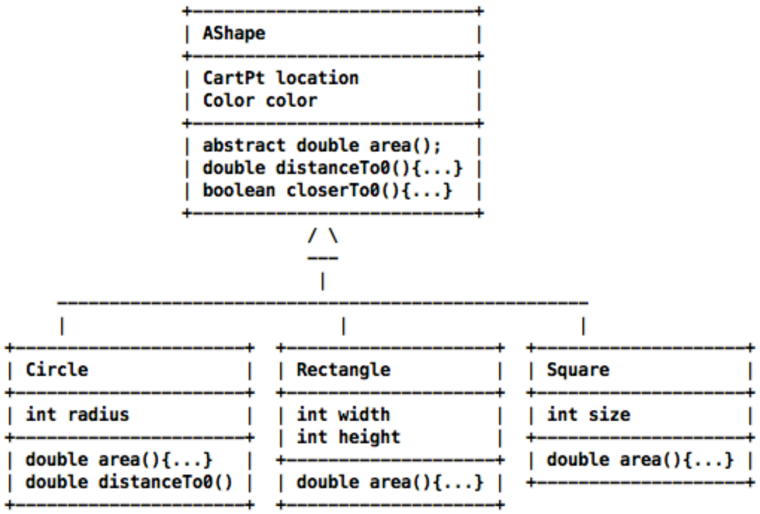
Design of abstractions: abstract class



```
                 +-----------------------+
                 | IShape                |
                 +-----------------------+
                 | double area();        |
                 | double distanceTo0(); |
                 | boolean closerTo0();  |
                 +-----------------------+
                            / \
                            ---
                             |
     ---------------------------------------------------------------
     |                                |                            |
+--------------------------+ +---------------------------+  +---------------------------+
| Circle                   | | Rectangle                 |  | Square                    |
+--------------------------+ +---------------------------+  +---------------------------+
| CartPt location          | | CartPt location           |  | CartPt location           |
| int radius               | | int width                 |  | int size                  |
| Color color              | | int height                |  | Color color               |
+--------------------------+ | Color color               |  +---------------------------+
| double area(){...}       | +---------------------------+  | double area(){...}        |
| double distanceTo0()     | | double area(){...}        |  | double distanceTo0(){...} |
| boolean closerTo0(){...} | | double distanceTo0(){...} |  | boolean closerTo0(){...}  |
+--------------------------+ | boolean closerTo0(){...}  |  +---------------------------+
                             +---------------------------+
```

Create an abstract class: common fields, methods

Design of abstractions: abstract class



```
                 +---------------------------+
                 | AShape                    |
                 +---------------------------+
                 | CartPt location           |
                 | Color color               |
                 +---------------------------+
                 | abstract double area();   |
                 | double distanceTo0(){...} |
                 | boolean closerTo0(){...}  |
                 +---------------------------+
                            / \
                            ---
                             |
     --------------------------------------------------
     |                          |                      |
+----------------------+ +---------------------+ +---------------------+
| Circle               | | Rectangle           | | Square              |
+----------------------+ +---------------------+ +---------------------+
| int radius           | | int width           | | int size            |
+----------------------+ | int height          | +---------------------+
| double area(){...}   | +---------------------+ | double area(){...} |
| double distanceTo0() | | double area(){...} | +---------------------+
+----------------------+ +---------------------+
```

Create an abstract class: common fields, methods

Design of abstractions: function objects

- sort a collection of the type T (what **ordering**?)

  comparator function: (T, T) -> int

- select all items that fit some **criterion**

  selector predicate: (T) -> boolean

- perform the desired **action**

  action method to perform

Difficult if the language does not support first class functions

Design of abstractions: parametrized types

- binary search trees of numbers, strings, books

  Tree<T> --> Tree<Integer>, Tree<String>, ...

- lists of persons, songs, images

  List<T> --> List<Person>, List<Song>, ...

Not needed in untyped languages

Design of abstractions: iterators

Some algorithms require that we examine all elements of a data set, one at a time.

Iterators, visitors, and specially designed classes or language constructs provide such service.

The algorithms then rely on these services to generate the needed data items, without the knowledge of how the data set is implemented.

Iterator may generate data from an array or from a file...

Design of abstractions: iterators

```
Iterator<T> (destructive, imperative):
   boolean hasNext()
   T next()

Traversal<T> (immutable iterator, functional):
   boolean isEmpty()
   T getFirst()
   Traversal<T> getRest()
```

Iterator may generate data from an array or from a file...
Program just handles the generated data one item at a time

Design of abstractions: abstract data types

- Vector (ArrayList) -- direct access structures
- Stack, Queue
- Priority Queue
- Map, HashMap -- (key - value) pairs
- Graph

The behavior is specified by the functions/methods only
Implementations can vary
See several implementations -- understand the trade-offs

Design Recipes - didactics

- Pedagogical intervention

  ask student where in the design recipe are they

  follow up with questions in the recipes

- Self-regulatory learning

  students learn to ask the same questions

  learn to work out the problems

Libraries for the beginners: Java

- Typical programming languages are not suitable for a beginner
- They contain features that the beginner does not understand, but the error messages refer to them
- Programming of inputs, outputs, and user interactions is difficult and beginner needs to learn a lot before he is ready to program them
- Design of tests requires understanding of the different ways of evaluating equality of data

Libraries for the beginners: Java

Programing language for the beginners: **FunJava**

- Every class can implement only one interface
- Every field must get initial value when defined in the class or when the constructor is invoked
- The value of the field never changes
- The language has only two statements:

  return expression

  if (condition) statement else statement

Typical programing language is not suitable for a beginner

Libraries for the beginners: Java

Programing language for the beginners: **FunJava**

- Every class can implement only one interface
- Every field must get initial value when defined in the class or when the constructor is invoked
- The value of the field never changes
- The language has only two statements:

    return expression

    if (condition) statement else statement

Contains features that the beginner does not understand, but the error messages refer to them - not a problem here

Libraries for the beginners: Java

Library for the beginners: **World, Canvas**

- simple functions for drawing of geometric shapes (circle, disk, rectangle, line, text)
- **World:** (programming of interactive games)

Canvas theCanvas -- accessible field
where the game scene is drawn

boolean draw() -- method that draws the
scene

Programming of inputs, outputs, and user interactions is difficult and beginner needs to learn a lot before he is ready to program them

Libraries for the beginners: Java

Library for the beginners: **World, Canvas**

-**World:** (programming of interactive games)

- actions:

  World onTick()

  World onKeyEvent(String ke)

  boolean endOfWorld()

- world begins the animation by invoking

  bigBang(int width, int height, double tick)

Programming of inputs, outputs, and user interactions is difficult and beginner needs to learn a lot before he is ready to program them

Libraries for the beginners: Java

Library for the beginners: **World, Canvas**

- **World:** (programming of interactive games)

  for advanced programmers

    mouse actions

    sound (MIDI notes to play on tick/key

      (programing of sequences of notes and their combinations)

    universe: client-server with messages

Programming of inputs, outputs, and user interactions is difficult and beginner needs to learn a lot before he is ready to program them

Libraries for the beginners: Java

Library for the beginners: **Tester**

- special library for the design and evaluation of tests
- Examples class: client for student code: data, methods

  - tests compare two objects by their value

  - compares inexact values within the given tolerance

  - special tests for constructors, exceptions, iterators, one-of options, value within a range, ...

Programming of inputs, outputs, and user interactions is difficult and beginner needs to learn a lot before he is ready to program them

Libraries for the beginners: Java

Library for the beginners: **Tester**

- produces a report with all results:
    - prints the values of all objects (pretty-print)
    - produces the results of all tests
    - if the test fails,
        - shows side-by-side the actual and expected values
        - marks the first place where the values differ
        - provides a link to the failed test

Programming of inputs, outputs, and user interactions is difficult and beginner needs to learn a lot before he is ready to program them

What is important:

- Instead of just using libraries teach students how libraries are built

    function(objects) that compare data

    algorithsm that use function(objects) (sort, filter, andmap)

- Abstract data types and their implementation
- Foundations of evaluation of complexity of algorithms and data structures

What is important:

- Principles of processing data from inputs and generating data for outputs:

  conversion of a String to numeric value it represents

  encoding of data when saved in files

  event handling - principles, and their use

  input and output streams

- Principles of design:

  test-first design

  one task - one function/procedure

Thank you for listening

People:

Matthias Felleisen, Matthew Flatt, Robby Findler, Kathi Fisler, Shriram Krishnamurthi, Emmanual Schanzer, Viera K. Proulx, Stephen Bloch

Program by Design:

http://www.programbydesign.org

Java libraries:

http://www.ccs.neu.edu/javalib

Laboratories, materials:

http:://www.ccs.neu.edu/home/vkp/Teaching

Curriculum for 6-9 grade:

http://www.bootstrapworld.org