The Pedagogy of Program Design

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Outline:

Curriculum Foundation

- Design Recipes
- Supporting Software

Curriculum Components

- BOOTSTRAP - young children
- TeachScheme - secondary schools, universities
- ReachJava - secondary schools, universities

Pedagogy of Program Design

- Design Recipes: Details

Our Experiences; Resources

Curriculum Foundation

Function design based on algebra

- every function consumes data, produces new data
- no change of state; no input/output difficulties

Design Recipe for understanding the design process

- several steps, clearly defined
- each step has goals and measure of success

Understanding information versus data

- represent information as data
- interpret the information that data represents

Supporting software: to focus on the essential concepts

- language levels and test support
- libraries for graphics, interaction, client/server

Understanding the design process

DESIGN RECIPE for functions

- 1: Problem analysis and data definition
- 2: Purpose statement and the header
- 3: Examples with expected outcomes
- 4: Inventory/Template of available data fields and methods
- 5: Function body
- 6: Tests

Pedagogical advantages:

Each step is well defined
-- with a tangible result
-- with a guidance on what questions to ask

DESIGN RECIPEs for data definitions, abstractions...

DESIGN RECIPE for data definitions

DESIGN RECIPE for data definitions

- can it be represented by a primitive type? - select the type
- are there several parts that represent one entity? - a class
- are there several related variants? - a union of classes
- add arrows to connect data definitions

Make examples of data

- convert information to data
- interpret data as information

Supporting software: to focus on the concepts

Software appropriate for students current knowledge

Language levels

- add complex features gradually

Test support

- it should be easy to test every function

Supporting libraries: students focus on the essentials

- graphics: define color, size, shape/image, position
- interactions: define scene after a time tick, key or mouse event
- client/server programming: design the communication protocol

Curriculum Components: BOOTSTRAP

6 - 8 grade afterschool program

10 lessons, 90 minutes each

Goals: to understand mathematical principles of computation

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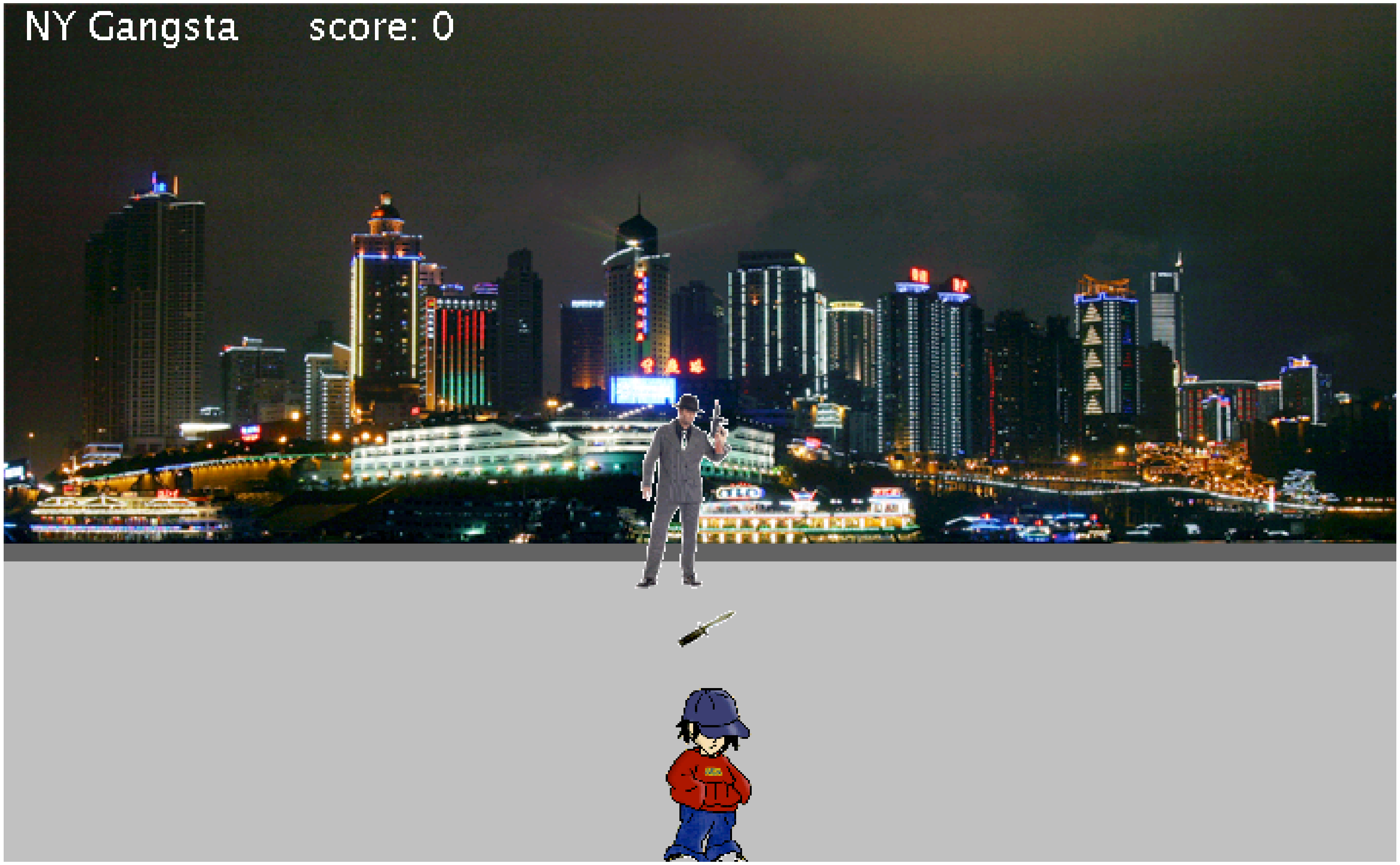

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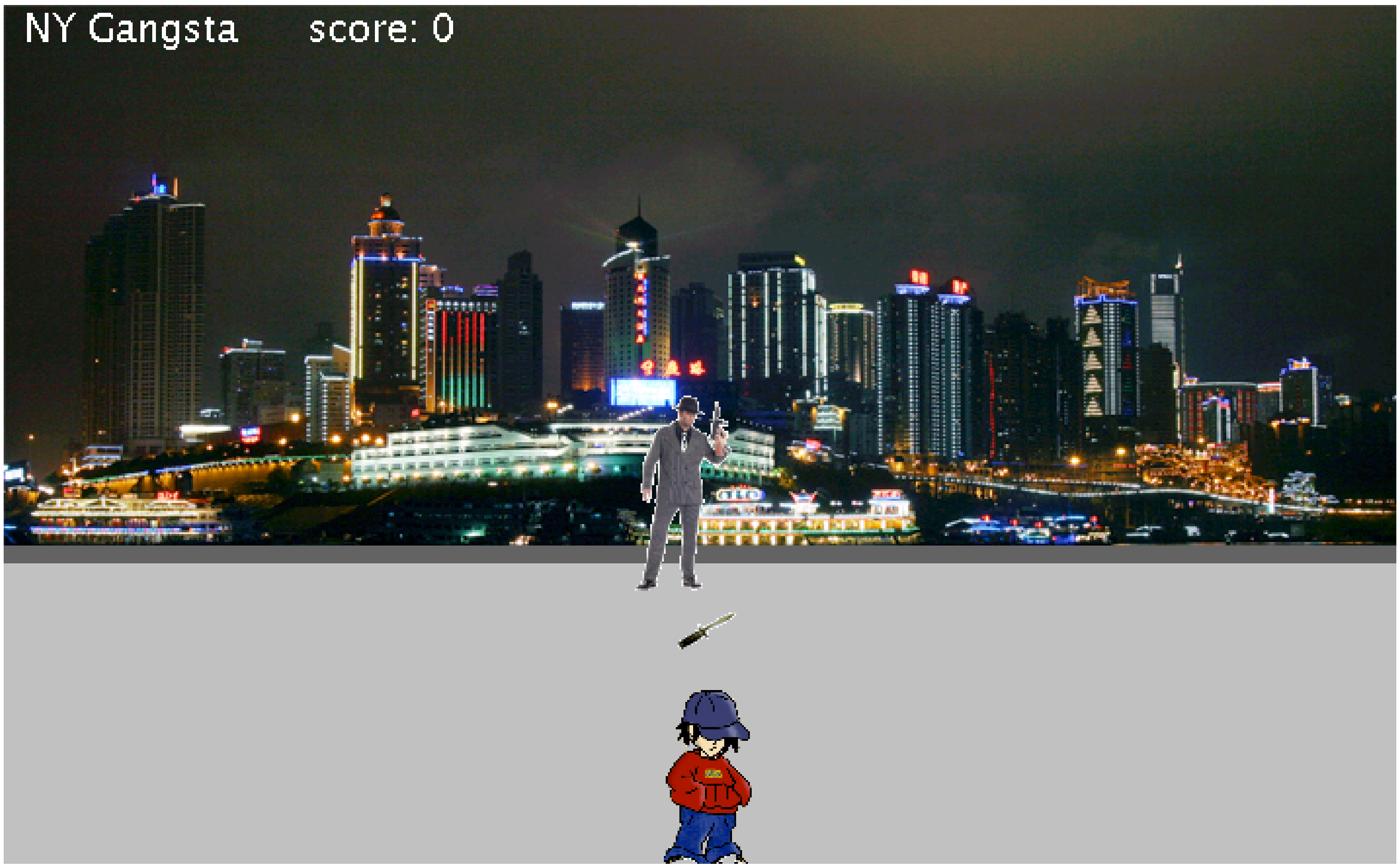

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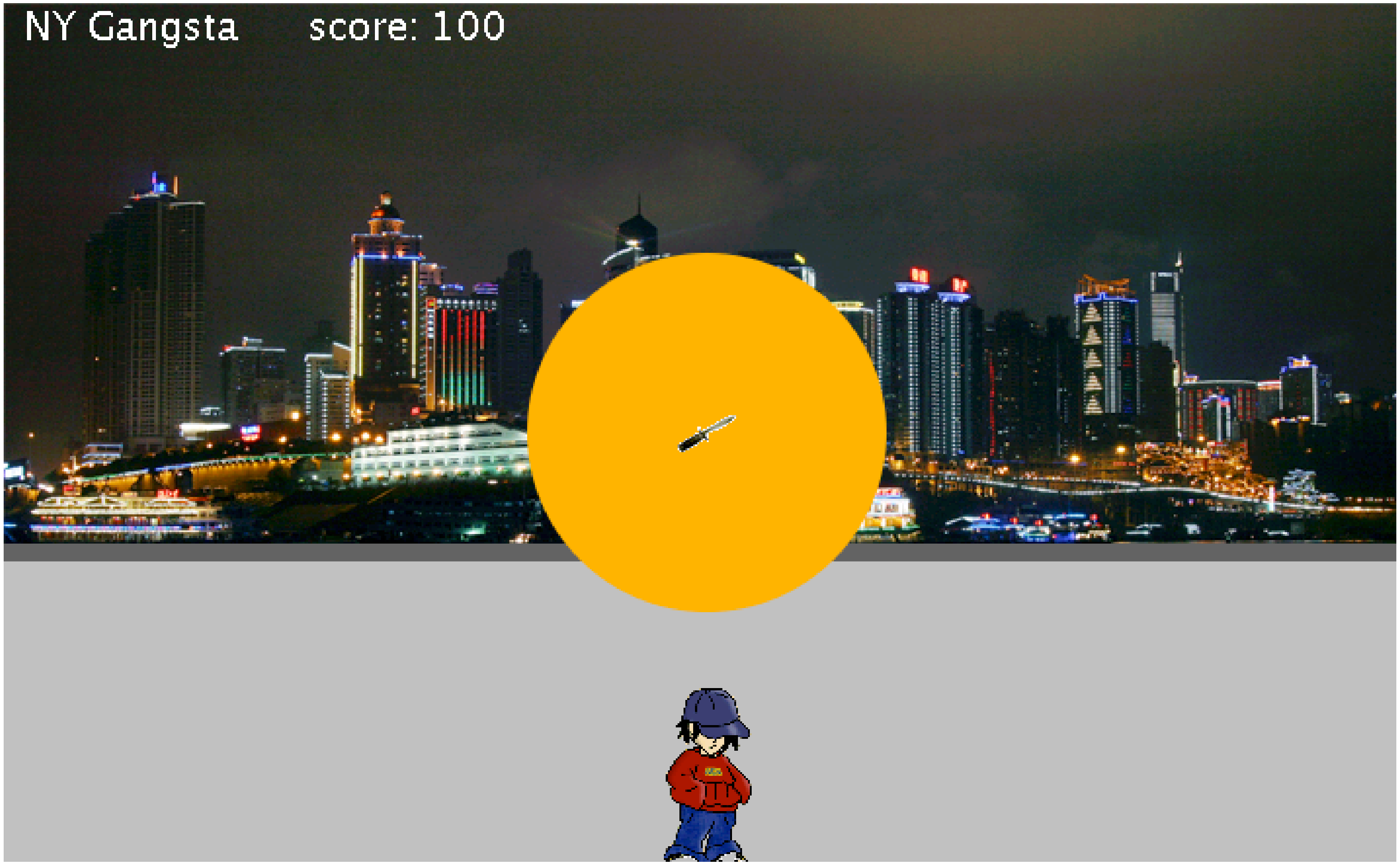

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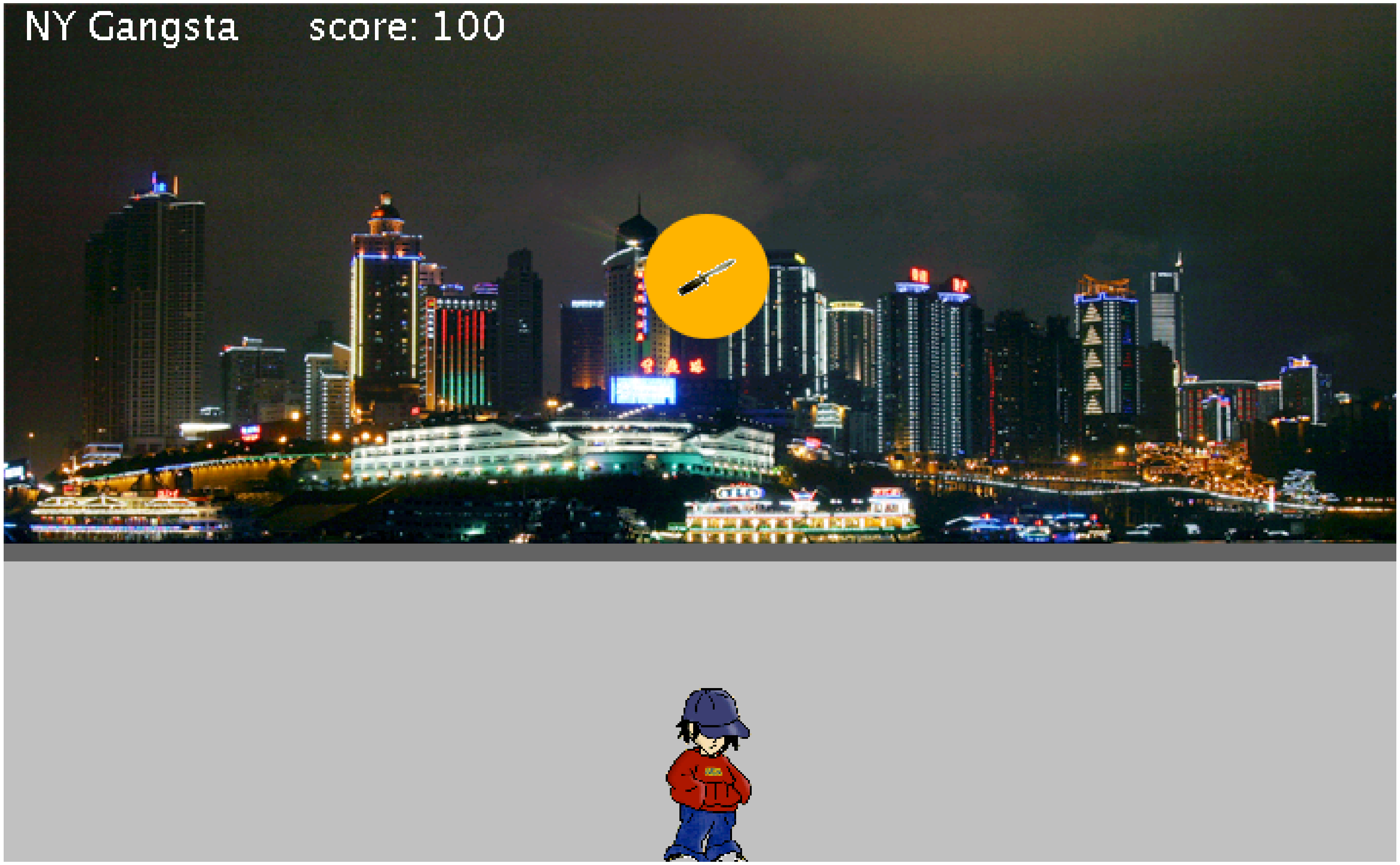

Curriculum Components: BOOTSTRAP

6 - 8 grade afterschool program

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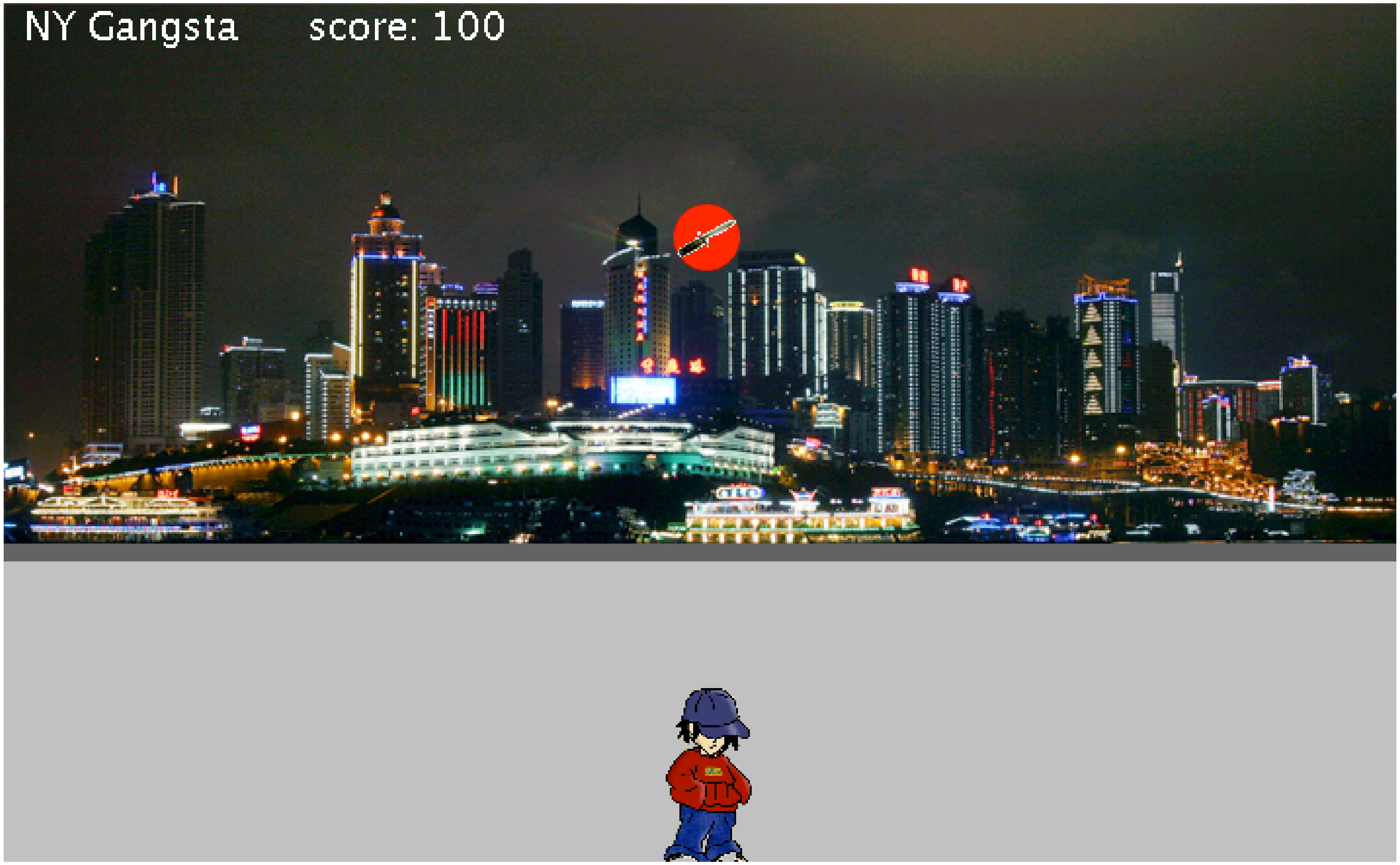


Curriculum Components: BOOTSTRAP

Student code:

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; Updating Code

; update-object : Number -> Number
; move the object up the screen
(define (update-object y)
  (- y 20))

(check-expect (update-object 34) 14)

; update-target-x : Number  -> Number
; return the new x-coordinate of the target
(define (update-target-x x)
  (+ x 7))

(check-expect (update-target-x 3) 10)

; update-target-y :  Number -> Number
; return the new y-coordinate of the target
(define (update-target-y y)
  250 )

; update-player : Number String -> Number
; make a new player that is shifted to the left or right
(define (update-player x dir)
  (cond
    [(string=? dir "left") (- x 60)]
    [(string=? dir "right") (+ x 60)]
    ))

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; Geometry Functions

; distance : Number Number Number Number-> Number
; determines the distance between the target's (x,y) and the object's (x,y)
(define (distance x1 y1 x2 y2)
  (sqrt (+ (expt (- x2 x1) 2 ) (expt (- y2 y1) 2 ))))


; collide? : Number Number Number Number -> Boolean
; return true if the coordinates are within 15 of each other
(define (collide? tx ty ox oy)
  (< (distance tx ty ox oy) 80))

; offscreen? : Number Number -> Boolean
; return true if the target's coordinates put it offscreen
(define (offscreen? x y)
  (or
  (> x 640)
  (< x 0)
  (< y 0)
  (> y 480)))
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; PROVIDED CODE - remove the semicolon from the lines below when all the functions are completed
(start TITLE background update-target-x update-target-y update-player
       update-object collide? target player object offscreen?)
```

Curriculum Components: BOOTSTRAP

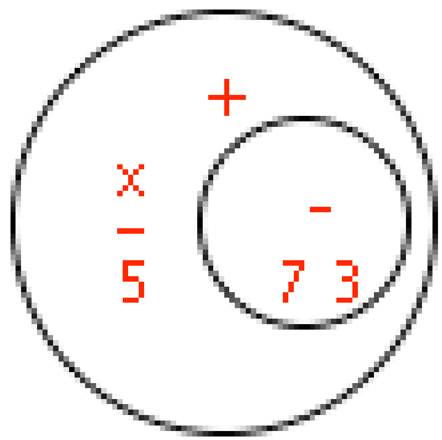
Pedagogy

simple but exact language

- expressions: circles of evaluation
- functions: substitution
- conditionals

library with required functions:

```
(update-object x)
(update-target-x x)
(update-target-y y)
(update-player dir)
(collide tx ty ox oy)
```



- images are data

Curriculum Components: TeachScheme!

How to Design Programs

Interactive functional environment

Simple Scheme-like language(s)

Focus on understanding the design of data

The shape of a function follows the shape of the data

Authors:

Matthias Felleisen, Robert Bruce Findler,

Matthew Flatt, Shriram Krishnamurthi

Curriculum Components: TeachScheme!

How to Design Programs

Textbook free online: htdp.org

DrScheme programming environment: DrScheme.org

Tools for the programmer:

- Stepper: shows expression evaluation
- Test support: evaluates tests, reports results
- Test coverage: show program parts not tested
- Dependency arrows: definition to use, or use to definition

http://www.teach-scheme.org/

Curriculum Components: TeachScheme!

DrScheme

```
;; convert the longitude to x coordinate
;; to-x: Num -> Num
(define (to-x longitude)
  (- 100 (round (* (/ (- longitude 60) 60) 100))))

;; Examples
(check-expect (to-x 89.649531) 51)
(check-expect (to-x 86.049533) 57)
(check-expect (to-x 93.632993) 44)
(check-expect (to-x 95.746061) 40)
(check-expect (to-x 85.804479) 57)


;; convert the latitude to x coordinate
;; to-y: Num -> Num
(define (to-y latitude)
  (- 100 (round (* (/ (- latitude 20) 30) 100))))

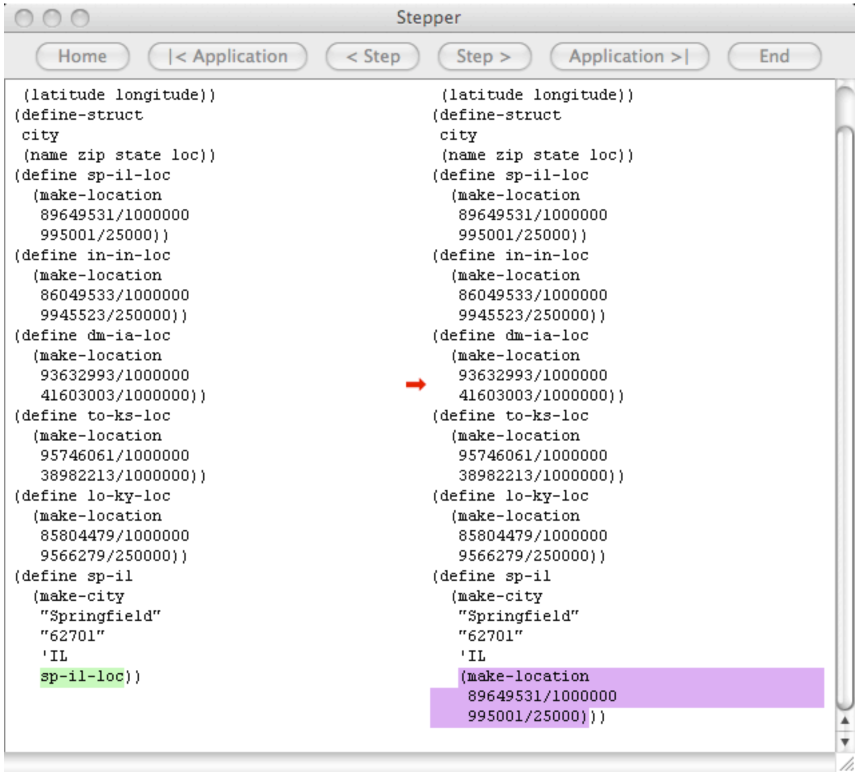
;; Examples
(check-expect (to-y 39.80004) 34)
(check-expect (to-y 39.782092) 34)
(check-expect (to-y 41.603003) 28)
(check-expect (to-y 38.982213) 37)
(check-expect (to-y 38.265116) 39)

;; convert the location to a posn
(define (to-posn aloc)
  (make-posn (to-x (location-latitude aloc))
             (to-y (location-longitude aloc))))

;; Examples
(check-expect (to-posn sp-il-loc) (make-posn 51 34))
(check-expect (to-posn in-in-loc) (make-posn 57 34))
(check-expect (to-posn dm-ia-loc) (make-posn 44 28))
(check-expect (to-posn to-ks-loc) (make-posn 40 37))
(check-expect (to-posn lo-ky-loc) (make-posn 57 39))
```

Curriculum Components: TeachScheme!

DrScheme



Curriculum Components: ReachJava

How to Design Classes

Textbook draft: 670 pages used in classrooms for five years

DrScheme programming environment: ProfessorJ languages

- language levels
- testing support
- libraries for interective graphics based games

Curriculum materials:

- Laboratory tutorials/projects
- Assignments

Standard Java support

The Pedagogy of Program Design

The main themes:

- Data vs. Information
- Program Design
- The Role of Testing
- Designing Reusable Programs: Abstractions

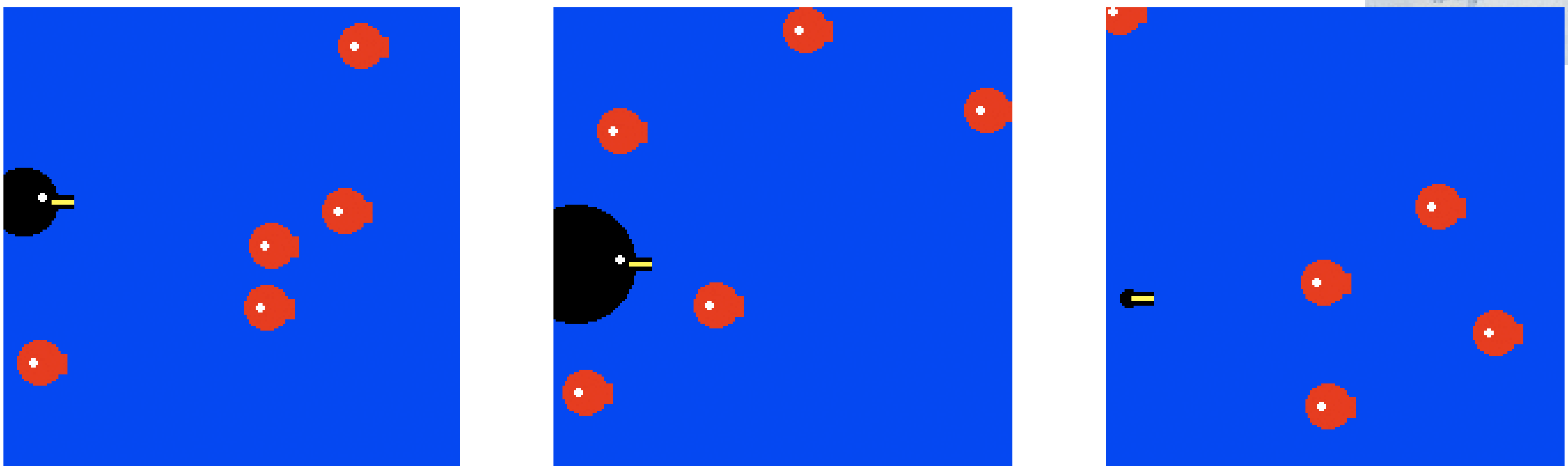
The team:

Matthias Felleisen, Robert Bruce Findler, Matthew Flatt

Kathryn E. Gray, Shriram Krishnamurthi, Viera K. Proulx

The Pedagogy of Program Design

Let's 'play' with the design of a simple game:



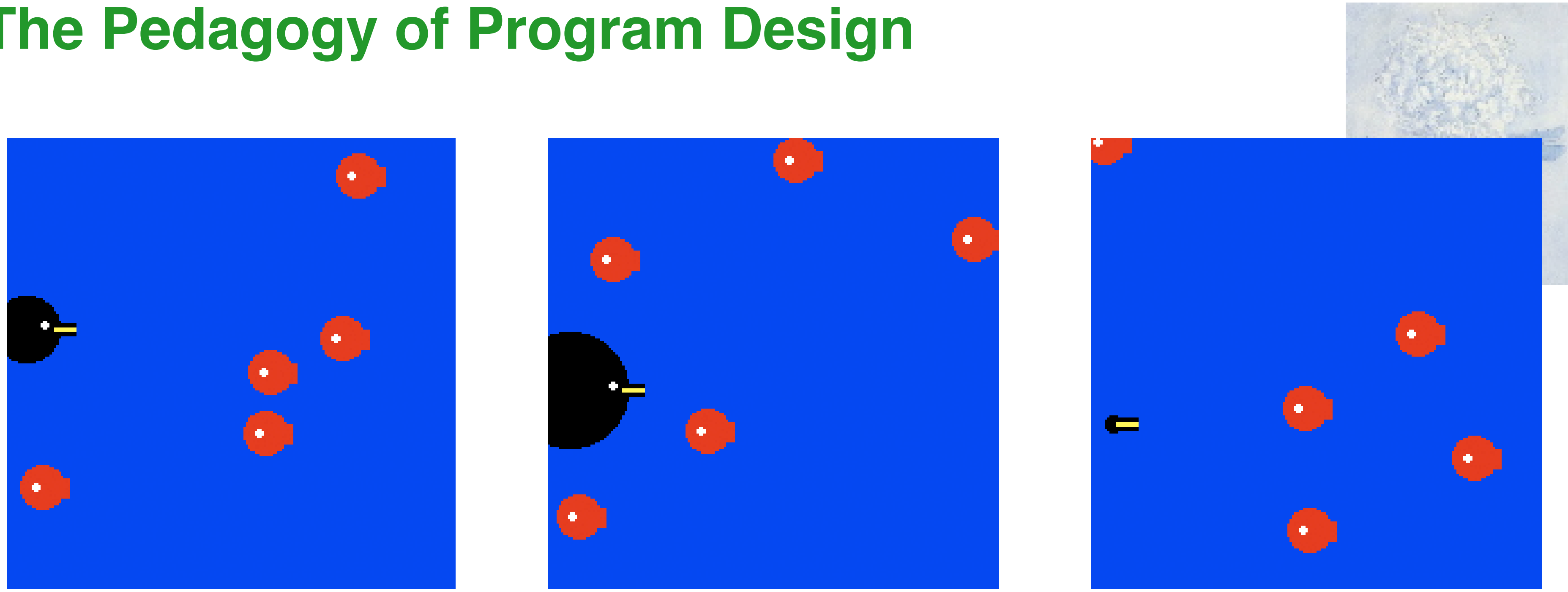
Fish swim across the screen, each is replaced by a new one when it escapes or is eaten

Shark waits, swimming up and down in response to the keys, gets hungrier as the time goes on

When the shark eats a fish it grows

The game ends when the shark dies of starvation

The Pedagogy of Program Design

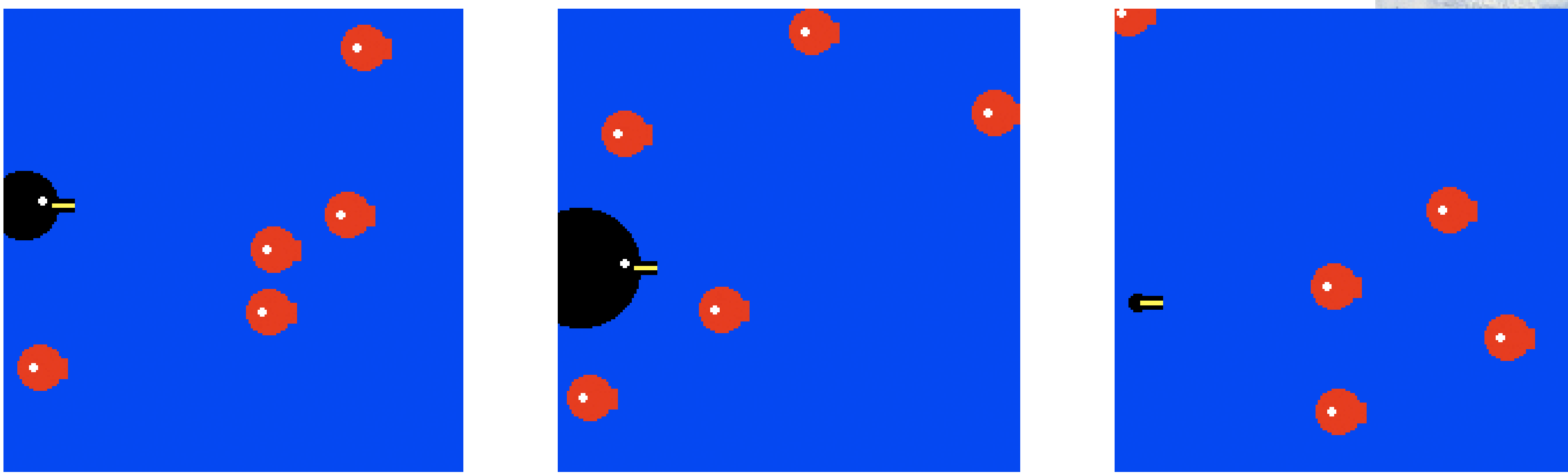


- How do we build the game?
  - We need a frame, a panel with graphics to draw
  - We need to learn how to use the **`Timer`**
  - We need to learn how to use the **`onKeyEventListener`**

Then we can start thinking about the game actions

Technical details hide the program design

The Pedagogy of Program Design



- How do **we** build the game? - what are the parts we need?
  - How do we draw? - make a scene from rectangles, circles with size, color
  - How do we animate? - create a scene for each tick
  - How do we respond to the keys? - define **`onKeyEvent`** method

No complicated system interaction - focus on the game actions

The Pedagogy of Program Design

Data vs. Information

Think about the problem, what information is available?

- How do we build the game? - what are the parts we need?
  - There is a shark - that moves up and down
  - There is a fish - or more than one - that swims
  - All should stay within the game area

The Pedagogy of Program Design

Data vs. Information

Think about the problem, what information is available?

- How do we build the game? - what are the parts we need?
  - There is a shark - that moves up and down
  - There is a fish - or more than one - that swims
  - All should stay within the game area

The Pedagogy of Program Design

Data vs. Information

Think about the problem, what information is available?

- Shark: what do we know about him?
  - where is the shark
  - how hungry is the shark
- Fish: where is the fish?
  - How fast is it swimming?
  - Did it swim out of the game area?
- Game area: how wide, how tall?
  - Background color?

The Pedagogy of Program Design

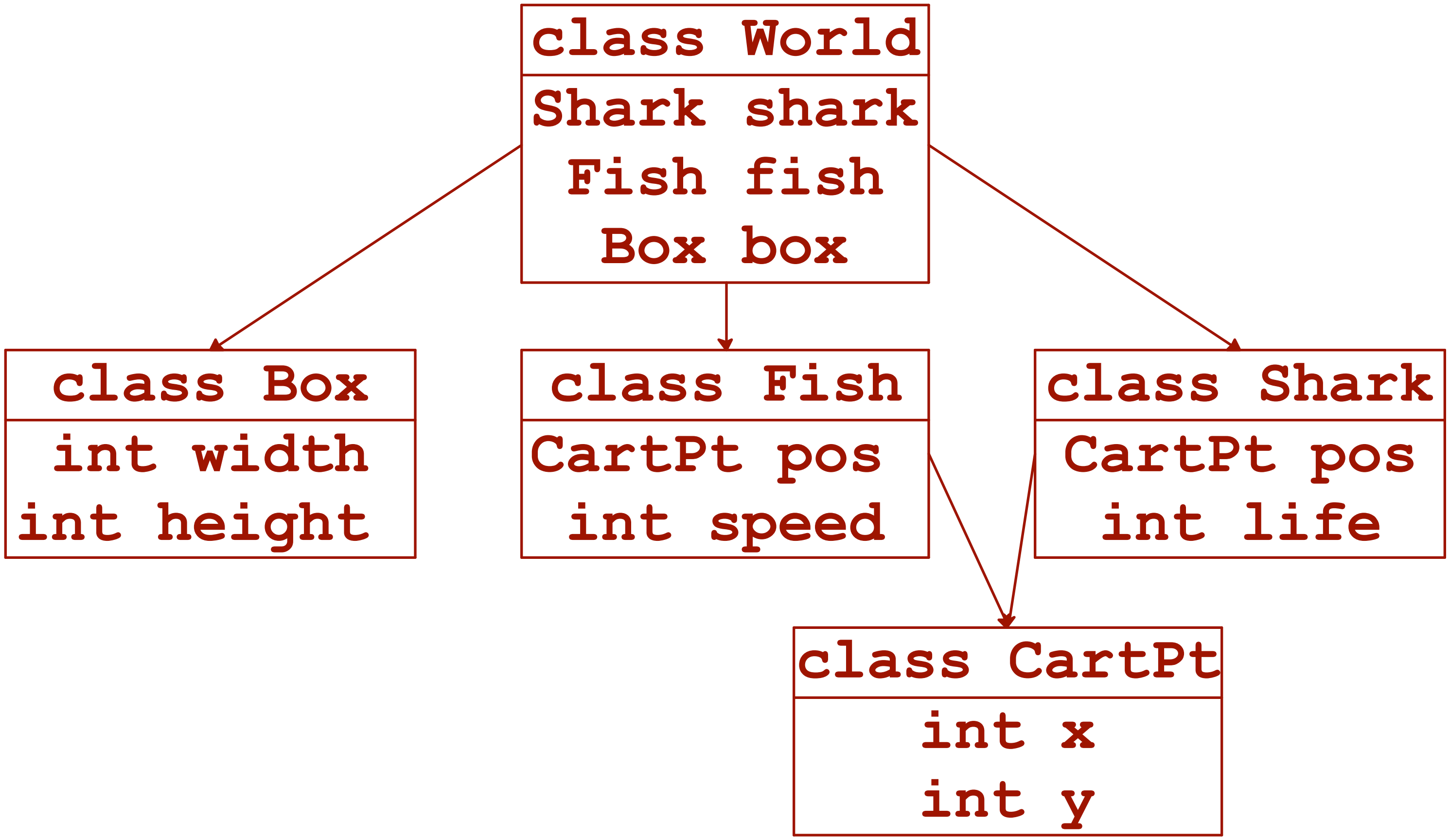
Data vs. Information

- World consists of the area, the fish and the shark
- Shark
  - Position - consists of the x and y coordinate
  - Life time remaining
- Fish
  - Position - consists of the x and y coordinate
  - ... maybe the speed
- Game area
  - width and height
  - we also have to draw the shapes

The Pedagogy of Program Design

Data vs. Information

Data definition for the world with **`CartPt`** : a class diagram



The Pedagogy of Program Design

Data vs. Information

Sample data

```
Fish fish = new Fish(new CartPt(200, 100), 5);

Shark shark = new Shark(new CartPt(20, 100), 30);

Box box = new Box(200, 200);

World w = new World(fish, shark, box);
```

The Pedagogy of Program Design

Data vs. Information

Sample data

```
Fish fish = new Fish(new CartPt(200, 100), 5);
```
a fish that swims at speed 5 starting from the mid-right of the box

```
Shark shark = new Shark(new CartPt(20, 100), 30);
```
a shark with 30 lives starting 20 pixels in from the mid-left of the box

```
Box box = new Box(200, 200);
```
the box of width and height 200

```
World w = new World(fish, shark, box);
```
the scene 200 by 200 with one fish on the right, one shark on the left

The Pedagogy of Program Design

Data vs. Information

- This is complicated enough to warrant separate attention
- We must make sure students understand what data the program works with

- Design Recipe for Data Definition:
  - can it be represented by a primitive type? - select the type
  - are there several parts that represent one entity? - a class
  - are there several related variants? - a union of classes
  - add arrows to connect data definitions

- **Convert information to data**
- **Interpret data as information**

The Pedagogy of Program Design

Data vs. Information

Sample data

```
Fish fish = new Fish(new CartPt(200, 100), 5);
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a fish that swims at speed 5 starting from the mid-right of the box

```
Shark shark = new Shark(new CartPt(20, 100), 30);
```
a shark with 30 lives starting 20 pixels in from the mid-left of the box

```
Box box = new Box(200, 200);
```
the box of width and height 200

```
World w = new World(fish, shark, box);
```
the scene 200 by 200 with one fish on the right, one shark on the left

The Pedagogy of Program Design

Designing the functionality

- Move the shark up and down in response to the arrow keys
- Move the fish left as the time goes on
- Replace the fish with a new one if it gets out of bounds
- Check if the shark ate the fish - if yes, replace the fish with a new one
- Starve the shark as the time goes on, check if he is dead

The Pedagogy of Program Design

Designing the functionality

- Move the shark up and down in response to the arrow keys
- Move the fish left as the time goes on
- Replace the fish with a new one if it gets out of bounds
- Check if the shark ate the fish - if yes,
  replace the fish with a new one
- Starve the shark as the time goes on, check if he is dead

The Pedagogy of Program Design

Designing the program

How do you eat an elephant? one bite at a time

- One task __ one function/method
- Make a wish list (a list of things to do later) ... when the task is too complex
- Think systematically about each small task

The Pedagogy of Program Design

Designing the program: Select a sub-problem

- Move the shark up and down in response to the arrow keys
- Move the fish left as the time goes on
- Replace the fish with a new one if it gets out of bounds
- Check if the shark ate the fish - if yes, replace the fish with a new one
- Starve the shark as the time goes on, check if he is dead

The Pedagogy of Program Design

Designing the program: One Task --- One Function/Method

- Check if the shark ate the fish
- Replace the fish with a new one

The Pedagogy of Program Design

Designing the program: One Task --- One Function/Method

Check if the shark ate the fish

Replace the fish with a new one

put the second task on a wish list

The Pedagogy of Program Design

Method Design - Step 1: Problem Analysis, Data Definition

Check if the shark ate the fish

What data do we need?

-- one **`Shark`** and one **`Fish`**

What class is responsible for this task?

-- could be either - choose **`Shark`**

-- the **`Fish`** becomes the method argument

What type of result do we produce?

-- a **`boolean`** value

The Pedagogy of Program Design

Method Design - Step 2: Purpose Statement and the Header

In the class `Fish` :

```
// check if this shark ate the given fish
boolean ateFish(Fish fishy){...}
```

What should we do next?

... well, when can the shark eat the fish?

... -- when they are close enough to each other

We can now reason about the method behavior

The Pedagogy of Program Design

Method Design - Step 3: Examples with Expected Outcomes

```
// check if this shark ate the given fish
boolean ateFish(Fish fishy){...}
```

The method produces a **`boolean`** result

... we need at least two examples

The shark and the fish far away from each other

The shark and the fish are close to each other

The Pedagogy of Program Design

Method Design - Step 3: Examples with Expected Outcomes

```
// check if this shark ate the given fish
boolean ateFish(Fish fishy){...}

Fish fish1 = new Fish(new CartPt(200, 100), 5);
Fish fish2 = new Fish(new CartPt(25, 100), 5);
Shark shark = new Shark(new CartPt(20, 100), 30);
```

`shark.ateFist(fish1)` ... expect `false`
`shark.ateFist(fish2)` ... expect `true`

The Pedagogy of Program Design

Method Design - Step 4: Inventory/Template

```
// check if this shark ate the given fish
boolean ateFish(Fish fishy){...}
```

Make an inventory of what we know about the shark and the fish

```
this.loc          -- CartPt
this.life         -- int
fishy.loc         -- CartPt
fishy.speed       -- int
```

it depends on how close are the `this.loc` and `fishy.loc`

The Pedagogy of Program Design

Method Design - Step 4: Inventory/Template

```
// check if this shark ate the given fish
boolean ateFish(Fish fishy){...}

this.loc         -- CartPt
this.life        -- int
fishy.loc        -- CartPt
fishy.speed      -- int
```

it depends on how close are the **this.loc** and **fishy.loc**

Remember: one task — one function/method

Design a method **boolean distTo(CartPt that)** in the class **CartPt**

The Pedagogy of Program Design

Method Design - Step 4: Inventory/Template

```
// check if this shark ate the given fish
boolean ateFish(Fish fishy){...}

this.loc          -- CartPt
this.life         -- int
fishy.loc         -- CartPt
fishy.speed       -- int
```

Design a method in the class `CartPt`

```
// compute the distance of this point to that
boolean distTo(CartPt that)
```

The Pedagogy of Program Design

Method Design - Step 4: Inventory/Template

```
// check if this shark ate the given fish
boolean ateFish(Fish fishy){...}

this.loc                      -- CartPt
this.life                     -- int
fishy.loc                     -- CartPt
fishy.speed                   -- int
this.loc.distTo(fishy.loc)    -- int
```

Design a method in the class **CartPt**

```
// compute the distance of this point to that
boolean distTo(CartPt that)
```

The Pedagogy of Program Design

Method Design - Step 5: Method Body

Designing method body:
... one question remains:
-- how close does the fish have to be for the shark to eat it?

-- we decide it must be within 20
-- of whatever unit we use to measure the distance

Here is the complete method - we hope:

```
// check if this shark ate the given fish
boolean ateFish(Fish fishy){
  return this.loc.distTo(fishy.loc) < 20;}
```

Are we done? ... **NO**

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Method Design - Step 6: Tests

What else needs to be done?

... how do we know we are correct?
... does the method work as we expected it to?

We already have examples with the expected outcomes!

Convert the examples into tests and test the method

```
// check if this shark ate the given fish
boolean ateFish(Fish fishy){
  return this.loc.distTo(fishy.loc) < 20;}
```

The Pedagogy of Program Design

Method Design - Step 6: Tests

```
// check if this shark ate the given fish
boolean ateFish(Fish fishy){
  return this.loc.distTo(fishy.loc) < 20;}

Fish fish1 = new Fish(new CartPt(200, 100), 5);
Fish fish2 = new Fish(new CartPt(25, 100), 5);
Shark shark = new Shark(new CartPt(20, 100), 30);

checkExpect(shark.ateFist(fish1), false);
checkExpect(shark.ateFist(fish2), true);
```

The Pedagogy of Program Design

Method Design - Step 6: Tests

```
// check if this shark ate the given fish
boolean ateFish(Fish fishy){
  return this.loc.distTo(fishy.loc) < 20;}

Fish fish1 = new Fish(new CartPt(200, 100), 5);
Fish fish2 = new Fish(new CartPt(25, 100), 5);
Shark shark = new Shark(new CartPt(20, 100), 30);

checkExpect(shark.ateFist(fish1), false);
checkExpect(shark.ateFist(fish2), true);
```

... add more tests if needed

The Pedagogy of Program Design

Designing a Method: The DESIGN RECIPE

1: Problem analysis and data definition
2: Purpose statement and the header
3: Examples with expected outcomes
4: Inventory/Template of available data fields and methods
5: Method body
6: Tests

Each step is well defined
-- with a tangible result
-- with a guidance on what questions to ask

The Pedagogy of Program Design

Other sub-problems --- use the same design process

- Move the shark up and down in response to the arrow keys
- Move the fish left as the time goes on
- Replace the fish with a new one if it gets out of bounds
- Check if the shark ate the fish - if yes, replace the fish with a new one
- Starve the shark as the time goes on, check if he is dead

The Pedagogy of Program Design

Designing Abstractions

A skill on its own: transcends programming

- motivated by observing repeated code patterns
- students are taught to design abstractions
- each abstraction motivates a new language construct or style

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Designing Abstractions - Why Teach Abstractions?

Eliminate code duplication - reduce maintenance costs

Design reusable code

Build libraries

Learn to use libraries

Software Support

Essential for students to understand the concepts

- Language levels
- Exploration of the program behavior and evaluation
- Test design, evaluation, reporting
- Graphics and interactions

Software Support

Graphics and interactions

- Drawing with minimal work needed
- In Scheme: images are data
- Games: inteface with a methods to program the behavior:
  - `onTick()` produce the scene after one clock tick
  - `onKeyEvent(String ke)`
    produce the scene in response to the key press `ke`
  - `bigBang(width, height speed)`
    run the animation of the given size at the given speed
- Support for client/server programming with messages

Experiences

BOOTSTRAP

- schools in five states, summer camps: over the past four years

TeachScheme!

- 700 secondary schools, many universities
  - excellent results over the past 15 years
    textbook translated into Polish, Spanish, German, ...

ReachJava -- How to Design Classes

- a number of universities - very good results
- workshops for teachers/instructors over the past five years

Testing Library

- a number of schools and universities - great response

THANK YOU

Resources

Web sites:

Main site for the TeachScheme/ReachJava! project:
http://www.teach-scheme.org

Lab materials, lecture notes, assignments:
http://www.ccs.neu.edu/home/vkp/HtDC.html

Tester library, World libraries: http://www.ccs.neu.edu/javalib

My home page: http://www.ccs.neu.edu/home/vkp