Object-Oriented Programming CS211

Announcements

- A2 due Wed night
- A3 posted soon after
- Prelim 1 conflicts:
  - We will post announcements on what to do

Object-Oriented Programming (*OOP*)

- What do we mean by ***object-oriented***?
  - Class is blueprint; specification
  - Object is specific instance
  - Object has state and behavior
- Problem solving…the gist:
  - Nouns become constants, enums, local variables, instance/class variables, objects
  - Verbs become operators or methods

OOP for Design

- Implementation
  - heap allocation of objects
    - Allocate memory with `new`
  - references to objects
    - `new Thing()` returns address of object
- Why use it?
  - modularity
  - code reuse
  - type safety
  - ease of design

Some Context

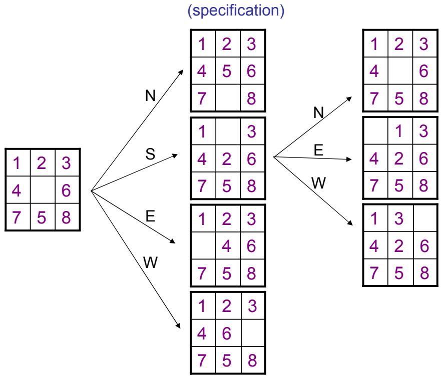
- Programming "in the large"
  - big applications require many programmers
- General approach
  - break problem into smaller subproblems
  - assign responsibility for each subproblem to somebody
  - keep the interfaces small!
- Each subproblem must have a *specification*
  - Functionality: What services must code provide?
  - Interface: What input conditions does the code expect? What output conditions does it guarantee?
- Job of the programmer: provide an *implementation* (code) that meets the specification

The Message

- Separate the *specification* from the *implementation*
  - called *data abstraction* in the literature
  - more modular, easier to maintain
  - implementation is hidden from the client, can be changed without changing the interface
  - the client's code does not break
- Object-oriented languages
  - encourage data abstraction
  - more modular code
- See `Puzzle` example…

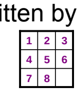
The 8-Puzzle

(specification)



Program Organization

- **`class Puzzle`**
  - an implementation of the game, written by you
  - functionality:



    - `init` — put puzzle in the initial state
    - `move` — move a tile **N**, **S**, **E**, or **W** to get a new state
    - `tile` — report which tile is in a given position
- **`class TestPuzzle`**
  - a client class, written by someone else
  - will communicate with `Puzzle` (your code) to play the game

Implementation

- Two subtasks
  - How do we represent a state (puzzle configuration)?
  - Given the representation, how do we implement `init`, `move`, and `tile`?
- Suppose no objects
  - What kinds of data to represent puzzle?
  - See posted examples
  - We'll focus on integer for now

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Representation of State: integer

1	2	3
4	9	6
7	5	8

→ `123496758`

- Model puzzle state as an integer:
  - Value is between `123456789` and `987654321`
  - `9` represents the empty square
- To convert integer `s` into a grid representation:
  - Remainder when `s` is divided by 10: tile in bottom right position
    - Java expression: `s%10`
  - Quotient after dividing by 10 gives encoding of remaining tiles
    - Java expression: `s/10`
  - Repeat remainder/quotient operations to extract remaining tiles
- This encoding may seem strange, but it arises many places in CS
  - Storing multidimensional arrays in memory

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Implementing Operations

- `init`: put into initial configuration

```
s = 123456879;
```

- `tile`: what tile is in position `(row,col)`?

```
return s/((int)Math.pow(10,8-
  (3*row+col)))%10;
```

- `move`: see examples

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A Key Question

- Where do we keep the state?
  1. method parameter/local variable
     - client keeps track of it
     - passed to `Puzzle` methods on each call
     - allocated on stack
  2. class variable of `Puzzle` class
     - client does not see it
     - allocated in static area
- These implementation choices affect the interface of the `Puzzle` class

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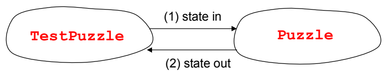
Interface L(ocal)



- State is implemented as local variable in class **`TestPuzzle`**
  - passed to/returned from methods in **`Puzzle`** class
- Interface of **`Puzzle`** class:

```
//return encoding of initial state
int init();
//return number of tile at grid (r,c)
int tile(int s, int r, int c);
//move to a new state, return new encoding
int move(int s, char d);
```


Implementation using L

```
public class TestPuzzle {

 public static void main(String[] args) {
     int state = Puzzle.init();
     display(state);
     state = Puzzle.move(state,'N');
     ...
 }

 public static void display(int s) {
   for (int r = 0; r < 3; r++) {
     for (int c = 0; c < 3; c++)
       System.out.print(Puzzle.tile(s,r,c)
         + " ");
     System.out.println();
   }
 }
}
```

Client

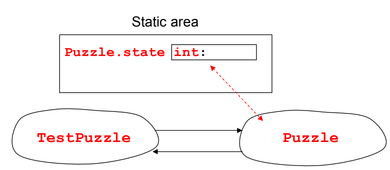
```
public class Puzzle {

  public static int init() {
    return 123456879;
  }

  public static int tile(int s, int r, int c) {
    return s/((int)Math.pow(10,8-(3*r+c)))%10;
  }

  public static int move(int s, char d) {
    ...
  }
}
```

Implementation

Critique of Interface L

- No data abstraction!
  - **`Puzzle`** class implementer chose to implement puzzle state as an **`int`**
  - This representation is exposed in the interface, so the client code is aware of it
  - Client's code may depend on this encoding
  - If **`Puzzle`** class implementer decides to change the implementatation (say, to represent state as a **`long`**), client code breaks

Interface S(tatic)



- State is implemented as class variable in class **`Puzzle`**
  - state does not have to be passed back and forth
  - representation is hidden from client
- Interface of **`Puzzle`** class:

```
void init(); //initialize the state
int tile(int r, int c); //return tile in position (r,c)
void move(char d); //move in direction d
```

Implementation using S

```
public class TestPuzzle {

 public static void main(String[] args) {
     Puzzle.init();
     display();
     Puzzle.move('N');
     ...
 }

 public static void display() {
   for (int r = 0;r < 3; r++) {
     for (int c = 0; c < 3; c++)
       System.out.print(Puzzle.tile(r,c)
         + " ");
     System.out.println();
   }
 }
}
```

```
public class Puzzle {
  private static int state;

  public static void init {
    state = 123456879;
  }

  public static int tile(int r, int c) {
    return state/((int)Math.pow(10,8-(3*r+c)))%10;
  }

  public static void move(char d) {
    ...
  }
}
```

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Critique of Interface S

- Data abstraction: yes!
  - `Puzzle` class implementer chose to implement state as `int`
  - State representation is not visible outside of `Puzzle` class
  - If `Puzzle` class implementer decides to change implementation of state to `long`, client code does not have to change
- Problem: only one client and one puzzle at

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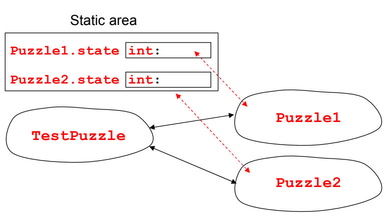
A Sneaky Solution



- Make copies of `Puzzle` class and rename them
- If client wants *n* puzzles, make *n* copies

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Sneaky Implementation of S

```
public class TestPuzzle {

 public static void main(String[] args) {
     Puzzle1.init();
     display1();
     Puzzle1.move('N');
     ...

     Puzzle2.init();
     display2();
     Puzzle2.move('N');
     ...
 }

 public static void display1() {
   ...
   }
 }

 public static void display2() {
   ...
 }
}
```

```
public class Puzzle1 {
  private static int state;

  public static void init {
    state = 123456879;
  }

  ...
}
```

```
public class Puzzle2 {
  private static int state;

  public static void init {
    state = 123456879;
  }

  ...
}
```

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Critique

- Data abstraction: yes
- Creation on demand: yes, but at cost of duplication of code
- Must know number of instances at compile time
- Naming issues
- How to improve all of this?

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The Case for Objects

- Copying and renaming gives us
  - a unique name for each instance of the puzzle
  - a separate variable to store the state of each instance
  - allows multiple simultaneous instances of the puzzle
- But all the instances have identical values!
- Can we design language mechanisms to support the creation of separate instances?

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Solution: Ask Gutenberg!

- Algorithm for making a copy of a book in the middle ages:
  - Hire a monk
  - Give monk paper and quill
  - Ask monk to copy text of book
- Algorithm for making *n* copies of a book
  - Hire a monk
  - Give monk lots of paper and quills
  - Ask monk to copy text of book *n* times
- Modern algorithm (Gutenberg, Strasbourg ca.1450 AD):
  - First make a template using movable type
  - Stamp out as many copies of book as needed
- Copying class code is like medieval approach to copying books!
- How do we exploit Gutenberg's insight in our context?
  - What is the template for puzzles?
  - How do we stamp out new puzzle instances from the template?
  - How do we name different puzzle instances?

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Gutenberg Bible
– The Huntington Collection

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Object-Oriented Languages

- The *class definition* is the template
- Instances of the class are called *objects*
- Objects are stamped out (created) in an area of memory called the *heap*
- *instance variables*: when different instances are stamped out, they will each have their own copies of all instance variables (e.g. **`state`**)
- *instance methods*: code is shared among all instances of the same class, but references to instance variables in the code access those belonging to the correct object!
- *constructor*: a special method associated with a class invoked to create new instances of that class

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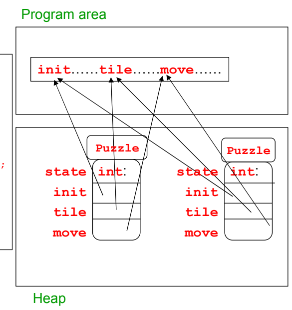
Heap Allocation

```
public class Puzzle {
  private int state;

  public void init() {
    state = 123456879;
  }

  public int tile(int r, int c) {
    return state/((int)Math.pow(10,8-(3*r+c)))%10;
  }

  public void move(char d) {
     ...
  }
}
```



- Heap shows two instances of class **`Puzzle`**
- Class name is used as type of object
- Each object has its own instance variables
- Instance variables are declared **`private`**, so not accessible to client
- Compiled instance methods are stored in Program area
- All objects of type **`Puzzle`** share code for instance methods as shown

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Naming Instances

- *Reference*: a variable that is a name for objects of some class
  - contains either a pointer to some object or **`null`**
- Reference type is class name:
  `Puzzle p1; //declare a reference variable`
- Creation of an object using a constructor and assignment to a reference:
  `p1 = new Puzzle(); //create a new object, call it p1`
  `Puzzle p2 = new Puzzle(); //can do both at once`
- Invoking instance method
  `p1.init();`
- Implementation:
  - examine object pointed to by **`p1`**
  - look inside object for starting address of method named **`init`**
  - invoke that method

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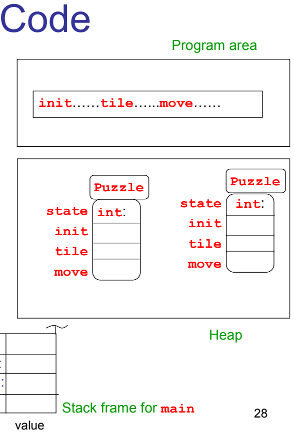
Client Code

```
public class TestPuzzle {

 public static void main(String[] args) {

     Puzzle puzzle1 = new Puzzle();
     Puzzle puzzle2 = new Puzzle();
     puzzle1.init();
     display(puzzle1);
     puzzle2.init();
     display(puzzle2);
     ...
 }

 public static void display(Puzzle p) {
   ...
 }
}
```



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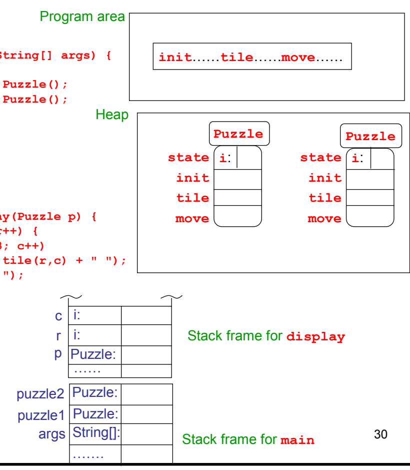
Method Invocation

- References can be passed as parameters
  - formal parameter becomes name for object in *callee*
  - callee can manipulate object using that name
  - on method return, ***caller*** sees any changes made to object by callee
- Example: **`display`** method
  - no need to have different code for each puzzle instance

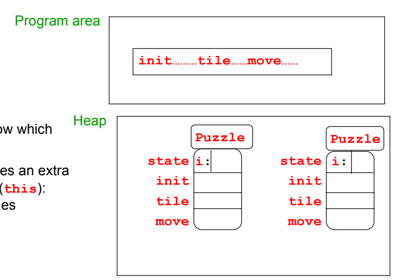

```
public class TestPuzzle {

 public static void main(String[] args) {

     Puzzle puzzle1 = new Puzzle();
     Puzzle puzzle2 = new Puzzle();
     puzzle1.init();
     display(puzzle1);
     puzzle2.init();
     display(puzzle2);
     ...
 }

 public static void display(Puzzle p) {
   for (int r = 0;r < 3; r++) {
     for (int c = 0; c < 3; c++)
       System.out.print(p.tile(r,c) + " ");
     System.out.println(" ");
   }
 }
}
```

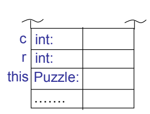


Accessing Instance Variables

```
...p1.tile(2,3)...
...p2.tile(0,1)...
```

- Q: How does **`tile`** method know which object to manipulate?
- A: Low-level code for **`tile`** takes an extra parameter: reference to object (**`this`**):
  `p1.tile(x,y)` becomes
  `p1.tile(p1,x,y)`





Stack frame for invocation of **`tile`**

Keyword **`this`**

- In instance method, **`this`** is a reference to object in which the method exists

```
public class TestPuzzle {

  public static void main(String[] args) {
    Puzzle puzzle1 = new Puzzle();
    puzzle1.init();
    ...
  }
}

public static void display(Puzzle p) {
   for (int r = 0; r < 3; r++) {
   ...
   }
}
```

```
public class Puzzle {

  ...
  public void move(char d) {
    ...
    TestPuzzle.display(this);
  }
  ...
}
```

Critique

- Data abstraction: yes
- Creation on demand: yes
- Duplicate class code: no
- Duplicate client code: no

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Garbage Collection

- Intuitively, an object is *live* at time *t* if that object is still in use and can be accessed by the program after time *t*
- Formally (recursive definition), an object O is *live* if:
  - The runtime stack contains a reference to O
  - There is a live object O' that contains a reference to O
- Everything else is *garbage*
  - Periodically, system detects garbage and reclaims it
  - Start with the stack, trace all references, mark all objects seen – anything not marked is garbage
- C, C++:
  - Pointer arithmetic makes it hard to determine what is a reference
  - Storage reclamation must be done explicitly by programmer (**`malloc`**, **`mfree`**)
  - Highly error-prone

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Conclusion

- Object-oriented languages support data abstraction and code reuse
- Objects (instances of a class) can be created on demand by client without breaking abstraction
- Client can hold a reference to an object, but implementation is hidden from it
- User-defined types: class names are used as types of objects and references

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