Systematic Program Development

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Printing Stars

Problem Statement

Print n lines of output of form

```
*
**
***
****
*****
...
```

- i-th line shall contain i stars
- n is provided by the user as text input.

Program Structure

```
public static void main(String[] args)
{
  int n = 0; // number of lines

  // read number n from user
  ...

  // print n lines
  ...
}
```

Two problems to be solved.

Input Problem

Read number n from user.

```
// read n, exits on empty input, retries on invalid input
while (true)
{
  System.out.print("Enter number of lines: ");
  n = Input.readInt();
  if (Input.isOkay()) break;
  if (Input.hasEnded())
  {
    System.out.println("No input given!");
    System.exit(-1);
  }
  System.out.println("Invalid input!");
  Input.clearError():
}
```

Printing Problem

Print n lines.

- Problem is of iterative nature:
  - Print one line after the other.

```
// print n lines
for (int i = 1; i <= n; i++)
  print line with i stars
```

Problem is reduced to a simpler subproblem.

Subproblem

Print line with i stars.

- Problem is of composed nature:
  - Print one star after the other.
  - Finally terminate line.

```
// print line with i stars
for (int j = 1; j <= i; j++)
  System.out.print("*");
System.out.println("");
```

Subproblem can be solved directly.

Printing Program

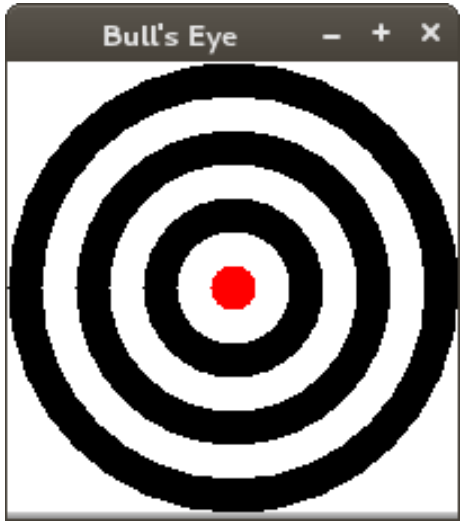
Insert solution of subproblem.

```
// print n lines
for (int i = 1; i <= n; i++)
{
  // print line with i stars
  for (int j = 1; j <= i; j++)
    System.out.print("*");
  System.out.println("");
}
```

All problems have been solved.

Drawing Circles

Problem Statement



- Draw a "bull's eye":
  - Alternating circles of black and white of particular width.
  - Innermost circle in red.
- Parameters: disk `RADIUS` and circle `WIDTH`.

General Program Structure

```
import kwm.*;
import java.awt.*;

public class BullsEye {
  public static void main(String[] args) {
    final int RADIUS = 100;   // disk radius
    final int WIDTH = 15;     // width of each circle drawn
    Drawing.begin("Bull's Eye", 2*RADIUS, 2*RADIUS);

    // draw bull's eye
    ...

    Drawing.end();
  }
}
```

Solution Strategy

Need an algorithm for solving the problem.

- Graphical primitive: `fillOval`.
  - Paint a filled ellipse (circular disk).
- Idea: paint one disk on top of each other.
  - Outermost disk in black.
  - Smaller disk in white.
  - ...
  - Smallest disk in red.

We will elaborate this idea to an algorithm/program.

Core Program Structure

```
// draw alternating circles of black and white
// starting with outermost circle with radius = RADIUS
// iteratively shrink radius by WIDTH until radius <= WIDTH
for (int radius = RADIUS; radius > WIDTH; radius -= WIDTH)
{
   switch color from black to white or from white to black
   draw circle with denoted radius and denoted color
}
draw innermost circle in red
```

- Switching the color from black to white and vice versa.
  - Need a boolean flag which indicates whether the next disk is black or white.
  - In each iteration, the value of the flag is inverted.

Need to refine the core program structure.

Refined Core Program Structure

```
boolean black = true;
for (int radius = RADIUS; radius > WIDTH; radius -= WIDTH)
{
   // set color, switch to other color
   if (black)
   {
       Drawing.graphics.setColor(Color.black);
       black = false;
   }
   else
   {
       Drawing.graphics.setColor(Color.white);
       black = true;
   }
   draw circle with denoted radius and denoted color
}
draw the innermost circle in red
```

Drawing a Circle

Draw circle with denoted radius and denoted color.

```
// draw circle of denoted radius with center (MID_X, MID_Y)
Drawing.graphics.fillOval(MID_X-radius, MID_Y-radius, 2*radius, 2*radius);
```

- Center coordinates MID_X and MID_Y.
  - Forgotten in our original problem statement.
  - Have to add them to the set of parameters.

```
final int RADIUS = ...;   // disk radius
final int WIDTH = ...;    // width of each circle drawn
final int MID_X = RADIUS; // x coordinate of center
final int MID_Y = RADIUS; // y coordinate of center
```

Drawing the Innermost Circle

Draw the innermost circle in red.

- Know how to draw the circle.
- Know the center coordinates MID_X and MID_Y.
- What is the radius of the circle?
  - Example: WIDTH=15; in last iteration $radius$=25.
  - Next update: $radius$=10; loop terminates.
  - Radius of red circle is 10.
- Problem: variable is declared local to the loop:

```
for (int radius = ...; ...; ...)
```

  - Final value is not visible outside of loop.

How to Determine the Innermost Radius?

1. Compute the final radius from RADIUS and WIDTH.
   - How?
2. Place code inside the loop:

```
for (int radius = RADIUS; radius > WIDTH; radius -= WIDTH)
 {
   ...
   if (radius-WIDTH <= WIDTH)
     draw circle of radius "radius-WIDTH" in red
 }
```

3. Draw variable declaration out of loop:

```
int radius = 0;
for (radius = RADIUS; radius > WIDTH; radius -= WIDTH)
  ...
draw circle of denoted radius in red
```

Drawing the Innermost Circle

Have the radius of the innermost circle

```
// draw red center circle
Drawing.graphics.setColor(Color.red);
Drawing.graphics.fillOval(MID_X-radius, MID_Y-radius, 2*radius, 2*radius);
```

Have solved all subproblems.

Analyzing Exam Grades

Problem Statement

- Analyze exam grades (1–5).
- Grades are read from the standard input stream.
- Determine the best grade, the worst grade, the average grade.
- Print results to standard output stream.
- Program shall process the grades of multiple exams.

General Program Structure

```
// analyze exam grades
char answer = 0;
do
{
  analyze exam;
  print result;
  ask user whether to continue;
}
while (answer == 'y');
```

- Iterative problem:
  - Analyze one exam.
  - Print the result.
  - Ask the user whether to continue.

Ask User Whether to Continue

```
// ask user whether to continue
while(true)
{
  System.out.print("Another exam (y/n)? ");
  answer = Input.readChar();
  if (Input.isOkay() && (answer == 'y' || answer == 'n')) break;
  if (Input.hasEnded())
  {
    System.out.println("Unexpected end of input!");
    System.exit(-1);
  }
  System.out.println("Invalid input!");
  Input.clearError();
}
```

Variable "answer" set to result.

Analyze Exam

```
// analyze exam
int count = 0;                // number of grades processed so far
int sum = 0;                  // sum of grades processed so far
int min = Integer.MAX_VALUE; // minimum grade processed so far
int max = Integer.MIN_VALUE; // maximum grade processed so far
read and process exam
```

- Need two values to compute the average:
  - Number of grades, sum of grades.
- Initialization of `min` and `max`:
  - First input will set `min` and `max` to new value.

Print Result

```
// print result
System.out.println("\nNumber of grades: " + count);
System.out.println("Best grade: " + min);
System.out.println("Worst grade: " + max);
System.out.println("Average grade: " + sum/count);
```

Based on minimum, maximum, sum, and count.

Read and Process Exam

We have to determine the end of an exam.

```
// read and process exam
while (true)
{
  int grade = 0;
  read grade
  if (grade == 0) break;
  process grade
}
```

We use "sentinel" grade 0 to denote the end of an exam.

Read Grade

```
// read grade
while(true)
{
  System.out.print("Enter grade " + (count+1) + " (0 when done): ");
  grade = Input.readInt();
  if (Input.isOkay() && 0 <= grade && grade <= 5) break;
  if (Input.hasEnded())
  {
    System.out.println("Unexpected end of input!");
    System.exit(-1);
  }
  System.out.println("Invalid input!");
  Input.clearError();
}
```

We have to perform sanity checks.

Process Grade

```
// process grade
count++;
sum += grade;
if (grade < min) min = grade;
if (grade > max) max = grade;
```

Now the initialization of `min` and `max` makes sense.

Abstraction Levels

Gradual reduction of problems.

```
analyze exam grades
  analyze exam
    read and process exam
      read grade
      process grade
  print result
  ask user whether to continue
```

Program structure reflects refinements.

Program Structure

```
char answer = 0;
do
{
  // analyze exam
  ...
  // read and process exam
  while (true)
  {
    int grade = 0;
    read grade
    if (grade == 0) break;
    process grade
  }
  print result
  ask user whether to continue
}
while (answer == 'y');
```

Testing the Program

```
Enter grade 1 (0 when done): 3
Enter grade 2 (0 when done): 4
Enter grade 3 (0 when done): 5
Enter grade 4 (0 when done): 0

Number of grades: 3
Best grade: 3
Worst grade: 5
Average grade: 4
```

Looks fine.

Testing the Program

```
Another exam (y/n)? y
Enter grade 1 (0 when done): 2
Enter grade 2 (0 when done): 4
Enter grade 3 (0 when done): 4
Enter grade 4 (0 when done): 0

Number of grades: 3
Best grade: 2
Worst grade: 4
Average grade: 3
```

Just great.

Testing the Program

```
Another exam (y/n)? y
Enter grade 1 (0 when done): 0

Number of grades: 0
Best grade: 2147483647
Worst grade: -2147483648
Exception in thread "main" java.lang.ArithmeticException: / by zero
        at Exams.main(Exams.java:51)
```

We forgot the case that an exam may have zero grades!

Revised Print Result

```
// print result
System.out.println("\nNumber of grades: " + count);
if (count > 0)
{
  System.out.println("Best grade: " + min);
  System.out.println("Worst grade: " + max);
  System.out.println("Average grade: " + sum/count);
}
```

Analysis only makes sense if there is at least one grade.

Testing the Program

```
Enter grade 1 (0 when done): 0

Number of grades: 0

Another exam (y/n)?
```

We fixed the bug.

Testing the Program

```
Another exam (y/n)? y
Enter grade 1 (0 when done): 2
Enter grade 2 (0 when done): 4
Enter grade 3 (0 when done): 4
Enter grade 4 (0 when done): 5
Enter grade 5 (0 when done): 0

Number of grades: 4
Best grade: 2
Worst grade: 5
Average grade: 3
```

Strange average.

Computing the Average

We examine the computation of the average:

- Our version uses integer division:

```
System.out.println("Average grade: " + sum/count);
```

- Better use floating point division:

```
System.out.println("Average grade: " + (float)sum/(float)count);
```

  – We can write this in a somewhat simpler way (how?).

When computing with numbers, we have to take care of the datatypes.

Testing the Program

```
Enter grade 1 (0 when done): 2
Enter grade 2 (0 when done): 4
Enter grade 3 (0 when done): 4
Enter grade 4 (0 when done): 5
Enter grade 5 (0 when done): 0

Number of grades: 4
Best grade: 2
Worst grade: 5
Average grade: 3.75
```

We have also solved this problem.

Stepwise Refinement

- Solution process:
  - Problem is decomposed into simpler subproblems.
  - Subproblems are decomposed again.
  - Ultimately, problems are simple enough to be solved directly.
- Implementation:
  - Structure of program reflects problem decomposition.
  - Problem: main method becomes big monolithic piece of code.

Bigger programs are decomposed into separate methods.