Processes and Threads

- Processes

- Threads
  - Creating Threads
  - Interrupting Threads
  - Joining Threads
  - Synchronization between Threads
  - ThreadLocal<T>

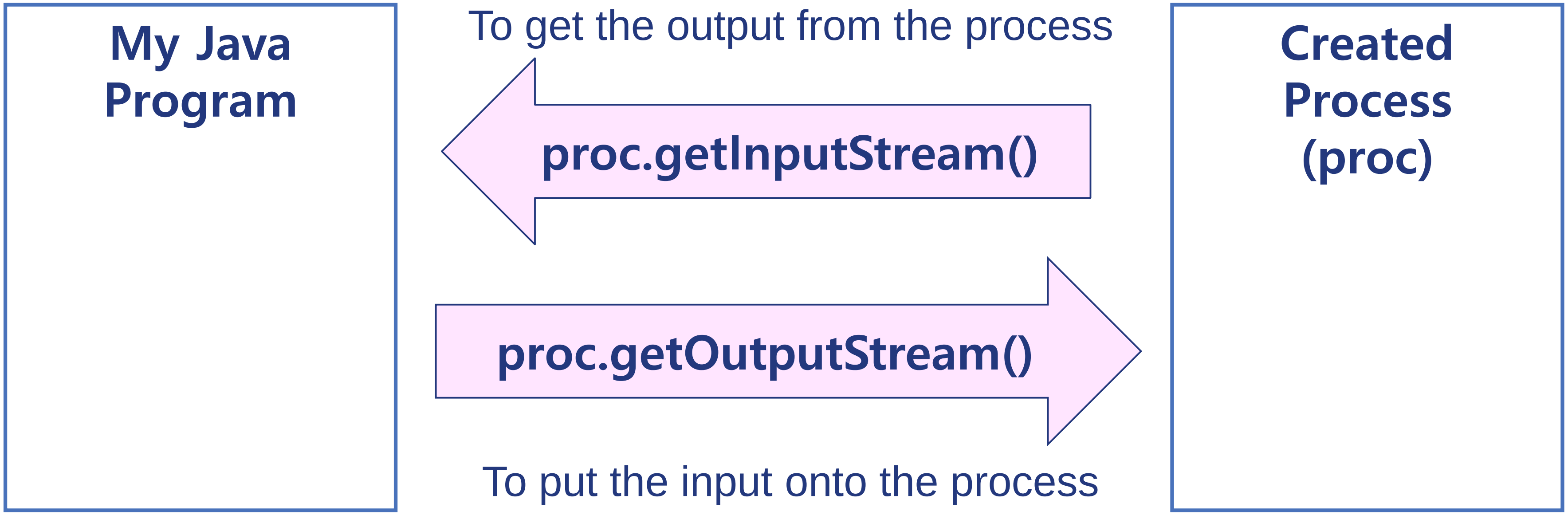
Creating and Executing Processes

- You can execute another program by **Process** class

```
public class Exec {
  public static void main(String[] args) {
     try {
        // method 1
        Process proc = Runtime.getRuntime().exec("cmd /c dir");
        // method 2
        Process proc = new ProcessBuilder("cmd", "/c“, “dir”).start();
     }
     catch (Exception e) { e.printStackTrace(); }
  }
}
```

Getting the Standard Input/Output from the Process

- You can interact with the created process by its standard input, output, and error streams.



My Java Program

To get the output from the process

proc.getInputStream()

Created Process (proc)

proc.getOutputStream()

To put the input onto the process

Getting the Output

- To get the output from the process, use getInputStream()

```
import java.io.*;
public class ShowDir {
 public static void main(String args[]) {
   try {
     String param = "C:" + File.separator;
     Process proc = Runtime.getRuntime().exec("cmd /c dir " + param);
     //Process proc = new ProcessBuilder("cmd", "/c", "dir", param).start();

     InputStream in = proc.getInputStream();        // new process → I
     byte buffer[] = new byte[1024];
     int n = -1;
     while ( (n = in.read(buffer)) != -1 )
        System.out.print(new String(buffer, 0, n));
     in.close();
   } catch(Exception e) { e.printStackTrace(); }
 }
}
```

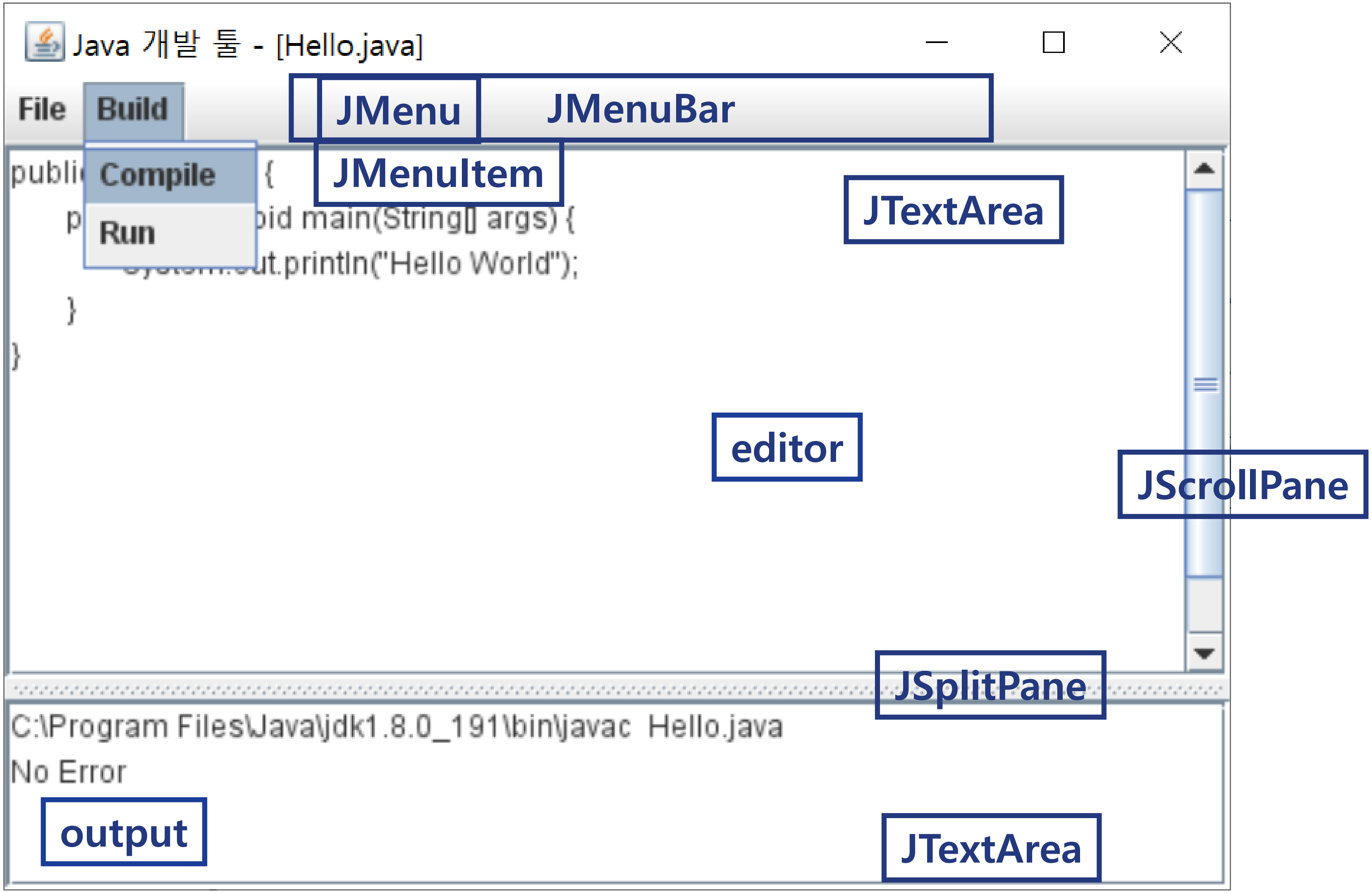
To put the input onto the process, use getOutputStream()

```
import java.io.*;
public class Less {
  public static void main(String args[]) throws Exception {
     Process proc = Runtime.getRuntime().exec("cmd /c more");
     InputStream in = proc.getInputStream();                  // new process ➔ I
     OutputStream out = proc.getOutputStream();               // I ➔ new process
     InputStream fin = (args.length > 0) ? new FileInputStream(args[0]) : System.in;

     int n;
     byte buffer[] = new byte[1024];
     while ( (n = fin.read(buffer)) != -1 ) out.write(buffer, 0, n); // I -> new process
     fin.close();
     out.close();

     while ( (n = in.read(buffer)) != -1)  // new process -> I
        System.out.print(new String(buffer, 0, n));
     in.close();
  }
}
```

Example: JavaIDE.java



```
publi          {
     p          oid main(String[] args) {
                ut.println("Hello World");
     }
}
```

```
C:\Program Files\Java\jdk1.8.0_191\bin\javac  Hello.java
No Error
```

```
public class JavaIDE extends JFrame {
  private String      javac = "C:₩₩Program Files₩₩Java₩₩jdk1.8.0_191₩₩bin₩₩javac" ;
  private String      java ="C:₩₩Program Files₩₩Java₩₩jre1.8.0_191₩₩bin₩₩java" ;

  private JFileChooser           fileChooser = new JFileChooser();
  private JTextArea              editor, output;
  private JMenuItem              compile, run;
  private String                 fileName;
  private File                   workingDirectory;

  public JavaIDE() {
     super("Java 개발 툴");
     setDefaultCloseOperation(EXIT_ON_CLOSE); setSize(500, 400);
     setJMenuBar(createMenus());

     editor = new JTextArea();  editor.setTabSize(2);
     output = new JTextArea();

     JSplitPane jsp = new JSplitPane(JSplitPane.VERTICAL_SPLIT);
     jsp.setTopComponent(new JScrollPane(editor));
     jsp.setBottomComponent(new JScrollPane(output));
     jsp.setDividerLocation(270);

     getContentPane().add(jsp, BorderLayout.CENTER);
     setVisible(true);
  }
```

```
private JMenuBar createMenus() {
    JMenuBar menuBar = new JMenuBar();
    menuBar.add(createFileMenu());
    menuBar.add(createBuildMenu());
    return menuBar;
}
private JMenu createFileMenu() {
    JMenu fileMenu = new JMenu("File");
    JMenuItem newMenuItem = new JMenuItem("New");
    newMenuItem.addActionListener(new NewHandler());
    fileMenu.add(newMenuItem);
    JMenuItem open = new JMenuItem("Open...");
    open.addActionListener(new OpenHandler());
    fileMenu.add(open);
    JMenuItem save = new JMenuItem("Save...");
    save.addActionListener(new SaveHandler());
    fileMenu.add(save);
    return fileMenu;
}
private JMenu createBuildMenu() {
    JMenu buildMenu = new JMenu("Build");
    compile = new JMenuItem("Compile"); compile.setEnabled(false);
    compile.addActionListener(new CompileHandler());
    buildMenu.add(compile);
    run = new JMenuItem("Run"); run.setEnabled(false);
    run.addActionListener(new RunHandler());
    buildMenu.add(run);
    return buildMenu;
}
```

```
class NewHandler implements ActionListener {
    public void actionPerformed(ActionEvent e) {
        fileName = "";
        setTitle("Java 개발 툴");
        editor.setText("");
        compile.setEnabled(false);
        run.setEnabled(false);
    }
}
class OpenHandler implements ActionListener {
    public void actionPerformed(ActionEvent e) {
        final int returnVal = fileChooser.showOpenDialog(null);
        if (returnVal != JFileChooser.APPROVE_OPTION) return;

        File file = fileChooser.getSelectedFile();
        fileName = file.getName();
        setTitle("Java 개발 툴 - [" + fileName + "]");

        workingDirectory = file.getParentFile();
        try {
            List<String> lines
            = Files.readAllLines(Paths.get(file.getPath()), Charset.forName("UTF-8"));
            editor.setText("");
            for (String line : lines) editor.append(line + "₩n");
        } catch(Exception ex) {  ex.printStackTrace(); }
        compile.setEnabled(true);
        run.setEnabled(true);
    }
}
```

```
class SaveHandler implements ActionListener {
    public void actionPerformed(ActionEvent e) {
        final int returnVal = fileChooser.showSaveDialog(null);
        if (returnVal != JFileChooser.APPROVE_OPTION) return;

        File file = fileChooser.getSelectedFile();
        fileName = file.getName();
        setTitle("Java 개발 툴 - [" + fileName + "]");

        workingDirectory = file.getParentFile();
        try {
            PrintWriter out = new PrintWriter(new FileWriter(file.getPath()));
            String source = editor.getText();
            out.println(source);
            out.close();
        } catch(Exception ex) {
            ex.printStackTrace();
        }
        compile.setEnabled(true);
        run.setEnabled(true);
    }
}
```

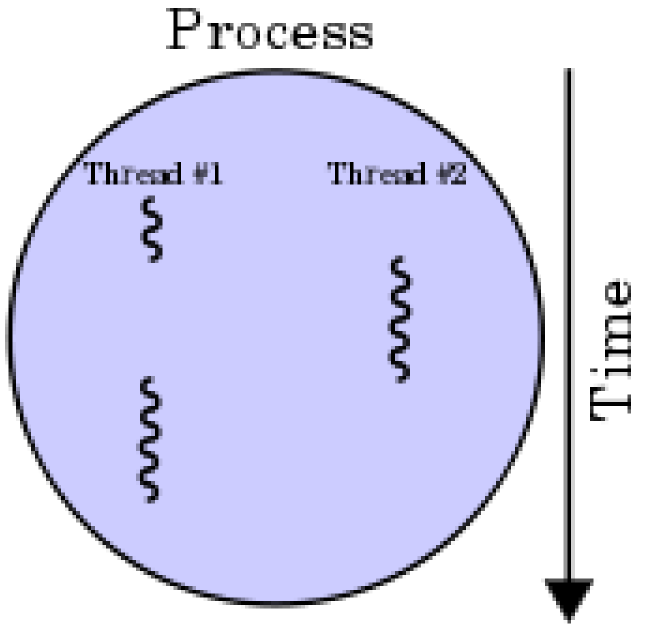
```
class CompileHandler implements ActionListener {
    public void actionPerformed(ActionEvent e) {
        String cmd = javac + "  " + fileName;
        output.setText(cmd + "₩n");
        try {
            Runtime runTime = Runtime.getRuntime();
            Process javacProcess = runTime.exec(cmd, null, workingDirectory);
            InputStream stdError = javacProcess.getErrorStream();

            boolean hasError = false;
            byte buffer[] = new byte[1024];
            int readBytes;
            while ( (readBytes = stdError.read(buffer)) != -1 ) {
                output.append(new String(buffer, 0, readBytes));
                hasError = true;
            }
            stdError.close();
            if ( !hasError ) output.append("No Error₩n");
        } catch (Exception ex) {
            ex.printStackTrace();
        }
    }
}
```

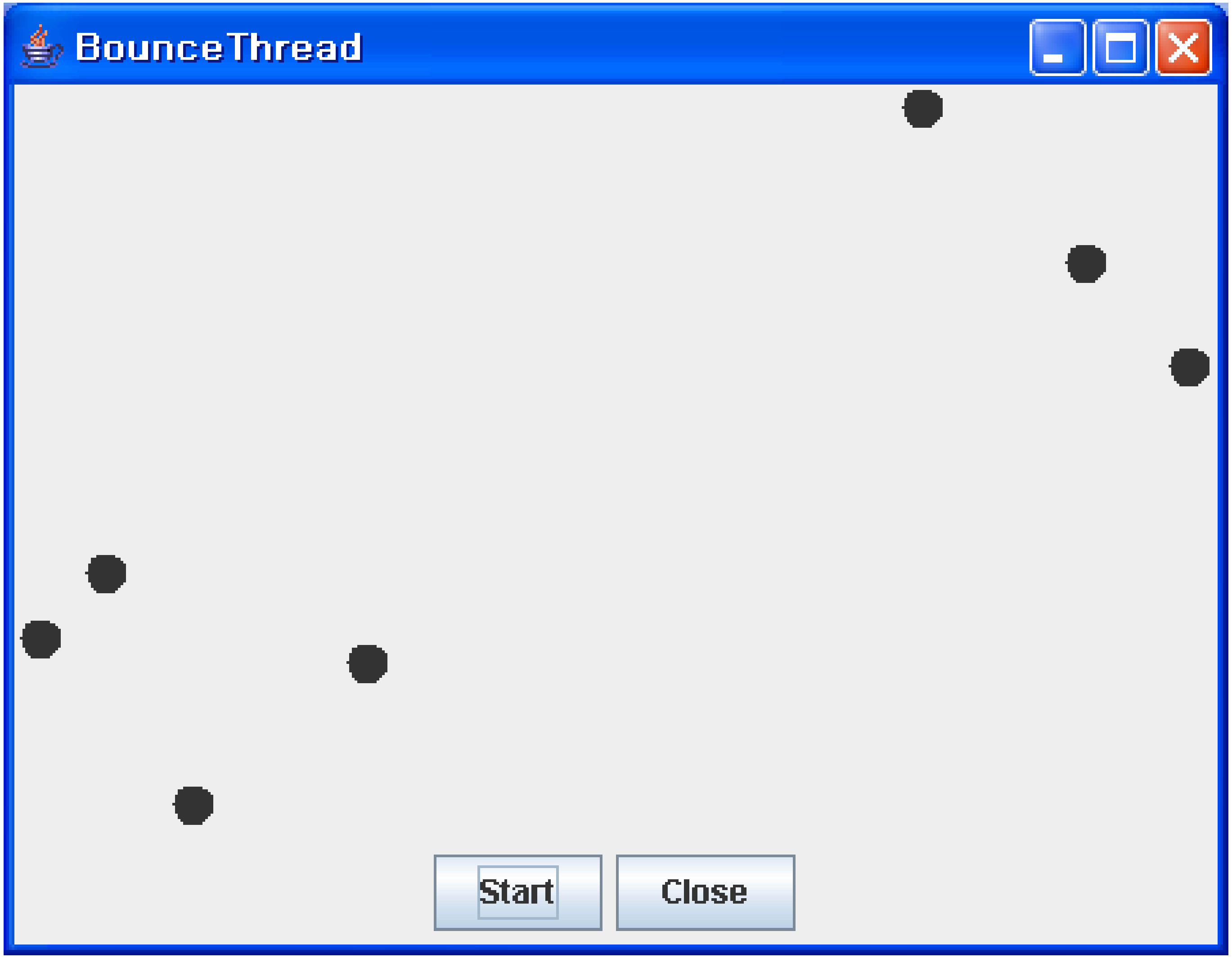
```
  class RunHandler implements ActionListener {
    public void actionPerformed(ActionEvent e) {
      final int index = fileName.lastIndexOf(".");
      String className = fileName.substring(0, index);
      String cmd = java + "  " + className;
      output.setText(cmd + "₩n");
      try {
        Runtime runtime = Runtime.getRuntime();
        Process javaProcss = runtime.exec(cmd, null, workingDirectory);
        InputStream stdOutput = javaProcss.getInputStream();
        byte buffer[] = new byte[1024]; int readBytes;
        while ( (readBytes = stdOutput.read(buf)) != -1 )
          output.append(new String(buf, 0, readBytes));
        stdOutput.close();
        InputStream stdError = javaProcss.getErrorStream();
        while ( (readBytes = stdError.read(buffer)) != -1 )
          output.append(new String(buffer, 0, readBytes));
        stdError.close();
      } catch (Exception ex) { ex.printStackTrace(); }
    }
  }
  public static void main(String args[]) { new JavaIDE(); }
}
```

Thread

- Basically, threads is like processes.
- Threads or processes support concurrent programming.
- In Java, threads are mainly used to implement concurrent programs.
- Thread is a lightweight process.
- A process can consist of multiple threads



Animating Bouncing Balls



Without Threads

```
import java.awt.*;
import java.awt.event.*;
import java.awt.geom.*;
import java.util.*;
import javax.swing.*;

/**
   Shows an animated bouncing ball.
*/
public class Bounce
{
   public static void main(String[] args)
   {
      JFrame frame = new BounceFrame();
      frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      frame.setVisible(true);
   }
}
```

```
/**
   A ball that moves and bounces off the edges of a rectangle
*/
class Ball {
   /**
      Moves the ball to the next position, reversing direction if it hits one of the edges
   */
   public void move(Rectangle2D bounds) { // java.awt.geom.Rectangle2D
      x += dx; y += dy;
      if (x < bounds.getMinX()) {  x = bounds.getMinX(); dx = -dx; }
      if (x + XSIZE >= bounds.getMaxX()) { x = bounds.getMaxX() - XSIZE;  dx= -dx;  }
      if (y < bounds.getMinY()) { y = bounds.getMinY();  dy = -dy; }
      if (y + YSIZE >= bounds.getMaxY()) { y = bounds.getMaxY() - YSIZE; dy = -dy; }
   }
   public Ellipse2D getShape() { return new Ellipse2D.Double(x, y, XSIZE, YSIZE); }

   private static final int XSIZE = 15;
   private static final int YSIZE = 15;
   private double x = 0;
   private double y = 0;
   private double dx = 1;
   private double dy = 1;
}
```

```
/**
   The panel that draws the balls.
*/
class BallPanel extends JPanel {
   /**
      Add a ball to the panel.
      @param b the ball to add
   */
   public void add (Ball b) {
      balls.add(b);
   }
   // overriding Jcomponent.paintComponent
   public void paintComponent (Graphics g) { // public abstract class Graphics
      super.paintComponent(g);
      Graphics2D g2 = (Graphics2D) g; // public abstract class Graphics2D extends Graphics
      for (Ball b : balls)
      {
         g2.fill(b.getShape()); // Actual drawing occurs here
      }
   }

   private List<Ball> balls = new ArrayList<>();
}
```

```
class BounceFrame extends JFrame {
   public BounceFrame() {
     setTitle("Bounce");
     setSize(DEFAULT_WIDTH, DEFAULT_HEIGHT);

      ballPanel = new BallPanel(); add(ballPanel, BorderLayout.CENTER);

      JPanel buttonPanel = new JPanel();
      addButton(buttonPanel, "Start", new ActionListener() {
            public void actionPerformed(ActionEvent event) { addBall(); }
         });
      // addButton(buttonPanel, "Start", (ActionEvent event) -> addBall());
      addButton(buttonPanel, "Close", new ActionListener() {
            public void actionPerformed(ActionEvent event) { System.exit(0); }
         });
     // addButton(buttonPanel, "Close", (ActionEvent event) -> System.exit(0));
      add(buttonPanel, BorderLayout.SOUTH);
   }
   private void addButton(Container container, String title, ActionListener listener) {
      JButton button = new JButton(title);
      container.add(button);
      button.addActionListener(listener);
   }
```

```
  /**
     Adds a bouncing ball to the panel and makes it bounce 1,000 times.
  */
  public void addBall() {
     try {
        Ball ball = new Ball();
        ballPanel.add(ball);
        for (int i = 1; i <= STEPS; i++) {
           ball.move(ballPanel.getBounds());
           ballPanel.paint(ballPanel.getGraphics());
           Thread.sleep(DELAY);
        }
     } catch (InterruptedException e) { }
  }
  private BallPanel ballPanel;
  public static final int DEFAULT_WIDTH = 450;
  public static final int DEFAULT_HEIGHT = 350;
  public static final int STEPS = 1000;
  public static final int DELAY = 3;
}
```

Before the completion of 1000 movements, another ball cannot be created !

Problems with the current program

- You cannot create a new ball before the current ball stops.
- Why ?
  - The reason is that the only one thread is moving the current ball.
  - Only after finishing the movement, creating a ball can be started !
- What’s a solution ?
  - To move each ball concurrently, individual thread for each ball is necessary !
  - Try the Bounce with multi-threads

With Threads

```
import java.awt.*;
import java.awt.event.*;
import java.awt.geom.*;
import java.util.*;
import javax.swing.*;

public class BounceThread {
  public static void main(String[] args) {
    JFrame frame = new BounceFrame();
    frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
    frame.setVisible(true);
  }
}
```

```
/**
   A runnable that animates a bouncing ball.
*/
class BallRunnable implements Runnable {
   public BallRunnable(Ball aBall, JPanel ballPanel) {
      ball = aBall;  this.ballPanel = ballPanel;
   }
   public void run() {
      try {
         for (int i = 1; i <= STEPS; i++) {
            ball.move(ballPanel.getBounds()); // update the location of the ball
            ballPanel.paint(ballPanel.getGraphics());
            Thread.sleep(DELAY);
         }
      } catch (InterruptedException e) { }
   }
   private Ball ball;
   private JPanel ballPanel;
   public static final int STEPS = 1000;
   public static final int DELAY = 3;
}
```

```
/**
   A ball that moves and bounces off the edges of a rectangle
*/
class Ball {
   /**
      Moves the ball to the next position, reversing direction if it hits one of the edges
   */
   public void move(Rectangle2D bounds) { // java.awt.geom.Rectangle2D
      x += dx; y += dy;
      if (x < bounds.getMinX()) {  x = bounds.getMinX(); dx = -dx; }
      if (x + XSIZE >= bounds.getMaxX()) { x = bounds.getMaxX() - XSIZE;  dx= -dx;  }
      if (y < bounds.getMinY()) { y = bounds.getMinY();  dy = -dy; }
      if (y + YSIZE >= bounds.getMaxY()) { y = bounds.getMaxY() - YSIZE; dy = -dy; }
   }
   /**
      Gets the shape of the ball at its current position.
   */
   public Ellipse2D getShape() { return new Ellipse2D.Double(x, y, XSIZE, YSIZE); }

   private static final int XSIZE = 15;
   private static final int YSIZE = 15;
   private double x = 0;
   private double y = 0;
   private double dx = 1;
   private double dy = 1;
}
```

```java
/**
   The panel that draws the balls.
*/
class BallPanel extends JPanel
{
   /**
      Add a ball to the panel.
      @param b the ball to add
   */
   public void add(Ball b) {
      balls.add(b);
   }

   public void paintComponent (Graphics g) {
      super.paintComponent(g);
      Graphics2D g2 = (Graphics2D) g;
      for (Ball b : balls) { g2.fill(b.getShape()); }
   }
   private List<Ball> balls = new ArrayList<>();
}
```

```
class BounceFrame extends JFrame {
   public BounceFrame() {
     setTitle("BounceThread");
      setSize(DEFAULT_WIDTH, DEFAULT_HEIGHT);

      ballPanel = new BallPanel();  add(ballPanel, BorderLayout.CENTER);
      JPanel buttonPanel = new JPanel();
      addButton(buttonPanel, "Start", new ActionListener() {
            public void actionPerformed(ActionEvent event) { addBall(); }
         });
       // addButton(buttonPanel, "Start", (ActionEvent event) -> addBall());
      addButton(buttonPanel, "Close", new ActionListener() {
            public void actionPerformed(ActionEvent event) { System.exit(0); }
         });
     // addButton(buttonPanel, "Close", (ActionEvent event) -> System.exit(0));
      add(buttonPanel, BorderLayout.SOUTH);
   }
   private void addButton(Container container, String title, ActionListener listener) {
      JButton button = new JButton(title);
      container.add(button);
      button.addActionListener(listener);
   }
```

```
  /**
    Adds a bouncing ball to the canvas and starts a thread to make it bounce
  */
  public void addBall() {
    Ball b = new Ball();
    ballPanel.add(b);
    Runnable r = new BallRunnable(b, ballPanel);
    Thread t = new Thread(r);
    t.start();
  }

 private BallPanel ballPanel;
 public static final int DEFAULT_WIDTH = 450;
 public static final int DEFAULT_HEIGHT = 350;
}
```

Whenever addBall() is called, that is, whenever “start” button is clicked, separate thread for each ball is created !

Because separate thread can move each ball, the main thread can process “start” button.

Two Methods for Creating Threads

- Method #1

```
class MyRunnable implements Runnable {
  public void run() {
    // task code
  }
}
…
Runnable r = new MyRunnable() ;
Thread t = new Thread(r) ;
t.start() ;
```

- Method #2

```
class MyThread extends Thread {
  public void run() {
    // task code
  }
}
…
MyThread t = new MyThread() ;
t.start() ;
```

Pausing Execution with Sleep

- Thread.sleep causes the current thread to suspend execution for a specified period.

```
public class SleepMessages {
    public static void main(String args[]) throws InterruptedException {
        String messages[] = {
            "1st message", "2nd message", "3rd message", "4th message"
        } ;
        for ( String message: messages) {
            // Pause for 4 seconds; but not guaranteed !
            Thread.sleep(4000);
            // Print a message
            System.out.println(message);
        }
    }
}
```

Interrupts

- An interrupt is an indication to a thread that it should stop what it is doing and do something else.
  - Thread.**interrupt**()
- It's up to the programmer to decide exactly how a thread responds to an interrupt, but it is very common for the thread to terminate

```
public class InterruptThread {
  // use a static inner class
  // because the inner class object is constructed inside a static method main()
  private static class SimpleRunnable implements Runnable {
    public void run() {
      String threadName = Thread.currentThread().getName();
      int i = 0 ;
      while ( true ) { // However, the loop never stops !
        System.out.printf("%s: %d%n", threadName, i) ;
        i ++ ;
      }
    }
  }
  public static void main(String[] args) {
    Thread thread = new Thread(new SimpleRunnable()) ;
    thread.start();
    Scanner scanner = new Scanner(System.in) ;
    scanner.next() ;
    thread.interrupt() ; // The thread is now interrupted !
  }
}
```

```
Thread-0: 0
Thread-0: 1
Thread-0: 2
Thread-0: 3
Thread-0: 4
…
```

Supporting Interrupts

- How does a thread support its own interruption? That is, how does the thread recognize that it has been interrupted !
- Method #1: Catch InterruptedException

```
while ( true ) {
  System.out.printf("%s: %d%n", threadName, i) ;
  i ++ ;
  try {
    // sleep method throw InterruptedException when interrupted
    Thread.sleep(100) ;
  } catch (InterruptedException e) {
    System.out.println(“Thread Terminated by Interrupt") ;
    break ;
  }
}
```

Supporting Interrupts

- Method #2
  - What if a thread goes a long time without invoking a method that throws InterruptedException?
  - Then it must periodically invoke **Thread.interrupted()**, which returns true if an interrupt has been received

```
while ( true ) {
  System.out.printf("%s: %d%n", threadName, i) ;
  i ++ ;
  if ( Thread.interrupted() )  {
    System.out.println("Thread Terminated by Interrupt") ;
    break ;
  }
}
```

```
public class InterruptThread {
  private static class SimpleRunnable implements Runnable {
    public void run() {
      String threadName = Thread.currentThread().getName();
      int i = 0 ;
      while ( true ) { // the loop can now stop !
        System.out.printf("%s: %d%n", threadName, i) ; i ++ ;
        /* // Method 1
        try { Thread.sleep(100) ; }
        catch (InterruptedException e) {
          System.out.println("Thread Terminated by Interrupt") ;
          break ;
        }
        */
        if ( Thread.interrupted() ) { // Method 2
          System.out.println("Thread Terminated by Interrupt") ; break ;
        }
      }
    }
  }
  public static void main(String[] args) {
    Thread thread = new Thread(new SimpleRunnable()) ;
    thread.start();
    Scanner scanner = new Scanner(System.in) ; scanner.next() ;
    thread.interrupt() ; // The thread is now interrupted !
  }
}
```

Join

- The join method allows one thread to wait for the completion of another.
- If t is another thread object,
  - t.join();
  - causes the current thread to pause execution until t's thread terminates

```
public static void main(String[] args) throws InterruptedException {
    Thread thread = new Thread(new SimpleRunnable()) ;
    thread.start();
    // wait maximum of 1 second for SimpleRunnable thread to finish.
    thread.join(1000); // join() or join(0) waits for ever
    if (thread.isAlive()) { thread.join(2000); }
    …
}
```

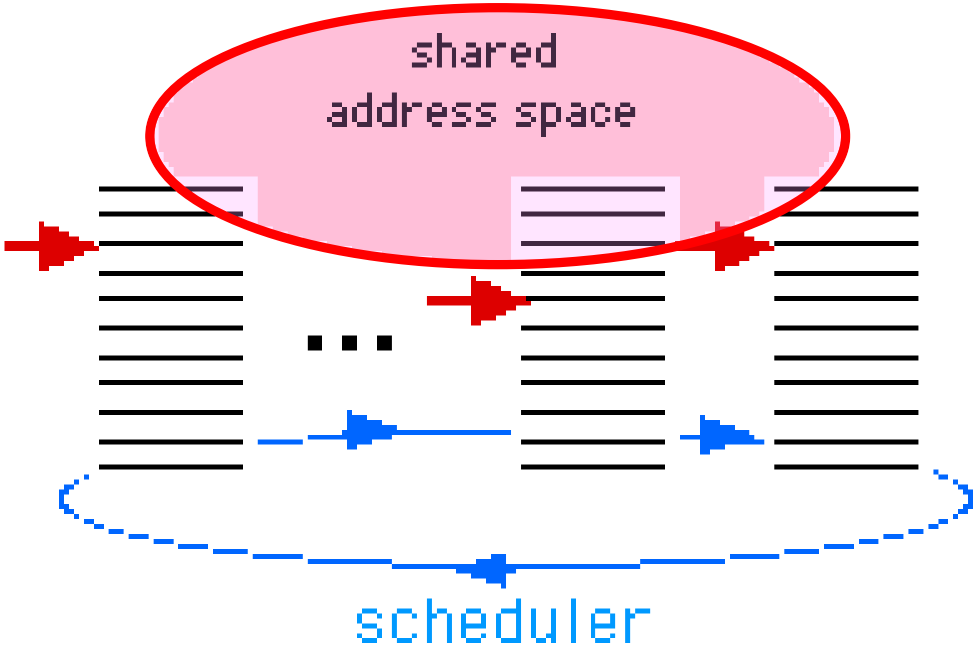
```
public class JoinThread {
    //Display a message, preceded by the name of the current thread
    private static void threadMessage(String message) {
        String threadName = Thread.currentThread().getName();
        System.out.format("%s: %s%n", threadName, message);
    }

    private static class SimpleRunnable implements Runnable {
        public void run() {
            String threadName = Thread.currentThread().getName();
            int i = 0 ;
            while ( true ) {
                System.out.printf("%s: %d%n", threadName, i) ;
                i ++ ;
                try { Thread.sleep(100) ; }
                catch (InterruptedException e) {
                    threadMessage("Terminated by Interrupt") ; break ;
                }
            }
            threadMessage("End");
        }
    }
    public static void main(String[] args) throws InterruptedException {
        Thread thread = new Thread(new SimpleRunnable()) ; thread.start();
        int waitingCount = 0 ;
        while (thread.isAlive()) {
            threadMessage("Still waiting...");
            thread.join(1000); //Wait maximum of 1 second for SimpleRunnable to finish.
            waitingCount ++ ;
            if ( waitingCount == 5 && thread.isAlive()) {
                threadMessage("Time is up!. It's time to interrupt " + thread.getName());
                thread.interrupt();
                thread.join(); // Shouldn't be long now -- wait indefinitely
            }
         }
        threadMessage("End!");
    }
}
```

```
main: Still waiting...
Thread-0: 0
…
main: Still waiting...
Thread-0: 10
…
main: Still waiting...
Thread-0: 20
…
main: Still waiting...
Thread-0: 30
…
main: Still waiting...
Thread-0: 40
…
main: Time is up!. It's time to interrupt Thread-0
Thread-0: Terminated by Interrupt
Thread-0: End
main: End!
```

Thread

- All the threads in a process share the address space
- Therefore, some shared address spaces need to be protected from concurrent access; otherwise, they may be corrupted.



An example of race condition

```
public class UnsynchBankTest {
  public static void main(String[] args) {
    // A bank is created with NACCOUNTS accounts
    Bank b = new Bank(NACCOUNTS, INITIAL_BALANCE);

    for (int i = 0; i < NACCOUNTS; i++) {
      // A thread is created for each account
      TransferRunnable r = new TransferRunnable(b, i, INITIAL_BALANCE);
      Thread t = new Thread(r);
      t.start();
    }
  }

  public static final int NACCOUNTS = 100;
  public static final double INITIAL_BALANCE = 1000;
}
```

Several threads will work on the same bank because the reference to the Bank is delivered to the thread

```
class Bank {
  public Bank(int n, double initialBalance) {
    accounts = new double[n];
    for (int i = 0; i < accounts.length; i++) accounts[i] = initialBalance;
  }
  public void transfer (int from, int to, double amount) {
    // unsafe when called from multiple threads operates on the same account
    if (accounts[from] < amount) return;
    System.out.print(Thread.currentThread());
    accounts[from] -= amount;
    System.out.printf(" %10.2f from %d to %d", amount, from, to);
    accounts[to] += amount;
    System.out.printf(" Total Balance: %10.2f%n", getTotalBalance());
  }
  public double getTotalBalance() {
    double sum = 0;
    for (double a : accounts) sum += a;
    return sum;
  }
  public int size() { return accounts.length; }
  private final double[] accounts; // A bank has n accounts; should be thread-safe
}
```

shared data(accounts[]) can be corrupted by multiple threads

The total balance should always be 100 * 1,000 = 100,000

```
class TransferRunnable implements Runnable {
   public TransferRunnable(Bank b, int from, double max) {
      bank = b; // All the threads share the bank
      fromAccount = from;
      maxAmount = max;
   }
   public void run() {
      try {
         while ( true ) {
            int toAccount = (int) (bank.size() * Math.random());
            double amount = maxAmount * Math.random();
            bank.transfer(fromAccount, toAccount, amount);
            Thread.sleep((int) (DELAY * Math.random()));
         }
      } catch (InterruptedException e) {}
   }
   private Bank bank;
   private int fromAccount;
   private double maxAmount;
   private int DELAY = 10;
}
```

Several threads will work on the same accounts at the same time

```
Thread[Thread-0,5,main]     573.27 from 0 to 18Thread[Thread-
1,5,main]Thread[Thread-2,5,main]Thread[Thread-3,5,main]Thread[Thread-
4,5,main]Thread[Thread-5,5,main]Thread[Thread-6,5,main]Thread[Thread-
7,5,main]Thread[Thread-8,5,main]Thread[Thread-9,5,main]     869.03 from 1 to 28
470.70 from 2 to 30     330.73 from 3 to 41     969.38 from 4 to 92     573.76 from 5
to 23     452.03 from 6 to 10     952.24 from 7 to 0     755.73 from 8 to 84 Total
Balance:   94922.15
 Total Balance:   95392.86
 Total Balance:   95723.59
 Total Balance:   96692.96
 Total Balance:   97266.73
 Total Balance:   97718.75
 Total Balance:   98671.00
 Total Balance:   99426.73
     308.69 from 9 to 17 Total Balance:   99426.73
 Total Balance:  100000.00
Thread[Thread-10,5,main]     677.39 from 10 to 59Thread[Thread-2,5,main]     172.38
from 2 to 98 Total Balance:   99322.61
Thread[Thread-6,5,main]      53.02 from 6 to 66 Total Balance:   99322.61
Thread[Thread-3,5,main]     240.86 from 3 to 47 Total Balance:   99322.61
Thread[Thread-2,5,main]     221.04 from 2 to 62 Total Balance:   99322.61
Thread[Thread-0,5,main]     497.56 from 0 to 77 Total Balance:   99322.61
 Total Balance:  100000.00
```

Ideal Expected Situation

Thread for account 100

```
public void transfer (
  int from(=100),
  int to(=300),
  double amount(=500)) {
     accounts[100] -= 500;
     t1 = accounts[300] ;
     t1 += 500;
     accounts[300] = t1 ;
}
```

100	200	300	t1	t2	Sum
1000	1000	1000			3000
500					
			1000		2500
			1500		
		1500			3000
500	1000	1500			3000
	0				2000
				1500	
				2500	
		2500			3000

Thread for account 200

```
public void transfer (
  int from(=200),
  int to(=300),
  double amount(=1000)) {

   accounts[200] -= 1000;
   t2 = accounts[300] ; // 1500
   t2 += 1000;  // 2500
   accounts[300] = t2 ;
}
```

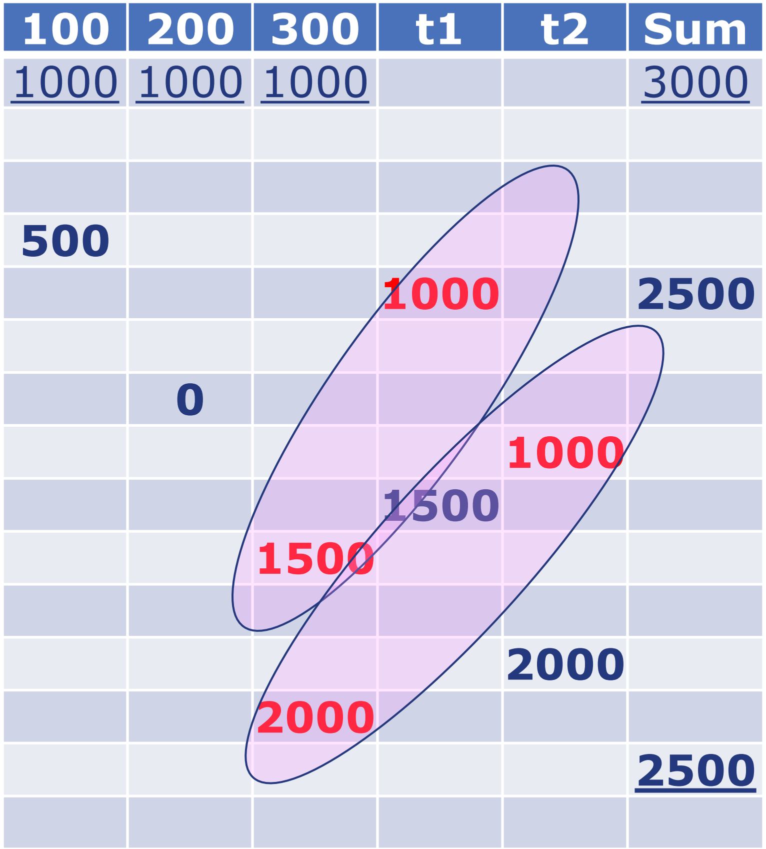
Real Problematic Situation: Race Condition

Thread for account 100

```
public void transfer (
  int from(=100),
  int to(=300),
  double amount(=500)) {
    accounts[100] -= 500;
    t1 = accounts[300] ;




    t1 += 500; // 1500
    accounts[300] = t1 ;
}
```



100	200	300	t1	t2	Sum
1000	1000	1000			3000
500					
			1000		2500
	0				
				1000	
			1500		
		1500			
				2000	
		2000			
					2500

Thread for account 200

```
public void transfer (
  int from(=200),
  int to(=300),
  double amount(=1000)) {



    accounts[200] -= 1000;
    t2 = accounts[300] ;




    t2 += 1000; // 2000
    accounts[300] = t2 ;
}
```

The period between reading and writing on account should not be interrupted by other threads

Synchronization using Lock Objects

```
import java.util.concurrent.locks.*;
public class SynchBankTest {
  public static void main(String[] args) {
    Bank b = new Bank(NACCOUNTS, INITIAL_BALANCE);
    for (int i = 0; i < NACCOUNTS; i++)
    {
      TransferRunnable r = new TransferRunnable(b, i, INITIAL_BALANCE);
      Thread t = new Thread(r);
      t.start();
    }
  }

  public static final int NACCOUNTS = 100;
  public static final double INITIAL_BALANCE = 1000;
}
```

```
class Bank {
  public Bank(int n, double initialBalance) {
    accounts = new double[n];
    for (int i = 0; i < accounts.length; i++) accounts[i] = initialBalance;
    bankLock = new ReentrantLock();

 }
 public void transfer(int from, int to, double amount) throws InterruptedException {
    bankLock.lock();
    try {


      System.out.print(Thread.currentThread());
      accounts[from] -= amount;
      System.out.printf(" %10.2f from %d to %d", amount, from, to);
      accounts[to] += amount;
      System.out.printf(" Total Balance: %10.2f%n", getTotalBalance());

    }
    finally { bankLock.unlock(); }
  }
```

As soon as one thread locks the lock object, no other thread can get past the lock statement

Critical section

Good ! Reentrant lock

```
public double getTotalBalance() {
    bankLock.lock();
    try {
      double sum = 0;
      for (double a : accounts) sum += a;
      return sum;
    }
    finally { bankLock.unlock(); }
  }
  public int size()  { return accounts.length; }

  private final double[] accounts;
  private Lock bankLock;
}
```

Critical section

```
class TransferRunnable implements Runnable {
  public TransferRunnable(Bank b, int from, double max) {
    bank = b;
    fromAccount = from;
    maxAmount = max;
  }
  public void run() {
    try {
      while (true) {
        int toAccount = (int) (bank.size() * Math.random());
        double amount = maxAmount * Math.random();
        bank.transfer(fromAccount, toAccount, amount);
        Thread.sleep((int) (DELAY * Math.random()));
      }
    }
    catch (InterruptedException e) {}
  }
  private Bank bank;
  private int fromAccount;
  private double maxAmount;
  private int DELAY = 10;
}
```

```
Thread[Thread-0,5,main]     749.07 from 0 to 49 Total Balance:  100000.00
Thread[Thread-1,5,main]     758.75 from 1 to 55 Total Balance:  100000.00
Thread[Thread-2,5,main]     498.47 from 2 to 66 Total Balance:  100000.00
Thread[Thread-3,5,main]     288.41 from 3 to 23 Total Balance:  100000.00
Thread[Thread-4,5,main]      91.94 from 4 to 57 Total Balance:  100000.00
Thread[Thread-5,5,main]     143.72 from 5 to 41 Total Balance:  100000.00
Thread[Thread-6,5,main]     507.47 from 6 to 83 Total Balance:  100000.00
Thread[Thread-7,5,main]     443.58 from 7 to 99 Total Balance:  100000.00
Thread[Thread-8,5,main]      20.96 from 8 to 79 Total Balance:  100000.00
Thread[Thread-3,5,main]     585.57 from 3 to 28 Total Balance:  100000.00
Thread[Thread-5,5,main]     782.21 from 5 to 39 Total Balance:  100000.00
Thread[Thread-0,5,main]     189.73 from 0 to 45 Total Balance:  100000.00
Thread[Thread-1,5,main]     205.57 from 1 to 52 Total Balance:  100000.00
Thread[Thread-4,5,main]     765.40 from 4 to 24 Total Balance:  100000.00
Thread[Thread-8,5,main]      30.21 from 8 to 99 Total Balance:  100000.00
Thread[Thread-9,5,main]     300.35 from 9 to 59 Total Balance:  100000.00
Thread[Thread-2,5,main]     201.73 from 2 to 80 Total Balance:  100000.00
Thread[Thread-9,5,main]     297.33 from 9 to 60 Total Balance:  100000.00
Thread[Thread-10,5,main]     653.55 from 10 to 22 Total Balance:  100000.00
Thread[Thread-11,5,main]     874.86 from 11 to 79 Total Balance:  100000.00
Thread[Thread-4,5,main]     108.56 from 4 to 96 Total Balance:  100000.00
Thread[Thread-8,5,main]     933.63 from 8 to 66 Total Balance:  100000.00
```

Why Need Condition Object?

- Now, what do we do when there is not enough money in the account?
- We wait until some other thread has added funds.
- But this thread has just gained exclusive access to the bankLock, so no other thread has a chance to make a deposit

```
public void transfer(int from, int to, int amount) {
 bankLock.lock();
 try {
   while (accounts[from] < amount) {
     // wait
     . . .
   }
   // transfer funds
   . . .
 }
 finally {
   bankLock.unlock();
 }
}
```

Condition Objects

- await()
  - The current thread is now deactivated and gives up the lock
  - it stays deactivated until another thread has called the signalAll method on the same condition
- signalAll()
  - When another thread has transferred money, it should call signalAll()

```
class Bank {
   public Bank(int n, double initialBalance) {
      bankLock = new ReentrantLock();
      sufficientFunds = bankLock.newCondition();
   }
 public void transfer(int from, int to, double amount) throws InterruptedException {
      bankLock.lock();
      try {
         while (accounts[from] < amount) sufficientFunds.await();
            // The current thread is now deactivated and gives up the lock.
            // This lets in another thread that can, we hope,
            // increase the account balance
         sufficientFunds.signalAll(); // Wakes up all waiting threads
      }
      finally { bankLock.unlock(); }
   }
```

Condition Objects

```
class Bank {
  public Bank(int n, double initialBalance) {
    accounts = new double[n];
    for (int i = 0; i < accounts.length; i++) accounts[i] = initialBalance;
    bankLock = new ReentrantLock(); // use true for fairness
    sufficientFunds = bankLock.newCondition();
  }
 public void transfer(int from, int to, double amount) throws InterruptedException {
    bankLock.lock();
    try {
      while (accounts[from] < amount) sufficientFunds.await();
        // causes the current thread to wait until it is signalled or interrupted
      System.out.print(Thread.currentThread());
      accounts[from] -= amount;
      System.out.printf(" %10.2f from %d to %d", amount, from, to);
      accounts[to] += amount;
      System.out.printf(" Total Balance: %10.2f%n", getTotalBalance());
      sufficientFunds.signalAll(); // Wakes up all waiting threads
    }
    finally { bankLock.unlock(); }
  }
```

BoundedBuffer

```
class BoundedBuffer {
   final Lock lock = new ReentrantLock();
   final Condition notFull  = lock.newCondition();
   final Condition notEmpty = lock.newCondition();

   final Object[] items = new Object[100];
   int putptr, takeptr, count;

   public void put(Object x)
      throws InterruptedException {
     lock.lock();
     try {
       while (count == items.length) notFull.await();
       items[putptr] = x;
       if (++putptr == items.length) putptr = 0;
       ++count;
       notEmpty.signal();
     } finally { lock.unlock(); }
   }
```

When it is full, the thread will block until a space becomes available

```
  public Object take() throws
InterruptedException {
      lock.lock();
      try {
        while (count == 0)
          notEmpty.await();
        Object x = items[takeptr];
        if (++takeptr == items.length)
          takeptr = 0;
        --count;
        notFull.signal();
        return x;
      } finally {
        lock.unlock();
      }
    }
  }
```

Synchronization using synchronized method

```
public synchronized void method() {
    method body
}
```

```
public void method() {
    implicitLock.lock() ;
    try {
      method body ;
    }
    finally { implicitLock.unlock() ; }
}
```

```
public class SynchBankTest2 {
   public static void main(String[] args) {
      Bank b = new Bank(NACCOUNTS, INITIAL_BALANCE);
      for (int i = 0; i < NACCOUNTS; i++) {
         TransferRunnable r = new TransferRunnable(b, i, INITIAL_BALANCE);
         Thread t = new Thread(r);
         t.start();
      }
   }

   public static final int NACCOUNTS = 100;
   public static final double INITIAL_BALANCE = 1000;
}
```

```
class Bank {
   public Bank(int n, double initialBalance) {
     accounts = new double[n];
     for (int i = 0; i < accounts.length; i++) accounts[i] = initialBalance;
   }
   public synchronized void transfer(int from, int to, double amount)
     throws InterruptedException {
     while (accounts[from] < amount)
        wait(); // equivalent to implicitCondition.await()
     System.out.print(Thread.currentThread());
     accounts[from] -= amount;
     System.out.printf(" %10.2f from %d to %d", amount, from, to);
     accounts[to] += amount;
     System.out.printf(" Total Balance: %10.2f%n", getTotalBalance());
     notifyAll(); // equivalent to implicitCondition.signalAll()
   }
   public synchronized double getTotalBalance() {
     double sum = 0;
     for (double a : accounts) sum += a;
     return sum;
   }
   public int size() { return accounts.length; }
   private final double[] accounts;
}
```

```
class TransferRunnable implements Runnable {
    public TransferRunnable(Bank b, int from, double max) {
      bank = b;
      fromAccount = from;
      maxAmount = max;
   }
   public void run() {
      try {
         while (true) {
            int toAccount = (int) (bank.size() * Math.random());
            double amount = maxAmount * Math.random();
           // synchronized transfer
            bank.transfer(fromAccount, toAccount, amount);
            Thread.sleep((int) (DELAY * Math.random()));
         }
      }
      catch (InterruptedException e) {}
   }

   private Bank bank;
   private int fromAccount;
   private double maxAmount;
    private int DELAY = 10;
}
```

ThreadLocal<T>

- create variables that can only be read and written by the same thread

```
public class ThreadLocalExample {

 public static void main(String[] args) throws InterruptedException {
   MyRunnable sharedRunnableInstance = new MyRunnable();

   Thread thread1 = new Thread(sharedRunnableInstance);
   Thread thread2 = new Thread(sharedRunnableInstance);

   thread1.start();
   thread2.start();

   thread1.join();
   thread2.join();
 }
```

ThreadLocal<T>

- ThreadLocal class provides a simple way to make code thread safe

```
static class MyRunnable implements Runnable {
  private ThreadLocal<Integer> threadLocal = new ThreadLocal<Integer>();
  private int threadShared;
  @Override
  public void run() {
    threadLocal.set( (int) (Math.random() * 100D) );
    threadShared = (int) (Math.random() * 100D) ;
    try {
      Thread.sleep(2000);
    } catch (InterruptedException e) {
    }
    System.out.println(Thread.currentThread().getName() + ":"
        + threadLocal.get() + ", " + threadShared);
  }
 }
}
```

```
Thread-1:50, 9
Thread-0:99, 9
```

References

- Core Java Volume 1 – Chapter 12 Concurrency

- Java Tutorials on Concurrency
  - https://docs.oracle.com/javase/tutorial/essential/concurrency/index.html

Q&A