

Многопоточность 1

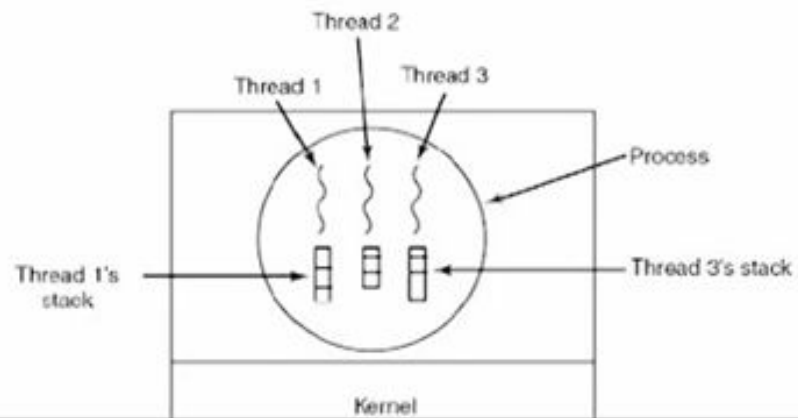
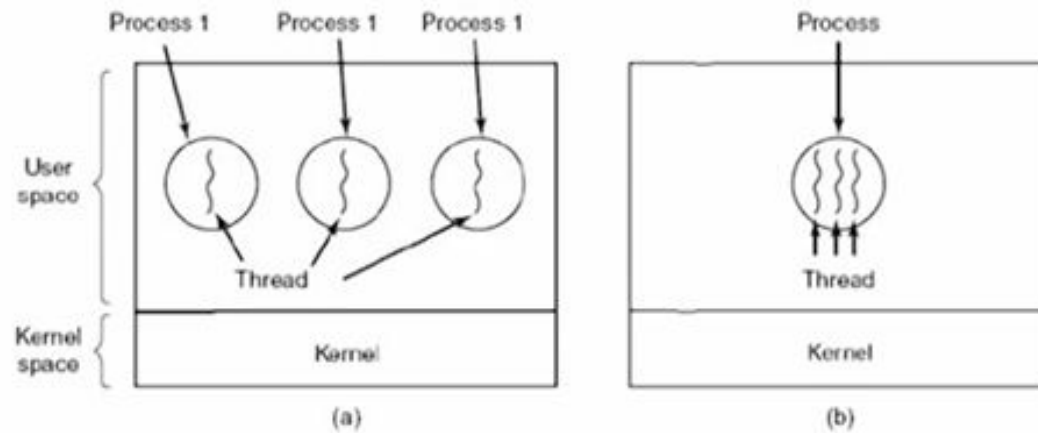
Concurrency

- Последовательная программа
 - Один процесс, последовательно выполняющий инструкции
- "Многопроцессная"(concurrent) программа
 - Несколько процессов, выполняющихся "одновременно"
- Варианты размещения процессов
 - Один процессор(ядро)
 - Многопроцессорная(-ядерная) система
 - Несколько машин

Зачем нужно несколько процессов?

- Естественность и удобство реализации
- Взаимодействие с пользователем, GUI
- Увеличение пропускной способности
- Увеличение скорости решения задачи

Процессы и потоки



Реализации потоков

- ОС: Pthreads (POSIX), Win32 threads, Solaris threads
- Библиотеки: Boost.Thread, OpenMP, Intel Threading Building Blocks
- Языки: Java, C#, Python, Erlang

Класс java.lang.Thread (Поток)

lecture1.helloworld.MyThread

```
1 public class MyThread extends Thread {
2
3     public void run() {
4         System.out.println("Hello World");
5         // do something...
6     }
7
8     public static void main(String[] args) {
9         MyThread t = new MyThread();
10        t.start();
11    }
12
13 }
```

Класс Person

lecture1.helloworld.Person

```
1 public class Person {
2
3     private String name;
4
5     public Person(String name) {
6         this.name = name;
7     }
8
9     public String getName() {
10        return name;
11    }
12
13 }
```

Интерфейс java.lang.Runnable (Задание)

lecture1.helloworld.RunnablePerson

```
1 public class RunnablePerson extends Person implements Runnable {
2
3     public RunnablePerson(String name) {
4         super(name);
5     }
6
7     public void run() {
8         for (int i=0; i<10; i++) {
9             System.out.println(getName() + ": Hello World");
10        }
11    }
12
13    public static void main(String[] args) {
14        RunnablePerson p1 = new RunnablePerson("Alice");
15        Thread t1 = new Thread(p1);
16        t1.start();
17        RunnablePerson p2 = new RunnablePerson("Bob");
18        Thread t2 = new Thread(p2);
19        t2.start();
20    }
21
22 }
```


Результаты запуска RunnablePerson

Bob: Hello World
Alice: Hello World
Bob: Hello World
Bob: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World

Alice: Hello World
Alice: Hello World
Alice: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World

Alice: Hello World
Alice: Hello World
Alice: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Alice: Hello World
Bob: Hello World
Bob: Hello World
Bob: Hello World

lecture1.bank.v1_seq.Bank

```
1 public class Bank {
2
3     private Map<String,Account> accounts;
4
5     public Bank() {
6         accounts = new HashMap<String,Account>();
7     }
8
9     public void addAccount(Account account) {
10        accounts.put(account.getId(), account);
11    }
12
13    public Account getAccount(String id) {
14        return accounts.get(id);
15    }
16
17 }
```

lecture1.bank.v1_seq.Account

```
1 public class Account {
2
3     private String id;
4     private int balance;
5
6     public Account(String id, int balance) {
7         this.id = id;
8         this.balance = balance;
9     }
10
11     public String getId() {
12         return id;
13     }
14
15     public int getBalance() {
16         return balance;
17     }
18
19     public void post(int value) {
20         balance += value;
21     }
```

lecture1.bank.v1_seq.Client

```
1 public class Client {
2
3     private Bank bank;
4     private BufferedReader in;
5     private PrintStream out;
6
7     public Client(Bank bank, BufferedReader in, PrintStream out) {
8         ...
9     }
10
11    public void run() {
12        ...
13    }
14
15    public static void main(String[] args) {
16        Bank bank = new Bank();
17        bank.addAccount(new Account("Acc001", 100));
18        BufferedReader in = new BufferedReader(
19            new InputStreamReader(System.in));
20        Client client = new Client(bank, in, System.out);
21        client.run();
22    }
}
```

Клиент v1 - run()

```
1 public void run() {
2     while(true) {
3         try {
4             out.print("Account Id: ");
5             String accountId = in.readLine();
6             Account account = bank.getAccount(accountId);
7             if (account == null) {
8                 throw new Exception("Account not found!");
9             } else {
10                out.println("Balance: " + account.getBalance());
11            }
12            out.print("Enter amount: ");
13            int value = Integer.parseInt(in.readLine());
14            if (account.getBalance() + value >= 0) {
15                account.post(value);
16                out.println("Balance: " + account.getBalance());
17            } else {
18                throw new Exception("Not enough money!");
19            }
20        } catch (Exception e) {
21            out.println("Error! " + e.getMessage());
22        }
23    }

```

```
1 Account Id: Acc000
2 Error! Account not found!
3 Account Id: Acc001
4 Balance: 100
5 Enter amount: -90
6 Balance: 10
7 Account Id: Acc001
8 Balance: 10
9 Enter amount: -90
10 Error! Not enough money!
```

lecture1.bank.v2_concurr.Client

```
1 public class Client extends Thread {
2
3     static final int numClients = 2;
4
5     private int id;
6     private Bank bank;
7     private BufferedReader in;
8     private PrintStream out;
9
10    public Client(int id, Bank bank,
11                BufferedReader in, PrintStream out) {
12        ...
13    }
14
15    public void run() {
16        ...
17    }
18
19    public static void main(String[] args) {
20        ...
21    }
22
```

Клиент v2 - main()

lecture1.bank.v2_concurr.Client

```
1 public static void main(String[] args) throws IOException {
2     Bank bank = new Bank();
3     bank.addAccount(new Account("Acc001", 100));
4     Client[] clients = new Client[numClients];
5     for (int i=0; i<numClients; i++) {
6         File inFile = new File(
7             "src/lecture1/bank/v2_concurr/input" + (i+1));
8         BufferedReader in = new BufferedReader(
9             new InputStreamReader(new FileInputStream(inFile)));
10        clients[i] = new Client(i+1, bank, in, System.out);
11        clients[i].start();
12    }
13 }
```

Входные данные

src/lecture1/bank/v2_concurr/input1

1 Acc001
2 -90

src/lecture1/bank/v2_concurr/input2

1 Acc001
2 -90

Результаты запусков

[1] Account Id: Acc001
[2] Account Id: Acc001
[2] Balance: 100
[2] Enter amount: -90
[2] Balance: 10
[1] Balance: 10
[1] Enter amount: -90
[1] Error! Not enough money!

[1] Account Id: Acc001
[1] Balance: 100
[2] Account Id: Acc001
[1] Enter amount: -90
[2] **Balance: 100**
[2] Enter amount: -90
[1] Balance: 10
[2] **Error! Not enough money!**

[1] Account Id: Acc001
[2] Account Id: Acc001
[1] Balance: 100
[1] Enter amount: -90
[2] Balance: 100
[2] Enter amount: -90
[1] Balance: 10
[2] **Balance: -80**

[1] Account Id: Acc001
[2] Account Id: Acc001
[2] Balance: 100
[2] Enter amount: -90
[1] Balance: 100
[1] Enter amount: -90
[1] **Balance: -80**
[2] **Balance: -80**

[1] Account Id: Acc001
[1] Balance: 100
[1] Enter amount: -90
[2] Account Id: Acc001
[2] Balance: 100
[2] Enter amount: -90
[2] Balance: 10
[1] **Balance: 10**

Отрицательный баланс

lecture1.bank.v2_concurr.Client

```
1 public void run() {
2     //while(true) { // run one transaction for testing
3         ...
4
5         out.println "[" + id + "]Enter amount: ";
6         int value = Integer.parseInt(in.readLine());
7         if (account.getBalance() + value >= 0) {
8             Thread.sleep(100);
9             account.post(value);
10            Thread.sleep(100);
11            out.println "[" + id + "]Balance: "
12                + account.getBalance());
13        } else {
14            throw new Exception("Not enough money!");
15        }
16
17        ...
18    //}
19 }
```

Возможная трасса run()

Client1

```
int value = Integer.parseInt(in.readLine());  
if (account.getBalance() + value >= 0) {
```

```
    account.post(value);  
    out.println "[" + id + "]Balance: "+  
    account.getBalance());
```

Client2

```
int value = Integer.parseInt(in.readLine());  
if (account.getBalance() + value >= 0) {  
    account.post(value);
```

```
    out.println "[" + id + "]Balance: "+  
    account.getBalance());
```

Результаты запусков

[1] Account Id: Acc001
[2] Account Id: Acc001
[2] Balance: 100
[2] Enter amount: -90
[2] Balance: 10
[1] Balance: 10
[1] Enter amount: -90
[1] Error! Not enough money!

[1] Account Id: Acc001
[1] Balance: 100
[2] Account Id: Acc001
[1] Enter amount: -90
[2] **Balance: 100**
[2] Enter amount: -90
[1] Balance: 10
[2] **Error! Not enough money!**

[1] Account Id: Acc001
[2] Account Id: Acc001
[1] Balance: 100
[1] Enter amount: -90
[2] Balance: 100
[2] Enter amount: -90
[1] Balance: 10
[2] **Balance: -80**

[1] Account Id: Acc001
[2] Account Id: Acc001
[2] Balance: 100
[2] Enter amount: -90
[1] Balance: 100
[1] Enter amount: -90
[1] **Balance: -80**
[2] **Balance: -80**

[1] Account Id: Acc001
[1] Balance: 100
[1] Enter amount: -90
[2] Account Id: Acc001
[2] Balance: 100
[2] Enter amount: -90
[2] Balance: 10
[1] **Balance: 10**

Возможная трасса post()

```
1 public void post(int value) {  
2     balance += value;  
3 }
```

Client1

value (-90)

balance (100)
+ (10)

balance = (10)

Client2

value (-90)

balance (100)
+ (10)
balance = (10)

Состояние гонки (Race Condition)

- Не все варианты чередования потоков (трассы), реализующиеся при выполнении программы, приводят к корректному результату
- Часто возникает при доступе к общим данным
- Трудно обнаруживать, воспроизводить и устранять

Безопасность (Safety)

Программа никогда не попадает в "плохое" состояние, в котором некоторые переменные имеют нежелательные значения

Синхронизация

- Безопасный доступ к общим данным
 - Устранение состояния гонок и нежелательных трасс программы
- Координация действий между потоками
 - Условная синхронизация (см. следующую лекцию)

Взаимное исключение (Mutual Exclusion)

- Требуется запретить выполнение критической секции более чем одним потоком (атомарность)
- В каждый момент времени внутри критической секции может находиться только один поток
- Остальные потоки ждут окончания выполнения секции первым потоком

Модификатор `synchronized`

lecture1.bank.v3_sync.Account

```
1 synchronized public int getBalance() {  
2     return balance;  
3 }  
4  
5 synchronized public void post(int value) {  
6     balance += value;  
7 }
```

Возможная трасса post()

```
1 public void post(int value) {  
2     balance += value;  
3 }
```

Client1

value (-90)

balance (100)
+ (10)

balance = (10)

Client2

value (-90)

balance (100)
+ (10)
balance = (10)

Модификатор synchronized

lecture1.bank.v3_sync.Account

```
1 synchronized public int getBalance() {  
2     return balance;  
3 }  
4  
5 synchronized public void post(int value) {  
6     balance += value;  
7 }
```

Результаты запусков

[1] Account Id: Acc001
[2] Account Id: Acc001
[2] Balance: 100
[2] Enter amount: -90
[2] Balance: 10
[1] Balance: 10
[1] Enter amount: -90
[1] Error! Not enough money!

[1] Account Id: Acc001
[1] Balance: 100
[2] Account Id: Acc001
[1] Enter amount: -90
[2] **Balance: 100**
[2] Enter amount: -90
[1] Balance: 10
[2] **Error! Not enough money!**

[1] Account Id: Acc001
[2] Account Id: Acc001
[1] Balance: 100
[1] Enter amount: -90
[2] Balance: 100
[2] Enter amount: -90
[1] Balance: 10
[2] **Balance: -80**

[1] Account Id: Acc001
[2] Account Id: Acc001
[2] Balance: 100
[2] Enter amount: -90
[1] Balance: 100
[1] Enter amount: -90
[1] **Balance: -80**
[2] **Balance: -80**

lecture1.bank.v3_sync.Client

```
1 out.println "[" + id + "]Balance: " + account.getBalance())
2 out.println "[" + id + "]Enter amount: ";
3 int value = Integer.parseInt(in.readLine());
4
5 synchronized (account) {
6     if (account.getBalance() + value >= 0) {
7         account.post(value);
8         out.println "[" + id + "]Balance: "
9             + account.getBalance());
10    } else {
11        throw new Exception("Not enough money!");
12    }
13 }
```

Результаты запусков

[1] Account Id: Acc001
[2] Account Id: Acc001
[2] Balance: 100
[2] Enter amount: -90
[2] Balance: 10
[1] Balance: 10
[1] Enter amount: -90
[1] Error! Not enough money!

[1] Account Id: Acc001
[1] Balance: 100
[2] Account Id: Acc001
[1] Enter amount: -90
[2] **Balance: 100**
[2] Enter amount: -90
[1] Balance: 10
[2] **Error! Not enough money!**

[1] Account Id: Acc001
[2] Account Id: Acc001
[1] Balance: 100
[1] Enter amount: -90
[2] Balance: 100
[2] Enter amount: -90
[1] Balance: 10
[2] **Balance: -80**

[1] Account Id: Acc001
[2] Account Id: Acc001
[2] Balance: 100
[2] Enter amount: -90
[1] Balance: 100
[1] Enter amount: -90
[1] **Balance: -80**
[2] **Balance: -80**

Результаты запусков

```
[1] Account Id: Acc001
[2] Account Id: Acc001
[2] Balance: 100
[2] Enter amount: -90
[2] Balance: 10
[1] Balance: 10
[1] Enter amount: -90
[1] Error! Not enough money!
```

```
[1] Account Id: Acc001
[1] Balance: 100
[2] Account Id: Acc001
[1] Enter amount: -90
[2] Balance: 100
[2] Enter amount: -90
[1] Balance: 10
[2] Error! Not enough money!
```

Результат

[1] Account Id: Acc001

[2] Account Id: Acc001

[1] Balance: 100

[1] Enter amount: (1 ДУМАЕТ... 2 ЖДЕТ...) -90

[1] Balance: 10

[2] Balance: 10

Bank

```
1 public void transfer(Account from, Account to, int value)
2     throws Exception {
3     if (value <= 0) {
4         throw new Exception("Amount must be positive!");
5     }
6     if (from.getBalance() < value) {
7         throw new Exception("Not enough money!");
8     } else {
9         from.post(-value);
10    }
11    to.post(value);
12 }
```

lecture1.bank.v4_deadlock.Bank

```
1 public void transfer(Account from, Account to, int value)
2     throws Exception {
3     if (value <= 0) {
4         throw new Exception("Amount must be positive!");
5     }
6     synchronized (from) {
7         if (from.getBalance() < value) {
8             throw new Exception("Not enough money!");
9         } else {
10            from.post(-value);
11        }
12        synchronized (to) {
13            to.post(value);
14        }
15    }
16 }
```

lecture1.bank.v4_deadlock.Client

```
1 out.println("[ " + id + "]" + "From Account Id: ");
2 String accountId = in.readLine();
3 Account account = bank.getAccount(accountId);
4 if (account == null) {
5     throw new Exception("Account not found!");
6 }
7
8 out.println("[ " + id + "]" + "To Account Id: ");
9 String toAccountId = in.readLine();
10 Account toAccount = bank.getAccount(toAccountId);
11 if (toAccount == null) {
12     throw new Exception("Account not found!");
13 }
14
15 out.println("[ " + id + "]" + "Enter transfer amount: ");
16 int value = Integer.parseInt(in.readLine());
17 bank.transfer(account, toAccount, value);
18 out.println("[ " + id + "]" + "Balance: " + account.getBalance());
```

src/lecture1/bank/v4_deadlock/input1

1 Acc001
2 Acc002
3 10

src/lecture1/bank/v4_deadlock/input2

1 Acc002
2 Acc001
3 20

Результаты

[2] From Account Id: Acc002
[2] From Account Id: Acc001
[2] Enter transfer amount: 20
[2] Balance: 80
[1] From Account Id: Acc001
[1] From Account Id: Acc002
[1] Enter transfer amount: 10
[1] Balance: 110

[1] From Account Id: Acc001
[1] From Account Id: Acc002
[1] Enter transfer amount: 10
[1] Balance: 90
[2] From Account Id: Acc002
[2] From Account Id: Acc001
[2] Enter transfer amount: 20
[2] Balance: 90

[1] From Account Id: Acc001
[1] From Account Id: Acc002
[1] Enter transfer amount: 10
[2] From Account Id: Acc002
[2] From Account Id: Acc001
[2] Enter transfer amount: 20
...

lecture1.bank.v4_deadlock.Bank

```
1 public void transfer(Account from, Account to, int value)
2     throws Exception {
3     if (value <= 0) {
4         throw new Exception("Amount must be positive!");
5     }
6     synchronized (from) {
7         if (from.getBalance() < value) {
8             throw new Exception("Not enough money!");
9         } else {
10            from.post(-value);
11        }
12        synchronized (to) {
13            to.post(value);
14        }
15    }
16 }
```

Взаимная блокировка (Deadlock)



Живучесть (Liveness)

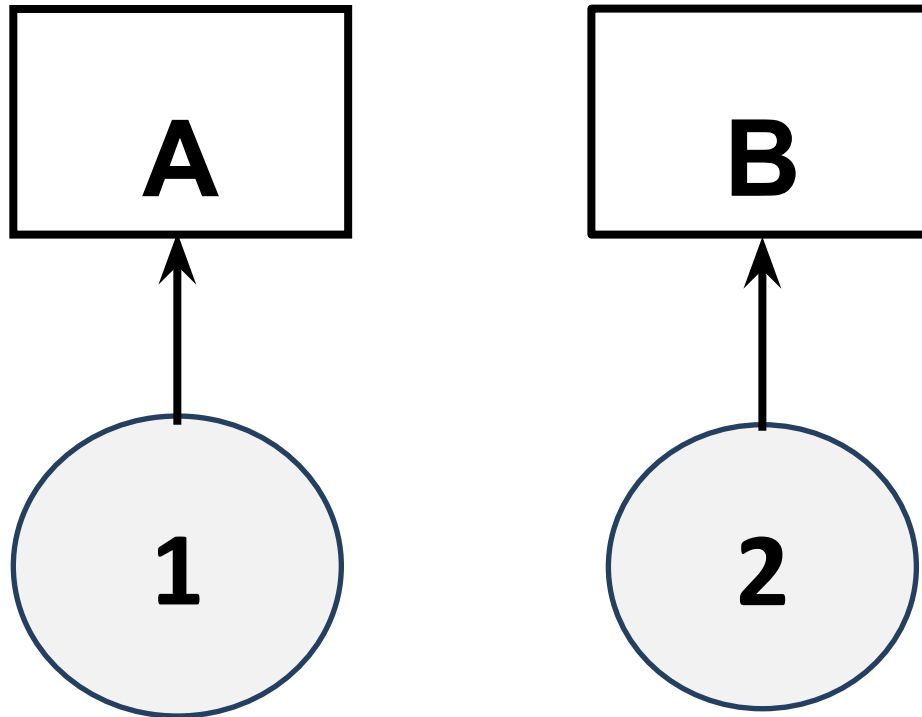
Программа в конце концов попадает в "хорошее" состояние, в котором все переменные имеют желаемые значения

Как избежать взаимной блокировки?

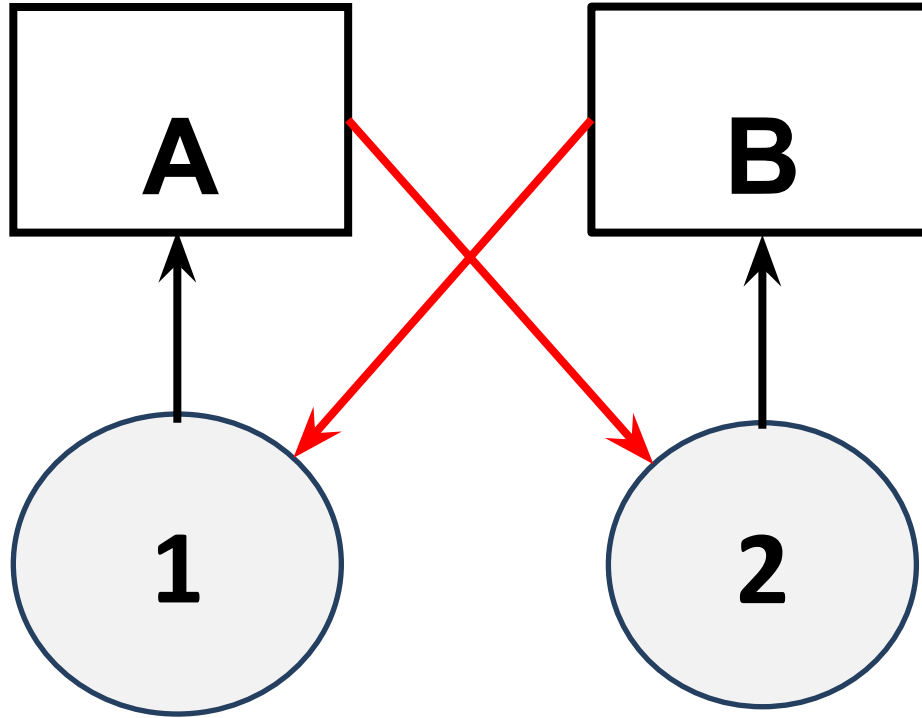
Условия возникновения взаимной блокировки

- Цикл в графе блокировок
- Каждый поток захватил как минимум один объект (lock) и ждет освобождения объекта, который захвачен следующим потоком в цикле
- Ни один из потоков не хочет уступить

Ни один из потоков не хочет уступать



Ни один из потоков не хочет уступать



Как избежать взаимной блокировки

Устранить любое из условий возникновения:

- Не захватывать более одной блокировки одновременно
- Всегда захватывать блокировки в одном порядке (упорядочить блокируемые объекты)
- Добровольно освобождать захваченную блокировку

Модифицированный Bank

lecture1.bank.v5_lockorder.Bank

```
1  int fromHash = System.identityHashCode(from);
2  int toHash = System.identityHashCode(to);
3  if (fromHash < toHash) {
4      synchronized (from) {
5          synchronized (to) {
6              doTransfer(from, to, value);
7          }
8      }
9  } else if (fromHash > toHash) {
10     synchronized (to) {
11         synchronized (from) {
12             doTransfer(from, to, value);
13         }
14     }
15 } else { // hash collision!
16     synchronized (tieLock) {
17         synchronized (from) {
18             synchronized (to) {
19                 doTransfer(from, to, value);
20             }
21         }
22     }
```


Пакет java.util.concurrent.locks

java.util.concurrent.locks.Lock

```
1 public interface Lock {
2     void lock();
3     void lockInterruptibly() throws InterruptedException;
4     boolean tryLock();
5     boolean tryLock(long timeout, TimeUnit unit)
6         throws InterruptedException;
7     void unlock();
8     ...
9 }
```

Схема использования

```
1 Lock lock = new ReentrantLock();
2 ...
3 lock.lock();
4 try {
5     // update object state
6     // catch exceptions and restore invariants if necessary
7 } finally {
8     lock.unlock();
9 }
```

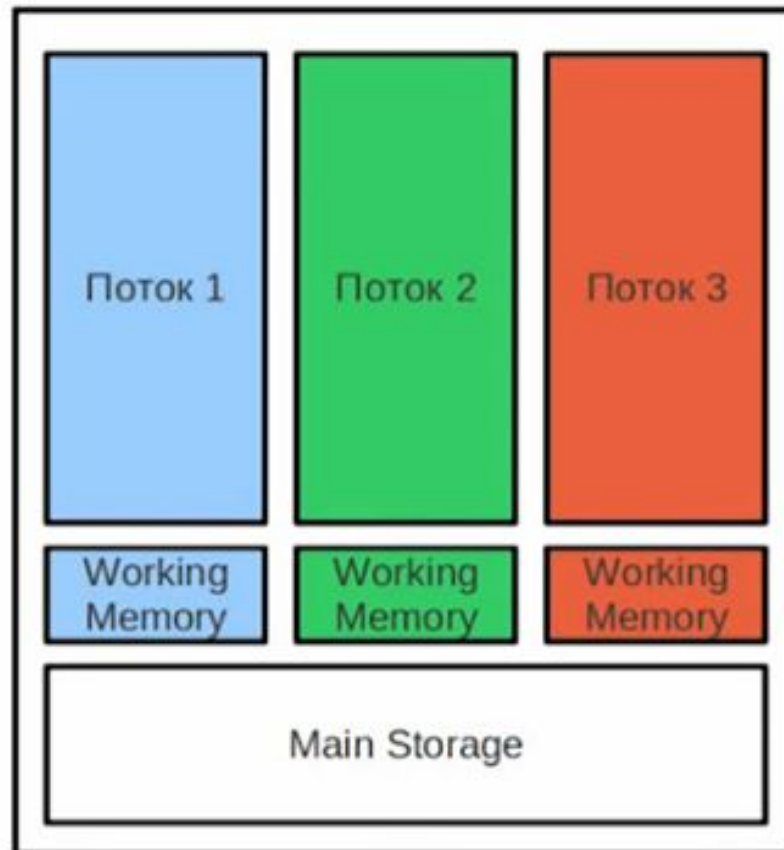
Еще одна реализация перевода

```
1  while (true) {
2      if (fromAcct.lock.tryLock()) {
3          try {
4              if (toAcct.lock.tryLock()) {
5                  try {
6                      if (fromAcct.getBalance().compareTo(amount) < 0)
7                          throw new InsufficientFundsException();
8                      else {
9                          fromAcct.debit(amount);
10                         toAcct.credit(amount);
11                         return true;
12                     }
13                 } finally {
14                     toAcct.lock.unlock();
15                 }
16             }
17         } finally {
18             fromAcct.lock.unlock();
19         }
20     }
21     if (System.nanoTime() < stopTime)
22         return false;
23     TimeUnit.NANOSECONDS.sleep(fixedDelay + rnd.nextLong() % randMod);
24 }
```

lecture1.stop.StopThread

```
1 public class StopThread {
2
3     private static boolean stopRequested;
4
5     public static void main(String[] args)
6         throws InterruptedException {
7         Thread backgroundThread = new Thread(new Runnable() {
8             public void run() {
9                 int i = 0;
10                while (!stopRequested)
11                    i++;
12            }
13        });
14        backgroundThread.start();
15        TimeUnit.SECONDS.sleep(1);
16        stopRequested = true;
17    }
18
19 }
```

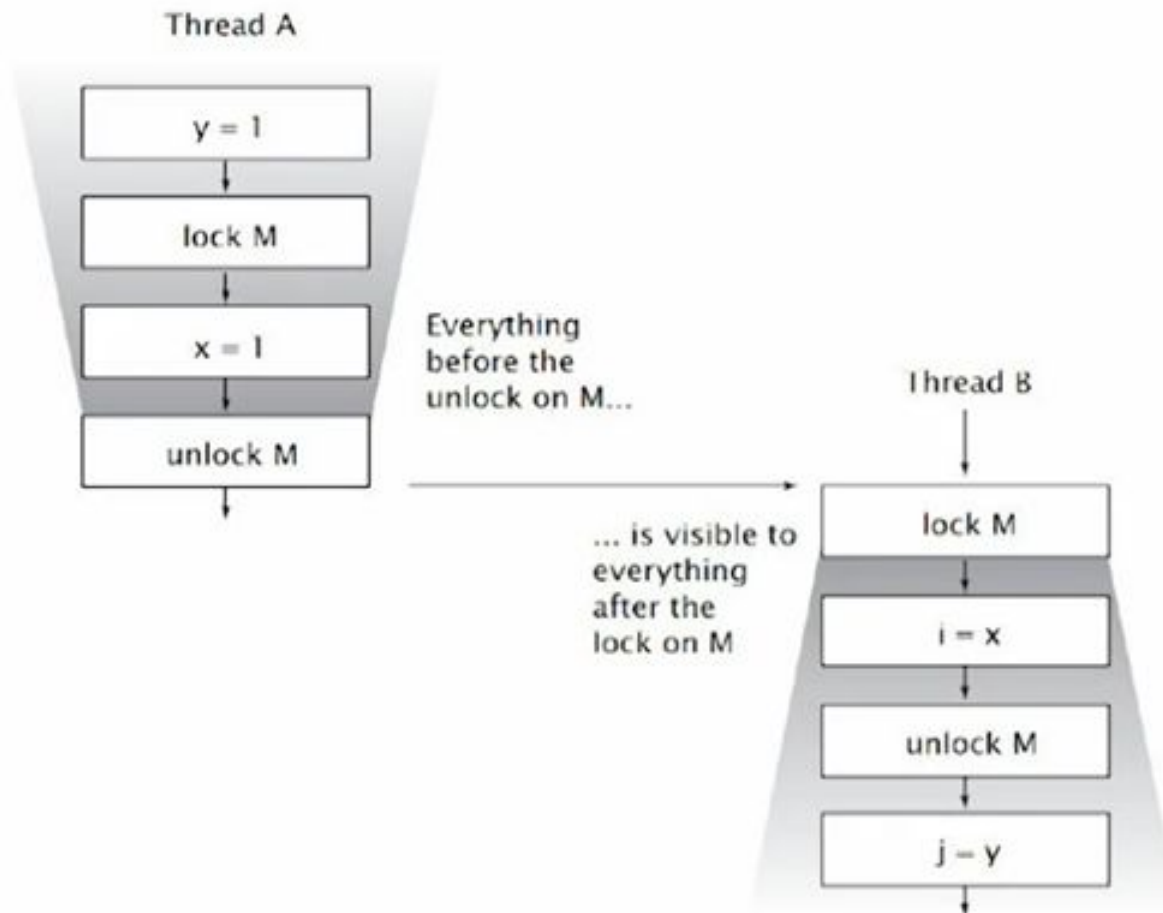
Java Memory Model



Пример с двумя переменными

```
1 public class NoVisibility {
2     private static boolean ready;
3     private static int number;
4
5     private static class ReaderThread extends Thread {
6         public void run() {
7             while (!ready)
8                 Thread.yield();
9             System.out.println(number);
10        }
11    }
12
13    public static void main(String[] args) {
14        new ReaderThread().start();
15        number = 42;
16        ready = true;
17    }
18 }
```

Обеспечение видимости изменений между потоками



lecture1.stop.StopThread

```
1 public class StopThread {
2
3     private static boolean stopRequested;
4
5     public static void main(String[] args)
6         throws InterruptedException {
7         Thread backgroundThread = new Thread(new Runnable() {
8             public void run() {
9                 int i = 0;
10                while (!stopRequested)
11                    i++;
12            }
13        });
14        backgroundThread.start();
15        TimeUnit.SECONDS.sleep(1);
16        stopRequested = true;
17    }
18
19 }
```

StopThread2

lecture1.stop.StopThread2

```
1 public class StopThread2 {
2
3     private static boolean stopRequested;
4
5     private static synchronized void requestStop() {
6         stopRequested = true;
7     }
8
9     private static synchronized boolean stopRequested() {
10        return stopRequested;
11    }
12
13    public static void main(String[] args) throws InterruptedException {
14        Thread backgroundThread = new Thread(new Runnable() {
15            public void run() {
16                int i = 0;
17                while (!stopRequested())
18                    i++;
19            }
20        });
21        backgroundThread.start();
22        TimeUnit.SECONDS.sleep(1);
23        requestStop();
24    }
25
26 }
```

Остановка потока

- Проверка флага (volatile!) внутри run()
- Thread.interrupt()
 - для заблокированных потоков выбрасывает InterruptedException
 - Работает для sleep(), join(), wait()
 - Не работает для I/O, synchronized
 - для не заблокированных потоков проверка Thread.interrupted()

Общая схема реализации

```
1  volatile boolean doneFlag;
2
3  public void run() {
4      try {
5          while(!doneFlag && !Thread.interrupted()) {
6              // do something...
7              // sleep...
8          }
9          // Exiting via while test
10     } catch (InterruptedException e) {
11         // Exiting via InterruptedException
12     }
13 }
```

Методы `yield()` и `sleep()`

```
1 public void run() {
2     while(...) {
3         // do something
4
5         Thread.yield();
6     }
7 }
```

```
1 public void run() {
2     try {
3         while(...) {
4             // do something
5
6             // Thread.sleep(100);
7             TimeUnit.MILLISECONDS.sleep(100);
8         }
9     } catch (InterruptedException e) {
10        System.err.println("Interrupted");
11    }
12 }
```

Приоритеты потоков

- 10 уровней приоритетов для Java-потоков
- JVM отображает эти приоритеты в приоритеты планировщика конкретной ОС \Rightarrow зависимость от платформы
- В подавляющем большинстве случаев достаточно приоритета по-умолчанию `Thread.NORM_PRIORITY`
- Попытки манипулировать приоритетами потоков приводят к зависимости от ОС и могут вызвать "голодание" (starvation)

Задача об обедающих философах



lecture1.philosophers.Philosopher

```
1 public class Philosopher {
2
3     int position;
4     Fork left;
5     Fork right;
6     int eatCount = 0;
7     long waitTime = 0;
8     long startWait;
9     Random rnd = new Random();
10
11     public Philosopher(int position, Fork left, Fork right) {
12         this.position = position;
13         this.left = left;
14         this.right = right;
15     }
```

Наивное решение

lecture1.philosophers.MyPhilosopher

```
1 public class MyPhilosopher extends Philosopher implements Runnable {
2
3     volatile boolean stopFlag = false;
4
5     public MyPhilosopher(int position, Fork left, Fork right) {
6         super(position, left, right);
7     }
8
9     public void run() {
10        while (!stopFlag) {
11            think();
12            synchronized (left) {
13                System.out.println("[Philosopher " + position
14                    + "] took left fork");
15                synchronized (right) {
16                    System.out.println("[Philosopher " + position
17                        + "] took right fork");
18                    eat();
19                }
20            }
21        }
22        System.out.println("[Philosopher " + position + "] stopped");
23    }
24 }
```

lecture1.philosophers.Run

```
1 public static void main(String[] args) throws Exception {
2     MyPhilosopher[] phils = new MyPhilosopher[count];
3
4     Fork last = new Fork();
5     Fork left = last;
6     for (int i=0; i<count; i++) {
7         Fork right = (i==count-1)?last:new Fork();
8         phils[i] = new MyPhilosopher(i, left, right);
9         left = right;
10    }
11
12    Thread[] threads = new Thread[count];
13    for (int i = 0; i < count; i++) {
14        threads[i] = new Thread(phils[i]);
15        threads[i].start();
16    }
17
18    Thread.sleep(60000);
19
20    for (MyPhilosopher phil : phils) {
21        phil.stopFlag = true;
22    }
23    for (Thread thread : threads) {
24        thread.join();
25    }
26    for (MyPhilosopher phil : phils) {
27        System.out.println("[Philosopher " + phil.position + "] ate " +
28            phil.eatCount + " times and waited " + phil.waitTime + " ms");
29    }
30 }
```


Результат 1

```
1 .....
2 [Philosopher 2] stopped
3 [Philosopher 3] took left fork
4 [Philosopher 1] took right fork
5 [Philosopher 1] is eating
6 [Philosopher 1] finished eating
7 [Philosopher 1] stopped
8 [Philosopher 0] took right fork
9 [Philosopher 0] is eating
10 [Philosopher 0] finished eating
11 [Philosopher 0] stopped
12 [Philosopher 4] took right fork
13 [Philosopher 4] is eating
14 [Philosopher 4] finished eating
15 [Philosopher 4] stopped
16 [Philosopher 3] took right fork
17 [Philosopher 3] is eating
18 [Philosopher 3] finished eating
19 [Philosopher 3] stopped
20 [Philosopher 0] ate 319 times and waited 28621 ms
21 [Philosopher 1] ate 319 times and waited 28350 ms
22 [Philosopher 2] ate 318 times and waited 28171 ms
23 [Philosopher 3] ate 326 times and waited 28253 ms
24 [Philosopher 4] ate 327 times and waited 28235 ms
```

Результат 2

```
1 .....
2 [Philosopher 3] is hungry
3 [Philosopher 3] took left fork
4 [Philosopher 1] took right fork
5 [Philosopher 1] is eating
6 [Philosopher 2] is thinking
7 [Philosopher 1] finished eating
8 [Philosopher 1] is thinking
9 [Philosopher 0] took right fork
10 [Philosopher 0] is eating
11 [Philosopher 2] is hungry
12 [Philosopher 2] took left fork
13 [Philosopher 0] finished eating
14 [Philosopher 0] is thinking
15 [Philosopher 4] took right fork
16 [Philosopher 4] is eating
17 [Philosopher 1] is hungry
18 [Philosopher 1] took left fork
19 [Philosopher 4] finished eating
20 [Philosopher 4] is thinking
21 [Philosopher 0] is hungry
22 [Philosopher 0] took left fork
23 [Philosopher 4] is hungry
24 [Philosopher 4] took left fork
```

Домашнее задание

- Предложите решение задачи об обедающих философях, исключающее
 - взаимную блокировку (deadlock)
 - голодание (starvation, livelock)
 - неравномерное распределение ресурсов (lack of fairness)
- Дополнительно требуется
 - минимизировать время ожидания философем еды
 - обеспечить масштабируемость решения при увеличении кол-ва философфов