CNT 4714 – Project 2 – Spring 2024

Title: "Project 2: An Application Employing Synchronized/Cooperating Multiple Threads In Java Using Locks – A Banking Simulator"
Points: 100 points
Due Date: Sunday February 11, 2024 by 11:59 pm (WebCourses time)

Objectives: To develop an application which requires cooperating, synchronized multiple threads of execution.

Description: In this project you will simulate the deposits and withdrawals made to a fictitious bank account (I'll let you use my real bank account if you promise to make only deposits! ☺). In this case the deposits and withdrawals will be made by user agents (synchronized threads). Synchronization is required for two reasons – (1) mutual exclusion (updates cannot be lost) and (2) because a withdrawal cannot occur if the amount of the withdrawal request is greater than the current balance in the account. This means that access to the account (the shared object) must be synchronized. This application requires cooperation and communication amongst the various agents (cooperating synchronized threads). (In other words, this problem is similar to the producer/consumer problem where there is more than one producer and more than one consumer process active simultaneously.) If a withdrawal agent attempts to withdraw an amount greater than the current balance in the account – then it must block itself and wait until a depositing agent has added money to the account before it can try again. As we covered in the lecture notes, this will require that the depositing agents signal all waiting withdrawing agents whenever a deposit is completed.

1. You should have five depositor agents (threads) and ten withdrawal agents (threads), and two auditor agents (threads) simultaneously executing. Use a FixedThreadPool() and an Executor object to control the threads.

2. To keep things relatively simple, assume that deposits are made in amounts ranging from $1 to $500 (whole dollars only) and withdrawals are made in amounts ranging from $1 to $99 (again, whole dollars only). Since we have more withdrawal threads than depositor threads, the account balance should constantly decrease over time. This will lead to withdrawal agents repeatedly blocking for insufficient funds. Start the simulation with a balance of $0 in the account.

3. Once a depositor agent (thread) has deposited into the account, put it to sleep for few milliseconds (randomly generate this number – don't use a constant sleep time) or so (depends a little bit on the speed of your system as to how long you will want to sleep the depositing threads - basically we want to ensure a lot more withdrawals than deposits) to allow other agents to execute.

4. For withdrawal agents, things will be a bit different depending on whether you are working on a single or multi-core processor.

    a. For single core processors, once a withdrawal agent has withdrawn funds from the account, have it yield the processor unit. Since the agent is giving up the processor voluntarily, it will be unlikely to run again (attempt a second withdrawal in a row), before another agent runs. Note however, that it does not prevent it from running again, if all other withdrawal agents are blocked and all depositors are sleeping, it will run again. So occasional back-to-back runs of withdrawal agents might occur (see below).
    b. For multi-core processors, once a withdrawal agent has executed, have it sleep for some random period of time (again, a few milliseconds should be fine). Depending on which core a thread is executing, yielding the CPU won't ensure that the same thread will not run again immediately. While, sleeping the thread will also not ensure that it will not run two or more times in succession, it is less likely to do so in the multi-core environment.
    c. What we don't want to happen is a single withdrawal agent gaining the CPU and then executing a long sequence of withdrawal operations. Recall though, that withdrawal agents block if they attempt to withdraw more than the current balance in the account.
    d. Similarly, we don't want depositor agents monopolizing the CPU either and causing the balance in the account to grow continuously. This would most likely occur when the withdrawal agents are sleeping too long in comparison to the average sleep time of the depositing agents. See page 11 for an illustration of this.

5. Assume all depositor, withdrawal, and auditor agents have the same priority. **Do not** give different priority to depositor, withdrawal, and auditor agents (threads). The auditor agents will also have normal priority and will simply run less frequently than the depositor and withdrawal threads (i.e., the auditor agents will sleep longer between runs than either depositor or withdrawal agents). See below.

6. The output from your program must look reasonably similar to the sample output shown below. The simulation output should show the action of each agent along with the account balance produced by the agent's transaction and the transaction number.

7. **Do not put the threads into a counted loop for your simulation.** In other words, the `run()` method for all threads should be an infinite loop. Just stop the simulation from your IDE after a few seconds.

8. **Do not use the Java synchronized statement.** I want you to handle the locking and signaling yourself. No monitors!

9. You must utilize a reentrant lock from the java.util.concurrent.locks package for implementing your locking protocols. We will specify no fairness policy for this application. **Do not create your own lock using a Boolean or any other type of variable.**

10. The Money Laundering Suppression Act, enacted by Congress in 1994, is a policy regulation that requires banking institutions to file currency transaction reports (CTRs) with the federal government (Department of the Treasury) for any deposits of $10,000 or more into a bank account. You are going to simulate this process by flagging any depositing transaction with a deposit value greater than $350.00 and any withdrawal amount greater than $75.00. You will flag the transaction in the normal output of the simulation as well as making an entry into a transaction log file (`transactions.csv`) which will keep track of all flagged transactions independently of the simulation. Each entry in the flagged transaction file will contain the transaction details, a timestamp (the date and time at which the transaction occurred), and the transaction number. See below for more details.

11. Every transaction made by a depositor or withdrawal agent will have a transaction number (an integer initialized to 1). This transaction number is printed out in the simulation run with each completed transaction. See output examples below.

12. The auditor agents (there are only 2 of these), simply verify the current balance in the account at random intervals and indicate how many transactions have occurred since the last audit of its type. There is one InternalBank auditor agent and one TreasuryDept auditor agent. The auditor agents do not make transactions on the account and do not affect the transaction number sequence. The auditor agents simply print the current account balance into the simulation

run and keep track of the number of transactions that have executed since the last auditor execution of that type. All depositor and withdrawal agents must wait (block) for any auditor agents to complete before continuing execution. Note that the auditors should run much less frequently than either depositor or withdrawal agents.

References:
Notes: Lecture Notes for Multithreaded Applications.

Restrictions:
Your source files shall begin with comments containing the following information:

```
/*  Name:
    Course: CNT 4714 Spring 2024
    Assignment title: Project 2 – Synchronized, Cooperating Threads Under Locking
    Due Date: February 11, 2024
*/
```

Input Specification: Internal to the program.

Output Specification: Console based. Your output should appear reasonably similar to the output shown below.

Deliverables:

(1) Zip up all of your .java files and submit them via WebCourses no later than 11:59pm Sunday February 11, 2024.

(2) Include a sufficient number of screen shots that illustrate the execution of your synchronized threaded application (the simulation output). See below for some representative examples. Your screenshots should illustrate all the different types of output we expect to see. Include as many screen shots as necessary. Label all screenshots clearly.

(3) Redirect the console output to an output file. Include a copy of this output file from a run of your banking simulation. This file output should be of sufficient length to include at least 100 transactions.

(4) Include a copy of your `transaction.csv` log file that matches the simulation output (see below for explanation).

Additional Information:

Shown below are some examples of the output from this program to help illustrate how your application is to operate and display the results. The last page illustrates execution runs that you do not want to produce.

```
<terminated> ABankingSimulator [Java Application] /Library/Java/JavaVirtualMachines/jdk-21.jdk/Contents/Home/bin/java  (Jan 29, 2024, 5:06:04 PM – 5:06:09 PM) [pid: 44930]
* * *  SIMULATION BEGINS...

Deposit  Agents                Withdrawal  Agents        Balance                                     Transaction Number
---------------                ------------------        ----------------------                      -------------------------
                            Agent WT3 withdraws $95   (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                            Agent WT4 withdraws $93   (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                            Agent WT5 withdraws $88   (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                            Agent WT6 withdraws $65   (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                            Agent WT2 withdraws $96   (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                            Agent WT1 withdraws $14   (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                            Agent WT7 withdraws $2    (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                            Agent WT8 withdraws $26   (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                            Agent WT9 withdraws $50   (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                            Agent WT0 withdraws $88   (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!


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        INTERNAL BANK AUDTIOR FINDS CURRENT ACCOUNT BALANCE TO BE: $0        Number of transactions since last Internal audit is: 0

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Agent DT3 deposits $348                                   (+)  Balance is $348                      1
Agent DT4 deposits $254                                   (+)  Balance is $602                      2
Agent DT1 deposits $114                                   (+)  Balance is $716                      3
Agent DT0 deposits $42                                    (+)  Balance is $758                      4
Agent DT2 deposits $417                                   (+)  Balance is $1175                     5

* * * Flagged Transaction - Depositor Agent DT2 Made A Deposit In Excess Of $350.00 USD - See Flagged Transaction Log.

                            Agent WT3 withdraws $12   (-)  Balance is $1163                     6
                            Agent WT5 withdraws $45   (-)  Balance is $1118                     7
                            Agent WT3 withdraws $68   (-)  Balance is $1050                     8
                            Agent WT8 withdraws $53   (-)  Balance is $997                      9
                            Agent WT0 withdraws $36   (-)  Balance is $961                      10
                            Agent WT0 withdraws $98   (-)  Balance is $863                      11

* * * Flagged Transaction - Withdrawal Agent WT0 Made A Withdrawal In Excess Of $75.00 USD - See Flagged Transaction Log.

                            Agent WT9 withdraws $47   (-)  Balance is $816                      12
                            Agent WT3 withdraws $53   (-)  Balance is $763                      13
                            Agent WT0 withdraws $81   (-)  Balance is $682                      14

* * * Flagged Transaction - Withdrawal Agent WT0 Made A Withdrawal In Excess Of $75.00 USD - See Flagged Transaction Log.

                            Agent WT9 withdraws $40   (-)  Balance is $642                      15
                            Agent WT4 withdraws $94   (-)  Balance is $548                      16

* * * Flagged Transaction - Withdrawal Agent WT4 Made A Withdrawal In Excess Of $75.00 USD - See Flagged Transaction Log.
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                        Agent WT4 withdraws $87        (-)  Balance is $461                                          17

* * * Flagged Transaction - Withdrawal Agent WT4 Made A Withdrawal In Excess Of $75.00 USD - See Flagged Transaction Log.

                        Agent WT6 withdraws $43        (-)  Balance is $418                                          18
                        Agent WT2 withdraws $36        (-)  Balance is $382                                          19
                        Agent WT8 withdraws $42        (-)  Balance is $340                                          20
                        Agent WT4 withdraws $7         (-)  Balance is $333                                          21
                        Agent WT1 withdraws $69        (-)  Balance is $264                                          22
                        Agent WT5 withdraws $27        (-)  Balance is $237                                          23
                        Agent WT7 withdraws $38        (-)  Balance is $199                                          24
                        Agent WT6 withdraws $7         (-)  Balance is $192                                          25
                        Agent WT3 withdraws $94        (-)  Balance is $98                                           26

* * * Flagged Transaction - Withdrawal Agent WT3 Made A Withdrawal In Excess Of $75.00 USD - See Flagged Transaction Log.

                        Agent WT2 withdraws $83        (-)  Balance is $15                                           27

* * * Flagged Transaction - Withdrawal Agent WT2 Made A Withdrawal In Excess Of $75.00 USD - See Flagged Transaction Log.

                        Agent WT9 withdraws $74        (*****) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT0 withdraws $53        (*****) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT3 withdraws $43        (*****) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT7 withdraws $33        (*****) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT4 withdraws $9         (-)  Balance is $6                                            28
                        Agent WT1 withdraws $86        (*****) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT5 withdraws $81        (*****) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT6 withdraws $98        (*****) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT8 withdraws $95        (*****) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT2 withdraws $78        (*****) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT4 withdraws $74        (*****) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!


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            INTERNAL BANK AUDTIOR FINDS CURRENT ACCOUNT BALANCE TO BE: $6          Number of transactions since last Internal audit is: 28

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      TREASURY DEPT AUDTIOR FINDS CURRENT ACCOUNT BALANCE TO BE: $192        Number of transactions since last Treasury audit is: 29

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Agent DT3 deposits $76                                    (+)  Balance is $268                              30
                          Agent WT2 withdraws $68         (-)  Balance is $200                              31
                          Agent WT8 withdraws $27         (-)  Balance is $173                              32
                          Agent WT6 withdraws $52         (-)  Balance is $121                              33
                          Agent WT8 withdraws $67         (-)  Balance is $54                               34
                          Agent WT4 withdraws $58         (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                          Agent WT7 withdraws $98         (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                          Agent WT0 withdraws $61         (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                          Agent WT1 withdraws $58         (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                          Agent WT2 withdraws $44         (-)  Balance is $10                               35
                          Agent WT9 withdraws $16         (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                          Agent WT3 withdraws $55         (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                          Agent WT8 withdraws $98         (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                          Agent WT5 withdraws $7          (-)  Balance is $3                                36
                          Agent WT6 withdraws $94         (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                          Agent WT2 withdraws $41         (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                          Agent WT5 withdraws $53         (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!


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      INTERNAL BANK AUDTIOR FINDS CURRENT ACCOUNT BALANCE TO BE: $3        Number of transactions since last Internal audit is: 8

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      TREASURY DEPT AUDTIOR FINDS CURRENT ACCOUNT BALANCE TO BE: $3        Number of transactions since last Treasury audit is: 7

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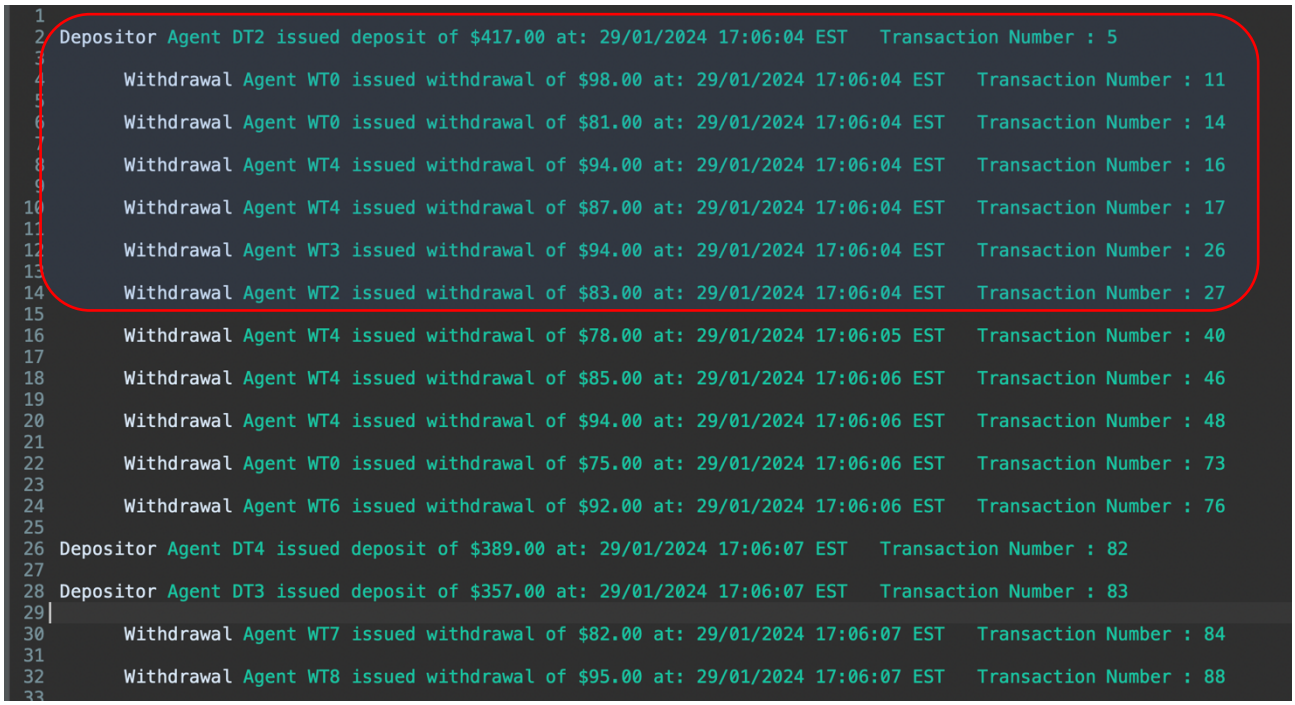
Agent DT0 deposits $116                                   (+)  Balance is $119                              37
Agent DT1 deposits $31                                    (+)  Balance is $150                              38
```

The transaction log file showing the first seven flagged transactions in the execution run shown above.



```
Depositor Agent DT2 issued deposit of $417.00 at: 29/01/2024 17:06:04 EST   Transaction Number : 5

      Withdrawal Agent WT0 issued withdrawal of $98.00 at: 29/01/2024 17:06:04 EST   Transaction Number : 11

      Withdrawal Agent WT0 issued withdrawal of $81.00 at: 29/01/2024 17:06:04 EST   Transaction Number : 14

      Withdrawal Agent WT4 issued withdrawal of $94.00 at: 29/01/2024 17:06:04 EST   Transaction Number : 16

      Withdrawal Agent WT4 issued withdrawal of $87.00 at: 29/01/2024 17:06:04 EST   Transaction Number : 17

      Withdrawal Agent WT3 issued withdrawal of $94.00 at: 29/01/2024 17:06:04 EST   Transaction Number : 26

      Withdrawal Agent WT2 issued withdrawal of $83.00 at: 29/01/2024 17:06:04 EST   Transaction Number : 27

      Withdrawal Agent WT4 issued withdrawal of $78.00 at: 29/01/2024 17:06:05 EST   Transaction Number : 40

      Withdrawal Agent WT4 issued withdrawal of $85.00 at: 29/01/2024 17:06:06 EST   Transaction Number : 46

      Withdrawal Agent WT4 issued withdrawal of $94.00 at: 29/01/2024 17:06:06 EST   Transaction Number : 48

      Withdrawal Agent WT0 issued withdrawal of $75.00 at: 29/01/2024 17:06:06 EST   Transaction Number : 73

      Withdrawal Agent WT6 issued withdrawal of $92.00 at: 29/01/2024 17:06:06 EST   Transaction Number : 76

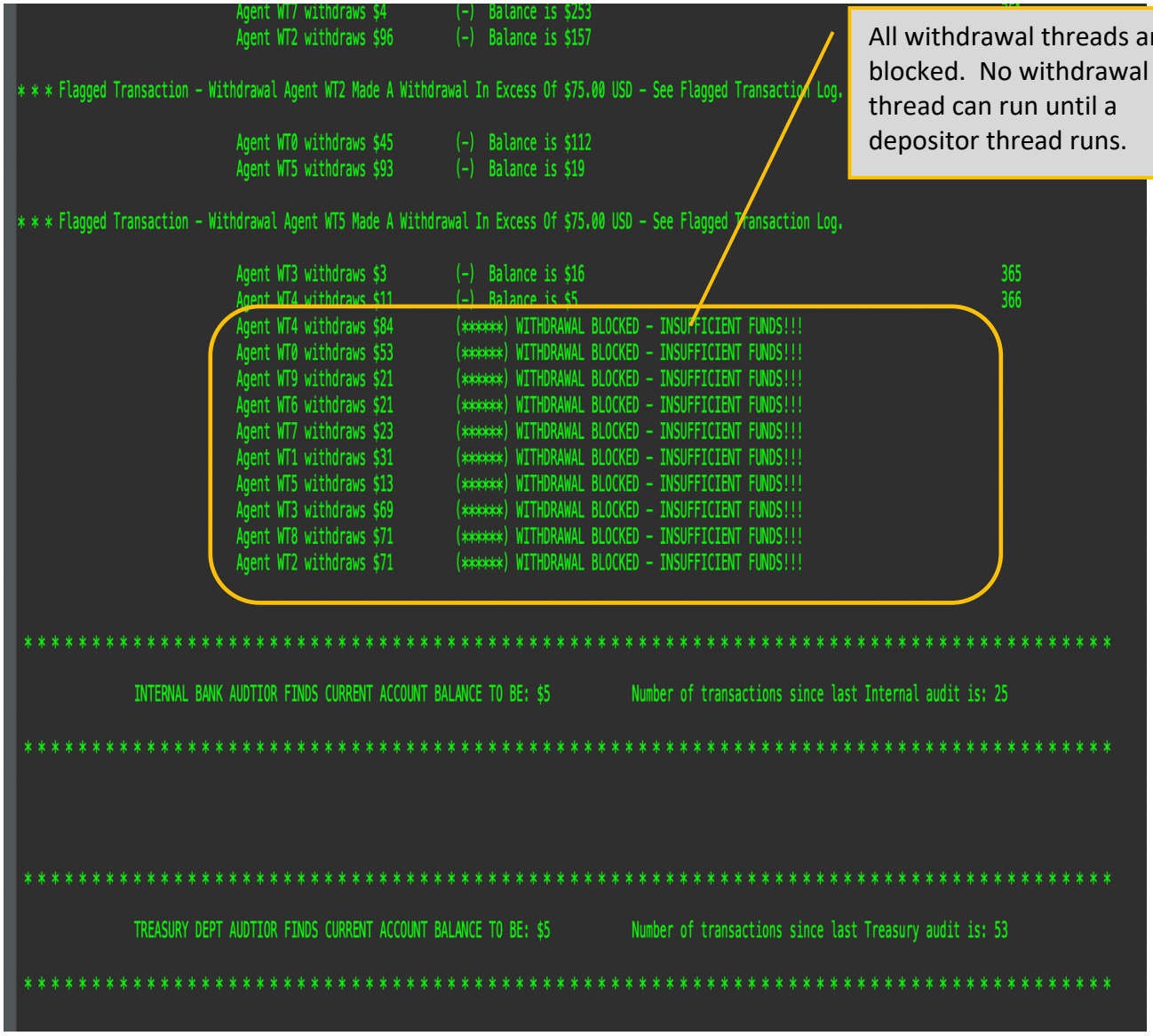
Depositor Agent DT4 issued deposit of $389.00 at: 29/01/2024 17:06:07 EST   Transaction Number : 82

Depositor Agent DT3 issued deposit of $357.00 at: 29/01/2024 17:06:07 EST   Transaction Number : 83

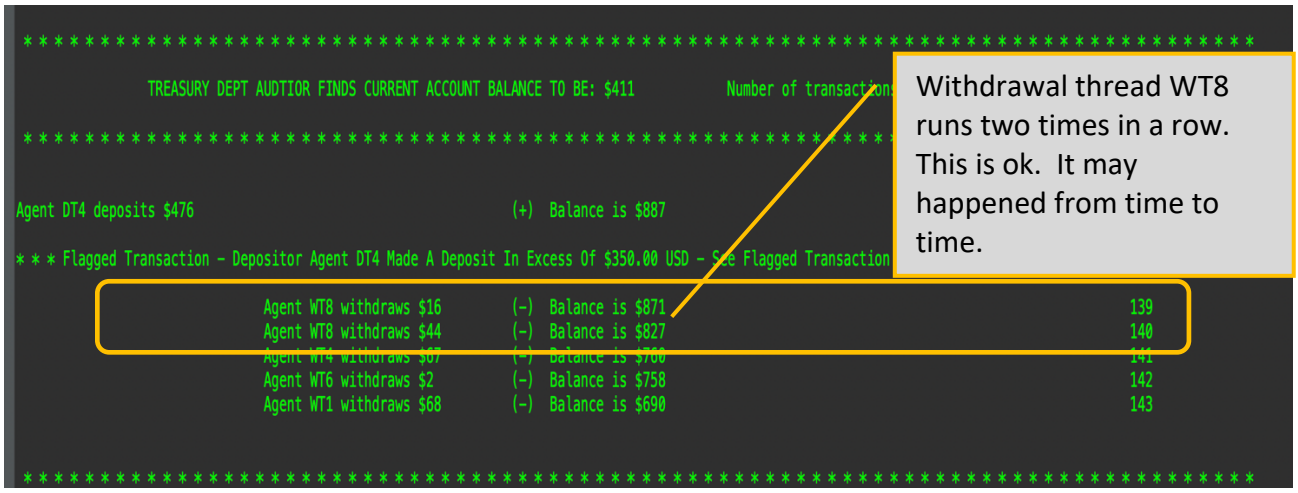
      Withdrawal Agent WT7 issued withdrawal of $82.00 at: 29/01/2024 17:06:07 EST   Transaction Number : 84

      Withdrawal Agent WT8 issued withdrawal of $95.00 at: 29/01/2024 17:06:07 EST   Transaction Number : 88
```

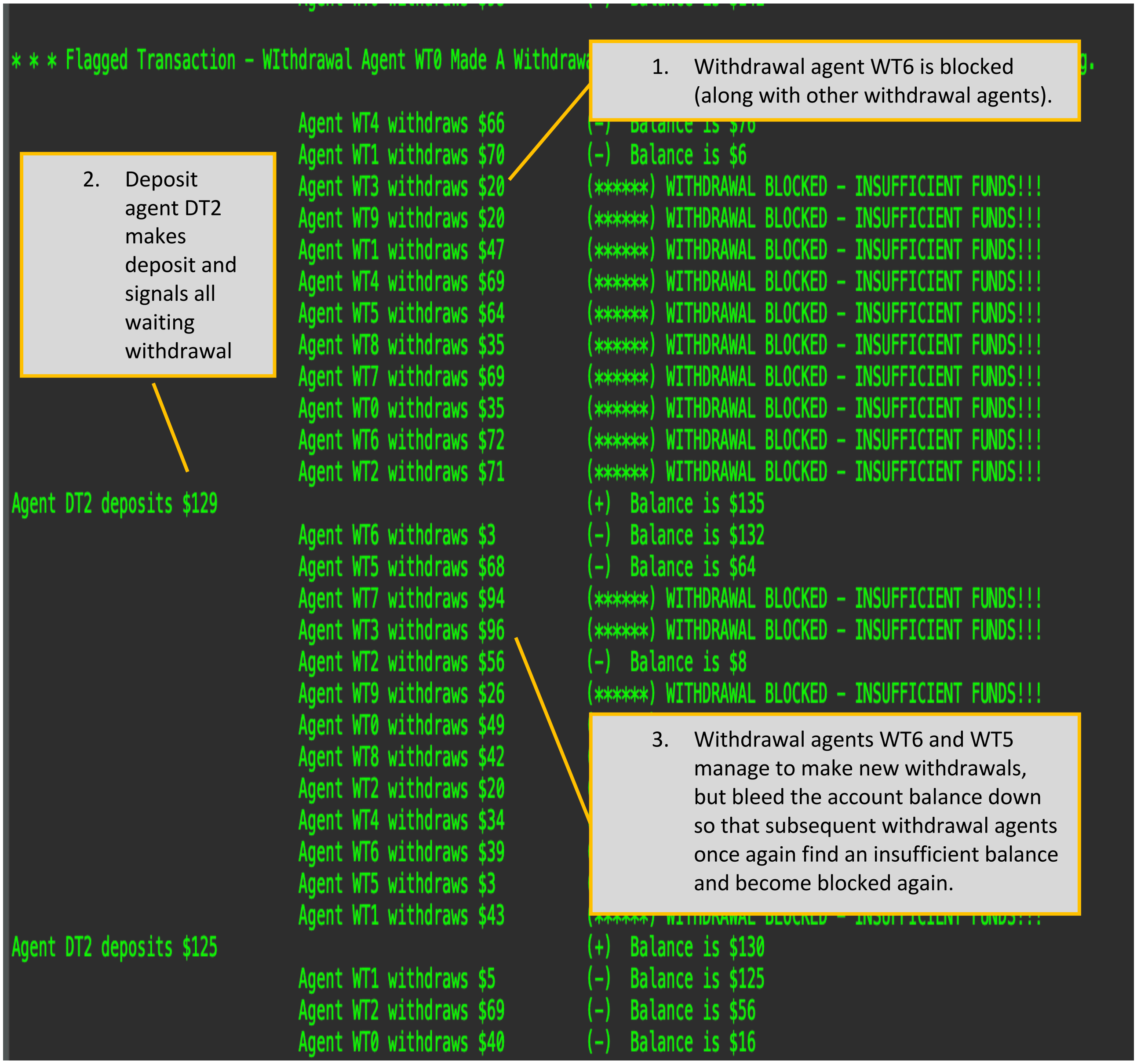
Some additional things to watch for:



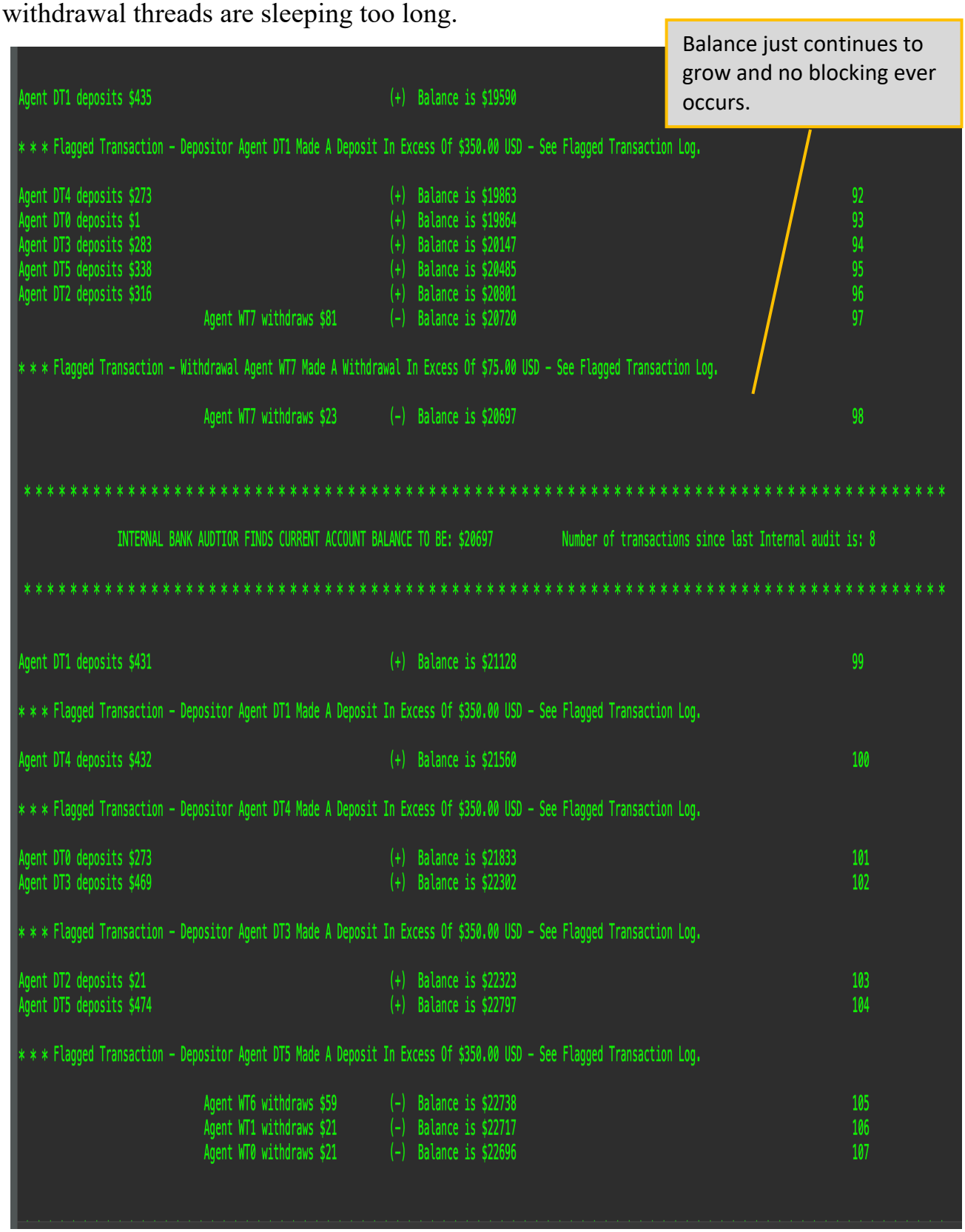
All withdrawal threads are blocked. No withdrawal thread can run until a depositor thread runs.



Withdrawal thread WT8 runs two times in a row. This is ok. It may happened from time to time.


* * * Flagged Transaction - WIthdrawal Agent WT0 Made A Withdrawa
1. Withdrawal agent WT6 is blocked (along with other withdrawal agents).
2. Deposit agent DT2 makes deposit and signals all waiting withdrawal
Agent WT4 withdraws $66
Agent WT1 withdraws $70 (-) Balance is $6
Agent WT3 withdraws $20 (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
Agent WT9 withdraws $20 (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
Agent WT1 withdraws $47 (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
Agent WT4 withdraws $69 (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
Agent WT5 withdraws $64 (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
Agent WT8 withdraws $35 (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
Agent WT7 withdraws $69 (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
Agent WT0 withdraws $35 (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
Agent WT6 withdraws $72 (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
Agent WT2 withdraws $71 (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
Agent DT2 deposits $129 (+) Balance is $135
Agent WT6 withdraws $3 (-) Balance is $132
Agent WT5 withdraws $68 (-) Balance is $64
Agent WT7 withdraws $94 (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
Agent WT3 withdraws $96 (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
Agent WT2 withdraws $56 (-) Balance is $8
Agent WT9 withdraws $26 (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
Agent WT0 withdraws $49
Agent WT8 withdraws $42
Agent WT2 withdraws $20
Agent WT4 withdraws $34
Agent WT6 withdraws $39
Agent WT5 withdraws $3
Agent WT1 withdraws $43
3. Withdrawal agents WT6 and WT5 manage to make new withdrawals, but bleed the account balance down so that subsequent withdrawal agents once again find an insufficient balance and become blocked again.
Agent DT2 deposits $125 (+) Balance is $130
Agent WT1 withdraws $5 (-) Balance is $125
Agent WT2 withdraws $69 (-) Balance is $56
Agent WT0 withdraws $40 (-) Balance is $16

We don't want to see this sort of scenario where the depositors are monopolizing the account. Indication is the depositor threads aren't sleeping long enough or the withdrawal threads are sleeping too long.



The Internal Bank auditor agent and the Treasury Dept auditor agents are not related and execute on different random intervals. They will typically see different account balances and a differing number of transaction executions between runs. This is shown below in two different scenarios.

```
                        Agent WT8 withdraws $99        (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT9 withdraws $47        (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT1 withdraws $66        (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT4 withdraws $24        (-)  Balance is $2                                          43
                        Agent WT4 withdraws $77        (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT7 withdraws $18        (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT0 withdraws $14        (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!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            INTERNAL BANK AUDTIOR FINDS CURRENT ACCOUNT BALANCE TO BE: $2          Number of transactions since last Internal audit is: 43

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Agent DT5 deposits $108                            (+)  Balance is $110                                        44


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            TREASURY DEPT AUDTIOR FINDS CURRENT ACCOUNT BALANCE TO BE: $110         Number of transactions since last Treasury audit is: 44

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Agent DT2 deposits $463                            (+)  Balance is $573                                        45
```

```
                        Agent WT9 withdraws $19        (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT6 withdraws $22        (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT3 withdraws $3         (-)  Balance is $12                                         257
                        Agent WT5 withdraws $76        (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT3 withdraws $56        (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!
                        Agent WT0 withdraws $68        (******) WITHDRAWAL BLOCKED - INSUFFICIENT FUNDS!!!


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            INTERNAL BANK AUDTIOR FINDS CURRENT ACCOUNT BALANCE TO BE: $12          Number of transactions since last Internal audit is: 11

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Agent DT0 deposits $241                            (+)  Balance is $253                                        258
Agent DT1 deposits $253                            (+)  Balance is $506                                        259
Agent DT4 deposits $292                            (+)  Balance is $798                                        260


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            TREASURY DEPT AUDTIOR FINDS CURRENT ACCOUNT BALANCE TO BE: $798          Number of transactions since last Treasury audit is: 67

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The auditor agents block any/all other agents from executing while an audit cycle is underway. You should never see any other agent running while an auditor agent is running.