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Lock-Free Linked List using Compare & Swap

Final Project

Distributed Algorithms and Systems

Larry Bush

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Write-up:

Attachments:

Instructions:

Compiling and Running (From Visual C++) :

This program workspace is set up to compile in Visual C++ in Multi-threaded Debug mode.
It is also set up to process the Test Sequence (see below).

The program is set up to redirect output to the file "output.h".

This can be changed to another file name or to the screen through Visual C++ by opening the Project-Settings menu, clicking on the Debug tab, and putting the arguments into the "Program Arguments" box.

If you output the test to the screen, it will not be very useful because the output is about 1,250 lines (unless you read very quickly).

Program File Description

File Purpose
---- -------

main.cpp This file contains the main function.
The main function creates a list test object and
runs the multithreaded test and integrity test.

test.h: Header file for the test class.
It declares the interface for the test class.

test.cpp Spawns threads and tests the list.

Implementation of test member functions.
This class performs a test on the Lock-Free linked list.
The test involves many threads.
Each thread initially inserts many nodes into the list.
Then, each thread iterates to the 25th node in the list and begins
inserting and deleting a bunch of nodes. It does this many times.
The objective is to create contention by having all of the threads
inserting and deleting in the same area.

The following are some of the Important Member Functions and
Member Data of the test class:

This class conatains 2 CriticalSection objects for syncronizing the
screen ouput and avoiding race conditions on the thread number member variable.

ThreadFunc()
multithreaded_test()
integrityTest()
TestFuctionF()

lockfreelist.h Declares and implements a Generic Lock-Free Linked List class.

This file contains three classes:

1. LockFreeList<ListType>
Implements a singly generic Lock-Free linked list.
It also conatins the list_node and iterator sub-structures.

The LockFreeList class stores objects in a linked list.

The Storage sturcture heirarchy of an object of type ListType looks like this:

LockFreeList(basenode) -> list_node(data) -> ListType

A LockFreeList object contains a pointer(basenode) to a list of nodes,
that are linked together. Each node contains a pointer (data) that
points to an object.

This class allows concurrent insertions and deletions into the list.

The inserting function does not need to provide mutual exclustion. The calling functions can insert, delete and traverse without being concerned with synchronization. The implementation is "Lock-Free."

Important functions:

begin()
erase()
delete_node()
insert()
update_iterator()

2. LockFreeList<ListType>::iterator

Implements a linked list iterator for LockFreeList.
(This is a sub-class of LockFreeList.)

Important functions:

update_iterator()
test_iterator()

Overloaded Operators:

++ prefix
++ postfix
=
==
!=
->
*

3. LockFreeList<ListType>::list_node

Implements a linked list node for LockFreeList
(This is a sub-class of LockFreeList.)

Important functions:

is_valid()
is_aux_cell()
is_normal_cell()
is_basenode()
is_lastnode()
is_not_basenode()
is_not_lastnode()
set_is_basenode()
set_is_lastnode()
compare_and_swap_next()

This class contains the CriticalSection object "m_sync_compare_and_swap" for making the compare and swap function atomic.

lock.h	This file declares the Lock class interface. It contains a CriticalSection pointer member variable. It also contains a constructor, destructor, and an unLock function.
lock.cpp	This file implements the Lock class member functions. It contains a CriticalSection pointer member variable. It also contains a constructor, destructor, and an unLock function. This class works with the CriticalSection class that I also created. The Lock constructor sets its internal pointer to a CriticalSection object that is passed in. Then it enters the critical section. The destructor uses the internal pointer to leave the critical section. Therefore, to use this lock, we must pass it a CriticalSection object upon instantiation. The lock can be directly unlocked using the unLock member function. However, the lock is unlocked automatically when it goes out of scope.
criticalsection.h	This file declares the critical section class interface. It contains a windows CRITICAL_SECTION object. It declares the constructor, destructor, enter and leave member functions.
criticalsection.cpp	This file implements the critical section class. This class makes it easier to instantiate, enter, and leave a Win32 critical section. When a CriticalSection object is created, it automatically creates a real Win32 critical section. Basically, the purpose of this class to make the calls object oriented rather than function oriented. It also makes them look nicer. The real benefit is when this object is used in conjunction with the lock object.

Program Test Sequence

This section explains the program test sequence and the sample output included in the accompanying attachment (Attachment 3).

Please refer to Attachment 5, files test.cpp and test.h for the complete test sequence code.

Note: This explaintion was also incorporated into the project write-up.

The test sequence described below is approximately the 10th significant iteration of the test sequence. I kept rewriting more robust versions that would test the ADT more exhaustively and create a lot of contention.

To test this ADT I created a separate class that runs a program test sequence. The test sequence was written to be exhaustive (many inserts, deletes and traversals) and to create a lot of contention. The test program runs 40 concurrent threads. Each thread makes about 1,000 insertions and 400 deletions for a total of about 40,000 insertions and about 16,000 deletions. The function "TestFunctionG" (in the attached file test.cpp) performs this thread specific testing sequence. The test sequence is as follows:

Each thread makes 500 insertions. It does this 10 nodes at a time, and then moves the iterator back to the beginning of the list.

Each thread then performs the following sequence 100 times.

1. Move the iterator to the begining of the list.
2. Iterate to the 25th cell (note iterating skips auxiliary cells).
3. Delete 2 nodes.
4. Iterate 2 nodes forward.
5. Insert 3 cells.
6. Move the iterator to the beginning of the list.
7. Iterate to the 25th real node.
8. Insert 3 nodes.
9. Iterate forward 2 nodes.
10. Delete 2 nodes.

Each of the 40 threads operate concurrently.
The general idea is that the deletions would cause the inserting iterators to "fall" back to its position. This would then make them perform operations on the same cell or on directly adjacent cells, creating contention.

The test program tracks various statistics to verify the results.

The contention created by the numerous insertions and deletions causes some of the insertions and deletions to fail. This is the intended behavior of the ADT.

When an insertion or deletion fails, it returns the value of false. When an insertion or deletion is successful, it returns the value of true.

Each thread keeps track of how many insertions and deletions it makes. It also keeps track of how many of these fail. Each thread then calculates a net number of additions to the list (i.e. successful insertions – successful deletions). Each thread then adds these figures to the (net) total number added to the test data structure (using a synchronization object to prevent race conditions on the value). That number is shown in the **Sample Output** as the "Sum of threads net additions to the list."

The number of successful and un-succesful insertions and deletions for each individual thread is also shown in the **"Sample Output" Attachment 3**. One interesting point that the data reveals is that the thread that finishes first typically has fewer failed insertions and deletions than the other threads. This is because it had more time in the insertion area by itself (or without as many other concurrently operating threads). In other words, it experiences less contention. The same is true for the threads that finish last. Note that the threads are run in order (1 – 40) but they do not necessarily finish in that order. This really depends on how much CPU time each thread is given.

The list data structure also tracks these additions and deletions. A synchronization object also protects the changes to this value. That number is shown below as the "List internal add/delete counter: ListSize."

After all of the threads have quit, the program runs an integrity test on the list. This is run in non-concurrent mode. It adds up all the normal and auxiliary nodes in the list and reports the figures ("List internal add/delete counter: ListSize" and "total_aux_cells").

You can see from the data below that all 3 measurements indicate the same number of normal cells in the list. This shows that the list functions are correctly executing the insertion and deletion requests. It also means that the ADT correctly reportes to the threads when these operations fail. In all the tests I performed, these numbers always matched.

You can see from the data in **Attachment 3** that there were numerous insertion failures. This is normally the case. It is a small percentage of the total attempts but with 40,000 inserts, the small percentage is a significant number (about 600 in total).

There are only 4 failed deletions in this run. There are usually 0 –5 for this particular test. The test attempts to create as much contention as possible by having 40 concurrent threads all inserting and deleting in the same area of the list (approximately from node 20 – 40). However, causing deletions to fail requires more contention than causing insertions to fail.

The data in the **Attachment 3** shows a list of the first 1,000 nodes in the final list. The data below also shows the total number of real nodes and auxiliary nodes. There is 1 more auxiliary node than normal cell in the final list. This is perfect because we need at least one more auxiliary node so that there is one before and after each cell.

The algorithm does not guarantee that there will be just 1 more auxiliary node than real nodes. However, this is usually the case. Sometimes there are a few more than needed. The algorithm attempts to remove them all, but depending on the type and amount of contention, it can leave some extras. They will be cleaned up later, but at any given moment, there may be some extra auxiliary nodes in the list. This is consistent with the intended operation of the ADT.

Attachment 3 includes a report on the contents and type of the first 1,000 cells so that you can see that this is so. The list also contains 1 basenode and 1 lastnode (the last node is not shown in the report).

Sample Output

The output on the following pages is explained in **Attachment 2 “Program Test Sequence**”

The Output includes the following:

Summary of List Activity

Individual Thread Activity

Integrity Test:

Summary of values:
Individual Node Detail (first 1,000 Nodes)

Summary of List Activity

Report from the treads:
Sum of threads net additions to the list : = 25485

Integrity test of list :
Integrity test : total_normal_cells = 25485
List internal add/delete counter: ListSize = 25485
total_aux_cells = 25486

Individual Thread Activity

(These are listed in the order that they finished.)

Thread 1:
total inserts = 1044:
total deletes = 400:
failed inserts = 6:
failed deletes = 0
I made a net of 644 additions to the list.

Thread 5:
total inserts = 1035:
total deletes = 400:
failed inserts = 15:
failed deletes = 0
I made a net of 635 additions to the list.

Thread 7:
total inserts = 1035:
total deletes = 400:
failed inserts = 15:
failed deletes = 0
I made a net of 635 additions to the list.

Thread 10:
total inserts = 1027:
total deletes = 400:
failed inserts = 23:
failed deletes = 0
I made a net of 627 additions to the list.

Thread 3:
total inserts = 1033:
total deletes = 400:
failed inserts = 17:
failed deletes = 0
I made a net of 633 additions to the list.

Thread 9:
total inserts = 1036:
total deletes = 400:
failed inserts = 14:
failed deletes = 0
I made a net of 636 additions to the list.

Thread 6:
total inserts = 1032:
total deletes = 400:
failed inserts = 18:
failed deletes = 0
I made a net of 632 additions to the list.

Thread 11:
total inserts = 1037:
total deletes = 400:
failed inserts = 13:
failed deletes = 0
I made a net of 637 additions to the list.

Thread 2:
total inserts = 1028:
total deletes = 399:
failed inserts = 22:
failed deletes = 1
I made a net of 629 additions to the list.

Thread 12:
total inserts = 1033:
total deletes = 399:
failed inserts = 17:
failed deletes = 1
I made a net of 634 additions to the list.

Thread 4:
total inserts = 1031:
total deletes = 400:
failed inserts = 19:
failed deletes = 0
I made a net of 631 additions to the list.

Thread 8:
total inserts = 1028:
total deletes = 400:
failed inserts = 22:
failed deletes = 0
I made a net of 628 additions to the list.

Thread 14:
total inserts = 1035:
total deletes = 400:
failed inserts = 15:
failed deletes = 0
I made a net of 635 additions to the list.

Thread 15:
total inserts = 1038:
total deletes = 400:
failed inserts = 12:
failed deletes = 0
I made a net of 638 additions to the list.

Thread 16:
total inserts = 1038:
total deletes = 400:
failed inserts = 12:
failed deletes = 0
I made a net of 638 additions to the list.

Thread 13:
total inserts = 1033:
total deletes = 400:
failed inserts = 17:
failed deletes = 0
I made a net of 633 additions to the list.

Thread 17:
total inserts = 1046:
total deletes = 400:
failed inserts = 4:
failed deletes = 0
I made a net of 646 additions to the list.

Thread 23:
total inserts = 1045:
total deletes = 400:
failed inserts = 5:
failed deletes = 0
I made a net of 645 additions to the list.

Thread 37:
total inserts = 1040:
total deletes = 400:
failed inserts = 10:
failed deletes = 0
I made a net of 640 additions to the list.

Thread 27:
total inserts = 1044:
total deletes = 400:
failed inserts = 6:
failed deletes = 0
I made a net of 644 additions to the list.

Thread 19:
total inserts = 1045:
total deletes = 400:
failed inserts = 5:
failed deletes = 0
I made a net of 645 additions to the list.

Thread 32:
total inserts = 1043:
total deletes = 400:
failed inserts = 7:
failed deletes = 0
I made a net of 643 additions to the list.

Thread 26:
total inserts = 1042:
total deletes = 400:
failed inserts = 8:
failed deletes = 0
I made a net of 642 additions to the list.

Thread 34:
total inserts = 1038:
total deletes = 400:
failed inserts = 12:
failed deletes = 0
I made a net of 638 additions to the list.

Thread 36:
total inserts = 1035:
total deletes = 399:
failed inserts = 15:
failed deletes = 1
I made a net of 636 additions to the list.

Thread 30:
total inserts = 1038:
total deletes = 399:
failed inserts = 12:
failed deletes = 1
I made a net of 639 additions to the list.

Thread 25:
total inserts = 1039:
total deletes = 399:
failed inserts = 11:
failed deletes = 1
I made a net of 640 additions to the list.

Thread 20:
total inserts = 1039:
total deletes = 399:
failed inserts = 11:
failed deletes = 1
I made a net of 640 additions to the list.

Thread 29:
total inserts = 1033:
total deletes = 400:
failed inserts = 17:
failed deletes = 0
I made a net of 633 additions to the list.

Thread 28:
total inserts = 1038:
total deletes = 400:
failed inserts = 12:
failed deletes = 0
I made a net of 638 additions to the list.

Thread 21:
total inserts = 1036:
total deletes = 400:
failed inserts = 14:
failed deletes = 0
I made a net of 636 additions to the list.

Thread 31:
total inserts = 1038:
total deletes = 400:
failed inserts = 12:
failed deletes = 0
I made a net of 638 additions to the list.

Thread 38:
total inserts = 1038:
total deletes = 400:
failed inserts = 12:
failed deletes = 0
I made a net of 638 additions to the list.

Thread 33:
total inserts = 1033:
total deletes = 400:
failed inserts = 17:
failed deletes = 0
I made a net of 633 additions to the list.

Thread 18:
total inserts = 1044:
total deletes = 400:
failed inserts = 6:
failed deletes = 0
I made a net of 644 additions to the list.

Thread 39:
total inserts = 1036:
total deletes = 400:
failed inserts = 14:
failed deletes = 0
I made a net of 636 additions to the list.

Thread 22:
total inserts = 1038:
total deletes = 400:
failed inserts = 12:
failed deletes = 0
I made a net of 638 additions to the list.

Thread 24:
total inserts = 1035:
total deletes = 400:
failed inserts = 15:
failed deletes = 0
I made a net of 635 additions to the list.

Thread 35:
total inserts = 1036:
total deletes = 400:
failed inserts = 14:
failed deletes = 0
I made a net of 636 additions to the list.

Thread 40:
  total inserts = 1037:
  total deletes = 400:
  failed inserts = 13:
  failed deletes = 0
I made a net of 637 additions to the list.

Integrity Test : Summary of values:

There are 691 nodes with the value 1.
There are 632 nodes with the value 2.
There are 654 nodes with the value 3.
There are 659 nodes with the value 4.
There are 664 nodes with the value 5.
There are 643 nodes with the value 6.
There are 665 nodes with the value 7.
There are 619 nodes with the value 8.
There are 685 nodes with the value 9.
There are 647 nodes with the value 10.
There are 616 nodes with the value 11.
There are 605 nodes with the value 12.
There are 634 nodes with the value 13.
There are 586 nodes with the value 14.
There are 593 nodes with the value 15.
There are 587 nodes with the value 16.
There are 635 nodes with the value 17.
There are 686 nodes with the value 18.
There are 665 nodes with the value 19.
There are 633 nodes with the value 20.
There are 615 nodes with the value 21.
There are 642 nodes with the value 22.
There are 672 nodes with the value 23.
There are 634 nodes with the value 24.
There are 637 nodes with the value 25.
There are 640 nodes with the value 26.
There are 674 nodes with the value 27.
There are 635 nodes with the value 28.
There are 598 nodes with the value 29.
There are 636 nodes with the value 30.
There are 643 nodes with the value 31.
There are 655 nodes with the value 32.
There are 604 nodes with the value 33.
There are 632 nodes with the value 34.
There are 629 nodes with the value 35.
There are 638 nodes with the value 36.
There are 626 nodes with the value 37.
There are 629 nodes with the value 38.
There are 614 nodes with the value 39.
There are 633 nodes with the value 40.

Integrity Test:

Individual Node Detail (first 1,000 Nodes)

node 0 is the basenode.
node 1 is an auxiliary cell.
node 2 is a normal cell and its value is 21
node 3 is an auxiliary cell.
node 4 is a normal cell and its value is 21
node 5 is an auxiliary cell.
node 6 is a normal cell and its value is 21
node 7 is an auxiliary cell.
node 8 is a normal cell and its value is 21
node 9 is an auxiliary cell.
node 10 is a normal cell and its value is 21
node 11 is an auxiliary cell.
node 12 is a normal cell and its value is 21
node 13 is an auxiliary cell.
node 14 is a normal cell and its value is 21
node 15 is an auxiliary cell.
node 16 is a normal cell and its value is 21
node 17 is an auxiliary cell.
node 18 is a normal cell and its value is 21
node 19 is an auxiliary cell.
node 20 is a normal cell and its value is 21
node 21 is an auxiliary cell.
node 22 is a normal cell and its value is 21
node 23 is an auxiliary cell.
node 24 is a normal cell and its value is 21
node 25 is an auxiliary cell.
node 26 is a normal cell and its value is 21
node 27 is an auxiliary cell.
node 28 is a normal cell and its value is 21
node 29 is an auxiliary cell.
node 30 is a normal cell and its value is 21
node 31 is an auxiliary cell.
node 32 is a normal cell and its value is 21
node 33 is an auxiliary cell.
node 34 is a normal cell and its value is 21
node 35 is an auxiliary cell.
node 36 is a normal cell and its value is 21
node 37 is an auxiliary cell.
node 38 is a normal cell and its value is 21
node 39 is an auxiliary cell.
node 40 is a normal cell and its value is 21
node 41 is an auxiliary cell.
node 42 is a normal cell and its value is 21
node 43 is an auxiliary cell.
node 44 is a normal cell and its value is 21
node 45 is an auxiliary cell.
node 46 is a normal cell and its value is 21
node 47 is an auxiliary cell.
node 48 is a normal cell and its value is 21
node 49 is an auxiliary cell.
node 50 is a normal cell and its value is 21
node 51 is an auxiliary cell.

node 52 is a normal cell and its value is 40
node 53 is an auxiliary cell.
node 54 is a normal cell and its value is 40
node 55 is an auxiliary cell.
node 56 is a normal cell and its value is 40
node 57 is an auxiliary cell.
node 58 is a normal cell and its value is 40
node 59 is an auxiliary cell.
node 60 is a normal cell and its value is 40
node 61 is an auxiliary cell.
node 62 is a normal cell and its value is 40
node 63 is an auxiliary cell.
node 64 is a normal cell and its value is 40
node 65 is an auxiliary cell.
node 66 is a normal cell and its value is 40
node 67 is an auxiliary cell.
node 68 is a normal cell and its value is 40
node 69 is an auxiliary cell.
node 70 is a normal cell and its value is 40
node 71 is an auxiliary cell.
node 72 is a normal cell and its value is 40
node 73 is an auxiliary cell.
node 74 is a normal cell and its value is 40
node 75 is an auxiliary cell.
node 76 is a normal cell and its value is 40
node 77 is an auxiliary cell.
node 78 is a normal cell and its value is 40
node 79 is an auxiliary cell.
node 80 is a normal cell and its value is 40
node 81 is an auxiliary cell.
node 82 is a normal cell and its value is 40
node 83 is an auxiliary cell.
node 84 is a normal cell and its value is 40
node 85 is an auxiliary cell.
node 86 is a normal cell and its value is 40
node 87 is an auxiliary cell.
node 88 is a normal cell and its value is 40
node 89 is an auxiliary cell.
node 90 is a normal cell and its value is 40
node 91 is an auxiliary cell.
node 92 is a normal cell and its value is 40
node 93 is an auxiliary cell.
node 94 is a normal cell and its value is 40
node 95 is an auxiliary cell.
node 96 is a normal cell and its value is 40
node 97 is an auxiliary cell.
node 98 is a normal cell and its value is 40
node 99 is an auxiliary cell.
node 100 is a normal cell and its value is 40
node 101 is an auxiliary cell.
node 102 is a normal cell and its value is 40
node 103 is an auxiliary cell.
node 104 is a normal cell and its value is 40
node 105 is an auxiliary cell.
node 106 is a normal cell and its value is 40
node 107 is an auxiliary cell.

node 108 is a normal cell and its value is 40
node 109 is an auxiliary cell.
node 110 is a normal cell and its value is 40
node 111 is an auxiliary cell.
node 112 is a normal cell and its value is 40
node 113 is an auxiliary cell.
node 114 is a normal cell and its value is 40
node 115 is an auxiliary cell.
node 116 is a normal cell and its value is 40
node 117 is an auxiliary cell.
node 118 is a normal cell and its value is 40
node 119 is an auxiliary cell.
node 120 is a normal cell and its value is 40
node 121 is an auxiliary cell.
node 122 is a normal cell and its value is 40
node 123 is an auxiliary cell.
node 124 is a normal cell and its value is 40
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node 151 is an auxiliary cell.
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node 165 is an auxiliary cell.
node 166 is a normal cell and its value is 40
node 167 is an auxiliary cell.
node 168 is a normal cell and its value is 40
node 169 is an auxiliary cell.
node 170 is a normal cell and its value is 35
node 171 is an auxiliary cell.
node 172 is a normal cell and its value is 35
node 173 is an auxiliary cell.
node 174 is a normal cell and its value is 35
node 175 is an auxiliary cell.
node 176 is a normal cell and its value is 35
node 177 is an auxiliary cell.
node 178 is a normal cell and its value is 40
node 179 is an auxiliary cell.
node 180 is a normal cell and its value is 40
node 181 is an auxiliary cell.
node 182 is a normal cell and its value is 40
node 183 is an auxiliary cell.
node 184 is a normal cell and its value is 40
node 185 is an auxiliary cell.
node 186 is a normal cell and its value is 40
node 187 is an auxiliary cell.
node 188 is a normal cell and its value is 40
node 189 is an auxiliary cell.
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node 191 is an auxiliary cell.
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node 195 is an auxiliary cell.
node 196 is a normal cell and its value is 40
node 197 is an auxiliary cell.
node 198 is a normal cell and its value is 40
node 199 is an auxiliary cell.
node 200 is a normal cell and its value is 40
node 201 is an auxiliary cell.
node 202 is a normal cell and its value is 35
node 203 is an auxiliary cell.
node 204 is a normal cell and its value is 35
node 205 is an auxiliary cell.
node 206 is a normal cell and its value is 35
node 207 is an auxiliary cell.
node 208 is a normal cell and its value is 35
node 209 is an auxiliary cell.
node 210 is a normal cell and its value is 35
node 211 is an auxiliary cell.
node 212 is a normal cell and its value is 35
node 213 is an auxiliary cell.
node 214 is a normal cell and its value is 35
node 215 is an auxiliary cell.
node 216 is a normal cell and its value is 35
node 217 is an auxiliary cell.
node 218 is a normal cell and its value is 35
node 219 is an auxiliary cell.

node 220 is a normal cell and its value is 35
node 221 is an auxiliary cell.
node 222 is a normal cell and its value is 35
node 223 is an auxiliary cell.
node 224 is a normal cell and its value is 35
node 225 is an auxiliary cell.
node 226 is a normal cell and its value is 35
node 227 is an auxiliary cell.
node 228 is a normal cell and its value is 40
node 229 is an auxiliary cell.
node 230 is a normal cell and its value is 40
node 231 is an auxiliary cell.
node 232 is a normal cell and its value is 40
node 233 is an auxiliary cell.
node 234 is a normal cell and its value is 40
node 235 is an auxiliary cell.
node 236 is a normal cell and its value is 40
node 237 is an auxiliary cell.
node 238 is a normal cell and its value is 40
node 239 is an auxiliary cell.
node 240 is a normal cell and its value is 40
node 241 is an auxiliary cell.
node 242 is a normal cell and its value is 40
node 243 is an auxiliary cell.
node 244 is a normal cell and its value is 40
node 245 is an auxiliary cell.
node 246 is a normal cell and its value is 40
node 247 is an auxiliary cell.
node 248 is a normal cell and its value is 40
node 249 is an auxiliary cell.
node 250 is a normal cell and its value is 40
node 251 is an auxiliary cell.
node 252 is a normal cell and its value is 40
node 253 is an auxiliary cell.
node 254 is a normal cell and its value is 40
node 255 is an auxiliary cell.
node 256 is a normal cell and its value is 40
node 257 is an auxiliary cell.
node 258 is a normal cell and its value is 40
node 259 is an auxiliary cell.
node 260 is a normal cell and its value is 40
node 261 is an auxiliary cell.
node 262 is a normal cell and its value is 40
node 263 is an auxiliary cell.
node 264 is a normal cell and its value is 35
node 265 is an auxiliary cell.
node 266 is a normal cell and its value is 35
node 267 is an auxiliary cell.
node 268 is a normal cell and its value is 35
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node 982 is a normal cell and its value is 31
node 983 is an auxiliary cell.
node 984 is a normal cell and its value is 31
node 985 is an auxiliary cell.
node 986 is a normal cell and its value is 31
node 987 is an auxiliary cell.
node 988 is a normal cell and its value is 31
node 989 is an auxiliary cell.
node 990 is a normal cell and its value is 38
node 991 is an auxiliary cell.
node 992 is a normal cell and its value is 38
node 993 is an auxiliary cell.
node 994 is a normal cell and its value is 38
node 995 is an auxiliary cell.
node 996 is a normal cell and its value is 38
node 997 is an auxiliary cell.
node 998 is a normal cell and its value is 38
node 999 is an auxiliary cell.
node 1000 is a normal cell and its value is 38
Press any key to continue