

Heap Damage, Get into the zone!



John Monti
IBM Poughkeepsie
jmonti@us.ibm.com



Trademarks

The following are trademarks of the International Business Machines Corporation in the United States and/or other countries.

Language Environment

z/OS

CICS

* Registered trademarks of IBM Corporation

The following are trademarks or registered trademarks of other companies.

Java and all Java-related trademarks and logos are trademarks of Sun Microsystems, Inc., in the United States and other countries.

Linux is a registered trademark of Linus Torvalds in the United States, other countries, or both.

Microsoft, Windows and Windows NT are registered trademarks of Microsoft Corporation.

UNIX is a registered trademark of The Open Group in the United States and other countries.

SET and Secure Electronic Transaction are trademarks owned by SET Secure Electronic Transaction LLC.

* All other products may be trademarks or registered trademarks of their respective companies.

Notes:

Performance is in Internal Throughput Rate (ITR) ratio based on measurements and projections using standard IBM benchmarks in a controlled environment. The actual throughput that any user will experience will vary depending upon considerations such as the amount of multiprogramming in the user's job stream, the I/O configuration, the storage configuration, and the workload processed. Therefore, no assurance can be given that an individual user will achieve throughput improvements equivalent to the performance ratios stated here.

IBM hardware products are manufactured from new parts, or new and serviceable used parts. Regardless, our warranty terms apply.

All customer examples cited or described in this presentation are presented as illustrations of the manner in which some customers have used IBM products and the results they may have achieved. Actual environmental costs and performance characteristics will vary depending on individual customer configurations and conditions.

This publication was produced in the United States. IBM may not offer the products, services or features discussed in this document in other countries, and the information may be subject to change without notice. Consult your local IBM business contact for information on the product or services available in your area.

All statements regarding IBM's future direction and intent are subject to change or withdrawal without notice, and represent goals and objectives only.

Information about non-IBM products is obtained from the manufacturers of those products or their published announcements. IBM has not tested those products and cannot confirm the performance, compatibility, or any other claims related to non-IBM products. Questions on the capabilities of non-IBM products should be addressed to the suppliers of those products.

Prices subject to change without notice. Contact your IBM representative or Business Partner for the most current pricing in your geography.



Agenda

- What do heaps look like?
- What kind of damage might you see?
- Who caused the damage?
- Getting closer to the zone!
- The HEAPZONE!
- Sources of Additional Information



What do heaps look like?

- Language Environment Storage Management
 - Heaps
 - Completely random access
 - Allows storage to be dynamically allocated at runtime
 - Enclave level control structures
 - Each 'main' has its own enclave and therefore heap
 - Each 'link' create a new enclave and therefore heap
 - pthreads share a single heap for all threads



What do heaps look like?

- Language Environment Storage Management
 - Heaps
 - Four independently maintained sets of heap segments all with similar layouts:
 - User Heap
 - COBOL WORKING-STORAGE
 - C/C++ (malloc() or operator new)
 - PL/I dynamic storage (allocate)
 - LE Anywhere Heap
 - COBOL and LE above the line CBs
 - LE Below Heap
 - COBOL and LE below the line CBs
 - Additional Heap
 - Defined by the user



What do heaps look like?

- Heap Layout
 - Based on algorithm from IBM's Watson Research Center
 - FAST 1ST!!!
 - Storage Efficiency 2nd
 - Error checks 3rd
 - Elements of user requested length
 - User responsible for requesting storage be freed.



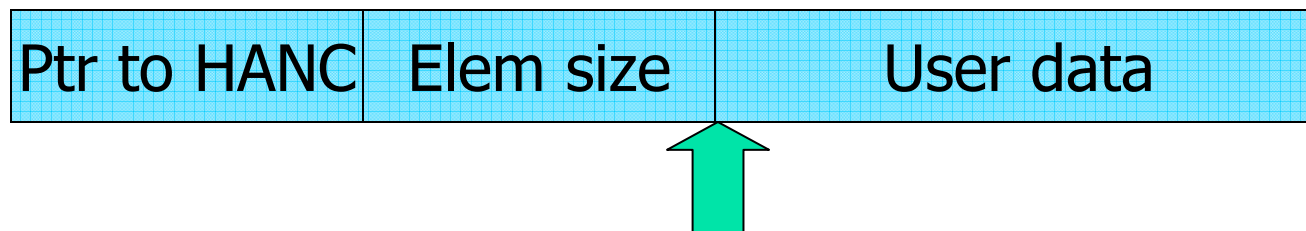
What do heaps look like?

- Heap Layout continued...
 - Header
 - x'20' byte header (8 fullwords of data)
 - Eyecatcher 'HANC'
 - Pointer to next Heap segment or HPCB
 - Pointer to previous Heap segment or HPCB
 - Heapid (user heap = 0)
 - Pointer to beginning of segment
 - Root address (largest free element in segment)
 - Heap Segment Length
 - Root element length (size of largest free element)



What do heaps look like?

- Heap Layout continued...
 - Allocated element
 - 8 byte header
 - Pointer to beginning of heap segment (HANC)
 - Size of element including header
 - User portion
 - Address returned to user





What do heaps look like?

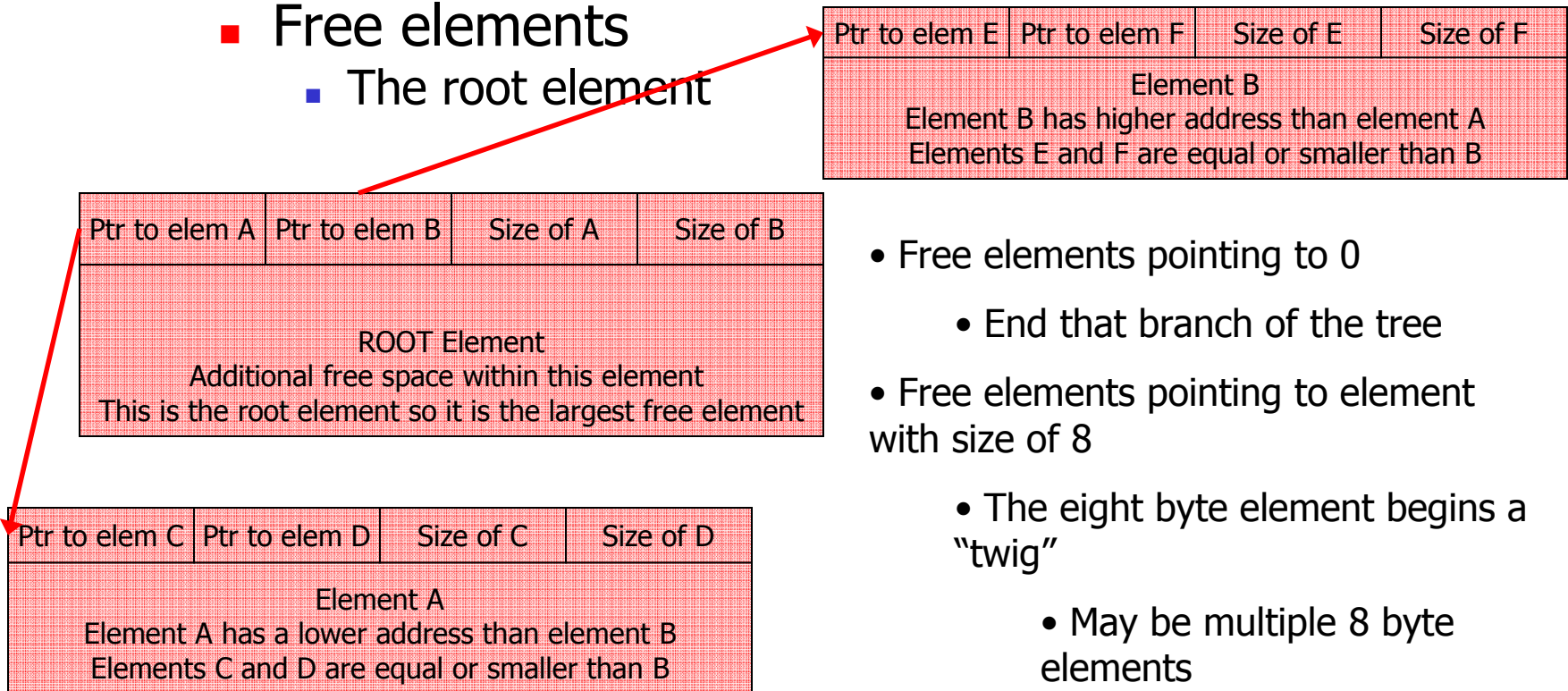
- Heap Layout continued...
 - Free elements
 - Maintained in a Cartesian Tree
 - Larger elements toward the root
 - Smaller elements toward the leaves
 - Lower addresses to the left
 - Higher addresses to the right
 - Each free area contains x'10' bytes of information about **OTHER** free elements.
 - Left node address
 - Right node address
 - Left node size
 - Right node size

What do heaps look like?

■ Heap Layout continued...

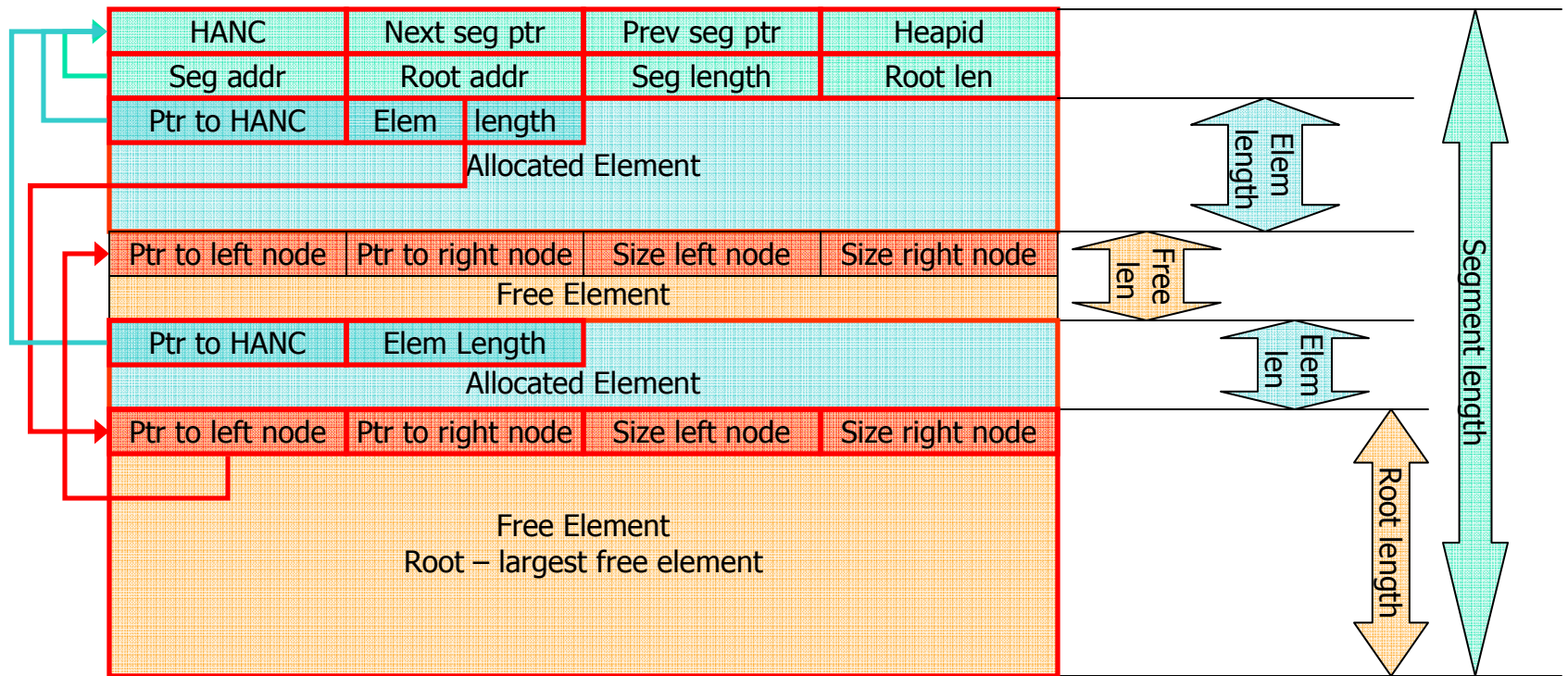
■ Free elements

■ The root element



- Free elements pointing to 0
 - End that branch of the tree
- Free elements pointing to element with size of 8
 - The eight byte element begins a "twig"
 - May be multiple 8 byte elements

- Heap Layout continued... A "simple" example





What do heaps look like?

- Processing

- Allocation

- The Free Element tree of the latest heap segment is searched starting at the root for the smallest element which will satisfy the request.
 - If no free element found in that segment earlier segments are searched.
 - If no free element is large enough to satisfy the request, an additional heap segment is allocated via GETMAIN.
 - The needed storage from the free element is then allocated (8 byte header filled out).
 - If additional storage is left over in the element it is added to the free tree as a new free element.
 - A pointer to the user storage (after the 8 byte header) is returned to the user.



What do heaps look like?

- Processing

- Free

- Size of element is determined from the 8 byte header.
 - Element (including header) is returned to the free tree
 - If free element is adjacent to an existing free element the elements are combined into a larger free element
 - The free tree will be restructured as necessary.
 - If the entire heap is now free the segment will be FREEMAINED if FREE is specified.



Let's cause some damage

■ Sample program to cause heap damage

```
000100  IDENTIFICATION DIVISION.  
000200  PROGRAM-ID. SHAREHP.  
000300  
000400  DATA DIVISION.  
000500  WORKING-STORAGE SECTION.  
000600      01 WS-EYE          PIC X(4) VALUE "WS-B".  
000700      01 HEAPID         PIC S9(9) BINARY VALUE 0.  
000800      01 STORAGE-SIZE-24 PIC S9(9) BINARY VALUE 24.  
000900      01 STORAGE-SIZE-16 PIC S9(9) BINARY VALUE 16.  
001000      01 STORAGE-SIZE-8  PIC S9(9) BINARY VALUE 8.  
001100      01 ADDRESS-0       POINTER.  
001200      01 ADDRESS-1     POINTER.  
001300      01 ADDRESS-2     POINTER.  
001400      01 WS-DATA.  
001500          03 WS-DATA1    PIC X(16) VALUE "1234567890123456".  
001600          03 WS-DATA2    PIC S9(9) BINARY VALUE 0.  
...  
003100  LINKAGE SECTION.  
003200      01 HEAP-DATA-AREA   PIC X(17).  
003300  PROCEDURE DIVISION.
```



Let's cause some damage

- Sample program to cause heap damage...

```
003400    MAIN-PROG.  
003500        DISPLAY "STARTING SHAREHP..."  
003600        CALL "CEEGTST" USING HEAPID, STORAGE-SIZE-16,  
003700                ADDRESS-0, FC.  
003900        CALL "CEEGTST" USING HEAPID, STORAGE-SIZE-16,  
004000                ADDRESS-1, FC.  
004200        CALL "CEEGTST" USING HEAPID, STORAGE-SIZE-16,  
004300                ADDRESS-2, FC.  
004400  
004500        CALL "CEEFRST" USING ADDRESS-1, FC.  
004600  
004700        SET ADDRESS OF HEAP-DATA-AREA TO ADDRESS-2.  
004800        MOVE WS-DATA TO HEAP-DATA-AREA.  
004900  
005000        CALL "CEEGTST" USING HEAPID, STORAGE-SIZE-8,  
005100                ADDRESS-1, FC.  
005200  
005300        CALL "CEEFRST" USING ADDRESS-0, FC.  
005400        CALL "CEEFRST" USING ADDRESS-1, FC.  
005500        CALL "CEEFRST" USING ADDRESS-2, FC.  
005600        GOBACK.
```



Let's cause some damage

- Output gives no clue to what happened

```
08.51.19 JOB25721 ---- WEDNESDAY, 16 FEB 2005 ----
08.51.20 JOB25721 $HASP373 JMONTIGO STARTED - WLM INIT - SRVCLASS WMLLONG - SYS AQFT
08.51.20 JOB25721 IEF403I JMONTIGO - STARTED - TIME=08.51.20
08.51.23 JOB25721 IEA995I SYMPTOM DUMP OUTPUT 345
345          USER COMPLETION CODE=4039 REASON CODE=00000000
345          TIME=08.51.21 SEQ=09748 CPU=0000 ASID=00BA
345          PSW AT TIME OF ERROR 078D1000 A01ECE96 ILC 2 INTC 0D
345          ACTIVE LOAD MODULE          ADDRESS=201256C0 OFFSET=000C77D6
345          NAME=CEEPLPKA
345          DATA AT PSW 201ECE90 - 00181610 0A0D58D0 D00498EC
345          AR/GR 0: 80AB5B3E/84000000 1: 00000000/84000FC7
345          2: 00000000/20381F88 3: 00000000/00000002
...
345          E: 00000000/A01E0DDE F: 00000000/00000000
345          END OF SYMPTOM DUMP
08.51.23 JOB25721 IEA993I SYSMDUMP TAKEN TO POSIX.JMONTI.SHARE.HEAP.SYSMDUMP
08.51.23 JOB25721 IEF450I JMONTIGO GO - ABEND=S000 U4038 REASON=00000001 347
347          TIME=08.51.23
```




Let's cause some damage

- Messages speak of damage but who?

STARTING SHAREHP...

CEE0802C Heap storage control information was damaged.

From compile unit SHAREHP at entry point SHAREHP at statement 896 at
compile unit offset +000005C2 at entry offset +000005C2 at address 201011B2.

- Messages can only:
 - Describe that there is damage
 - Tell where the program was when it first saw the damage
 - But CANNOT tell who was at fault!



Let's cause some damage

■ More information from CEEDUMP

CEE3DMP V1 R6.0: Condition processing resulted in the unhandled condition.

02/16/05 8:51:23 AM

Page: 1

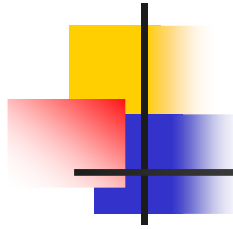
Information for enclave SHAREHP

Information for thread 8000000000000000

Traceback:

| DSA Addr | Program Unit | PU Addr | PU Offset | Entry | E Addr | E Offset | Statement | Load Mod | Service | Status |
|----------|--------------|----------|-----------|----------|----------|-----------|-----------|----------|---------|-----------|
| 20381648 | CEEHDSP | 201DD170 | +00003F58 | CEEHDSP | 201DD170 | +00003F58 | | CEEPLPKA | UQ91316 | Call |
| 203814B0 | CEEHSGLT | 201EF1B8 | +0000005C | CEEHSGLT | 201EF1B8 | +0000005C | | CEEPLPKA | HLE7709 | Exception |
| 20381398 | CEEV#GTS | 202BBFF8 | +00000698 | CEEV#GTS | 202BBFF8 | +00000698 | | CEEPLPKA | HLE7709 | Call |
| 203812E8 | CEEVGTST | 202CC720 | +00000072 | CEEVGTST | 202CC720 | +00000072 | | CEEPLPKA | HLE7709 | Call |
| 20381100 | IGZCFCC | 2034AB78 | +000002CA | IGZCFCC | 2034AB78 | +000002CA | | IGZCPAC | | Call |
| 20381030 | SHAREHP | 20100BF0 | +000005C2 | SHAREHP | 20100BF0 | +000005C2 | 896 | SHAREHP | | Call |

- Has details about what led up to the DETECTION of the damage
 - CEEV#GTS recognized there was damage
- We are told who "detected" the error, not who "caused" the error.



Let's cause some damage

- Looking at the damage more closely

```
Initial (User) Heap : 203A1018
+000000 203A1018 C8C1D5C3 201230B8 201230B8 00000000 A03A1018 203A1160 00008000 00007EB8 | HANC.....-.....=.|
+000020 203A1038 203A1018 000000E0 000000D3 00000000 00000000 00000000 00000000 00000000 | .....L.....|
+000040 203A1058 00000000 00000000 C9C7E9E2 D9E3C3C4 00000000 00000000 00000000 00000000 | .....IGZSRTCD.....|
+000060 203A1078 00000000 00000000 E2E8E2D6 E4E34040 00000000 00000000 0E000000 00000000 | .....SYSOUT .....|
+000080 203A1098 0F000000 00000000 E6E260C2 00000000 00000000 00000000 00000028 00000000 | .....WS-B.....|
+0000A0 203A10B8 00000010 00000000 00000008 00000000 203A1120 00000000 203A1138 00000000 | .....|
+0000C0 203A10D8 203A1150 00000000 F1F2F3F4 F5F6F7F8 F9F0F1F2 F3F4F5F6 00000000 00000000 | ...&...1234567890123456.....|
+0000E0 203A10F8 00000000 00000000 00000000 00000000 E6E260C5 00000000 00000000 00000000 | .....WS-E.....|
+000100 203A1118 203A1018 00000018 00000000 00000000 00000000 00000000 00000000 00000000 | .....|
+000120 203A1138 00000000 00000000 00000000 00000000 203A1018 00000018 F1F2F3F4 F5F6F7F8 | .....12345678|
+000140 203A1158 F9F0F1F2 F3F4F5F6 003A1130 00000000 00000018 00000000 00000000 00000000 | 90123456.....|
+000160 203A1178 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 | .....|
+000180 203A1198 - +007FFF 203A9017 same as above
```

- Damage normally occurs in User Heap so check there first

| | | | | | | | | |
|----------|-----------|----------|---------------|----------|----------|----------|----------|----------|
| 203A1018 | C8C1D5C3 | 201230B8 | 201230B8 | 00000000 | A03A1018 | 203A1160 | 00008000 | 00007EB8 |
| 203A1038 | 203A1018 | 000000E0 | 000000D3 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1058 | 00000000 | 00000000 | C9C7E9E2 | D9E3C3C4 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1078 | 00000000 | 00000000 | E2E8E2D6 | E4E34040 | 00000000 | 00000000 | 0E000000 | 00000000 |
| 203A1098 | 0F000000 | 00000000 | E6E260C2 | 00000000 | 00000000 | 00000000 | 00000028 | 00000000 |
| 203A10B8 | 00000010 | 00000000 | 00000008 | 00000000 | 203A1120 | 00000000 | 203A1138 | 00000000 |
| 203A10D8 | 203A1150 | 00000000 | F1F2F3F4 | F5F6F7F8 | F9F0F1F2 | F3F4F5F6 | 00000000 | 00000000 |
| 203A10F8 | 00000000 | 00000000 | 00000000 | 00000000 | E6E260C5 | 00000000 | 00000000 | 00000000 |
| 203A1118 | 203A1018 | 00000018 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1138 | 00000000 | 00000000 | 00000000 | 00000000 | 203A1018 | 00000018 | F1F2F3F4 | F5F6F7F8 |
| 203A1158 | F9F0F1F2 | F3F4F5F6 | 003A1130 | 00000000 | 00000018 | 00000000 | 00000000 | 00000000 |
| 203A1178 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1198 | - +007FFF | 203A9017 | same as above | | | | | |

| | HANC | Next | Prev | HeapId | | Root | Len | R. Len |
|----------|----------------------------------|----------|----------|----------|----------|----------|----------|----------|
| 203A1018 | C8C1D5C3 | 201230B8 | 201230B8 | 00000000 | A03A1018 | 203A1160 | 00008000 | 00007EB8 |
| 203A1038 | 203A1018 | 000000E0 | 000000D3 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1058 | 00000000 | 00000000 | C9C7E9E2 | D9E3C3C4 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1078 | 00000000 | 00000000 | E2E8E2D6 | E4E34040 | 00000000 | 00000000 | 0E000000 | 00000000 |
| 203A1098 | 0F000000 | 00000000 | E6E260C2 | 00000000 | 00000000 | 00000000 | 00000028 | 00000000 |
| 203A10B8 | 00000010 | 00000000 | 00000008 | 00000000 | 203A1120 | 00000000 | 203A1138 | 00000000 |
| 203A10D8 | 203A1150 | 00000000 | F1F2F3F4 | F5F6F7F8 | F9F0F1F2 | F3F4F5F6 | 00000000 | 00000000 |
| 203A10F8 | 00000000 | 00000000 | 00000000 | 00000000 | E6E260C5 | 00000000 | 00000000 | 00000000 |
| 203A1118 | 203A1018 | 00000018 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1138 | 00000000 | 00000000 | 00000000 | 00000000 | 203A1018 | 00000018 | F1F2F3F4 | F5F6F7F8 |
| 203A1158 | F9F0F1F2 | F3F4F5F6 | 003A1130 | 00000000 | 00000018 | 00000000 | 00000000 | 00000000 |
| 203A1178 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1198 | - +007FFF 203A9017 same as above | | | | | | | |



Let's cause some damage

■ Sample program CEEDUMP

```
Initial (User) Heap                               : 203A1018
+000000 203A1018 C8C1D5C3 201230B8 201230B8 00000000 A03A1018 203A1160 00008000 00007EB8 | HANC.....-.....=.|
+000020 203A1038 203A1018 000000E0 000000D3 00000000 00000000 00000000 00000000 00000000 | .....L.....|
+000040 203A1058 00000000 00000000 C9C7E9E2 D9E3C3C4 00000000 00000000 00000000 00000000 | .....IGZSRTCD.....|
+000060 203A1078 00000000 00000000 E2E8E2D6 E4E34040 00000000 00000000 0E000000 00000000 | .....SYSOUT .....|
+000080 203A1098 0F000000 00000000 E6E260C2 00000000 00000000 00000000 00000028 00000000 | .....WS-B.....|
+0000A0 203A10B8 00000010 00000000 00000008 00000000 203A1120 00000000 203A1138 00000000 | .....|
+0000C0 203A10D8 203A1150 00000000 F1F2F3F4 F5F6F7F8 F9F0F1F2 F3F4F5F6 00000000 00000000 | ...&...1234567890123456.....|
+0000E0 203A10F8 00000000 00000000 00000000 00000000 E6E260C5 00000000 00000000 00000000 | .....WS-E.....|
+000100 203A1118 203A1018 00000018 00000000 00000000 00000000 00000000 00000000 00000000 | .....|
+000120 203A1138 00000000 00000000 00000000 00000000 203A1018 00000018 F1F2F3F4 F5F6F7F8 | .....12345678|
+000140 203A1158 F9F0F1F2 F3F4F5F6 003A1130 00000000 00000018 00000000 00000000 00000000 | 90123456.....|
+000160 203A1178 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 | .....|
+000180 203A1198 - +007FFF 203A9017                same as above
```

- The crash resulted in the CEE0802C error.
- This is a simple case with a single small heap.
- Large heaps and/or multiple heaps are difficult to diagnose by hand.
- Problem 1!!!!



Let's cause some damage

■ Problem 2 – modify the program slightly

```
003600      CALL "CEEGTST" USING HEAPID, STORAGE-SIZE-16,  
003700                          ADDRESS-0, FC.  
003800  
003900      CALL "CEEGTST" USING HEAPID, STORAGE-SIZE-16,  
004000                          ADDRESS-1, FC.  
004100  
004200      CALL "CEEGTST" USING HEAPID, STORAGE-SIZE-16,  
004300                          ADDRESS-2, FC.  
004400  
004500      CALL "CEEFRST" USING ADDRESS-1, FC.  
004600  
004700      SET ADDRESS OF HEAP-DATA-AREA TO ADDRESS-2.  
004800      MOVE WS-DATA TO HEAP-DATA-AREA.  
004900  
004910      CALL "CEEGTST" USING HEAPID, STORAGE-SIZE-24,  
004920                          ADDRESS-1, FC.  
004930  
005000      CALL "CEEGTST" USING HEAPID, STORAGE-SIZE-8,  
005100                          ADDRESS-1, FC.  
005200      GOBACK.
```



Let's cause some damage

■ Problem 2 – Hit and Run!

```
Initial (User) Heap                                     : 203A1018
+000000 203A1018 C8C1D5C3 1FF230B8 1FF230B8 00000000 A03A1018 203A1180 00008000 00007E98
+000020 203A1038 203A1018 000000E0 000000D3 00000000 00000000 00000000 00000000 00000000
+000040 203A1058 00000000 00000000 C9C7E9E2 D9E3C3C4 00000000 00000000 00000000 00000000
+000060 203A1078 00000000 00000000 E2E8E2D6 E4E34040 00000000 00000000 0E000000 00000000
+000080 203A1098 0F000000 00000000 E6E260C2 00000000 00000000 00000000 00000018 00000000
+0000A0 203A10B8 00000010 00000000 00000008 00000000 203A1120 00000000 203A1168 00000000
+0000C0 203A10D8 203A1150 00000000 F1F2F3F4 F5F6F7F8 F9F0F1F2 F3F4F5F6 00000000 00000000
+0000E0 203A10F8 00000000 00000000 00000000 00000000 E6E260C5 00000000 00000000 00000000
+000100 203A1118 203A1018 00000018 00000000 00000000 00000000 00000000 00000000 00000000
+000120 203A1138 00000000 00000000 00000000 00000000 203A1018 00000018 F1F2F3F4 F5F6F7F8
+000140 203A1158 F9F0F1F2 F3F4F5F6 203A1018 00000020 00000018 00000000 00000000 00000000
+000160 203A1178 00000000 00000000 003A1130 00000000 00000018 00000000 00000000 00000000
+000180 203A1198 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000
+0001A0 203A11B8 - +007FFF 201A9017 same as above
```

- Same overlay occurs with element at 203A1160
- However damage now moved to 203A1180 – HIT AND RUN!!!!
- Why? Bigger problem!

| | HANC | Next | Prev | HeapId | | Root | Len | R. Len |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| 203A1018 | C8C1D5C3 | 201230B8 | 201230B8 | 00000000 | A03A1018 | 203A1160 | 00008000 | 00007EB8 |
| 203A1038 | 203A1018 | 000000E0 | 000000D3 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1058 | 00000000 | 00000000 | C9C7E9E2 | D9E3C3C4 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1078 | 00000000 | 00000000 | E2E8E2D6 | E4E34040 | 00000000 | 00000000 | 0E000000 | 00000000 |
| 203A1098 | 0F000000 | 00000000 | E6E260C2 | 00000000 | 00000000 | 00000000 | 00000028 | 00000000 |
| 203A10B8 | 00000010 | 00000000 | 00000008 | 00000000 | 203A1120 | 00000000 | 203A1138 | 00000000 |
| 203A10D8 | 203A1150 | 00000000 | F1F2F3F4 | F5F6F7F8 | F9F0F1F2 | F3F4F5F6 | 00000000 | 00000000 |
| 203A10F8 | 00000000 | 00000000 | 00000000 | 00000000 | E6E260C5 | 00000000 | 00000000 | 00000000 |
| 203A1118 | 203A1018 | 00000018 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1138 | 00000000 | 00000000 | 00000000 | 00000000 | 203A1018 | 00000018 | F1F2F3F4 | F5F6F7F8 |
| 203A1158 | F9F0F1F2 | F3F4F5F6 | 003A1130 | 00000000 | 00000018 | 00000000 | 00000000 | 00000000 |
| 203A1178 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |

Request for 32 (x'20') bytes comes in – 24 + 8 byte header
Follow root to 203A1160 – non zero pointer – but size only x'18 – no room

| | HANC | Next | Prev | HeapId | | Root | Len | R. Len |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| 203A1018 | C8C1D5C3 | 201230B8 | 201230B8 | 00000000 | A03A1018 | 203A1160 | 00008000 | 00007EB8 |
| 203A1038 | 203A1018 | 000000E0 | 000000D3 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1058 | 00000000 | 00000000 | C9C7E9E2 | D9E3C3C4 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1078 | 00000000 | 00000000 | E2E8E2D6 | E4E34040 | 00000000 | 00000000 | 0E000000 | 00000000 |
| 203A1098 | 0F000000 | 00000000 | E6E260C2 | 00000000 | 00000000 | 00000000 | 00000028 | 00000000 |
| 203A10B8 | 00000010 | 00000000 | 00000008 | 00000000 | 203A1120 | 00000000 | 203A1138 | 00000000 |
| 203A10D8 | 203A1150 | 00000000 | F1F2F3F4 | F5F6F7F8 | F9F0F1F2 | F3F4F5F6 | 00000000 | 00000000 |
| 203A10F8 | 00000000 | 00000000 | 00000000 | 00000000 | E6E260C5 | 00000000 | 00000000 | 00000000 |
| 203A1118 | 203A1018 | 00000018 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1138 | 00000000 | 00000000 | 00000000 | 00000000 | 203A1018 | 00000018 | F1F2F3F4 | F5F6F7F8 |
| 203A1158 | F9F0F1F2 | F3F4F5F6 | 003A1130 | 00000000 | 00000018 | 00000000 | 00000000 | 00000000 |
| 203A1178 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |

So use the first x'20' bytes for a new allocated element.

| | HANC | Next | Prev | HeapId | | Root | Len | R. Len |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| 203A1018 | C8C1D5C3 | 201230B8 | 201230B8 | 00000000 | A03A1018 | 203A1160 | 00008000 | 00007EB8 |
| 203A1038 | 203A1018 | 000000E0 | 000000D3 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1058 | 00000000 | 00000000 | C9C7E9E2 | D9E3C3C4 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1078 | 00000000 | 00000000 | E2E8E2D6 | E4E34040 | 00000000 | 00000000 | 0E000000 | 00000000 |
| 203A1098 | 0F000000 | 00000000 | E6E260C2 | 00000000 | 00000000 | 00000000 | 00000028 | 00000000 |
| 203A10B8 | 00000010 | 00000000 | 00000008 | 00000000 | 203A1120 | 00000000 | 203A1138 | 00000000 |
| 203A10D8 | 203A1150 | 00000000 | F1F2F3F4 | F5F6F7F8 | F9F0F1F2 | F3F4F5F6 | 00000000 | 00000000 |
| 203A10F8 | 00000000 | 00000000 | 00000000 | 00000000 | E6E260C5 | 00000000 | 00000000 | 00000000 |
| 203A1118 | 203A1018 | 00000018 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1138 | 00000000 | 00000000 | 00000000 | 00000000 | 203A1018 | 00000018 | F1F2F3F4 | F5F6F7F8 |
| 203A1158 | F9F0F1F2 | F3F4F5F6 | 003A1130 | 00000000 | 00000018 | 00000000 | 00000000 | 00000000 |
| 203A1178 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |

Remainder of free element must be returned to free tree.
So copy the information from existing free element.

| | HANC | Next | Prev | HeapId | | Root | Len | R. Len |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| 203A1018 | C8C1D5C3 | 201230B8 | 201230B8 | 00000000 | A03A1018 | 203A1160 | 00008000 | 00007EB8 |
| 203A1038 | 203A1018 | 000000E0 | 000000D3 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1058 | 00000000 | 00000000 | C9C7E9E2 | D9E3C3C4 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1078 | 00000000 | 00000000 | E2E8E2D6 | E4E34040 | 00000000 | 00000000 | 0E000000 | 00000000 |
| 203A1098 | 0F000000 | 00000000 | E6E260C2 | 00000000 | 00000000 | 00000000 | 00000028 | 00000000 |
| 203A10B8 | 00000010 | 00000000 | 00000008 | 00000000 | 203A1120 | 00000000 | 203A1138 | 00000000 |
| 203A10D8 | 203A1150 | 00000000 | F1F2F3F4 | F5F6F7F8 | F9F0F1F2 | F3F4F5F6 | 00000000 | 00000000 |
| 203A10F8 | 00000000 | 00000000 | 00000000 | 00000000 | E6E260C5 | 00000000 | 00000000 | 00000000 |
| 203A1118 | 203A1018 | 00000018 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1138 | 00000000 | 00000000 | 00000000 | 00000000 | 203A1018 | 00000018 | F1F2F3F4 | F5F6F7F8 |
| 203A1158 | F9F0F1F2 | F3F4F5F6 | 003A1130 | 00000000 | 00000018 | 00000000 | 00000000 | 00000000 |
| 203A1178 | 00000000 | 00000000 | 003A1130 | 00000000 | 00000018 | 00000000 | 00000000 | 00000000 |

Remainder of free element must be returned to free tree.
So copy the information from existing free element.

| | HANC | Next | Prev | HeapId | | Root | Len | R. Len |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| 203A1018 | C8C1D5C3 | 201230B8 | 201230B8 | 00000000 | A03A1018 | 203A1160 | 00008000 | 00007EB8 |
| 203A1038 | 203A1018 | 000000E0 | 000000D3 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1058 | 00000000 | 00000000 | C9C7E9E2 | D9E3C3C4 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1078 | 00000000 | 00000000 | E2E8E2D6 | E4E34040 | 00000000 | 00000000 | 0E000000 | 00000000 |
| 203A1098 | 0F000000 | 00000000 | E6E260C2 | 00000000 | 00000000 | 00000000 | 00000028 | 00000000 |
| 203A10B8 | 00000010 | 00000000 | 00000008 | 00000000 | 203A1120 | 00000000 | 203A1138 | 00000000 |
| 203A10D8 | 203A1150 | 00000000 | F1F2F3F4 | F5F6F7F8 | F9F0F1F2 | F3F4F5F6 | 00000000 | 00000000 |
| 203A10F8 | 00000000 | 00000000 | 00000000 | 00000000 | E6E260C5 | 00000000 | 00000000 | 00000000 |
| 203A1118 | 203A1018 | 00000018 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 | 00000000 |
| 203A1138 | 00000000 | 00000000 | 00000000 | 00000000 | 203A1018 | 00000018 | F1F2F3F4 | F5F6F7F8 |
| 203A1158 | F9F0F1F2 | F3F4F5F6 | 201A1018 | 00000020 | 00000018 | 00000000 | 00000000 | 00000000 |
| 203A1178 | 00000000 | 00000000 | 003A1130 | 00000000 | 00000018 | 00000000 | 00000000 | 00000000 |

Now create the allocated element
Problem 2! Damage has moved



Getting closer to the zone!

- **SYSMDUMP – IPCS**
 - **Use VERBX LEDATA 'HEAP'**
 - **First ENSM – Enclave Storage Management CB**

Language Environment Product 04 V01 R06.00

Heap Storage Control Blocks

```
ENSM: 201230A0
+000000 EYE_CATCHER:ENSM ST_HEAP_ALLOC_FLAG:00000000
+000008 ST_HEAP_ALLOC_VAL:00000000 ST_HEAP_FREE_FLAG:00000000
+000010 ST_HEAP_FREE_VAL:00000000 REPORT_STORAGE:00000000
+000018 UHEAP:C8D7C3C2 203A1018 203A1018 00008000 00008000 00002000 00001000 00000000 00
+000048 AHEAP:C8D7C3C2 2037D000 2037D000 00004000 00002000 00002000 00001000 00000000 00
+000078 BHEAP:C8D7C3C2 20123118 20123118 00002000 00001000 00002000 00001000 80000000 00
+0000A8 ENSM_ADDL_HEAPS:F0F00000
```



Getting closer to the zone!

- **SYSMDUMP – IPCS**

- Then HPCB and header for user heap

User Heap Control Blocks

```
HPCB: 201230B8
+000000 EYE_CATCHER:HPCB FIRST:203A1018 LAST:203A1018

HANC: 203A1018
+000000 EYE_CATCHER:HANC NEXT:201230B8 PREV:201230B8
+00000C HEAPID:00000000 SEG_ADDR:A03A1018 ROOT_ADDR:203A1160
+000018 SEG_LEN:00008000 ROOT_LEN:00007EB8
```

This is the last heap segment in the current heap.



Getting closer to the zone!

- **SYSMDUMP – IPCS**

- Next is the free tree information

- NOTE: *ERROR* indicates an error was found

Free Storage Tree for Heap Segment 203A1018

| | Node | Node | Parent | Left | Right | Left | Right |
|---|----------|----------|----------|----------|----------|----------|----------|
| Depth | Address | Length | Node | Node | Node | Length | Length |
| 0 | 203A1160 | 00007EB8 | 00000000 | 003A1130 | 00000000 | 00000018 | 00000000 |
| *ERROR* The left node address does not fall within the current heap segment | | | | | | | |



Getting closer to the zone!

- **SYSMDUMP – IPCS**
 - Next map all elements in heap segment

Map of Heap Segment 203A1018

To display entire segment: IP LIST 203A1018 LEN(X'00008000') ASID(X'0181')

203A1038: Allocated storage element, length=000000E0. To display: IP LIST
203A1038 LEN(X'000000E0') ASID(X'0181')

203A1040: 000000D3 00000000 00000000 00000000 00000000 00000000 00000000
00000000 |...L.....|

203A1118: Allocated storage element, length=00000018. To display: IP LIST
203A1118 LEN(X'00000018') ASID(X'0181')

203A1120: 00000000 00000000 00000000 00000000
|.....|



Getting closer to the zone!

- **SYSMDUMP – IPCS**
 - Showing error as we go...

```
203A1130: Allocated storage element, length=00000000. To display: IP LIST
203A1130 LEN(X'00000008') ASID(X'0181')
203A1138: 00000000 00000000
|.....|
```

```
*ERROR* The heap segment address in the allocated storage element header is not
valid
WARNING This storage element may be a free storage node not found during free
storage tree validation
*ERROR* The length of this storage element is zero
WARNING Attempting to identify a resume location after encountering a storage
element validation error
```



Getting closer to the zone!

- **SYSMDUMP – IPCS**
 - Finally Summary information
 - Amount of allocated and free storage
 - Number of elements
 - Identifies if there were errors in this heap segment
 - Problem 1 solved!

Summary of analysis for Heap Segment 203A1018:

```
Amounts of identified storage:  Free:00007EB8  Allocated:00000110  Total:00007FC8
Number of identified areas   :  Free:         1  Allocated:         4  Total:         5
00000018 bytes of storage were not accounted for.
Errors were found while processing this heap segment.
This is the last heap segment in the current heap.
```



Getting closer to the zone!

- HEAPCHK runtime option
 - Runtime debug tool to help diagnose a heap damage problem
 - In many cases any heap damage may not be noticed until significant time has passed – A hit and run!
 - The HEAPCHK runtime option forces all the heap segments to be validated on a regular basis.
 - Gets a dump closer to the the one at fault.
 - Generates a U4042 ABEND
 - Use System dump, if needed, to debug.



Getting closer to the zone!

- HEAPCHK runtime option ...
 - HEAPCHK(ON|OFF,freq,delay,depth,pooldepth)
 - ON - turns HEAPCHK on (performance dog)
 - OFF - normal processing
 - freq
 - Defaults to 1, indicates every call to a heap routine (get or free) validates the heap
 - Other values for less frequent checks
 - delay
 - Allows some number of calls to occur prior to 'freq' being used.
 - depth
 - Depth of traceback for storage leak
 - pooldepth
 - Depth of heappools trace



Getting closer to the zone!

■ Output with HEAPCHK(ON)

```
17.12.44 JOB22865 ---- WEDNESDAY, 16 FEB 2005 ----
17.12.45 JOB22865 $HASP373 JMONTIGO STARTED - WLM INIT - SRVCLASS WLMLONG - SYS AQFT
17.12.45 JOB22865 IEF403I JMONTIGO - STARTED - TIME=17.12.45
17.12.48 JOB22865 IEA995I SYMPTOM DUMP OUTPUT 937
937      USER COMPLETION CODE=4042 REASON CODE=00000000
937      TIME=17.12.45 SEQ=11443 CPU=0000 ASID=018E
937      PSW AT TIME OF ERROR 078D1000 A01AB242 ILC 2 INTC 0D
937      ACTIVE LOAD MODULE ADDRESS=201256C0 OFFSET=00085B82
937      NAME=CEEPLPKA
937      DATA AT PSW 201AB23C - 00181610 0A0D47F0 B10A1811
937      AR/GR 0: 80AB5B3E/84000000 1: 00000000/84000FCA
937      2: 00000000/00000000 3: 00000000/00000001
...
937      E: 00000000/00000000 F: 00000000/00000000
937      END OF SYMPTOM DUMP
17.12.48 JOB22865 IEA993I SYSMDUMP TAKEN TO POSIX.JMONTI.SHARE.HEAP.SYSMDUMP
17.12.48 JOB22865 IEF450I JMONTIGO GO - ABEND=S000 U4042 REASON=00000000 939
939      TIME=17.12.48
```



Getting closer to the zone!

- Very good output with HEAPCHK(ON)
 - In this case CEE37xx messages are very meaningful
 - The damage has not yet moved
 - Full debug may still need to be done with SYSMDUMP and IPCS
 - Use a storage alteration (SA) SLIP if needed (non-CICS)
 - Problem 2 Solved! ?

STARTING SHAREHP...

CEE3701W Heap damage found by HEAPCHK run-time option.

CEE3707I Left pointer is bad in the free tree at 203A1160 in the heap segment beginning at 203A1018.

```
203A1140: 00000000 00000000 203A1018 00000018 F1F2F3F4 F5F6F7F8 F9F0F1F2
F3F4F5F6 |.....1234567890123456|
```

```
203A1160: 003A1130 00000000 00000018 00000000 00000000 00000000 00000000
00000000 |.....|
```

CEE3702S Program terminating due to heap damage.



The HEAPZONE!



The HEAPZONE!





The HEAPZONE!



The HEAPZONE!





Summary

- Summary for heaps
 - Heap used for dynamic storage
 - CEEDUMPs contain information on heap errors but they are difficult to find
 - SYSTEM DUMPs using LEDATA 'HEAP' make debug much simpler
 - Use HEAPCHK runtime option to debug
 - Big performance hit
 - Use HEAPZONES as a fast alternative!



Sources of Additional Info



- All Language Environment documentation available on the z/OS DVD collection and on the Language Environment website
 - Language Environment Debug Guide
 - Language Environment Runtime Messages
 - Language Environment Programming Reference
 - Language Environment Programming Guide
 - Language Environment Customization
 - Language Environment Migration Guide
 - Language Environment Writing ILC Applications
- Language Environment Web site
 - http://www-03.ibm.com/systems/z/os/zos/features/lang_environment/

