Look What I Found Under The Bar!

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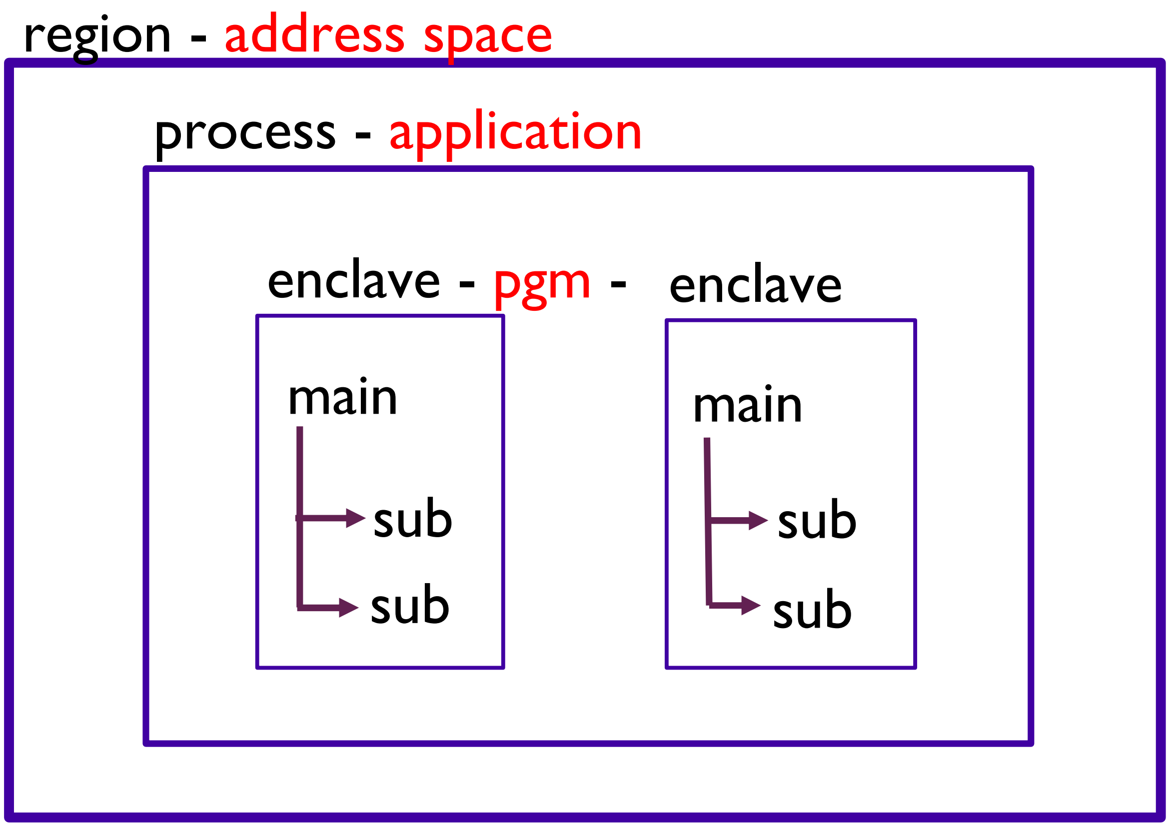
Agenda

- Overview of Language Environment storage areas
  - Control blocks, stack, heap
  - Which can you control?
- How to control Language Environment Storage
- Tuning Storage
- More advanced tuning
- Sources of Additional Information

Language Environment Storage Areas

- Language Environment Control Blocks
  - Region level
    - Normally 1 region per address space
  - Process level
    - Normally 1 process per address space
  - Enclave level
    - Potentially many per address space
  - Thread level
    - Potentially very many per address space

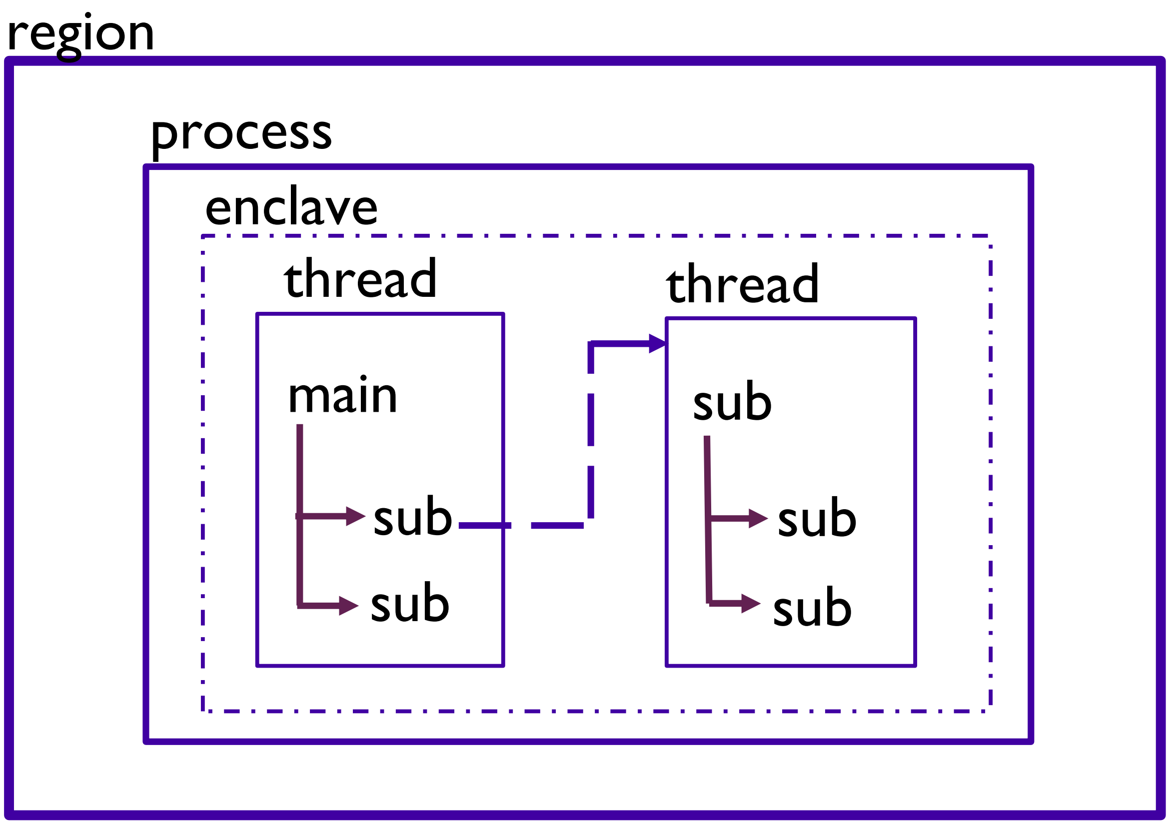
Language Environment Storage Areas



Language Environment Storage Areas

- Language Environment Enclave
  - Every "main" program is a new enclave
  - Every "link" is a new enclave
  - Contains
    - CEECAA, CEEEDB, CEEOCB, stacks, heaps, environment variables, and much more!
  - "Extra" enclaves are expensive both to initialize and in storage usage.

Language Environment Storage Areas



Language Environment Storage Areas

- Language Environment Thread
  - Only created by pthread_create()
  - Contains
    - CEECAA, stacks, and a little more
  - Threads are not nearly as expensive as enclaves.
  - Used mostly by C/C++
  - Enterprise PL/I multitasking uses threads

Language Environment Storage Areas

- Language Environment Stacks
  - Stacks
    - Last In, First Out structures
    - Allow programs to be reentrant
    - Thread level structures
      - "Main" programs have separate stacks
      - "Linked" programs have separate stacks
      - Pthreads have separate stacks

Language Environment Storage Areas

- Language Environment supports 2 independent stacks
  - User stack – (poorly named)
    - Used by user programs and Language Environment
  - Library stack
    - Used “rarely” by Language Environment
    - Always below the 16M line

Language Environment Storage Areas

- DATA in stacks
  - "Chunks" are called stack segments
    - Made up of 1 or more DSAs
  - DSA – Dynamic Save Area
    - Also called a "stack frame"
  - DSAs contain
    - Register Save Area (RSA)
    - NAB – Next Available Byte
    - Automatic (local) variables
      - C – int i;
      - PL/I – declare i fixed;
      - NOT COBOL WORKING-STORAGE
        - COBOL LOCAL-STORAGE in stack

Language Environment Storage Areas

- Language Environment Heaps
  - Heaps
    - Completely random access
    - Allows storage to be dynamically allocated at runtime
  - Enclave level control structures
    - Each 'main' has a separate stack and heap
    - Each 'link' causes a separate stack and heap
    - pthreads share a single heap for all threads

Language Environment Storage Areas

- Language Environment 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

Controlling Storage

- Run-time options dealing with stacks
  - STACK(init,inc,ANY|BELOW,KEEP|FREE,dsInit,dsInc)
    - Init - Initial size of storage "chunk" allocated and managed by LE for user stack
    - Inc - When init is full, size of next storage "chunk" (increment)
    - ANY|BELOW - Location of storage
      - ANY Anywhere in 2G virtual storage
      - Below Always below 16M line
        - Required when all31(OFF)
    - KEEP|FREE - What to do when done with inc
      - KEEP Do not free the storage "chunks"
      - FREE Free the storage "chunks"
    - DsInit - Initial size of storage "chunk" (XPLINK)
    - DsInc - When initial full, size of next "chunk" (XPLINK)

Controlling Storage

- Run-time options dealing with stacks
  - LIBSTACK(init,inc,KEEP|FREE)
    - Init - Initial size of storage "chunk" allocated and managed by LE for library stack
    - Inc - When init is full, size of next storage "chunk" (increment)
    - KEEP|FREE - What to do when done with inc
      - KEEP Do not free the storage "chunks"
      - FREE Free the storage "chunks"

    NOTE: No ANY|BELOW, LIBSTACK always below the 16M line

Controlling Storage

- Run-time options dealing with stacks
  - THREADSTACK(ON|OFF,init,inc,ANY|BELOW,KEEP|FREE, dsInit,dsInc)
    - ON|OFF – Whether or not to use THREADSTACK for pthreads
    - Init - Initial size of storage "chunk" (like STACK)
    - Inc - Increment size of storage "chunk" (like STACK)
    - ANY|BELOW - Location of storage
      - ANY Anywhere in 2G virtual storage
      - Below Always below 16M line
        - Required when all31(OFF)
    - KEEP|FREE - What to do when done with inc
      - KEEP Do not free the storage "chunks"
      - FREE Free the storage "chunks"
    - DsInit, Dsinc – XPLINK "chunk" sizes

Controlling Storage

- Runtime options dealing with the heaps
  - HEAP(init,inc,ANY|BELOW,KEEP|FREE,int24,inc24)
    - User heap - mostly application use
    - init - Initial size of the "chunk" of storage obtained to be managed by LE for user heap
    - Inc - When initial "chunk" is full, size of next "chunk" (minimum)
    - ANY|BELOW - Location of "chunk‟
      - Not sensitive to ALL31 setting
    - KEEP | FREE - What to do when done with the increment when empty
      - KEEP - Do not free the storage "chunks"
      - FREE - Free the storage "chunks"
    - int24 - Initial size of the "chunk" of storage obtained
      - (if ANY specified but BELOW requested (minimum))
    - inc24 - Size of next "chunk"
      - (if ANY specified but BELOW requested (minimum))

Controlling Storage

- Runtime options dealing with the heaps...
  - ANYHEAP(init,inc,ANY|BELOW,KEEP|FREE)
    - Thread stack storage lives in anyheap!!! Tune if multi-threaded
    - LE use - normally above the line
    - init - Same as HEAP.
    - inc - Same as HEAP. (minimum)
    - ANY | BELOW - Location of storage
    - KEEP | FREE - Same as HEAP
  - BELOWHEAP(init,inc,KEEP|FREE)
    - LE use - always below the line
    - init - Same as HEAP.
    - inc - Same as HEAP. (minimum)
    - KEEP | FREE - Same as HEAP

Initializing Storage

- STORAGE(getheap, freeheap,dsa alloc)
  - Getheap – Initialize heap storage
    - NONE – no overhead
    - One byte hex value to initialize storage with when heap element obtained
      - 00 similar to WSCLEAR option
      - Relatively low overhead
  - Freeheap – Initial heap storage
    - NONE – no overhead
    - One byte hex value to initialize storage with when heap element freed
      - Useful for debug purposes or security
      - Relatively low overhead

Initializing Storage

- STORAGE(getheap, freeheap,dsa alloc)
  - DSA alloc – Initialize stack storage
    - NONE – No initialization – no overhead
    - CLEAR – Entire unused initial stack segment is cleared just before the main program is given control – low overhead
    - A one byte hex value to initialize storage with when stack frame (DSA) is obtained
      - EXTREMELY HIGH OVERHEAD
      - EXTREMELY HIGH OVERHEAD
      - EXTREMELY HIGH OVERHEAD

Initializing Storage

- Simple program that makes lots of calls
  - STORAGE(,,none)

```
- ==========================================================
-                                   REGION           --- ST
- STEPNAME PROCSTEP PGMNAME     CC    USED         CPU TIME
- GO                STORRTO     00     60K       0:00:00.56
```

  - STORAGE(,,00)

```
- ==========================================================
-                                   REGION           --- ST
- STEPNAME PROCSTEP PGMNAME     CC    USED         CPU TIME
- GO                STORRTO     00     60K       0:00:02.15
```

  - STORAGE(,,CLEAR)

```
- ==========================================================
-                                   REGION           --- ST
- STEPNAME PROCSTEP PGMNAME     CC    USED         CPU TIME
- GO                STORRTO     00     60K       0:00:00.57
```

Initializing Storage

- Best ways to ensure the proper initial value for your variables
  - Use compiler initialization
  - Set them prior to use in your program

Tuning storage

- Objectives
  - Use as little storage as possible
  - Have program run as efficiently as possible
- The above objectives are often at odds with each other. (But not always)
- One way to make a program run faster is to “throw” more storage at it.
  - Care must be taken to use storage wisely
  - Much of what will talk about can be done without recompiling or reworking the program.

Tuning storage

- Simple example
  - In a test environment (not production) use the RPTSTG run-time option.
  - A report will be generated describing the storage used by the program.
  - This information can be used to assist with better settings of Language Environment run-time options

Tuning storage

- Simple example

```
Storage Report for Enclave main 02/07/11 5:12:26 PM
Language Environment V01 R12.00

    STACK statistics:
      Initial size:                                        131072
      Increment size:                                      131072
      Maximum used by all concurrent threads:                4792
      Largest used by any thread:                            4792
      Number of segments allocated:                             1
      Number of segments freed:                                 0
    THREADSTACK statistics:
      Initial size:                                             0
      Increment size:                                           0
      Maximum used by all concurrent threads:                   0
      Largest used by any thread:                               0
      Number of segments allocated:                             0
      Number of segments freed:                                 0
```

Tuning storage

- Simple example…

```
LIBSTACK statistics:
  Initial size:                                     4096
  Increment size:                                   4096
  Maximum used by all concurrent threads:              0
  Largest used by any thread:                          0
  Number of segments allocated:                        0
  Number of segments freed:                            0
THREADHEAP statistics:
  Initial size:                                     4096
  Increment size:                                   4096
  Maximum used by all concurrent threads:              0
  Largest used by any thread:                          0
  Successful Get Heap requests:                        0
  Successful Free Heap requests:                       0
  Number of segments allocated:                        0
  Number of segments freed:                            0
```

Tuning storage

- Simple example…

```
HEAP statistics:
  Initial size:                                         32768
  Increment size:                                       32768
  Total heap storage used (sugg. initial size):          3328
  Successful Get Heap requests:                             4
  Successful Free Heap requests:                            2
  Number of segments allocated:                             1
  Number of segments freed:                                 0
HEAP24 statistics:
  Initial size:                                          8192
  Increment size:                                        4096
  Total heap storage used (sugg. initial size):             0
  Successful Get Heap requests:                             0
  Successful Free Heap requests:                            0
  Number of segments allocated:                             0
  Number of segments freed:                                 0
```

Tuning storage

- Simple example...

```
ANYHEAP statistics:
  Initial size:                                         16384
  Increment size:                                        8192
  Total heap storage used (sugg. initial size):           616
  Successful Get Heap requests:                             6
  Successful Free Heap requests:                            2
  Number of segments allocated:                             1
  Number of segments freed:                                 0
BELOWHEAP statistics:
  Initial size:                                          8192
  Increment size:                                        4096
  Total heap storage used (sugg. initial size):             0
  Successful Get Heap requests:                             0
  Successful Free Heap requests:                            0
  Number of segments allocated:                             0
  Number of segments freed:                                 0
```

Tuning storage

- Now using stack(8k,4k) heap(4k,4k)

```
STACK statistics:
  Initial size:                                        8192
  Increment size:                                      4096
  Maximum used by all concurrent threads:              4792
  Largest used by any thread:                          4792
  Number of segments allocated:                           1
  Number of segments freed:                               0
  ...snip...
HEAP statistics:
  Initial size:                                        4096
  Increment size:                                      4096
  Total heap storage used (sugg. initial size):        3328
  Successful Get Heap requests:                           4
  Successful Free Heap requests:                          2
  Number of segments allocated:                           1
  Number of segments freed:                               0
```

Tuning storage

- A bit more meaty!
  - Testcase requests 50000 random pieces of storage of sizes from 1 to 32K in size
  - Then the storage is freed.
  - We’ll run the program without tuning
  - We’ll then re-run the program (same random values) after tuning
  - Have we saved storage? Performance?

Tuning storage

- Untuned example

```
STACK statistics:
   Initial size:                                      131072
   Increment size:                                    131072
   Maximum used by all concurrent threads:            204184
   Largest used by any thread:                        204184
   Number of segments allocated:                           3
   Number of segments freed:                               0
   ...Snip...
HEAP statistics:
   Initial size:                                       32768
   Increment size:                                     32768
   Total heap storage used (sugg. initial size):   819229056
   Successful Get Heap requests:                       50002
   Successful Free Heap requests:                      50000
   Number of segments allocated:                       27949
   Number of segments freed:                               0
```

- Note: 27949 segments of 32k each – 915,832,832 bytes

Tuning storage

- Tuned HEAP(100M,100M) STACK(256K,256K)

```
STACK statistics:
  Initial size:                                          262144
  Increment size:                                        262144
  Maximum used by all concurrent threads:                200944
  Largest used by any thread:                            200944
  Number of segments allocated:                               1
  Number of segments freed:                                   0
  ...Snip...
HEAP statistics:
  Initial size:                                       104857600
  Increment size:                                     104857600
  Total heap storage used (sugg. initial size):       818334944
  Successful Get Heap requests:                           50002
  Successful Free Heap requests:                          50000
  Number of segments allocated:                               8
  Number of segments freed:                                   0
```

- Note: 8 segments of 100M each – 838,860,800 bytes!!!

Tuning storage

- Look what else happened!
  - Untuned

```
- ==============================================================================
-                                          REGION        --- STEP TIMINGS ---
- STEPNAME PROCSTEP PGMNAME      CC         USED      CPU TIME  ELAPSED TIME     EXCP
- CLPG     COMPILE  CBCDRVR      00          72K    0:00:00.06    0:00:02.84     1590
- CLPG     PLKED    EDCPRLK      04          60K    0:00:00.01    0:00:00.99      534
- CLPG     LKED     HEWL         00          92K    0:00:00.01    0:00:00.63      174
- CLPG     GO       PGM=*.DD     00          60K    0:00:15.44    0:00:18.02      505
```

  - Tuned

```
- ==============================================================================
-                                          REGION        --- STEP TIMINGS ---
- STEPNAME PROCSTEP PGMNAME      CC         USED      CPU TIME  ELAPSED TIME     EXCP
- CLPG     COMPILE  CBCDRVR      00          72K    0:00:00.06    0:00:03.67     1555
- CLPG     PLKED    EDCPRLK      04          60K    0:00:00.01    0:00:01.25      535
- CLPG     LKED     HEWL         00          92K    0:00:00.01    0:00:00.50      170
- CLPG     GO       PGM=*.DD     00          60K    0:00:00.12    0:00:01.45      501
```

Tuning storage

- What about KEEP vs FREE
  - Testcase requests 50000 random pieces of storage of sizes from 1 to 32K in size
  - Free 20000 pieces, then get 20000 more
  - Free everything
  - We'll run the program without tuning and FREE
  - We'll run the program without tuning and KEEP
  - What have we done to storage and performance?

Tuning storage

- Untuned

```
HEAP statistics: (Using FREE)
  Initial size:                                          32768
  Increment size:                                        32768
  Total heap storage used (sugg. initial size):      819982896
  Successful Get Heap requests:                          70002
  Successful Free Heap requests:                         69999
  Number of segments allocated:                          39122
  Number of segments freed:                              39120
HEAP statistics: (Using KEEP)
  Initial size:                                          32768
  Increment size:                                        32768
  Total heap storage used (sugg. initial size):      819983152
  Successful Get Heap requests:                          70002
  Successful Free Heap requests:                         70000
  Number of segments allocated:                          27952
  Number of segments freed:                                  0
```

- Note: You can't determine storage used to back segments now

Tuning storage

- Performance – not a huge difference but KEEP is faster!
  - FREE

```
- ===============================================================================
-                                                 REGION        --- STEP TIMINGS ---
- STEPNAME PROCSTEP PGMNAME      CC        USED      CPU TIME  ELAPSED TIME     EXCP
- CLPG     COMPILE  CBCDRVR      00         72K   0:00:00.06    0:00:04.95     1496
- CLPG     PLKED    EDCPRLK      04         60K   0:00:00.01    0:00:02.46      504
- CLPG     LKED     HEWL         00         92K   0:00:00.01    0:00:01.13      171
- CLPG     GO       PGM=*.DD     00         60K   0:00:25.79    0:01:02.34      474
```

  - KEEP

```
- ===============================================================================
-                                                 REGION        --- STEP TIMINGS ---
- STEPNAME PROCSTEP PGMNAME      CC        USED      CPU TIME  ELAPSED TIME     EXCP
- CLPG     COMPILE  CBCDRVR      00         72K   0:00:00.06    0:00:03.15     1493
- CLPG     PLKED    EDCPRLK      04         60K   0:00:00.01    0:00:00.87      505
- CLPG     LKED     HEWL         00         92K   0:00:00.01    0:00:00.46      171
- CLPG     GO       PGM=*.DD     00         60K   0:00:22.34    0:00:24.85      469
```

Tuning storage

- Look what happens when we tune.

```
HEAP statistics:
  Initial size:                                     104857600
  Increment size:                                   104857600
  Total heap storage used (sugg. initial size):     819088944
  Successful Get Heap requests:                         70002
  Successful Free Heap requests:                        69999
  Number of segments allocated:                             8
  Number of segments freed:                                 0

- ===========================================================================
-                                          REGION       --- STEP TIMINGS ---
- STEPNAME PROCSTEP PGMNAME      CC          USED      CPU TIME  ELAPSED TIME     EXCP
- CLPG     COMPILE  CBCDRVR      00           72K    0:00:00.06    0:00:02.67     1499
- CLPG     PLKED    EDCPRLK      04           60K    0:00:00.01    0:00:00.81      547
- CLPG     LKED     HEWL         00           92K    0:00:00.01    0:00:00.32      171
- CLPG     GO       PGM=*.DD     00           60K    0:00:00.15    0:00:01.04      496
```

More advanced tuning

- What about those pesky Language Environment control blocks?
  - No externals to help
  - Effort can be made to reduce the number of enclaves
  - Use dynamic calls rather than linking to next program
  - Hard to see the results without using system tools… but let's try

More advanced tuning

- Simple program does a LINK to another program
  - A new enclave is created
  - This 2^{nd} program continues to get storage until it runs out
  - It is able to obtain 21568K of storage

More advanced tuning

- Add to program to call down through 5 nested enclaves
  - Last enclave is able to obtain 20576K of storage
- Add to program to call down through 10 nested enclaves
  - Last enclave is able to obtain 19808K of storage
- Storage being consumed is to:
  - Load programs
  - Create enclave control blocks
    - This includes stacks and heaps
  - 1760K of storage usage (21568K-19808K)

More advanced tuning

- Change programs to use dynamic call rather than LINK
  - One call case – 21728K of storage available
  - Five call case – 21664K of storage available
  - Ten call case – 21600K of storage available
- Note how much less storage is consumed.
  - Basically just the amount to load the programs
  - 128K for 10 calls deep (21728K-21600K)

Summary

- Storage run-time option has high overhead for initializing the stack
- Use RPTSTG to tune your stack, heap and other storage sizes
- KEEP is faster than FREE
- Use dynamic call versus LINK
  - Requires program update or recompile

Sources of Additional Info

- All Language Environment documentation available on the Language Environment Web site
  - Language Environment Debugging Guide
  - Language Environment Programming Reference
  - Language Environment Programming Guide
- Language Environment Web site
  - http://www.ibm.com/systems/z/os/zos/features/lang_environment