z/OS Virtual Memory

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Agenda

- Memory Management Basics
- VSM Overview
- VSM DIAGxx Options
- VSM Health Checks
- Large Pages and Their Value

Z/OS BASIC MEMORY MANAGEMENT CONCEPTS

z/OS Memory Types

- There are three z/OS memory types used to process system and user/application storage requests:
  - Real frames: the physical main memory.
  - Auxiliary: paging dataset slots and storage-class memory (SCM) blocks.
  - Virtual pages: created through dynamic address translation (DAT) for multiple address spaces.

(This presentation uses the traditional term “storage” and more common term “memory” interchangeably.)

Processor Storage Overview

On the box

External

Processor Cache

Main Memory

Storage-Class Memory

Paging Datasets

Real Storage

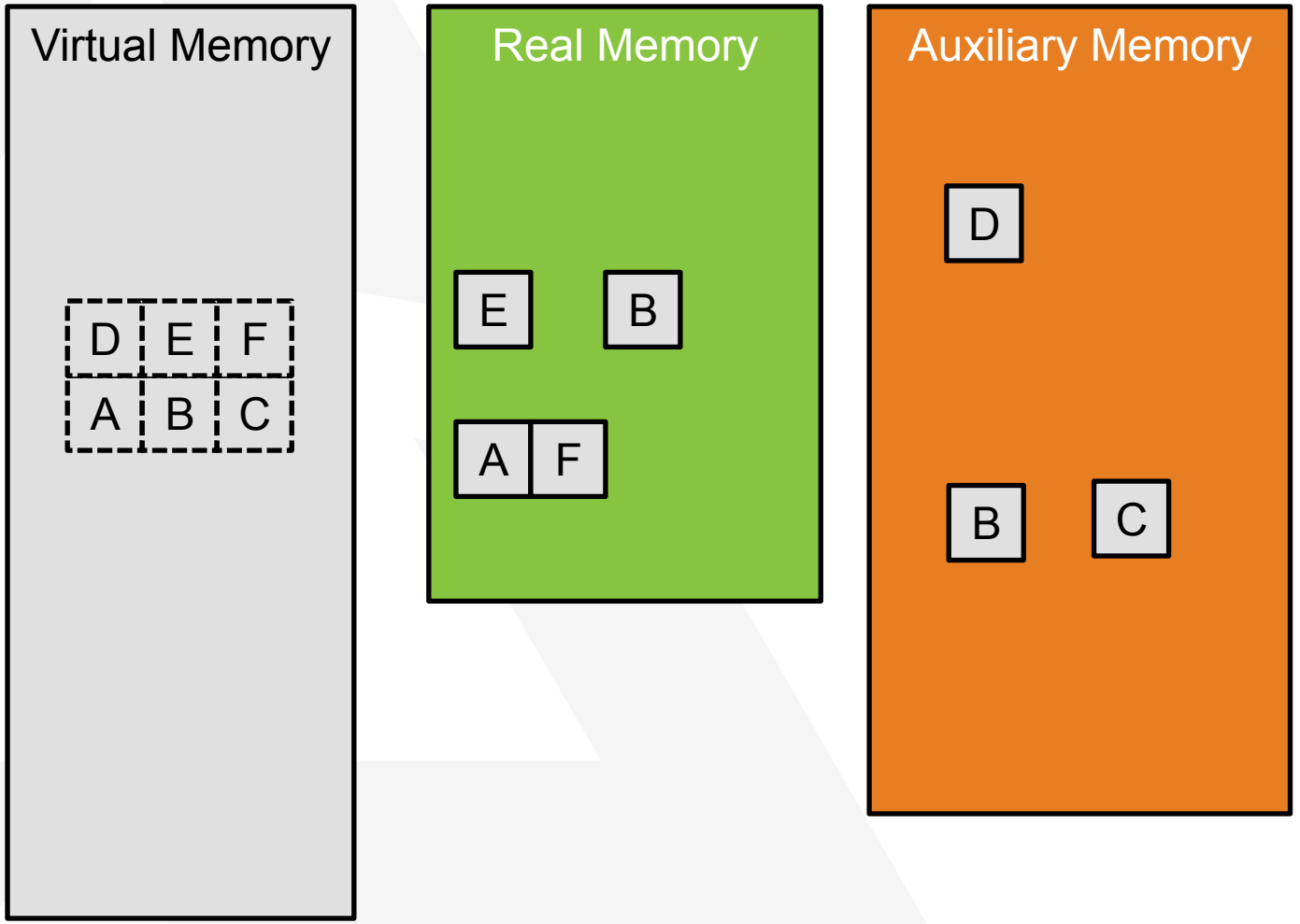
Auxiliary Storage

Increasing Speed

Increasing Capacity

Virtual Memory

- Pages of data in virtual is backed by real or auxiliary storage.
- Contiguous in virtual are typically not contiguous when backed.
- In some cases a page can be backed both in real and aux.
- DAT tables translate virtual addresses to real addresses.

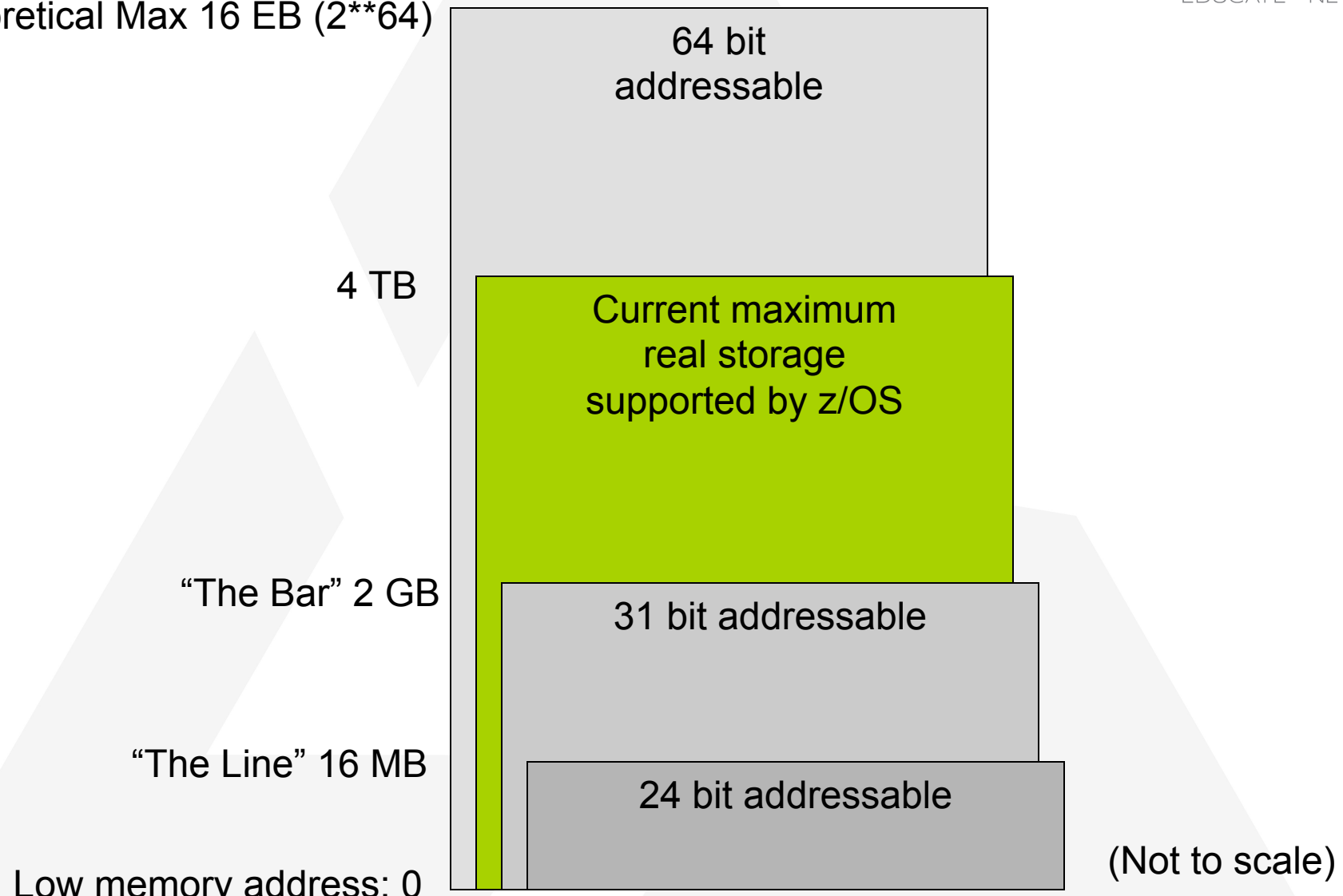


The Memory Managers

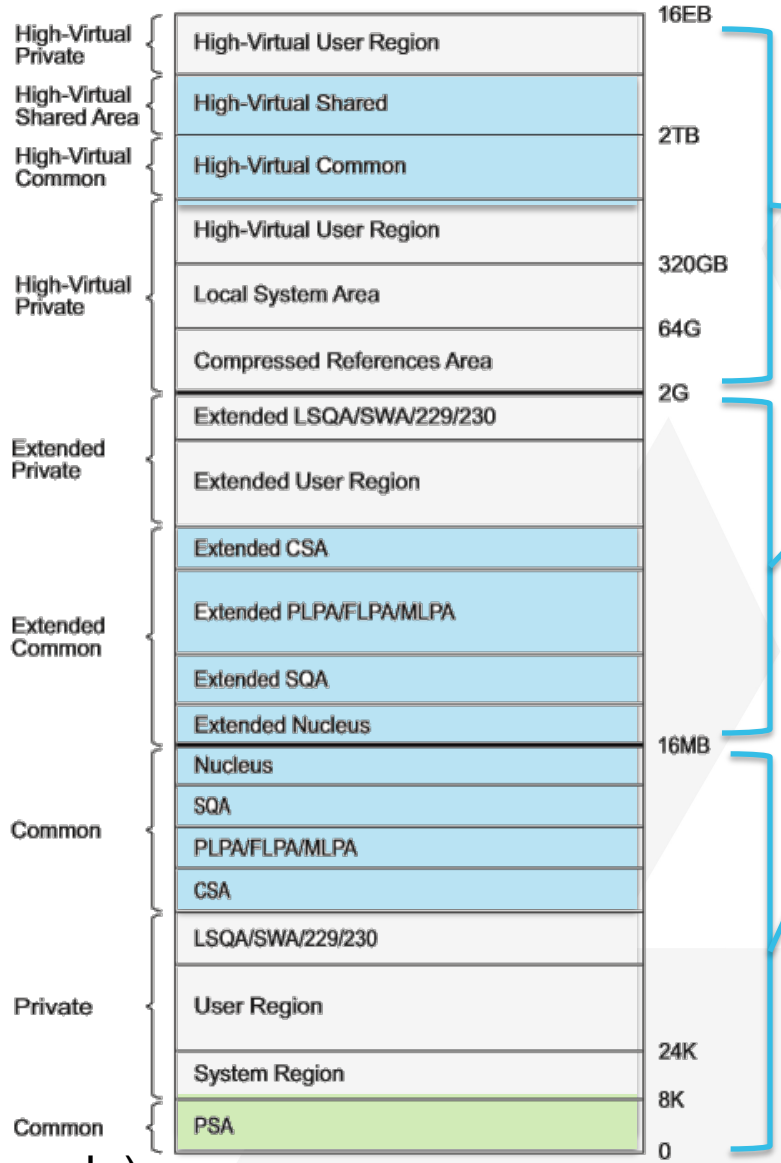
- The Virtual Storage Manager (VSM)
  - Receives the requests to obtain and release virtual storage.
  - Keeps track of the allocated and free virtual areas for the different types of storage below the 2G bar.
- The Real Storage Manager (RSM)
  - Backs the virtual storage pages with real storage frames.
  - Keeps track of the various frames needed for the different areas of virtual storage.
  - Manages 64-bit “above the bar” virtual.
- The Auxiliary Storage Manager (ASM)
  - Reads and writes pages to/from auxiliary storage.

Virtual/Real Sizes

Theoretical Max 16 EB (2**64)



Full Virtual Memory Map

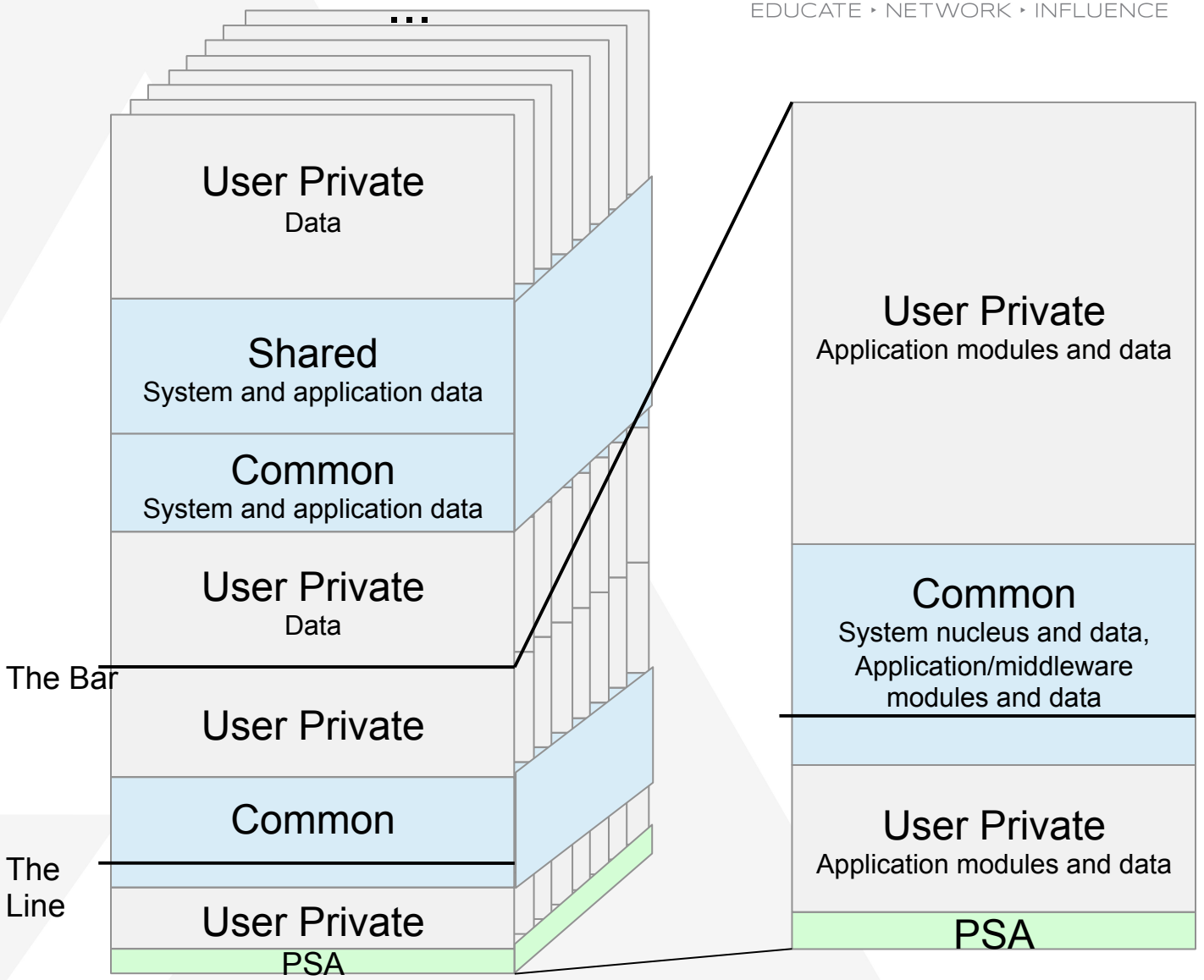


(Not to scale)

- Three addressing ranges:
  - 64-bit: 2G-16EB “Above the Bar”
  - 31-bit: 16MB-2G “Above the Line”
  - 24-bit: 0-16MB “Below the Line”
- Each has both private and common areas.

Common, Private, Shared

- Private storage is unique to each address space.
- Common storage is global to every address space.
- Share storage access can be granted to multiple address spaces.
- The Prefix Save Area (PSA) is a special area unique to each processor.



Memory Attributes

- **Viewability: Private, Common, Shared.**
- **Type:**
  - Pageable – Default for most cases. Can be backed in real or auxiliary.
  - Fixed – Use if doing I/O, running in a FLIH, or obtaining real address.
  - DREF – Use if disabled but don't need fixed.
- **Residency:**
  - Virtual: Controlled by first part of LOC option on STORAGE OBTAIN for 24 and 31 bit virtual. E.g. LOC=(31,xx).
    - IARV64/IARST64/IARCP64 are always 64-bit virtual.
  - Real: Controlled by second part to LOC option, e.g. LOC=(xx,64).
    - Only enforced if fixed.
    - LOC=(31,64) should be used by most applications.
    - 64-bit services (IARV64 et al) use 64-bit real backing.
- **Ownership:** Task, Address Space, System.
- **Others:** Key, Fetch Protection, Executable, and more.

Virtual Above and Below “The Bar”

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- Below 2G:
  - Storage requests by using the following services:
    - Getmain/Freemain, Storage Obtain/Release, CPOOL (cell pool).
    - Allocate in 8 byte increments.
- Above 2G:
  - Storage requests by using the following services:
    - IARV64 (GETSTOR/GETCOMMON/GETSHARED), IARCP64 (cell pool), IARST64.
    - IARV64 allocates in 1MB increments. Use IARST64 and IARCP64 to obtain smaller increments.

VSM: VIRTUAL STORAGE MANAGER

z/OS Memory Managers: VSM

- Virtual Storage Manager
- Address Space-centric view of the system and processes.
- Objectives:
  - Control the allocation/deallocation of 31-bit virtual storage addresses.
  - Efficiency – minimum overhead per request.
- Associate a storage protection key with each virtual storage block requested.
- Maintain storage use information by generating SMF records.

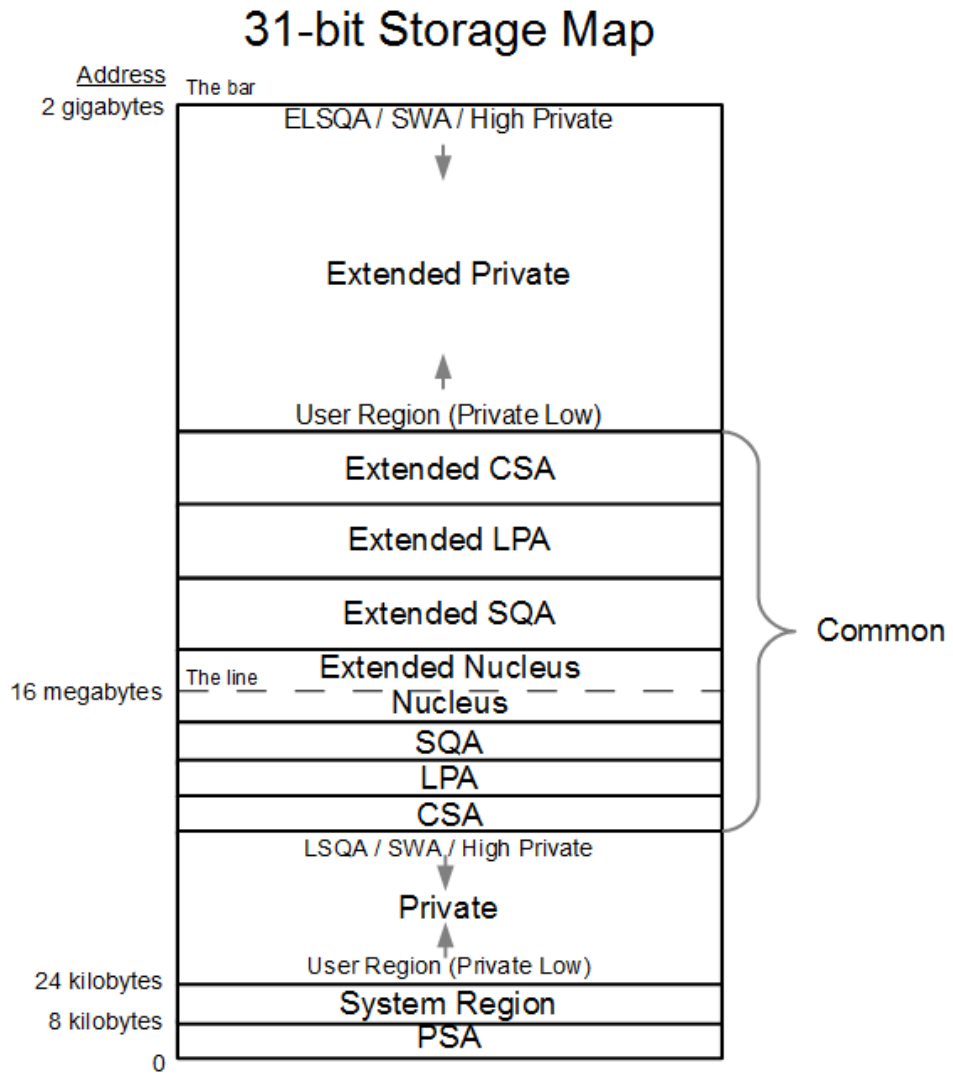
VSM Services

VSM:

- GETMAIN – Allocate 31-bit virtual.
- FREEMAIN – Free 31-bit virtual.
- STORAGE – Newer service to allocate/free 31-bit virtual.
- CPOOL – 31-bit cell pool service.

31-Bit Address Space Memory Map

- 31-bit (below the bar) virtual is managed by VSM.
- Sizes of CSA, ECSA, SQA, ESQA are specified via IEASYSxx parmlib member.



VSM Storage Management Rules

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- z/OS manages 31-bit virtual storage through the use of subpools designed to accommodate a variety of storage needs.
- Storage is allocated or assigned to a subpool in one page (4K) multiples.
- Storage belonging to different subpools cannot occupy the same page.
- Storage with different storage keys cannot occupy the same page.
- Storage belonging to different TCBs cannot occupy the same page.

Private Subpool Attributes

- **Subpool numbers**: 0 – 255
- **Storage protection:** Keys 0 – 15
- **User Region (AKA Low Private):**
  - Subpools 0 – 132, 250 – 252
  - TCB-related
  - Keyed storage
  - Unauthorized
  - General purpose subpools
- **High Private:**
  - Subpools 229, 230, 249
  - TCB-related
  - Keyed storage
  - Authorized
  - Special authorization application storage needs
- **ELSQA/LSQA:**
  - Subpool 255 (mainly)
  - Fixed, key 0 storage
  - Address space-related, not TCB-related

See MVS Diagnosis: Reference, Chapter 9, for additional subpool information

Virtual Storage Areas: Common

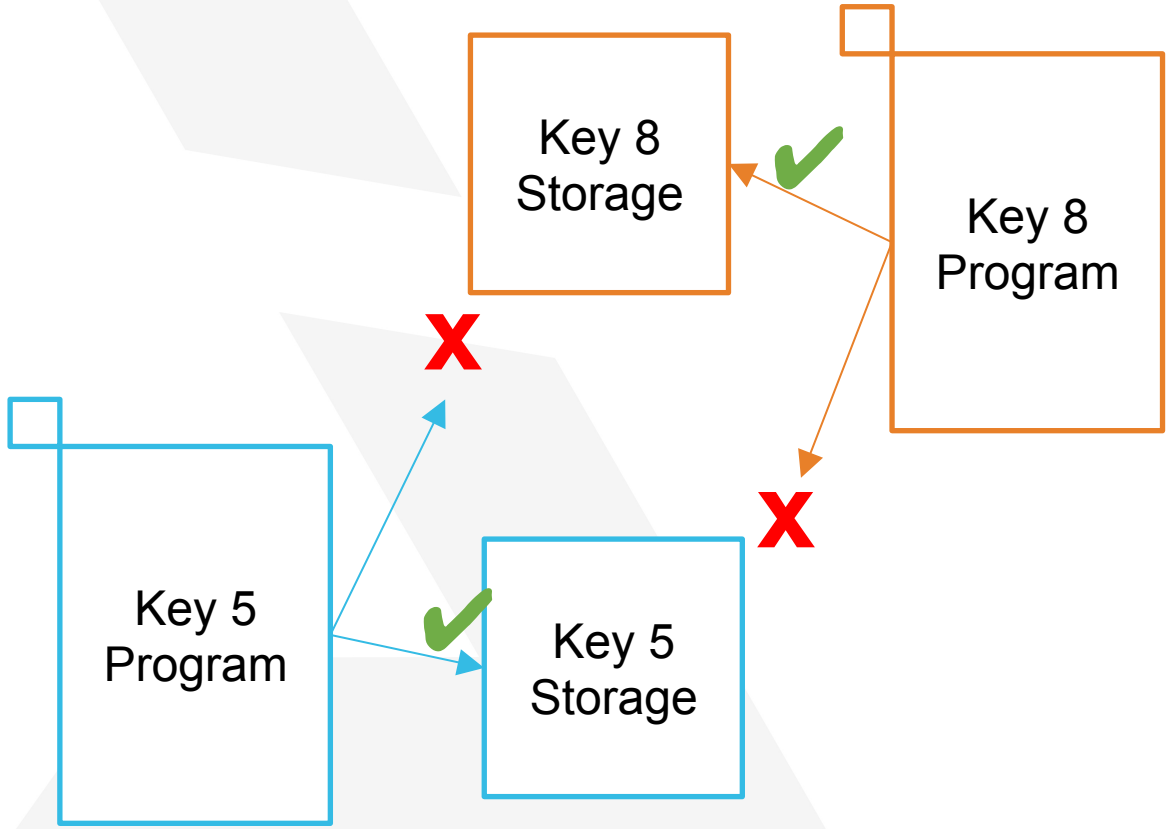
- **Common (Global) Storage**
- **Shared by all address spaces**
  - Contents of a particular virtual address is the same for all address spaces.
  - Accessible using the DAT tables for any address space.
- **Different (separate) areas of common storage.**
  - **Prefixed Save Area (PSA)** – Maps fixed hardware and software locations for the related processor
  - **Common Service Area (CSA)**
    - Pageable and fixed data areas
    - Some load to global modules
  - **Link Pack Area (LPA)**
    - Pageable Link Pack Area (PLPA)
      - Built at IPL time from libraries specified in LPALSTxx or PROGxx.
      - Contains SVC routines, access methods, and other read-only system programs, some select read-only re-enterable user programs that an be shared among users of the system, some frequently used refreshable SYS1.LINKLIB and SYS1.CMDLIB modules.
    - Modified Link Pack Area (MLPA)
      - Built at IPL time as specified in IEALPAxx.
  - **System Queue Area (SQA)**
    - Contains tables and queues relating to the entire system
    - When not enough SQA storage available, storage may be taken from CSA
  - **Nucleus (NUC)**
    - Built at IPL time
    - Read-only nuc, Read-write nuc

Virtual Storage Areas: Private

- Private (Local) Storage
- Not shared across address spaces (each address space has its own)
  - Content of a particular virtual address not same in another address space
- Different (separate) areas within the private area
  - **System Region**
    - GETMAINs for tasks running under RCT
  - **'Low-end' of private area**
    - User Region
  - **'High-end' of private area**
    - Local System Queue Area (LSQA)
    - Area for system tables and queues
    - associated with the users address space
    - Scheduler Work Area (SWA) – Contains control blocks for Initiator/Scheduler
    - Subpools 229 and 230
    - Storage obtained in requestor's storage protect key
    - Used for control blocks only obtained by auth programs with appropriate key

Storage Key Protection

- Storage keys ensure only programs with the right permissions have access to storage.
- If a program attempts to access a page in the wrong key an ABEND results.



Storage Key Details

- Pages have a storage key and fetch protect status.
- Programs run in a PSW key.
- Programs can only read and write to pages that have a storage key matching their PSW key, with the following exceptions:
  - Programs running with PSW key 0 can read and write to any key.
  - All programs can read and write key 9 storage.
  - All programs can read any storage that is not fetch protected.
- System keys are 0-7.
- User keys 8-15.

Changing Keys

- In addition to PSW key, each program has a PSW key mask (PKM) in control register 3.
  - This is initially set to match the programs PSW-key but can be changed on attach or PC routines.
- Programs can only change to a key defined by their PKM.
- Additionally authorized programs (key 0-7, supervisor state, or APF authorized) can change to any key.
- A program must be Supervisor State and Key 0 to change the storage key of a page.

EXECUTABLE=NO

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- Exploiting of z14's Instruction Execution Protection.
- New keyword EXECUTABLE.
- Specify on STORAGE OBTAIN & RELEASE (and IARV64).
- EXECUTABLE=YES is default and matches old behavior.
- EXECUTABLE=NO indicates it will not be executed.
  - ABEND0C4-4 will result if execution is attempted.
- Helps prevent security exposures that rely on injecting executable code into data buffers.
  - Best to use EXECUTABLE=NO if you know its not executable.
- Supported for non-LSQA private subpools.

VSM DIAGXX AND HEALTH CHECKS

VSM DIAGxx Statements

- VSM TRACE … – Enable GETMAIN, FREEMAIN, STORAGE (GFS) trace.
  - Many options for filtering.
- VSM TRACK … – Enable the Common Storage Tracker.
- VSM CHECKREGIONLOSS(256K,10M) – Provides way to recycle initiators when their storage becomes fragmented.
- ALLOWUSERKEYCSA(NO|YES) – YES allows user-key CSA. Default and recommendation is NO.
  - v2.3 is last release to support YES.
- VSM BESTFITCSA(NO|YES) – YES may avoid CSA fragmentation. NO is default.
- TRAPS … -- Various other diagnostic functions (mostly undocumented).

Common Storage Tracker

- Tracks owners of currently obtained SQA/ESQA and CSA/ECSA storage.
  - Address and length of storage.
  - ASID, jobname, and PSW address of owner.
  - Time and date of GETMAIN.
- Activated via DIAGxx parmlib member
  - Can be activated/deactivated at any time.
  - DIAGxx: VSM TRACK CSA(ON) SQA(ON)
  - Set DIAG=XX

Viewing Tracker Data

- VERBX VSMDATA 'OWNCOMM DETAIL'
- Formats a detailed report of common storage usage.

```
ASID Job Name Id       St T Address  Length   Ret Addr MM/DD/YYYY HH:MM:SS CAUB     GQE
---- -------- -------- -- - -------- -------- -------- ---------- -------- -------- --------
0028 IBMUSER  TSU00016 Ac C 00B44400 00000088 23FCC9D6 09/12/2005 16:45:45 0241FEB0 01DDD6A0
 Data ------> 23FAF2D8 23DB5D80 E3606000 00000088  *..2Q..).T--....h*

0028 IBMUSER  TSU00016 Ac S 00FC5018 00000030 00CA5024 09/12/2005 16:45:45 0241FEB0 01E35AF0
 Data ------> 00000000 00000000 00F97B80 00000028  *.........9#.....*

0028 IBMUSER  TSU00016 Ac S 00FC5048 00000030 00CA5024 09/12/2005 16:45:45 0241FEB0 01E35148
 Data ------> 00000000 00000000 00F97B80 00000028  *.........9#.....*

0028 IBMUSER  TSU00016 Ac S 022E7A28 00000018 039E5364 09/12/2005 16:45:57 0241FEB0 01E43C88
 Data ------> E2E8E2F1 40404040 00000000 00000000  *SYS1    ........*

0028 IBMUSER  TSU00016 Ac S 02313068 00000080 23F3D918 09/12/2005 16:45:58 0241FEB0 01E35C40
 Data ------> D1E2C1C2 00000000 00000080 01000001  *JSAB............*

0028 IBMUSER  TSU00016 Ac S 02546000 00000060 00D3D1AE 09/12/2005 16:45:58 0241FEB0 01E35C70
 Data ------> E2E3D8C5 F500005C 00000000 00000000  *STQE5..*........*

0028 IBMUSER  TSU00016 Ac S 025C1578 00000048 2466F036 09/12/2005 16:45:57 0241FEB0 01E35BC8
 Data ------> D3D4C1C2 00000000 7FF4EF60 7FF4EF60  *LMAB....."4.-"4.-*
```

VSM Health Checks

- VSM_CSA_CHANGE – Warn if CSA size is different this IPL.
- VSM_CSA_THRESHOLD – Warn if CSA is getting full.
- VSM_SQA_LIMIT – Warn if SQA size is too small.
- VSM_PVT_LIMIT – Warn if private area is too small.
- VSM_CSA_LIMIT – Warn if CSA size is too small.
- VSM_SQA_THRESHOLD – Warn if SQA is getting too full.
  – Note that some installation normally overflow SQA into CSA.
- VSM_ALLOWUSERKEYCSA – Warns if using insecure “YES” option.
- VSM_CSA_LARGEST_FREE – Warns if CSA is becoming fragmented.

RSM AND LARGE PAGES

Large Pages: What Are They?

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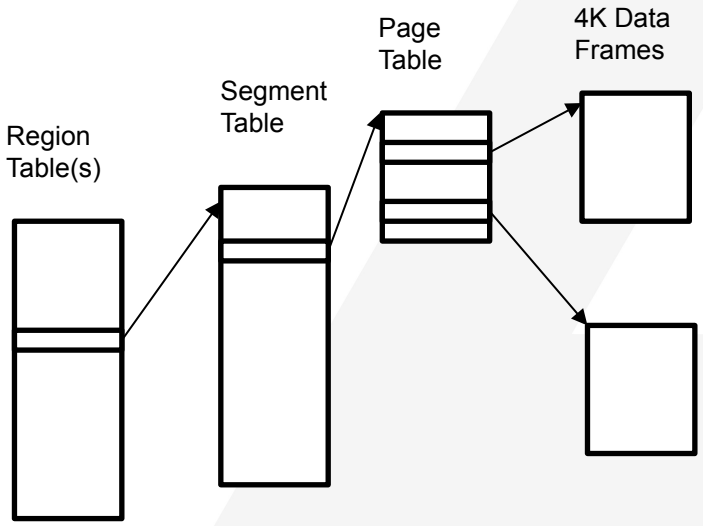
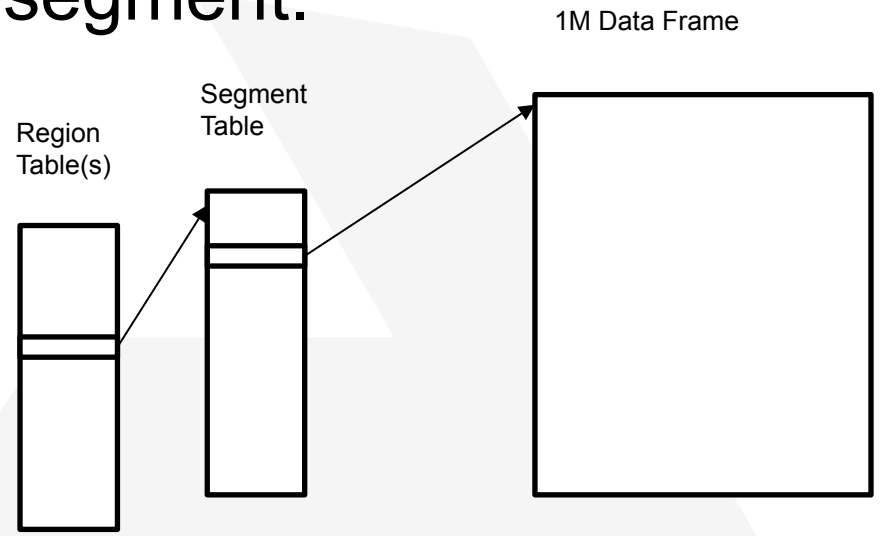
4K Pages:

- Page table points to 4K frames.
- Uses up to 256 TLB entries per segment.



1M Pages:

- No page table.
- Segment table points to 1M frames.
- Uses only one TLB entry per segment.



Importance of Exploiting Large Pages

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- Problem: Performance degradation due to increased TLB (Translation Lookaside Buffer) misses.
  - Over the past years application memory sizes have dramatically increased due to support for 64-bit addressing in both physical and virtual memory.
  - TLB sizes have remained relatively small due to low access time requirements and hardware space limitations.
  - Therefore TLB coverage today represents a much smaller fraction of an applications working set size leading to a larger number of TLB misses.
  - Applications can suffer a significant performance penalty resulting from an increased number of TLB misses as well as the increased cost of each TLB miss.

Importance of Exploiting Large Pages

- Benefits: Increase TLB coverage without proportionally enlarging the TLB size by using large pages:
  - Large pages will provide exploiters with better TLB coverage, and therefore better performance by decreasing the number of TLB misses that an application incurs.
  - Less time spent converting virtual addresses into physical addresses.
  - Less page faults as whole 1MB is backed at once instead of for each 4k page.
  - A large page is a memory page larger than an ordinary 4K base page. z/OS supports the following 2 large page sizes:
    - 1MB.
    - 2GB.

Key Exploiters of Large Pages

- Db2:
  - 1M (V10) and 2G (V11) page frame size for PGFIX(YES) pools.
  - FRAMESIZE parameter in Db2 11.
  - IBM evaluation shows:
    - 1-3% improvement from 4K frames to 1M frames (zEC12).
    - 1-3% improvement from 1M frames to 2G frames (z13).
- Java™:
  - Pageable 1MB is default as of Java 7.
  - Use option -Xlp to control the page size such as to use 2GB pages.
  - WAS Day Trader benchmarks showed up to an 8% performance improvement.
- z/OS itself uses large pages in many places when they are available.

Large Pages in 31-bit Virtual

- The most significant benefit of large pages comes from applications that use vast amounts of data (e.g. 64-bit).
  - 31-bit applications can gain benefits as well if they frequently touch many pages together.
- 31-bit private via STORAGE OBTAIN and CPOOL:
  - LOC=(31|EXPLICIT,PAGEFRAMESIZE1MB).
  - Indicates to back pages in 64-bit real and prefer 1MB frames.
  - Only 0-127, 129-132, 240, 244 or 250-252 (Private low, pageable).
- Data spaces via DSPSERV:
  - PAGEFRAMESIZE=1M on CREATE (changes default to BACK=64).
  - BLOCKS does not need to be multiple of 256.

Large Frame Areas (Pre-v2.3)

- 1MB LFAREA - Large Frame Area
  - Fixed storage each frame is 1MB
  - Defined by LFAREA (1M=) (IEASYSxx)
  - Included in Available Frame Count when INCLUDE1MAFC=YES
- PLAREA – Pageable Large Area
  - Pageable storage each frame is 1MB.
  - System defined size approximately (online storage at IPL time)/8 if enough storage is left above 2G after LFAREA and Quad Area are defined.
  - Allocated on SCM capable machines.
  - Can overflow in the LFAREA.
- 2GB LFAREA Large Frame Area
  - Fixed storage each frame is 2GB
  - Defined by LFAREA (2G =) (IEASYSxx)
  - Not included in Available Frame Count – used only for 2G requests
  - Reserved for specific 2GB memory objects

Large Frame Areas in z/OS v2.3

- 1MB LFAREA - Large Frame Area
  - No longer physical range.
  - Managed dynamically in non-reconfigurable memory above 2G bar.
  - Capped by LFAREA (1M=) (IEASYSxx)
  - INCLUDE1MAFC=NO is ignored.
- PLAREA – Pageable Large Area
  - No longer physical range.
  - Managed dynamically in non-reconfigurable memory above 2G bar.
  - No cap.
- 2GB LFAREA Large Frame Area
  - Unchanged in v2.3.

Sizing LFAREA for Fixed 1MB

- Calculate how much you will need for Db2 buffer pools, JVM Heaps, etc.
- Best to add additional memory corresponding to the specified LFAREA size to existing system memory.
- Have enough 4K frames to handle your 4K workload needs (both pageable and fixed).
  - Have enough 4K frames above the bar to avoid RSM breaking down free 1M frames and paging or page movement for 4K page Fixes
    - Include RSM needs for memory mapping - 1/64 total online real at IPL (4g for 256G system)
    - System address space memory usage.
    - Include enough spare 4K frames for taking dumps quickly.
- Doc APAR OA34024 gives some guidance on how to size the LFAREA.

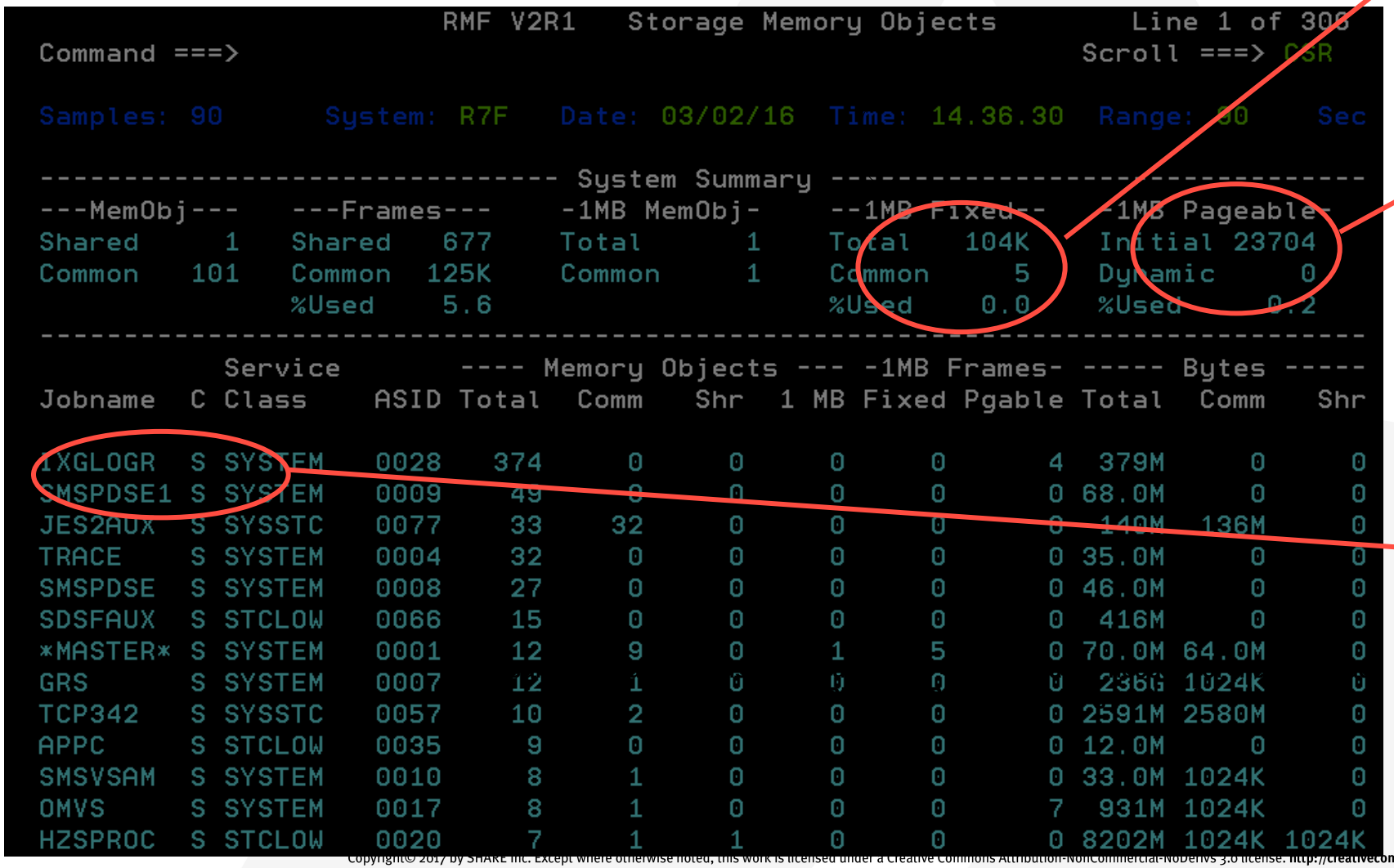
Sizing LFAREA for Pageable 1M (Pre-v2.3)

- Pageable Large Pages overflow into the LFAREA when PLAREA is depleted.
- If you want to ensure your system has enough Pageable Large Pages specify additional memory for the LFAREA to also accommodate Pageable Large Pages.
- The following z/OS System Console command D VS,LFAREA can be used to display LFAREA usage by 1MB fixed, 4K, and 1MB pageable large pages.

```
RESPONSE=PA1
 IAR019I  17.13.02 DISPLAY VIRTSTOR 175
  SOURCE =  OM
  TOTAL LFAREA = 120422M , 0G
  LFAREA AVAILABLE = 0M , 0G
  LFAREA ALLOCATED (1M) = 0M
  LFAREA ALLOCATED (4K) = 0M
  MAX LFAREA ALLOCATED (1M) = 0M
  MAX LFAREA ALLOCATED (4K) = 0M
  LFAREA ALLOCATED (PAGEABLE1M) = 120422M
  MAX LFAREA ALLOCATED (PAGEABLE1M) = 120422M
  LFAREA ALLOCATED NUMBER OF 2G PAGES = 0
  MAX LFAREA ALLOCATED NUMBER OF 2G PAGES = 0
```

Right-Sizing the LFAREA

RMF Monitor III - STORF



```
                        RMF V2R1   Storage Memory Objects          Line 1 of 306
Command ===>                                                  Scroll ===> CSR

Samples: 90      System: R7F   Date: 03/02/16  Time: 14.36.30  Range: 90     Sec

------------------------------ System Summary -------------------------------
---MemObj---    ---Frames---    -1MB MemObj-    --1MB Fixed--    -1MB Pageable-
Shared     1    Shared   677    Total      1    Total    104K    Initial 23704
Common   101    Common  125K    Common     1    Common      5    Dynamic     0
               %Used    5.6                     %Used     0.0    %Used       0.2
-----------------------------------------------------------------------------
          Service       ---- Memory Objects --- -1MB Frames- ----- Bytes -----
Jobname   C Class    ASID Total  Comm    Shr  1 MB Fixed Pgable Total  Comm    Shr

IXGLOGR   S SYSTEM   0028   374     0      0      0     0      4  379M     0      0
SMSPDSE1  S SYSTEM   0009    49     0      0      0     0      0 68.0M     0      0
JES2AUX   S SYSSTC   0077    33    32      0      0     0      0  140M  136M      0
TRACE     S SYSTEM   0004    32     0      0      0     0      0 35.0M     0      0
SMSPDSE   S SYSTEM   0008    27     0      0      0     0      0 46.0M     0      0
SDSFAUX   S STCLOW   0066    15     0      0      0     0      0  416M     0      0
*MASTER*  S SYSTEM   0001    12     9      0      1     5      0 70.0M 64.0M      0
GRS       S SYSTEM   0007    12     1      0      0     0      0  236G 1024K      0
TCP342    S SYSSTC   0057    10     2      0      0     0      0 2591M 2580M      0
APPC      S STCLOW   0035     9     0      0      0     0      0 12.0M     0      0
SMSVSAM   S SYSTEM   0010     8     1      0      0     0      0 33.0M 1024K      0
OMVS      S SYSTEM   0017     8     1      0      0     0      7  931M 1024K      0
HZSPROC   S STCLOW   0020     7     1      1      0     0      0 8202M 1024K 1024K
```

Monitor and adjust LFAREA parms based on workload.

Pre-v2.3, track Pagable large overflow into LFAREA. Average number of 1 MB frames in the LFAREA that were used to satisfy 1 MB pageable page request.

Note: all system address space large page usage.

z/OS v2.3 Large Page Display

```
F AXR,IAXDMEM
IAR049I DISPLAY MEMORY V1.0
PAGEABLE 1M STATISTICS
 4824.0MB : TOTAL SIZE
 4585.0MB : AVAILABLE FOR PAGEABLE 1M PAGES
    3.0MB : IN-USE FOR PAGEABLE 1M PAGES
    3.0MB : MAX IN-USE FOR PAGEABLE 1M PAGES
    1.0MB : FIXED PAGEABLE 1M FRAMES
LFAREA 1M STATISTICS - SOURCE = IEASYS23
   64.0MB : TOTAL SIZE
   62.0MB : AVAILABLE FOR FIXED 1M PAGES
    2.0MB : IN-USE FOR FIXED 1M PAGES
    2.0MB : MAX IN-USE FOR FIXED 1M PAGES
LFAREA 2G STATISTICS - SOURCE = IEASYS23
    0.0MB : TOTAL SIZE = 0
    0.0MB : AVAILABLE FOR 2G PAGES = 0
    0.0MB : IN-USE FOR 2G PAGES = 0
    0.0MB : MAX IN-USE FOR 2G PAGES = 0
```

- New display in v2.3 with large page statistics.
- Pageable 1MB stats including number of 1M still available. If often low, consider adding memory.
- LFAREA 1M stats including total size (cap).
- LFAREA 2G stats.

Other Performance Techniques

- Large pages have great benefits but there are many other ways to gain performance.
- Applications:
  - Avoid frequent obtaining and freeing storage.
    - Use cell pools or pre-allocated storage on common paths instead of GETMAIN each time.
  - Buffer data instead of a second I/O or long calculation.
  - Multi-threaded applications should consider cache alignment of frequently used fields.
    - Keep frequent updates in separate cache lines from unrelated frequent reads.
- Installations:
  - Ensure plenty of memory is available.
    - Avoid all paging if performance is a premium.
  - Use storage-class memory (SCM) such as Flash Express or Virtual Flash Memory (VFM).

And much more… performance and tuning is a vast topic barely touched on here.

Questions?

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BACKUP

Virtual Storage Areas: Common

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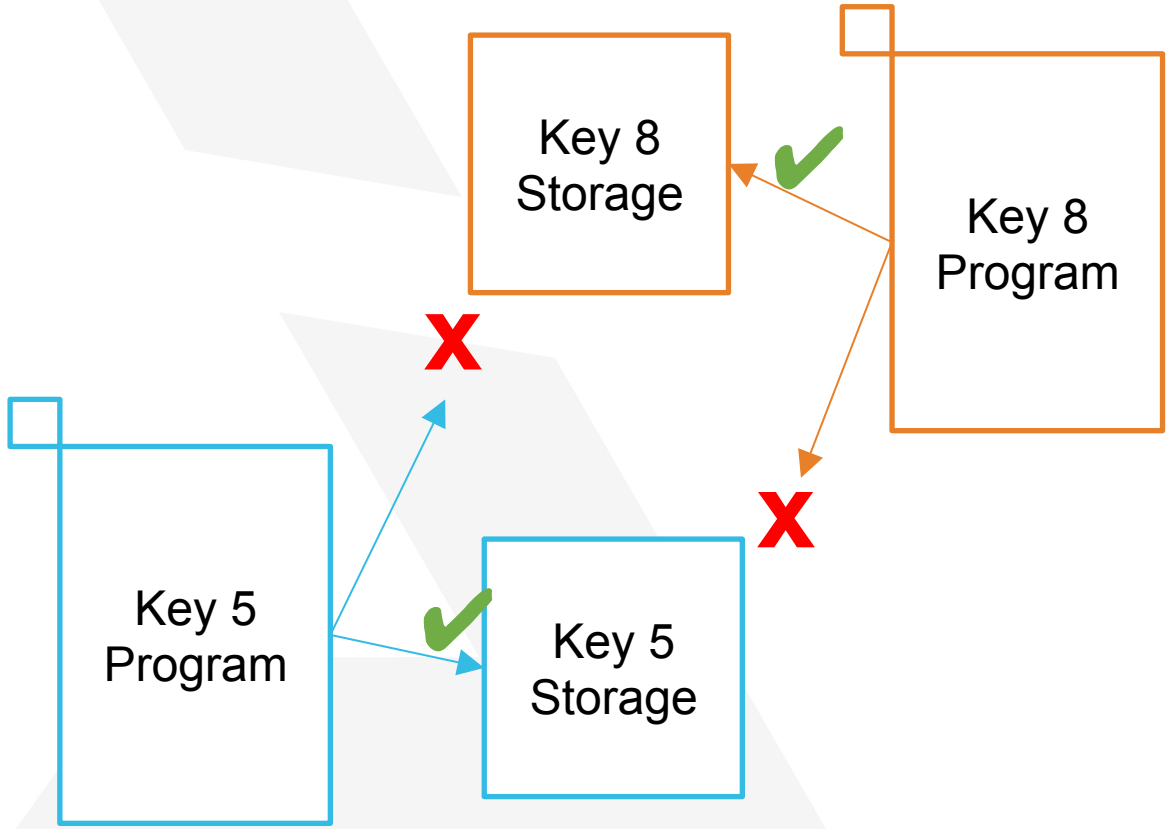
      - Built at IPL time from libraries specified in LPALSTxx or PROGxx.
      - Contains SVC routines, access methods, and other read-only system programs, some select read-only re-enterable user programs that an be shared among users of the system, some frequently used refreshable SYS1.LINKLIB and SYS1.CMDLIB modules.
    - Fixed Link Pack Area (FLPA)
      - Built at IPL time as specified in IEAFIXxx.
    - Modified Link Pack Area (MLPA)
      - Built at IPL time as specified in IEALPAxx.
  - System Queue Area (SQA)
    - Contains tables and queues relating to the entire system
    - When not enough SQA storage available, storage may be taken from CSA
  - Nucleus (NUC)
    - Built at IPL time
    - Read-only nuc, Read-write nuc

Virtual Storage Areas: Private

- Private (Local) Storage
- Not shared across address spaces (each address space has its own)
  - Content of a particular virtual address not same in another address space
- Accessible only using the DAT tables from that address space
- Different (separate) areas within the private area
    - System Region
      - GETMAINs for tasks running under RCT
    - ‘Low-end’ of private area
      - User Region
    - ‘High-end’ of private area
      - Local System Queue Area (LSQA)
      - Area for system tables and queues
      - associated with the users address space
      - Scheduler Work Area (SWA) – Contains control blocks for Initiator/Scheduler
      - Subpools 229 and 230
      - Storage obtained in requestor’s storage protect key
      - Used for control blocks only obtained by auth programs with appropriate key

Storage Key Protection

- Storage keys ensure only programs with the right permissions have access to storage.
- If a program attempts to access a page in the wrong key an ABEND results.



Storage Key Details

- Pages have a storage key and fetch protect status.
- Programs run in a PSW key.
- Programs can only read and write to pages that have a storage key matching their PSW key, with the following exceptions:
  - Programs running with PSW key 0 can read and write to any key.
  - All programs can read and write key 9 storage.
  - All programs can read any storage that is not fetch protected.
- System keys are 0-7.
- User keys 8-15.

Changing Keys

- In addition to PSW key, each program has a PSW key mask (PKM) in control register 3.
  - This is initially set to match the programs PSW-key but can be changed on attach or PC routines.
- Programs can only change to a key defined by their PKM.
- Additionally authorized programs (key 0-7, supervisor state, or APF authorized) can change to any key.
- A program must be Supervisor State and Key 0 to change the storage key of a page.

DIAGxx TRAPS for 64-bit

- IarCp64InitGet – Put non-zero into cells on get for test.
- IarCp64InitFree – Put non-zero into cells on free for test.
- IarCp64Trailer – Always use cell trailer to detect overflow.
- IarSt64InitGet – Put non-zero into storage on get for test.
- IarSt64InitFree – Put non-zero into storage on free for test.
- IarSt64Trailer – Always use storage trailer to detect overflow.