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Real Kernel Debugging in a Virtualized Environment

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Agenda

- Introduction
- Basic CP commands for debugging
- Tracing execution of the guest system
- Program Status Word
- Examples
  - Modify system memory
  - Operation Exception

System Setup

- Linux System as a z/VM guest
- z/VM 6.2
- Examples with SLES11 SP1
- Nothing special used, so should work with others as well

CP Commands

- BEGIN
- DISPLAY
- SLEEP
- STOP
- STORE
- TRACE

CP Commands

- BEGIN
- DISPLAY
- SLEEP
- STOP
- STORE
- TRACE
- Need Class G Priveleges

Pausing the Guest System

```
#CP STOP
#CP BEGIN
```

Stop the guest system and continue to run.

Pausing the Guest System

```
#CP SLEEP
#CP BEGIN
```

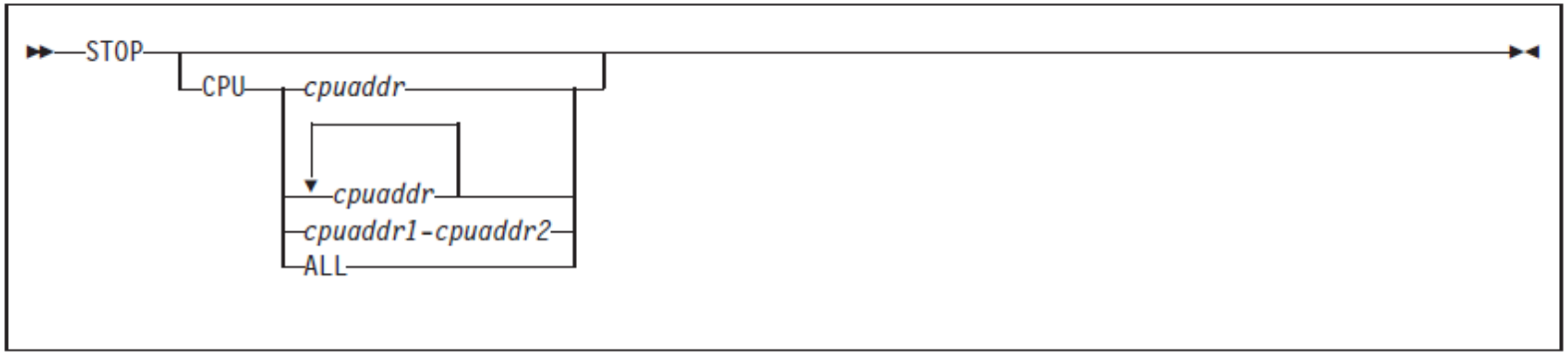
Set the guest system to sleep.
Basically the same as STOP.

Pausing the Guest System

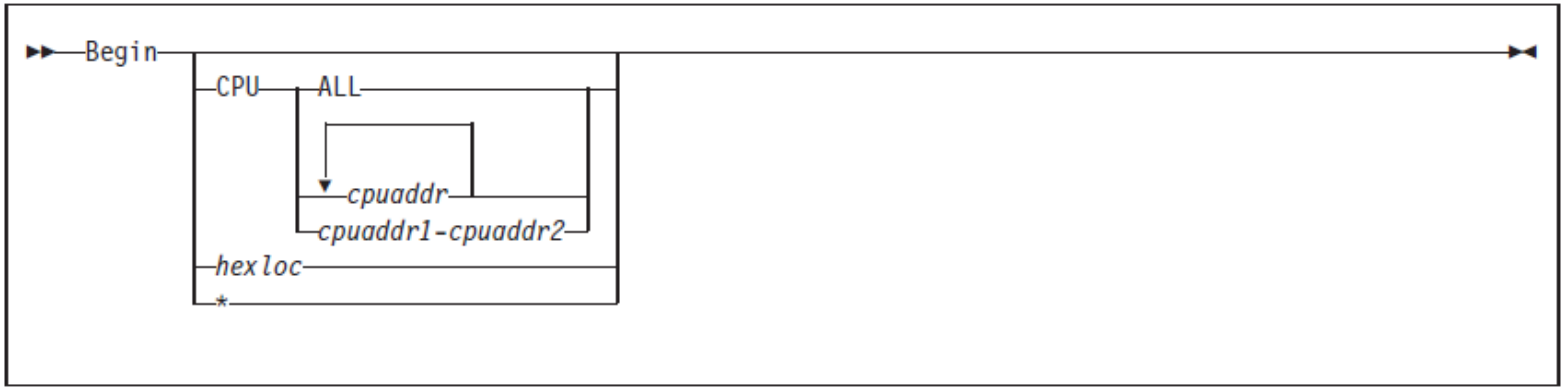
```
#CP SLEEP 10 SEC
```

Let the guest system sleep for 10 seconds. Can also be minutes or hours.

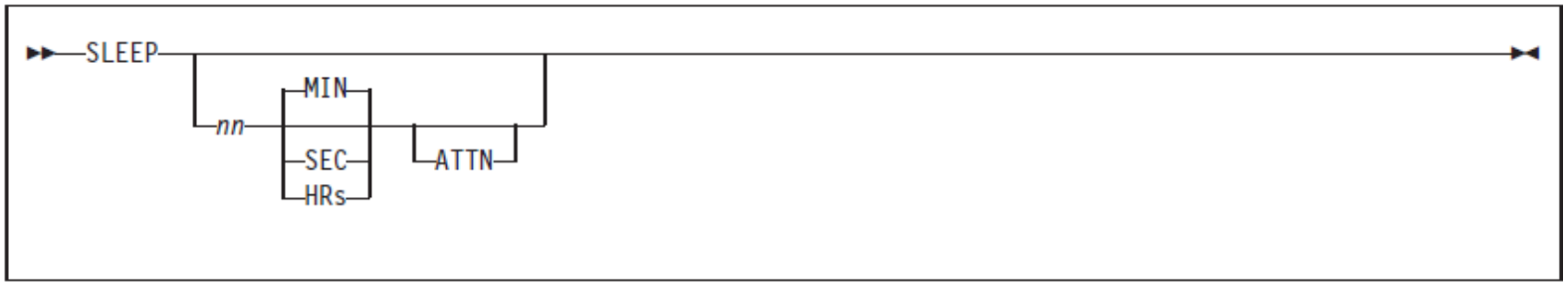
STOP



BEGIN



SLEEP



DISPLAY

- Display general-purpose registers

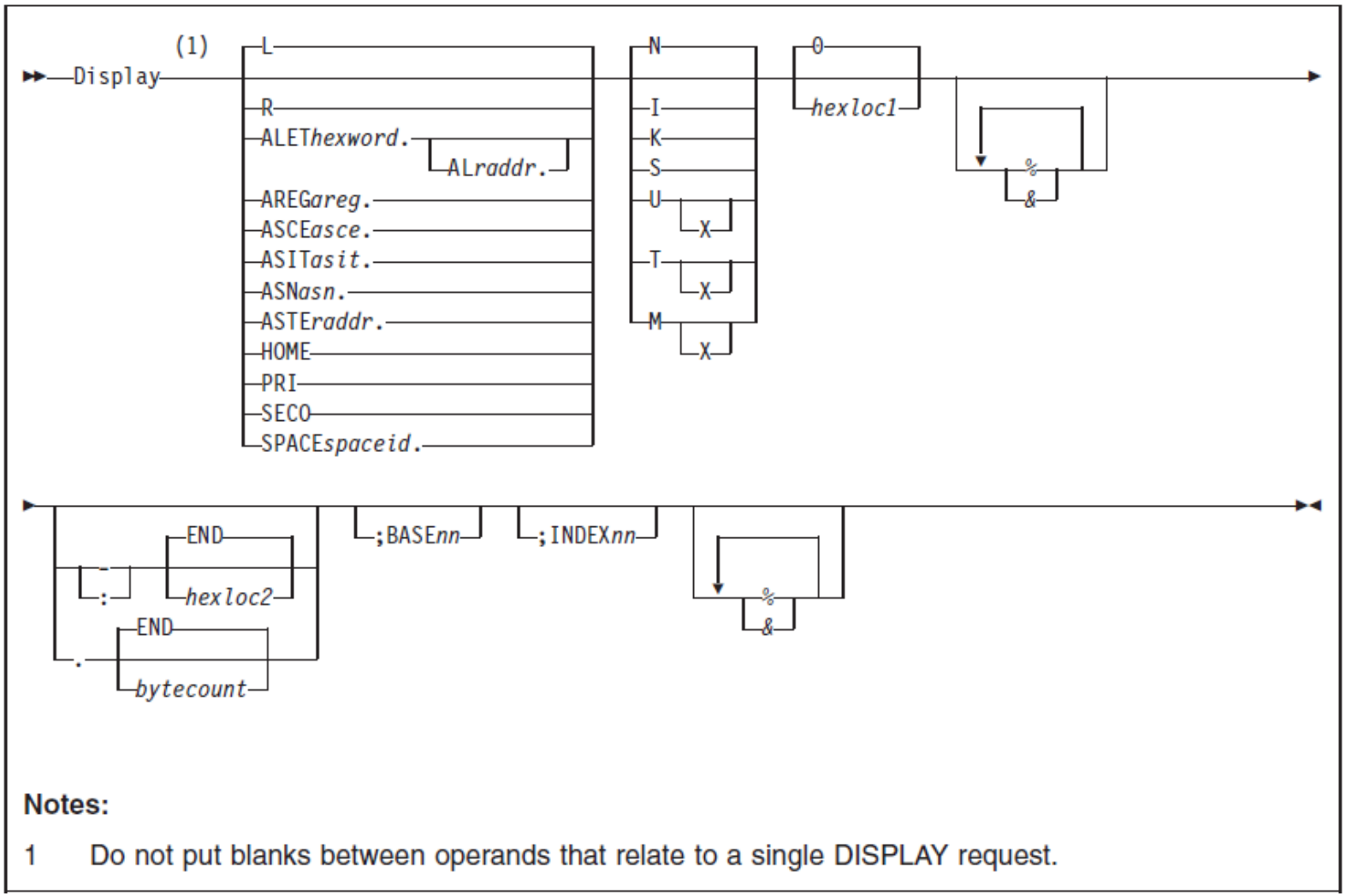
```
DISPLAY G
00: GPR  0 =  00000000  8000060C  00000001  FF9B1518
00: GPR  4 =  FF9B1528  001B8F70  8000066C  FF9B1500
00: GPR  8 =  800004EC  800F17B0  80000670  801C05E0
00: GPR 12 =  001B6000  0016A930  00057898  FF9B12F0
```

DISPLAY

- Display general registers-purpose in 64 bit format

```
DISPLAY GG
00: GRG  0 =  0000000000000000  000000008000060C
00: GRG  2 =  0000000000000001  000003FFFF9B1518
00: GRG  4 =  000003FFFF9B1528  00000200001B8F70
00: GRG  6 =  000000008000066C  000003FFFF9B1500
00: GRG  8 =  00000000800004EC  00000000800F17B0
00: GRG 10 =  0000000080000670  00000000801C05E0
00: GRG 12 =  00000200001B6000  000002000016A930
00: GRG 14 =  0000020000057898  000003FFFF9B12F0
```

DISPLAY



Notes:

1 Do not put blanks between operands that relate to a single DISPLAY request.

Display Storage

- Display Linux virtual storage

```
DISPLAY 80002040
00: V80002040   0000007F                                  06 R2E3FE040
```

Display Storage

- Display Linux real storage

```
DISPLAY R2E3FE040
00: R2E3FE040   0000007F                                  06
```

Modify Storage

- Modify Linux virtual storage

```
STORE 80002040 18
00: Store complete.
DISPLAY 80002040
00: V80002040  00000018                                  06 R2E3FE040
```

Trace

Display current trace settings

```
QUERY TRACE
00: No trace sets defined
```

Trace

Trace any write operation to a memory location
Operation is stopped at this point

```
TRACE STORE INTO 80002060
```

This is a breakpoint

Trace

```
QUERY TRACE
00:
00: NAME  INITIAL     (ACTIVE)
00:
00:   1     STORE   FROM  0000000000000000-FFFFFFFFFFFFFFFF
00:               INTO  80002060
00:         TERM    NOPRINT  NORUN  SIM
00:         SKIP 00000  PASS 00000  STOP 00000  STEP 00000
00:         CMD  NONE
00:
```

Trace

End tracing and remove all trace settings

```
TRACE END
00: Trace ended
```

Trace

```
QUERY TRACE
00: No trace sets defined
```

Trace

Set 2 breakpoint

```
TRACE STORE INTO 80002050
TRACE STORE INTO 80002060
```

Trace

```
QUERY TRACE
00:
00: NAME  INITIAL     (ACTIVE)
00:
00:   1     STORE   FROM  0000000000000000-FFFFFFFFFFFFFFFF
00:                 INTO  80002050
00:         TERM    NOPRINT  NORUN  SIM
00:         SKIP 00000  PASS 00000  STOP 00000  STEP 00000
00:         CMD  NONE
00:
00:   2     STORE   FROM  0000000000000000-FFFFFFFFFFFFFFFF
00:                 INTO  80002060
00:         TERM    NOPRINT  NORUN  SIM
00:         SKIP 00000  PASS 00000  STOP 00000  STEP 00000
00:         CMD  NONE
00:
```

Trace

Remove a single trace setting

```
TRACE DELETE 1
```

Trace

```
QUERY TRACE
00:
00: NAME  INITIAL     (ACTIVE)
00:
00:   2     STORE   FROM  0000000000000000-FFFFFFFFFFFFFFFF
00:                 INTO  80002060
00:         TERM    NOPRINT  NORUN  SIM
00:         SKIP 00000  PASS 00000  STOP 00000  STEP 00000
00:         CMD  NONE
00:
```

Trace

Set a breakpoint on a instruction address

```
TRACE END
TRACE INSTRUCTION PSWA 8000060C
```

Trace

Set a breakpoint on a instruction address

```
TRACE END
TRACE INSTRUCTION PSWA 8000060C
QUERY TRACE
00:
00: NAME  INITIAL     (ACTIVE)
00:
00:   1     INSTR   PSWA  8000060C
00:         TERM    NOPRINT  NORUN  SIM
00:         SKIP 00000  PASS 00000  STOP 00000  STEP 00000
00:         CMD  NONE
00:
```

Trace

Set a breakpoint on a instruction address without interrupting operation

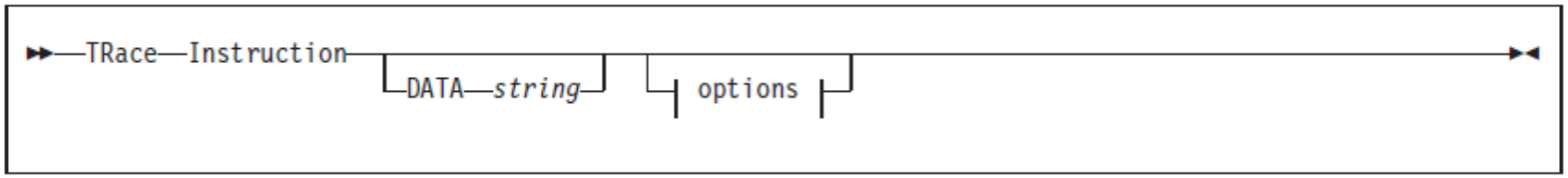
```
TRACE END
TRACE INSTRUCTION PSWA 8000060C RUN
```

Trace

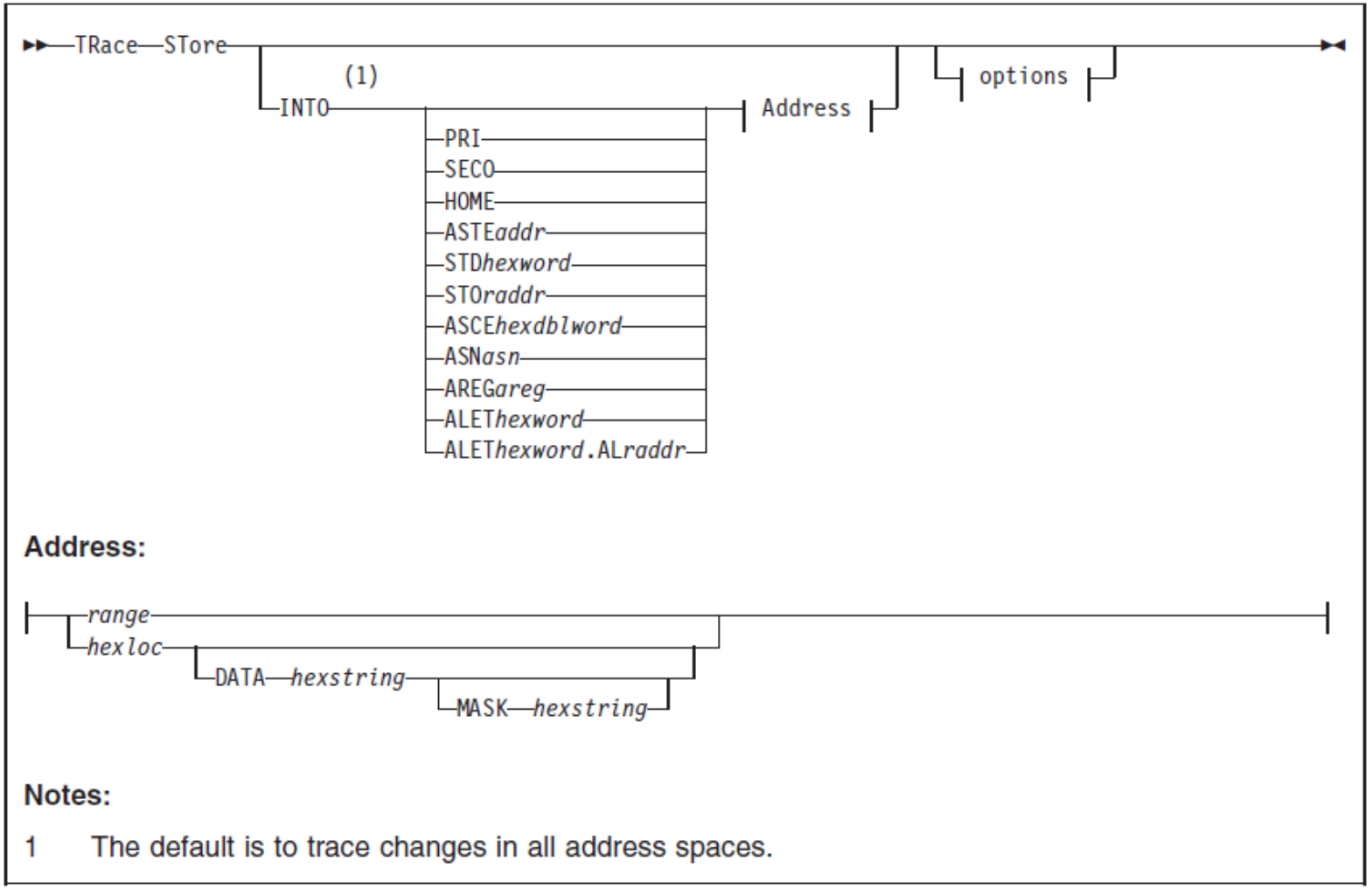
Set a breakpoint on a instruction address without interrupting operation

```
TRACE END
TRACE INSTRUCTION PSWA 8000060C RUN
QUERY TRACE
00:
00: NAME  INITIAL     (ACTIVE)
00:
00:   1     INSTR   PSWA  8000060C
00:         TERM    NOPRINT  RUN    SIM
00:         SKIP 00000  PASS 00000  STOP 00000  STEP 00000
00:         CMD  NONE
00:
```

TRACE



TRACE STORE


TRace STore
(1)
INTO
PRI
SECO
HOME
ASTEaddr
STDhexword
STOraddr
ASCEhexdblword
ASNasn
AREGareg
ALEThexword
ALEThexword.ALraddr
Address
options
Address:
range
hexloc
DATA hexstring
MASK hexstring
Notes:
1 The default is to trace changes in all address spaces.

Program Status Word

- Display Program Status Word

```
DISPLAY PSWG
```

Program Status Word

- Display Program Status Word

```
#CP DISPLAY PSWG
00: PSW = 07060001 80000000 00000000 00115326
```

Program Status Word

- Show Program Status Word

```
#CP DISPLAY PSWG
00: PSW = 07060001 80000000 00000000 00115326
```

Shows always the same
Why ?

Program Status Word

- Show Program Status Word

```
#CP DISPLAY PSWG
00: PSW = 07060001 80000000 00000000 00115326
```

Shows always the same
Why ?

Where is the program execution currently

Program Status Word

```
#CP STOP
DISPLAY PSWG
00: PSW = 07060001 80000000 00000000 00115326
```

Look up instruction address in /boot/System.map

```
0000000000114ef4 T arch_setup_additional_pages
0000000000115064 T vdso_free_per_cpu
0000000000115100 T vdso_alloc_per_cpu
00000000001152a0 T vtime_stop_cpu
000000000011537c T s390_get_idle_time
0000000000115408 T init_virt_timer
0000000000115420 T init_cpu_vtimer
```

Program Status Word

Display all Program Status Words

```
DISPLAY PSWG ALL
00: PSW = 07060001 80000000 00000000 00115326
00: EXT 1004  130 OLD 07060001 80000000 00000000 00115326
00:           1B0 NEW 04040001 80000000 00000000 001184CC
00: SVC 00A8  140 OLD 0705C001 80000000 00000200 003C136A
00:           1C0 NEW 07040001 80000000 00000000 00117DAC
00: PRG 0004  150 OLD 0705D001 80000000 00000200 0011A43E
00:           1D0 NEW 04040001 80000000 00000000 00118068
00: MCH 0000  160 OLD 00000000 00000000 00000000 00000000
00:           1E0 NEW 00000001 80000000 00000000 001185BA
00: I/O 0003  170 OLD 07060001 80000000 00000000 00115326
00:           1F0 NEW 04040001 80000000 00000000 001182F4
```

Program Status Word

```
00: PRG 0004  150 OLD 0705D001 80000000 00000200 0011A43E
00:           1D0 NEW 04040001 80000000 00000000 00118068
```

```
grep 118068 /boot/System.map
0000000000118068 T pgm_check_handler
```

Program Status Word

```
00: I/O 0003  170 OLD 07060001 80000000 00000000 00115326
00:           1F0 NEW 04040001 80000000 00000000 001182F4
```

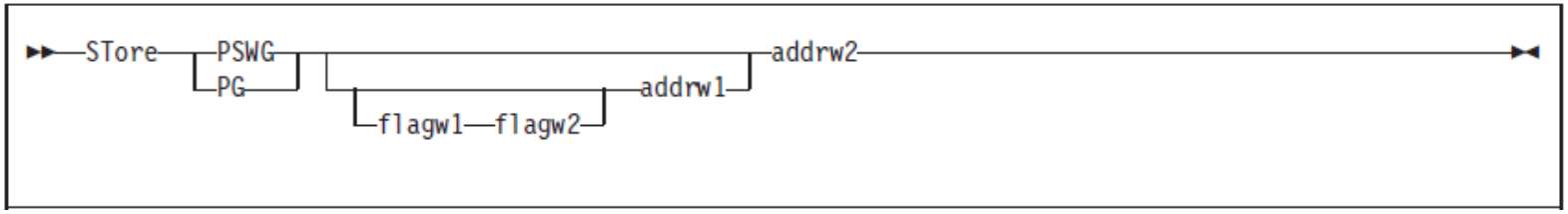
```
grep -i 1182F4 /boot/System.map
000000000001182f4 T io_int_handler
```

Program Status Word

```
00: SVC 00A8  140 OLD 0705C001 80000000 00000200 003C136A
00:           1C0 NEW 07040001 80000000 00000000 00117DAC
```

```
grep -i 117DAC /boot/System.map
0000000000117dac t __critical_start
0000000000117dac T system_call
```

STORE PSWG



Modify system memory

Simple example code prints a variable, changes the variable and prints it again

```
#include <stdio.h>

int a = 34;

int main() {
        printf("Code Segment   = %p\n", &main);
        printf("Data Segment a = %p\n", &a);

        printf("a = %d\n", a);
        a = 127;
        printf("a = %d\n", a);

        return 0;
}
```

Modify system memory

Normal execution

```
./memory
Code Segment    = 0x8000060c
Data Segment a = 0x80002040
a = 34
a = 127
```

Modify system memory

Set break point at entrance of main()

```
#CP STOP
TRACE INSTRUCTION PSWA 8000060C
BEGIN
```

Modify system memory

```
./memory
```

```
00:   -> 0000000080000060C"   STMG     EBBFF0580024 >> 000003FFFF86B348      CC 2
DISPLAY PSWG
00: PSW = 0705E001 80000000 00000000 80000612
DISPLAY 80002040
00: V80002040   00000022                                 06 R2E3FE040
```

Modify system memory

```
./memory
```

```
00:   -> 0000000080000060C"  STMG    EBBFF0580024 >> 000003FFFF86B348     CC 2
DISPLAY PSWG
00: PSW = 0705E001 80000000 00000000 80000612
DISPLAY 80002040
00: V80002040  00000022                          06 R2E3FE040
TRACE STORE INTO 80002040
BEGIN
```

Set a breakpoint on the variable a

Modify system memory

```
./memory
```

```
00:   -> 0000000080000668"   ST       50201000 >> 0000000080002040      CC 0
DISPLAY 80002040
00: V80002040   0000007F                              06 R2E3FE040
```

Modify system memory

```
./memory
```

```
00:   -> 0000000080000668"  ST       50201000 >> 0000000080002040      CC 0
DISPLAY 80002040
00: V80002040  0000007F                          06 R2E3FE040
STORE 80002040 18
00: Store complete.
```

Modify value of variable a

Modify system memory

```
./memory
```

```
00:   -> 0000000080000668"  ST       50201000 >> 0000000080002040      CC 0
DISPLAY 80002040
00: V80002040  0000007F                          06 R2E3FE040
STORE 80002040 18
00: Store complete.
DISPLAY 80002040
00: V80002040  00000018                          06 R2E3FE040
```

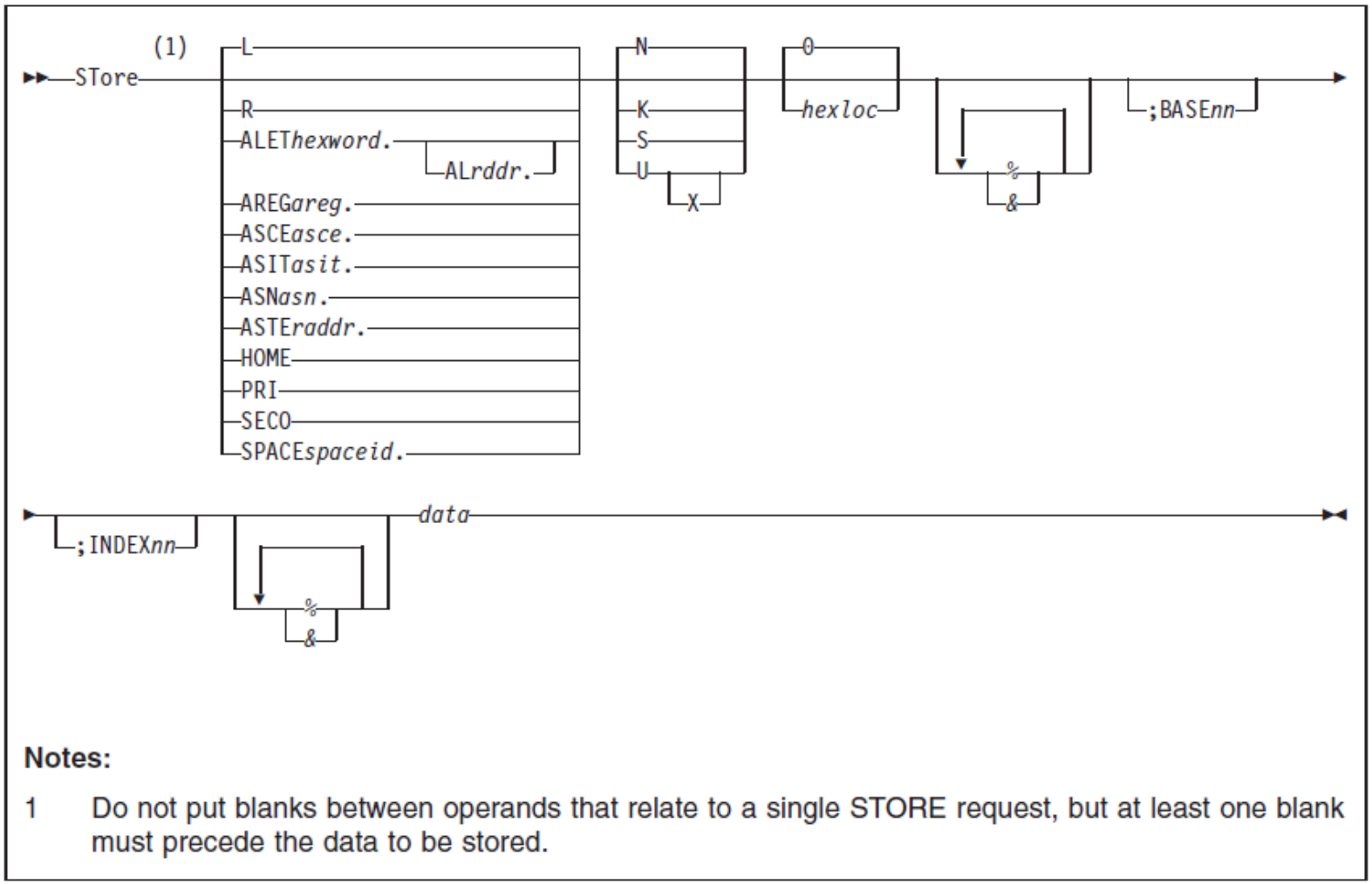
Modify system memory

```
./memory
Code Segment    = 0x8000060c
Data Segment a = 0x80002040
a = 34
a = 24
```

Modify system memory

```
QUERY TRACE
00:
00:  NAME   INITIAL      (ACTIVE)
00:
00:    1      INSTR    PSWA   80000060C
00:           TERM     NOPRINT  NORUN   SIM
00:           SKIP 00000   PASS 00000   STOP  00000   STEP  00000
00:           CMD   NONE
00:
00:    2      STORE    FROM   0000000000000000-FFFFFFFFFFFFFFFF
00:                    INTO   80002040
00:           TERM     NOPRINT  NORUN   SIM
00:           SKIP 00000   PASS 00000   STOP  00000   STEP  00000
00:           CMD   NONE
00:
```

STORE



Notes:

1 Do not put blanks between operands that relate to a single STORE request, but at least one blank must precede the data to be stored.

Operation Exception

- Force an operation exception

Operation Exception

```
#CP STOP
TRACE INSTRUCTION PSWA 8000060C
BEGIN
```

Operation Exception

```
./memory
```

```
00:   -> 0000000080000060C"  STMG    EBBFF0580024 >> 000003FFFF86B348     CC 2
DISPLAY PSWG
00: PSW = 0705E001 80000000 00000000 80000612
STORE 80000060C CC000000
BEGIN
```

Operation Exception

```
./memory
Code Segment    = 0x8000060c
Data Segment a = 0x80002040
a = 34
a = 127
```

Surprise !
The modified instruction was not hit !

Operation Exception

Let’s do it again !

```
./memory
```

```
00:   -> 000000008000060C"  ????    CC0000000024     0000000000000000
00:                                                  0000000000000024
00: *** 000000008000060C"       PROG    0001 -> 0000000000118068’
00:                OPERATION
```

Operation Exception

```
00:   -> 000000008000060C"   ????     CC0000000024     0000000000000000
00:                                                    0000000000000024
00: *** 000000008000060C"        PROG     0001 -> 0000000000118068'
00:                 OPERATION
BEGIN
```

```
./memory
Illegal instruction
```

Operation Exception

```
00:   -> 0000000080000060C"   ????     CC0000000024     0000000000000000
00:                                                     0000000000000024
00: *** 0000000080000060C"       PROG     0001 -> 0000000000118068'
00:                 OPERATION
BEGIN
```

Let's look where the exception is handled

```
grep 118068 /boot/System.map
0000000000118068 T pgm_check_handler
```

Summary

- Full guest memory accessible
- You might have to find out real addresses
- Can modify anything
- Done by z/VM
  - Disassembly
  - Virtual to Real address translation
  - Program-Interuption codes

Links

- VMCP Commands and Utilities Reference
  `http://publibz.boulder.ibm.com/epubs/pdf/hcse4b21.pdf`
- Debugging on Linux for S/390 & z/Architecture by Denis Joseph Barrow
  `http://www.kernel.org/doc/Documentation/s390/Debugging390.txt`
- Linux for S/390 - ELF Application Binary Interface Supplement
  `ftp://archive.download.redhat.com/pub/redhat/linux/7.2/en/os/s390/doc/l3`

Questions ?

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