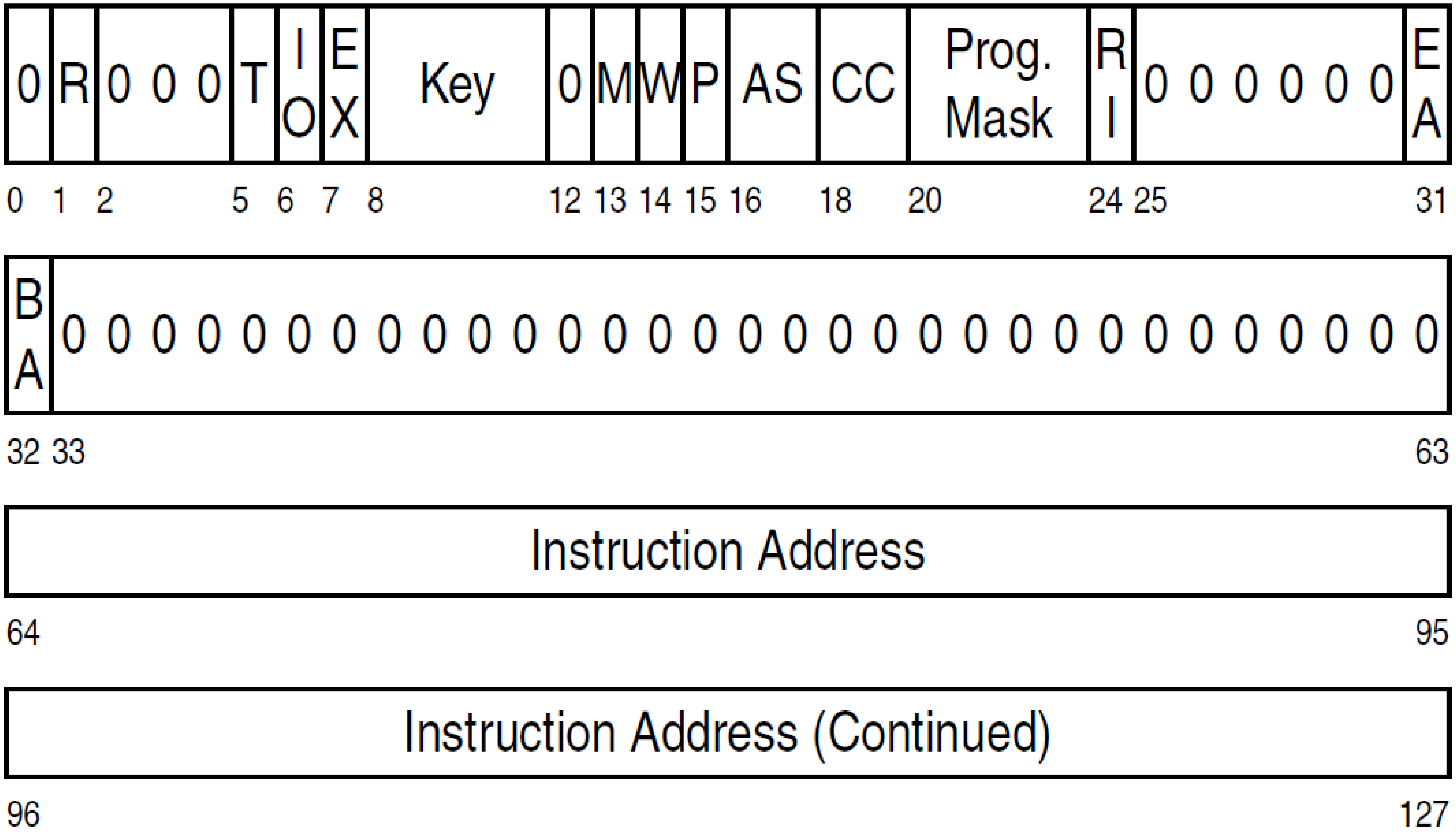
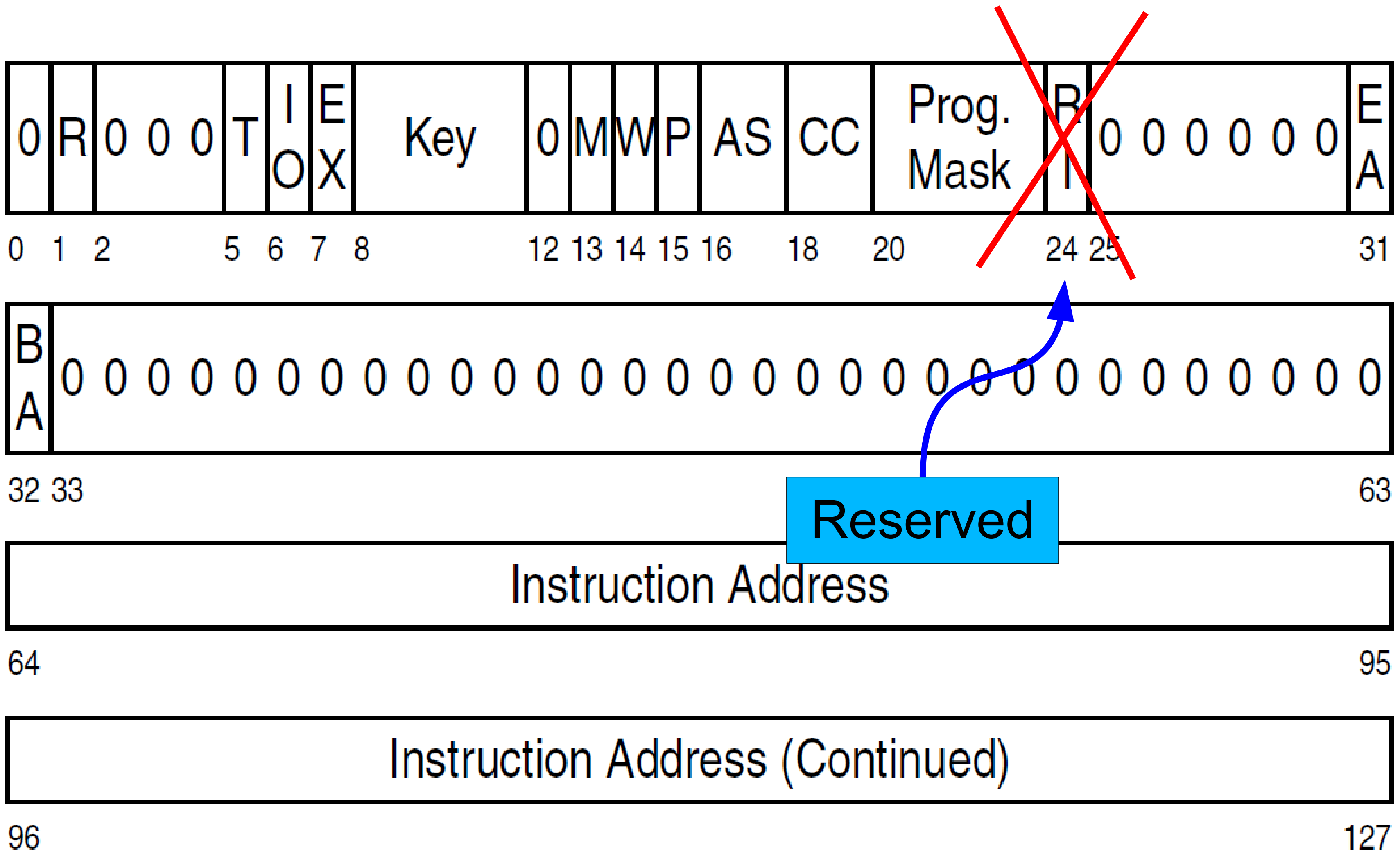
Richard Cebula - IBM HLASM

SHARE Pittsburgh 2014 High Level Assembler Bootcamp (16153, 16154, 16155)

Program Status Word (PSW)



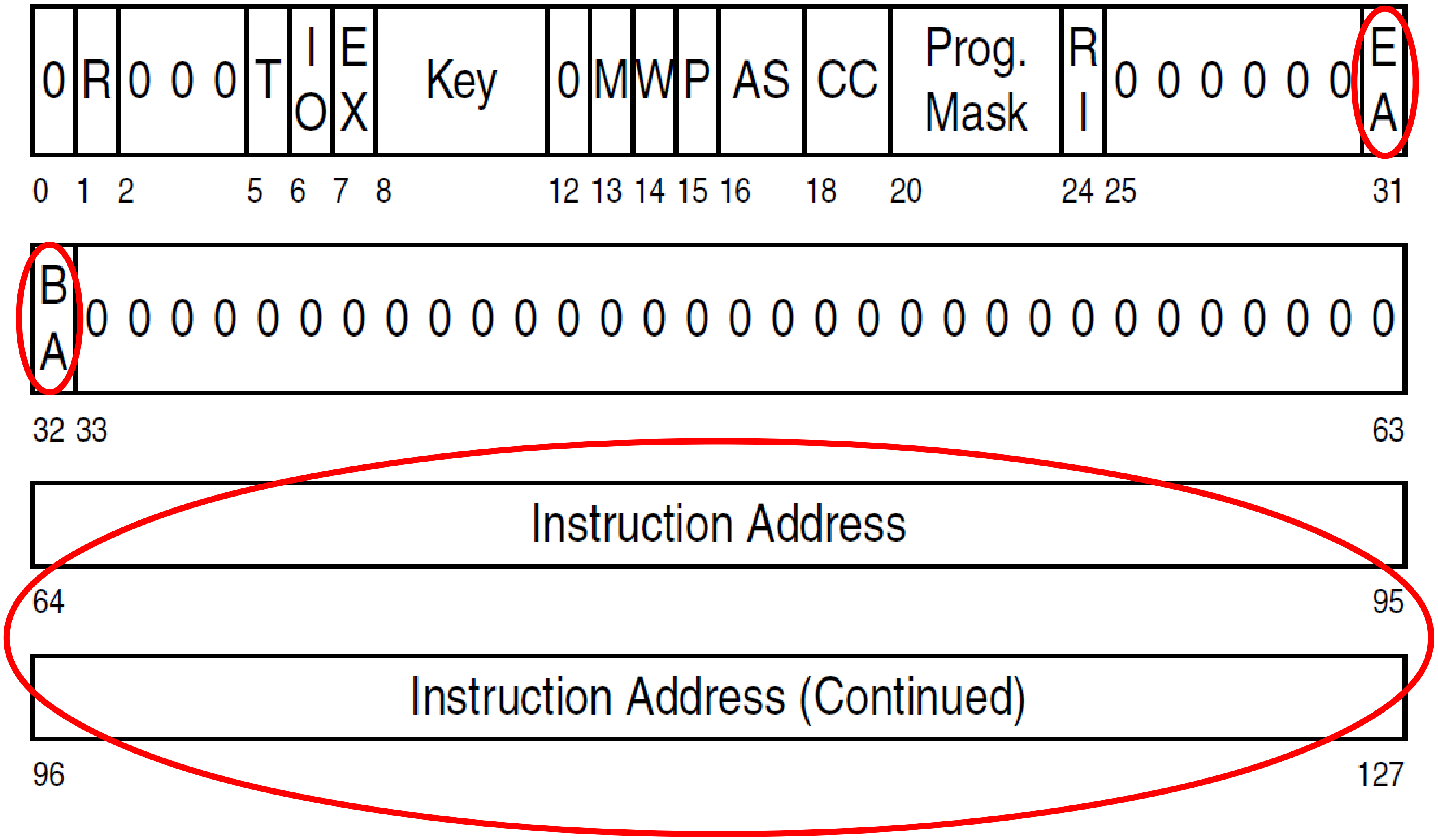
Program Status Word (PSW)



Program Status Word (PSW)

- The Program Status Word (PSW) is a register in the processor which includes control information to determine the state of the CPU.
- The z/Architecture PSW is 128-bits in length
  - Bits 0-32 contain flag bits indicating control information for the CPU
  - Bits 33-63 are 0
  - Bits 64-127 contain the instruction address
- EPSW – Extract PSW
  - Obtain bits 0-63 of the PSW and place them into operands of the instruction
- LPSW(E) – Load PSW (Extended)
  - Replace the entire PSW with the contents of storage
  - This means that the instruction branches – well might do...

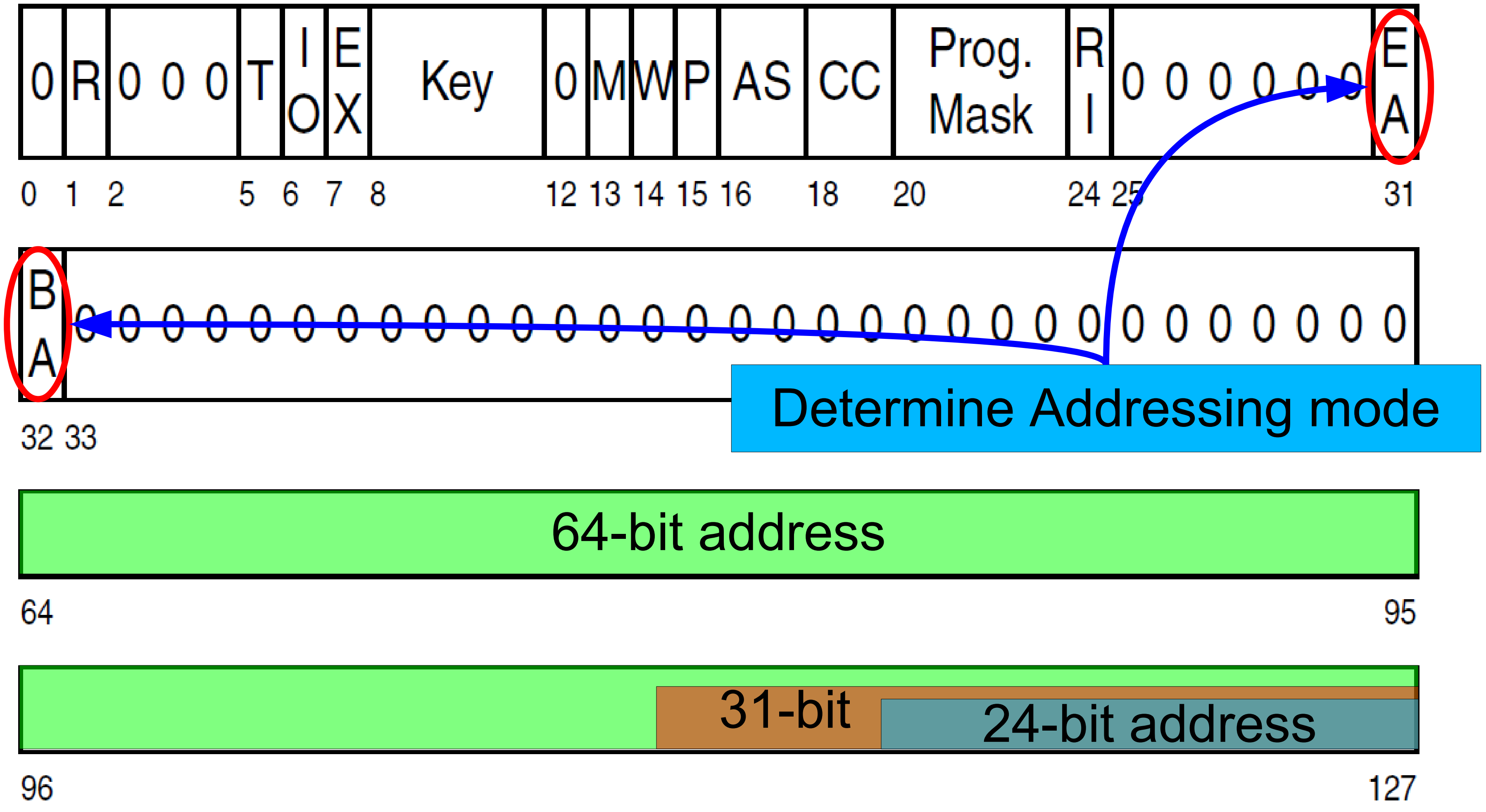
Program Status Word (PSW) – Addresses



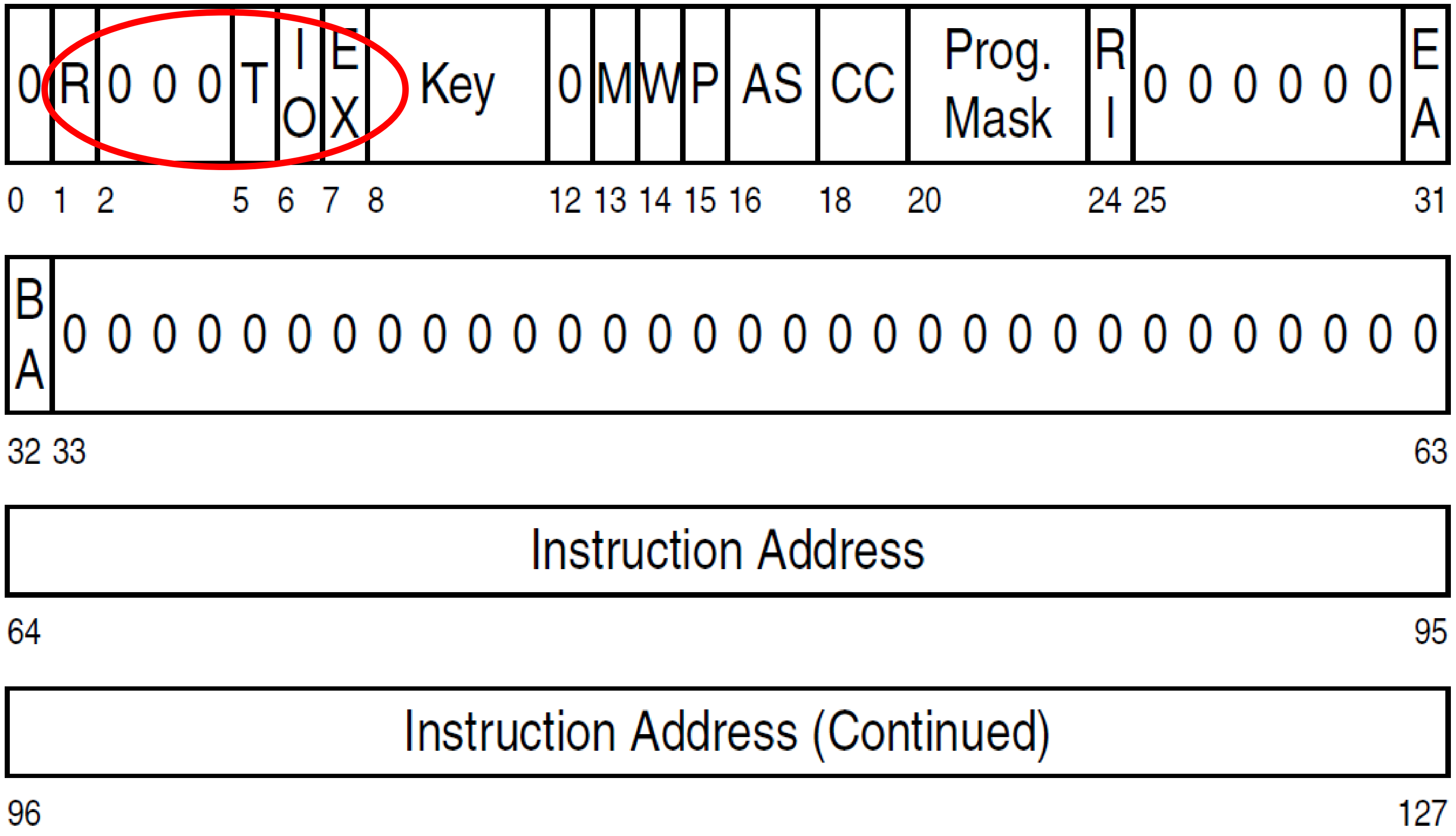
Program Status Word (PSW) – Addresses

- Since the z/Architecture can run in a number of addressing modes, the instruction address is determined by a variable number of bits in the PSW. The current addressing mode is determined by bits 31-32 of the PSW with the following combinations:
  - 00 → 24-bit mode
  - 01 → 31-bit mode
  - 10 → invalid
  - 11 → 64-bit mode
- Bits 64-127 are used to determine the address of the next instruction to be executed
  - However, some instructions may be interrupted and therefore the PSW may point at the same instruction which was being executed so that it is redriven

Program Status Word (PSW) – Instruction Address



Program Status Word (PSW) – Flag bits

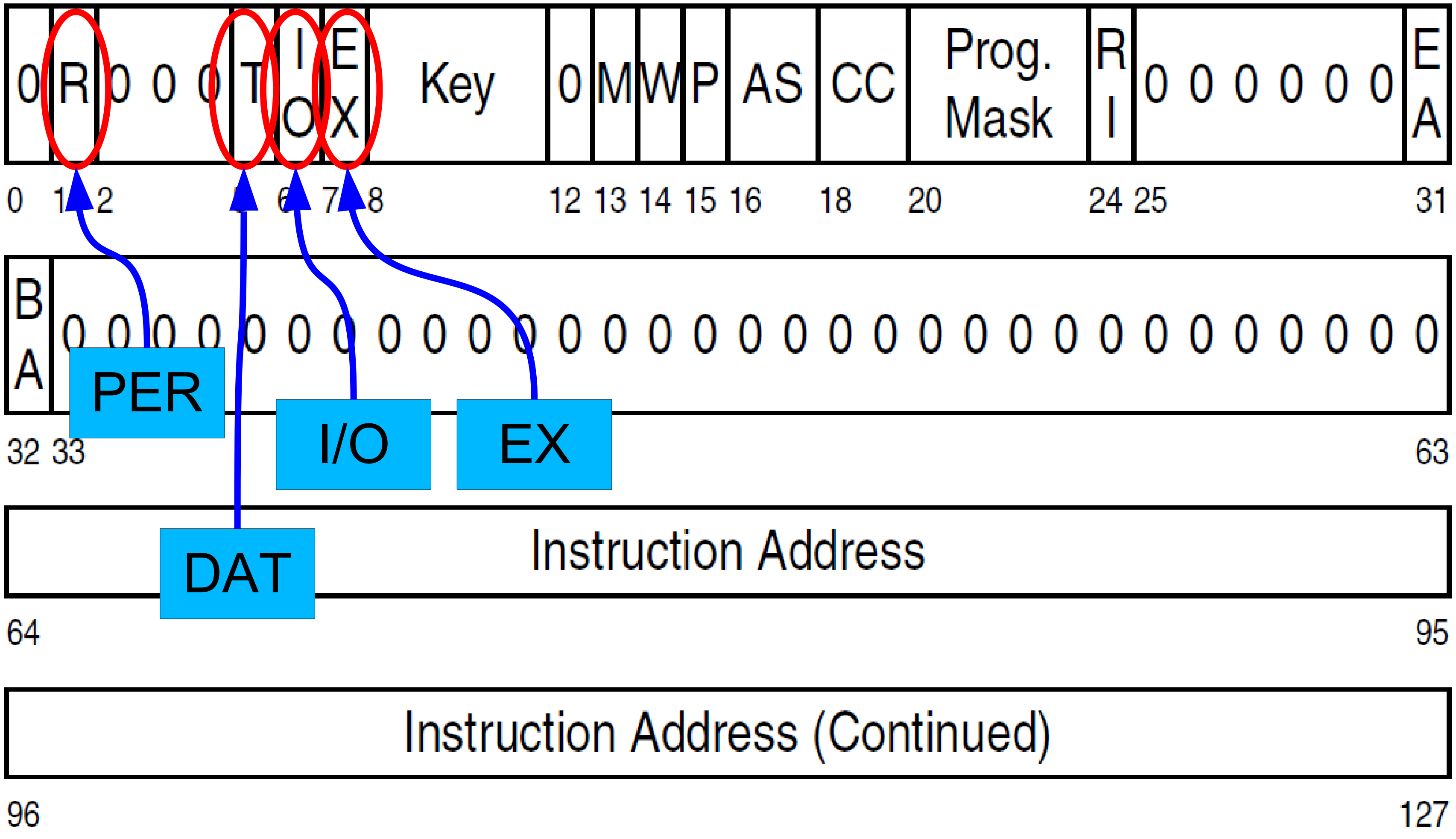


Program Status Word (PSW) – Flag bits

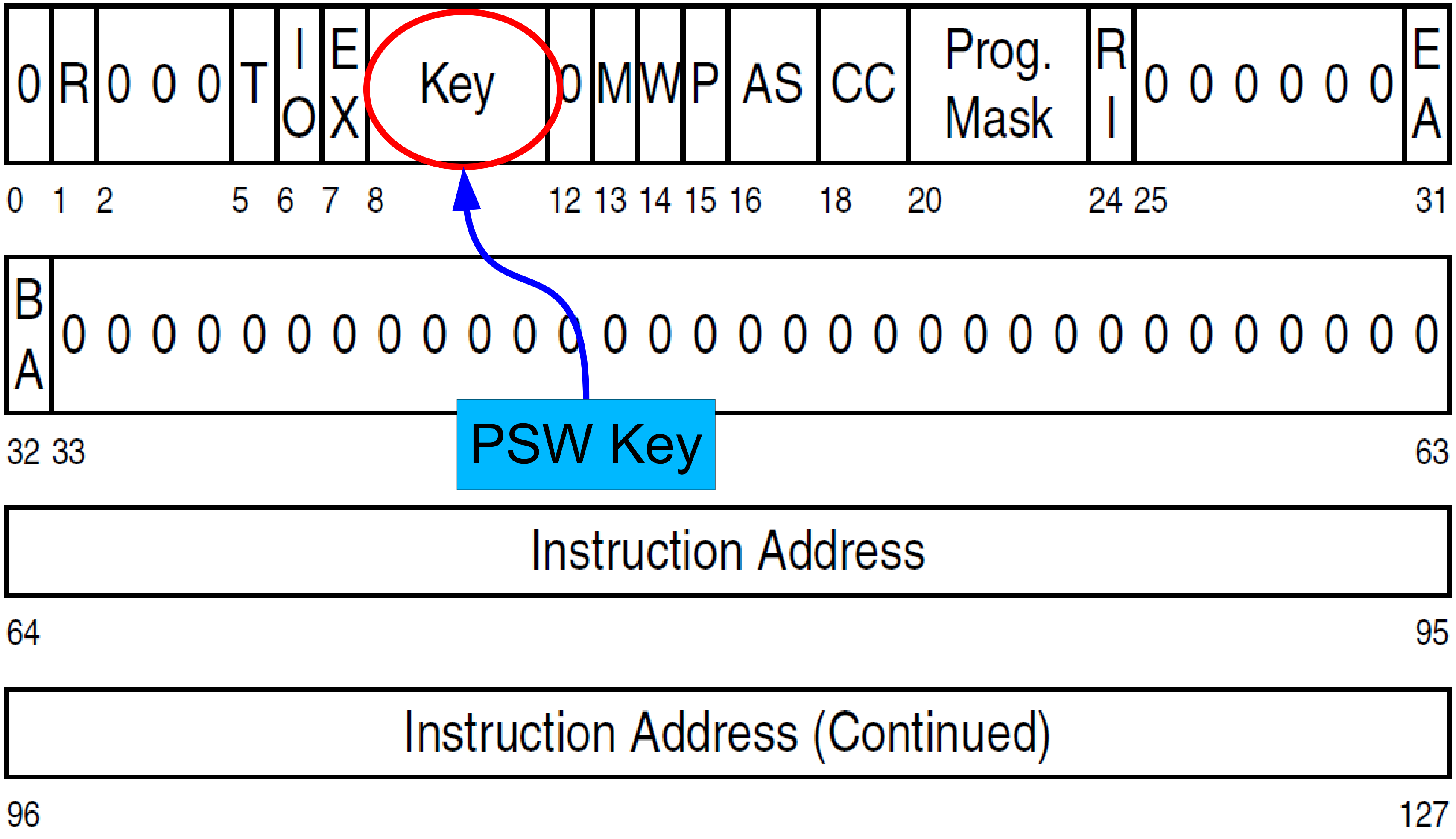
(A bit value of 1 indicates that the CPU is enabled for a function unless stated otherwise)

- Bit 1 – Program Event Recording (PER) Mask
  - Controls whether the CPU is enabled for interrupts associated with PER
- Bit 5 – DAT Mode
  - Controls whether the CPU has Dynamic Address Translation turned on
- Bit 6 – I/O Mask
  - Controls whether the CPU is enabled for interrupts
- Bit 7 – External Mask
  - Controls whether the CPU is enabled for external interrupts

Program Status Word (PSW) – Flag bits



Program Status Word (PSW) – PSW Key



Program Status Word (PSW) – PSW Key

- Bits 8-11 are used to represent the PSW Key (value of 0-15)
- PSW Keys are used to provide a security mechanism over various regions of memory with key 0 being the most secure
- Whenever an instruction attempts to access a storage location that is protected against that type of reference (read/write of storage) and the storage key does not match the access key, a protection exception is recognised.
- Programs running in PSW key 0 have read write access to storage in every storage key
- Programs in keys 1 – 15 have read access to:
  - Storage which matches their PSW key
  - Storage (in any key) that's not fetch protected
  - Storage in key 9 if the hardware feature “subsystem storage protection override” is installed
- Programs in keys 1-15 have write access to:
  - Storage whose key matches their PSW key
  - Storage in key 9 if subsystem storage protection override is installed

Program Status Word (PSW) – PSW Key – Manipulation

- IPK – Insert PSW Key
  - Used to *insert* the PSW Key *into* register 2
  - Used to store a copy of the current PSW Key typically before a switch to another key.
  - Bits 56-59 of register 2 are updated to contain the PSW Key, bits 60-63 are set to 0 and all other bits remain unmodified
- IPK cannot be used when bit 36 of CR0 is set to 0 and in problem state
- SPKA – Set PSW Key from Address
  - Used to set the PSW Key from an *address value*
  - Bits 56-59 of the 2nd operand are inserted into the PSW Key
- SPKA can only be used to set a key to which the current task is allowed to set a key determined by the PSW Key mask in CR3
- Both IPK and SPKA are privileged instructions

Program Status Word (PSW) – PSW Key – Manipulation

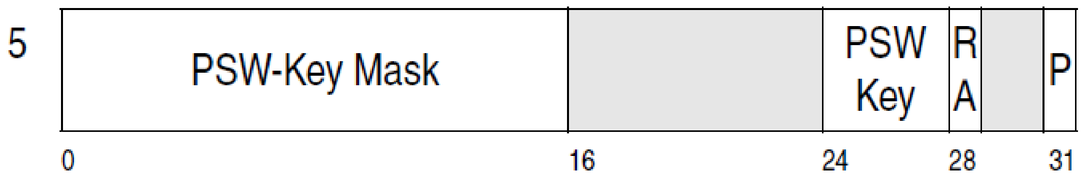
- MVCK – Move with Key
  - Moves an operand with an access key specified as part of the instruction
  - If the program is not enabled to use that access key, then a privileged operation exception is raised
  - Can be a slow instruction

- BSA – Branch and Set Authority
  - Used to branch to another place in code and set the PSW key at the same time
  - Works as a flip-flop branching from “base authority” state to “reduced authority” state

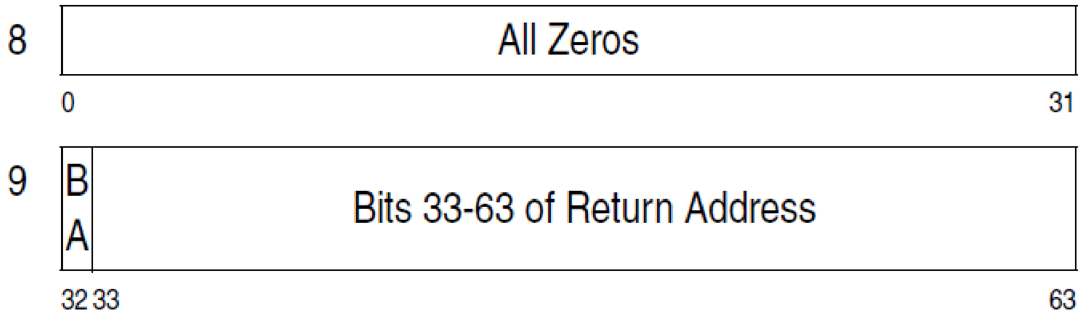
Program Status Word (PSW) – PSW Key – BSA Operation

- BSA – Branch and Set Authority – example scenario
  - A service routine, e.g. a middleware service begins in the *base authority* state
  - The routine issues a BSA to switch to running a user routine
  - The user routine runs in *reduced authority* state
  - When the user routine wants to invoke the middleware service, it issues a BSA which branches back to a fixed location in the middleware and the state is returned to running in base authority state
- The control of the states is determined by the Dispatchable Unit Control Table (DUCT)

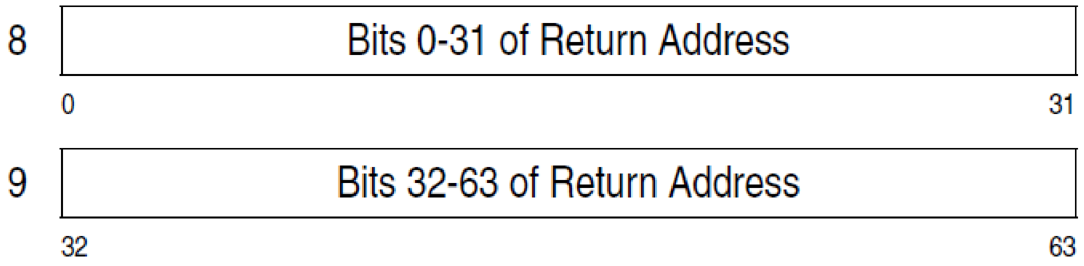
Program Status Word (PSW) – PSW Key – BSA Operation - DUCT



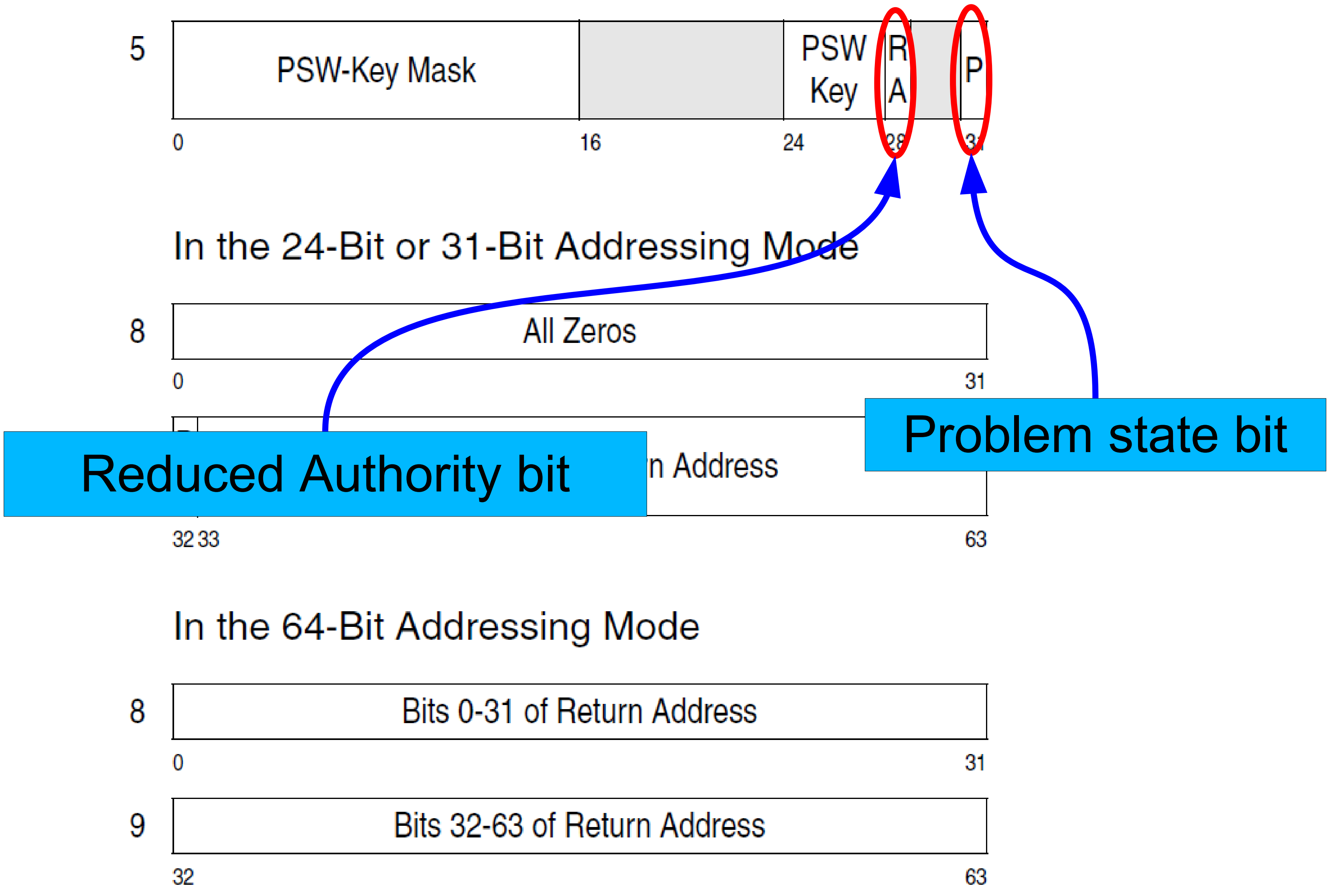
In the 24-Bit or 31-Bit Addressing Mode



In the 64-Bit Addressing Mode



Program Status Word (PSW) – PSW Key – BSA Operation


5
PSW-Key Mask
PSW Key
R A
P
0
16
24
28
31
In the 24-Bit or 31-Bit Addressing Mode
8
All Zeros
0
31
n Address
32 33
63
In the 64-Bit Addressing Mode
8
Bits 0-31 of Return Address
0
31
9
Bits 32-63 of Return Address
32
63
Reduced Authority bit
Problem state bit

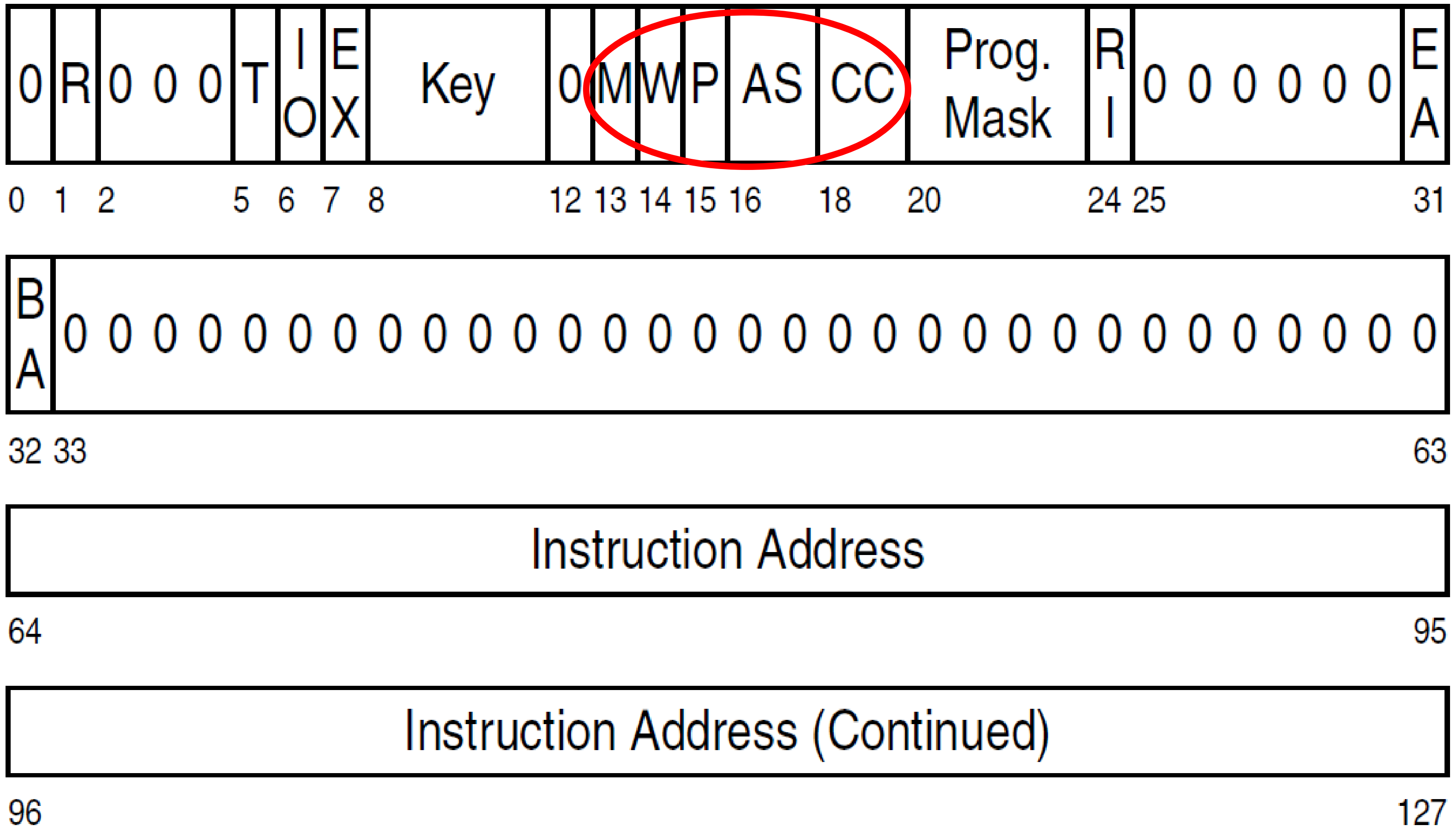
Program Status Word (PSW) – PSW Key – BSA Operation – BA

- When the BSA instruction is used in base authority, the following is stored in the DUCT:
  - The PSW-key Mask (from CR3)
  - The current PSW Key
  - Problem state bit
  - The return address
- BSA then sets the Reduced Authority bit (RA) to 1 and loads:
  - The PSW-key Mask into CR3 from operand 1
  - The PSW Key from operand 1
  - The branch address into the PSW

Program Status Word (PSW) – PSW Key – BSA Operation – RA

- When the BSA instruction is used in reduced authority, the following is restored from the DUCT:
  - The PSW-key Mask (to CR3)
  - The current PSW Key (to the PSW)
  - Problem state bit (to the PSW)
  - The return address (to the PSW – therefore the machine branches...)
- BSA then sets the Reduced Authority bit (RA) to 0

Program Status Word (PSW) – More flag bits



Program Status Word (PSW) – More flag bits

- Bit 13 – Machine Check Mask
  - Controls whether the CPU is enabled for interrupts by machine check conditions
- Bit 14 – Wait State
  - If on, the machine is waiting and no instructions are processed but interrupts may take place.
- Bit 15 – Problem State
  - The machine operates in two states – problem state (used for user code) and supervisor state (used for privileged code)
  - If an attempt is made to execute a privileged instruction in problem state, then a privileged operation exception occurs.
    Some instructions are *semi-privileged* and may or may not be permitted to execute in problem state depending on the outcome of other flags
  - All instructions are valid in supervisor state

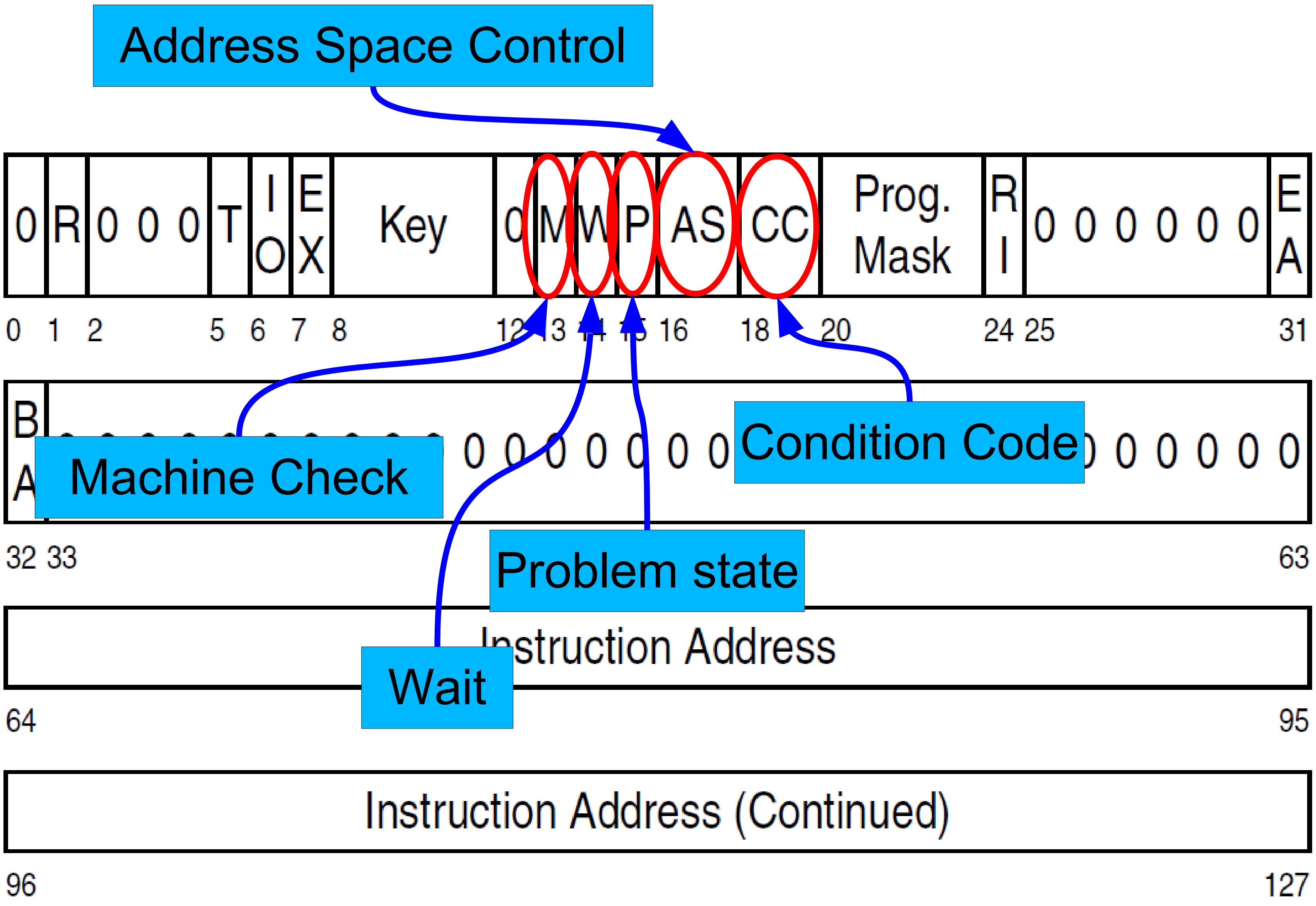
Program Status Word (PSW) – More flag bits

- Bit 16-17 – Address-Space Control
  - Determines how addresses are handled in conjunction with bit 5 (DAT) via the following table:

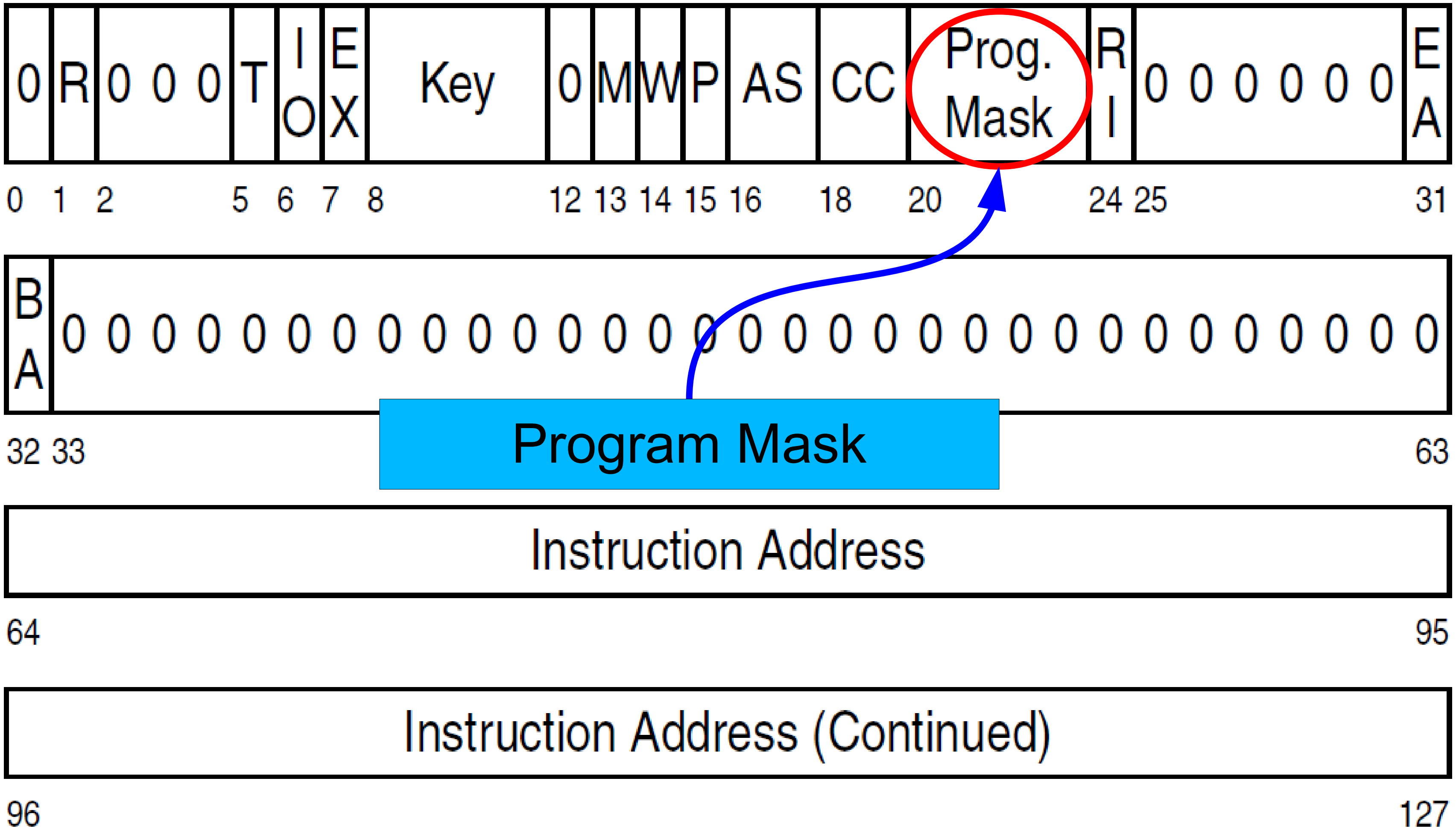
5	16	17	DAT	Mode	Instruction Addresses	Logical Addresses
0	0	0	Off	Real Mode	Real	Real
0	0	1	Off	Real Mode	Real	Real
0	1	0	Off	Real Mode	Real	Real
0	1	1	Off	Real Mode	Real	Real
1	0	0	On	Primary-space Mode	Primary virtual	Primary virtual
1	0	1	On	Access-register Mode	Primary virtual	AR specified vrt
1	1	0	On	Secondary-space Mode	Primary virtual	Secondary vrt
1	1	1	On	Home-space Mode	Home virtual	Home virtual

- Bits 18-19 – Condition Code

Program Status Word (PSW) – More flag bits



Program Status Word (PSW) – PSW Key – Program Mask



Program Status Word (PSW) – Program Mask

- Bits 20-23 – Program Mask
  - Controls a set of program exceptions
  - When the corresponding bit is on, the exception results in an interrupt

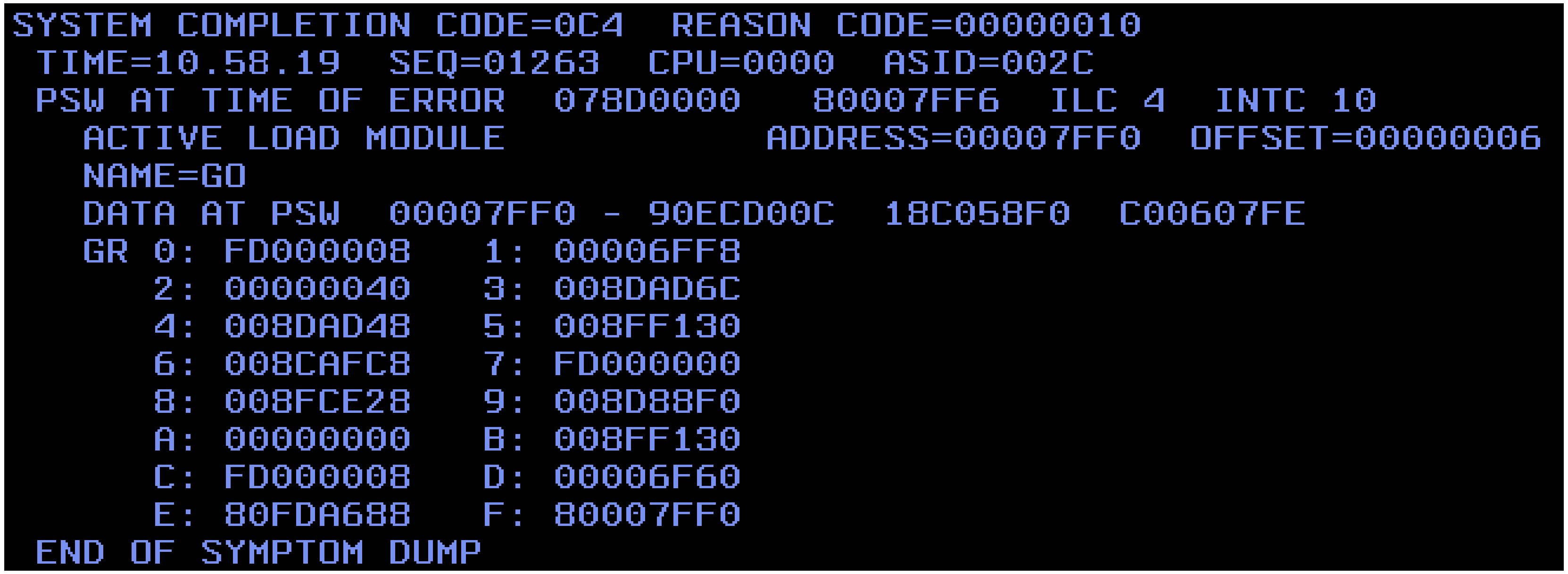
Program Mask PSW bit	Program Exception
20	Fixed-point overflow
21	Decimal overflow
22	HFP exponent underflow
23	HFP significance

- The Program Mask can be manipulated by using the instruction SET PROGRAM MASK (SPM)
- The contents of the Program Mask can be examined using the instruction INSERT PROGRAM MASK (IPM)

Program Status Word (PSW) – Using the PSW for debugging

- The PSW stores invaluable information about the general state of the machine during a program's execution
- The most interesting time to examine a PSW is when something goes wrong. Even a summary dump will provide the programmer with:
  - The contents of the PSW
  - The contents of the general purpose registers
  - The next instruction to be executed

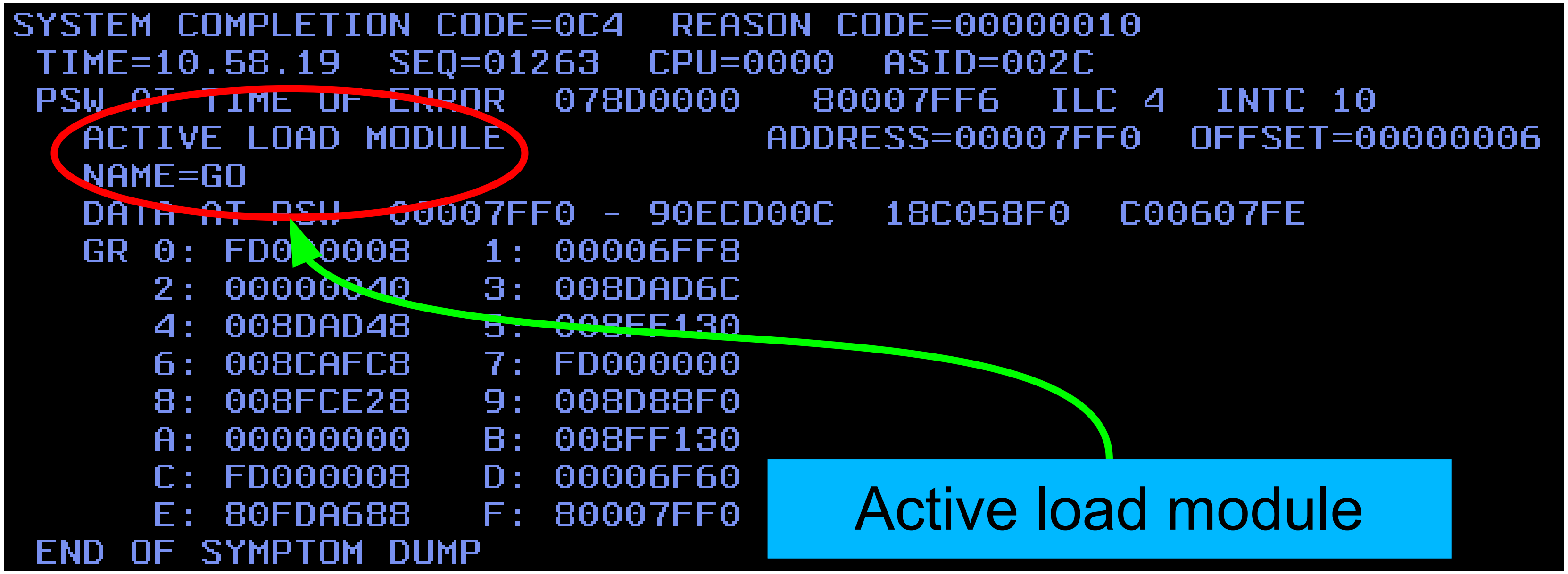
Program Status Word (PSW) – Something has gone wrong



```
SYSTEM COMPLETION CODE=0C4  REASON CODE=00000010
 TIME=10.58.19  SEQ=01263  CPU=0000  ASID=002C
 PSW AT TIME OF ERROR  078D0000   80007FF6  ILC 4  INTC 10
   ACTIVE LOAD MODULE           ADDRESS=00007FF0  OFFSET=00000006
   NAME=GO
   DATA AT PSW  00007FF0 - 90ECD00C  18C058F0  C00607FE
   GR 0: FD000008   1: 00006FF8
      2: 00000040   3: 008DAD6C
      4: 008DAD48   5: 008FF130
      6: 008CAFC8   7: FD000000
      8: 008FCE28   9: 008D88F0
      A: 00000000   B: 008FF130
      C: FD000008   D: 00006F60
      E: 80FDA688   F: 80007FF0
 END OF SYMPTOM DUMP
```

- Running a job has resulted in an 0C4 ABEND occurring. The summary dump in the job may be enough information to work out what has gone wrong.

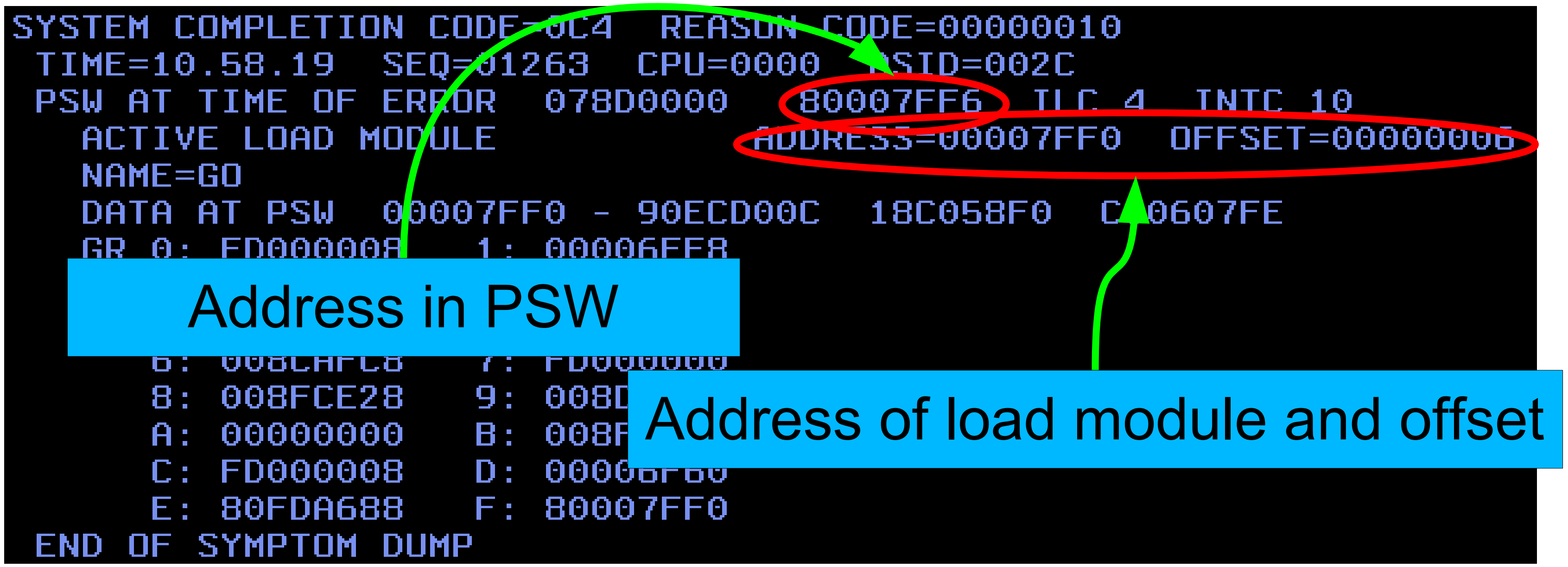
Program Status Word (PSW) – Something has gone wrong



```
SYSTEM COMPLETION CODE=0C4  REASON CODE=00000010
 TIME=10.58.19  SEQ=01263  CPU=0000  ASID=002C
 PSW AT TIME OF ERROR  078D0000   80007FF6  ILC 4  INTC 10
   ACTIVE LOAD MODULE           ADDRESS=00007FF0  OFFSET=00000006
   NAME=GO
   DATA AT PSW  00007FF0 - 90ECD00C  18C058F0  C00607FE
   GR 0: FD000008   1: 00006FF8
      2: 00000040   3: 008DAD6C
      4: 008DAD48   5: 008FF130
      6: 008CAFC8   7: FD000000
      8: 008FCE28   9: 008D88F0
      A: 00000000   B: 008FF130
      C: FD000008   D: 00006F60
      E: 80FDA688   F: 80007FF0
 END OF SYMPTOM DUMP
```

- First, look at the active load module
  - In this example, the load module name is GO since the LKEDG JCL procedure was used. From this we already know that the error occurred in our load module and not in either the assembler, linkage editor nor other part of z/OS

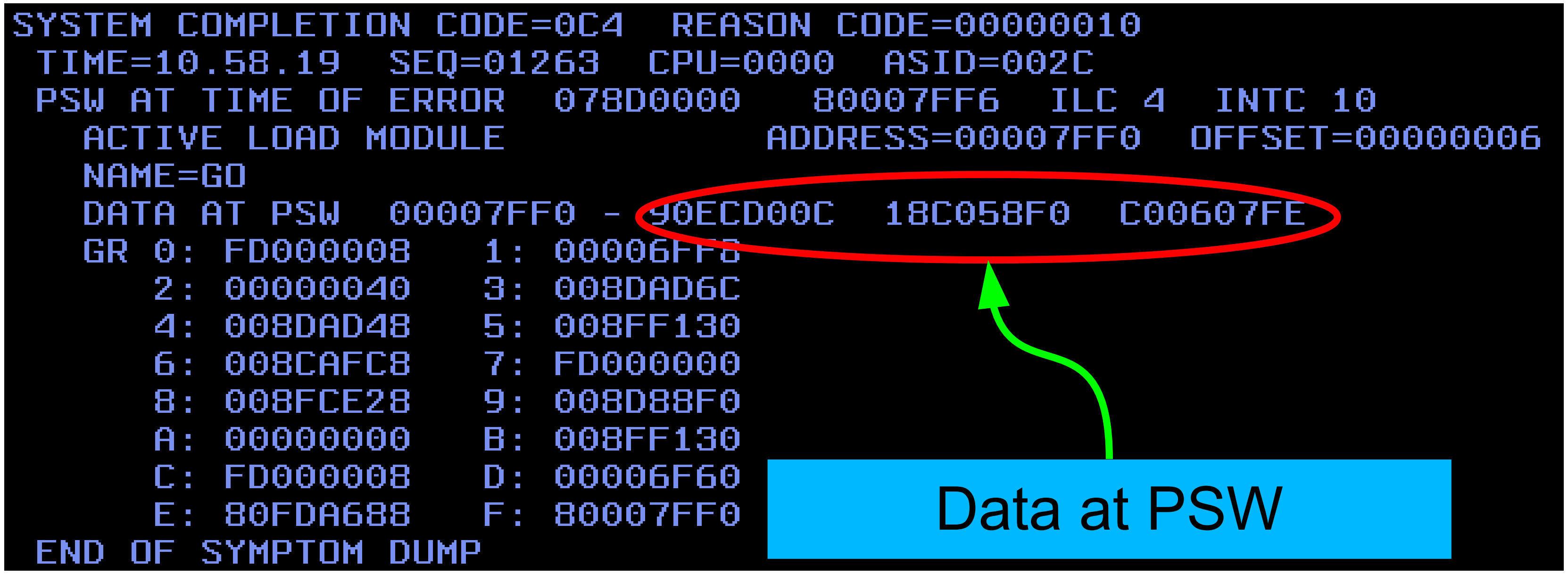
Program Status Word (PSW) – Something has gone wrong



```
SYSTEM COMPLETION CODE=0C4  REASON CODE=00000010
 TIME=10.58.19  SEQ=01263  CPU=0000  ASID=002C
 PSW AT TIME OF ERROR  078D0000   80007FF6  ILC 4  INTC 10
   ACTIVE LOAD MODULE           ADDRESS=00007FF0  OFFSET=00000006
   NAME=GO
   DATA AT PSW  00007FF0 - 90ECD00C  18C058F0  C00607FE
   GR 0: FD000008   1: 00006FF8
      6: 008CAFC8   7: FD000000
      8: 008FCE28   9: 008D
      A: 00000000   B: 008F
      C: FD000008   D: 00006F60
      E: 80FDA688   F: 80007FF0
 END OF SYMPTOM DUMP
```

- Next, double check the information in the PSW against the other information in the summary dump
  - The PSW shows that the next instruction address to be executed is X'7FF6'
  - This agrees with the data in the dump showing the address of the load module (X'7FF0') and the offset into the load module (X'0006')

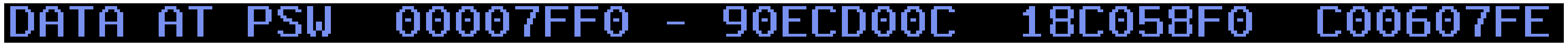
Program Status Word (PSW) – Something has gone wrong



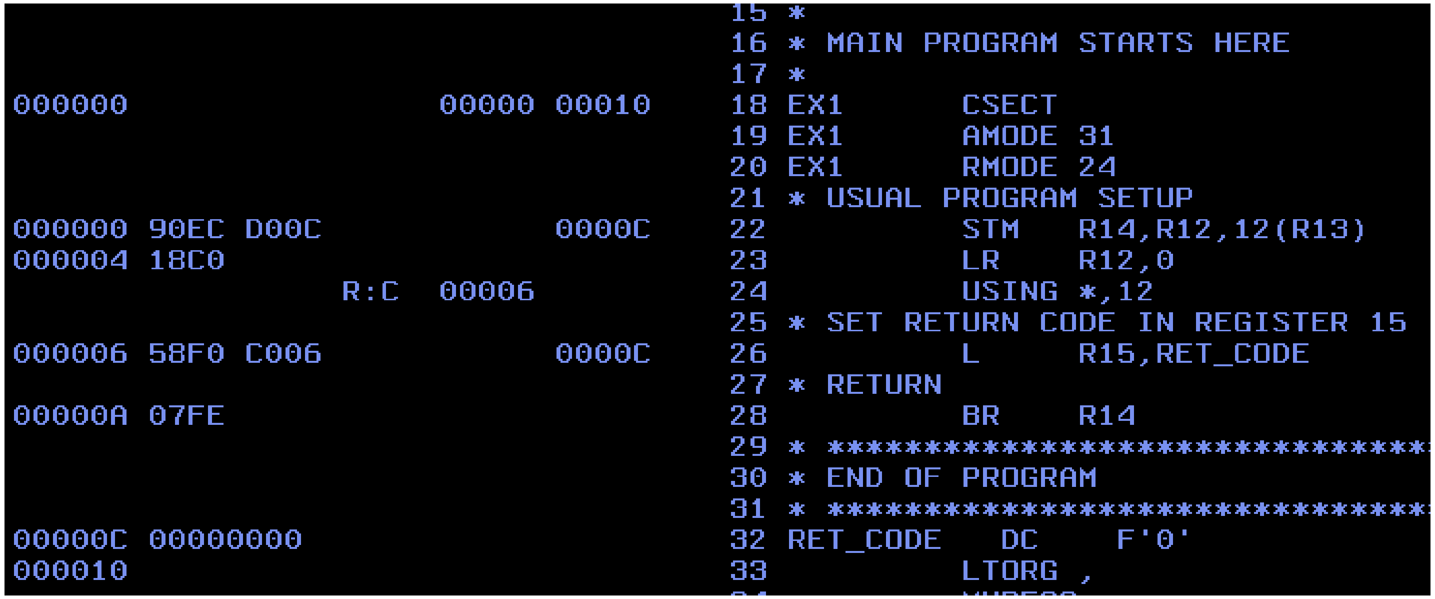
```
SYSTEM COMPLETION CODE=0C4  REASON CODE=00000010
 TIME=10.58.19  SEQ=01263  CPU=0000  ASID=002C
 PSW AT TIME OF ERROR  078D0000   80007FF6  ILC 4  INTC 10
   ACTIVE LOAD MODULE           ADDRESS=00007FF0  OFFSET=00000006
   NAME=GO
   DATA AT PSW  00007FF0 - 90ECD00C  18C058F0  C00607FE
   GR 0: FD000008   1: 00006FF8
      2: 00000040   3: 008DAD6C
      4: 008DAD48   5: 008FF130
      6: 008CAFC8   7: FD000000
      8: 008FCE28   9: 008D88F0
      A: 00000000   B: 008FF130
      C: FD000008   D: 00006F60
      E: 80FDA688   F: 80007FF0
 END OF SYMPTOM DUMP
```

- The data at the PSW shows the instructions which were, are being, and will be executed

Program Status Word (PSW) – Something has gone wrong



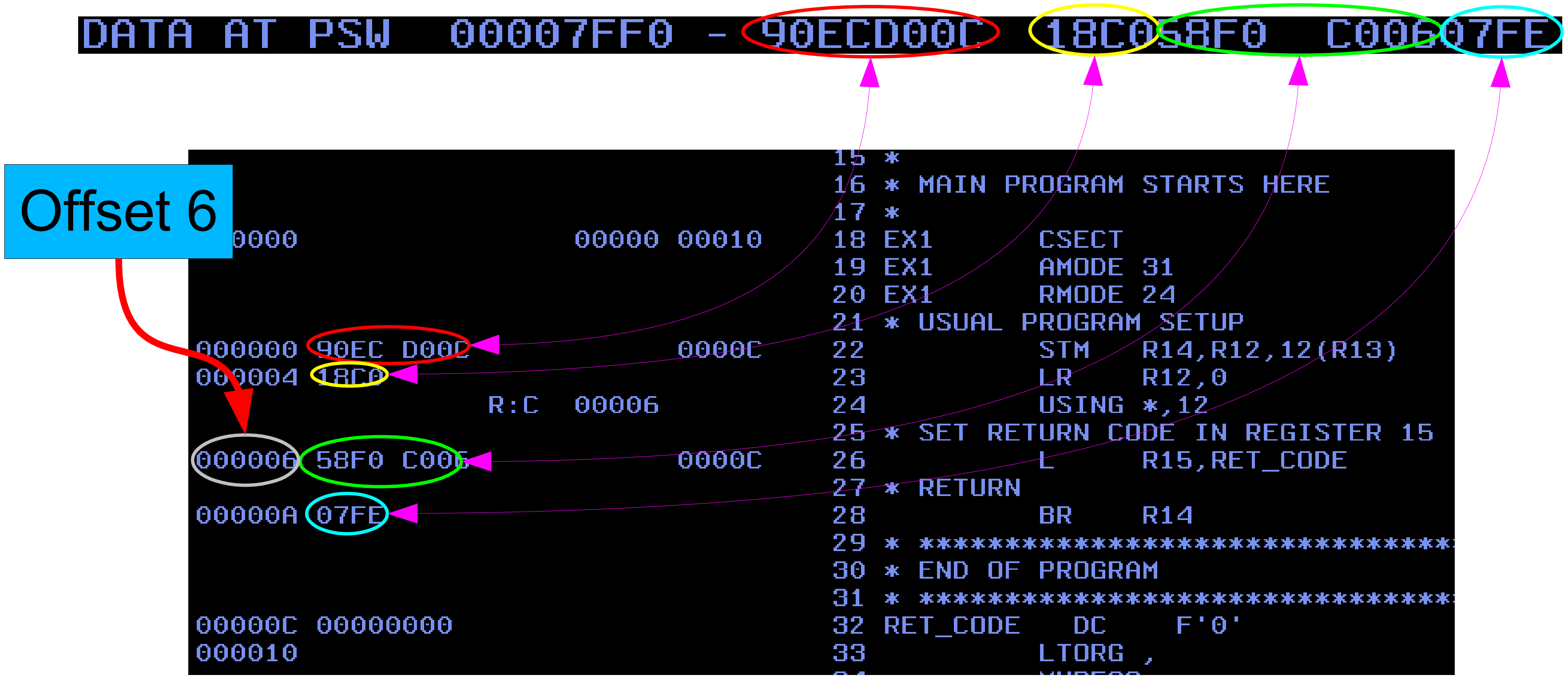
```
DATA AT PSW  00007FF0 - 90ECD00C  18C058F0  C00607FE
```



```
                                        *
                                        * MAIN PROGRAM STARTS HERE
                                        *
000000                 00000 00010      EX1      CSECT
                                        EX1      AMODE 31
                                        EX1      RMODE 24
                                        * USUAL PROGRAM SETUP
000000 90EC D00C             0000C               STM   R14,R12,12(R13)
000004 18C0                                      LR    R12,0
                  R:C  00006                     USING *,12
                                        * SET RETURN CODE IN REGISTER 15
000006 58F0 C006             0000C               L     R15,RET_CODE
                                        * RETURN
00000A 07FE                                      BR    R14
                                        * ******************************
                                        * END OF PROGRAM
                                        * ******************************
00000C 00000000                         RET_CODE   DC    F'0'
000010                                           LTORG ,
```

▪ Examining the program listing at offset 6 shows where the error occurred. Using the data at the PSW and looking at the machine code generated by HLASM in the listing confirms this and that so far our diagnosis of the problem is correct

Program Status Word (PSW) – Something has gone wrong



```
DATA AT PSW  00007FF0 - 90ECD00C  18C058F0  C00607FE
```

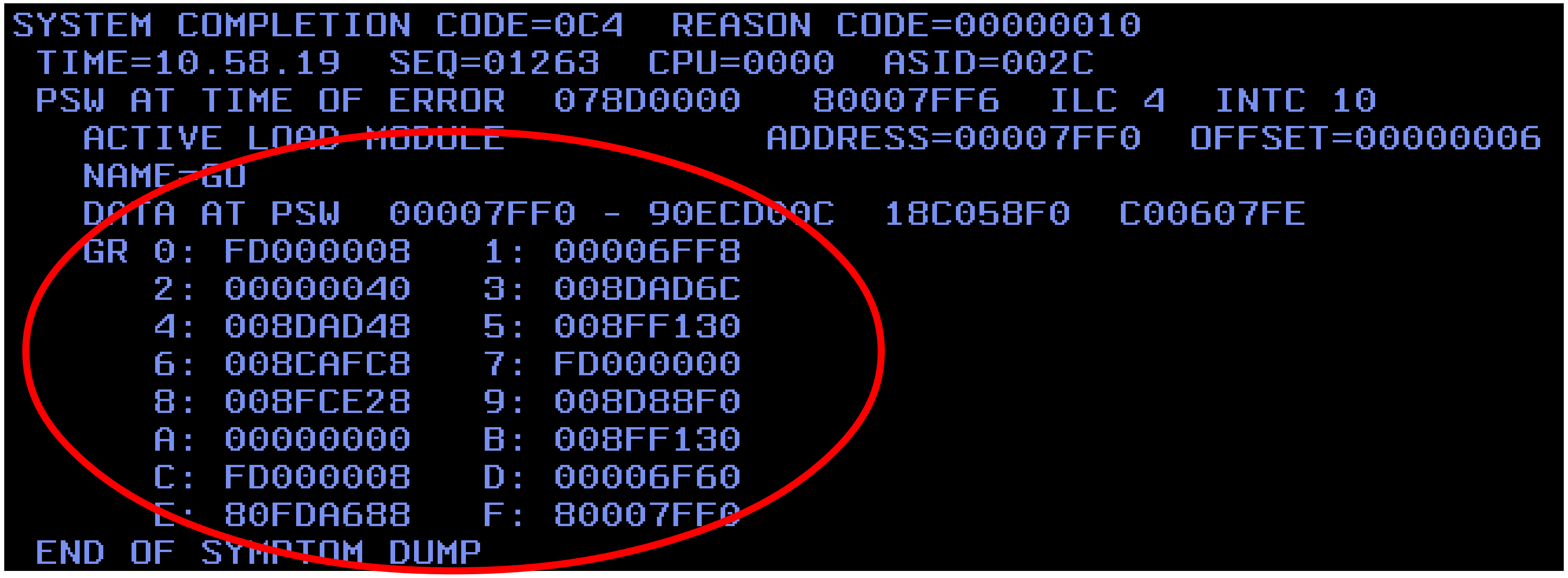
```
000000                   00000 00010     15 *
                                         16 * MAIN PROGRAM STARTS HERE
                                         17 *
                                         18 EX1      CSECT
                                         19 EX1      AMODE 31
                                         20 EX1      RMODE 24
                                         21 * USUAL PROGRAM SETUP
000000 90EC D00C               0000C     22          STM   R14,R12,12(R13)
000004 18C0                              23          LR    R12,0
                    R:C  00006           24          USING *,12
                                         25 * SET RETURN CODE IN REGISTER 15
000006 58F0 C006               0000C     26          L     R15,RET_CODE
                                         27 * RETURN
00000A 07FE                              28          BR    R14
                                         29 * ******************************
                                         30 * END OF PROGRAM
                                         31 * ******************************
00000C 00000000                          32 RET_CODE   DC    F'0'
000010                                   33          LTORG ,
```

- Examining the program listing at offset 6 shows where the error occurred. Using the data at the PSW and looking at the machine code generated by HLASM in the listing confirms this and that so far our diagnosis of the problem is correct
- We now know the instruction which caused the error was:
  58F0 C006 → L R15,RET_CODE

Program Status Word (PSW) – Something has gone wrong

- At this stage of our debugging we know:
  - The load module name that caused the error
  - The offset into the load module at which the error occurred
- We have also double-checked that what was printed in the summary dump is confirmed by the data at the PSW
- Examining the instruction at fault, we determine the following:
  - 58F0 C006 → L   R15,RET_CODE
  - 58 – OPCODE = LOAD
  - F – Register 15, the register to be loaded
  - 0 – Index register (unused since it has a value of 0)
  - C – Base register is register 12
  - 006 – Displacement from the base register from which the data will be loaded
- So, the instruction is attempting to load register 15 with the contents of memory at an offset of 6 from register 12.

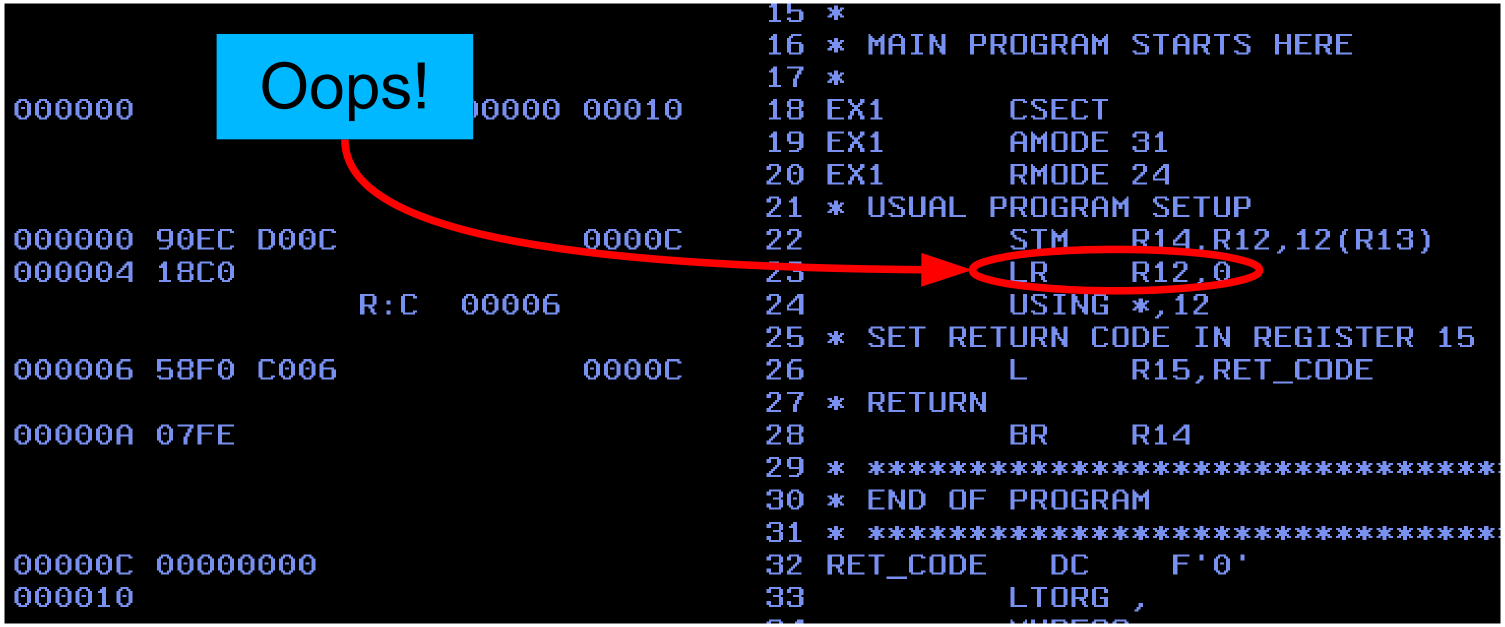
Program Status Word (PSW) – Something has gone wrong



```
SYSTEM COMPLETION CODE=0C4  REASON CODE=00000010
 TIME=10.58.19  SEQ=01263  CPU=0000  ASID=002C
 PSW AT TIME OF ERROR  078D0000   80007FF6  ILC 4  INTC 10
   ACTIVE LOAD MODULE           ADDRESS=00007FF0  OFFSET=00000006
   NAME=GO
   DATA AT PSW  00007FF0 - 90ECD00C  18C058F0  C00607FE
   GR 0: FD000008   1: 00006FF8
      2: 00000040   3: 008DAD6C
      4: 008DAD48   5: 008FF130
      6: 008CAFC8   7: FD000000
      8: 008FCE28   9: 008D88F0
      A: 00000000   B: 008FF130
      C: FD000008   D: 00006F60
      E: 80FDA688   F: 80007FF0
 END OF SYMPTOM DUMP
```

- The summary dump also shows the contents of the general purpose registers
- The value in register 12 is X'FD000008'
- The instruction at fault is attempting to load a value from address X'FD00000E' – which is unaddressable by our program and therefore the cause of the error
- Note that the value of register 12 is the same as the value of register 0...

Program Status Word (PSW) – Something has gone wrong



```
                                          15 *
                                          16 * MAIN PROGRAM STARTS HERE
                                          17 *
000000                  )0000 00010       18 EX1      CSECT
                                          19 EX1      AMODE 31
                                          20 EX1      RMODE 24
                                          21 * USUAL PROGRAM SETUP
000000 90EC D00C              0000C       22          STM   R14,R12,12(R13)
000004 18C0                               23          LR    R12,0
                    R:C  00006            24          USING *,12
                                          25 * SET RETURN CODE IN REGISTER 15
000006 58F0 C006              0000C       26          L     R15,RET_CODE
                                          27 * RETURN
00000A 07FE                               28          BR    R14
                                          29 * ******************************
                                          30 * END OF PROGRAM
                                          31 * ******************************
00000C 00000000                           32 RET_CODE   DC    F'0'
000010                                    33          LTORG ,
```

- Looking back through the program, we can see that register 12 was loaded with the value of register 0 during program startup
- It looks as if the programmer made a typo and instead of using LR 12,0 should have used BALR 12,0 in order to load the address of the next instruction into register 12. This would make sense since they are using register 12 to establish addressability to the program's data
- Correcting this mistake fixes the program

Program Status Word (PSW) – Using the PSW for debugging

- Using the data in the summary dump, the PSW and the program listing has allowed us to fix the cause of the error.
- Although this is a simple example, it demonstrates the basics of debugging assembler problems.