

Sprawozdanie z laboratorium 1 Technika Mikroprocesorowa

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Wprowadzenie

Zadanie zostało zrealizowane najpierw w języku Python, a następnie przy użyciu ukłkadu FPGA "Zybo" produkcji Digilent w środowisku Vivado 2024.1 w języku opisu sprzętu (HDL) Verilog. Zadanie miało na celu zademonstrowanie rozwoju sprzętu typu RISC (Reduced instruction set computer).

Rozwiązania zadań

Zadanie 3.5 – Podstawowy program

Program na niezmodyfikowanym kodzie. Podany program wykonuje kolejno polecenia:

- 80 (1000 0000) Wpisz 0 do rejestru r0 100 kod instrukcji mov reg,#imm; 0 wskaźnik rejestru r0, 0000 wartość
- 90 (1001 0000) Wpisz 0 do rejestru r1 100 kod instrukcji mov reg, #imm;, 1 wskaźnik rejestru r1, 0000 wartość
- 3. EE (1110 1110) Wpisz wartość rejestru r0 na komórkę o wskaźniku 14 111 kod instrukcji str reg, addr;, 0 wskaźnik rejestru r0, 1110 wskaźnik komórki 14
- 4. 86 (1000 0110) Wpisz 6 do rejestru r0 100 kod instrukcji mov reg, #imm;, 0 wskaźnik rejestru r0, 0110 wartość
- 5. DD (1101 1101) Wybierz wartość z pamięci o wskaźniku 13 i wpisz ją do rejestru r0 110 kod instrukcji ldr reg, addr;, 1 wskaźnik rejestru r1, 1101 wskaźnik komórki pamięci 13
- 6. 20 (0010 0000) Dodaj rejestry r0 i r1 i zapisz wynik w r0 0010 kod instrukcji add r0, r1; (0 może umownie wskazywać na rejestr r0, wtedy instrukcja 0011 mogłaby oznaczać tę samą operację tylko z wpisaniem wartości do rejestru r1), 0000 nieużywane dane
- 7. EE (1110 1110) Wpisz wartość rejestru r0 na komórkę o wskaźniku 14 111 kod instrukcji str reg, addr;, 0 wskaźnik rejestru r0, 1110 wskaźnik komórki pamięci 14

```
R=00 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 R=00 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05
                 pc=0
                 pc=0 A=0
c=1 r0=B
           r1=5
                                                                                                   0B
                                                                                                       00
           r1=5
                 pc=1 A=0
                             R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B
c=2 r0=B
                 pc=1 A=0
                             R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00
c=3 r0=0 r1=5
                             R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00
                 pc=0 A=0
c=1 r0=0
           r1=0
    r0=0
           r1=0
                 pc=1 A=0
                             R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B
                 pc=1 A=0
c=3 r0=0
                                                                                                       99
           r1=0
                 pc=1 A=0
                             R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00
c=0 r0=0
           r1=0
                             R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00
c=1 r0=0 r1=0
                 pc=0 A=0
                             R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00
c=2 r0=0
                 pc=1 A=0
           r1=0
c=3 r0=0
           r1=0
                 pc=1 A=0
                             R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B
                 pc=1 A=0
c=0
    r0=0
           r1=0
                                                                                                       00
                 pc=1 A=1
                             R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00
c=1 r0=0
           r1=0
                             R=90 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00
c=2 r0=0 r1=0
                 pc=2 A=1
                             R=90 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 R=90 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 R=90 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00
                 pc=2 A=1
c=3 r0=0
           r1=0
    r0=0
           r1=0
                 pc=2
                       A=1
                 pc=2 A=2
c=1 r0=0
           r1=0
                 pc=3 A=2
                             R=EE W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00
c=2 r0=0 r1=0
                             R=EE W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 R=0B W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 R=00 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00
c=3 r0=0 r1=0
                 pc=3 A=E
c=0 r0=0
           r1=0
                 pc=3 A=E
c=1/r0=0
           r1=0
                 pc=3 A=3
                             R=86 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00
c=2
    r0=0
           r1=0
                  oc=4 A=3
                                                                                                       00
                 pc=4 A=3
                             R=86 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00
c=3
    r0=6 r1=0
                                                                                                       00
                             R=86 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00 R=86 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00 R=DD W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00 R=DD W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00
c=0
    r0=6 r1=0
                 pc=4 A=3
c=1 r0=6 r1=0
                 pc=4 A=4
                 pc=5
c=2
    rØ=6
           r1=0
                       A=4
                 pc=5 A=D
c=3 r0=6
           r1=0
c=0 r0=6
                             R=05 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00
           r1=5
                 pc=5 A=D
                                                                                                       00
                 pc=5 A=5
                             R=05 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00
c=1 r0=6
           r1=5
                                                                                                       00
                             R=20 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 R=20 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 00 00
           r1=5
                 pc=6 A=5
c=2 r0=6
                                                                                                       00
c=3 r0=B
           r1=5
                 pc=6 A=5
                                                                                                       00
                             R=20 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00
c=0
           r1=5
                 pc=6 A=5
    r0=B
                                                                                                       00
c=1 r0=B r1=5
                             R=20 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00
                 pc=6 A=6
                                                                                                       99
c=2
    r0=B
           r1=5
                 pc=7 A=6
                             R=EE W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00
                             R=EE W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00
c=3 r0=B r1=5
                 pc=7 A=E
           r1=5
                             R=00 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00
c=0 r0=B
                 pc=7
                        A=E
                             R=0B W=0B M: 80
                                                         86 DD 20 EE 00 00
                                                                                00
                                                                                   00
                                                                                       00 00
    r0=B
           r1=5
                 pc=7
                        A=7
                                                 90 EE
                                                                                                   0B
                                                                                                       00
                             R=00 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00
           r1=5
    r0=B
                 pc=8
                       A=7
c=3 r0=B r1=5 pc=0 A=7 R=00 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00
                 pc=0 A=7 R=00 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00
    r0=B r1=5
```

Rys. 1 – Wykonanie programu pierwszego na FPGA

```
W=0B M: 80 90 EE 86 DD 20 EE 00 00
W=0B M: 80 90 EE 86 DD 20 EE 00 00
                  pc=0
                              R=00
                                                                                 00
                                                                                      00
                  pc=0 A=0
                             R=00
           r1=5
                                                                                 00
                                                                                     00
                                                                                         00
                                                                                                 05
c=1 r0=B
                                                                                             00
                                                                                                     0B
                                                                                                         00
                  pc=1 A=0
                             R=80
                                   W=0B M: 80
                                                  90
                                                      EE 86 DD
                                                                  20
                                                                     EE 00
                                                                             00
                                                                                 00
                                                                                     00
c=2 r0=B
           r1=5
                             R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00
                                                                                 00 00 00 00 05 0B
c=3 r0=0 r1=5
                  pc=1 A=0
                                                                                                         00
                             R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B
c=1 r0=0
           r1=0
                  pc=0 A=0
                                                                                                         90
    r0=0
           r1=0
                  pc=1 A=0
                  pc=1 A=0
                                                                                                         99
    r0=0
           r1=0
                  pc=1 A=0
                             R=80 W=0B M: 80
                                                  90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B
    r0=0 r1=0
                                                                                                         00
                             R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B
c=1 r0=0 r1=0
                  pc=0 A=0
                                                                                                         00
                             R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B
                  pc=1 A=0
c=2 r0=0
                                                                                                         00
           r1=0
    r0=0
           r1=0
                  pc=1
                        A=0
                             R=80 W=0B M: 80
                                                  90 EE 86 DD 20 EE 00 00
                  pc=1 A=0
                                                                                 00
                                                                                     00 00 00 05 0B
c=0
    r0=0
           r1=0
                                                                                                         00
                  pc=1 A=1
                             R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05
c=1 r0=0
           r1=0
                                                                                                     0B
                                                                                                         00
                             R=90 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B
c=2 r0=0 r1=0
                  pc=2 A=1
                                                                                                         00
                             R=90 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B R=90 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B R=90 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 00 05 0B
                  pc=2
                        A=1
c=3 r0=0
           r1=0
                                                                                                         99
    r0=0
           r1=0
                  pc=2
c=0
                        A=1
                  pc=2
                        A=2
                                                                                                         00
c=1 r0=0
           r1=0
                             R=EE W=08 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 08 R=EE W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 08 R=08 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 08 R=00 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 00 00
                  pc=3 A=2
c=2 r0=0 r1=0
                                                                                                         00
c=3 r0=0 r1=0
                  pc=3 A=E
                                                                                                         00
                  pc=3 A=E
                                                                                                         00
c=0 r0=0
           r1=0
c=1/r0=0
           r1=0
                  pc=3 A=3
                                                                                                         00
                             R=86 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00
c=2
                  oc=4 A=3
    r0=0
           r1=0
                                                                                                         00
                             R=86 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00
c=3
    r0=6 r1=0
                  pc=4 A=3
                                                                                                         00
                             R=86 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 R=86 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00
c=0
    r0=6 r1=0
                  pc=4 A=3
                                                                                                         00
c=1 r0=6 r1=0
                  pc=4 A=4
                                                                                                         00
                             R=DD W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 R=DD W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00
c=2
    rØ=6
           r1=0
                  pc=5
                        A=4
                                                                                                         00
c=3 r0=6 r1=0
                  pc=5
                        A=D
                                                                                                         00
                  pc=5
                             R=05 W=00 M: 80
                                                  90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00
c=0
    r0=6
           r1=5
                        A=D
                                                                                                         00
                  pc=5
                              R=05 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00
c=1 r0=6
           r1=5
                        A=5
                                                                                                         00
                                    W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00
c=2 r0=6
           r1=5
                  pc=6 A=5
                             R=20
                                                                                                         00
c=3
    r0=B
           r1=5
                  pc=6 A=5
                             R=20
                                                                                                         00
                                    W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00
                  pc=6 A=5
                             R=20
c=0
    r0=B r1=5
                                                                                                         00
                  pc=6 A=6
                             R=20 W=00 M: 80
c=1 r0=B r1=5
                                                  90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00
                                                                                                         00
c=2
    r0=B
           r1=5
                  pc=7 A=6
                             R=EE W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00
                             R=EE W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00
c=3 r0=B r1=5
                  pc=7 A=E
                                                                                                         00
                                                  90 EE 86 DD 20 EE 00 00
c=0 r0=B
           r1=5
                  pc=7
                                    W=0B M: 80
                                                                                 00
                                                                                     00 00 00 05 00
                                                                                                         00
                        A=E
                             R=00
     r0=B
                  pc=7
                              R=0B W=0B M:
                                              80
                                                  90
                                                      EE
                                                          86
                                                              DD
                                                                  20
                                                                     EE
                                                                          00
                                                                              00
                                                                                 00
                                                                                     00
                                                                                         00
                                                                                             00
                                                                                                     0B
                                                                                                         00
           r1=5
                                                                  20
                                                      EE
                                                                     EE
                                                                                 00
                                                                                     00
                                                                                                 05
    r0=B
           r1=5
                  pc=8
                        A=7
                             R=00 W=0B M: 80
                                                  90
                                                          86
                                                              DD
                                                                          00
                                                                             00
                                                                                         00
                                                                                             00
                                                                                                     0B
                                                                                                         00
           r1=5
                  pc=0 A=7
                             R=00 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B
                                                                                                         00
c=3 r0=B
    r0=B
           r1=5
                  pc=0 A=7
                             R=00 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B
                                                                                                         00
```

c=1 r0=0 r1=0 pc=0 A=0 R=00 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 c=2 r0=0 r1=0 pc=1 A=0 R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 c=3 r0=0 r1=0 pc=1 A=0 R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 c=0 r0=0 r1=0 pc=1 A=0 R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 c=1 r0=0 r1=0 pc=1 A=1 R=80 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 c=2 r0=0 r1=0 pc=2 A=1 R=90 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 c=3 r0=0 r1=0 pc=2 A=1 R=90 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 c=0 r0=0 r1=0 pc=2 A=1 R=90 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 c=1 r0=0 r1=0 pc=2 A=2 R=90 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 c=2 r0=0 r1=0 pc=3 A=2 R=EE W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 c=3 r0=0 r1=0 pc=3 A=E R=EE W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 c=0 r0=0 r1=0 pc=3 A=E R=0B W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 00 05 0B 00 c=1 r0=0 r1=0 pc=3 A=3 R=00 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 00 00 00 c=2 r0=0 r1=0 pc=4 A=3 R=86 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00 c=3 r0=6 r1=0 pc=4 A=3 R=86 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00 c=0 r0=6 r1=0 pc=4 A=3 R=86 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00 c=1 r0=6 r1=0 pc=4 A=4 R=86 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00 c=2 r0=6 r1=0 pc=5 A=4 R=DD W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00 c=3 r0=6 r1=0 pc=5 A=D R=DD W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00 c=0 r0=6 r1=5 pc=5 A=D R=05 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 00 00 c=1 r0=6 r1=5 pc=5 A=5 R=05 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00 c=2 (0=6) 1=5 pc=6 A=5 R=20 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00 c=3 r0=B r1=5 pc=6 A=5 R=20 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00 c=0 r0=B r1=5 pc=6 A=5 R=20 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00 c=1 r0=B r1=5 pc=6 A=6 R=20 W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00 c=2 r0=B r1=5 pc=7 A=6 R=EE W=00 M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00 c=3 r0=B r1=5 pc=7 A=E R=EE W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00 c=0 r0=B r1=5 pc=7 A=E R=00 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 00 00 c=1 r0=B r1=5 pc=7 A=7 R=0B W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 c=2 r0=B r1=5 pc=8 A=7 R=00 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00 c=3 r0=B r1=5 pc=0 A=7 R=00 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00

c=0 r0=B r1=5 pc=0 A=7 R=00 W=0B M: 80 90 EE 86 DD 20 EE 00 00 00 00 00 00 05 0B 00

STR R0, [14]

pc update 2 -> 3 fetch opcode EE mem addres 2->E(14) ex: write 00 to E(14)

MOV R0, #6

pc update 3 -> 4 fetch opcode 86 ex: value r0 0->6

LDR R1, [13]

pc update 4 -> 5 fetch opcode DD mem addres D(13) -> value 5 ex: value r1 0->5

ADD R0, R1

pc update 5 -> 6 ex: value r0 -> 5+6 = B

STR R0, [14]

pc update 6 -> 7 fetch opcode EE mem addres 6->E(14) ex: write B to E(14)

JMP 0

pc update 7 -> 8 fetch opcode 00 ex: pc update 8->0 Program na niezmodyfikowanym kodzie. Podany program wykonuje kolejno polecenia:

- 80 (1000 0000) Wpisz 0 do rejestru r0 100 kod instrukcji mov reg,#imm; 0 wskaźnik rejestru r0, 0000 wartość
- 92 (1001 0010) Wpisz 2 do rejestru r1 100 kod instrukcji mov reg,#imm; 1 wskaźnik rejestru r1, 0010 wartość
- 3. 86 (10000 0110) Wpisz 6 do rejestru r0 100 kod instrukcji mov reg,#imm; 0 wskaźnik rejestru r0, 0110 wartość
- 4. 30 (0011 0000) Dodaj rejestry r0 i r1 i zapisz wynik w r1 0011 kod instrukcji add r1, r0;, 1 wskaźnik rejestru r1, 0000 nieużywane dane
- 5. FE (1111 1110) Wpisz wartość rejestru r1 na komórkę o wskaźniku 14 111 kod instrukcji str reg, addr;, 1 wskaźnik rejestru, 1110 wskaźnik komórki pamięci 14
- 6. 8D (1000 0110) Wpisz 13 do rejestru 0 100 kod instrukcji mov reg, #imm;, 0 wskaźnik rejestru r0, 0110 wartość
- 7. 40 (0100 0000) Wykonaj mnożenie r0 * r1 i 4 starsze bity wpisz do r0 młodsze do r1 0100 kod instrukcji mul r1, r0; 0000 niewykorzystana wartość

```
87 🖨
              begin
88
                  state <= 3:
89 🖨
                  if (opcode [7] == 0)
                                                       //jesli bit 7 ma wartosc 0, to operacja arytmetyczna lub skok
90 ⊖
91 🖨
                                                      //analizujemy bity 6, 5 i 4...
                      case (opcode [6:4])
                                                      //jesli wszystkie sa ustawione na 000...
92 E
                          3'b0000:
93 ⊡
                          begin
                                                       //wykonujemy skok pod adres dany stala natychmiastowa
 95
                              pc <= opcode[3:0];
                                                      //zaladuj do PC vartosc znaleziona v bitach 3:0 kodu instrukcji
96 🖨
                          end
97
 98 🖨
                          3'b010:
                                                       //jesli bity 6:4 maja wartosc 010...
99 🖯
                          begin
                              r0 <= r0 + r1;
                                                       //wykonujemy dodavanie: add r0, r1 (r0 = r0 + r1)
                          end
102 |
103 🖨
                          3'b011:
                                                       //jesli bity 6:4 maja wartosc 011...
104 E
                          begin
105
                              rl <= rl + r0;
                                                      //wykonujemy dodavanie: add r1, r0 (r1 = r1 + r0)
106 A
                          end
107
108 🖨
                          3'b100:
                                                       //jesli bity 6:4 maja wartosc 100...
109 (
                              r0 <= r0 * r1 / 16;
                                                      // Wykonujemy mnożenie i zapisujemy starsze bity do r0
111
                              r1 <= r0 * r1 % 16;
                                                      // Wykonujemy mnożenie i zapisujemy młodsze bity do rl
112 (
                          end
113 A
                      endcase
114 🖨
```

Rys. 2 – Implementacja wymaganych instrukcji

```
r0=0 r1=0 pc=0 A=0 R=00 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00
c=1
                         R=80
                                        80
                                            92 86
                                                      FE 8D 40 00
                                                                    00
                                                                       00
c=2
    r0=0
         r1=0
               pc=1 A=0
                               W=00
                                     М:
                                                  30
                                                                          00
                                                                              00
                                                                                 00
                                                                                    00
                                                                                        00
                                                         8D 40 00 00 00
                               W=00 M:
                                        80
    r0=0
         r1=0
               pc=1 A=0
                          R=80
                                            92
                                               86
                                                  30
                                                      FΕ
                                                                          00
                                                                             00
                                                                                 00
                                           92
92
                                               86
                                                      FE
FE
               pc=1 A=0
                                                  30
30
                                                         8D 40 00 00 00 00 00 00
c=0
         r1=0
                         R=80
                               W=00
                                     M:
                                        80
                                                                                        00
    r0=0
                                                                                            00
    r0=0
          r1=0
               pc=1 A=1
                          R=80
                               W=00
                                     M:
                                        80
                                               86
                                                         8D 40 00
                                                                   00
                                                                       00
                                                                          00
                                                                              00
                                                                                 00
                          R=92
                                            92 86 30
                                                      FE 8D 40 00 00 00 00 00
               pc=2
                                        80
                               W=00
                                                                                 00
c=2
    r0=0
         r1=0
                     A=1
                                     М:
               pc=2 A=1
                          R=92
                               W=00
                                        80
                                           92 86 30
                                                      FE 8D 40 00 00 00 00 00 00 00
c=3
    r0=0
         r1=2
                                     Μ:
                                           92 86 30
92 86 30
92 86 30
92 86 30
         r1=2
               pc=2
                               W=00
                                        80
                                                  30 FE 8D 40 00 00 00 00 00 00 00 00
c=0
    r0=0
                     A=1
                          R=92
                                    М:
                                                      FE 8D 40 00 00 00 00 00 00 00 FE 8D 40 00 00 00 00 00 00 00 00 FE 8D 40 00 00 00 00 00 00 00 00
                                        80
80
         r1=2
r1=2
                               W=00
    r0=0
               pc=2
                     A=2
                          R=92
                                     M:
c=1
                               W=00
    r0=0
               pc=3
                     A=2
                          R=86
                                     M:
                          R=86
         r1=2
               pc=3
                     A=2
                               W=00
                                        80
c=3
    r0=6
                                     М:
                                           92 86
         r1=2
               pc=3
                          R=86
                               W=00
                                    M:
                                        80
                                                  30
c=0
                     A=2
                               W=00
                                        80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00
                          R=86
c=1
    r0=6 r1=2
               pc=3 A=3
                                     M:
                                           92 86 30 FE 8D 40 00 00 00 00 00 00 00 92 86 30 FE 8D 40 00 00 00 00 00 00 00
c=2
    r0=6
         r1=2
               pc=4 A=3
                          R=30
                               W=00
                                     M:
                                        80
          r1=8
               pc=4
                          R=30
                               W=00
                                     M:
                                        80
c=3
    r0=6
                     A=3
    r0=6
         r1=8
               pc=4
                     A=3
                         R=30
                               W=00
                                     M:
                                        80
                                            92 86 30
                                                      FE 8D 40 00 00 00 00 00
                                                                                 00
c=0
                               pc=4
                          R=30
    r0=6
         r1=8
                     A=4
               pc=5 A=4
c=2
    r0=6 r1=8
                          R=FE
c=3
    r0=6
          r1=8
               pc=5
                     A=E
                          R=FE
    r0=6
          r1=8
                     A=E
                          R=00
c=0
               pc=5
                          R=08
c=1
    r0=6
         r1=8
               pc=5
                     A=5
               pc=6
                     A=5
c=2
    r0=6
          r1=8
                          R=8D
c=3
         r1=8
               pc=6
                     A=5
                          R=8D
    r@=D
          r1=8
                     A=5
                          R=8D
c=0
    r0=D
               pc=6
               pc=6 A=6
         r1=8
                          R=8D
c=1
    r0=D
c=2
    r0=D r1=8
               pc=7 A=6
                          R=40
                               r0=6 r1=8
               pc=7 A=6
                          R=40
c=3
               pc=7
                          R=40
    r0=6
         r1=8
                     A=6
c=0
c=1
    r0=6
          r1=8
               pc=7
                     A=7
                          R=40
               pc=8 A=7
                          R=00
c=2
    r0=6
         r1=8
c=3
    r0=6
         r1=8
               pc=0
                     A=7
                          R=00
               pc=0 A=7
    r0=6 r1=8
                          R=00
c=0
                                                      FE 8D 40 00 00
FE 8D 40 00 00
               pc=0 A=0
                                            92 86
c=1
    r0=6
         r1=8
                          R=00
                               W=08
                                     M:
                                        80
                                                  30
                                                         8D 40 00 00 00 00
                                                                              00
                                            92 86 30
                                        80
                                                                       00
                          R=80
                               W=08
                                                                          00
                                                                              00
    r0=6
         r1=8
               pc=1 A=0
                                     M:
                                                                                 00
c=2
                          R=80
                               W=08
                                        80
                                            92 86 30
                                                      FE 8D 40 00 00 00 00 00 00
c=3
    r0=0
         r1=8
               pc=1 A=0
                                     М:
                                                      c=0
    r0=0
         r1=8
               pc=1 A=0
                          R=80
                               W=08
                                     M:
                                        80
                                            92
                                               86
                                                  30
                                           92
92
               pc=1 A=1
                               W=08
                                        80
                                               86
                                                  30
         r1=8
                          R=80
                                     M:
c=1
    r0=0
                                        80
                                                  30
    r0=0
               pc=2
                     A=1
                          R=92
                               W=08
                                     M:
                                               86
c=2
                                            92 86 30
               pc=2
                          R=92
                                        80
c=3
    r0=0
          r1=2
                     A=1
                               W=08
                                     М:
                          R=92
                               W=08
                                        80
                                           92 86
                                                  30
                                                      FE 8D 40 00 00 00 00 00 00
c=0
    r0=0
         r1=2
               pc=2 A=1
                                     M:
                                        80
                                            92
                                               86
                                                  30
                                                         8D 40 00 00 00 00 00 00
c=1
    r0=0
         r1=2
               pc=2
                     A=2
                          R=92
                               W=08
                                     M:
                                                      FΕ
                                                                                    00
                                                                                        08
                                                                                           00
               pc=3 A=2 R=86 W=08 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 pc=3 A=2 R=86 W=08 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 pc=3 A=2 R=86 W=08 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00
         r1=2
r1=2
r1=2
                                                                                        08
c=2
    r0=0
                                                                                            00
c=3
    r0=6
                                                                                        08
c=0
    r0=6
                                                                                        08
```

Rys. 3 – Wykonanie programu drugiego na FPGA

c=1 r0=0 r1=0 pc=0 A=0 R=00 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 00 c=2 r0=0 r1=0 pc=1 A=0 R=80 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 00 c=3 r0=0 r1=0 pc=1 A=0 R=80 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 c=0 r0=0 r1=0 pc=1 A=0 R=80 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 00 c=1 r0=0 r1=0[pc=1]A=1 R=80 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 c=2 r0=0 r1=0 pc=2 A=1 R=92 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 c=3 r0=0 r1=2 pc=2 A=1 R=92 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 c=0 r0=0 r1=2 pc=2 A=1 R=92 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 00 c=1 r0=0 r1=2 pc=2 A=2 R=92 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 00 c=2[r0=0]r1=2 pc=3 A=2 R=86 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 00 c=3 r0=6 r1=2 pc=3 A=2 R=86 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 00 c=0 r0=6 r1=2 pc=3 A=2 R=86 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 00 c=1 r0=6 r1=2 pc=3 A=3 R=86 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 c=2 r0=6 r1=2 pc=4 A=3 R=30 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 c=3 r0=6r1=8 pc=4 A=3 R=30 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 c=0 r0=6 r1=8 pc=4 A=3 R=30 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 c=1 r0=6 r1=8 pc=4 A=4 R=30 W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 c=2 r0=6 r1=8 pc=5 A=4 R=FE W=00 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 c=3 r0=6 r1=8 pc=5 A=E R=FE W=08 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 c=0 r0=6 r1=8 pc=5 A=E R=00 W=08 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 00 c=1 r0=6 r1=8 pc=5 A=5 R=08 W=08 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 00 c=2 f0=6 r1=8 bc=6 A=5 R=8D W=08 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 08 00 c=3 r0=D r1=8 pc=6 A=5 R=8D W=08 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 08 00 c=0 r0=D r1=8 pc=6 A=5 R=8D W=08 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 00 c=1 r0=D r1=8 pc=6A=6 R=8D W=08 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 00 c=2 f0=D r1=8 pc=7 A=6 R=40 W=08 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 08 00 c=3 0=6 r1=8 pc=7 A=6 R=40 W=08 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 00 c=0 r0=6 r1=8 pc=7 A=6 R=40 W=08 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 00 c=1 r0=6 r1=8 c=7 A=7 R=40 W=08 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 08 00 c=2 r0=6 r1=8 oc=8 A=7 R=00 W=08 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 c=3 r0=6 r1=8 pc=0 A=7 R=00 W=08 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 00 00

c=0 r0=6 r1=8 pc=0 A=7 R=00 W=08 M: 80 92 86 30 FE 8D 40 00 00 00 00 00 00 00 00 00

MOV R1, #2

pc update 1 -> 2 fetch opcode 92 ex: value r1 0->2

MOV R0, #6

pc update 2 -> 3 fetch opcode 86 ex: value r0 0->6

ADD R1, R0

pc update 3 -> 4 ex: value r1 -> 2+6 = 8

STR R1, [14]

pc update 4 -> 5 fetch opcode FE mem addres 6->E(14) ex: write 8 to E(14)

MOV RO, #D

pc update 5 -> 6 fetch opcode 8D ex: value r0 6->D

MUL R1, R0

pc update 6 -> 7 ex: value r0 -> 6; r1->8 // D(13) * 8 = 104 = 0x68

JMP 0

pc update 7 -> 8 fetch opcode 00 ex: pc update 8->0