Computer Architectures
Exam of 12.2.2024 - part I

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A - Question #2

Let's consider a generic processor that executes 32-bit instructions, uses 32-bit addresses, and performs branch predictions via a Branch Target Buffer (BTB) composed of 8 entries.
Assuming that the BTB only stores branch taken predictions and starts from a known state (shown at the bottom of the page), report the content of the BTB after the execution of the following instructions:

1	div.d f1, f2, f3	located at the address *0x00048000*
2	beq f1, f2, lab1	located at the address *0x00048004*; the branch is taken, and the branch target address is *0x00048010*
3	add.d f2, f4, f5	located at the address *0x00048010*
4	bne f2, f3, lab2	located at the address *0x00048014*; the branch is taken, and the branch target address is *0x00048030*
5	mul.d f7, f7, f8	located at the address *0x00048030*
6	sub r1, r1, 1	located at the address *0x00048034*
7	beqz r1, term	located at the address *0x00048038*; the branch is not taken
8	jr r2	located at the address *0x0004803c*; the branch is taken, and the branch target address is *0x00048000*
9	div.d f1, f2, f3	located at the address *0x00048000*
10	beq f1, f2, lab1	located at the address *0x00048004*; the branch is taken, and the branch target address is *0x00048010*
11	add.d f2, f4, f5	located at the address *0x00048010*
12	bne f2, f3, lab2	located at the address *0x00048014*; the branch is not taken
13	sub.d f6, f6, f10	located at the address *0x00048018*
14	beqz f6, lab3	located at the address *0x0004801c*; the branch is taken, and the branch target address is *0x00048038*
15	beqz r1, term	located at the address *0x00048038*; the branch is taken, and the branch target address is *0x00048040*
16	halt	located at the address *0x00048040*

The use of the calculator is forbidden. Before starting to fill the BTB itself, it is necessary to fill in the contents of this table so as to understand which entry of the BTB each instruction will refer to.
Hint: To calculate the BTB entry corresponding to each branch instruction, remember that you should exclude the last two bits from the instruction address as they are always equal to 0.

Instruction	Address in Hex	Address in Binary	Entry No.
div.d f1, f2, f3	0x00048000	0000 0000 0000 0100 1000 0000 000**0 00**00	0
beq f1, f2, lab1	0x00048004	0000 0000 0000 0100 1000 0000 000**0 01**00	1
add.d f2, f4, f5	0x00048010	0000 0000 0000 0100 1000 0000 000**1 00**00	4
bne f2, f3, lab2	0x00048014	0000 0000 0000 0100 1000 0000 000**1 01**00	5
mul.d f7, f7, f8	0x00048030	0000 0000 0000 0100 1000 0000 001**1 00**00	4
sub r1, r1, 1	0x00048034	0000 0000 0000 0100 1000 0000 001**1 01**00	5
beqz r1, term	0x00048038	0000 0000 0000 0100 1000 0000 001**1 10**00	6
jr r2	0x0004803c	0000 0000 0000 0100 1000 0000 001**1 11**00	7
sub.d f6, f6, f10	0x00048018	0000 0000 0000 0100 1000 0000 000**1 10**00	6
beqz f6, lab3	0x0004801c	0000 0000 0000 0100 1000 0000 000**1 11**00	7
halt	0x00048040	0000 0000 0000 0100 1000 0000 010**0 00**00	0

Then, describe the state of the BTB in each step and, upon completion, report the total number of correct and incorrect predictions.
Hint: "Smart" cut and paste is accepted/recommended.

0. BTB initial content (***must not be changed***)

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00047fe0	0x00048000
2	0x00047fa4	0x00047fb8
3	0x00000000	0x00000000

Entry No.	Address	Target
4	0x00047f8c	0x00047fa0
5	0x00047f58	0x00047f80
6	0x00000000	0x00000000
7	0x00000000	0x00000000

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1. BTB content after ***div.d f1, f2, f3*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00047fe0	0x00048000
2	0x00047fa4	0x00047fb8
3	0x00000000	0x00000000

Entry No.	Address	Target
4	0x00047f8c	0x00047fa0
5	0x00047f58	0x00047f80
6	0x00000000	0x00000000
7	0x00000000	0x00000000

2. BTB content after ***beq f1, f2, lab1*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	**0x00048004**	**0x00048010**
2	0x00047fa4	0x00047fb8
3	0x00000000	0x00000000

Entry No.	Address	Target
4	0x00047f8c	0x00047fa0
5	0x00047f58	0x00047f80
6	0x00000000	0x00000000
7	0x00000000	0x00000000

3. BTB content after ***add.d f2, f4, f5*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00048004	0x00048010
2	0x00047fa4	0x00047fb8
3	0x00000000	0x00000000

Entry No.	Address	Target
4	0x00047f8c	0x00047fa0
5	0x00047f58	0x00047f80
6	0x00000000	0x00000000
7	0x00000000	0x00000000

4. BTB content after ***bne f2, f3, lab2*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00048004	0x00048010
2	0x00047fa4	0x00047fb8
3	0x00000000	0x00000000

Entry No.	Address	Target
4	0x00047f8c	0x00047fa0
5	**0x00048014**	**0x00048030**
6	0x00000000	0x00000000
7	0x00000000	0x00000000

5. BTB content after ***mul.d f7, f7, f8*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00048004	0x00048010
2	0x00047fa4	0x00047fb8
3	0x00000000	0x00000000

Entry No.	Address	Target
4	0x00047f8c	0x00047fa0
5	0x00048014	0x00048030
6	0x00000000	0x00000000
7	0x00000000	0x00000000

6. BTB content after ***sub r1, r1, 1*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00048004	0x00048010
2	0x00047fa4	0x00047fb8
3	0x00000000	0x00000000

Entry No.	Address	Target
4	0x00047f8c	0x00047fa0
5	0x00048014	0x00048030
6	0x00000000	0x00000000
7	0x00000000	0x00000000

7. BTB content after ***beqz r1, term*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00048004	0x00048010
2	0x00047fa4	0x00047fb8
3	0x00000000	0x00000000

Entry No.	Address	Target
4	0x00047f8c	0x00047fa0
5	0x00048014	0x00048030
6	**0x00000000**	**0x00000000**
7	0x00000000	0x00000000

8. BTB content after ***jr r2*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00048004	0x00048010
2	0x00047fa4	0x00047fb8
3	0x00000000	0x00000000

Entry No.	Address	Target
4	0x00047f8c	0x00047fa0
5	0x00048014	0x00048030
6	0x00000000	0x00000000
7	**0x0004803c**	**0x00048000**

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9. BTB content after ***div.d f1, f2, f3*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00048004	0x00048010
2	0x00047fa4	0x00047fb8
3	0x00000000	0x00000000

Entry No.	Address	Target
4	0x00047f8c	0x00047fa0
5	0x00048014	0x00048030
6	0x00000000	0x00000000
7	0x0004803c	0x00048000

10. BTB content after ***beq f1, f2, lab1*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	**0x00048004**	**0x00048010**
2	0x00047fa4	0x00047fb8
3	0x00000000	0x00000000

Entry No.	Address	Target
4	0x00047f8c	0x00047fa0
5	0x00048014	0x00048030
6	0x00000000	0x00000000
7	0x0004803c	0x00048000

11. BTB content after ***add.d f2, f4, f5*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00048004	0x00048010
2	0x00047fa4	0x00047fb8
3	0x00000000	0x00000000

Entry No.	Address	Target
4	0x00047f8c	0x00047fa0
5	0x00048014	0x00048030
6	0x00000000	0x00000000
7	0x0004803c	0x00048000

12. BTB content after ***bne f2, f3, lab2*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00048004	0x00048010
2	0x00047fa4	0x00047fb8
3	0x00000000	0x00000000

Entry No.	Address	Target
4	0x00047f8c	0x00047fa0
5	**0x00000000**	**0x00000000**
6	0x00000000	0x00000000
7	0x0004803c	0x00048000

13. BTB content after ***sub.d f6, f6, f10*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00048004	0x00048010
2	0x00047fa4	0x00047fb8
3	0x00000000	0x00000000

Entry No.	Address	Target
4	0x00047f8c	0x00047fa0
5	0x00000000	0x00000000
6	0x00000000	0x00000000
7	0x0004803c	0x00048000

14. BTB content after ***beqz f6, lab3*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00048004	0x00048010
2	0x00047fa4	0x00047fb8
3	0x00000000	0x00000000

Entry No.	Address	Target
4	0x00047f8c	0x00047fa0
5	0x00000000	0x00000000
6	0x00000000	0x00000000
7	**0x0004801c**	**0x00048038**

15. BTB content after ***beqz r1, term*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00048004	0x00048010
2	0x00047fa4	0x00047fb8
3	0x00000000	0x00000000

Entry No.	Address	Target
4	0x00047f8c	0x00047fa0
5	0x00000000	0x00000000
6	**0x00048038**	**0x00048040**
7	0x0004801c	0x00048038

16. BTB content after ***halt*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00048004	0x00048010
2	0x00047fa4	0x00047fb8
3	0x00000000	0x00000000

Entry No.	Address	Target
4	0x00047f8c	0x00047fa0
5	0x00000000	0x00000000
6	0x00048038	0x00048040
7	0x0004801c	0x00048038

Total number of correct predictions: __**2**__ Total number of incorrect predictions: __**6**__

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B - Question #2

Let's consider a generic processor that executes 32-bit instructions, uses 32-bit addresses, and performs branch predictions via a Branch Target Buffer (BTB) composed of 8 entries.
Assuming that the BTB only stores branch taken predictions and starts from a known state (shown at the bottom of the page), report the content of the BTB after the execution of the following instructions:

1	div.d f1, f2, f3	located at the address *0x0000370c*
2	beq f1, f2, lab1	located at the address *0x00003710*; the branch is taken, and the branch target address is *0x00003724*
3	add.d f2, f4, f5	located at the address *0x00003724*
4	bne f2, f3, lab2	located at the address *0x00003728*; the branch is taken, and the branch target address is *0x0000373c*
5	mul.d f7, f7, f8	located at the address *0x0000373c*
6	sub r1, r1, 1	located at the address *0x00003740*
7	beqz r1, term	located at the address *0x00003744*; the branch is not taken
8	jr r2	located at the address *0x00003748*; the branch is taken, and the branch target address is *0x0000370c*
9	div.d f1, f2, f3	located at the address *0x0000370c*
10	beq f1, f2, lab1	located at the address *0x00003710*; the branch is taken, and the branch target address is *0x00003724*
11	add.d f2, f4, f5	located at the address *0x00003724*
12	bne f2, f3, lab2	located at the address *0x00003728*; the branch is not taken
13	sub.d f6, f6, f10	located at the address *0x0000372c*
14	beqz f6, lab3	located at the address *0x00003730*; the branch is taken, and the branch target address is *0x00003744*
15	beqz r1, term	located at the address *0x00003744*; the branch is taken, and the branch target address is *0x00003750*
16	halt	located at the address *0x00003750*

The use of the calculator is forbidden. Before starting to fill the BTB itself, it is necessary to fill in the contents of this table so as to understand which entry of the BTB each instruction will refer to.
Hint: To calculate the BTB entry corresponding to each branch instruction, remember that you should exclude the last two bits from the instruction address as they are always equal to 0.

Instruction	Address in Hex	Address in Binary	Entry No.
div.d f1, f2, f3	0x0000370c	0000 0000 0000 0000 0011 0111 000**0 11**00	3
beq f1, f2, lab1	0x00003710	0000 0000 0000 0000 0011 0111 000**1 00**00	4
add.d f2, f4, f5	0x00003724	0000 0000 0000 0000 0011 0111 001**0 01**00	1
bne f2, f3, lab2	0x00003728	0000 0000 0000 0000 0011 0111 001**0 10**00	2
mul.d f7, f7, f8	0x0000373c	0000 0000 0000 0000 0011 0111 001**1 11**00	7
sub r1, r1, 1	0x00003740	0000 0000 0000 0000 0011 0111 010**0 00**00	0
beqz r1, term	0x00003744	0000 0000 0000 0000 0011 0111 010**0 01**00	1
jr r2	0x00003748	0000 0000 0000 0000 0011 0111 010**0 10**00	2
sub.d f6, f6, f10	0x0000372c	0000 0000 0000 0000 0011 0111 001**0 11**00	3
beqz f6, lab3	0x00003730	0000 0000 0000 0000 0011 0111 001**1 00**00	4
halt	0x00003750	0000 0000 0000 0000 0011 0111 010**1 00**00	4

Then, describe the state of the BTB in each step and, upon completion, report the total number of correct and incorrect predictions.
Hint: "Smart" cut and paste is accepted/recommended.

0. BTB initial content (***must not be changed***)

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00000000	0x00000000
2	0x0000364c	0x0000365c
3	0x0000367c	0x0000370c

Entry No.	Address	Target
4	0x00003654	0x00003670
5	0x00000000	0x00000000
6	0x00003634	0x00003644
7	0x00000000	0x00000000

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1. BTB content after ***div.d f1, f2, f3*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00000000	0x00000000
2	0x0000364c	0x0000365c
3	0x0000367c	0x0000370c

Entry No.	Address	Target
4	0x00003654	0x00003670
5	0x00000000	0x00000000
6	0x00000000	0x00000000
7	0x00000000	0x00000000

2. BTB content after ***beq f1, f2, lab1*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00000000	0x00000000
2	0x0000364c	0x0000365c
3	0x0000367c	0x0000370c

Entry No.	Address	Target
4	**0x00003710**	**0x00003724**
5	0x00000000	0x00000000
6	0x00003634	0x00003644
7	0x00000000	0x00000000

3. BTB content after ***add.d f2, f4, f5*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00000000	0x00000000
2	0x0000364c	0x0000365c
3	0x0000367c	0x0000370c

Entry No.	Address	Target
4	0x00003710	0x00003724
5	0x00000000	0x00000000
6	0x00003634	0x00003644
7	0x00000000	0x00000000

4. BTB content after ***bne f2, f3, lab2*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00000000	0x00000000
2	**0x00003728**	**0x0000373c**
3	0x0000367c	0x0000370c

Entry No.	Address	Target
4	0x00003710	0x00003724
5	0x00000000	0x00000000
6	0x00003634	0x00003644
7	0x00000000	0x00000000

5. BTB content after ***mul.d f7, f7, f8*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00000000	0x00000000
2	0x00003728	0x0000373c
3	0x0000367c	0x0000370c

Entry No.	Address	Target
4	0x00003710	0x00003724
5	0x00000000	0x00000000
6	0x00003634	0x00003644
7	0x00000000	0x00000000

6. BTB content after ***sub r1, r1, 1*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00000000	0x00000000
2	0x00003728	0x0000373c
3	0x0000367c	0x0000370c

Entry No.	Address	Target
4	0x00003710	0x00003724
5	0x00000000	0x00000000
6	0x00003634	0x00003644
7	0x00000000	0x00000000

7. BTB content after ***beqz r1, term*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	**0x00000000**	**0x00000000**
2	0x00003728	0x0000373c
3	0x0000367c	0x0000370c

Entry No.	Address	Target
4	0x00003710	0x00003724
5	0x00000000	0x00000000
6	0x00003634	0x00003644
7	0x00000000	0x00000000

8. BTB content after ***jr r2*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00000000	0x00000000
2	**0x00003748**	**0x0000370c**
3	0x0000367c	0x0000370c

Entry No.	Address	Target
4	0x00003710	0x00003724
5	0x00000000	0x00000000
6	0x00003634	0x00003644
7	0x00000000	0x00000000

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9. BTB content after ***div.d f1, f2, f3*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00000000	0x00000000
2	0x00003748	0x0000370c
3	0x0000367c	0x0000370c

Entry No.	Address	Target
4	0x00003710	0x00003724
5	0x00000000	0x00000000
6	0x00003634	0x00003644
7	0x00000000	0x00000000

10. BTB content after ***beq f1, f2, lab1*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00000000	0x00000000
2	0x00003748	0x0000370c
3	0x0000367c	0x0000370c

Entry No.	Address	Target
4	**0x00003710**	**0x00003724**
5	0x00000000	0x00000000
6	0x00003634	0x00003644
7	0x00000000	0x00000000

11. BTB content after ***add.d f2, f4, f5*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00000000	0x00000000
2	0x00003748	0x0000370c
3	0x0000367c	0x0000370c

Entry No.	Address	Target
4	0x00003710	0x00003724
5	0x00000000	0x00000000
6	0x00003634	0x00003644
7	0x00000000	0x00000000

12. BTB content after ***bne f2, f3, lab2*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00000000	0x00000000
2	**0x00000000**	**0x00000000**
3	0x0000367c	0x0000370c

Entry No.	Address	Target
4	0x00003710	0x00003724
5	0x00000000	0x00000000
6	0x00003634	0x00003644
7	0x00000000	0x00000000

13. BTB content after ***sub.d f6, f6, f10*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00000000	0x00000000
2	0x00000000	0x00000000
3	0x0000367c	0x0000370c

Entry No.	Address	Target
4	0x00003710	0x00003724
5	0x00000000	0x00000000
6	0x00003634	0x00003644
7	0x00000000	0x00000000

14. BTB content after ***beqz f6, lab3*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00000000	0x00000000
2	0x00000000	0x00000000
3	0x0000367c	0x0000370c

Entry No.	Address	Target
4	**0x00003730**	**0x00003744**
5	0x00000000	0x00000000
6	0x00003634	0x00003644
7	0x00000000	0x00000000

15. BTB content after ***beqz r1, term*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	**0x00003744**	**0x00003750**
2	0x00000000	0x00000000
3	0x0000367c	0x0000370c

Entry No.	Address	Target
4	0x00003730	0x00003744
5	0x00000000	0x00000000
6	0x00003634	0x00003644
7	0x00000000	0x00000000

16. BTB content after ***halt*** execution

Entry No.	Address	Target
0	0x00000000	0x00000000
1	0x00003744	0x00003750
2	0x00000000	0x00000000
3	0x0000367c	0x0000370c

Entry No.	Address	Target
4	0x00003730	0x00003744
5	0x00000000	0x00000000
6	0x00003634	0x00003644
7	0x00000000	0x00000000

Total number of correct predictions: __**2**__ Total number of incorrect predictions: __**6**__