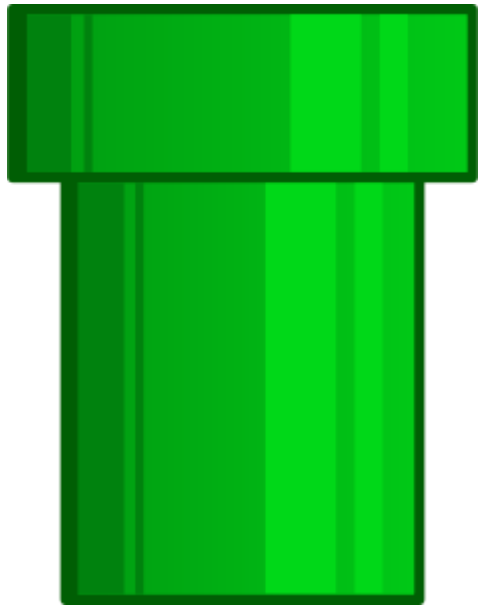
Pipelining

Kjartan Johannesen



Dagsorden

- Lidt pipeline teori
  - Ressourcer
  - Afhængigheder
  - Forwarding

- Løsning af eksamenssæt
  - Simpel pipeline — Re-Exam 2022/2023, Q 1.3.1
  - 2-vejs superskalar — Exam 2022/2023, Q 1.2.2
  - 4-vejs out-of-order — Re-Exam 2022/2023, Q 1.3.2

Ressourcer

- Ressourcer (ved simpel pipeline):
  - Fe – Instruktionshentning (fetch)
  - De – Instruktionsafkodning (decode)
  - Ex – Udførelse af aritmetik (execute)
  - Me – Tilgang til lager hvis load eller store (memory)
  - Wb – Odatering af registre med resultat (writeback)

- Eksempler på ressourcebegrænsninger:
  - Simpel pipeline:
    - Fe: 1, De: 1, Ex: 1, Me: 1, Wb: 1
    - Dette betyder at vi har en af hver ressource, hvilket betyder at kun en instruktion kan være i hver fase samtidig.
  - Superskalar:
    - Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2
    - Her har to af alle ressourcer bortset fra Ex og Me som vi kun har en enkelt af hver af.

Afhængigheder

- Format på instruktioner:
  - Load: rd, imm(rs1)
  - Store: rs2, imm(rs1)
  - Alle andre: rd, rs1, rs2/imm/label

- Eksempler på dataafhængigheder
  - depend(Ex, rs1) betyder at rs1 skal være klar inden denne instruktion kan udføre Ex.
  - produce(Wb, rd) betyder at rd bliver skrevet til i Wb-fasen af denne instruktion.
  - depend(Fe, PC) betyder at program counter skal være klar før denne instruktion kan gå ind i Fe (Fetch-fasen).

Eksempler på kontrolafhængigheder for hop ved hopforudsigelse (branch prediction):

- hop baglæns taget: produce(De, PC)
- hop baglæns ikke taget: produce(Ex, PC)
- hop forlæns taget: produce(Ex, PC)
- hop forlæns ikke taget: -

Forwarding

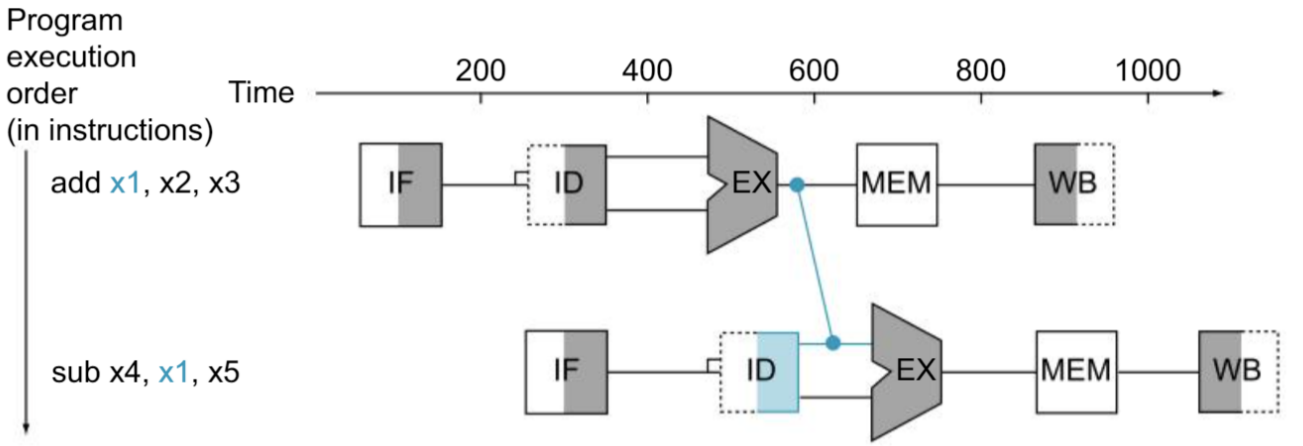
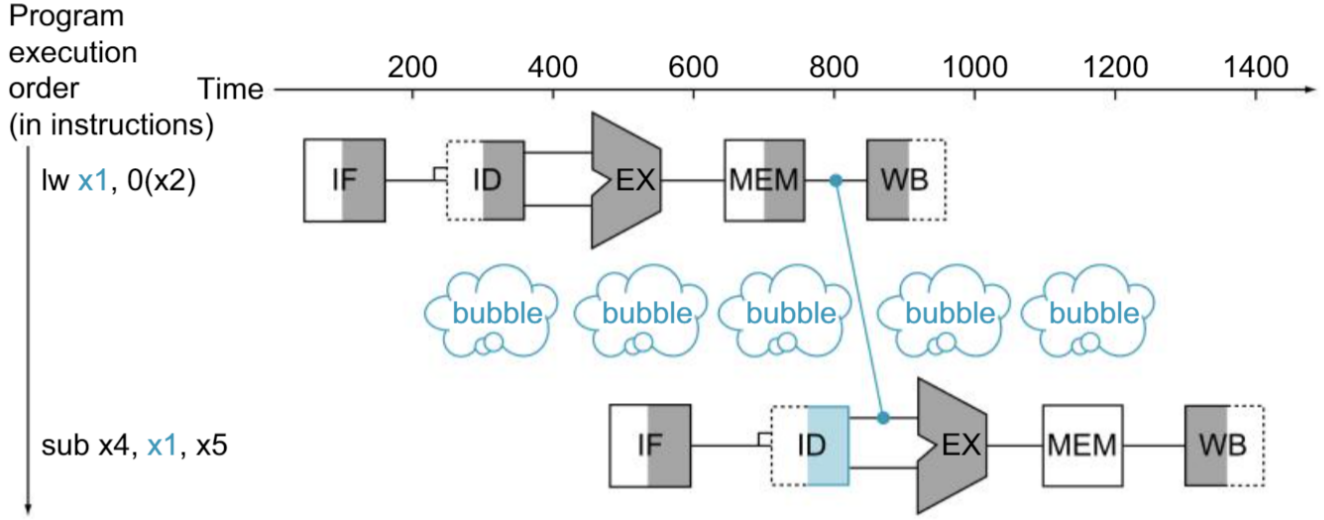


FIGURE 4.31 Graphical representation of forwarding. The connection shows the forwarding path from the output of the EX stage of `add` to the input of the EX stage for `sub`, replacing the value from register `x1` read in the second stage of `sub`.



- For alu-operationer er resultatet klart efter Ex
- For load-operationer er det klart efter Me eller tilsvarende

Re-Exam 2022/2023, Q 1.3.1

- Ressourcer:

  Fe:1, De:1, Ex:1, Me:1, Wb:1

- Antagelse:
  - Hop er forudsagt som bagudtagne, som beskrevet i noten. Dvs. PC bliver opdateret i De hvis hoppet er korrekt forudsagt.

Question 1.3.1: Give an execution diagram for a simple 5-stage pipeline with full forwarding as described in COD.

	Code	Timing
	.L7:	
1	slli a4,a5,2	
2	add a4,a3,a4	
3	lw a4,0(a4)	
4	add a0,a0,a4	
5	addi a5,a5,1	
6	blt a5,a1,.L7	
	L3: L7:	
7	slli a4,a5,2	
8	add a4,a3,a4	
9	lw a4,0(a4)	
10	add a0,a0,a4	
11	addi a5,a5,1	
10	blt a5,a1,.L7	

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4																				
3	lw a4, 0(a4)																				
4	add a0, a0, a4																				
5	addi a5, a5, 1																				
6	blt a5, a1,.L7																				
	.L7																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)																				
4	add a0, a0, a4																				
5	addi a5, a5, 1																				
6	blt a5, a1,.L7																				
	.L7																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)																				
4	add a0, a0, a4																				
5	addi a5, a5, 1																				
6	blt a5, a1,.L7																				
	.L7																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Her bliver resultatet af slli forwarded til add,
så det allerede kan bruges efter slli's Ex-fase.

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)			Fe	De	Ex	Me	Wb													
4	add a0, a0, a4																				
5	addi a5, a5, 1																				
6	blt a5, a1,.L7																				
	.L7																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)			Fe	De	Ex	Me	Wb													
4	add a0, a0, a4				Fe	De	Ex	Ex	Me	Wb											
5	addi a5, a5, 1																				
6	blt a5, a1,.L7																				
	.L7																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)			Fe	De	Ex	Me	Wb													
4	add a0, a0, a4				Fe	De	Ex	Ex	Me	Wb											
5	addi a5, a5, 1				Der stalles i Ex fordi a4 endnu ikke er klar																
6	blt a5, a1,.L7																				
	.L7																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)			Fe	De	Ex	Me	Wb													
4	add a0, a0, a4				Fe	De	Ex	Ex	Me	Wb											
5	addi a5, a5, 1																				
6	blt a5, a1,.L7																				
	.L7																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Her bliver resultatet af lw forwarded til add, så det allerede kan bruges efter lw's Me-fase.

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)			Fe	De	Ex	Me	Wb													
4	add a0, a0, a4				Fe	De	Ex	Ex	Me	Wb											
5	addi a5, a5, 1					Fe	De	De	Ex	Me	Wb										
6	blt a5, a1,.L7																				
	.L7																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)			Fe	De	Ex	Me	Wb													
4	add a0, a0, a4				Fe	De	Ex	Ex	Me	Wb											
5	addi a5, a5, 1					Fe	De	De	Ex	Me	Wb										
6	blt a5, a1,.L7						Der stalles i De fordi Ex ikke er tilgængelig														
	.L7																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)			Fe	De	Ex	Me	Wb													
4	add a0, a0, a4				Fe	De	Ex	Ex	Me	Wb											
5	addi a5, a5, 1					Fe	De	De	Ex	Me	Wb										
6	blt a5, a1,.L7						Fe	Fe	De	Ex	Me	Wb									
	.L7																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)			Fe	De	Ex	Me	Wb													
4	add a0, a0, a4				Fe	De	Ex	Ex	Me	Wb											
5	addi a5, a5, 1					Fe	De	De	Ex	Me	Wb										
6	blt a5, a1,.L7						Fe	Fe	De	Ex	Me	Wb									
	.L7																				
7	slli a4, a5, 2									Fe	De	Ex	Me	Wb							
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)			Fe	De	Ex	Me	Wb													
4	add a0, a0, a4				Fe	De	Ex	Ex	Me	Wb											
5	addi a5, a5, 1					Fe	De	De	Ex	Me	Wb										
6	blt a5, a1,.L7						Fe	Fe	De	Ex	Me	Wb									
	.L7																				
7	slli a4, a5, 2									Fe	De	Ex	Me	Wb							
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Det er et korrekt forudsagt bagudtagent hop, så program counter (PC) er opdateret i De-fasen for blt, og vi kan fetche i den efterfølgende fase.

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)			Fe	De	Ex	Me	Wb													
4	add a0, a0, a4				Fe	De	Ex	Ex	Me	Wb											
5	addi a5, a5, 1					Fe	De	De	Ex	Me	Wb										
6	blt a5, a1,.L7						Fe	Fe	De	Ex	Me	Wb									
	.L7																				
7	slli a4, a5, 2									Fe	De	Ex	Me	Wb							
8	add a4, a3, a4										Fe	De	Ex	Me	Wb						
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)			Fe	De	Ex	Me	Wb													
4	add a0, a0, a4				Fe	De	Ex	Ex	Me	Wb											
5	addi a5, a5, 1					Fe	De	De	Ex	Me	Wb										
6	blt a5, a1,.L7						Fe	Fe	De	Ex	Me	Wb									
	.L7																				
7	slli a4, a5, 2									Fe	De	Ex	Me	Wb							
8	add a4, a3, a4										Fe	De	Ex	Me	Wb						
9	lw a4, 0(a4)											Fe	De	Ex	Me	Wb					
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)			Fe	De	Ex	Me	Wb													
4	add a0, a0, a4				Fe	De	Ex	Ex	Me	Wb											
5	addi a5, a5, 1					Fe	De	De	Ex	Me	Wb										
6	blt a5, a1,.L7						Fe	Fe	De	Ex	Me	Wb									
	.L7																				
7	slli a4, a5, 2									Fe	De	Ex	Me	Wb							
8	add a4, a3, a4										Fe	De	Ex	Me	Wb						
9	lw a4, 0(a4)											Fe	De	Ex	Me	Wb					
10	add a0, a0, a4												Fe	De	Ex	Ex	Me	Wb			
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)			Fe	De	Ex	Me	Wb													
4	add a0, a0, a4				Fe	De	Ex	Ex	Me	Wb											
5	addi a5, a5, 1					Fe	De	De	Ex	Me	Wb										
6	blt a5, a1,.L7						Fe	Fe	De	Ex	Me	Wb									
	.L7																				
7	slli a4, a5, 2									Fe	De	Ex	Me	Wb							
8	add a4, a3, a4										Fe	De	Ex	Me	Wb						
9	lw a4, 0(a4)											Fe	De	Ex	Me	Wb					
10	add a0, a0, a4												Fe	De	Ex	Ex	Me	Wb			
11	addi a5, a5, 1													Fe	De	De	Ex	Me	Wb		
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)			Fe	De	Ex	Me	Wb													
4	add a0, a0, a4				Fe	De	Ex	Ex	Me	Wb											
5	addi a5, a5, 1					Fe	De	De	Ex	Me	Wb										
6	blt a5, a1,.L7						Fe	Fe	De	Ex	Me	Wb									
	.L7																				
7	slli a4, a5, 2									Fe	De	Ex	Me	Wb							
8	add a4, a3, a4										Fe	De	Ex	Me	Wb						
9	lw a4, 0(a4)											Fe	De	Ex	Me	Wb					
10	add a0, a0, a4												Fe	De	Ex	Ex	Me	Wb			
11	addi a5, a5, 1													Fe	De	De	Ex	Me	Wb		
12	blt a5, a1,.L7														Fe	Fe	De	Ex	Me	Wb	

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)			Fe	De	Ex	Me	Wb													
4	add a0, a0, a4				Fe	De	>>	Ex	Me	Wb											
5	addi a5, a5, 1					Fe	>>	De	Ex	Me	Wb										
6	blt a5, a1,.L7						>>	Fe	De	Ex	Me	Wb									
	.L7																				
7	slli a4, a5, 2									Fe	De	Ex	Me	Wb							
8	add a4, a3, a4										Fe	De	Ex	Me	Wb						
9	lw a4, 0(a4)											Fe	De	Ex	Me	Wb					
10	add a0, a0, a4												Fe	De	>>	Ex	Me	Wb			
11	addi a5, a5, 1													Fe	>>	De	Ex	Me	Wb		
12	blt a5, a1,.L7														>>	Fe	De	Ex	Me	Wb	

Re-Exam 2022/2023, Q 1.3.1: simple 5-stage pipeline with full forwarding.

Ressourcer: Fe:1, De:1, Ex1, Me:1, Wb:1 med forudsagt bagudtagne hop.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fe	De	Ex	Me	Wb															
2	add a4, a3, a4		Fe	De	Ex	Me	Wb														
3	lw a4, 0(a4)			Fe	De	Ex	Me	Wb													
4	add a0, a0, a4				Fe	De	>>	Ex	Me	Wb											
5	addi a5, a5, 1					Fe	>>	De	Ex	Me	Wb										
6	blt a5, a1,.L7						>>	Fe	De	Ex	Me	Wb									
	.L7																				
7	slli a4, a5, 2	1								Fe	De	Ex	Me	Wb							
8	add a4, a3, a4	2									Fe	De	Ex	Me	Wb						
9	lw a4, 0(a4)	3										Fe	De	Ex	Me	Wb					
10	add a0, a0, a4	4											Fe	De	>>	Ex	Me	Wb			
11	addi a5, a5, 1	5												Fe	>>	De	Ex	Me	Wb		
12	blt a5, a1,.L7	6													>>	Fe	De	Ex	Me	Wb	
	IPC = 6/8								1	2	3	4	5	6	7	8					

Exam 2022/2023, Q 1.2.2

- Superskalar:
  - Flere instruktioner samtidig
  - Forskellige længder flow
  - depend(Ex, rd)

- Resourcer:
  - Instruktionsfaser:
    - load: Fe De Ag Me Wb
    - store: Fe De Ag Me
    - andre: Fe De Ex Wb
  - Ressourcer: Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2

- Hop forudsigelse:
  - Vi antager at hop kan forudsiges i De-fasen

Question 1.2.2: Give an execution diagram for a 2-way in-order superscalar with single cycle cache access as presented first in the section on super scalars in the online course notes. Explain shortly any assumptions you may have to make.

	Code	Timing
	`.L3:`	
1	`sb a5,0(a1)`	
2	`lbu a5,1(a0)`	
3	`addi a0,a0,1`	
4	`addi a1,a1,1`	
5	`bne a5,zero,.L3`	
	`L3:`	
6	`sb a5,0(a1)`	
7	`lbu a5,1(a0)`	
8	`addi a0,a0,1`	
9	`addi a1,a1,1`	
10	`bne a5,zero,.L3`	

Exam 2022/2023, Q 1.2.2: 2-way in-order superscalar with single cycle cache access and full forwarding

Ressourcer: Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2, med forudsagt bagudtagne hop i De

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	`.L3`																				
1	`sb a5, 0(a1)`	Fe	De	Ag	Me																
2	`lbu a5, 1(a0)`																				
3	`addi a0, a0, 1`																				
4	`addi a1, a1, 1`																				
5	`bne a5, zero, 1`																				
	`L3:`																				
6	`sb a5, 0(a1)`																				
7	`lbu a5, 1(a0)`																				
8	`addi a0, a0, 1`																				
9	`addi a1, a1, 1`																				
10	`bne a5, zero, 1`																				

Exam 2022/2023, Q 1.2.2: 2-way in-order superscalar with single cycle cache access and full forwarding

Ressourcer: Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2, med forudsagt bagudtagne hop i De

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	`.L3`																				
1	`sb a5, 0(a1)`	Fe	De	Ag	Me																
2	`lbu a5, 1(a0)`	Fe	De	De	Ag	Me	Wb														
3	`addi a0, a0, 1`																				
4	`addi a1, a1, 1`																				
5	`bne a5, zero, 1`																				
	`L3:`																				
6	`sb a5, 0(a1)`																				
7	`lbu a5, 1(a0)`																				
8	`addi a0, a0, 1`																				
9	`addi a1, a1, 1`																				
10	`bne a5, zero, 1`																				

Exam 2022/2023, Q 1.2.2: 2-way in-order superscalar with single cycle cache access and full forwarding

Ressourcer: Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2, med forudsagt bagudtagne hop i De

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	`.L3`																				
1	`sb a5, 0(a1)`	Fe	De	Ag	Me																
2	`lbu a5, 1(a0)`	Fe	De	De	Ag	Me	Wb														
3	`addi a0, a0, 1`																				
4	`addi a1, a1, 1`																				
5	`bne a5, zero, 1`																				
	`L3:`																				
6	`sb a5, 0(a1)`																				
7	`lbu a5, 1(a0)`																				
8	`addi a0, a0, 1`																				
9	`addi a1, a1, 1`																				
10	`bne a5, zero, 1`																				

der stalles fordi vi kun har en Ag som ikke er tilgængelig

Exam 2022/2023, Q 1.2.2: 2-way in-order superscalar with single cycle cache access and full forwarding

Ressourcer: Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2, med forudsagt bagudtagne hop i De

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	`.L3`																				
1	`sb a5, 0(a1)`	Fe	De	Ag	Me																
2	`lbu a5, 1(a0)`	Fe	De	De	Ag	Me	Wb														
3	`addi a0, a0, 1`		Fe	De	Ex	Wb															
4	`addi a1, a1, 1`																				
5	`bne a5, zero, 1`																				
	`L3:`																				
6	`sb a5, 0(a1)`																				
7	`lbu a5, 1(a0)`																				
8	`addi a0, a0, 1`																				
9	`addi a1, a1, 1`																				
10	`bne a5, zero, 1`																				

Exam 2022/2023, Q 1.2.2: 2-way in-order superscalar with single cycle cache access and full forwarding

Ressourcer: Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2, med forudsagt bagudtagne hop i De

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	`.L3`																				
1	`sb a5, 0(a1)`	Fe	De	Ag	Me																
2	`lbu a5, 1(a0)`	Fe	De	De	Ag	Me	Wb														
3	`addi a0, a0, 1`		Fe	De	Ex	Wb															
4	`addi a1, a1, 1`																				
5	`bne a5, zero, 1`																				
	`L3:`																				
6	`sb a5, 0(a1)`																				
7	`lbu a5, 1(a0)`																				
8	`addi a0, a0, 1`																				
9	`addi a1, a1, 1`																				
10	`bne a5, zero, 1`																				

addi går ind i Wb-fasen før lbu. Muligt fordi rd=a0 for addi er klart.

Exam 2022/2023, Q 1.2.2: 2-way in-order superscalar with single cycle cache access and full forwarding

Ressourcer: Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2, med forudsagt bagudtagne hop i De

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	`.L3`																				
1	`sb a5, 0(a1)`	Fe	De	Ag	Me																
2	`lbu a5, 1(a0)`	Fe	De	De	Ag	Me	Wb														
3	`addi a0, a0, 1`		Fe	De	Ex	Wb															
4	`addi a1, a1, 1`		Fe	Fe	De	Ex	Wb														
5	`bne a5, zero, 1`																				
	`L3:`																				
6	`sb a5, 0(a1)`																				
7	`lbu a5, 1(a0)`																				
8	`addi a0, a0, 1`																				
9	`addi a1, a1, 1`																				
10	`bne a5, zero, 1`																				

Exam 2022/2023, Q 1.2.2: 2-way in-order superscalar with single cycle cache access and full forwarding

Ressourcer: Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2, med forudsagt bagudtagne hop i De

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	`.L3`																				
1	`sb a5, 0(a1)`	Fe	De	Ag	Me																
2	`lbu a5, 1(a0)`	Fe	De	De	Ag	Me	Wb														
3	`addi a0, a0, 1`		Fe	De	Ex	Wb															
4	`addi a1, a1, 1`		Fe	Fe	De	Ex	Wb														
5	`bne a5, zero, 1`																				
	`L3:`																				
6	`sb a5, 0(a1)`																				
7	`lbu a5, 1(a0)`																				
8	`addi a0, a0, 1`																				
9	`addi a1, a1, 1`																				
10	`bne a5, zero, 1`																				

der stalles fordi vi kun har to De og ingen af dem er tilgængelige

Exam 2022/2023, Q 1.2.2: 2-way in-order superscalar with single cycle cache access and full forwarding

Ressourcer: Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2, med forudsagt bagudtagne hop i De

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	`.L3`																				
1	`sb a5, 0(a1)`	Fe	De	Ag	Me																
2	`lbu a5, 1(a0)`	Fe	De	De	Ag	Me	Wb														
3	`addi a0, a0, 1`		Fe	De	Ex	Wb															
4	`addi a1, a1, 1`		Fe	Fe	De	Ex	Wb														
5	`bne a5, zero, 1`			Fe	De	Ex	Ex														
	`L3:`																				
6	`sb a5, 0(a1)`																				
7	`lbu a5, 1(a0)`																				
8	`addi a0, a0, 1`																				
9	`addi a1, a1, 1`																				
10	`bne a5, zero, 1`																				

Exam 2022/2023, Q 1.2.2: 2-way in-order superscalar with single cycle cache access and full forwarding

Ressourcer: Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2, med forudsagt bagudtagne hop i De

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	`.L3`																				
1	`sb a5, 0(a1)`	Fe	De	Ag	Me																
2	`lbu a5, 1(a0)`	Fe	De	De	Ag	Me	Wb														
3	`addi a0, a0, 1`		Fe	De	Ex	Wb															
4	`addi a1, a1, 1`		Fe	Fe	De	Ex	Wb														
5	`bne a5, zero, 1`			Fe	De	Ex	Ex														
	`L3:`																				
6	`sb a5, 0(a1)`					Fe	De	Ag	Me												
7	`lbu a5, 1(a0)`																				
8	`addi a0, a0, 1`																				
9	`addi a1, a1, 1`																				
10	`bne a5, zero, 1`																				

Exam 2022/2023, Q 1.2.2: 2-way in-order superscalar with single cycle cache access and full forwarding

Ressourcer: Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2, med forudsagt bagudtagne hop i De

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L3																				
1	sb a5, 0(a1)	Fe	De	Ag	Me																
2	lbu a5, 1(a0)	Fe	De	De	Ag	Me	Wb														
3	addi a0, a0, 1		Fe	De	Ex	Wb															
4	addi a1, a1, 1		Fe	Fe	De	Ex	Wb														
5	bne a5, zero, 1			Fe	De	Ex	Ex														
	L3:																				
6	sb a5, 0(a1)					Fe	De	Ag	Me												
7	lbu a5, 1(a0)																				
8	addi a0, a0, 1																				
9	addi a1, a1, 1																				
10	bne a5, zero, 1																				

Korrekt forudsagt bagudtagent hop, så PC bliver opdateret i bne's De-fase

Exam 2022/2023, Q 1.2.2: 2-way in-order superscalar with single cycle cache access and full forwarding

Ressourcer: Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2, med forudsagt bagudtagne hop i De

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	`.L3`																				
1	`sb a5, 0(a1)`	Fe	De	Ag	Me																
2	`lbu a5, 1(a0)`	Fe	De	De	Ag	Me	Wb														
3	`addi a0, a0, 1`		Fe	De	Ex	Wb															
4	`addi a1, a1, 1`		Fe	Fe	De	Ex	Wb														
5	`bne a5, zero, 1`			Fe	De	Ex	Ex														
	`L3:`																				
6	`sb a5, 0(a1)`					Fe	De	Ag	Me												
7	`lbu a5, 1(a0)`					Fe	De	De	Ag	Me	Wb										
8	`addi a0, a0, 1`																				
9	`addi a1, a1, 1`																				
10	`bne a5, zero, 1`																				

Exam 2022/2023, Q 1.2.2: 2-way in-order superscalar with single cycle cache access and full forwarding

Ressourcer: Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2, med forudsagt bagudtagne hop i De

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L3																				
1	sb a5, 0(a1)	Fe	De	Ag	Me																
2	lbu a5, 1(a0)	Fe	De	De	Ag	Me	Wb														
3	addi a0, a0, 1		Fe	De	Ex	Wb															
4	addi a1, a1, 1		Fe	Fe	De	Ex	Wb														
5	bne a5, zero, 1			Fe	De	Ex	Ex														
	L3:																				
6	sb a5, 0(a1)					Fe	De	Ag	Me												
7	lbu a5, 1(a0)					Fe	De	De	Ag	Me	Wb										
8	addi a0, a0, 1						Fe	De	Ex	Wb											
9	addi a1, a1, 1																				
10	bne a5, zero, 1																				

Exam 2022/2023, Q 1.2.2: 2-way in-order superscalar with single cycle cache access and full forwarding

Ressourcer: Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2, med forudsagt bagudtagne hop i De

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L3																				
1	sb a5, 0(a1)	Fe	De	Ag	Me																
2	lbu a5, 1(a0)	Fe	De	De	Ag	Me	Wb														
3	addi a0, a0, 1		Fe	De	Ex	Wb															
4	addi a1, a1, 1		Fe	Fe	De	Ex	Wb														
5	bne a5, zero, 1			Fe	De	Ex	Ex														
	L3:																				
6	sb a5, 0(a1)					Fe	De	Ag	Me												
7	lbu a5, 1(a0)					Fe	De	De	Ag	Me	Wb										
8	addi a0, a0, 1						Fe	De	Ex	Wb											
9	addi a1, a1, 1						Fe	Fe	De	Ex	Wb										
10	bne a5, zero, 1																				

Exam 2022/2023, Q 1.2.2: 2-way in-order superscalar with single cycle cache access and full forwarding

Ressourcer: Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2, med forudsagt bagudtagne hop i De

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	`.L3`																				
1	`sb a5, 0(a1)`	Fe	De	Ag	Me																
2	`lbu a5, 1(a0)`	Fe	De	De	Ag	Me	Wb														
3	`addi a0, a0, 1`		Fe	De	Ex	Wb															
4	`addi a1, a1, 1`		Fe	Fe	De	Ex	Wb														
5	`bne a5, zero, 1`			Fe	De	Ex	Ex														
	`L3:`																				
6	`sb a5, 0(a1)`					Fe	De	Ag	Me												
7	`lbu a5, 1(a0)`					Fe	De	De	Ag	Me	Wb										
8	`addi a0, a0, 1`						Fe	De	Ex	Wb											
9	`addi a1, a1, 1`						Fe	Fe	De	Ex	Wb										
10	`bne a5, zero, 1`							Fe	De	Ex	Ex										

Exam 2022/2023, Q 1.2.2: 2-way in-order superscalar with single cycle cache access and full forwarding

Ressourcer: Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2, med forudsagt bagudtagne hop i De

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L3																				
1	sb a5, 0(a1)	Fe	De	Ag	Me																
2	lbu a5, 1(a0)	Fe	>>	De	Ag	Me	Wb														
3	addi a0, a0, 1		Fe	De	Ex	Wb															
4	addi a1, a1, 1		>>	Fe	De	Ex	Wb														
5	bne a5, zero, 1			Fe	De	>>	Ex														
	L3:																				
6	sb a5, 0(a1)					Fe	De	Ag	Me												
7	lbu a5, 1(a0)					Fe	>>	De	Ag	Me	Wb										
8	addi a0, a0, 1						Fe	De	Ex	Wb											
9	addi a1, a1, 1						>>	Fe	De	Ex	Wb										
10	bne a5, zero, 1							Fe	De	>>	Ex										

Exam 2022/2023, Q 1.2.2: 2-way in-order superscalar with single cycle cache access and full forwarding

Ressourcer: Fe:2, De:2, Ex:2, Ag:1, Me:1, Wb:2, med forudsagt bagudtagne hop i De

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L3																				
1	sb a5, 0(a1)	Fe	De	Ag	Me																
2	lbu a5, 1(a0)	Fe	>>	De	Ag	Me	Wb														
3	addi a0, a0, 1		Fe	De	Ex	Wb															
4	addi a1, a1, 1		>>	Fe	De	Ex	Wb														
5	bne a5, zero, 1			Fe	De	>>	Ex														
	L3:																				
6	sb a5, 0(a1)	1				Fe	De	Ag	Me												
7	lbu a5, 1(a0)	2				Fe	>>	De	Ag	Me	Wb										
8	addi a0, a0, 1	3					Fe	De	Ex	Wb											
9	addi a1, a1, 1	4					>>	Fe	De	Ex	Wb										
10	bne a5, zero, 1	5						Fe	De	>>	Ex										
	IPC = 5/4				1	2	3	4													

Re-Exam 2022/2023, Q 1.3.2

- Out-of-order afvikling:
  - Faser med stort forbogstav skal afvikles in-order
  - Faser med lille forbogstav kan afvikles out-of-order
  - Latenstid for alu-operation: 1 cyklus, for load: 4 cykler.

- Resourcer:
  - Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4

Instruktioner i denne opgave:

- ALU-op: Fa Fb Fc De Fu Al Rn Qu pk rd ex wb Ca Cb
- out-of-order: pk, rd, ex, wb

- branch: Fa Fb Fc De Fu Al Rn Qu pk rd ex Ca Cb
- out-of-order: pk, rd, ex

- load: Fa Fb Fc De Fu Al Rn Qu pk rd ag ma mb mc wb Ca Cb
- outoforder: pk, rd, ex, ag, ma, mb, mc, wb

Question 1.3.2: Give an execution diagram for a 4-way out-of-order with realistic (3-stage pipelined) cache access as presented in the section on out-of-order microarchitecture in the online course notes.

	Code	Timing
	.L7:	
1	slli a4,a5,2	
2	add a4,a3,a4	
3	lw a4,0(a4)	
4	add a0,a0,a4	
5	addi a5,a5,1	
6	blt a5,a1,.L7	
	L3:	
7	slli a4,a5,2	
8	add a4,a3,a4	
9	lw a4,0(a4)	
10	add a0,a0,a4	
11	addi a5,a5,1	
10	blt a5,a1,.L7	

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb						
2	add a4, a3, a4																				
3	lw a4, 0(a4)																				
4	add a0, a0, a4																				
5	addi a5, a5, 1																				
6	blt a5, a1,.L7																				
	L7:																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb						
2	add a4, a3, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	Ca	Cb					
3	lw a4, 0(a4)																				
4	add a0, a0, a4																				
5	addi a5, a5, 1																				
6	blt a5, a1,.L7																				
	L7:																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb						
2	add a4, a3, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	Ca	Cb					
3	lw a4, 0(a4)																				
4	add a0, a0, a4																				
5	addi a5, a5, 1																				
6	blt a5, a1,.L7																				
	L7:																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

1 cyklus latenstid fordi slli er en alu-operation
og add skal bruge værdien i a4 som operand

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb						
2	add a4, a3, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	Ca	Cb					
3	lw a4, 0(a4)	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb	
4	add a0, a0, a4																				
5	addi a5, a5, 1																				
6	blt a5, a1,.L7																				
	L7:																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb						
2	add a4, a3, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	Ca	Cb					
3	lw a4, 0(a4)	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb	
4	add a0, a0, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb
5	addi a5, a5, 1																				
6	blt a5, a1,.L7																				
	L7:																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb						
2	add a4, a3, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	Ca	Cb					
3	lw a4, 0(a4)	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb	
4	add a0, a0, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb
5	addi a5, a5, 1										4 cykler, fordi der ventes på a4 fra lw										
6	blt a5, a1,.L7																				
	L7:																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb						
2	add a4, a3, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	Ca	Cb					
3	lw a4, 0(a4)	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb	
4	add a0, a0, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb
5	addi a5, a5, 1		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	--	Ca	Cb
6	blt a5, a1,.L7																				
	L7:																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb						
2	add a4, a3, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	Ca	Cb					
3	lw a4, 0(a4)	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb	
4	add a0, a0, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb
5	addi a5, a5, 1		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	--	Ca	Cb
6	blt a5, a1,.L7																				
	L7:																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Der ventes her fordi Ca og Cb er in-order

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
	.L7																				
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb						
2	add a4, a3, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	Ca	Cb					
3	lw a4, 0(a4)	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb	
4	add a0, a0, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb
5	addi a5, a5, 1		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	--	Ca	Cb
6	blt a5, a1,.L7		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	--	--	--	--	--	Ca	Cb
	L7:																				
7	slli a4, a5, 2																				
8	add a4, a3, a4																				
9	lw a4, 0(a4)																				
10	add a0, a0, a4																				
11	addi a5, a5, 1																				
12	blt a5, a1,.L7																				

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1
	.L7																						
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb								
2	add a4, a3, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	Ca	Cb							
3	lw a4, 0(a4)	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb			
4	add a0, a0, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb		
5	addi a5, a5, 1		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	--	Ca	Cb		
6	blt a5, a1,.L7		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	--	--	--	--	--	Ca	Cb		
	L7:																						
7	slli a4, a5, 2			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	Ca	Cb		
8	add a4, a3, a4																						
9	lw a4, 0(a4)																						
10	add a0, a0, a4																						
11	addi a5, a5, 1																						
12	blt a5, a1,.L7																						

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1
	.L7																						
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb								
2	add a4, a3, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	Ca	Cb							
3	lw a4, 0(a4)	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb			
4	add a0, a0, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb		
5	addi a5, a5, 1		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	--	Ca	Cb		
6	blt a5, a1,.L7		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	--	--	--	--	--	Ca	Cb		
	L7:																						
7	slli a4, a5, 2			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	Ca	Cb		
8	add a4, a3, a4																						
9	lw a4, 0(a4)																						
10	add a0, a0, a4																						
11	addi a5, a5, 1																						
12	blt a5, a1,.L7																						

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1
	.L7																						
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb								
2	add a4, a3, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	Ca	Cb							
3	lw a4, 0(a4)	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb			
4	add a0, a0, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb		
5	addi a5, a5, 1		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	--	Ca	Cb		
6	blt a5, a1,.L7		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	--	--	--	--	--	Ca	Cb		
	L7:																						
7	slli a4, a5, 2			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	Ca	Cb		
8	add a4, a3, a4	Fa starter en cyklus senere da det tager en cyklus at forudsige et hop for ooo iht. noten																					
9	lw a4, 0(a4)																						
10	add a0, a0, a4																						
11	addi a5, a5, 1																						
12	blt a5, a1,.L7																						

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1
	.L7																						
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb								
2	add a4, a3, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	Ca	Cb							
3	lw a4, 0(a4)	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb			
4	add a0, a0, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb		
5	addi a5, a5, 1		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	--	Ca	Cb		
6	blt a5, a1,.L7		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	--	--	--	--	--	Ca	Cb		
	L7:																						
7	slli a4, a5, 2			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	Ca	Cb		
8	add a4, a3, a4			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	--	--	--	--	Ca	Cb	
9	lw a4, 0(a4)																						
10	add a0, a0, a4																						
11	addi a5, a5, 1																						
12	blt a5, a1,.L7																						

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1
	.L7																						
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb								
2	add a4, a3, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	Ca	Cb							
3	lw a4, 0(a4)	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb			
4	add a0, a0, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb		
5	addi a5, a5, 1		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	--	Ca	Cb		
6	blt a5, a1,.L7		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	--	--	--	--	--	Ca	Cb		
	L7:																						
7	slli a4, a5, 2			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	Ca	Cb		
8	add a4, a3, a4			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	--	--	--	--	Ca	Cb	
9	lw a4, 0(a4)			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb	
10	add a0, a0, a4																						
11	addi a5, a5, 1																						
12	blt a5, a1,.L7																						

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1
	.L7																						
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb								
2	add a4, a3, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	Ca	Cb							
3	lw a4, 0(a4)	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb			
4	add a0, a0, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb		
5	addi a5, a5, 1		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	--	Ca	Cb		
6	blt a5, a1,.L7		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	--	--	--	--	--	Ca	Cb		
	L7:																						
7	slli a4, a5, 2			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	Ca	Cb		
8	add a4, a3, a4			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	--	--	--	--	Ca	Cb	
9	lw a4, 0(a4)			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb	
10	add a0, a0, a4			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb
11	addi a5, a5, 1																						
12	blt a5, a1,.L7																						

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1
	.L7																						
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb								
2	add a4, a3, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	Ca	Cb							
3	lw a4, 0(a4)	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb			
4	add a0, a0, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb		
5	addi a5, a5, 1		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	--	Ca	Cb		
6	blt a5, a1,.L7		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	--	--	--	--	--	Ca	Cb		
	L7:																						
7	slli a4, a5, 2			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	Ca	Cb		
8	add a4, a3, a4			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	--	--	--	--	Ca	Cb	
9	lw a4, 0(a4)			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb	
10	add a0, a0, a4			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb
11	addi a5, a5, 1				Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	--	Ca	Cb
12	blt a5, a1,.L7																						

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1
	.L7																						
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb								
2	add a4, a3, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	Ca	Cb							
3	lw a4, 0(a4)	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb			
4	add a0, a0, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb		
5	addi a5, a5, 1		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	--	Ca	Cb		
6	blt a5, a1,.L7		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	--	--	--	--	--	Ca	Cb		
	L7:																						
7	slli a4, a5, 2			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	Ca	Cb		
8	add a4, a3, a4			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	--	--	--	--	Ca	Cb	
9	lw a4, 0(a4)			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb	
10	add a0, a0, a4			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb
11	addi a5, a5, 1				Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	--	Ca	Cb
12	blt a5, a1,.L7				Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	--	--	--	--	--	Ca	Cb

Re-Exam 2022/2023, Q 1.3.2: 4-way out-of-order with realistic (3-stage pipelined) cache access.

Ressourcer: Fa:4, Fb:4, Fc:4, De:4, Fu:4, Al:4, Rn:4 Qu:4 [Qu-Ca]:64, Ca:4 Cb:4 med branch-prediction
Latenstider for pick: 1 cyklus for ALU-operation, 4 for load-operationer.

		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1
	.L7																						
1	slli a4, a5, 2	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	Ca	Cb								
2	add a4, a3, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	Ca	Cb							
3	lw a4, 0(a4)	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb			
4	add a0, a0, a4	Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb		
5	addi a5, a5, 1		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	--	Ca	Cb		
6	blt a5, a1,.L7		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	--	--	--	--	--	Ca	Cb		
	L7:																						
7	slli a4, a5, 2	1		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	Ca	Cb		
8	add a4, a3, a4	2		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	wb	--	--	--	--	Ca	Cb	
9	lw a4, 0(a4)	3		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	pk	rd	ag	ma	mb	mc	wb	Ca	Cb	
10	add a0, a0, a4	4		Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	--	--	--	--	--	pk	rd	ex	wb	Ca	Cb
11	addi a5, a5, 1	5			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	pk	rd	ex	wb	--	--	--	--	--	Ca	Cb
12	blt a5, a1,.L7	6			Fa	Fb	Fc	De	Fu	Al	Rn	Qu	--	pk	rd	ex	--	--	--	--	--	Ca	Cb

IPC = 6/2 = 3

1 2