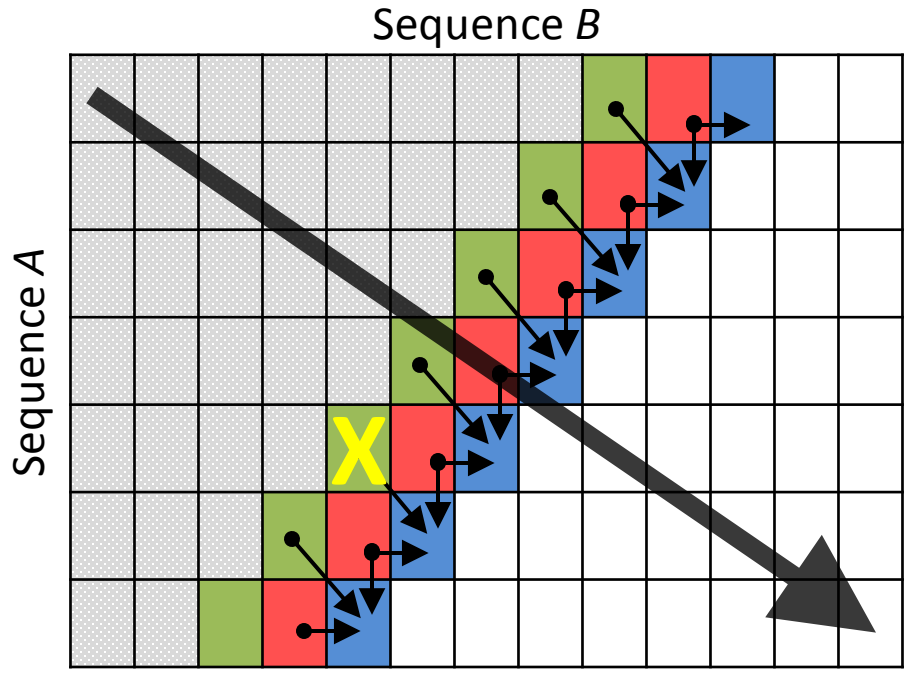
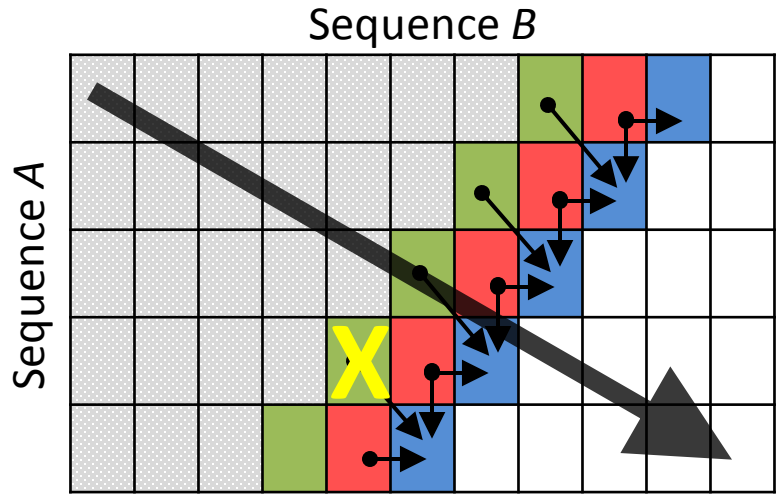
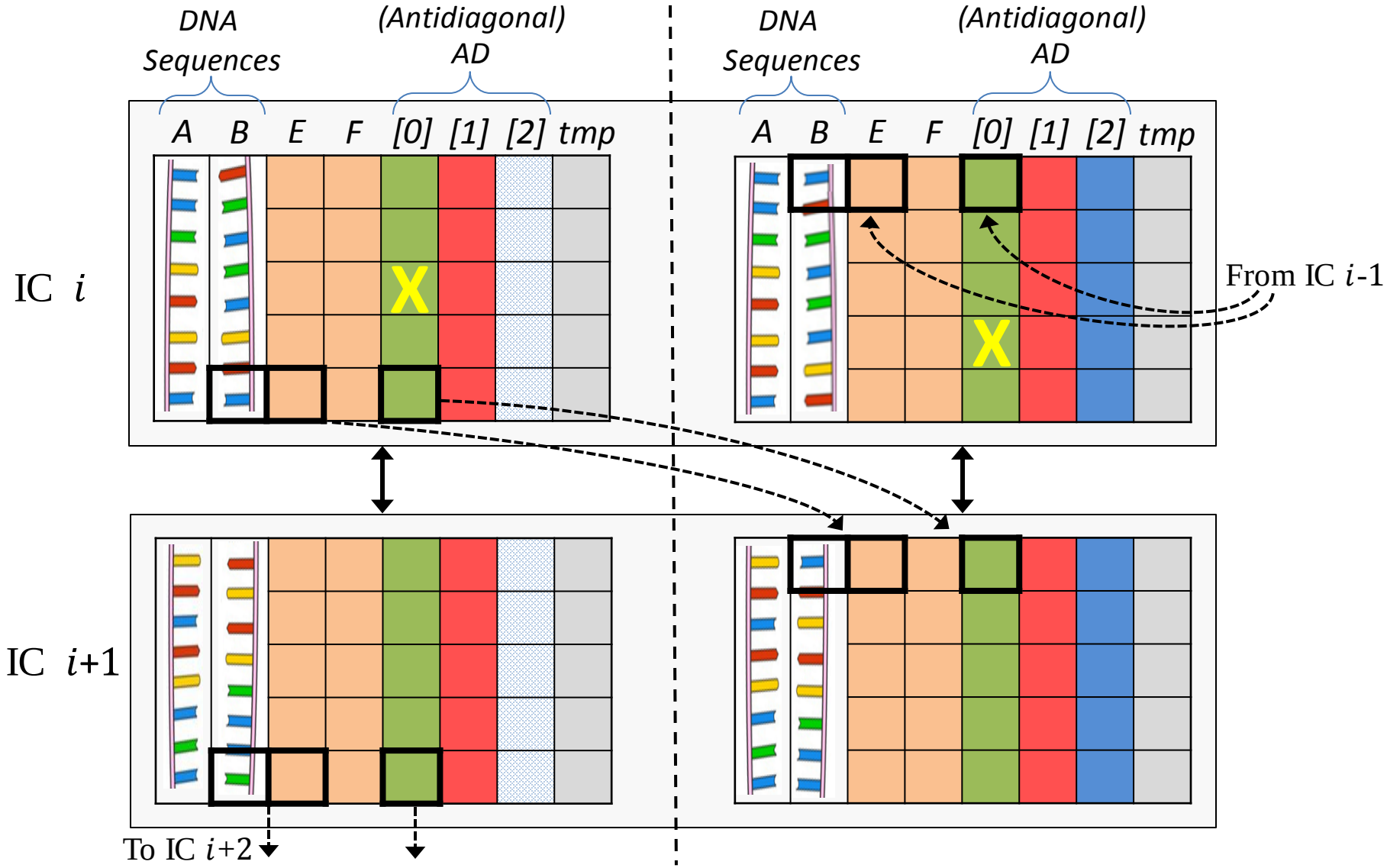
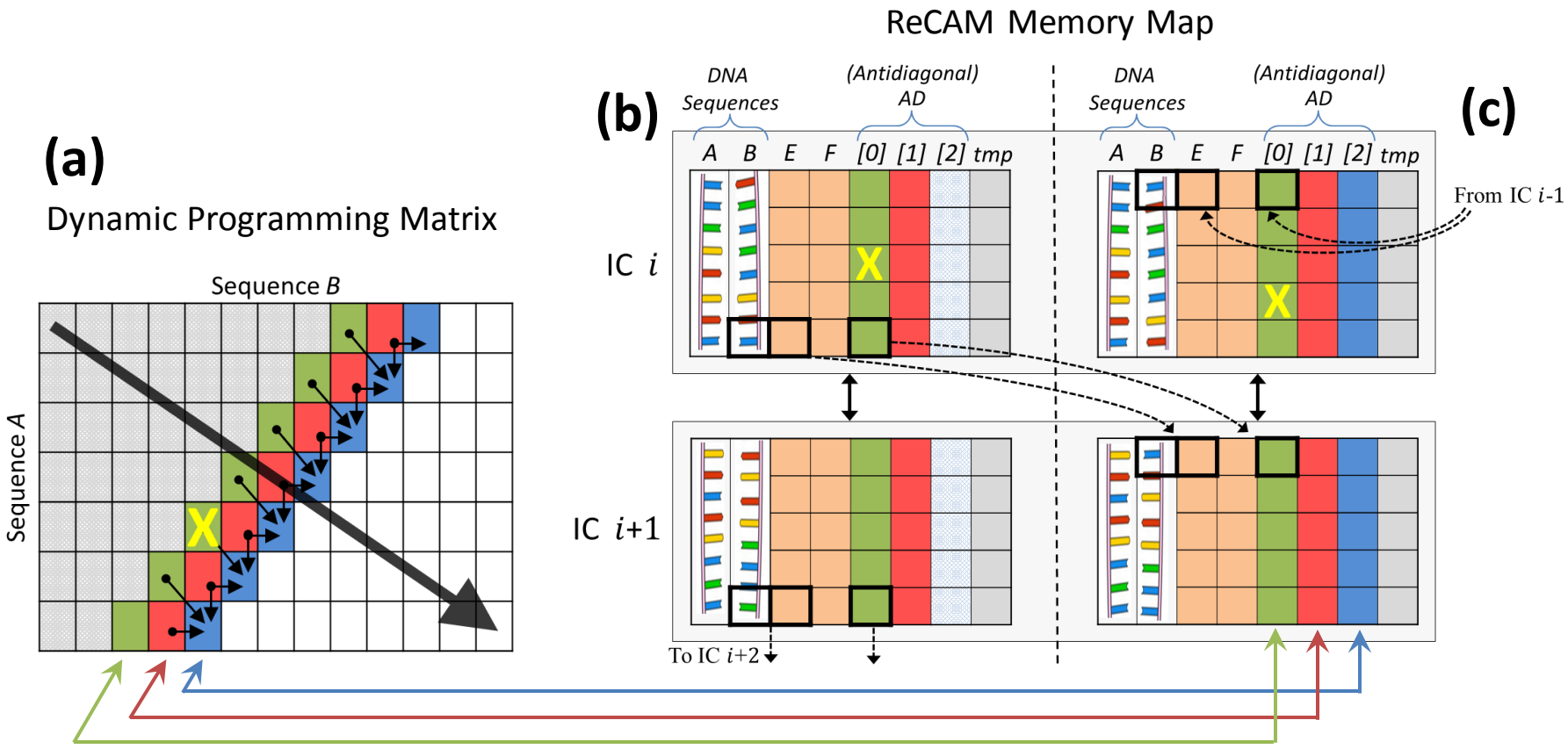
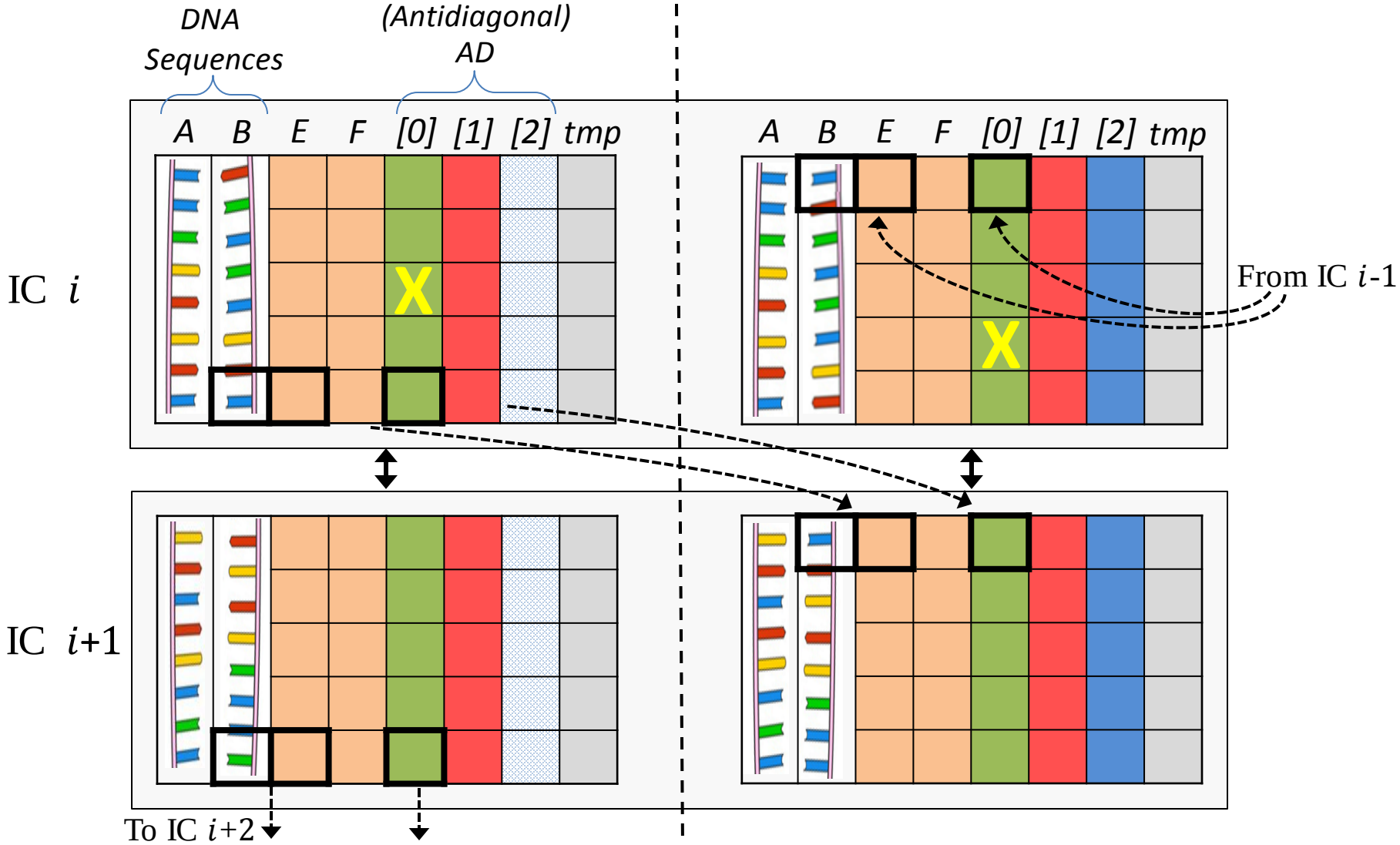
Fig 2

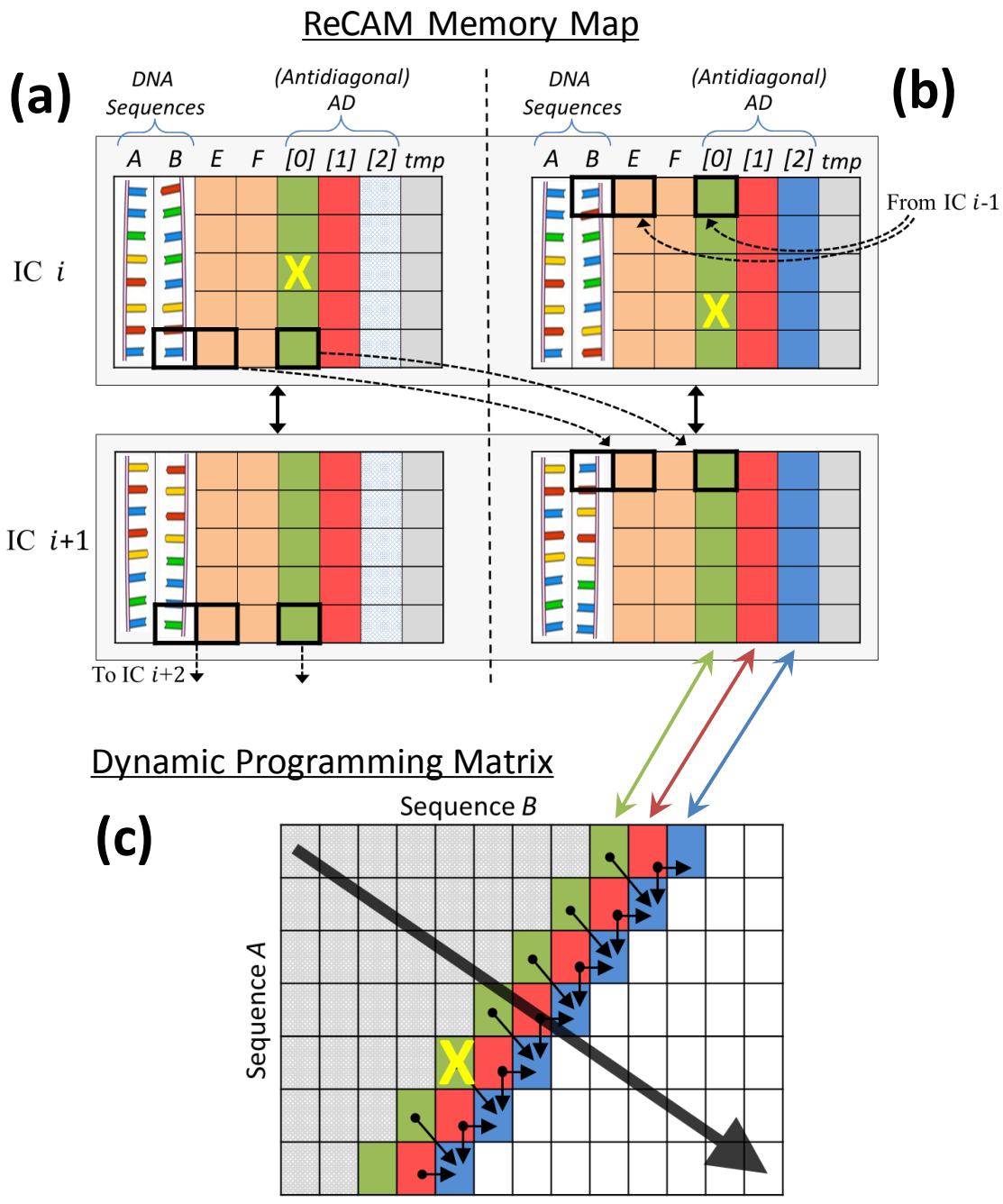


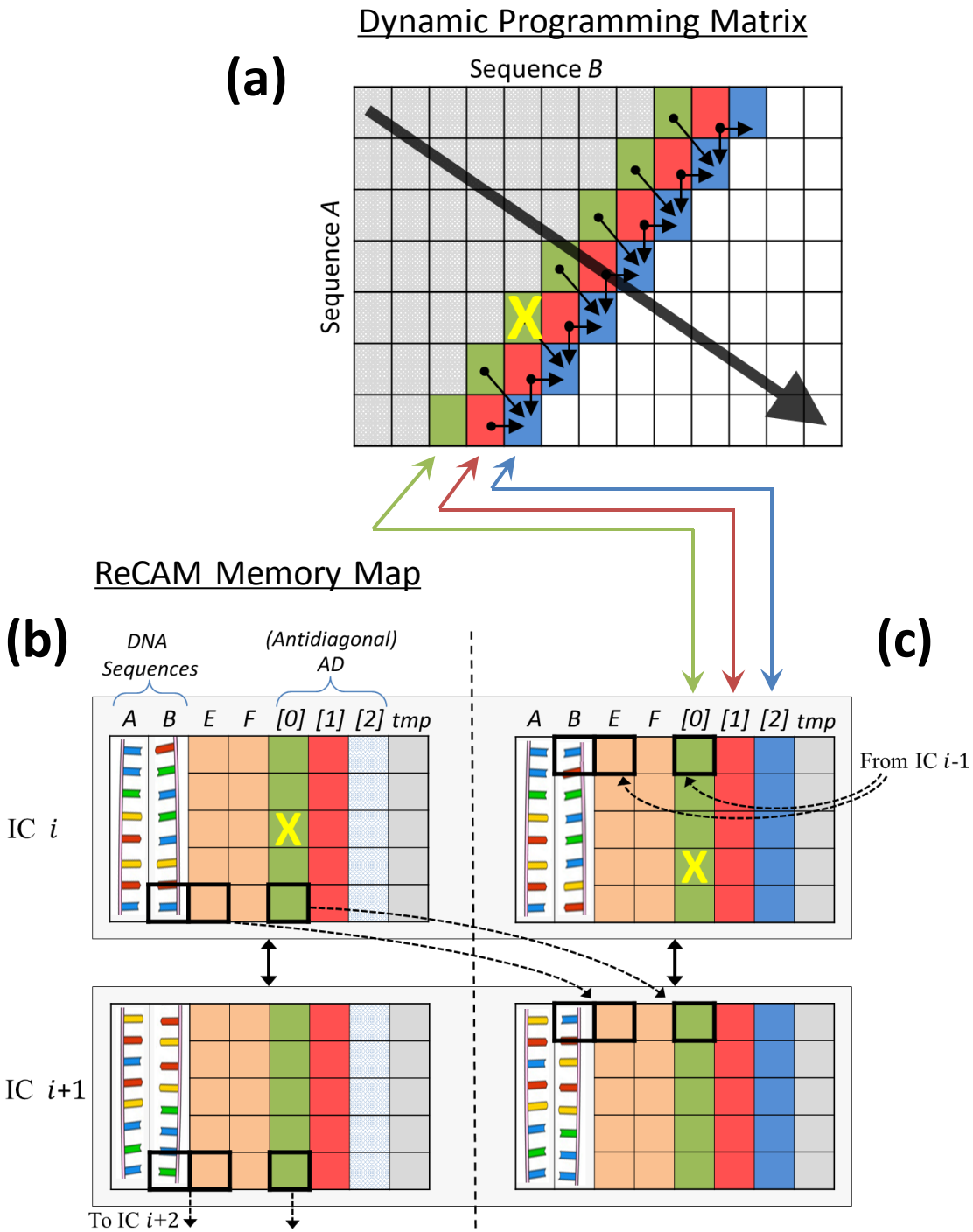

Sequence *B*
Sequence *A*
X

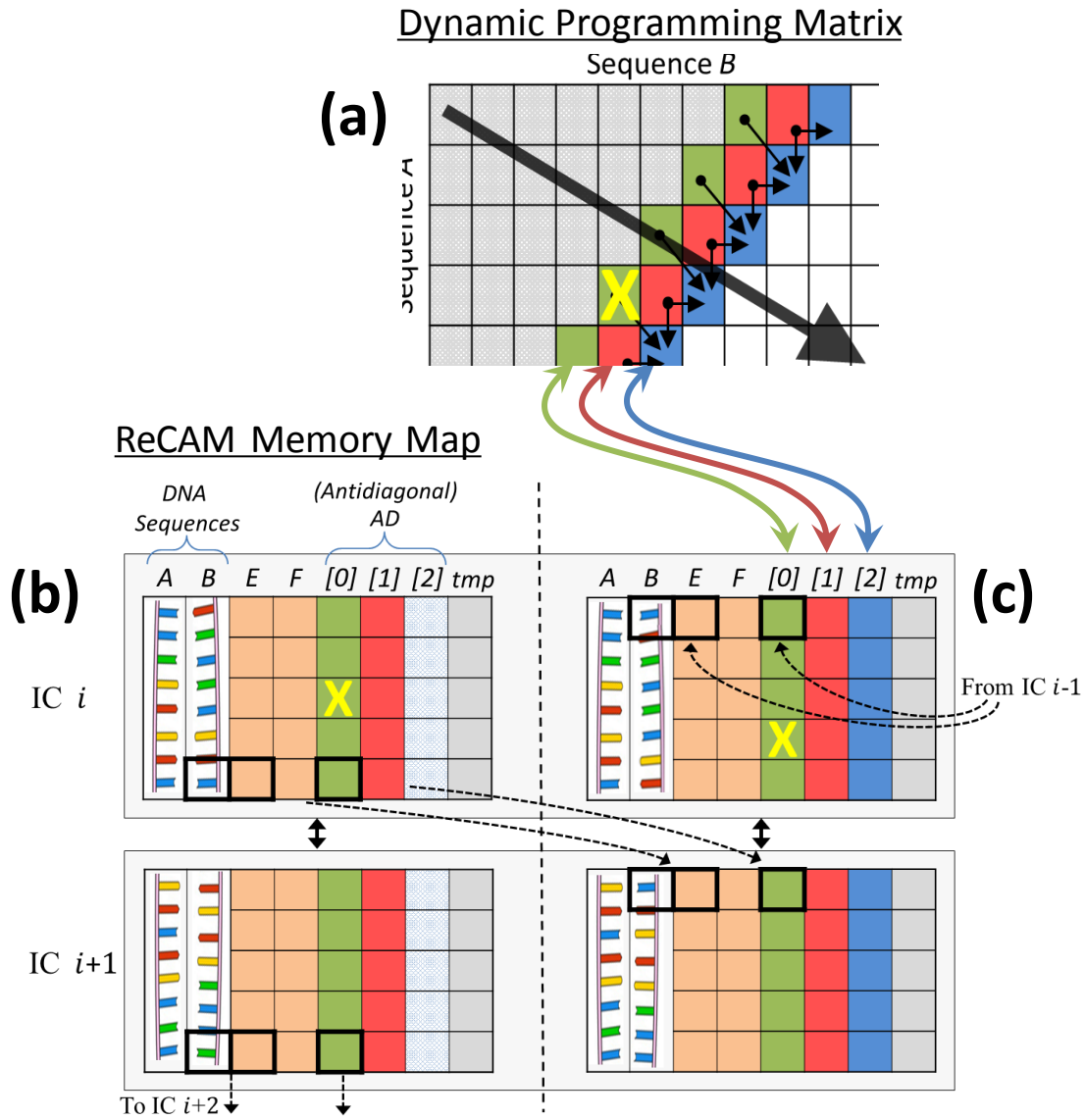

DNA Sequences
(Antidiagonal) AD
DNA Sequences
(Antidiagonal) AD
A B E F [0] [1] [2] tmp
A B E F [0] [1] [2] tmp
IC i
From IC i-1
IC i+1
To IC i+2

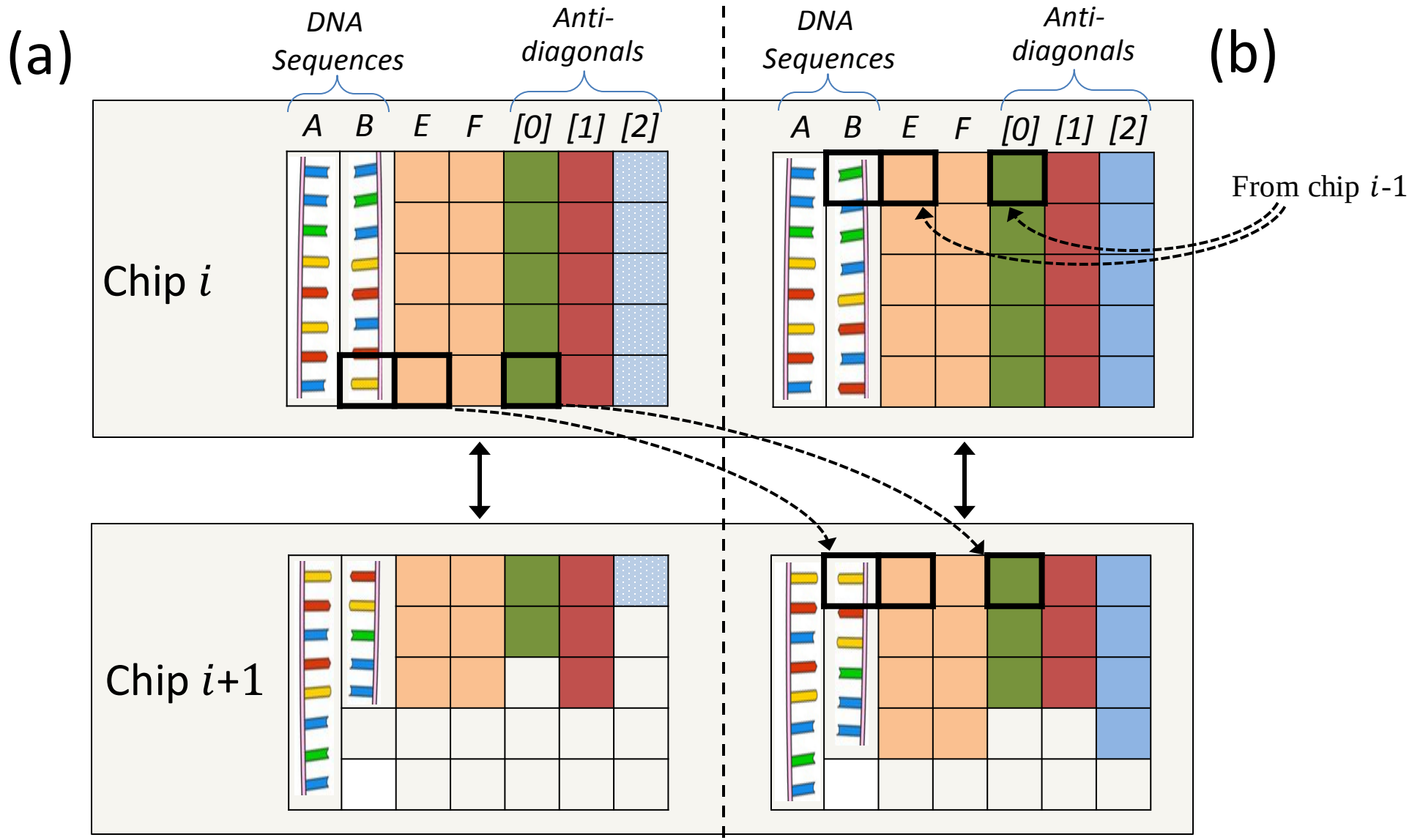

(a)
Dynamic Programming Matrix
Sequence B
Sequence A
X
(b)
ReCAM Memory Map
DNA Sequences
(Antidiagonal) AD
A B E F [0] [1] [2] tmp
IC i
IC i+1
To IC i+2
(c)
From IC i-1


DNA Sequences
(Antidiagonal) AD
A B E F [0] [1] [2] tmp
A B E F [0] [1] [2] tmp
IC i
IC i+1
From IC i-1
To IC i+2


ReCAM Memory Map
(a)
DNA Sequences
(Antidiagonal) AD
A B E F [0] [1] [2] tmp
IC i
IC i+1
To IC i+2
(b)
DNA Sequences
(Antidiagonal) AD
A B E F [0] [1] [2] tmp
From IC i-1
Dynamic Programming Matrix
(c)
Sequence B
Sequence A


Dynamic Programming Matrix
(a)
Sequence B
Sequence A
X
ReCAM Memory Map
(b)
(c)
DNA Sequences
(Antidiagonal) AD
A B E F [0] [1] [2] tmp
IC i
IC i+1
From IC i-1
To IC i+2


Dynamic Programming Matrix
Sequence B
(a)
Sequence A
X
ReCAM Memory Map
DNA Sequences
(Antidiagonal) AD
(b)
A B E F [0] [1] [2] tmp
IC i
IC i+1
To IC i+2
(c)
A B E F [0] [1] [2] tmp
From IC i-1


(a)
DNA Sequences
Anti-diagonals
A
B
E
F
[0]
[1]
[2]
Chip i
Chip i+1
(b)
DNA Sequences
Anti-diagonals
From chip i-1

How it works in Parallel

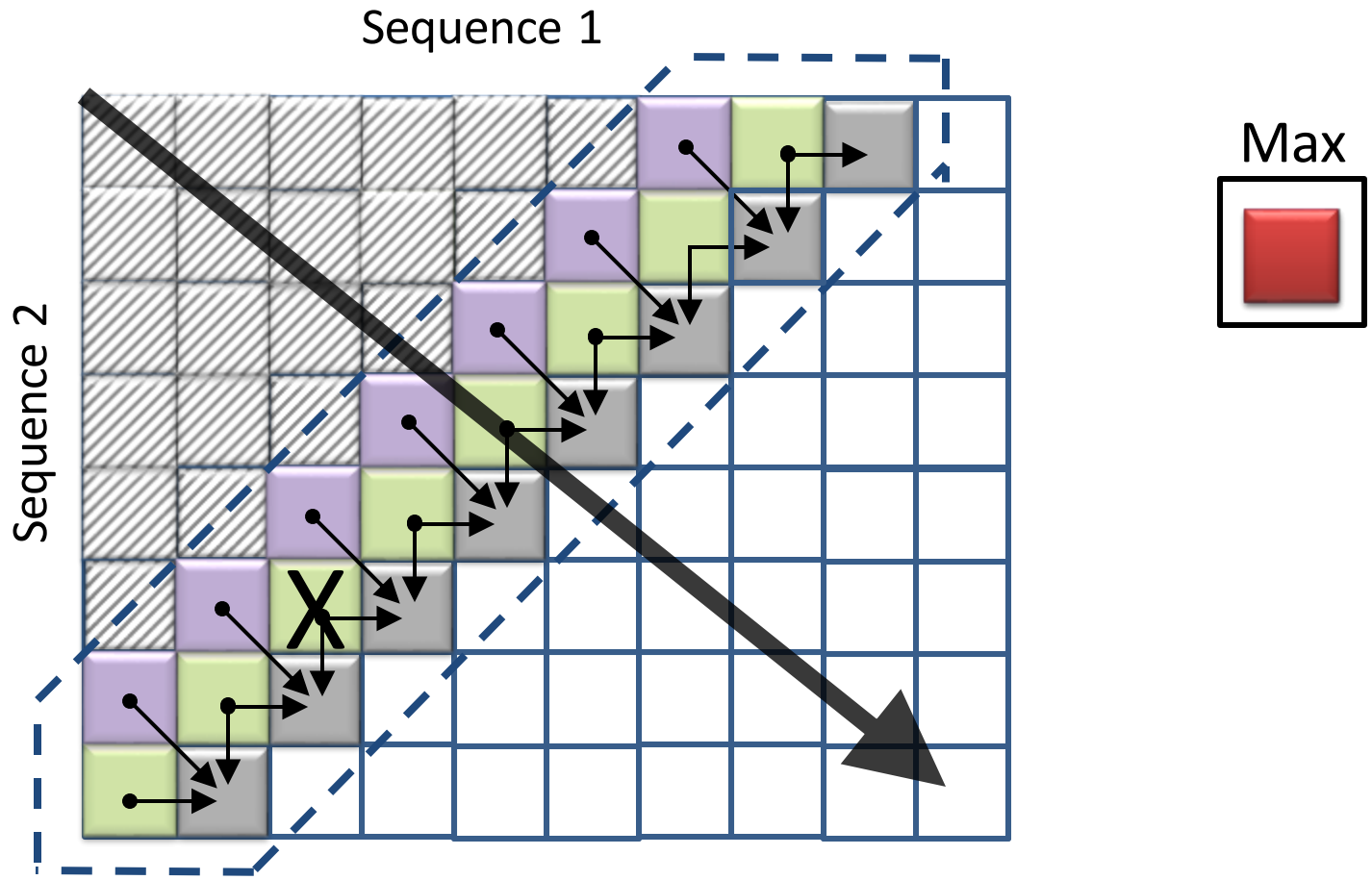


Fig 2

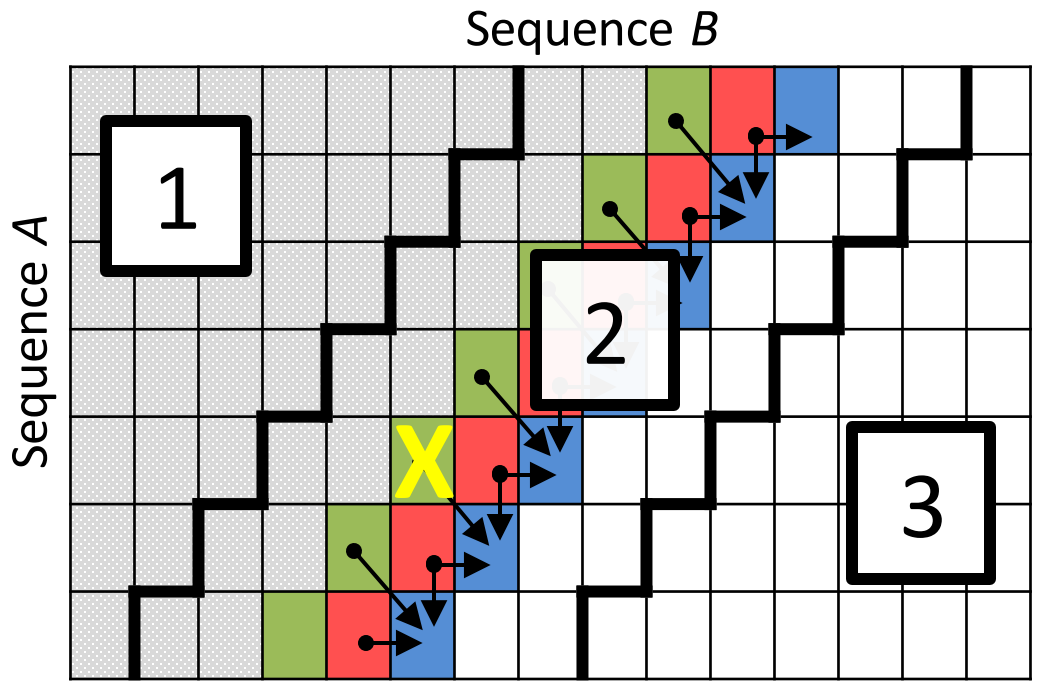
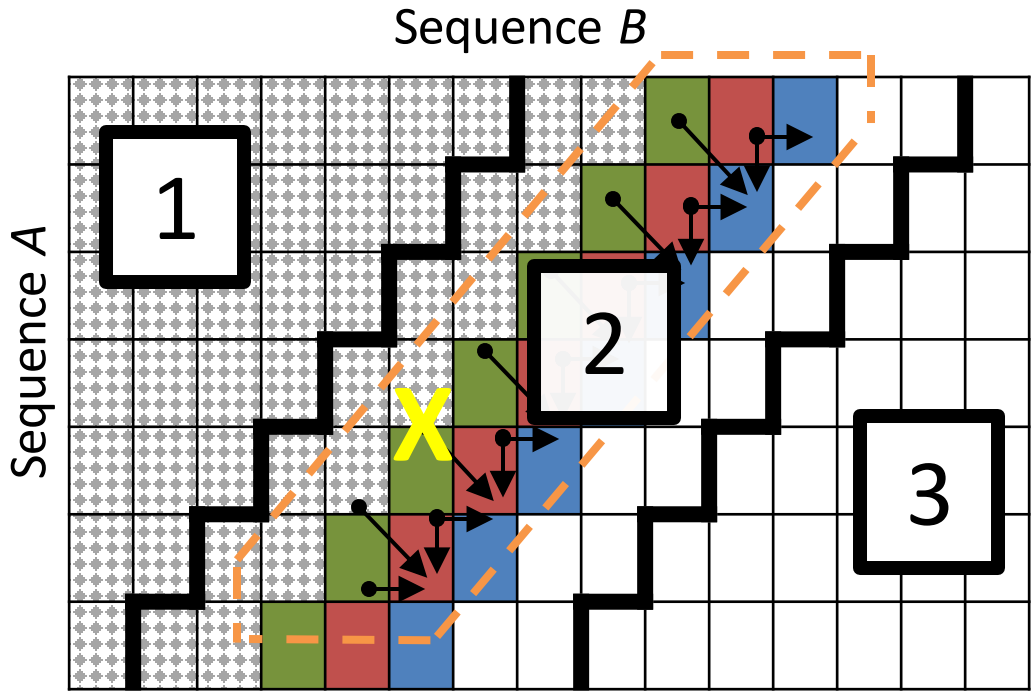
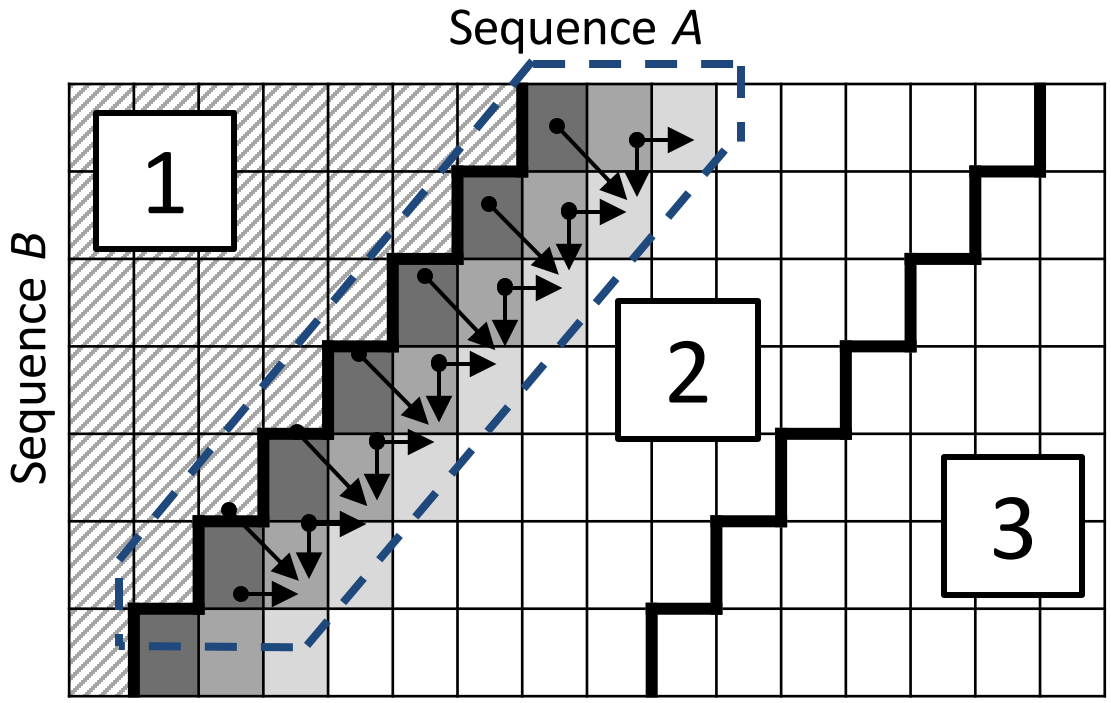


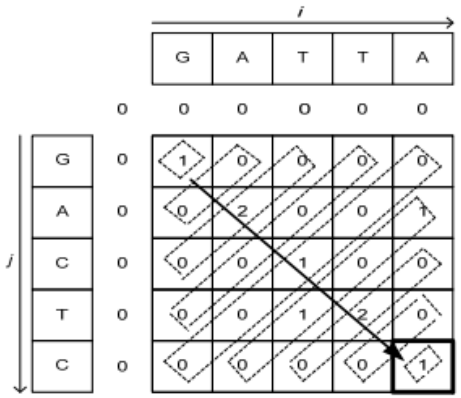
Fig 2

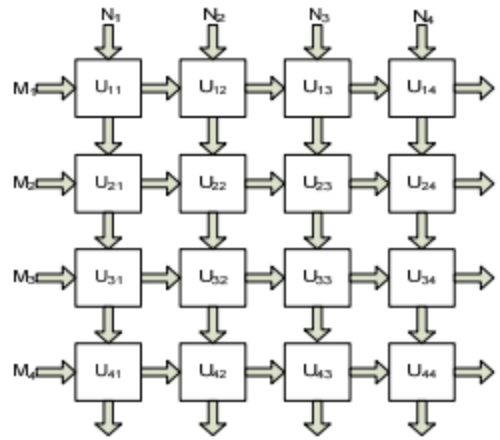


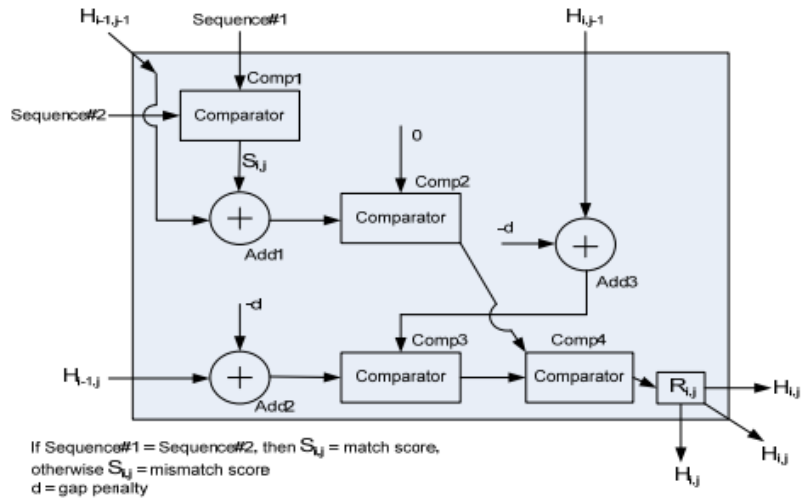
How it works in Parallel



Systolic Implementation



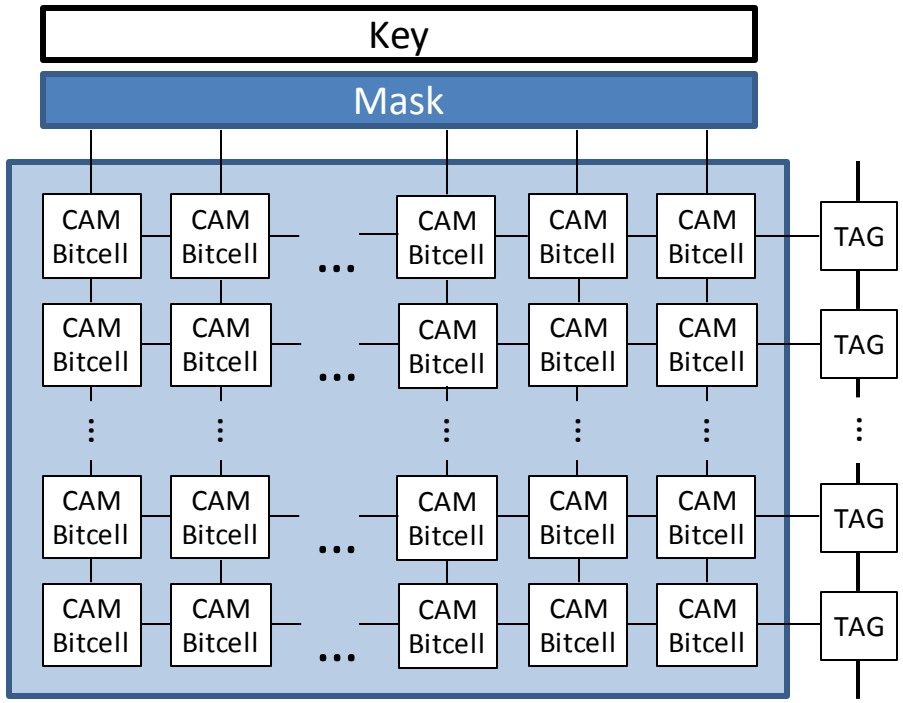


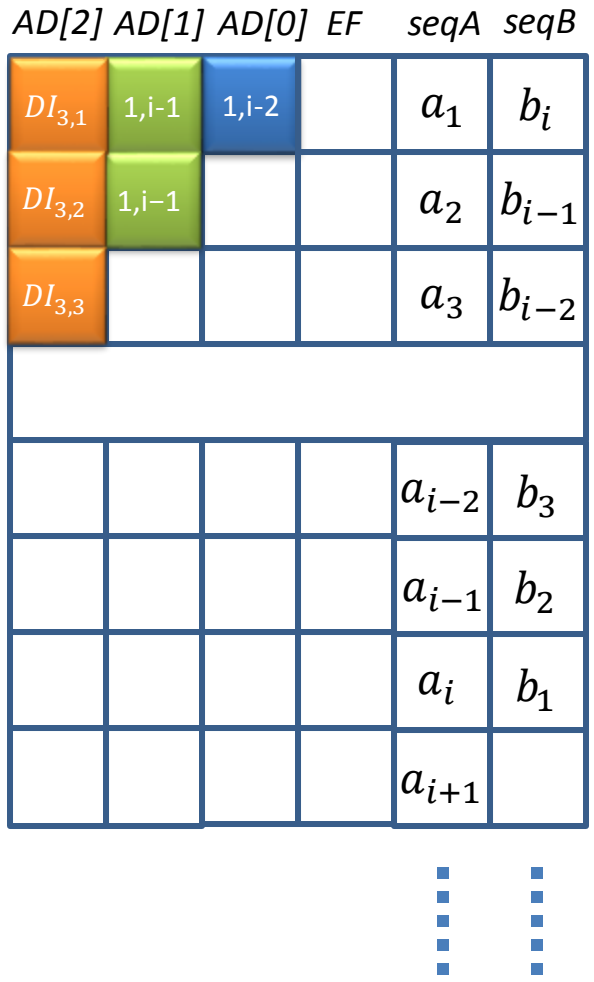


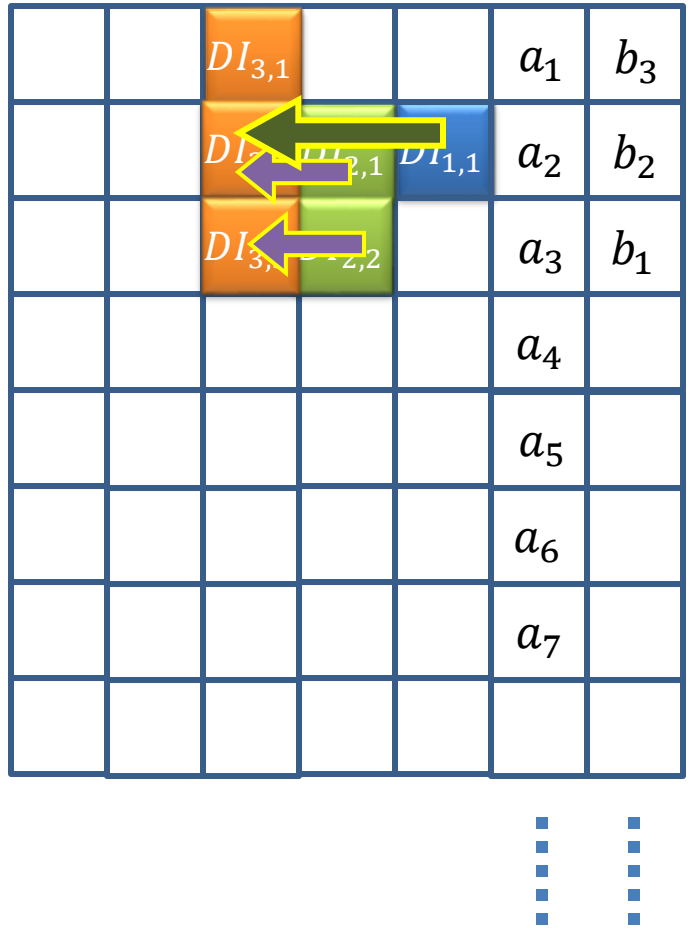
(1) Yu, Chi Wai, et al. "A Smith-Waterman systolic cell." *New Algorithms, Architectures and Applications for Reconfigurable Computing*. Springer US, 2005. 291-300.

(2) Zhang, Peiheng, Guangming Tan, and Guang R. Gao. "Implementation of the Smith-Waterman algorithm on a reconfigurable supercomputing platform." *Proceedings of the 1st international workshop on High-performance reconfigurable computing technology and applications: held in conjunction with SC07*. ACM, 2007.

(3) Hasan, Laiq, Yahya M. Khawaja, and Abdul Bais. "A Systolic Array Architecture for the Smith-Waterman Algorithm with High Performance Cell Design." *IADIS European Conf. Data Mining*. 2008.

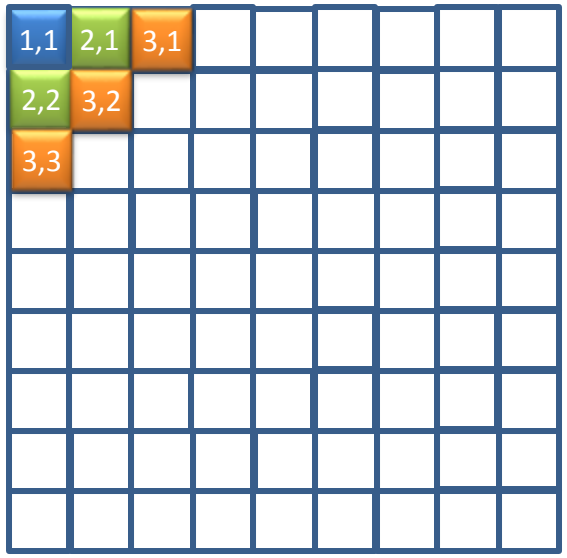

Key
Mask
CAM Bitcell
TAG

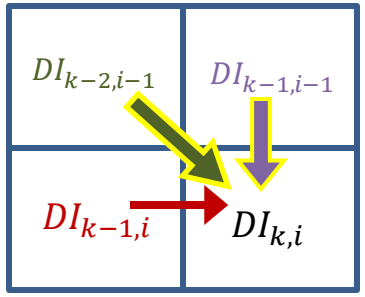

AD[2]
AD[1]
AD[0]
EF
seqA
seqB
$DI_{3,1}$
1,i-1
1,i-2
$DI_{3,2}$
1,i−1
$DI_{3,3}$
a_1
b_i
a_2
b_{i-1}
a_3
b_{i-2}
a_{i-2}
b_3
a_{i-1}
b_2
a_i
b_1
a_{i+1}


$DI_{3,1}$
$DI_{1,1}$
a_1
b_3
a_2
b_2
a_3
b_1
a_4
a_5
a_6
a_7

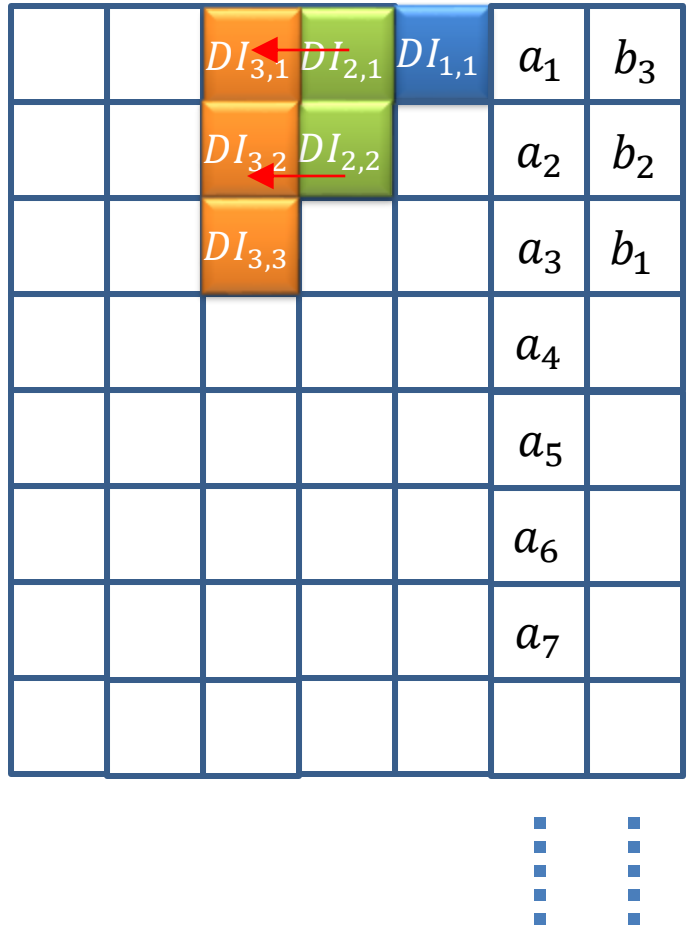
How it works

Dynamic Programming Matrix



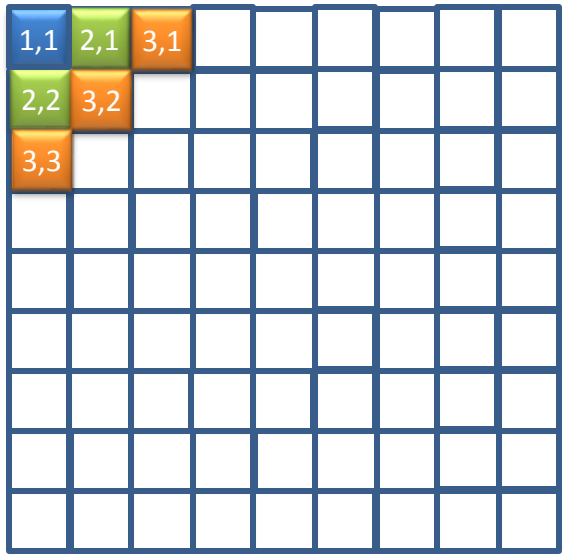


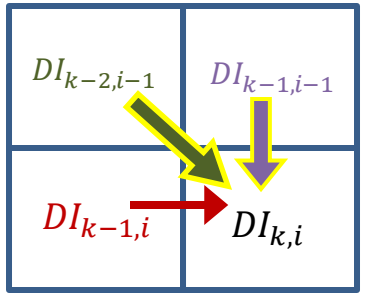
ReCAM (iteration start)



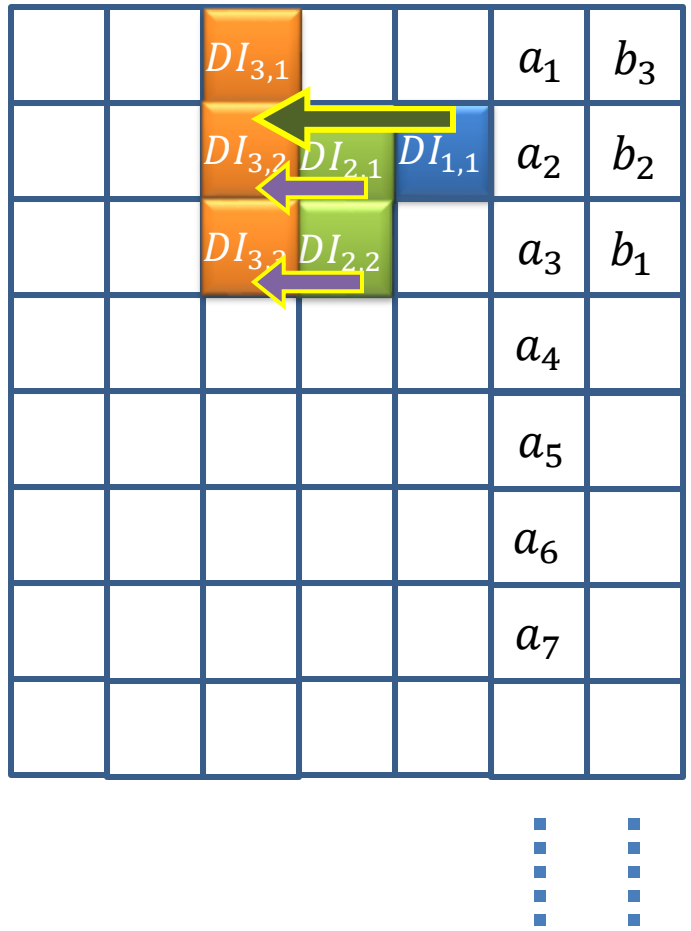
How it works

Dynamic Programming Matrix



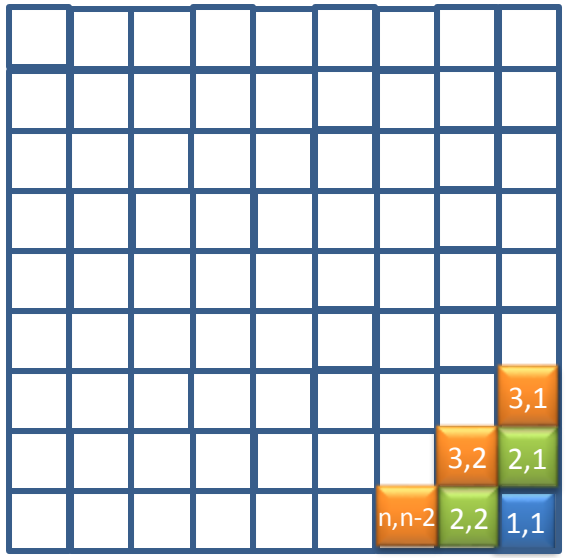


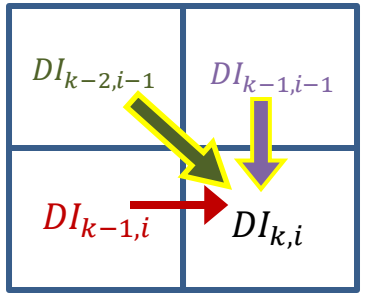
ReCAM (iteration end)



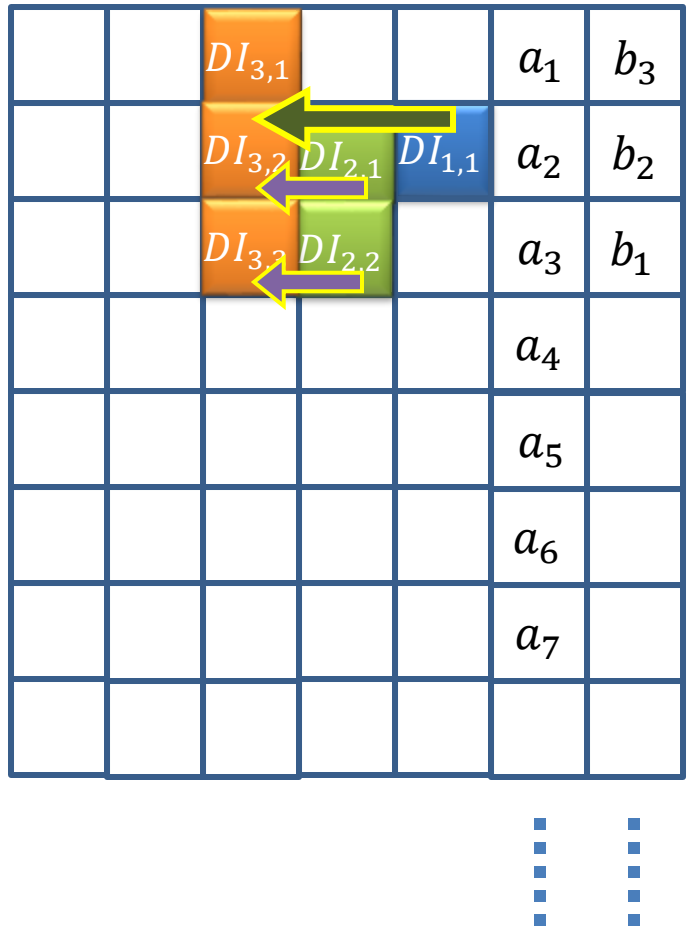
How it works

Dynamic Programming Matrix



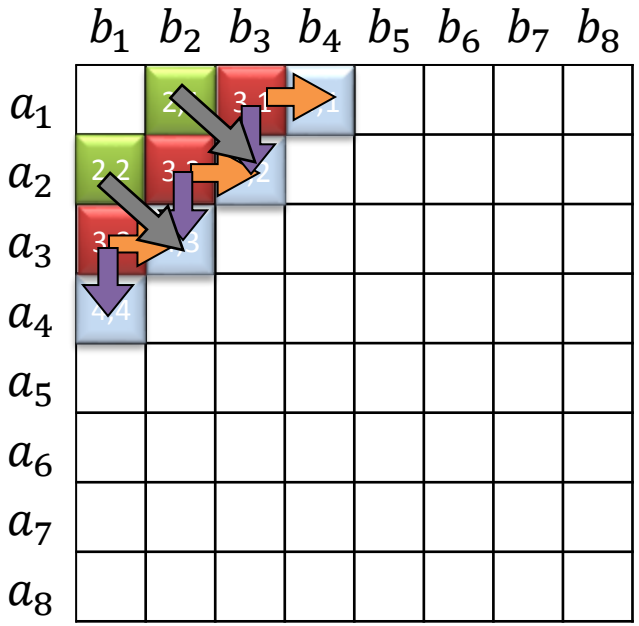


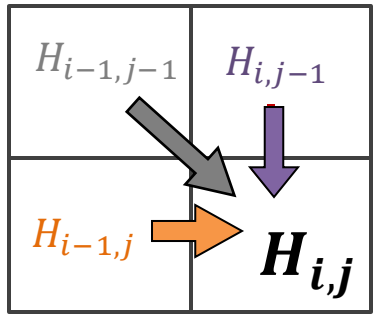
ReCAM (iteration end)



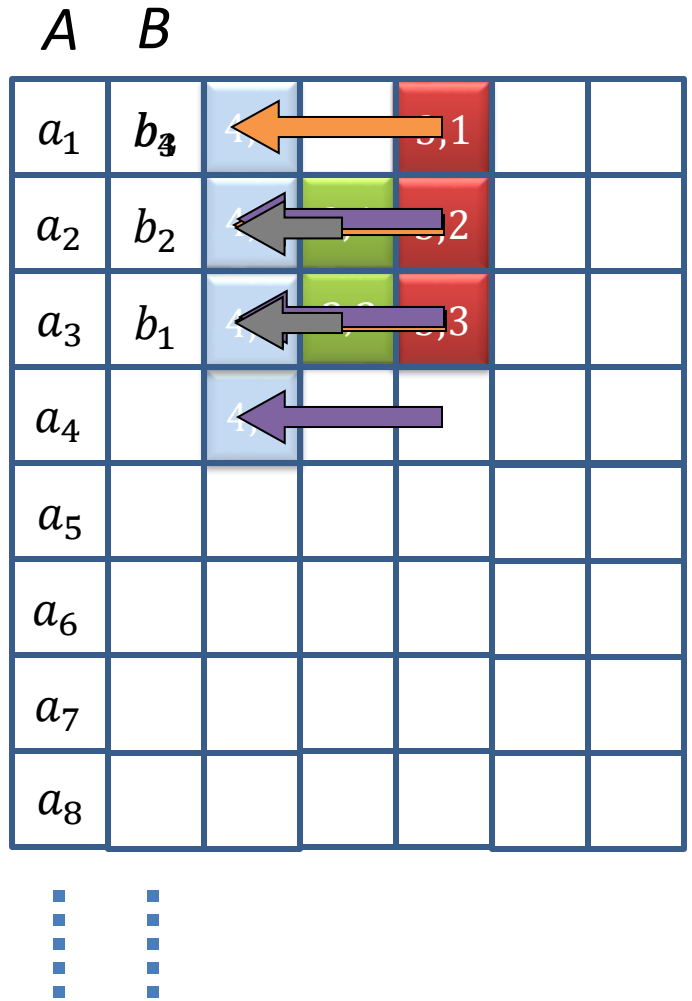
Mapping the Algorithm to Device

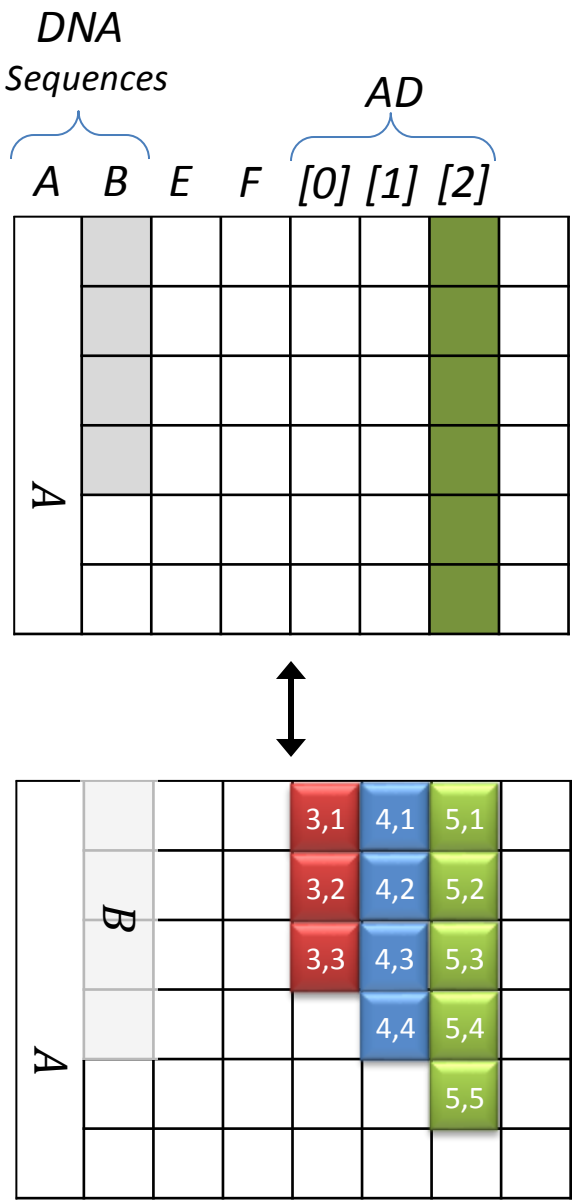
Dynamic Programming Matrix

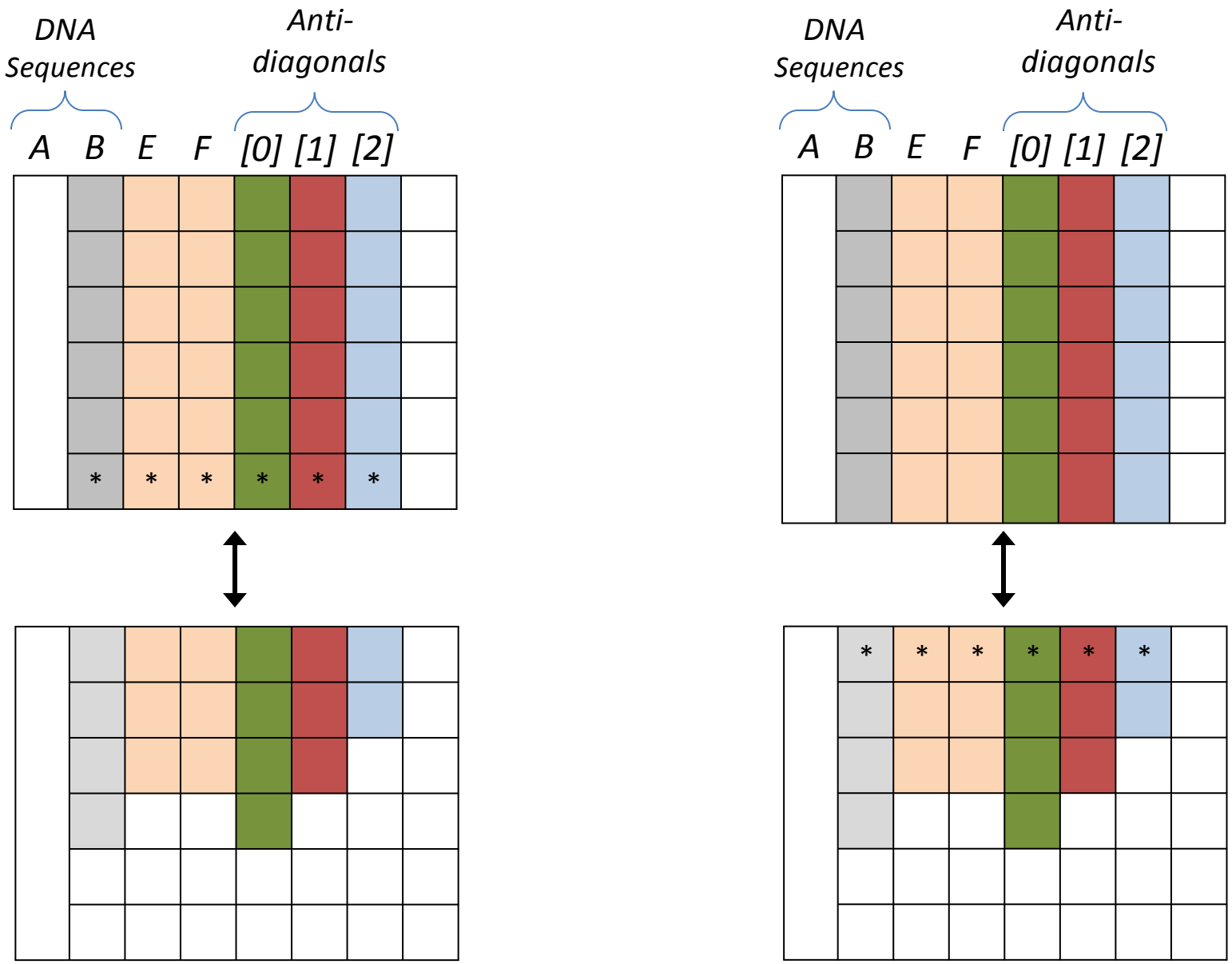


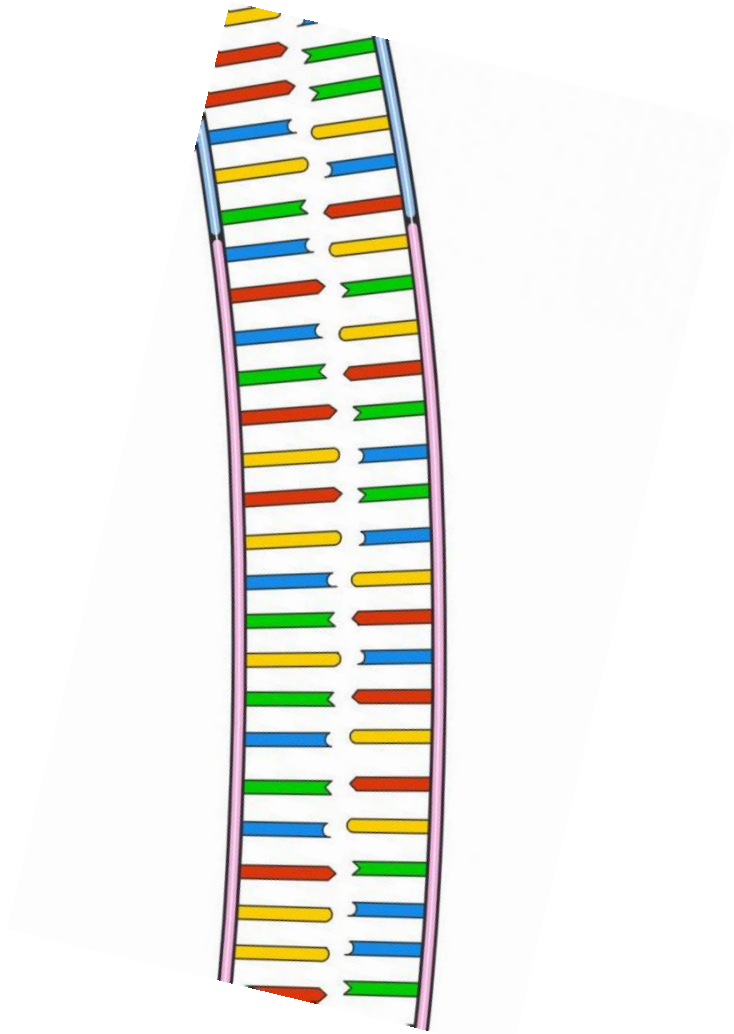


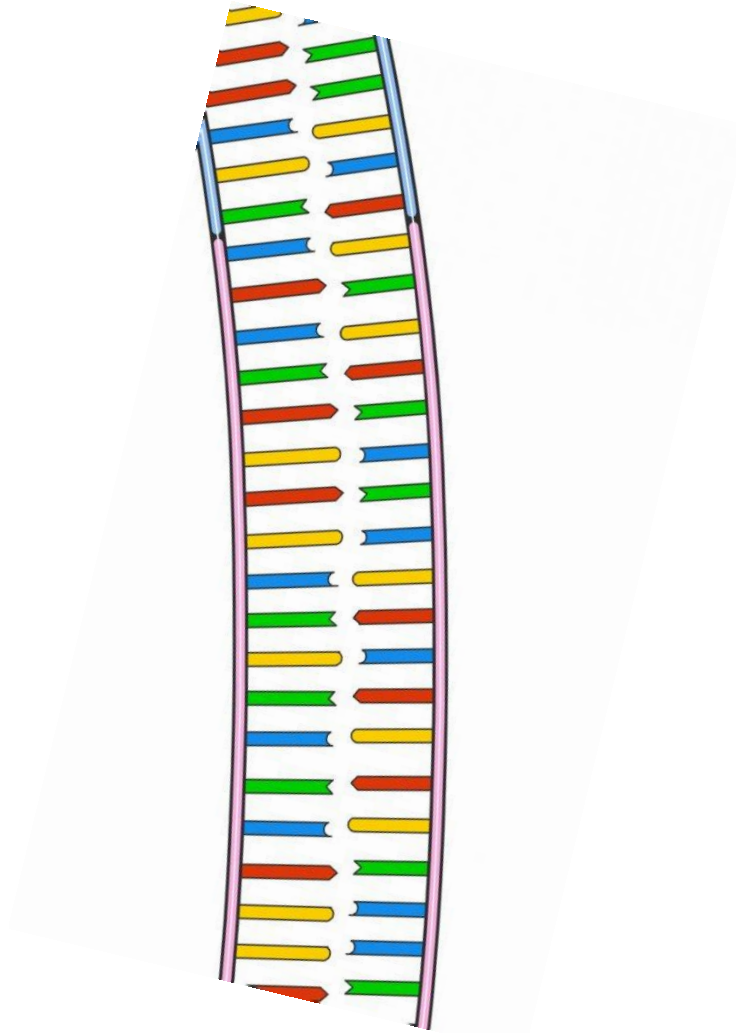
ReCAM




DNA
Sequences
AD
A
B
E
F
[0]
[1]
[2]
A
B
A
3,1
4,1
5,1
3,2
4,2
5,2
3,3
4,3
5,3
4,4
5,4
5,5


DNA Sequences
Anti-diagonals
A
B
E
F
[0]
[1]
[2]
*
DNA Sequences
Anti-diagonals
A
B
E
F
[0]
[1]
[2]
*





(a)

AD[2]	AD[1]	AD[0]	F	E	seqA	seqB
$H_{1,i-3}$	$H_{1,i-1}$	$H_{1,i-2}$	$F_{1,i-1}$	$E_{1,i-1}$	A_1	B_{i-1}
$H_{2,i-4}$	$H_{2,i-2}$	$H_{2,i-3}$	$F_{2,i-2}$	$E_{2,i-2}$	A_2	B_{i-2}
$H_{1,i-5}$	$H_{3,i-3}$	$H_{3,i-4}$	$F_{3,i-3}$	$E_{3,i-3}$	A_3	B_{i-3}
			...			
	$H_{i-2,2}$	$H_{i-2,1}$	$F_{i-2,2}$	$E_{i-2,2}$	A_{i-2}	B_2
	$H_{i-1,1}$		$F_{i-1,1}$	$E_{i-1,1}$	A_{i-1}	B_1
					A_i	
					A_{i+1}	
			...			

(b)

AD[2]	AD[1]	AD[0]	F	E	seqA	seqB
$H_{1,i}$	$H_{1,i-1}$		$F_{1,i}$	$E_{1,i}$	A_1	B_i
$H_{2,i-1}$	$H_{2,i-2}$	$H_{1,i-2}$	$F_{2,i-1}$	$E_{2,i-1}$	A_2	B_{i-1}
$H_{3,i-2}$	$H_{3,i-3}$	$H_{2,i-3}$	$F_{3,i-2}$	$E_{3,i-2}$	A_3	B_{i-2}
			...			
$H_{i-2,3}$	$H_{i-2,2}$	$H_{i-3,2}$	$F_{i-2,3}$	$E_{i-2,3}$	A_{i-2}	B_3
$H_{i-1,2}$	$H_{i-1,1}$	$H_{i-2,1}$	$F_{i-1,2}$	$E_{i-1,2}$	A_{i-1}	B_2
$H_{i,1}$			$F_{i,1}$	$E_{i,1}$	A_i	B_1
					A_{i+1}	
			...			

Beginning

End

(a)

AD[2]	*AD[1]*	*AD[0]*	*F*	*E*	*seqA*	*seqB*
$H_{1,i-3}$	$H_{1,i-1}$	$H_{1,i-2}$	$F_{1,i-1}$	$E_{1,i-1}$	a_1	b_{i-1}
$H_{2,i-4}$	$H_{2,i-2}$	$H_{2,i-3}$	$F_{2,i-2}$	$E_{2,i-2}$	a_2	b_{i-2}
$H_{1,i-5}$	$H_{3,i-3}$	$H_{3,i-4}$	$F_{3,i-3}$	$E_{3,i-3}$	a_3	b_{i-3}
			...			
	$H_{i-2,2}$	$H_{i-2,1}$	$F_{i-2,2}$	$E_{i-2,2}$	a_{i-2}	b_2
	$H_{i-1,1}$		$F_{i-1,1}$	$E_{i-1,1}$	a_{i-1}	b_1
					a_i	
					a_{i+1}	
			...			

(b)

AD[2]	*AD[1]*	*AD[0]*	*F*	*E*	*seqA*	*seqB*
$H_{1,i}$	$H_{1,i-1}$		$F_{1,i}$	$E_{1,i}$	a_1	b_i
$H_{2,i-1}$	$H_{2,i-2}$	$H_{1,i-2}$	$F_{2,i-1}$	$E_{2,i-1}$	a_2	b_{i-1}
$H_{3,i-2}$	$H_{3,i-3}$	$H_{2,i-3}$	$F_{3,i-2}$	$E_{3,i-2}$	a_3	b_{i-2}
			...			
$H_{i-2,3}$	$H_{i-2,2}$	$H_{i-3,2}$	$F_{i-2,3}$	$E_{i-2,3}$	a_{i-2}	b_3
$H_{i-1,2}$	$H_{i-1,1}$	$H_{i-2,1}$	$F_{i-1,2}$	$E_{i-1,2}$	a_{i-1}	b_2
$H_{i,1}$			$F_{i,1}$	$E_{i,1}$	a_i	b_1
					a_{i+1}	
			...			

Beginning

End

(a)

Seq. A	*Seq. B*	*E*	*F*	*AD[0]*	*AD[1]*	*AD[2]*
a_1	b_{i-1}	$E_{1,i-1}$	$F_{1,i-1}$	$H_{1,i-2}$	$H_{1,i-1}$	$H_{1,i-3}$
a_2	b_{i-2}	$E_{2,i-2}$	$F_{2,i-2}$	$H_{2,i-3}$	$H_{2,i-2}$	$H_{2,i-4}$
a_3	b_{i-3}	$E_{3,i-3}$	$F_{3,i-3}$	$H_{3,i-4}$	$H_{3,i-3}$	$H_{1,i-5}$
			...			
a_{i-2}	b_2	$E_{i-2,2}$	$F_{i-2,2}$	$H_{i-2,1}$	$H_{i-2,2}$	
a_{i-1}	b_1	$E_{i-1,1}$	$F_{i-1,1}$		$H_{i-1,1}$	
a_i						
a_{i+1}						
			...			

(b)

Seq. A	*Seq. B*	*E*	*F*	*AD[0]*	*AD[1]*	*AD[2]*
a_1	b_i	$E_{1,i}$	$F_{1,i}$		$H_{1,i-1}$	$H_{1,i}$
a_2	b_{i-1}	$E_{2,i-1}$	$F_{2,i-1}$	$H_{1,i-2}$	$H_{2,i-2}$	$H_{2,i-1}$
a_3	b_{i-2}	$E_{3,i-2}$	$F_{3,i-2}$	$H_{2,i-3}$	$H_{3,i-3}$	$H_{3,i-2}$
			...			
a_{i-2}	b_3	$E_{i-2,3}$	$F_{i-2,3}$	$H_{i-3,2}$	$H_{i-2,2}$	$H_{i-2,3}$
a_{i-1}	b_2	$E_{i-1,2}$	$F_{i-1,2}$	$H_{i-2,1}$	$H_{i-1,1}$	$H_{i-1,2}$
a_i	b_1	$E_{i,1}$	$F_{i,1}$			$H_{i,1}$
a_{i+1}						
			...			

Final iterations (last iteration)

(a)

AD[2]	AD[1]	AD[0]	F	E	seqA	seqB
...						
$H_{m-2,n-1}$		$H_{m-2,n}$			a_{n-2}	
$H_{m-1,n-2}$	$H_{m-1,n}$	$H_{m-1,n-1}$	$F_{m-1,n}$	$E_{m-1,n}$	a_{n-1}	b_m
$H_{m,n-3}$	$H_{m,n-1}$	$H_{m,n-2}$	$F_{m,n-1}$	$E_{m,n-1}$	a_n	b_{m-1}

(b)

AD[2]	AD[1]	AD[0]	F	E	seqA	seqB
...						
					a_{n-2}	
	$H_{m-1,n}$	$H_{m-2,n}$			a_{n-1}	
$H_{m,n}$	$H_{m,n-1}$	$H_{m-1,n-1}$	$F_{m,n}$	$E_{m,n}$	a_n	b_m

Final iterations (last iteration)

(a)

AD[2]	*AD[1]*	*AD[0]*	*F*	*E*	*seqA*	*seqB*
		...				
$H_{m-2,\,n-1}$	D.C.	$H_{m-2,\,n}$	D.C.	D.C.	a_{n-2}	D.C.
$H_{m-1,\,n-2}$	$H_{m-1,n}$	$H_{m-1,\,n-1}$	$F_{m-1,n}$	$E_{m-1,n}$	a_{n-1}	b_m
$H_{m,\,n-3}$	$H_{m,n-1}$	$H_{m,\,n-2}$	$F_{m,n-1}$	$E_{m,n-1}$	a_n	b_{m-1}

(b)

AD[2]	*AD[1]*	*AD[0]*	*F*	*E*	*seqA*	*seqB*
		...				
D.C.	D.C.	D.C.	D.C.	D.C.	a_{n-2}	D.C.
D.C.	$H_{m-1,n}$	$H_{m-2,\,n}$	D.C.	D.C.	a_{n-1}	D.C.
$H_{m,n}$	$H_{m,n-1}$	$H_{m-1,\,n-1}$	$F_{m,n}$	$E_{m,n}$	a_n	b_m