A New Algorithm for Best Subsquence Alignments with Application to tRNA-rRNA Comparisons

Felipe Lima Morais

Instituto de computação - UNICAMP

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Alinhamento local

► T.F. Smith e M.S. Waterman, 1981, foram os primeiros a abordar o problema do alinhamento local.

Programação Dinâmica para encontrar o Alinhamento local

O alinhamento de duas cadeias vazias, tem pontuação 0.

$$H[i,0] = 0$$
$$H[0,j] = 0$$

Existe 4 possibilidades para o alinhamento:

$$H[i,j] = max egin{cases} H[i-1,j] + g \ H[i-1,j-1] + p(i,j) \ H[i,j-1] + g \ 0 \end{cases}$$

O algoritmo proposto

Identificar todas as subsequencia similares que não se interceptam, com uma pontuação de similaridade igual ou superior a algum nível predefinido.

O algoritmo proposto

Realiza pequenas alterações nos valores da matriz de entrada para que seja apresentados as outras subsequencias.

Programação Dinâmica para o Algoritmo

$$W_{k=}v.k$$

$$H[i,j] = max \begin{cases} H[i-1,j] + v \\ H[i-1,j-1] + p(i,j) \\ H[i,j-1] + v \\ 0 \end{cases}$$

Programação Dinâmica para o Algoritmo

$$H^*[i,j] = max \begin{cases} H[i-1,j] + v \\ H[i,j-1] + v \\ 0 \end{cases}$$

Pontuação

$$s(a, a) = 10$$

$$s(a,b)=-9$$

$$w_{k=}-20.k$$

	&	Α	G	Т	С	С	G	Α	G	G	G	С	Т	Α	С	Т	С	Т	Α	С	T	G	Α	Α	_C_
&	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
С	0	0	0	0	10	10	0	0	0	0	0	10	0	0	10	0	10	0	0	10	0	0	0	0	10
С	0	0	0	0	10	20	1	0	0	0	0	10	1	0	10	1	10	1	0	10	1	0	0	0	10
Α	0	10	0	0	0	1	11	11	0	0	0	0	1	11	0	1	0	1	11	0	1	0	10	10	0
Α	0	10	1	0	0	0	0	21	2	0	0	0	0	11	2	0	0	0	11	2	0	0	10	20	1
T	0	0	1	11	0	0	0	1	12	0	0	0	10	0	2	12	0	10	0	2	12	0	0	1	11
С	0	0	0	0	21	10	0	0	0	3	0	10	0	1	10	0	22	2	1	10	0	3	0	0	11
T	0	0	0	10	1	12	1	0	0	0	0	0	20	0	0	20	2	32	12	0	20	0	0	0	0
Α	0	10	0	0	1	0	3	11	0	0	0	0	0	30	10	0	11	12	42	22	2	11	10	10	0
С	0	0	1	0	10	11	0	0	2	0	0	10	0	10	40	20	10	2	22	52	32	12	2	1	20
I	0	0 10	0	11	0	1	2	0	0	0	0	0	20	0	20	50	30	20	2	32	62	42	22 52	2	0
Α	0		0	0	2	0	0	12	0	0	0	0	0	30 10	10	30	41	21	30	12 40	42 22	53	52 44	32 43	12
С	0	0		0 11	10	12 1	0	0	3	0	0	10	0		40	20	40	32	12		50	33	24	35	42
G	0	0	0 10	0	2	0	3 11	0	0 10	0 10	0 10	0	20	0 11	20	50 30	30 41	50 30	30 41	20 21	30	60	40	20	34 26
C	0	0	0	1	10	12	0	2	0	10	1	20	0	0	21	10	40	32	21	51	31	40	51	31	30
T	0	0	0	10	0	1	3	0	0	0	0	0	30	10	1	31	20	50	30	31	61	41	31	42	22
Ť	0	0	0	10	1	0	0	0	0	0	0	0	10	21	1	11	22	30	41	21	41	52	32	22	33
Ġ	0	0	10	0	1	0	10	0	10	10	10	0	0	1	12	0	2	13	21	32	21	51	43	23	13
Č	0	0	0	1	10	11	0	1	0	1	1	20	0	Ó	11	3	10	0	4	31	23	31	42	34	33
A	0	10	0	0	0	1	2	10	0	0	0	0	11	10	0	2	0	1	10	11	22	14	41	52	32
G	0	0	20	Ô	0	0	11	0	20	10	10	0	0	2	1	0	0	0	0	1	2	32	21	32	43
T	0	0	0	30	10	0	0	2	0	11	1	1	10	0	0	11	0	10	0	0	11	12	23	12	23
A	0	10	0	10	21	1	0	10	0	0	2	0	0	20	0	0	2	0	20	0	0	2	22	33	13
С	0	0	1	0	20	31	11	0	1	0	0	12	0	0	30	10	10	0	0	30	10	0	2	13	43

						0	Algorit	mo Pro	posto							Exe	cução							Com	plexi
	&	Α	G	Т	С	С	G	Α	G	G	G	С	Т	Α	С	Т	С	Т	Α	С	Т	G	Α	Α	С
&	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
С	0	0	0	0	10	10	0	0	0	0	0	10	0	0	10	0	10	0	0	10	0	0	0	0	10
С	0	0	0	0	10	20	1	0	0	0	0	10	1	0	10	1	10	1	0	10	1	0	0	0	10
Α	0	10	0	0	0	1	11	11	0	0	0	0	1	11	0	1	0	1	11	0	1	0	10	10	0
Α	0	10	1	0	0	0	0	21	2	0	0	0	0	11	2	0	0	0	11	2	0	0	10	20	1
Т	0	0	1	11	0	0	0	1	12	0	0	0	10	0	2	12	0	10	0	2	12	0	0	1	11
С	0	0	0	0	21	10	0	0	0	3	0	10	0	1	10	0	22	2	1	10	0	3	0	0	11
Т	0	0	0	10	1	12	1	0	0	0	0	0	20	0	0	20	2	32	12	0	20	0	0	0	0
Α	0	10	0	0	1	0	3	11	0	0	0	0	0	30	10	0	11	12	42	22	2	11	10	10	0
С	0	0	1	0	10	11	0	0	2	0	0	10	0	10	40	20	10	2	22	52	32	12	2	1	20
Т	0	0	0	11	0	1	2	0	0	0	0	0	20	0	20	50	30	20	2	32	62	42	22	2	0
Α	0	10	0	0	2	0	0	12	0	0	0	0	0	30	10	30	41	21	30	12	42	53	52	32	12
С	0	0	1	0	10	12	0	0	3	0	0	10	0	10	40	20	40	32	12	40	22	33	44	43	42
Т	0	0	0	11	0	1	3	0	0	0	0	0	20	0	20	50	30	50	30	20	50	30	24	35	34
G	0	0	10	0	2	0	11	0	10	10	10	0	0	11	0	30	41	30	41	21	30	60	40	20	26
С	0	0	0	1	10	12	0	2	0	1	1	20	0	0	21	10	40	32	21	51	31	40	51	31	30
Т	0	0	0	10	0	1	3	0	0	0	0	0	30	10	1	31	20	50	30	31	61	41	31	42	22
Т	0	0	0	10	1	0	0	0	0	0	0	0	10	21	1	11	22	30	41	21	41	52	32	22	33
G	0	0	10	0	1	0	10	0	10	10	10	0	0	1	12	0	2	13	21	32	21	51	43	23	13
С	0	0	0	1	10	11	0	1	0	1	1	20	0	0	11	3	10	0	4	31	23	31	42	34	33
Α	0	10	0	0	0	1	2	10	0	0	0	0	11	10	0	2	0	1	10	11	22	14	41	52	32
G	0	0	20	0	0	0	11	0	20	10	10	0	0	2	1	0	0	0	0	1	2	32	21	32	43
Т	0	0	0	30	10	0	0	2	0	11	1	1	10	0	0	11	0	10	0	0	11	12	23	12	23
Α	0	10	0	10	21	1	0	10	0	0	2	0	0	20	0	0	2	0	20	0	0	2	22	33	13
С	0	0	1	0	20	31	11	0	1	0	0	12	0	0	30	10	10	0	0	30	10	0	2	13	43

						0	Algorit	mo Pro	posto							Exe	cução							Com	plexidad
	&	Α	G	Т	С	С	G	Α	G	G	G	С	Т	Α	С	Т	С	Т	Α	С	Т	G	Α	Α	С
-&	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
С	0	0	0	0	10	10	0	0	0	0	0	10	0	0	10	0	10	0	0	10	0	0	0	0	10
С	0	0	0	0	10	20	1	0	0	0	0	10	1	0	10	1	10	1	0	10	1	0	0	0	10
Α	0	10	0	0	0	1	11	11	0	0	0	0	1	11	0	1	0	1	11	0	1	0	10	10	0
Α	0	10	1	0	0	0	0	21	2	0	0	0	0	11	2	0	0	0	11	2	0	0	10	20	1
Т	0	0	1	11	0	0	0	1	12	0	0	0	10	0	2	12	0	10	0	2	12	0	0	1	11
С	0	0	0	0	21	10	0	0	0	3	0	10	0	1	10	0	22	2	1	10	0	3	0	0	11
Т	0	0	0	10	1	12	1	0	0	0	0	0	20	0	0	20	2	32	12	0	20	0	0	0	0
Α	0	10	0	0	1	0	3	11	0	0	0	0	0	30	10	0	11	12	42	22	2	11	10	10	0
С	0	0	1	0	10	11	0	0	2	0	0	10	0	10	40	20	10	2	22	52	32	12	2	1	20
Т	0	0	0	11	0	1	2	0	0	0	0	0	20	0	20	50	30	20	2	32	62	42	22	2	0
Α	0	10	0	0	2	0	0	12	0	0	0	0	0	30	10	30	41	21	30	12	42	53	52	32	12
С	0	0	1	0	10	12	0	0	3	0	0	10	0	10	40	20	40	32	12	40	22	33	44	43	42
Т	0	0	0	11	0	1	3	0	0	0	0	0	20	0	20	50	30	50	30	20	50	30	24	35	34
G	0	0	10	0	2	0	11	0	10	10	10	0	0	11	0	30	41	30	41	21	30	60	40	20	26
С	0	0	0	1	10	12	0	2	0	1	1	20	0	0	21	10	40	32	21	51	31	40	51	31	30
Т	0	0	0	10	0	1	3	0	0	0	0	0	30	10	1	31	20	50	30	31	61	41	31	42	22
Т	0	0	0	10	1	0	0	0	0	0	0	0	10	21	1	11	22	30	41	21	41	52	32	22	33
G	0	0	10	0	1	0	10	0	10	10	10	0	0	1	12	0	2	13	21	32	21	51	43	23	13
С	0	0	0	1	10	11	0	1	0	1	1	20	0	0	11	3	10	0	4	31	23	31	42	34	33
Α	0	10	0	0	0	1	2	10	0	0	0	0	11	10	0	2	0	1	10	11	22	14	41	52	32
G	0	0	20	0	0	0	11	0	20	10	10	0	0	2	1	0	0	0	0	1	2	32	21	32	43
Т	0	0	0	30	10	0	0	2	0	11	1	1	10	0	0	11	0	10	0	0	11	12	23	12	23
Α	0	10	0	10	21	1	0	10	0	0	2	0	0	20	0	0	2	0	20	0	0	2	22	33	13
С	0	0	1	0	20	31	11	0	1	0	0	12	0	0	30	10	10	0	0	30	10	0	2	13	43

Programação Dinâmica para o Algoritmo

$$H^*[i,j] = max \begin{cases} H[i-1,j] + v \\ H[i,j-1] + v \\ 0 \end{cases}$$

0				O Algor	itmo Prop	osto				Ex	ecução				Co	omple
		 С	Т	Α	С	Т	С	Т	Α	С	Т	G	Α	Α	С	
	&	 0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	С	 10	0	0	10	0	10	0	0	10	0	0	0	0	10	
	С	 10	1	0	10	1	10	1	0	10	1	0	0	0	10	
	Α	 0	1	11	0	1	0	1	11	0	1	0	10	10	0	
	Α	 0	0	11	2	0	0	0	11	2	0	0	10	20	1	
	Т	 0	10	0	2	12	0	10	0	2	12	0	0	1	11	
	С	 10	0	1	10	0	22	2	1	10	0	3	0	0	11	
	Т	 0	20	0	0	20	2	32	12	0	20	0	0	0	0	
	Α	 0	0	30	10	0	11	12	42	22	2	11	10	10	0	
	С	 10	0	10	40	20	10	2	22	52	32	12	2	1	20	
	Т	 0	20	0	20	50	30	20	2	32	62	42	22	2	0	
	Α	 0	0	30	10	30	41	21	30	12	42	53	52	32	12	
	С	 10	0	10	40	20	40	32	12	40	22	33	44	43	42	
	Т	 0	20	0	20	50	30	50	30	20	50	30	24	35	34	
	G	 0	0	11	0	30	41	30	41	21	30	60	40	20	26	
	С	 20	0	0	21	10	40	32	21	51	31	40	51	31	30	
	Т	 0	30	10	1	31	20	50	30	31	61	41	31	42	22	

21

41

41

4 31 23 31 42 34 33

10 11 22 14 41 52 32

13 21 32 21 51 43 23 13

0

1

52 32

22 33

10 21 1 11 22 30

11 10 0 2

0

12 0

11 3

2

10

0

0 0

0

20 0

...

G

Α

0				O Algori	tmo Propo	sto				Exe	cução				Co	omple
		 С	Т	Α	С	Т	С	Т	Α	С	Т	G	Α	Α	С	
	&	 0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	С	 0*	0*	0	10	0	10	0	0	10	0	0	0	0	10	
	С	 10*	1	0	10	1	10	1	0	10	1	0	0	0	10	
	Α	 0	1	11	0	1	0	1	11	0	1	0	10	10	0	
	Α	 0	0	11	2	0	0	0	11	2	0	0	10	20	1	
	Τ	 0	10	0	2	12	0	10	0	2	12	0	0	1	11	
	С	 10	0	1	10	0	22	2	1	10	0	3	0	0	11	
	Т	 0	20	0	0	20	2	32	12	0	20	0	0	0	0	
	Α	 0	0	30	10	0	11	12	42	22	2	11	10	10	0	
	С	 10	0	10	40	20	10	2	22	52	32	12	2	1	20	
	Τ	 0	20	0	20	50	30	20	2	32	62	42	22	2	0	
	Α	 0	0	30	10	30	41	21	30	12	42	53	52	32	12	
	С	 10	0	10	40	20	40	32	12	40	22	33	44	43	42	
	Τ	 0	20	0	20	50	30	50	30	20	50	30	24	35	34	
	G	 0	0	11	0	30	41	30	41	21	30	60	40	20	26	
	С	 20	0	0	21	10	40	32	21	51	31	40	51	31	30	
	Τ	 0	30	10	1	31	20	50	30	31	61	41	31	42	22	
	Τ	 0	10	21	1	11	22	30	41	21	41	52	32	22	33	
	G	 0	0	1	12	0	2	13	21	32	21	51	43	23	13	
	С	 20	0	0	11	3	10	0	4	31	23	31	42	34	33	
	Α	 0	11	10	0	2	0	1	10	11	22	14	41	52	32	

			O Algori	tmo Propo	sto				Exe	cução				С	omple
	 С	Т	Α	С	Т	С	Т	Α	С	Т	G	Α	Α	С	
&	 0	0	0	0	0	0	0	0	0	0	0	0	0	0	
С	 0	0*	0	10	0	10	0	0	10	0	0	0	0	10	
С	 10*	0	0*	10	1	10	1	0	10	1	0	0	0	10	
Α	 0	1*	11	0	1	0	1	11	0	1	0	10	10	0	
Α	 0	0	11	2	0	0	0	11	2	0	0	10	20	1	
Τ	 0	10	0	2	12	0	10	0	2	12	0	0	1	11	
С	 10	0	1	10	0	22	2	1	10	0	3	0	0	11	
Т	 0	20	0	0	20	2	32	12	0	20	0	0	0	0	
Α	 0	0	30	10	0	11	12	42	22	2	11	10	10	0	
С	 10	0	10	40	20	10	2	22	52	32	12	2	1	20	
Τ	 0	20	0	20	50	30	20	2	32	62	42	22	2	0	
Α	 0	0	30	10	30	41	21	30	12	42	53	52	32	12	
С	 10	0	10	40	20	40	32	12	40	22	33	44	43	42	
Τ	 0	20	0	20	50	30	50	30	20	50	30	24	35	34	
G	 0	0	11	0	30	41	30	41	21	30	60	40	20	26	
С	 20	0	0	21	10	40	32	21	51	31	40	51	31	30	
Т	 0	30	10	1	31	20	50	30	31	61	41	31	42	22	
Т	 0	10	21	1	11	22	30	41	21	41	52	32	22	33	
G	 0	0	1	12	0	2	13	21	32	21	51	43	23	13	
С	 20	0	0	11	3	10	0	4	31	23	31	42	34	33	
Α	 0	11	10	0	2	0	1	10	11	22	14	41	52	32	

				O Algoriti	no Propos	sto				Exec	cução				Com	ple
		С	Т	Α	С	Т	С	Т	Α	С	Т	G	Α	Α	С	
&		0	0	0	0	0	0	0	0	0	0	0	0	0	0	
С		0	0*	0	10	0	10	0	0	10	0	0	0	0	10	
С		10*	0	0*	10	1	10	1	0	10	1	0	0	0	10	
Α		0	1*	0	0*	1	0	1	11	0	1	0	10	10	0	
Α		0	0	11*	2	0	0	0	11	2	0	0	10	20	1	
Т		0	10	0	2	12	0	10	0	2	12	0	0	1	11	
С		10	0	1	10	0	22	2	1	10	0	3	0	0	11	
Τ		0	20	0	0	20	2	32	12	0	20	0	0	0	0	
Α		0	0	30	10	0	11	12	42	22	2	11	10	10	0	
С		10	0	10	40	20	10	2	22	52	32	12	2	1	20	
Т		0	20	0	20	50	30	20	2	32	62	42	22	2	0	
Α		0	0	30	10	30	41	21	30	12	42	53	52	32	12	
С		10	0	10	40	20	40	32	12	40	22	33	44	43	42	
Т		0	20	0	20	50	30	50	30	20	50	30	24	35	34	
G		0	0	11	0	30	41	30	41	21	30	60	40	20	26	
С		20	0	0	21	10	40	32	21	51	31	40	51	31	30	
Τ		0	30	10	1	31	20	50	30	31	61	41	31	42	22	
Т		0	10	21	1	11	22	30	41	21	41	52	32	22	33	
G		0	0	1	12	0	2	13	21	32	21	51	43	23	13	
С		20	0	0	11	3	10	0	4	31	23	31	42	34	33	
Α		0	11	10	0	2	0	1	10	11	22	14	41	52	32	

			O Algorit	mo Propo	sto				Execu	ção				Com
	 С	Т	Α	С	Т	С	Т	Α	С	Т	G	Α	Α	С
&	 0	0	0	0	0	0	0	0	0	0	0	0	0	0
С	 0	0*	0	10	0	10	0	0	10	0	0	0	0	10
С	 10*	0	0*	10	1	10	1	0	10	1	0	0	0	10
Α	 0	1*	0	0*	1	0	1	11	0	1	0	10	10	0
Α	 0	0	11*	0	0*	0	0	11	2	0	0	10	20	1
Τ	 0	10	0	2*	0	0*	10	0	2	12	0	0	1	11
С	 10	0	1	10	0*	0	0*	1*	10	0	3	0	0	11
Τ	 0	20	0	0	20	0*	32	12	0	20	0	0	0	0
Α	 0	0	30	10	0	11*	12	42	22	2	11	10	10	0
С	 10	0	10	40	20	10	2	22	52	32	12	2	1	20
Τ	 0	20	0	20	50	30	20	2	32	62	42	22	2	0
Α	 0	0	30	10	30	41	21	30	12	42	53	52	32	12
С	 10	0	10	40	20	40	32	12	40	22	33	44	43	42
Τ	 0	20	0	20	50	30	50	30	20	50	30	24	35	34
G	 0	0	11	0	30	41	30	41	21	30	60	40	20	26
С	 20	0	0	21	10	40	32	21	51	31	40	51	31	30
Τ	 0	30	10	1	31	20	50	30	31	61	41	31	42	22
Τ	 0	10	21	1	11	22	30	41	21	41	52	32	22	33
G	 0	0	1	12	0	2	13	21	32	21	51	43	23	13
С	 20	0	0	11	3	10	0	4	31	23	31	42	34	33
Α	 0	11	10	0	2	0	1	10	11	22	14	41	52	32

ão				O Algorit	mo Propos	sto				Execução				(Complexida	d
		 С	Т	Α	С	Т	С	Т	Α	С	Т	G	Α	Α	С	
	&	 0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	С	 0	0*	0	10	0	10	0	0	10	0	0	0	0	10	
	С	 10*	0	0*	10	1	10	1	0	10	1	0	0	0	10	
	Α	 0	1*	0	0*	1	0	1	11	0	1	0	10	10	0	
	Α	 0	0	11*	0	0*	0	0	11	2	0	0	10	20	1	
	Т	 0	10	0	2*	0	0*	10	0	2	12	0	0	1	11	
	С	 10	0	1	10	0*	0	0*	1*	10	0	3	0	0	11	
	Т	 0	20	0	0	20	0*	0	0*	0*	20	0	0	0	0	
	Α	 0	0	30	10	0	11*	0*	0	0*	0*	11*	10	10	0	
	С	 10	0	10	40	20	10	2*	0*	0	0*	0*	2*	1	20	
	Т	 0	20	0	20	50	30	20	0*	0*	0	0*	0*	0*	0*	
	Α	 0	0	30	10	30	41	21	30*	10*	0*	53	52	32	12	
	С	 10	0	10	40	20	40	32	12	40*	20*	33	44	43	42	
	Т	 0	20	0	20	50	30	50	30	20	50*	30	24	35	34	
	G	 0	0	11	0	30	41	30	41	21	30	60	40	20	26	
	С	 20	0	0	21	10	40	32	21	51	31	40	51	31	30	
	Т	 0	30	10	1	31	20	50	30	31	61	41	31	42	22	
	Т	 0	10	21	1	11	22	30	41	21	41	52	32	22	33	
	G	 0	0	1	12	0	2	13	21	32	21	51	43	23	13	
	С	 20	0	0	11	3	10	0	4	31	23	31	42	34	33	
	Α	 0	11	10	0	2	0	1	10	11	22	14	41	52	32	

...

					sto				Execução					
	 С	Т	Α	С	Т	С	Т	Α	С	Т	G	Α	Α	С
&	 0	0	0	0	0	0	0	0	0	0	0	0	0	0
С	 0	0*	0	10	0	10	0	0	10	0	0	0	0	10
С	 10*	0	0*	10	1	10	1	0	10	1	0	0	0	10
Α	 0	1*	0	0*	1	0	1	11	0	1	0	10	10	0
Α	 0	0	11*	0	0*	0	0	11	2	0	0	10	20	1
Τ	 0	10	0	2*	0	0*	10	0	2	12	0	0	1	11
С	 10	0	1	10	0*	0	0*	1*	10	0	3	0	0	11
Т	 0	20	0	0	20	0*	0	0*	0*	20	0	0	0	0
Α	 0	0	30	10	0	11*	0*	0	0*	0*	11*	10	10	0
С	 10	0	10	40	20	10	2*	0*	0	0*	0*	2*	1	20
Т	 0	20	0	20	50	30	20	0*	0*	0	0*	0*	0*	0*
Α	 0	0	30	10	30	41	21	30*	10*	0*	0*	10*	10*	0*
С	 10	0	10	40	20	40	32	12	40*	20*	0*	44	43	42
Т	 0	20	0	20	50	30	50	30	20	50*	30*	24	35	34
G	 0	0	11	0	30	41	30	41	21	30	60	40	20	26
С	 20	0	0	21	10	40	32	21	51	31	40	51	31	30
Т	 0	30	10	1	31	20	50	30	31	61	41	31	42	22
Т	 0	10	21	1	11	22	30	41	21	41	52	32	22	33
G	 0	0	1	12	0	2	13	21	32	21	51	43	23	13
С	 20	0	0	11	3	10	0	4	31	23	31	42	34	33
Α	 0	11	10	0	2	0	1	10	11	22	14	41	52	32
•••	 													

			O Algorit	mo Propos	sto				Execução				Com	plexidade
	 С	Т	Α	С	Т	С	Т	Α	С	Т	G	Α	Α	С
&	 0	0	0	0	0	0	0	0	0	0	0	0	0	0
С	 0	0*	0	10	0	10	0	0	10	0	0	0	0	10
С	 10*	0	0*	10	1	10	1	0	10	1	0	0	0	10
Α	 0	1*	0	0*	1	0	1	11	0	1	0	10	10	0
Α	 0	0	11*	0	0*	0	0	11	2	0	0	10	20	1
Т	 0	10	0	2*	0	0*	10	0	2	12	0	0	1	11
С	 10	0	1	10	0*	0	0*	1*	10	0	3	0	0	11
Т	 0	20	0	0	20	0*	0	0*	0*	20	0	0	0	0
Α	 0	0	30	10	0	11*	0*	0	0*	0*	11*	10	10	0
С	 10	0	10	40	20	10	2*	0*	0	0*	0*	2*	1	20
Т	 0	20	0	20	50	30	20	0*	0*	0	0*	0*	0*	0*
Α	 0	0	30	10	30	41	21	30*	10*	0*	0*	10*	10*	0*
С	 10	0	10	40	20	40	32	12	40*	20*	0*	0*	1*	20*
Т	 0	20	0	20	50	30	50	30	20	50*	30*	10*	35	34
G	 0	0	11	0	30	41	30	41	21	30	60	40*	20	26
С	 20	0	0	21	10	40	32	21	51	31	40	51	31	30
Т	 0	30	10	1	31	20	50	30	31	61	41	31	42	22
Т	 0	10	21	1	11	22	30	41	21	41	52	32	22	33
G	 0	0	1	12	0	2	13	21	32	21	51	43	23	13
С	 20	0	0	11	3	10	0	4	31	23	31	42	34	33
Α	 0	11	10	0	2	0	1	10	11	22	14	41	52	32
	 							•••						

					sto				Execução					
	 С	Т	Α	С	Т	С	Τ	Α	С	Т	G	Α	Α	С
&	 0	0	0	0	0	0	0	0	0	0	0	0	0	0
С	 0	0*	0	10	0	10	0	0	10	0	0	0	0	10
С	 10*	0	0*	10	1	10	1	0	10	1	0	0	0	10
Α	 0	1*	0	0*	1	0	1	11	0	1	0	10	10	0
Α	 0	0	11*	0	0*	0	0	11	2	0	0	10	20	1
Т	 0	10	0	2*	0	0*	10	0	2	12	0	0	1	11
С	 10	0	1	10	0*	0	0*	1*	10	0	3	0	0	11
Т	 0	20	0	0	20	0*	0	0*	0*	20	0	0	0	0
Α	 0	0	30	10	0	11*	0*	0	0*	0*	11*	10	10	0
С	 10	0	10	40	20	10	2*	0*	0	0*	0*	2*	1	20
Τ	 0	20	0	20	50	30	20	0*	0*	0	0*	0*	0*	0*
Α	 0	0	30	10	30	41	21	30*	10*	0*	0*	10*	10*	0*
С	 10	0	10	40	20	40	32	12	40*	20*	0*	0*	1*	20*
Т	 0	20	0	20	50	30	50	30	20	50*	30*	10*	0*	0*
G	 0	0	11	0	30	41	30	41	21	30	60	40*	20*	0*
С	 20	0	0	21	10	40	32	21	51	31	40	51	31	30
Т	 0	30	10	1	31	20	50	30	31	61	41	31	42	22
Т	 0	10	21	1	11	22	30	41	21	41	52	32	22	33
G	 0	0	1	12	0	2	13	21	32	21	51	43	23	13
С	 20	0	0	11	3	10	0	4	31	23	31	42	34	33
Α	 0	11	10	0	2	0	1	10	11	22	14	41	52	32

Custo

ightharpoonup para encontrar um novo alinhamento, usa em média $n^2/4$.

Custo

$$O(n^2) + A.O(L^2).$$

Função Afim

- ► Implementar a usando função afim com O(n²).
- ► Usando três matrizes H_{i,j}, E_{i,j} e F_{i,j}.
- ▶ Aplicando em todas as matrizes, a mesma função H*.