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

Felipe Lima Morais

Instituto de computação - UNICAMP

November 30, 2016

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:

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

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

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

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

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

	&	A	G	T	C	C	G	A	G	G	G	C	T	A	C	T	C	T	A	C	T	G	A	A	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
C	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
C	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
A	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
A	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
C	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
A	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
C	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
T	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
A	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
C	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
T	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
C	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
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
T	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
C	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
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	0	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
C	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

	&	A	G	T	C	C	G	A	G	G	G	C	T	A	C	T	C	T	A	C	T	G	A	A	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
C	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
C	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
A	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
A	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
C	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
A	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
C	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
T	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
A	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
C	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
T	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
C	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
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
T	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
C	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
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	0	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
C	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

	&	A	G	T	C	C	G	A	G	G	G	C	T	A	C	T	C	T	A	C	T	G	A	A	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
C	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
C	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
A	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
A	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
C	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
A	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
C	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
T	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
A	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
C	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
T	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
C	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
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
T	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
C	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
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	0	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
C	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

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

	...	C	T	A	C	T	C	T	A	C	T	G	A	A	C
&	...	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	...	0	0	0	10	0	10	0	0	10	0	0	0	0	10
C	...	10	1	0	10	1	10	1	0	10	1	0	0	0	10
A	...	0	1	11	0	1	0	1	11	0	1	0	10	10	0
A	...	0	0	11	2	0	0	0	11	2	0	0	10	20	1
T	...	0	10	0	2	12	0	10	0	2	12	0	0	1	11
C	...	10	0	1	10	0	22	2	1	10	0	3	0	0	11
T	...	0	20	0	0	20	2	32	12	0	20	0	0	0	0
A	...	0	0	30	10	0	11	12	42	22	2	11	10	10	0
C	...	10	0	10	40	20	10	2	22	52	32	12	2	1	20
T	...	0	20	0	20	50	30	20	2	32	62	42	22	2	0
A	...	0	0	30	10	30	41	21	30	12	42	53	52	32	12
C	...	10	0	10	40	20	40	32	12	40	22	33	44	43	42
T	...	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
C	...	20	0	0	21	10	40	32	21	51	31	40	51	31	30
T	...	0	30	10	1	31	20	50	30	31	61	41	31	42	22
T	...	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
C	...	20	0	0	11	3	10	0	4	31	23	31	42	34	33
A	...	0	11	10	0	2	0	1	10	11	22	14	41	52	32
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

	...	C	T	A	C	T	C	T	A	C	T	G	A	A	C
&	...	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	...	**0***	**0***	0	10	0	10	0	0	10	0	0	0	0	10
C	...	**10***	1	0	10	1	10	1	0	10	1	0	0	0	10
A	...	0	1	11	0	1	0	1	11	0	1	0	10	10	0
A	...	0	0	11	2	0	0	0	11	2	0	0	10	20	1
T	...	0	10	0	2	12	0	10	0	2	12	0	0	1	11
C	...	10	0	1	10	0	22	2	1	10	0	3	0	0	11
T	...	0	20	0	0	20	2	32	12	0	20	0	0	0	0
A	...	0	0	30	10	0	11	12	42	22	2	11	10	10	0
C	...	10	0	10	40	20	10	2	22	52	32	12	2	1	20
T	...	0	20	0	20	50	30	20	2	32	62	42	22	2	0
A	...	0	0	30	10	30	41	21	30	12	42	53	52	32	12
C	...	10	0	10	40	20	40	32	12	40	22	33	44	43	42
T	...	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
C	...	20	0	0	21	10	40	32	21	51	31	40	51	31	30
T	...	0	30	10	1	31	20	50	30	31	61	41	31	42	22
T	...	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
C	...	20	0	0	11	3	10	0	4	31	23	31	42	34	33
A	...	0	11	10	0	2	0	1	10	11	22	14	41	52	32
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

	...	C	T	A	C	T	C	T	A	C	T	G	A	A	C
&	...	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	...	**0**	**0***	0	10	0	10	0	0	10	0	0	0	0	10
C	...	**10***	**0**	**0***	10	1	10	1	0	10	1	0	0	0	10
A	...	0	**1***	11	0	1	0	1	11	0	1	0	10	10	0
A	...	0	0	11	2	0	0	0	11	2	0	0	10	20	1
T	...	0	10	0	2	12	0	10	0	2	12	0	0	1	11
C	...	10	0	1	10	0	22	2	1	10	0	3	0	0	11
T	...	0	20	0	0	20	2	32	12	0	20	0	0	0	0
A	...	0	0	30	10	0	11	12	42	22	2	11	10	10	0
C	...	10	0	10	40	20	10	2	22	52	32	12	2	1	20
T	...	0	20	0	20	50	30	20	2	32	62	42	22	2	0
A	...	0	0	30	10	30	41	21	30	12	42	53	52	32	12
C	...	10	0	10	40	20	40	32	12	40	22	33	44	43	42
T	...	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
C	...	20	0	0	21	10	40	32	21	51	31	40	51	31	30
T	...	0	30	10	1	31	20	50	30	31	61	41	31	42	22
T	...	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
C	...	20	0	0	11	3	10	0	4	31	23	31	42	34	33
A	...	0	11	10	0	2	0	1	10	11	22	14	41	52	32
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

	...	C	T	A	C	T	C	T	A	C	T	G	A	A	C
&	...	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	...	**0**	**0***	0	10	0	10	0	0	10	0	0	0	0	10
C	...	**10***	**0**	**0***	10	1	10	1	0	10	1	0	0	0	10
A	...	0	**1***	**0**	**0***	1	0	1	11	0	1	0	10	10	0
A	...	0	0	**11***	2	0	0	0	11	2	0	0	10	20	1
T	...	0	10	0	2	12	0	10	0	2	12	0	0	1	11
C	...	10	0	1	10	0	22	2	1	10	0	3	0	0	11
T	...	0	20	0	0	20	2	32	12	0	20	0	0	0	0
A	...	0	0	30	10	0	11	12	42	22	2	11	10	10	0
C	...	10	0	10	40	20	10	2	22	52	32	12	2	1	20
T	...	0	20	0	20	50	30	20	2	32	62	42	22	2	0
A	...	0	0	30	10	30	41	21	30	12	42	53	52	32	12
C	...	10	0	10	40	20	40	32	12	40	22	33	44	43	42
T	...	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
C	...	20	0	0	21	10	40	32	21	51	31	40	51	31	30
T	...	0	30	10	1	31	20	50	30	31	61	41	31	42	22
T	...	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
C	...	20	0	0	11	3	10	0	4	31	23	31	42	34	33
A	...	0	11	10	0	2	0	1	10	11	22	14	41	52	32
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

	...	C	T	A	C	T	C	T	A	C	T	G	A	A	C
&	...	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	...	**0**	**0***	0	10	0	10	0	0	10	0	0	0	0	10
C	...	**10***	**0**	**0***	10	1	10	1	0	10	1	0	0	0	10
A	...	0	**1***	**0**	**0***	1	0	1	11	0	1	0	10	10	0
A	...	0	0	**11***	**0**	**0***	0	0	11	2	0	0	10	20	1
T	...	0	10	0	**2***	**0**	**0***	10	0	2	12	0	0	1	11
C	...	10	0	1	10	**0***	**0**	**0***	**1***	10	0	3	0	0	11
T	...	0	20	0	0	20	**0***	32	12	0	20	0	0	0	0
A	...	0	0	30	10	0	**11***	12	42	22	2	11	10	10	0
C	...	10	0	10	40	20	10	2	22	52	32	12	2	1	20
T	...	0	20	0	20	50	30	20	2	32	62	42	22	2	0
A	...	0	0	30	10	30	41	21	30	12	42	53	52	32	12
C	...	10	0	10	40	20	40	32	12	40	22	33	44	43	42
T	...	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
C	...	20	0	0	21	10	40	32	21	51	31	40	51	31	30
T	...	0	30	10	1	31	20	50	30	31	61	41	31	42	22
T	...	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
C	...	20	0	0	11	3	10	0	4	31	23	31	42	34	33
A	...	0	11	10	0	2	0	1	10	11	22	14	41	52	32
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

	...	C	T	A	C	T	C	T	A	C	T	G	A	A	C
&	...	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	...	**0**	**0***	0	10	0	10	0	0	10	0	0	0	0	10
C	...	**10***	**0**	**0***	10	1	10	1	0	10	1	0	0	0	10
A	...	0	**1***	**0**	**0***	1	0	1	11	0	1	0	10	10	0
A	...	0	0	**11***	**0**	**0***	0	0	11	2	0	0	10	20	1
T	...	0	10	0	**2***	**0**	**0***	10	0	2	12	0	0	1	11
C	...	10	0	1	10	**0***	**0**	**0***	**1***	10	0	3	0	0	11
T	...	0	20	0	0	20	**0***	**0**	**0***	**0***	20	0	0	0	0
A	...	0	0	30	10	0	**11***	**0***	**0**	**0***	**0***	**11***	10	10	0
C	...	10	0	10	40	20	10	**2***	**0***	**0**	**0***	**0***	**2***	1	20
T	...	0	20	0	20	50	30	20	**0***	**0***	**0**	**0***	**0***	**0***	**0***
A	...	0	0	30	10	30	41	21	**30***	**10***	**0***	53	52	32	12
C	...	10	0	10	40	20	40	32	12	**40***	**20***	33	44	43	42
T	...	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
C	...	20	0	0	21	10	40	32	21	51	31	40	51	31	30
T	...	0	30	10	1	31	20	50	30	31	61	41	31	42	22
T	...	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
C	...	20	0	0	11	3	10	0	4	31	23	31	42	34	33
A	...	0	11	10	0	2	0	1	10	11	22	14	41	52	32
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

	...	C	T	A	C	T	C	T	A	C	T	G	A	A	C
&	...	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	...	**0**	**0***	0	10	0	10	0	0	10	0	0	0	0	10
C	...	**10***	**0**	**0***	10	1	10	1	0	10	1	0	0	0	10
A	...	0	**1***	**0**	**0***	1	0	1	11	0	1	0	10	10	0
A	...	0	0	**11***	**0**	**0***	0	0	11	2	0	0	10	20	1
T	...	0	10	0	**2***	**0**	**0***	10	0	2	12	0	0	1	11
C	...	10	0	1	10	**0***	**0**	**0***	**1***	10	0	3	0	0	11
T	...	0	20	0	0	20	**0***	**0**	**0***	**0***	20	0	0	0	0
A	...	0	0	30	10	0	**11***	**0***	**0**	**0***	**0***	**11***	10	10	0
C	...	10	0	10	40	20	10	**2***	**0***	**0**	**0***	**0***	**2***	1	20
T	...	0	20	0	20	50	30	20	**0***	**0***	**0**	**0***	**0***	**0***	**0***
A	...	0	0	30	10	30	41	21	**30***	**10***	**0***	**0***	**10***	**10***	**0***
C	...	10	0	10	40	20	40	32	12	**40***	**20***	**0***	44	43	42
T	...	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
C	...	20	0	0	21	10	40	32	21	51	31	40	51	31	30
T	...	0	30	10	1	31	20	50	30	31	61	41	31	42	22
T	...	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
C	...	20	0	0	11	3	10	0	4	31	23	31	42	34	33
A	...	0	11	10	0	2	0	1	10	11	22	14	41	52	32
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

	...	C	T	A	C	T	C	T	A	C	T	G	A	A	C
&	...	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	...	**0**	**0***	0	10	0	10	0	0	10	0	0	0	0	10
C	...	**10***	**0**	**0***	10	1	10	1	0	10	1	0	0	0	10
A	...	0	**1***	**0**	**0***	1	0	1	11	0	1	0	10	10	0
A	...	0	0	**11***	**0**	**0***	0	0	11	2	0	0	10	20	1
T	...	0	10	0	**2***	**0**	**0***	10	0	2	12	0	0	1	11
C	...	10	0	1	10	**0***	**0**	**0***	**1***	10	0	3	0	0	11
T	...	0	20	0	0	20	**0***	**0**	**0***	**0***	20	0	0	0	0
A	...	0	0	30	10	0	**11***	**0***	**0**	**0***	**0***	**11***	10	10	0
C	...	10	0	10	40	20	10	**2***	**0***	**0**	**0***	**0***	**2***	1	20
T	...	0	20	0	20	50	30	20	**0***	**0***	**0**	**0***	**0***	**0***	**0***
A	...	0	0	30	10	30	41	21	**30***	**10***	**0***	**0***	**10***	**10***	**0***
C	...	10	0	10	40	20	40	32	12	**40***	**20***	**0***	**0***	**1***	**20***
T	...	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
C	...	20	0	0	21	10	40	32	21	51	31	40	51	31	30
T	...	0	30	10	1	31	20	50	30	31	61	41	31	42	22
T	...	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
C	...	20	0	0	11	3	10	0	4	31	23	31	42	34	33
A	...	0	11	10	0	2	0	1	10	11	22	14	41	52	32
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

	...	C	T	A	C	T	C	T	A	C	T	G	A	A	C
&	...	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	...	**0**	**0***	0	10	0	10	0	0	10	0	0	0	0	10
C	...	**10***	**0**	**0***	10	1	10	1	0	10	1	0	0	0	10
A	...	0	**1***	**0**	**0***	1	0	1	11	0	1	0	10	10	0
A	...	0	0	**11***	**0**	**0***	0	0	11	2	0	0	10	20	1
T	...	0	10	0	**2***	**0**	**0***	10	0	2	12	0	0	1	11
C	...	10	0	1	10	**0***	**0**	**0***	**1***	10	0	3	0	0	11
T	...	0	20	0	0	20	**0***	**0**	**0***	**0***	20	0	0	0	0
A	...	0	0	30	10	0	**11***	**0***	**0**	**0***	**0***	**11***	10	10	0
C	...	10	0	10	40	20	10	**2***	**0***	**0**	**0***	**0***	**2***	1	20
T	...	0	20	0	20	50	30	20	**0***	**0***	**0**	**0***	**0***	**0***	**0***
A	...	0	0	30	10	30	41	21	**30***	**10***	**0***	**0***	**10***	**10***	**0***
C	...	10	0	10	40	20	40	32	12	**40***	**20***	**0***	**0***	**1***	**20***
T	...	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***
C	...	20	0	0	21	10	40	32	21	51	31	40	51	31	30
T	...	0	30	10	1	31	20	50	30	31	61	41	31	42	22
T	...	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
C	...	20	0	0	11	3	10	0	4	31	23	31	42	34	33
A	...	0	11	10	0	2	0	1	10	11	22	14	41	52	32
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Custo

- 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 $O(n^2)$.
- Usando três matrizes $H_{i,j}$, $E_{i,j}$ e $F_{i,j}$.
- Aplicando em todas as matrizes, a mesma função H^*.