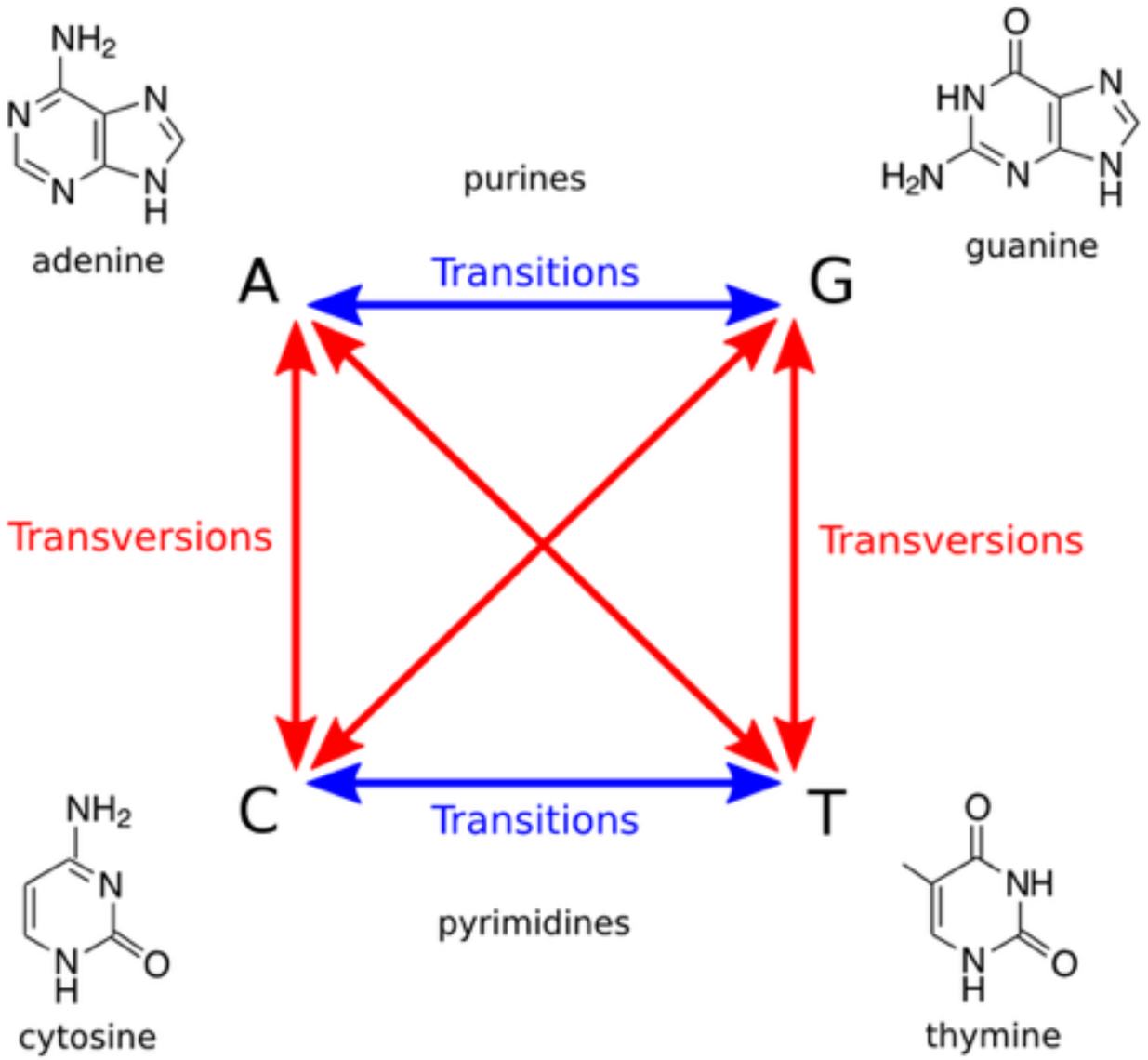
		Y							
		ϵ	G	C	T	A	T	A	C
X	ϵ	0	1	2	3	4	5	6	7
	G	1	0	1	2	3	4	5	6
	C	2	1	0	1	2	3	4	5
	G	3	1	1	1	2	3	4	5
	T	4	2	2	1	2	3	4	5
	A	5	3	3	2	1	2	3	4
	T	6	4	4	3	2	1	2	3
	G	7	5	5	4	3	2	2	3
	C	8	6	5	5	4	3	3	2



Human *transition to transversion ratio* (AKA *ti/tv*) is ~2.1

```
G G G T A G C G G G T T T A A C
| | | | |   | | | | | | | | | |
G G G T A A C G G G T T T A A C
```

Human substitution rate ≈ 1 in 1,000

```
G G G T A G C G G G T T T A A C
| | | | |     | | | | | | | | |
G G G T A - - G G G T T T A A C
```

Small-gap rate is ≈ 1 in 3,000

Penalty matrix

	A	C	G	T	-
A	0	4	2	4	8
C	4	0	4	2	8
G	2	4	0	4	8
T	4	2	4	0	8
-	8	8	8	8	

2 *Transitions* (A↔G, C↔T)

4 *Transversions*

8 *Gaps*

$$\texttt{edist}(\alpha x, \beta y) = \min \begin{cases} \texttt{edist}(\alpha, \beta) + \delta(x, y) \\ \texttt{edist}(\alpha x, \beta) + 1 \\ \texttt{edist}(\alpha, \beta y) + 1 \end{cases}$$

$$\texttt{galign}(\alpha x, \beta y) = \min \begin{cases} \texttt{galign}(\alpha, \beta) + p(x, y) \\ \texttt{galign}(\alpha x, \beta) + p(x, -) \\ \texttt{galign}(\alpha, \beta y) + p(-, y) \end{cases}$$

Use penalty matrix

Global alignment

	ϵ	T	A	T	G	T	C	A	T	G	C
ϵ	0	8	16	24	32	40	48	56	64	72	80
T	8	0	8	16	24	32	40	48	56	64	72
A	16	8	0	8	16	24	32	40	48	56	64
C	24	16	8	2	10	18	24	32	40	48	56
G	32	24	16	10	2	10	18	26	34	40	48
T	40	32	24	16	10	2	10	18	26	34	42
C	48	40	32	24	18	10	2	10	18	26	34
A	56	48	40	32	26	18	10	2	10	18	26
G	64	56	48	40	32	26	18	10	6	10	18
C	72	64	56	48	40	34	26	18	12	10	10

	A	C	G	T	-
A	0	4	2	4	8
C	4	0	4	2	8
G	2	4	0	4	8
T	4	2	4	0	8
-	8	8	8	8	

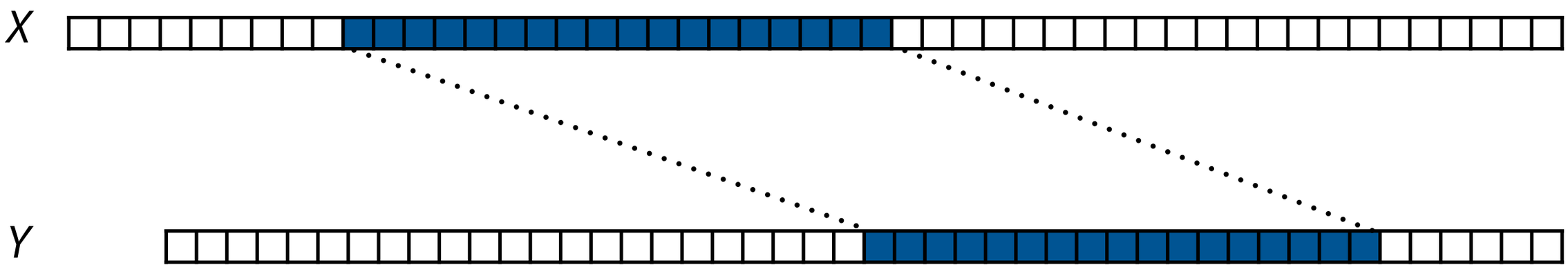
Global alignment

	ϵ	T	A	T	G	T	C	A	T	G	C
ϵ	0	8	16	24	32	40	48	56	64	72	80
T	8	0	8	16	24	32	40	48	56	64	72
A	16	8	0	8	16	24	32	40	48	56	64
C	24	16	8	2	10	18	24	32	40	48	56
G	32	24	16	10	2	10	18	26	34	40	48
T	40	32	24	16	10	2	10	18	26	34	42
C	48	40	32	24	18	10	2	10	18	26	34
A	56	48	40	32	26	18	10	2	10	18	26
G	64	56	48	40	32	26	18	10	6	10	18
C	72	64	56	48	40	34	26	18	12	10	8

	A	C	G	T	-
A	0	4	2	4	8
C	4	0	4	2	8
G	2	4	0	4	8
T	4	2	4	0	8
-	8	8	8	8	

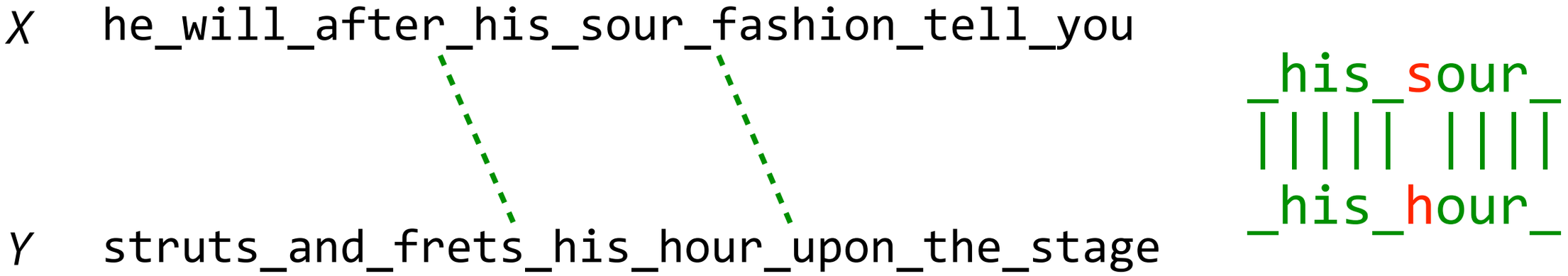
Local alignment

Find the most similar *pair of substrings* from X and Y



Local alignment

Find the most similar *pair of substrings* from X and Y



$$\texttt{lalign}(\alpha\mathrm{x}, \beta\mathrm{y}) = \max \begin{cases} \texttt{lalign}(\alpha, \beta) + s(\mathrm{x}, \mathrm{y}) \\ \texttt{lalign}(\alpha\mathrm{x}, \beta) + s(\mathrm{x}, \text{-}) \\ \texttt{lalign}(\alpha, \beta\mathrm{y}) + s(\text{-}, \mathrm{y}) \\ 0 \end{cases}$$

Scoring matrix: matches are positive, differences negative

	A	C	G	T	-
A	2	-4	-4	-4	-6
C	-4	2	-4	-4	-6
G	-4	-4	2	-4	-6
T	-4	-4	-4	2	-6
-	-6	-6	-6	-6	

Y

X		ϵ	T	A	T	A	T	G	C	G	G	C	G	T	T	T
	ϵ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	G	0	0	0	0	0	0	2	0	2	2	0	2	0	0	0
	G	0	0	0	0	0	0	2	0	2	4	0	2	0	0	0
	T	0	2	0	2	0	2	0	0	0	0	0	0	4	2	2
	A	0	0	4	0	4	0	0	0	0	0	0	0	0	0	0
	T	0	2	0	6	0	6	0	0	0	0	0	0	2	2	2
	G	0	0	0	0	2	0	8	2	2	2	0	2	0	0	0
	C	0	0	0	0	0	0	2	10	4	0	4	0	0	0	0
	T	0	2	0	2	0	2	0	4	6	0	0	0	2	2	2
	G	0	0	0	0	0	0	4	0	6	8	2	2	0	0	0
	G	0	0	0	0	0	0	2	0	2	8	4	4	0	0	0
	C	0	0	0	0	0	0	0	4	0	2	10	4	0	0	0
	G	0	0	0	0	0	0	2	0	6	2	4	12	6	0	0
	C	0	0	0	0	0	0	0	4	0	2	4	6	8	2	0
	T	0	2	0	2	0	2	0	0	0	0	0	0	8	10	4
	A	0	0	4	0	4	0	0	0	0	0	0	0	2	4	6

Y

		ϵ	T	A	T	A	T	G	C	G	G	C	G	T	T	T
	ϵ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	G	0	0	0	0	0	0	2	0	2	2	0	2	0	0	0
	G	0	0	0	0	0	0	2	0	2	4	0	2	0	0	0
	T	0	2	0	2	0	2	0	0	0	0	0	0	4	2	2
	A	0	0	4	0	4	0	0	0	0	0	0	0	0	0	0
	T	0	2	0	6	0	6	0	0	0	0	0	0	2	2	2
	G	0	0	0	0	2	0	8	2	2	2	0	2	0	0	0
	C	0	0	0	0	0	0	2	10	4	0	4	0	0	0	0
X	T	0	2	0	2	0	2	0	4	6	0	0	0	2	2	2
	G	0	0	0	0	0	0	4	0	6	8	2	2	0	0	0
	G	0	0	0	0	0	0	2	0	2	6	4	4	0	0	0
	C	0	0	0	0	0	0	0	4	0	2	10	4	0	0	0
	G	0	0	0	0	0	0	2	0	6	2	4	12	6	0	0
	C	0	0	0	0	0	0	0	4	0	2	4	6	8	2	0
	T	0	2	0	2	0	2	0	0	0	0	0	0	8	10	4
	A	0	0	4	0	4	0	0	0	0	0	0	0	2	4	6

```
Y T A T G C - G G C G
  | | | | |   | | | |
X T A T G C T G G C G
```