

$$S = \left(\begin{array}{c|ccccc} & \text{sent signal} & & & & \\ \text{intention} \downarrow & 1\text{kHz} & 2\text{kHz} & 3\text{kHz} & 4\text{kHz} & 5\text{kHz} \\ \hline \textit{eagle} & 1.0 & 0.0 & 0.0 & 0.0 & 0.0 \\ \textit{snake} & 0.0 & 0.0 & 1.0 & 0.0 & 0.0 \\ \textit{tiger} & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 \end{array} \right)$$

$$R = \left(\begin{array}{c|ccc} & \text{interpretation} & & \\ \text{received signal} \downarrow & \textit{eagle} & \textit{snake} & \textit{tiger} \\ \hline 1\text{kHz} & 1.0 & 0.0 & 0.0 \\ 2\text{kHz} & 1.0 & 0.0 & 0.0 \\ 3\text{kHz} & 0.0 & 1.0 & 0.0 \\ 4\text{kHz} & 0.0 & 0.0 & 1.0 \\ 5\text{kHz} & 0.0 & 0.0 & 1.0 \end{array} \right)$$

$$U = \left(\begin{array}{c|ccccc} & \text{received signal} & & & & \\ \text{sent signal } \downarrow & 1\text{kHz} & 2\text{kHz} & 3\text{kHz} & 4\text{kHz} & 5\text{kHz} \\ \hline 1\text{kHz} & 0.7 & 0.2 & 0.1 & 0.0 & 0.0 \\ 2\text{kHz} & 0.2 & 0.6 & 0.2 & 0.0 & 0.0 \\ 3\text{kHz} & 0.0 & 0.2 & 0.6 & 0.2 & 0.0 \\ 4\text{kHz} & 0.0 & 0.0 & 0.2 & 0.6 & 0.2 \\ 5\text{kHz} & 0.0 & 0.0 & 0.1 & 0.2 & 0.7 \end{array} \right)$$

The “communicative accuracy” (payoff, fitness) is given by:

$$F(L, L') = \frac{1}{2} \sum_{m=1}^M \sum_{f=1}^F \left[S_{mf} \left(\sum_{f'=1}^F U'_{ff'} R'_{f'm} \right) + S'_{mf} \left(\sum_{f'=1}^F U_{ff'} R_{f'm} \right) \right]$$

Nowak & Krakauer (1999) show that the maximum fitness of phonemically coded languages is higher.

- However, crucial is that there is a path of *ever increasing fitness* from non-phonemic (L^-) to phonemic (L^+) languages. I.e.

$$F(L^+, L^+) > F(L^+, L^-) > F(L^-, L^-).$$

N & K further show that for every mixed strategies, more phonemically coded languages will always do better.

$$S = \left(\begin{array}{c|cccccc} & \text{sent signal} & & & & & \\ \text{intention} \downarrow & a & b & c & ab & cd & ef \\ \hline \text{eagle} & 1-x & 0.0 & 0.0 & x & 0.0 & 0.0 \\ \text{snake} & 0.0 & 1-x & 0.0 & 0.0 & x & 0.0 \\ \text{tiger} & 0.0 & 0.0 & 1-x & 0.0 & 0.0 & x \end{array} \right)$$

$$U = \left(\begin{array}{c|cccccc} & \text{received signal} & & & & & \\ \text{sent signal} \downarrow & a & b & c & ab & cd & ef \\ \hline a & low & h & h & 0 & 0 & 0 \\ b & h & low & h & 0 & 0 & 0 \\ c & h & h & low & 0 & 0 & 0 \\ ab & 0 & 0 & 0 & high & l & l \\ cd & 0 & 0 & 0 & l & high & l \\ ef & 0 & 0 & 0 & l & l & high \end{array} \right)$$

- However, cost of additional system (memory, confusion) and temporal dimension of holistic signals are completely ignored.