S1 Appendix

S1.A Algorithm. Parsing the sequence with the ddHCRP as both a generative and recognition model. We use the ddHCRP back-off procedure to obtain the probability of a customer corresponding to the key press, and to update the ddHCRP seating arrangements probabilistically with a new customer corresponding to the actual event (i.e. the instruction that differs from the key press in the case of errors).

- \( \mathbf{e} \): vector of all events
- \( \mathbf{k} \): vector of all key presses
- \( \mathbf{c} \): vector of customer seating arrangement
- \( \mathbf{\alpha} \): vector of HCRP strength values
- \( \mathbf{\lambda} \): vector of HCRP decay rate values
- \( N \): maximum context depth

procedure \textsc{Parse}(\mathbf{e}, \mathbf{k}, \mathbf{c}, \mathbf{\alpha}, \mathbf{\lambda})

\[
\begin{align*}
P & \leftarrow \emptyset \\
t & \leftarrow 0 \\
\text{while } t < |\mathbf{e}| \text{ do} & \\
& \quad \text{if } t==0 \text{ then} \\
& \quad \quad \mathbf{u} \leftarrow \emptyset \\
& \quad \text{else} \\
& \quad \quad \text{left } \leftarrow \max(0, t - N) \\
& \quad \quad \text{right } \leftarrow t - 1 \\
& \quad \quad \mathbf{u} \leftarrow \mathbf{e}_{\text{left:right}} \\
& \quad \text{end if} \\
& \quad P \leftarrow \textsc{CustomerProb}(\mathbf{u}, \mathbf{k}_t, t, \mathbf{c}, \mathbf{\alpha}, \mathbf{\lambda}) \Rightarrow \text{append key press prob. computed by SLB Algorithm.} \\
& \quad \mathbf{c} \leftarrow \textsc{AddCustomer}(\mathbf{u}, \mathbf{e}_t, t, \mathbf{c}, \mathbf{\alpha}, \mathbf{\lambda}) \Rightarrow \text{update seating arrangement by SLC Algorithm.} \\
& \quad t \leftarrow t + 1 \\
& \text{end while} \\
& \text{return } P \\
\end{align*}
\]

end procedure
S1.B Algorithm. Generative process of the ddHCRP: computing the probability of an observation via the back-off procedure.

\[ u \]: vector of previous events (context)
\[ l \]: label of the observation
\[ L \]: number of all labels
\[ t \]: trial
\[ c \]: vector of customer seating arrangement
\[ \alpha \]: vector of HCRP strength values
\[ \lambda \]: vector of HCRP decay rate values
\[ n \]: HCRP level

**function** \( \text{CUSTOMERPROB}(u, l, t, c, \alpha, \lambda, n=None) \)

- **if** \( n=\text{None} \) **then**
  - \( n \leftarrow |u| + 1 \)
  - **▷** start back-off procedure from level \( n \)

- **end if**

- **if** \( n=0 \) **then**
  - return \( 1/L \)
  - **▷** uninformed base distribution

- **else**
  - \( C_u \leftarrow |u| \)
    - **▷** number of customers with dish \( l \) in restaurant \( u \)
  - \( old \leftarrow \sum_{i=0}^{C_u} e^{-\delta_{ui} \lambda} \)
    - **▷** weighted sum of recency of customers with dish \( l \) in restaurant \( u \)
  - \( new \leftarrow \alpha_u \)
    - **▷** prior strength of level
  - \( norm \leftarrow \alpha_u + \sum_{i=0}^{C_u} e^{-\delta_{ui} \lambda} \)
  - **return** \( \frac{old}{norm} + \frac{new}{norm} \times \text{CUSTOMERPROB}(\pi(u), l, t, c, \alpha, \lambda, n-1) \)
    - **▷** back off to level below

- **end if**

**end function**
S1.C Algorithm. Recognition process of the ddHCRP: update the HCRP seating arrangements with new observation.

\[ u: \text{vector of previous events (context)} \]
\[ l: \text{label of the observation} \]
\[ t: \text{trial} \]
\[ c: \text{vector of customer seating arrangement} \]
\[ \alpha: \text{vector of HCRP strength values} \]
\[ \lambda: \text{vector of HCRP decay rate values} \]
\[ n: \text{HCRP level} \]

**procedure ADD_CUSTOMER(u, l, t, c, \alpha, \lambda, n=None)**

*if* \( n=None \) *then*

\[ n \leftarrow |u| + 1 \quad \triangleright \text{start back-off procedure from level } n \]

*end if*

*if* \( n=0 \) *then*

\[ \text{return } c \quad \triangleright \text{backed off to level } 0 \]

*else*

\[ C_{ul} \leftarrow |c_{ul}| \quad \triangleright \text{number of previous customers with dish } l \text{ in restaurant } u \]

\[ c_{ul} \leftarrow \langle t \rangle \quad \triangleright \text{append customer timestamp to vector of customers with dish } l \text{ in restaurant } u \]

\[ \text{With probabilities proportional to:} \]
\[ \sum_{i=0}^{C_{ul}} e^{-\delta_{ul}^i} \quad \triangleright \text{weighted sum of recency of previous customers with dish } l \text{ in restaurant } u \]

\[ \text{return } c \quad \triangleright \text{terminate back-off} \]

\[ \alpha_{ul} \times \text{CUSTOMER_PROB}(\pi(u), l, t, c, \alpha, \lambda, n-1): \quad \triangleright \text{weighted label probability on level below} \]

*end if*

*end procedure*