

$$\sigma(x) = \frac{1}{1+e^x}$$

$$\begin{aligned} \frac{\partial \sigma}{\partial x}(x) &= \frac{\partial}{\partial x} \left(\frac{e^x}{1+e^x} \right) = \frac{(1+e^x)e^x - e^x(e^x)}{(1+e^x)^2} = \left(\frac{e^x}{1+e^x} \right) \left(\frac{1-e^x+e^x}{(1+e^x)} \right) \\ &= \sigma(x) \left(\frac{1+e^x}{1+e^x} - \frac{e^x}{(1+e^x)} \right) = \sigma(x)(1-\sigma(x)) \end{aligned}$$

Thus $\frac{\partial \sigma(x)}{\partial x}(x) = \sigma(x)(1-\sigma(x))$.

Objective function:

$$\arg \max_{V_c, V_w} = \Sigma_{(w,c) \in D} \log(\sigma(\langle v_c, v_w \rangle)) + \Sigma_{(w,c) v \in D'} \log(\sigma(-\langle v_c, v_w \rangle))$$

$$\nabla_{v_c} (\langle v_c, v_w \rangle)_k = \frac{\partial}{\partial (v_c)_k} \sum_i (v_c)_i (v_w)_i = \frac{\partial}{\partial (v_c)_k} \left(\sum_{i \neq k} (v_c)_i (v_w)_i + (v_c)_k (v_w)_k \right) = (v_w)_k$$

by symmetry, the gradient $\nabla_{v_w} \langle v_c, v_w \rangle$ is v_c . Let $B \in \mathbb{R}^{n \times m}$.

$$\nabla_B (\langle v_c, v_w \rangle_B)_{kl} = \frac{\partial}{\partial B_{kl}} \sum_{ij} B_{ij} (v_c)_i (v_w)_j =$$

$$\frac{\partial}{\partial B_{kl}} \left(\sum_{i,j \neq k} (v_c)_i (v_w)_j + B_{kl} (v_c)_k (v_w)_l \right) = (v_c)_l (v_w)_k = (v_c \otimes v_w)_{kl}$$

Then the gradient of $\log(\sigma(\langle v_c, v_w \rangle))$ with respect to v_c is

$$\begin{aligned} \frac{\partial}{\partial (v_c)_k} (\log(\sigma(\langle v_c, v_w \rangle))) &= \left(\frac{1}{\sigma(\langle v_c, v_w \rangle)} \right) (\sigma(\langle v_c, v_w \rangle) (1 - \sigma(\langle v_c, v_w \rangle))) (v_w)_k \\ &= (1 - \sigma(\langle v_c, v_w \rangle)) (v_w)_k \end{aligned}$$

again by symmetry we can show that the gradient with respect to v_w is similarly $\nabla_{v_w} (\log(\sigma(\langle v_c, v_w \rangle))) = (1 - \sigma(\langle v_c, v_w \rangle)) v_c$

Let $P \in \mathbb{R}^{n \times n}$ and $U, V \in \mathbb{R}^{n \times d}$ and let $f = \|P - UV^T\|_F^2$

$$\begin{aligned}
(\nabla_U f)_{ij} &= \frac{\partial}{\partial U_{ij}} \|P - UV^T\|_F^2 = \frac{\partial}{\partial U_{ij}} \left(\sum_{i_1, i_2=1}^n (P_{i_1, i_2} - \sum_{i_3=1}^d U_{i_1, i_3} V_{i_3, i_2}^T)^2 \right) \\
&= \frac{\partial}{\partial U_{ij}} \left(\left[\sum_{i_1 \neq i, i_2=1}^n (P_{i_1, i_2} - \sum_{i_3=1}^d U_{i_1, i_3} V_{i_3, i_2}^T)^2 \right] + (P_{i, i_2} - \sum_{i_3=1}^d U_{i, i_3} V_{i_3, i_2}^T)^2 \right) \\
&= \frac{\partial}{\partial U_{ij}} \sum_{i_2=1}^n (P_{i, i_2} - \sum_{i_3=1}^d U_{i, i_3} V_{i_3, i_2}^T)^2 \\
&= \sum_{i_2=1}^n 2(P_{i, i_2} - \sum_{i_3=1}^d U_{i, i_3} V_{i_3, i_2}^T) \frac{\partial}{\partial U_{ij}} (P_{i, i_2} - \sum_{i_3=1}^d U_{i, i_3} V_{i_3, i_2}^T) \\
&= \sum_{i_2=1}^n 2(P_{i, i_2} - \sum_{i_3=1}^d U_{i, i_3} V_{i_3, i_2}^T) (V_{j, i_2}^T) \\
&= \sum_{i_2=1}^n 2(P_{i, i_2} - (UV^T)_{i, i_2}) (V_{i_2, j}) = 2(PV - UV^T V)_{ij} \\
(\nabla_V f)_{ij} &= \frac{\partial}{\partial V_{ij}} \|P - UV^T\|_F^2 = \frac{\partial}{\partial V_{ij}} \|P^T - VU^T\|_F^2
\end{aligned}$$

Now note that by the generality of the last gradient computation we can show that $\nabla_V f = 2(P^T U - VU^T U)$.

Consider the function $g = \lambda \|U\|_F^2$ for $\lambda \in \mathbb{R}$, then the gradient with respect to U is

$$(\nabla_U g)_{ij} = \lambda \frac{\partial}{\partial U_{ij}} \left(\sum_{i_1, i_2=1}^{n, d} U_{i_1, i_2}^2 \right) = \lambda \frac{\partial}{\partial U_{ij}} \left(\left[\sum_{i_1 \neq i, i_2 \neq j}^{n, d} U_{i_1, i_2}^2 \right] + U_{ij}^2 \right) = 2\lambda U_{ij}$$

Let $P \in \mathbb{R}^{n \times n}$, $U \in \mathbb{R}^{n \times d}$, and $B \in \mathbb{R}^{d \times d}$. Consider the function $f : \mathbb{R}^{n \times n} \times \mathbb{R}^{n \times d} \times \mathbb{R}^{d \times d} \mapsto \mathbb{R}$ such that

$$f(P, U, B) = \|P - UBB^T U^T\|_F^2$$

useful gradients

$$\begin{aligned} & \frac{\partial}{\partial U_{ij}} \left(- \sum_{i_3, i_4}^{d, d} U_{i, i_3} C_{i_3, i_4} U_{i, i_4} \right) \\ &= - \frac{\partial}{\partial U_{ij}} \left(\sum_{i_3 \neq j, i_4}^{d, d} U_{i, i_3} C_{i_3, i_4} U_{i, i_4} + \sum_{i_4}^d U_{i, j} C_{j, i_4} U_{i, i_4} \right) \\ &= - \frac{\partial}{\partial U_{ij}} \left(\sum_{i_3 \neq j, i_4 \neq j}^{d, d} U_{i, i_3} C_{i_3, i_4} U_{i, i_4} + \sum_{i_3 \neq j}^d U_{i, i_3} C_{i_3, j} U_{i, j} + \sum_{i_4}^d U_{i, j} C_{j, i_4} U_{i, i_4} \right) \\ &= - \frac{\partial}{\partial U_{ij}} \left(\sum_{i_3 \neq j, i_4 \neq j}^{d, d} U_{i, i_3} C_{i_3, i_4} U_{i, i_4} + \sum_{i_3 \neq j}^d U_{i, i_3} C_{i_3, j} U_{i, j} + \sum_{i_4 \neq j}^d U_{i, j} C_{j, i_4} U_{i, i_4} + U_{i, j} C_{j, j} U_{i, j} \right) \\ &= - \frac{\partial}{\partial U_{ij}} \left(\sum_{i_3 \neq j}^d U_{i, i_3} C_{i_3, j} U_{i, j} + \sum_{i_4 \neq j}^d U_{i, j} C_{j, i_4} U_{i, i_4} + U_{i, j} C_{j, j} U_{i, j} \right) \\ &= - \left(\sum_{i_3 \neq j}^d U_{i, i_3} C_{i_3, j} + \sum_{i_4 \neq j}^d C_{j, i_4} U_{i, i_4} + 2U_{i, j} C_{j, j} \right) \\ &= - \left(\sum_{i_3}^d U_{i, i_3} C_{i_3, j} + \sum_{i_4}^d C_{j, i_4} U_{i, i_4} \right) = UC_{i, j} + CU_{ji}^T = UC_{i, j} + UC_{i, j}^T \end{aligned}$$

$$\frac{\partial}{\partial U_{ij}} \text{Tr}(UCU^T UCU^T)$$

Letting $C = BB^T$

$$\begin{aligned}
(\nabla_U f)_{ij} &= \frac{\partial}{\partial U_{ij}} \|P - UBB^T U^T\|_F^2 = \frac{\partial}{\partial U_{ij}} \|P - UCU^T\|_F^2 = \frac{\partial}{\partial U_{ij}} \sum_{i_1, i_2}^{n, n} (P_{i_1, i_2} - (UCU^T)_{i_1, i_2})^2 \\
&= \frac{\partial}{\partial U_{ij}} \sum_{i_1, i_2}^{n, n} (P_{i_1, i_2} - \sum_{i_3}^d (U_{i_1, i_3} (CU^T)_{i_3, i_2})^2 = \frac{\partial}{\partial U_{ij}} \sum_{i_1, i_2}^{n, n} (P_{i_1, i_2} - \sum_{i_3, i_4}^{d, d} U_{i_1, i_3} C_{i_3, i_4} U_{i_4, i_2}^T)^2 \\
&= \frac{\partial}{\partial U_{ij}} \sum_{i_1, i_2}^{n, n} (P_{i_1, i_2} - \sum_{i_3, i_4}^{d, d} U_{i_1, i_3} C_{i_3, i_4} U_{i_2, i_4})^2 \\
&= \frac{\partial}{\partial U_{ij}} ([\sum_{\substack{i_1, i_2 \\ \{i_1, i_2\} \neq i}}^{n, n} (P_{i_1, i_2} \sum_{i_3, i_4}^{d, d} U_{i_1, i_3} C_{i_3, i_4} U_{i_2, i_4})^2] \\
&\quad + [\sum_{i_2}^n (P_{i, i_2} - \sum_{i_3, i_4}^{d, d} U_{i, i_3} C_{i_3, i_4} U_{i_2, i_4})^2] + [\sum_{i_1}^n (P_{i_1, i} - \sum_{i_3, i_4}^{d, d} U_{i_1, i_3} C_{i_3, i_4} U_{i, i_4})^2]) \\
&= \frac{\partial}{\partial U_{ij}} ([\sum_{i_2}^n (P_{i, i_2} - \sum_{i_3, i_4}^{d, d} U_{i, i_3} C_{i_3, i_4} U_{i_2, i_4})^2] + [\sum_{i_1}^n (P_{i_1, i} - \sum_{i_3, i_4}^{d, d} U_{i_1, i_3} C_{i_3, i_4} U_{i, i_4})^2])
\end{aligned}$$

Note that each terms of the sum can be computed as

$$\begin{aligned}
&\frac{\partial}{\partial U_{ij}} \sum_{i_2}^n (P_{i, i_2} - \sum_{i_3, i_4}^{d, d} U_{i, i_3} C_{i_3, i_4} U_{i_2, i_4})^2 \\
&= \frac{\partial}{\partial U_{ij}} (\sum_{i_2 \neq i}^n (P_{i, i_2} - \sum_{i_3, i_4}^{d, d} U_{i, i_3} C_{i_3, i_4} U_{i_2, i_4})^2 + (P_{i, i} - \sum_{i_3, i_4}^{d, d} U_{i, i_3} C_{i_3, i_4} U_{i, i_4})^2) \\
&= \sum_{i_2 \neq i}^n 2(P_{i, i_2} - \sum_{i_3, i_4}^{d, d} U_{i, i_3} C_{i_3, i_4} U_{i_2, i_4})(-\sum_{i_4}^d C_{j, i_4} U_{i_2, i_4}) \\
&\quad + 2(P_{i, i} - \sum_{i_3, i_4}^{d, d} U_{i, i_3} C_{i_3, i_4} U_{i, i_4})(-\sum_{i_3}^d U_{i, i_3} C_{i_3, j} - \sum_{i_4}^d C_{j, i_4} U_{i, i_4}) \\
&= \sum_{i_2 \neq i}^n [2(P_{i, i_2} - UCU_{i, i_2}^T)(-CU_{j, i_2}^T)] + 2(P_{i, i} - UCU_{i, i}^T)(-UC_{i, j} - UC_{i, j}^T) \\
&= \sum_{i_2}^n [2(P_{i, i_2} - UCU_{i, i_2}^T)(-UC_{i_2, j}^T)] + 2(P_{i, i} - UCU_{i, i}^T)(-UC_{i, j})
\end{aligned}$$

$$\begin{aligned}
& \frac{\partial}{\partial U_{ij}} \sum_{i_1}^n (P_{i_1,i} - \sum_{i_3,i_4}^{d,d} U_{i_1,i_3} C_{i_3,i_4} U_{i,i_4})^2 \\
&= \sum_{i_1 \neq i}^n \left[\frac{\partial}{\partial U_{ij}} (P_{i_1,i} - \sum_{i_3,i_4}^{d,d} U_{i_1,i_3} C_{i_3,i_4} U_{i,i_4})^2 \right] + \frac{\partial}{\partial U_{ij}} (P_{i,i} - \sum_{i_3,i_4}^{d,d} U_{i,i_3} C_{i_3,i_4} U_{i,i_4})^2 \\
&= \sum_{i_1 \neq i}^n 2(P_{i_1,i} - \sum_{i_3,i_4}^{d,d} U_{i_1,i_3} C_{i_3,i_4} U_{i,i_4}) \left(- \sum_{i_3}^d U_{i_1,i_3} C_{i_3,j} \right) \\
&\quad + 2(P_{i,i} - \sum_{i_3,i_4}^{d,d} U_{i,i_3} C_{i_3,i_4} U_{i,i_4}) \left(- \left(\sum_{i_3}^d U_{i,i_3} C_{i_3,j} + \sum_{i_4}^d C_{j,i_4} U_{i,i_4} \right) \right) \\
&= \sum_{i_1 \neq i}^n [2(P_{i_1,i} - UCU_{i,i}^T)(-UC_{i_1,j})] + 2(P_{i,i} - UCU_{i,i}^T)(-UC_{i,j}^T - CU_{j,i}^T) \\
&= \sum_{i_1}^n [2(P_{i_1,i} - UCU_{i,i}^T)(-UC_{i_1,j})] + 2(P_{i,i} - UCU_{i,i}^T)(-CU_{j,i}^T)
\end{aligned}$$

plugging these back into the original computation we get

$$\begin{aligned}
&= \sum_{i_1}^n [2(P_{i_1,i} - UCU_{i,i}^T)(-UC_{i_1,j})] + \sum_{i_2}^n [2(P_{i,i_2} - UCU_{i,i_2}^T)(-UC_{i_2,j}^T)] \\
&\quad + 2(P_{i,i} - UCU_{i,i}^T)(-(UC_{i,j} + CU_{j,i}^T))
\end{aligned}$$