# VRKG4Rec: Virtual Relational Knowledge Graph for Recommendation

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**(WSDM-2023)** https://github.com/lulu0913/VRKG4Rec

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**Reported by Ke Gan**

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# Introduction

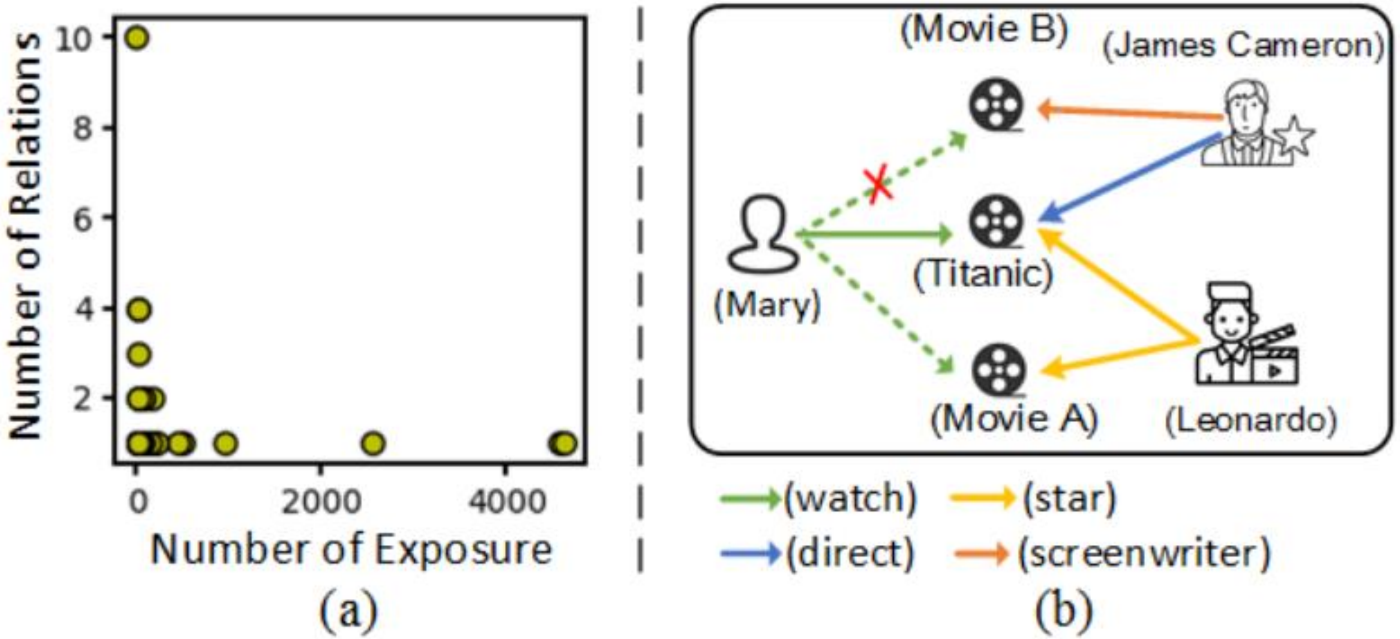



**Figure 1: Illustration of two kinds of motivations. (a)The long-tail relation distribution of Last.FM dataset. (b)An illustration example of necessity of considering the relevance of different relations**

# Approach

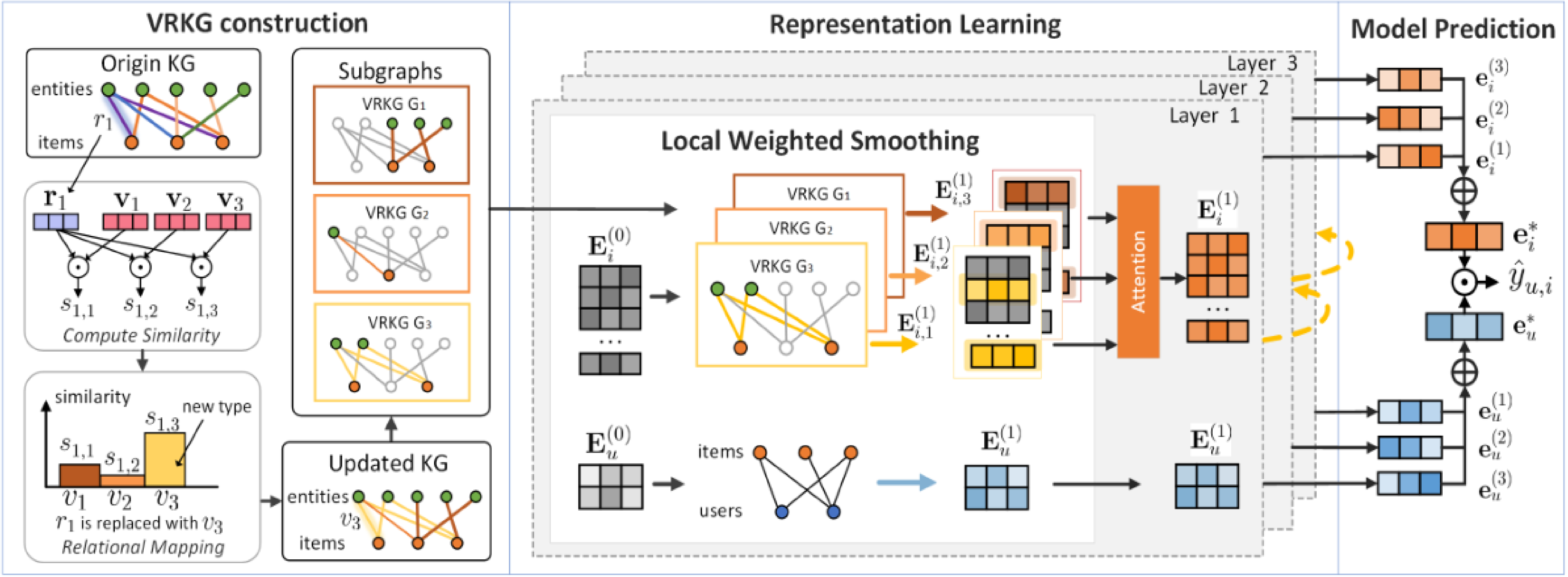



Figure 2: Overview of the proposed VRKG4Rec model

# Approach



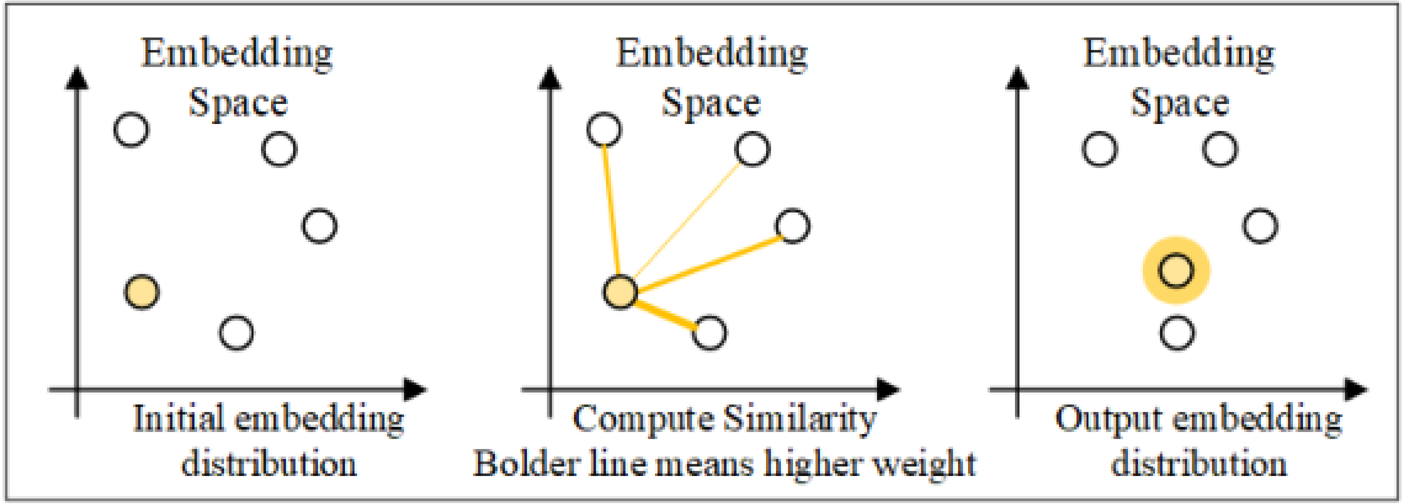
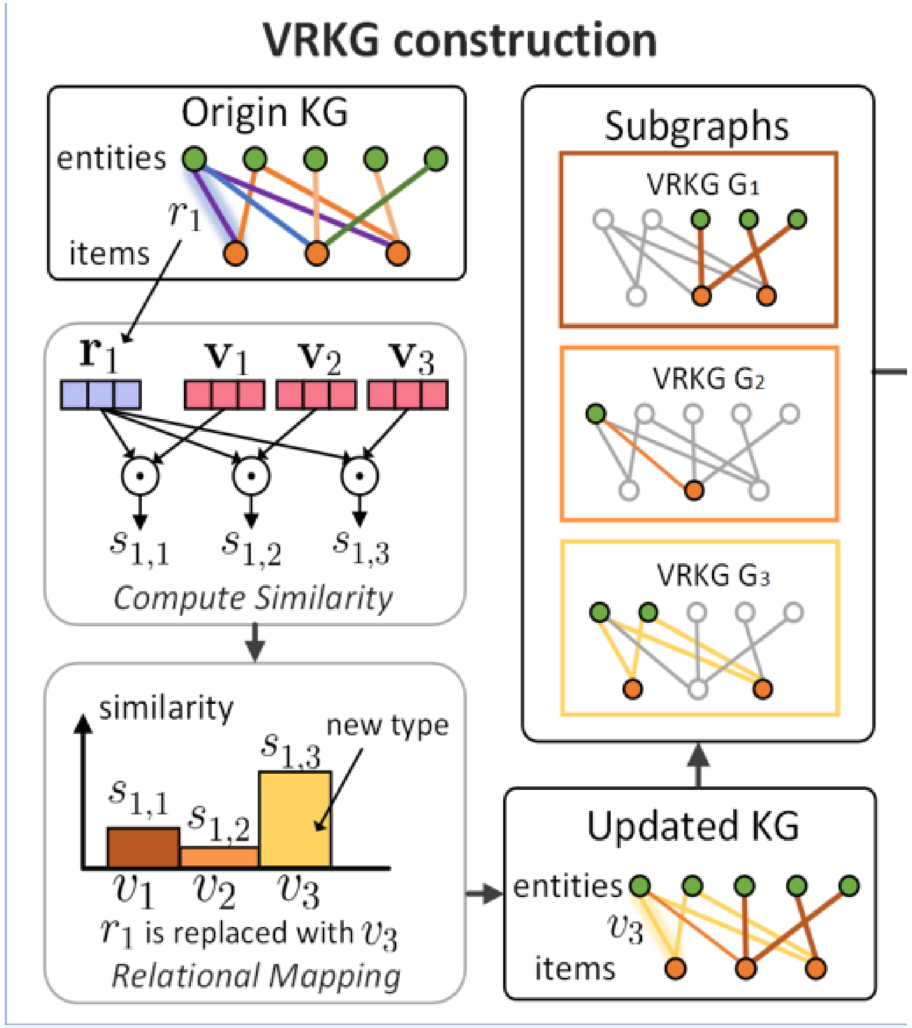



**Figure 3: Core operation of LWS with single iteration**

# Approach




$$\mathrm{V} = (\mathrm{v}_1, \mathrm{v}_2, \dots, \mathrm{v}_K)^{\top}, \tag{1}$$

$$\mathrm{s}_\mathrm{p} = (g(\mathrm{r}_\mathrm{p}, \mathrm{v}_1), g(\mathrm{r}_\mathrm{p}, \mathrm{v}_2), \dots, g(\mathrm{r}_\mathrm{p}, \mathrm{v}_K)) \tag{2}$$

$$g(\mathrm{r}_\mathrm{p}, \mathrm{v}_\mathrm{k}) = {\mathrm{r}_\mathrm{p}}^{\top} \mathrm{v}_\mathrm{k} \tag{3}$$

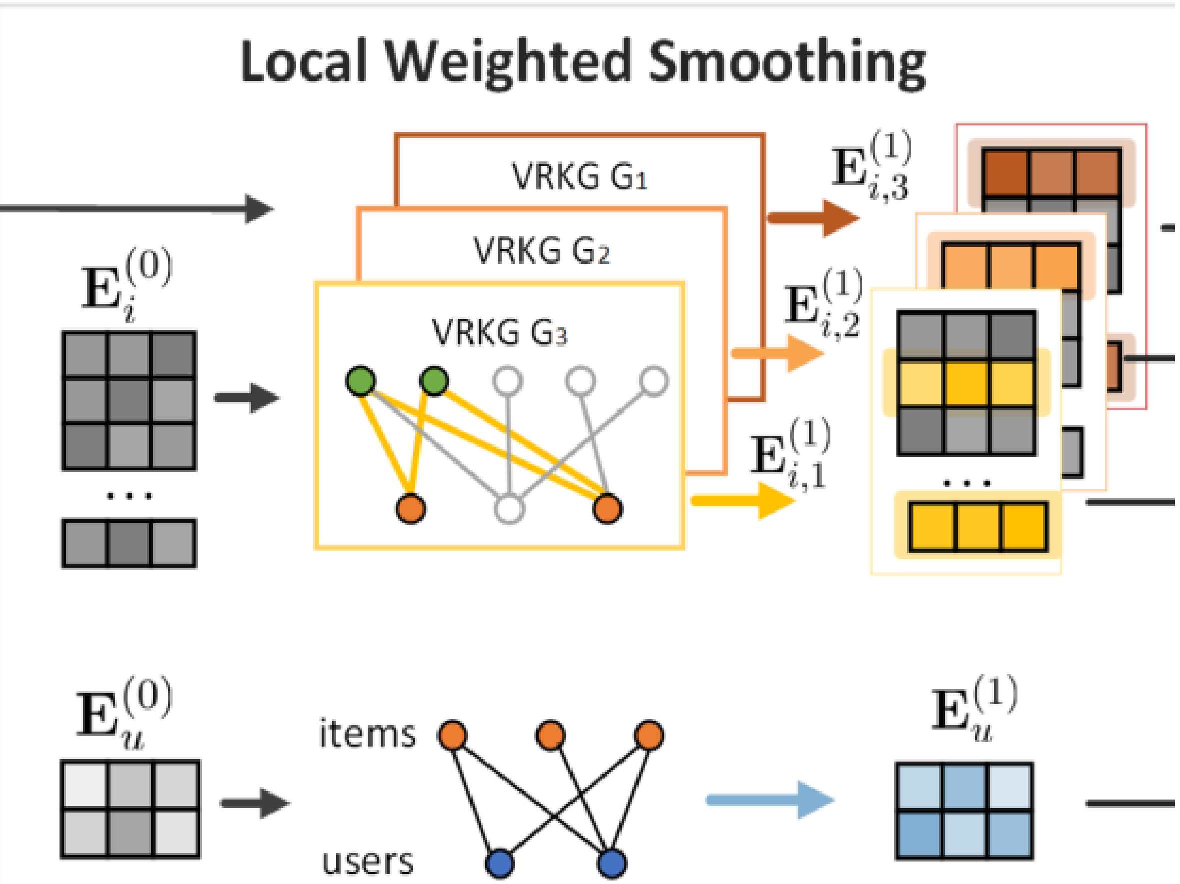
$$k' = \arg\max \mathrm{s}_\mathrm{p} \tag{4}$$

$$= \underset{k=1,2,\dots,K}{\arg\max} (g(\mathrm{r}_\mathrm{p}, \mathrm{v}_1), \dots, g(\mathrm{r}_\mathrm{p}, \mathrm{v}_\mathrm{k}), \dots) \tag{5}$$

$$(h, r_p, t) \leftarrow (h, v_{k'}, t). \tag{6}$$

$$\mathcal{G}_k = \{(h, r', t) \mid (h, r', t) \in \mathcal{G}', r' = v_k\}. \tag{7}$$

# Approach




$$e_{h,k}^{(1)} = f_{LWS}\left(\{(e_h^{(0)}, e_t^{(0)}) \mid t \in \mathcal{N}_k(h)\}\right), \tag{15}$$

$$e_{\mathcal{N}_k(h)}^{(0)} = \sum_{t \in \mathcal{N}_k(h)} \pi(h,t) e_t^{(0)}, \tag{8}$$

$$\pi(h,t) = e_h^{(0)\top} \cdot e_t^{(0)}, \tag{9}$$

$$u_h^{(1)} = \mathrm{AGG}(e_h^{(0)}, e_{\mathcal{N}_k(h)}^{(0)}) \tag{10}$$

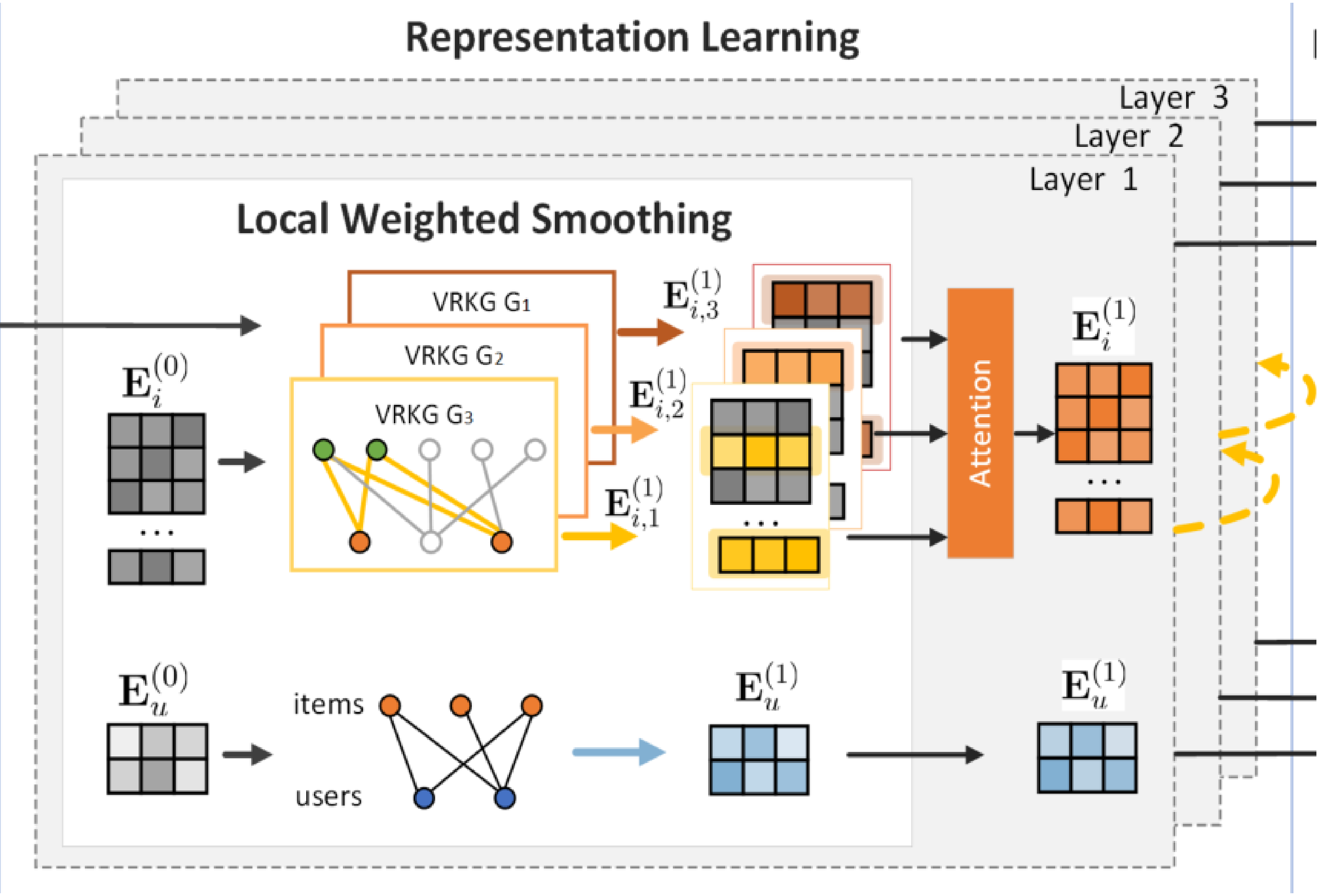
$$= \mathrm{NORM}(e_h^{(0)} + e_{\mathcal{N}_k(h)}^{(0)}), \tag{11}$$

$$\mathrm{NORM}(u) = \frac{u}{\|u\|} \cdot \frac{\|u\|^2}{\|u\|^2 + 1}, \tag{12}$$

$$u_{h,k}^{(1)} = f_{agg}\left(\{(e_h^{(0)}, e_t^{(0)}) \mid t \in \mathcal{N}_k(h)\}\right) \tag{13}$$

$$u_{h,k}^{(q)} = f_{agg}\left(\{(u_{h,k}^{(q-1)}, e_t^{(0)}) \mid t \in \mathcal{N}_k(h)\}\right), \tag{14}$$

# Approach




$$e_h^{(1)} = \alpha_1 e_{h,1}^{(1)} + \alpha_2 e_{h,2}^{(1)} + \ldots + \alpha_K e_{h,K}^{(1)} \tag{16}$$

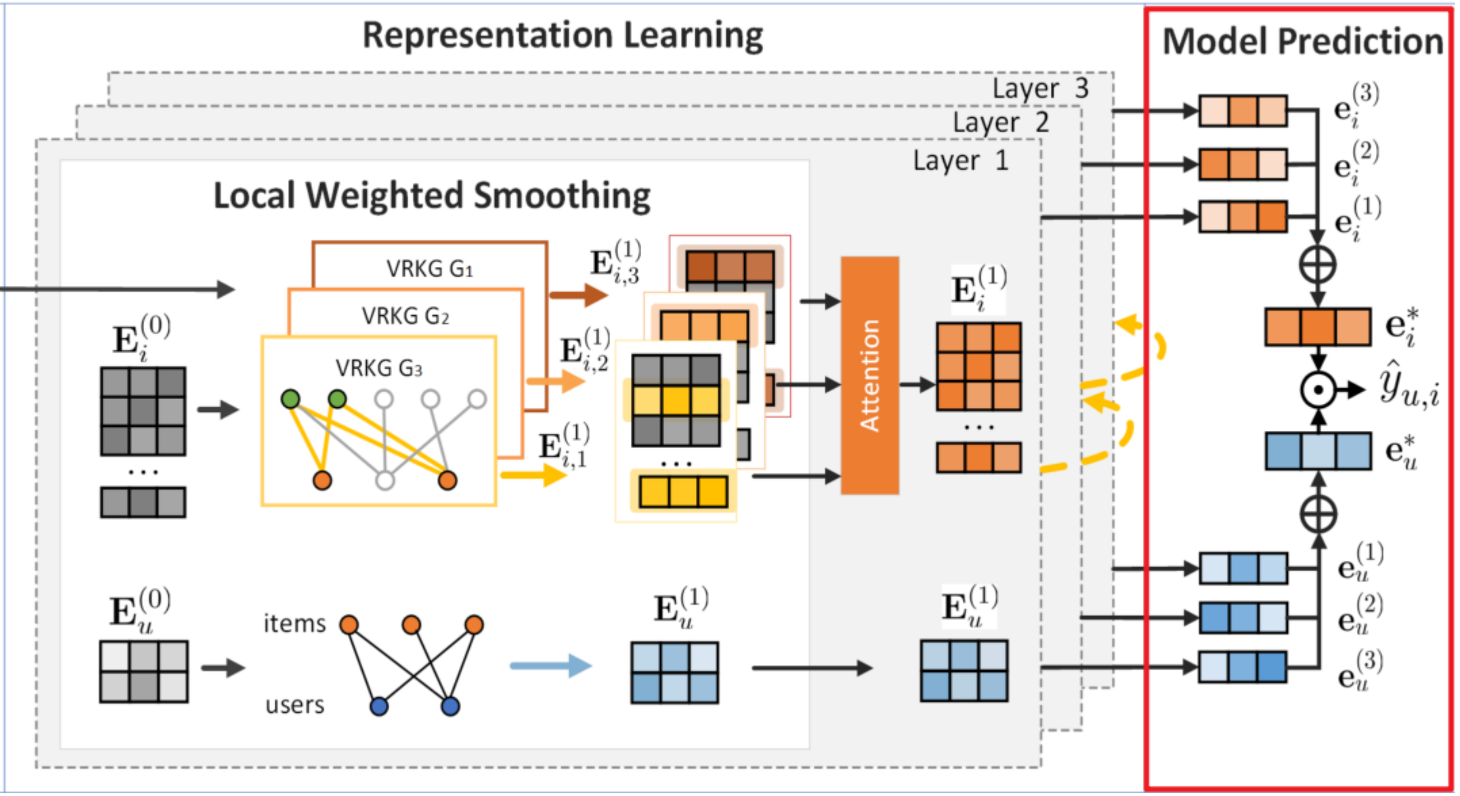
$$e_h^{(1)} = \sum_{k=1}^{K} \alpha_k f_{LWS}\left(\{(e_h^{(0)}, e_t^{(0)}) \mid t \in \mathcal{N}_k(h)\}\right), \tag{17}$$

$$e_h^{(l)} = \sum_{k=1}^{K} \alpha_k f_{LWS}\left(\{(e_h^{(l-1)}, e_t^{(l-1)}) \mid t \in \mathcal{N}_k(h)\}\right), \tag{18}$$

$$e_u^{(l)} = f_{LWS}\left(\{(e_u^{(l-1)}, e_i^{(l-1)}) \mid i \in \mathcal{N}(u)\}\right), \tag{19}$$

$$e_i^{(l)} = e_h^{(l)}$$

# Approach




$$e_u^* = e_u^{(0)} + \ldots + e_u^{(L)} \tag{20}$$

$$e_i^* = e_i^{(0)} + \ldots + e_i^{(L)} \tag{21}$$

$$\hat{y}_{ui} = e_u^{(*)\top} e_i^{(*)}. \tag{22}$$

$$\mathcal{L}_{BPR} = \sum_{(u,i,j)\in O} -\ln \sigma(\hat{y}_{ui} - \hat{y}_{uj}), \tag{23}$$

$$O = \{(u,i,j) \mid (u,i) \in O^+, (u,j) \in O^-\}$$

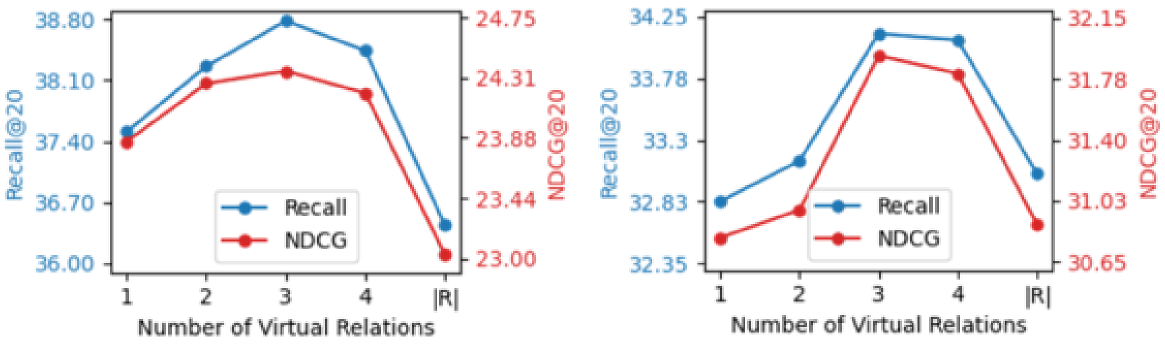
$$\mathcal{L} = \mathcal{L}_{BPR} + \lambda \|\Theta\|_2^2, \tag{24}$$

# Experiment

**Table 2: Overall comparison of performance**

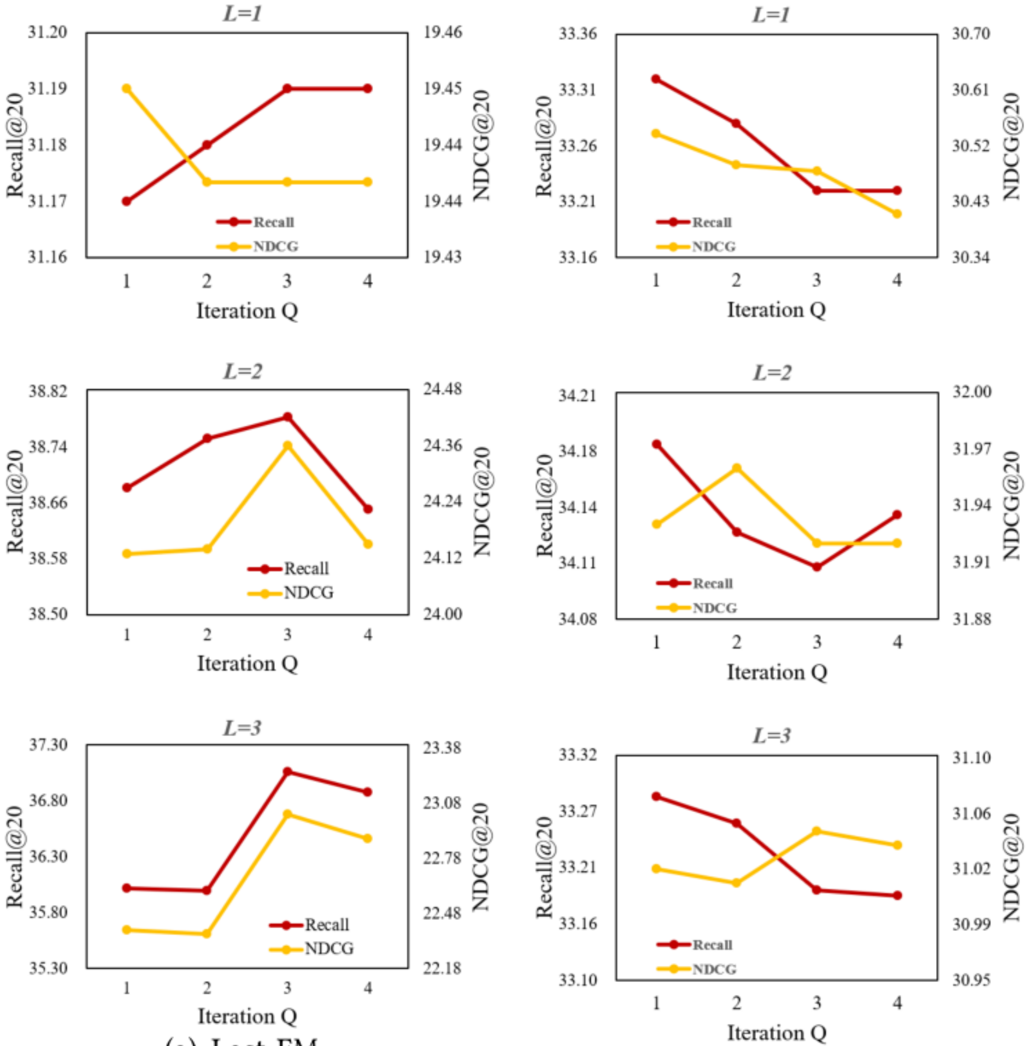
| Dateset | Model | *metric@1* (%) | | | *metric@5* (%) | | | *metric@10* (%) | | | *metric@20* (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | recall | NDCG | HR | recall | NDCG | HR | recall | NDCG | HR | recall | NDCG | HR |
| Last | FM | 1.93 | 4.40 | 4.40 | 5.33 | 4.67 | 12.80 | 8.83 | 6.07 | 19.40 | 14.02 | 7.72 | 28.01 |
| | NFM | 1.50 | 3.90 | 3.90 | 5.95 | 4.80 | 13.20 | 9.52 | 6.26 | 21.10 | 14.97 | 8.05 | 29.90 |
| | CKE | 4.43 | 10.31 | 10.31 | 13.06 | 11.26 | 26.58 | 18.85 | 13.62 | 35.02 | 26.95 | 16.25 | 46.11 |
| | KGAT | 2.42 | 5.67 | 5.67 | 7.86 | 9.49 | 16.76 | 12.56 | 12.58 | 25.92 | 20.59 | 16.71 | 37.67 |
| | KGIN | 6.06 | 13.98 | 13.98 | 17.42 | 15.24 | 35.92 | 24.96 | 18.32 | 47.07 | 35.49 | 21.69 | 59.07 |
| | proposed | **6.79** | **16.34** | **16.34** | **20.15** | **17.62** | **39.84** | **28.05** | **20.85** | **50.69** | **38.78** | **23.02** | **61.84** |
| | Improv. | +12.05% | +14.44% | +14.44% | +15.67% | +15.62% | +10.91% | +12.38% | +13.81% | +7.69% | +9.27% | +6.13% | +4.69% |
| ML | FM | 3.53 | 32.70 | 32.70 | 11.65 | 27.57 | 64.30 | 19.41 | 26.88 | 76.50 | 29.11 | 27.98 | 85.10 |
| | NFM | 2.98 | 27.70 | 27.70 | 11.62 | 24.88 | 62.40 | 17.88 | 23.80 | 74.40 | 27.59 | 24.84 | 84.30 |
| | CKE | 3.85 | 33.54 | 33.54 | 13.62 | 28.78 | 66.65 | 21.19 | 27.89 | 78.29 | 31.30 | 29.18 | 86.51 |
| | KGAT | 2.63 | 23.15 | 23.15 | 10.03 | 20.68 | 57.01 | 16.98 | 21.09 | 71.59 | 26.37 | 23.05 | 82.15 |
| | KGIN | **4.69** | 11.99 | 11.99 | **15.14** | 12.92 | 31.22 | 22.66 | 15.95 | 43.22 | 31.50 | 19.35 | 53.22 |
| | proposed | 4.29 | **36.74** | **36.74** | 15.01 | **31.38** | **70.13** | **23.29** | **30.53** | **80.55** | **34.12** | **31.92** | **88.34** |
| | Improv. | -8.69% | +9.54% | +9.54% | -0.85% | +9.03% | +5.22% | +2.78% | +9.47% | +2.89% | +8.31% | +9.39% | +2.12% |

# Experiment




(a) Last.FM (b) Moive-1M

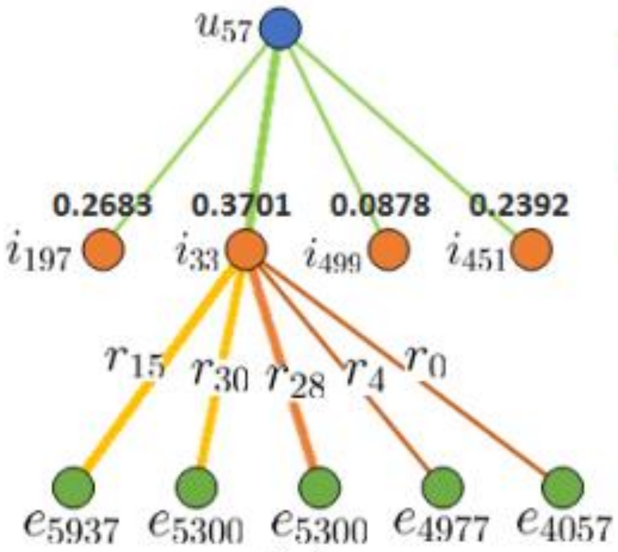
**Figure 4: Impact of VRKGs**




(a) Last-FM (b) Movie-1M

**Figure 5: Impact of iteration Q and Layer L**

# Experiment




(a)


(b)

| Virtual Relation | $V_0$ | $V_1$ | $V_2$ |
|---|---|---|---|
| Exposure Count | 14,145 | 12,493 | 4,398 |

(c)

# Thank you!