

# Variational Inference

Material adapted from David Blei University of Maryland EXERCISE

# Useful Reference: $\Psi(x)$

X	$\Psi(x)$
1	-0.577215664902
2	0.422784335098
3	0.922784335098
4	1.25611766843
5	1.50611766843
6	1.70611766843
7	1.8727843351
8	2.01564147796
9	2.14064147796

Also: from scipy.special import digamma

### Example

Three topics, same documents as last time

$$\beta = \begin{bmatrix} \text{cat} & \text{dog} & \text{hamburger} & \text{iron} & \text{pig} \\ .26 & .185 & .185 & .185 & .185 \\ .185 & .185 & .26 & .185 & .185 \\ .185 & .185 & .185 & .26 & .185 \end{bmatrix}$$
 (1)

- Assume uniform γ: (2.0, 2.0, 2.0)
- Compute update for  $\phi$

$$\phi_{ni} \propto \beta_{iv} \exp\left(\Psi(\gamma_i) - \Psi\left(\sum_j \gamma_j\right)\right)$$
 (2)

• For a the first word (dog) in the document: dog cat cat pig

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$$\beta = \begin{bmatrix} \text{cat} & \text{dog} & \text{hamburger} & \text{iron} & \text{pig} \\ .26 & .185 & .185 & .185 & .185 \\ .185 & .185 & .26 & .185 & .185 \\ .185 & .185 & .185 & .26 & .185 \end{bmatrix}$$
 (1)

- Assume uniform γ: (2.0, 2.0, 2.0)
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$$\phi_{ni} \propto \beta_{iv} \exp\left(\Psi(\gamma_i) - \Psi\left(\sum_j \gamma_j\right)\right)$$
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For a the first word (dog) in the document: dog cat cat pig

$$\beta = \left[ \begin{array}{ccccc} \text{cat} & \text{dog} & \text{hamburger} & \text{iron} & \text{pig} \\ .26 & .185 & .185 & .185 & .185 \\ .185 & .185 & .26 & .185 & .185 \\ .185 & .185 & .185 & .26 & .185 \end{array} \right] \qquad \qquad \begin{matrix} \phi_{\textit{ni}} \propto \\ \beta_{\textit{lv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right)$$

 $\gamma = (2.000, 2.000, 2.000)$ 

$$\beta = \left[ \begin{array}{ccccc} \text{cat} & \text{dog} & \text{hamburger} & \text{iron} & \text{pig} \\ .26 & .185 & .185 & .185 & .185 \\ .185 & .185 & .26 & .185 & .185 \\ .185 & .185 & .185 & .26 & .185 \end{array} \right] \qquad \qquad \begin{matrix} \phi_{\textit{ni}} \propto \\ \beta_{\textit{lv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right)$$

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- $\phi(0) \propto 0.185 \times \exp(\Psi(2.000) \Psi(2.000 + 2.000 + 2.000)) = 0.051$

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- After normalization: {0.333, 0.333, 0.333}

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- After normalization: {0.333, 0.333, 0.333}

$$\beta = \left[ \begin{array}{ccccc} \text{cat} & \text{dog} & \text{hamburger} & \text{iron} & \text{pig} \\ .26 & .185 & .185 & .185 & .185 \\ .185 & .185 & .26 & .185 & .185 \\ .185 & .185 & .185 & .26 & .185 \end{array} \right] \qquad \qquad \begin{matrix} \phi_{\textit{ni}} \propto \\ \beta_{\textit{lv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right)$$

 $\gamma = (2.000, 2.000, 2.000)$ 

$$\beta = \left[ \begin{array}{ccccc} \text{cat} & \text{dog} & \text{hamburger} & \text{iron} & \text{pig} \\ .26 & .185 & .185 & .185 & .185 \\ .185 & .185 & .26 & .185 & .185 \\ .185 & .185 & .185 & .26 & .185 \end{array} \right] \qquad \qquad \begin{matrix} \phi_{\textit{ni}} \propto \\ \beta_{\textit{lv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \beta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \\ \theta_{\textit{nv}} \exp \left( \Psi(\gamma_{\textit{l}}) - \Psi \left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right)$$

- $\gamma = (2.000, 2.000, 2.000)$
- $\phi(0) \propto 0.260 \times \exp(\Psi(2.000) \Psi(2.000 + 2.000 + 2.000)) = 0.072$

$$\beta = \left[ \begin{array}{ccccc} \text{cat} & \text{dog} & \text{hamburger} & \text{iron} & \text{pig} \\ .26 & .185 & .185 & .185 & .185 \\ .185 & .185 & .26 & .185 & .185 \\ .185 & .185 & .185 & .26 & .185 \end{array} \right] \qquad \qquad \begin{matrix} \phi_{\textit{ni}} \propto \\ \beta_{\textit{lv}} \exp \left( \Psi(\gamma_{\textit{i}}) - \Psi\left( \sum_{\textit{j}} \gamma_{\textit{j}} \right) \right) \end{matrix}$$

- $\gamma = (2.000, 2.000, 2.000)$
- $\phi(0) \propto 0.260 \times \exp(\Psi(2.000) \Psi(2.000 + 2.000 + 2.000)) = 0.072$
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$$\beta = \left[ \begin{array}{ccccc} \text{cat} & \text{dog} & \text{hamburger} & \text{iron} & \text{pig} \\ .26 & .185 & .185 & .185 & .185 \\ .185 & .185 & .26 & .185 & .185 \\ .185 & .185 & .185 & .26 & .185 \end{array} \right] \qquad \qquad \phi_{ni} \propto \\ \beta_{nv} \exp \left( \Psi(\gamma_i) - \Psi\left( \sum_j \gamma_j \right) \right)$$

- $\gamma = (2.000, 2.000, 2.000)$
- $\phi(0) \propto 0.260 \times \exp(\Psi(2.000) \Psi(2.000 + 2.000 + 2.000)) = 0.072$
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Material adapted from David Blei

$$\beta = \left[ \begin{array}{ccccc} \text{cat} & \text{dog} & \text{hamburger} & \text{iron} & \text{pig} \\ .26 & .185 & .185 & .185 & .185 \\ .185 & .185 & .26 & .185 & .185 \\ .185 & .185 & .185 & .26 & .185 \end{array} \right] \qquad \qquad \phi_{ni} \propto \\ \beta_{nv} \exp \left( \Psi(\gamma_i) - \Psi\left( \sum_j \gamma_j \right) \right)$$

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- $\phi(2) \propto 0.185 \times \exp(\Psi(2.000) \Psi(2.000 + 2.000 + 2.000)) = 0.051$
- After normalization: {0.413, 0.294, 0.294}

### Update $\gamma$

- Document: dog cat cat pig
- Update equation

$$\gamma_i = \alpha_i + \sum_n \phi_{ni} \tag{3}$$

• Assume  $\alpha = (.1, .1, .1)$ 

### Update $\gamma$

- Document: dog cat cat pig
- Update equation

$$\gamma_i = \alpha_i + \sum_n \phi_{ni} \tag{3}$$

• Assume  $\alpha = (.1, .1, .1)$ 

	$\phi_{0}$	$\phi_{ extsf{1}}$	$\phi_{2}$
dog	.333	.333	.333
cat	.413	.294	.294
pig	.333	.333	.333
$\alpha$	0.1	0.1	0.1
sum	1.592	1.354	1.354

Note: do not normalize!

### Update $\gamma$

- Document: dog cat cat pig
- Update equation

$$\gamma_i = \alpha_i + \sum_n \phi_{ni} \tag{3}$$

• Assume  $\alpha = (.1, .1, .1)$ 

	$oldsymbol{\phi}_{0}$	$oldsymbol{\phi}_{1}$	$\phi_{ exttt{2}}$	
dog	.333	.333	.333	
cat	.413	.294	.294	x2
pig	.333	.333	.333	
α	0.1	0.1	0.1	
sum	1.592	1.354	1.354	

Note: do not normalize!

### Update $\beta$

- lacksquare Count up all of the  $\phi$  across all documents
- For each topic, divide by total
- Corresponds to maximum likelihood of expected counts

## Update $\beta$

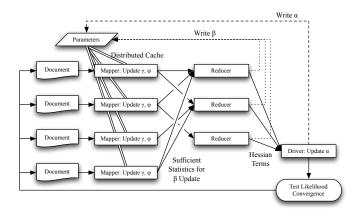
- Count up all of the  $\phi$  across all documents
- For each topic, divide by total
- Corresponds to maximum likelihood of expected counts
- Unlike Gibbs sampling, no Dirichlet prior

### **Automatic Inference**



### **Parallel LDA**

## Zhai et al, 2012



#### Online I DA

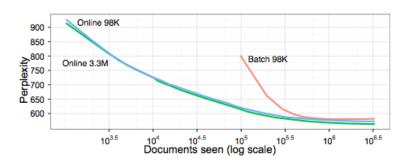
### Hoffman and Blei, 2010

### Algorithm 2 Online variational Bayes for LDA

```
Define \rho_t \triangleq (\tau_0 + t)^{-\kappa}
Initialize \lambda randomly.
for t = 0 to \infty do
    E step:
    Initialize \gamma_{tk} = 1. (The constant 1 is arbitrary.)
    repeat
        Set \phi_{twk} \propto \exp\{\mathbb{E}_{\sigma}[\log \theta_{tk}] + \mathbb{E}_{\sigma}[\log \beta_{kw}]\}
        Set \gamma_{tk} = \alpha + \sum_{w} \phi_{twk} n_{tw}
    until \frac{1}{k'}\sum_{k} |\text{change in}\gamma_{tk}| < 0.00001
    M step:
    Compute \bar{\lambda}_{kw} = \eta + D n_{tw} \phi_{twk}
    Set \lambda = (1 - \rho_t)\lambda + \rho_t \tilde{\lambda}.
end for
```

### **Online LDA**

# Hoffman and Blei, 2010



#### Online I DA

### Hoffman and Blei, 2010

- Initialize λ<sup>(0)</sup> randomly.
- 2: Set the step-size schedule  $\rho_t$  appropriately.
- 3: repeat
- Sample a data point  $x_i$  uniformly from the data set. 4:
- Compute its local variational parameter, 5:

$$\phi = \mathbb{E}_{\lambda^{(t-1)}}[\eta_g(x_i^{(N)}, z_i^{(N)})].$$

Compute intermediate global parameters as though  $x_i$  is replicated N times, 6:

$$\hat{\lambda} = \mathbb{E}_{\phi}[\eta_g(x_i^{(N)}, z_i^{(N)})].$$

7: Update the current estimate of the global variational parameters,

$$\lambda^{(t)} = (1 - \rho_t)\lambda^{(t-1)} + \rho_t \hat{\lambda}.$$

8: until forever

Material adapted from David Blei | UMD

#### **Best of Both Worlds**

Algorithm 1 Algorithm for hybrid stochastic variational-Gibbs inference.

```
for t \in 1, ..., \infty do
   \rho_t \leftarrow \left(\frac{1}{t_0 + t}\right)^{\kappa}
   sample minibatch \mathcal{B}
   for d \in \mathcal{B} do
        initialize z_d^0
        discard B burn-in sweeps
        for sample s \in 1, ..., S do
            for token i \in 1, ..., N_d do
                sample z_{di}^s \propto (\alpha + N_{dk}) e^{\mathbb{E}_q[\log \beta_{kw}]}
            end for
        end for
   end for
   \lambda_{kw}^{t} \leftarrow (1 - \rho_t)\lambda_{kw}^{t-1} + \rho_t \left(\eta + \frac{D}{|\mathcal{B}|}\hat{N}_{kw}\right)
end for
```

Material adapted from David Blei | UMD Varia

### Zhai and Boyd-Graber, 2013



## Zhai and Boyd-Graber, 2013

minibatch-5	minibatch-8	minibatch-10			minibatch-120
102-club	118-club	132-rock			0-appear
115-issuee	128-copy	194-issue			1-hulk
127-cover	137-cover	215-series			2-wolverin
130-copy	138-issue	217-copy			3-annual
197-appear	180-appear	226-cover			4-copy 5-rider
	319-rock				6-comicstrip
289-rock	493-annual	261-appear			7-cover
450-annual		588-annual			8-force
584-series	639-series	949-force			9-captain
811-forcee	877-force	1074-rider			11-issue
1090-rider	1003-rider	6038-comicstrip			12-series
	7075-captain	6520-mutant			16-mutant
F		9569-captain			
		oooo oaptam			41-rock
5	8	10			
captain	comicstrip	hulk			
seqitur	mutant	mazelyah			
	patlafontain				

# Zhai and Boyd-Graber, 2013

minibatch-5	minibatch-8	minibatch-10	minibatch-16		minibatch-120
102-club	118-club	132-rock	87-series		0-appear
115-issuee	128-copy	194-issue	161-issue		
127-cover	137-cover	215-series	283-copy		
130-copy	138-issue	217-copy	306-appear		
197-appear	180-appear	226-cover	307-cover		
289-rock	319-rock	261-appear	502-annual		
450-annual	493-annual	588-annual	814-force		7-cover
584-series	639-series	949-force	1194-rider		8-force
811-forcee	877-force	1074-rider	8944-hulk		9-captain
1090-rider	1003-rider		10819-comicstrip		11-issue
1090-rider	7075-captain	6038-comicstrip	11301-mutant		12-series
	7075-captain	6520-mutant			16-mutant
		9569-captain	14335-captain		41-rock
5	8	10	16		
captain	comicstrip	hulk	wolverin		
seqitur	mutant	mazelyah	albion		
	patlafontain				

## Zhai and Boyd-Graber, 2013

minibatch-5	minibatch-8	minibatch-10	minibatch-16	minibatch-17		minibatch-120
102-club	118-club	132-rock	87-series	82-series		0-appear
115-issuee	128-copy	194-issue	161-issue	162-issue		1-hulk
127-cover	137-cover	215-series	283-copy	288-copy		2-wolverin 3-annual
130-copy	138-issue	217-copy	306-appear	294-appear		4-copy
197-appear	180-appear	226-cover	307-cover	311-cover		5-rider
289-rock	319-rock	261-appear	502-annual	512-annual		6-comicstrip
450-annual	493-annual	588-annual	814-force	830-force		7-cover
584-series	639-series	949-force	1194-rider	4782-wolverin		8-force
811-forcee	877-force	1074-rider	8944-hulk	9659-hulk		9-captain
1090-rider	1003-rider	6038-comicstrip	10819-comicstrip	11527-comicstrip		11-issue
1090-Huel	7075-captain		11301-mutant	12009-mutant		12-series
	7075-captairi	6520-mutant	14335-captain	15040-captain		16-mutant
		9569-captain	14335-captain	15040-captain		41-rock
5	8	10	16	17		
captain	comicstrip	hulk	wolverin	lacy		
seqitur	mutant	mazelyah	albion			
	patlafontain					

## Zhai and Boyd-Graber, 2013

minibatch-5	minibatch-8	minibatch-10	minibatch-16	minibatch-17	minibatch-39	minibatch-83	minibatch-120
102-club	118-club	132-rock	87-series	82-series	1-annual		
115-issuee	128-copy	194-issue	161-issue	162-issue	2-rock		
127-cover	137-cover	215-series	283-copy	288-copy	3-wolverin		
130-copy	138-issue	217-copy	306-appear	294-appear	4-appear		
197-appear	180-appear	226-cover	307-cover	311-cover	5-comicstrip 6-series		
289-rock	319-rock	261-appear	502-annual	512-annual	7-mutant		
450-annual	493-annual	588-annual	814-force	830-force	8-cover		
584-series	639-series	949-force	1194-rider	4782-wolverin	12-issue		
	877-force		8944-hulk	9659-hulk	14-hulk		
811-forcee	1003-rider	1074-rider	10819-comicstrip		16-copy		
1090-rider		6038-comicstrip		11527-comicstrip	53-force		
	7075-captain	6520-mutant	11301-mutant	12009-mutant	57-rider		
		9569-captain	14335-captain	15040-captain			
					86-captain		
5	8	10	16	17	39		
captain	comicstrip	hulk	wolverin	lacy	izzo		
seqitur	mutant	mazelyah	albion				
	patlafontain						

## Zhai and Boyd-Graber, 2013

		minibatch-17	minibatch-39	minibatch-83	minibatch-120
132-rock	87-series	82-series	1-annual	0-captain	0-appear
194-issue	161-issue	162-issue	2-rock	1-appear	1-hulk
215-series	283-copy	288-copy	3-wolverin	3-hulk	2-wolverin
217-copy	/ <del></del>			5-rock	3-annual
<b>————</b>				6-wolverin	4-copy 5-rider
220 00001				9-comicstrip	6-comicstrip
Zo i appeai	/			12-annal	
588-annual	814-force	830-force			7-cover 8-force
949-force	1194-rider	4782-wolverin	12-issue		9-captain
1074-rider	8944-hulk	9659-hulk	14-hulk	16-cover	11-issue
6038-comicstrip	10819-comicstrip	11527-comicstrip	16-copy	19-copy	12-series
in 6520-mutant	11301-mutant	12009-mutant	53-force	23-issue	16-mutant
9569-captain	14335-captain	15040-captain	57-rider	280-rider	41-rock
			86-captain		41-1008
10	16	17	39	83	
hulk	wolverin	lacy	izzo	gown	
mazelyah	albion				
n	,				
e e e e e e e e e e e e e e e e e e e	y 194-issue or 215-series e 217-copy ar 226-cover ( 261-appear al 588-annual s 949-force a 1074-rider of 6038-comicstrip ain 9569-captain	194-issue	194-issue	194-issue	10

## Zhai and Boyd-Graber, 2013

minibatch-5	minibatch-8	minibatch-10	minibatch-16	minibatch-17	minibatch-39	minibatch-83	minibatch-120
102-club	118-club	132-rock	87-series	82-series	1-annual	0-captain	0-appear
115-issuee	128-copy	194-issue	161-issue	162-issue	2-rock	1-appear	1-hulk
127-cover	137-cover	215-series	283-copy	288-copy	3-wolverin	3-hulk	2-wolverin 3-annual
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197-appear	180-appear	226-cover	307-cover	311-cover	6-series	6-wolverin	5-rider
289-rock	319-rock	261-appear	502-annual	512-annual	7-mutant	9-comicstrip	6-comicstrip
450-annual	493-annual	588-annual	814-force	830-force	8-cover	12-annal	7-cover
584-series	639-series	949-force	1194-rider	4782-wolverin	12-issue	13-mutant	8-force
811-forcee	877-force	1074-rider	8944-hulk	9659-hulk	14-hulk	15-series	9-captain
1090-rider	1003-rider		10819-comicstrip	11527-comicstrip	16-copy	16-cover	11-issue
1090-rider		6038-comicstrip			53-force	19-copy	12-series
	7075-captain	6520-mutant	11301-mutant	12009-mutant	57-rider	23-issue	16-mutant
		9569-captain	14335-captain	15040-captain		280-rider	41-rock
					86-captain		
5	8	10	16	17	39	83	]
captain	comicstrip	hulk	wolverin	lacy	izzo	gown	
seqitur	mutant	mazelyah	albion				
	patlafontain						
captain	comicstrip mutant	10 hulk			86-captain 39	83	41-rock

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minibatch-5	minibatch-8	minibatch-10	minibatch-16	minibatch-17	minibatch-39	minibatch-83	minibatch-120
102-club	118-club	132-rock	87-series	82-series	1-annual	0-captain	0-appear
115-issuee	128-copy	194-issue	161-issue	162-issue	2-rock	1-appear	1-hulk
127-cover	137-cover	215-series	283-copy	288-copy	3-wolverin	3-hulk	2-wolverin
130-copy	138-issue	217-copy	306-appear	294-appear	4-appear	5-rock	3-annual
197-appear	180-appear	226-cover	307-cover	311-cover	5-comicstrip	6-wolverin	4-copy 5-rider
289-rock	319-rock		502-annual	512-annual	6-series 7-mutant	9-comicstrip	6-comicstrip
	493-annual	261-appear	814-force		8-cover	12-annal	7-cover
450-annual		588-annual	<b></b>	830-force		13-mutant	8-force
584-series	639-series	949-force	1194-rider	4782-wolverin	12-issue	15-series	9-captain
811-forcee	877-force	1074-rider	8944-hulk	9659-hulk	14-hulk	16-cover	11-issue
1090-rider	1003-rider	6038-comicstrip	10819-comicstrip	11527-comicstrip	16-copy	19-copy	12-series
	7075-captain	6520-mutant	11301-mutant	12009-mutant	53-force	23-issue	16-mutant
		9569-captain	14335-captain	15040-captain	57-rider	280-rider	
					86-captain	200 11001	41-rock
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5	8	10	16	17	39	83	l
captain	comicstrip	hulk	wolverin	lacy	izzo	gown	l
seqitur	mutant	mazelyah	albion				l
	patlafontain						l