# Variational Auto-encoders: Representations for image generation and semi-supervised learning

JIANBO CHEN, BILLY FANG, CHENG JU *Departments of Statistics and Biostatistics, UC Berkeley* CS 294-129, FALL 2016

## BACKGROUND, DATA, TOOLS

- Variational auto-encoders are useful for generating new examples from observed data
- Learns latent encoding of data
- Can be used for semi-supervised learning
- Data: MNIST digits dataset and SVHN dataset
- Tools: TensorFlow, GeForce GTX 770 GPU

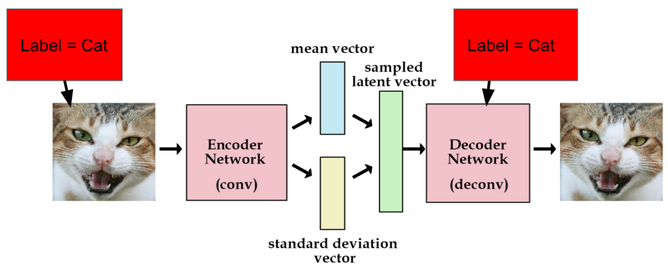
## VARIATIONAL AUTO-ENCODER

- latent variable model: $z \sim \mathcal{N}(0, I)$, $x \mid z \sim f(x; z, \theta)$ (e.g. Bernoulli)
- variational inference: maximize lower bound on log likelihood

$$\log p(x) \geq \mathbb{E}_{z \sim Q(\cdot \mid x)}[\log p(x \mid z)] - \mathrm{KL}(Q(z \mid x) \| p(z)).$$

## CONDITIONAL VAE (CVAE)

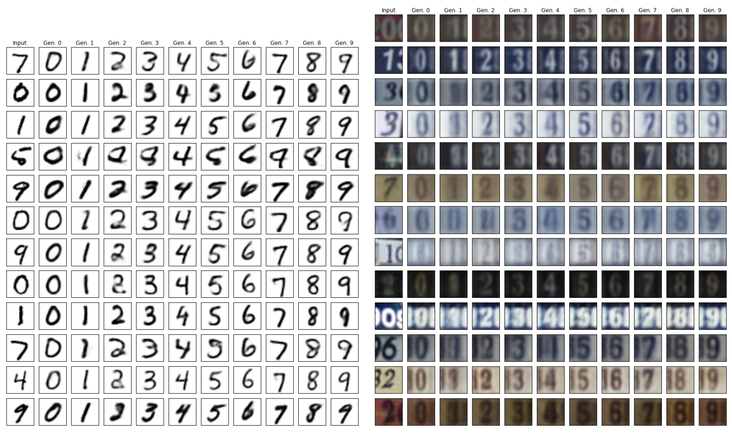
- condition everything on label $y$




$$\log p(x \mid y) \geq \mathbb{E}_{z \sim Q(\cdot \mid y, x)}[\log p(x \mid y, z)] - \mathrm{KL}(Q(z \mid x, y) \| p(z \mid y)).$$

## CVAE FOR COMPLETION


## CVAE FOR STYLE TRANSFER




## SEMI-SUPERVISED LEARNING (SSL) VAE

- Handle datasets with missing labels
- Models label distribution
- Labeled and unlabeled examples enter loss differently

$$\log p(x, y) \geq \mathbb{E}_{z \sim Q(z \mid x, y)}[\log p(x \mid y, z) + \log p(y)] - \mathrm{KL}(Q(z \mid x, y) \| p(z)) =: -\mathcal{L}(x, y)$$

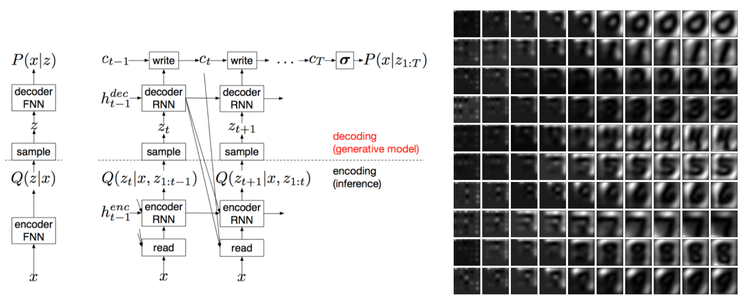
$$\log p(x) \geq \sum_y q(y \mid x)(-\mathcal{L}(x, y)) + H(q(y \mid x))$$

Validation/test error on MNIST (55000 training examples)

| | 1000 labeled | 600 labeled |
|---|---|---|
| Fully connected | 4.7%/ 5.1% | 11.5%/12.0% |
| Convolutional | 4.2%/4.8% | 6.0%/6.2% |
| Kingma et al. [3] | 2.4% | 2.6% |

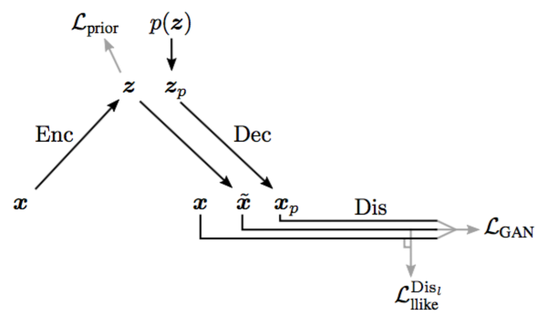
## DRAW

- attention-based sequential generation
- RNN structure




## ADDING GANS

- VAE output is often blurry
- Add discriminator to encourage sharpness
- Replace decoder loss with comparison of discriminator layers




## CVAE WITH GAN

CVAEGAN results here

## SSL WITH GANS

CVAEGAN results here

## DRAW WITH GANS

CVAEGAN results here

## FUTURE DIRECTIONS

a

## REFERENCES

[1] Carl Doersch. Tutorial on variational autoencoders. *arXiv preprint arXiv:1606.05908*, 2016.

[2] Karol Gregor, Ivo Danihelka, Alex Graves, Danilo Jimenez Rezende, and Daan Wierstra. DRAW: A recurrent neural network for image generation. *arXiv preprint arXiv:1502.04623*, 2015.

[3] Diederik P Kingma, Shakir Mohamed, Danilo Jimenez Rezende, and Max Welling. Semi-supervised learning with deep generative models. In *Advances in Neural Information Processing Systems*, pages 3581–3589, 2014.

[4] Diederik P Kingma and Max Welling. Auto-encoding variational bayes. *arXiv preprint arXiv:1312.6114*, 2013.

[5] Anders Boesen Lindbo Larsen, Søren Kaae Sønderby, and Ole Winther. Autoencoding beyond pixels using a learned similarity metric. *arXiv preprint arXiv:1512.09300*, 2015.