CS 4824/ECE 4424: Generative Adversarial Networks

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Generative networks

- Neural networks are typically used for classification or regression
  - Input: data
  - Output: class or prediction

- Can we design neural networks that can generate data?
  - Input: random vector
  - Output: data
Generative networks

- Several types of generative networks
  - Boltzmann machines
  - Sigmoid belief networks
  - Variational autoencoders
  - Generative adversarial networks
  - Generative moment matching networks
  - Sum-product networks
  - Normalizing flows
  - …
Generative Adversarial Networks

- Approach based on game theory

- Two networks:
  - Generator $g(z; W_g) \rightarrow x$
  - Discriminator $d(x; W_d) \rightarrow \Pr(x \text{ is real})$

- Objective

$$\min_{W_g} \max_{W_d} \sum \log \Pr(X_n \text{ is real} ; W_d) + \log \Pr(G(Z_n; W_g) \text{ is fake} ; W_d)$$

$$= \min_{W_g} \max_{W_d} \sum \log d(X_n; W_d) + \log (1 - d(G(Z_n; W_g); W_d))$$
Generative Adversarial Networks

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$$\min_{W_g} \max_{W_d} \sum_n \log \Pr(x_n \text{ is real}; W_d) + \log \Pr(g(z_n; W_g) \text{ is fake}; W_d)$$

$$\equiv \min_{W_g} \max_{W_d} \sum_n \log d(x_n; W_d) + \log \left(1 - d(g(z_n; W_g); W_d)\right)$$
Generative Adversarial Networks

- Schematic
GAN training

- We have a min-max optimization
  - Optimize the discriminator by stochastic gradient ascent
  - Optimize the generator by stochastic gradient descent
GAN training

- Repeat until convergence
  - For k steps do
    - Sample \( z_1, ..., z_N \) from \( Pr(z) \)
    - Sample \( x_1, ..., x_N \) from training set
    - Update discriminator by ascending its stochastic gradient
      \[
      \nabla_{W_d} \left( \frac{1}{N} \sum_{n=1}^{N} \left[ \log d(x_n; W_d) + \log \left( 1 - d(g(z_n; W_g); W_d) \right) \right] \right)
      \]
    - Sample \( z_1, ..., z_N \) from \( Pr(z) \)
    - Update generator by descending its stochastic gradient
      \[
      \nabla_{W_g} \left( \frac{1}{N} \sum_{n=1}^{N} \log \left( 1 - d(g(z_n; W_g); W_d) \right) \right)
      \]
GAN training

- In the limit (with sufficiently expressive networks, sufficient data and global convergence)
  
  \[ \Pr(x|z; W_g) \rightarrow \text{true data distribution} \]
  
  \[ \Pr(x \text{ is real}; W_d) \rightarrow 0.5 \text{ (for real and fake data)} \]

- Problems in practice:
  - Imbalance: one network may dominate the other
  - Local convergence
Images generated with GANs training

- Right columns are nearest neighbour training examples of adjacent column