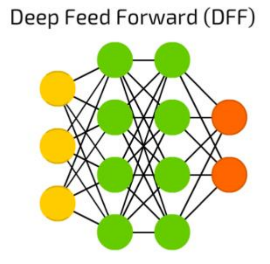
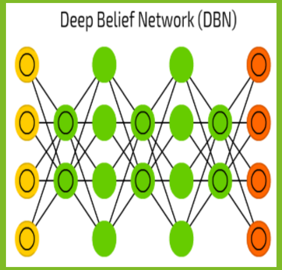
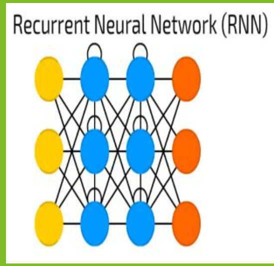
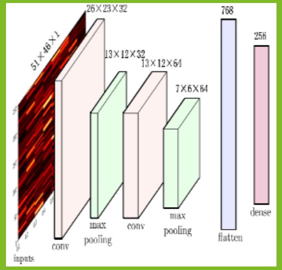
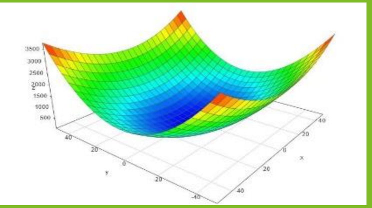
Deep Learning CSI_7_DEL

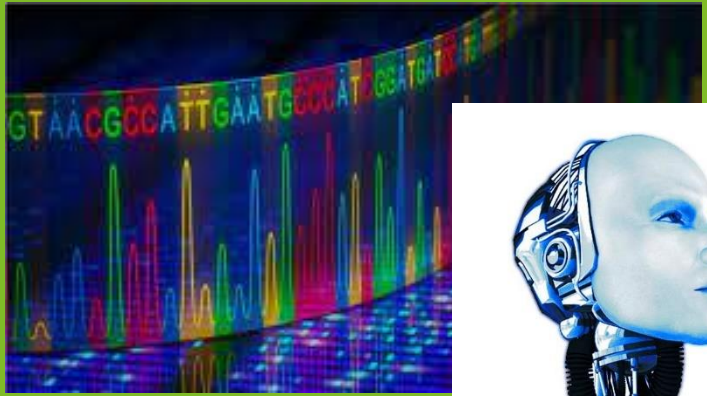


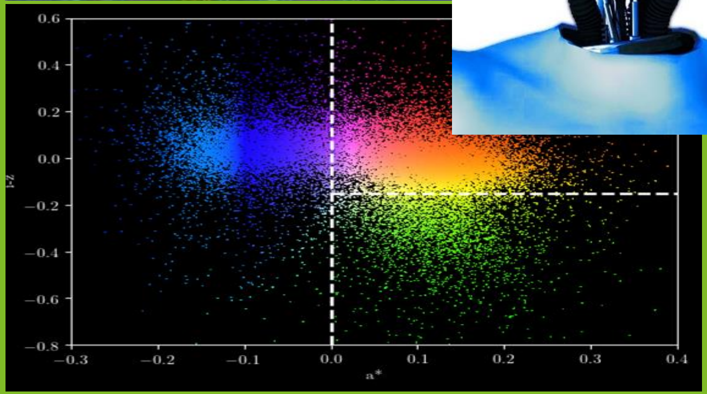


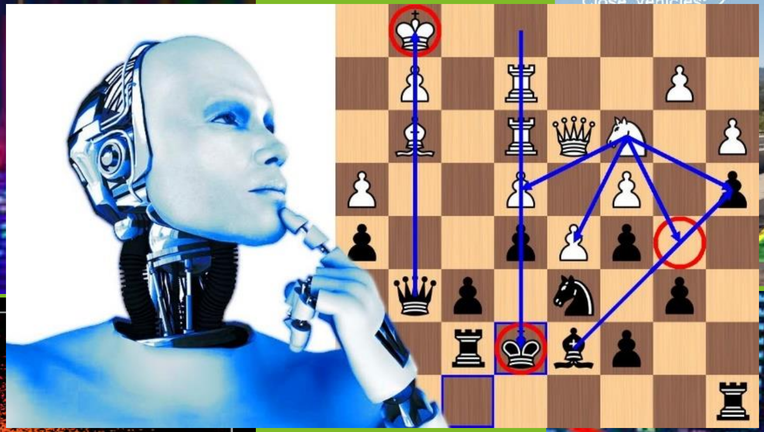


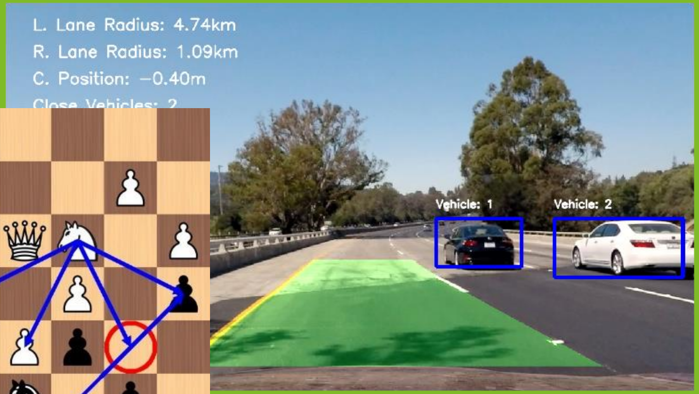












Week 8:Restricted Boltzmann Machine (RBM)

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Lecture points

- Boltzmann Machine.
- Restricted Boltzmann Machine
- RBM applications.
- Gibbs Sampling
- Contrastive Divergence

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Boltzmann Machine

- Unsupervised **Generative** Deep Learning models.
- Introduced by Geoffrey Hinton and Terry Sejnowski in 1985
- Learns the probability distribution over a set of inputs.
- An energy-based model
- Only binary input and output is allowed

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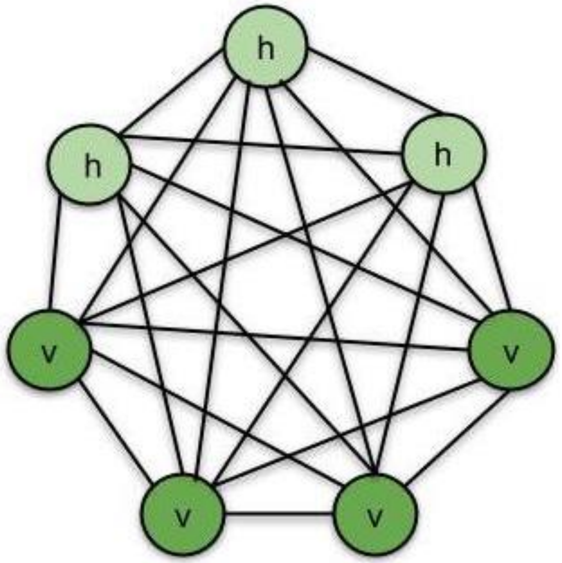
Boltzmann Machine

- **Boltzmann distribution** used in the sampling distribution (Ludwig Boltzmann)
- Contains two types of neurons: **hidden and visible**.
- Each neuron is connected to the other (**bidirectional connections**)



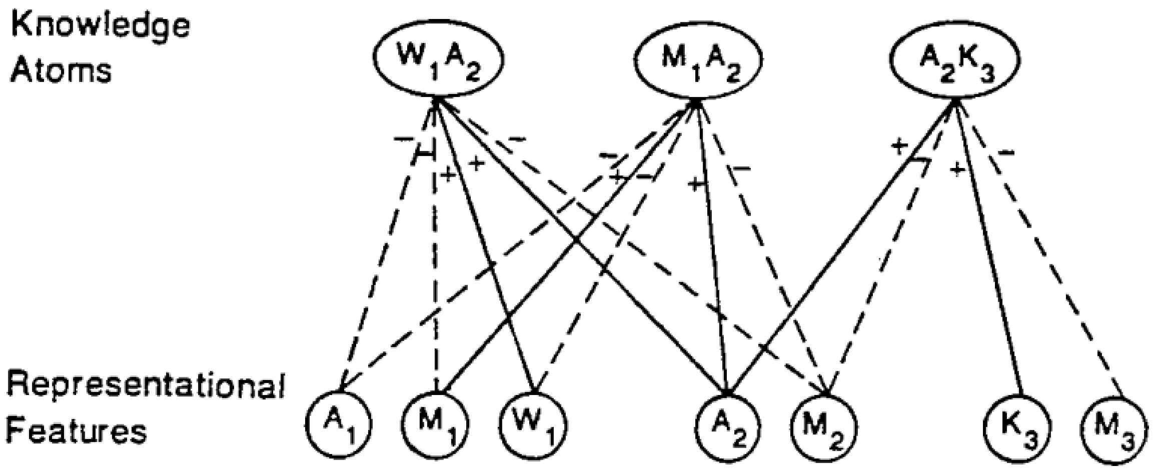
v= visible neurons **h**= hidden neurons

Types of Boltzmann

- Restricted Boltzmann Machines (RBM)
- Deep Belief Networks (DBN)
- Deep Boltzmann Machines (DBM)

Restricted Boltzmann Machines

- First introduced under the name “Harmonium model” by Smolensky (1986)
- Traditional Boltzmann Machine has connections growing exponentially.
- Unidirectional graphical model.
- Used to build Deep Belief Networks and Deep Boltzmann Machine



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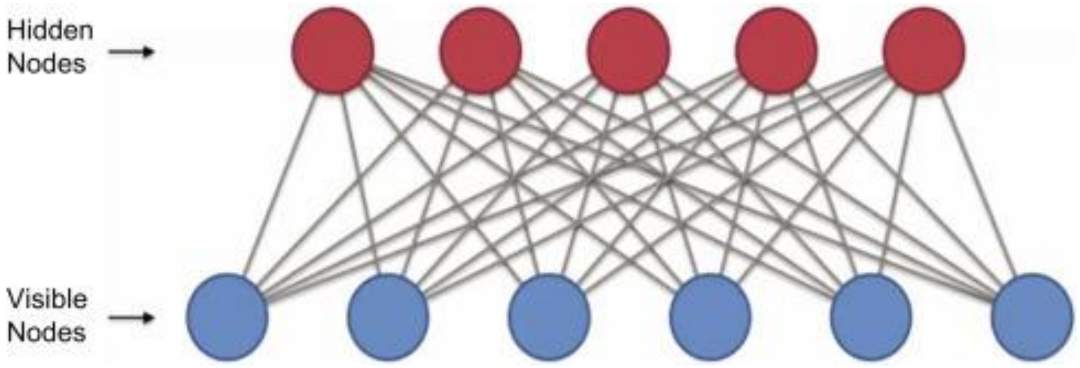
RBM: Architecture

- Shallow two-layer neural network.
- **Visible** neurons **only connects** to **hidden** neurons
- **Hidden** neurons **only connects** to **visible** neurons
- Each hidden neuron represents a data feature or pattern



RBM Applications

- Commonly used in **unsupervised** classification of images, text, voice etc.
- Heals the curse of dimensionality
- Pattern recognition and features extraction. (Autoencoders)
- Solve **imbalanced data** problem (One class dominates the other classes in the training data).
- **Noisy label problems** (Some observations in the training data contain wrongly assigned label).

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Conditional RBM for recommender system

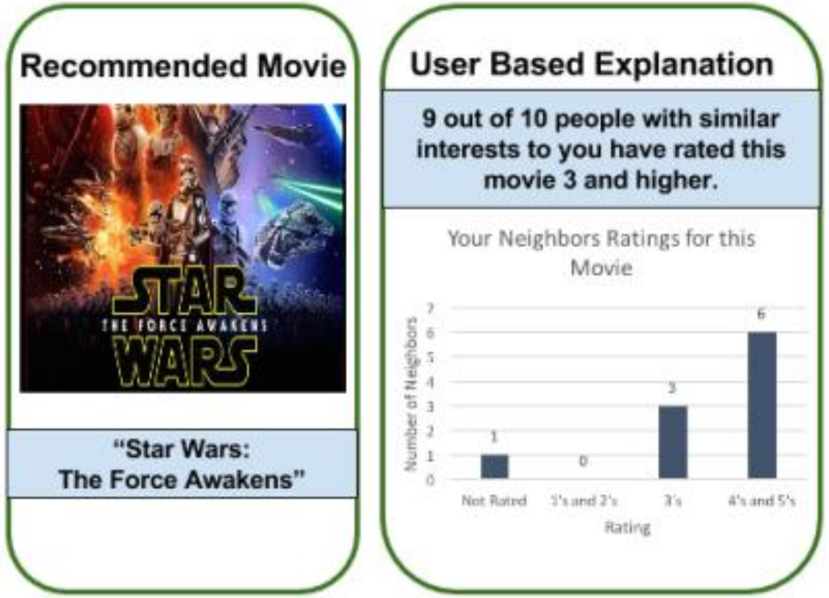

Figure 1. An example of a user-based neighbor style explanation for a recommended item.

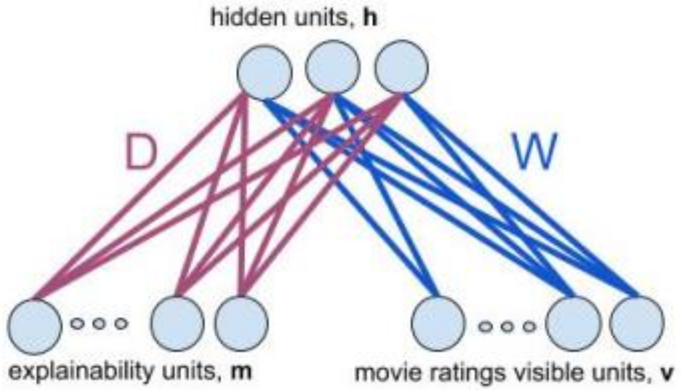

Figure 2. Conditional RBM for explainabilty.

Source: www.researchgate.net/publication/304350819_Explainable_Restricted_Boltzmann_Machines_for_Collaborative_Filtering

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RBM: Hidden and Visible units

- For any given hidden or visible neuron, to set any state The weighted combination of all input needs to be calculated.
- In For any hidden unit h_i, he probability P that h_i can be turn on can be computed as follow:

$$P(h_i = 1) = \frac{1}{1-e^{-z_i}}$$

(a sigmoid basically also called partition function)

z_i represents the sum of all input combinations:

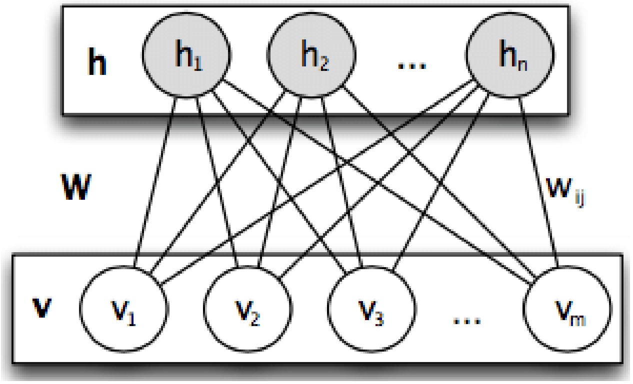
$$\mathrm{z_i} = \sum_j w_{ji} v_i + b_i$$

Where w_{ji} is the weight connection between the visible and the hidden neurons and b_i is the bias added to the visible neuron.

- Similarly, for any visible unit v_i, he probability P that v_i can be turn on can be computed as follow:

$$P(v_i = 1) = \frac{1}{1-e^{-y_i}}$$

$$Where\ \ y_i = \sum_j w_{ji} v_i + b_i$$



Energy function

- RBM is energy-based model
- Analogous to the **cost function** in other neural networks.
- The training algorithm attempts to minimize the energy function
- **Low energy** translates to **high probability** (High accuracy)
- Standard energy function with biases a_i, b_i and weights w_{ji}:

$$E(v,h) = -\sum_i a_i v_i - \sum_j b_j h_j - \sum_{i,j} w_{ij} v_i h_j$$
$$= -a^T v - b^T h - v^T W h$$

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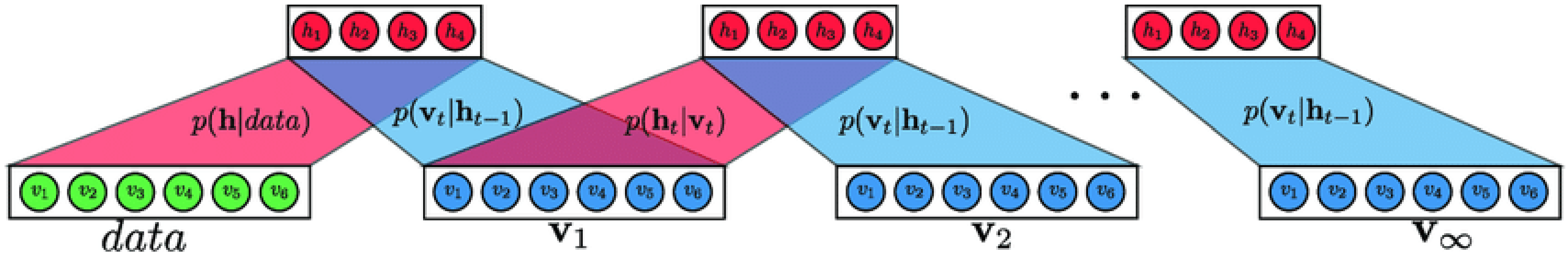
RBM Training

- RBM are trained using Stochastic Gradient Descent (SGD).
- There are two training steps
- Gibbs sampling
- Contrastive divergence.

Gibb sampling

- The search technique used in the training for RBM is called Gibbs sampling.
- A variant of Markov chain Monte Carlo method (MCMC) introduced by German and German (1984)
- Gibbs sampling calculates two parts:
  - **Part one** $P(v_i = 1|\, h) = \frac{1}{1-e^{(-(w_{ij}h_j+a_i))}} \; = \; \sigma(\sum_j w_{ij}h_j + a_i)$
  - **Part two:** $P(h_i = 1|\, v) = \frac{1}{1-e^{(-(w_i h_j+b_i))}} \; = \; \sigma(w_{ij}h_j + b_i)$



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Gibbs sampling steps

Step 1: Initialize a matrix Q=0 where the estimates will be stored.
Step 2: Pick a random vector v.
Step 3: Repeat for *N* The following:

Sample $\mathrm{h} \sim p(h|v) = \sigma(b + W^T v)$

Sample $\mathrm{v} \sim p(v|h) = \sigma(a + Wh)$

$Q < -Q + vh^T$

Step 4: End results => $E(v_i, h_i) \approx \frac{1}{N} Q$

Usually, Gibbs sampling tends to be slow.

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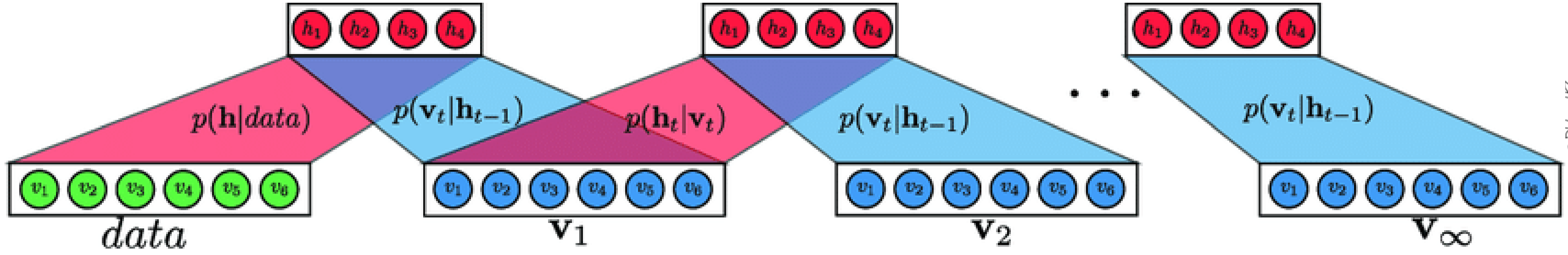
Contrastive Divergence

- A Markovian chain training technique used to learn the gradients of RBM
- The goal is to optimize weights and minimize the energy function.
- The weight values are updated during the contrastive divergence.

$$\Delta W = \boldsymbol{v}_0 \otimes p(\boldsymbol{h}_0 | \boldsymbol{v}_o) - \boldsymbol{v}_k \otimes p(\boldsymbol{h}_k | \boldsymbol{v}_k)$$
$$W_{new} = W_{old} + \Delta W$$



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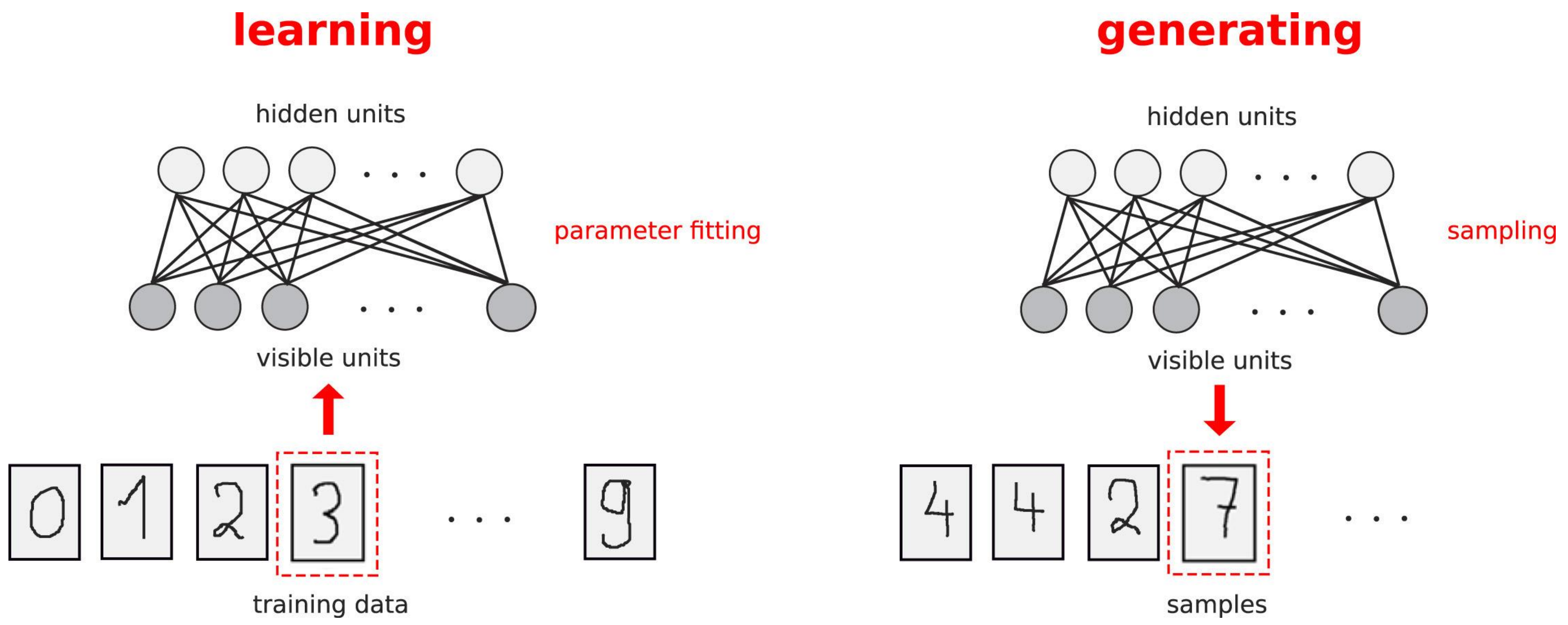
Learning and generating samples



Source: https://ars.els-cdn.com/content/image/1-s2.0-S0031320313002495-gr1_lrg.jpg

Training

- Finally, The gradient of the log likelihood of p with respect to w_ij connections between hidden and visible neuros can be calculated.

$$\frac{\partial \log p(v)}{\partial w_{ij}} = < v_i h_j >^0 - < v_i h_j >^\infty$$

- Where $< v_i h_j >$ is the average over many generated samples

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Summary

- RBM networks are energy-based.
- Learn the probability distribution of a given input.
- Use Markovian techniques for learning and generating samples (Gibbs sampling and contrastive divergence)
- Useful for recognising patterns, curse of dimensionality and recommender systems.

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Questions & Answers

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