Deep Learning

Recommender Systems & Embeddings

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Adapted from material by Charles Ollion & Olivier Grisel

Outline

Embeddings

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Dropout Regularization

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Embeddings

From Real to Symbolic

- Previously, we have looked at models that deal with real-valued inputs
- This means that the input is already a number, or can be easily converted to a number
- But what if the input is a symbol?

Symbolic variable

- Text: characters, words, bigrams...
- Recommender Systems: item ids, user ids
- Any categorical descriptor: tags, movie genres, visited URLs, skills on a resume, product categories...

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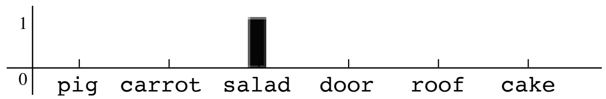
Notation:

$$\text{Symbol } s \text{ in vocabulary } V$$

One-hot representation

$$\textit{onehot}(\text{'salad'}) = [0, 0, 1, \ldots, 0] \in \{0, 1\}^{|V|}$$



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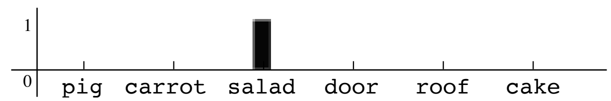

- Sparse, discrete, large dimension $|V|$
- Each axis has a meaning
- Symbols are equidistant from each other:

euclidean distance = $\sqrt{2}$

Embedding

$$embedding(\text{'salad'}) = [3.28, -0.45, \ldots 7.11]$$

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- Continuous and dense
- Can represent a huge vocabulary in low dimension, typically: $d \in \{16, 32, \ldots, 4096\}$
- Axis have no meaning *a priori*
- Embedding metric can capture semantic distance

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Neural Networks compute transformations on continuous vectors

Implementation with Keras

Size of vocabulary $n = |V|$, size of embedding d

```
# input: batch of integers
Embedding(output_dim=d, input_dim=n, input_length=1)
# output: batch of float vectors
```

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- $\mathbf{W}$ are trainable parameters of the model

Distance and similarity in Embedding space

Euclidean distance

$d(x, y) = ||x - y||_2$

- Simple with good properties
- Dependent on norm (embeddings usually unconstrained)

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Cosine similarity

$cosine(x, y) = \frac{x \cdot y}{||x|| \cdot ||y||}$

- Angle between points, regardless of norm
- $cosine(x, y) \in (-1, 1)$
- Expected cosine similarity of random pairs of vectors is 0

Visualizing Embeddings

- Visualizing requires a projection in 2 or 3 dimensions
- Objective: visualize which embedded symbols are similar

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t-SNE

Visualizing data using t-SNE, L van der Maaten, G Hinton, *The Journal of Machine Learning Research*, 2008

t-Distributed Stochastic Neighbor Embedding

- Unsupervised, low-dimension, non-linear projection
- Optimized to preserve relative distances between nearest neighbors
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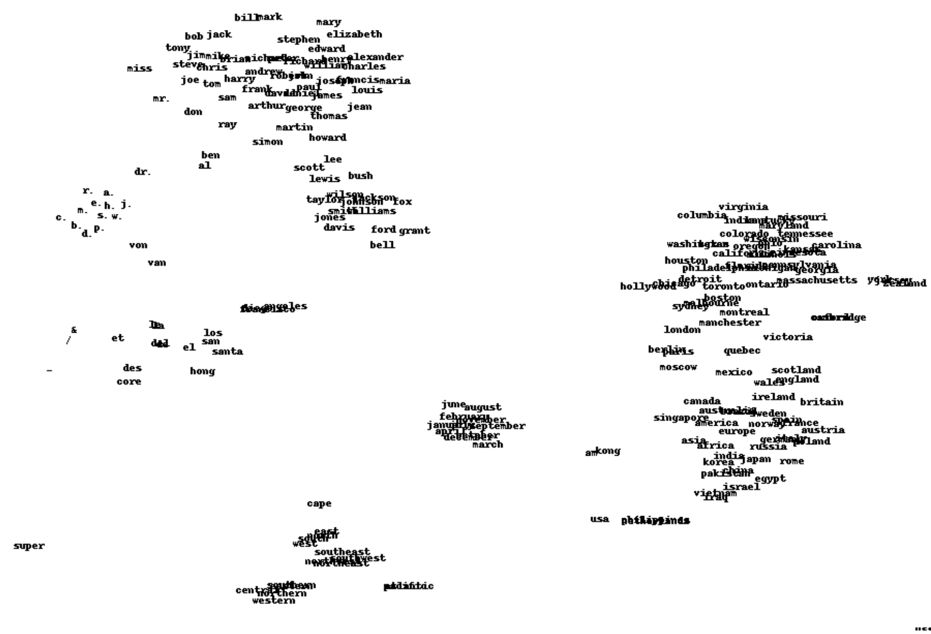
t-SNE projection is non deterministic (depends on initialization)

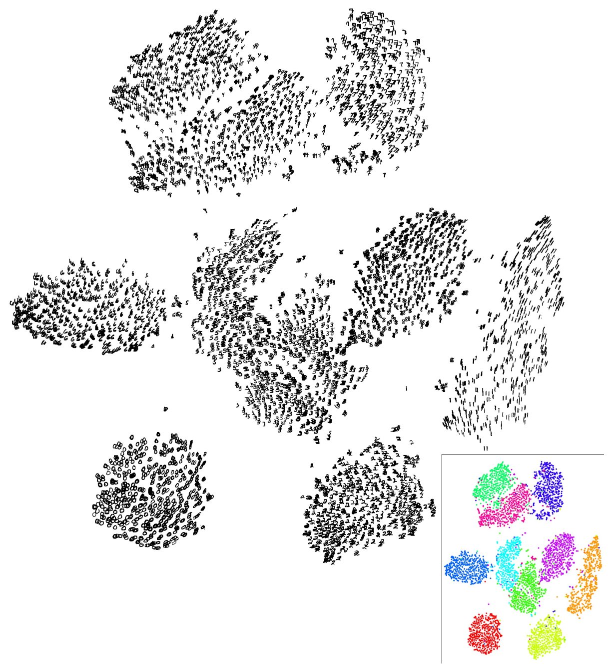
- Critical parameter: perplexity, usually set to 20, 30
- See http://distill.pub/2016/misread-tsne/

Example word vectors



excerpt from work by J. Turian on a model trained by R. Collobert et al. 2008

Visualizing Mnist



Dropout Regularization

Overfitting

- When we have a large number of parameters, we can fit the training data very well
- In fact, a model with enough parameters can fit any dataset perfectly
- Liken this to memorizing every answer to a test, rather than learning the material

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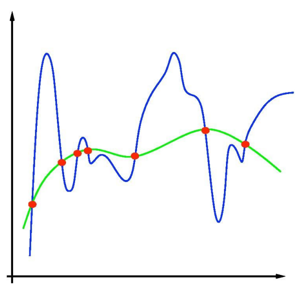
- When we have a large number of parameters, we can fit the training data very well
- In fact, a model with enough parameters can fit any dataset perfectly
- Liken this to memorizing every answer to a test, rather than learning the material
- When this happens, our model's ability to generalize to new data is compromised
- This is called overfitting

Bias - Variance Tradeoff

- Overfitting is a symptom of a model that has too much capacity
- A model with a a lot of parameters can fit the training data very well
- We call this a high variance model
- A model with too few parameters can't fit the training data well
- We call this a high bias model - it relies more on the structure of the model than the data



Regularization

Width of the network

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Width of the network

Depth of the network

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L_2 penalty on weights

Regularization

Width of the network

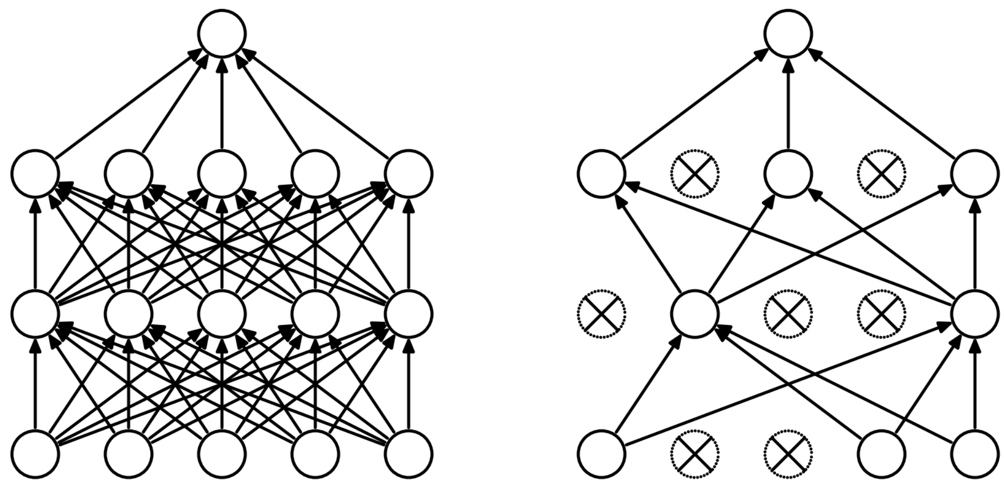
Depth of the network

L_2 penalty on weights

Dropout

- Randomly set activations to 0 with probability p
- Typically only enabled at training time

Dropout



(a) Standard Neural Net (b) After applying dropout.

Dropout: A Simple Way to Prevent Neural Networks from Overfitting, Srivastava et al., *Journal of Machine Learning Research* 2014

Dropout

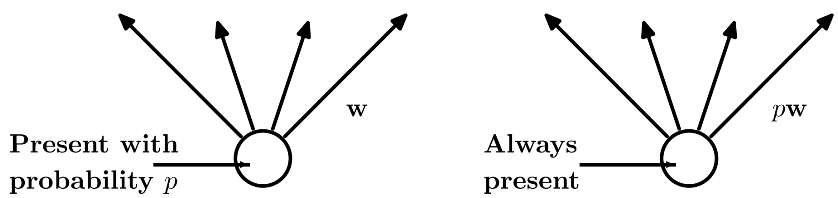
Interpretation

- Reduces the network dependency to individual neurons
- More redundant representation of data

Ensemble interpretation

- Equivalent to training a large ensemble of shared-parameters, binary-masked models
- Each model is only trained on a single data point

Dropout



(a) At training time (b) At test time

At test time, multiply weights by p to keep same level of activation

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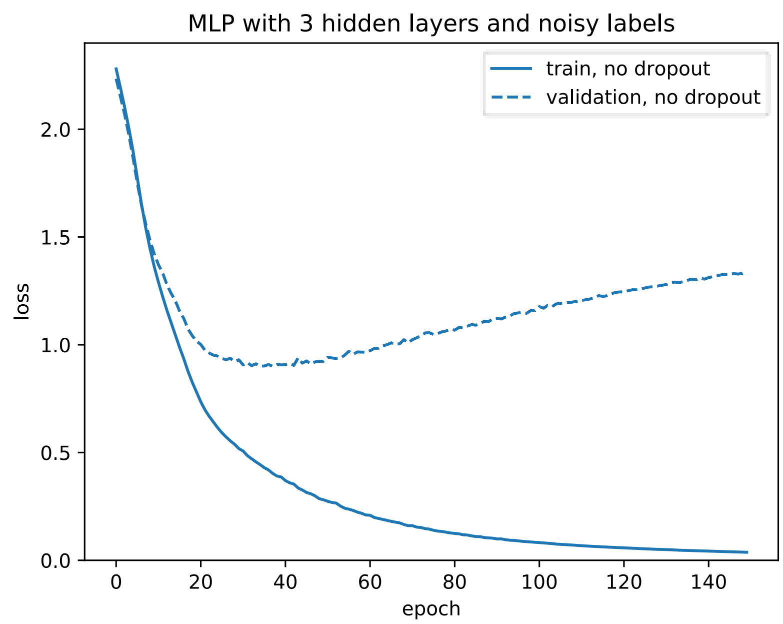
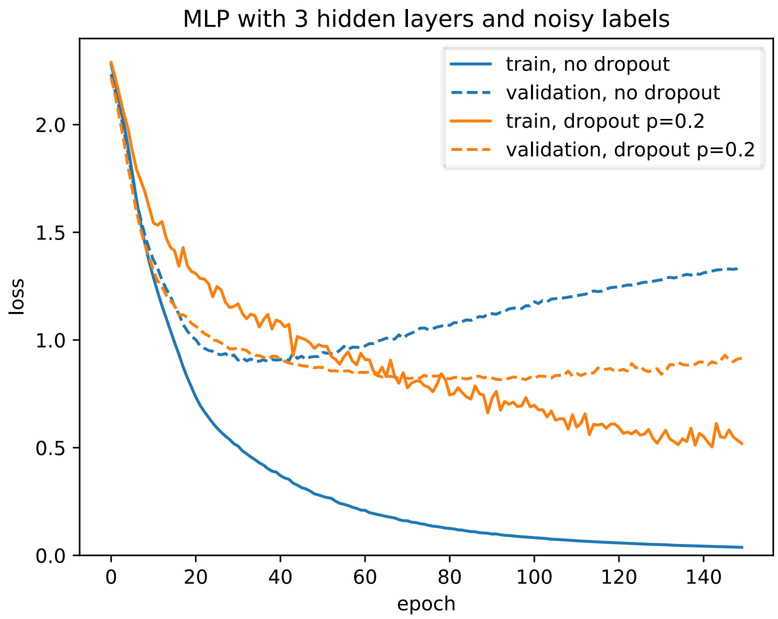
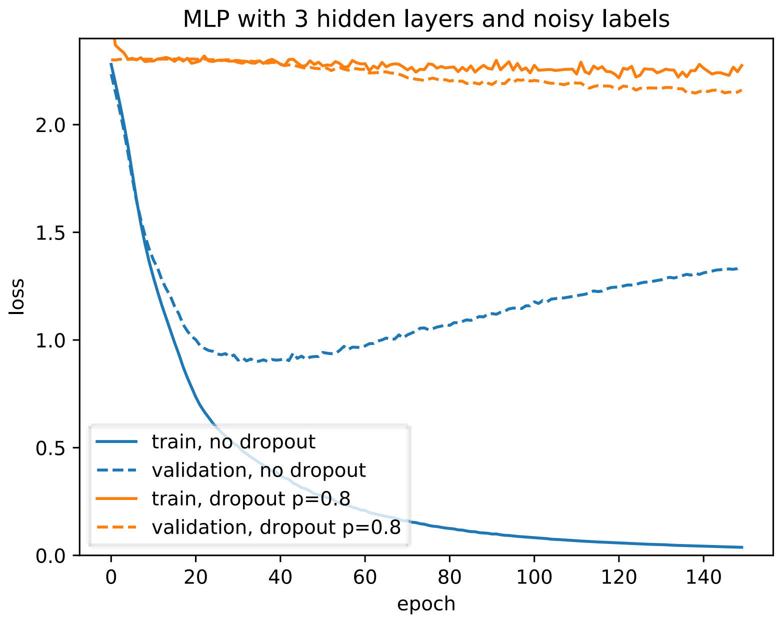
Overfitting Noise



A bit of Dropout



Too much: Underfitting



Implementation with Keras

```
model = Sequential()
model.add(Dense(hidden_size, input_shape, activation='relu'))
model.add(Dropout(p=0.5))
model.add(Dense(hidden_size, activation='relu'))
model.add(Dropout(p=0.5))
model.add(Dense(output_size, activation='softmax'))
```

Recommender Systems

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Recommend contents and products

Movies on Netflix and YouTube, weekly playlist and related Artists on Spotify, books on Amazon, related apps on app stores, "Who to Follow" on twitter...

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RecSys 101

Content-based vs Collaborative Filtering (CF)

Content-based: user metadata (gender, age, location...) and item metadata (year, genre, director, actors)

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Hybrid systems: CF + metadata to mitigate the cold-start problem

Explicit vs Implicit Feedback

Explicit: positive and negative feedback

- Examples: review stars and votes
- Regression metrics: Root Mean Squared Error (RMSE), Mean Absolute Error (MAE)...

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Implicit: positive feedback only

- Examples: page views, plays, comments...
- Ranking metrics: ROC AUC, precision at rank, NDCG...

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Implicit (and Explicit) feedback distribution **impacted by UI/UX changes** and the **RecSys deployment** itself.

Ethical Considerations of Recommender Systems

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Amplification of existing discriminatory and unfair behaviors / bias

- Example: gender bias in ad clicks (fashion / jobs)
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Amplification of the filter bubble and opinion polarization

- Personalization can amplify "people only follow people they agree with"
- Optimizing for "engagement" promotes content that causes strong emotional reaction (and turns normal users into *haters*?)
- RecSys can exploit weaknesses of some users, lead to addiction
- Addicted users clicks over-represented in future training data

Call to action

Designing Ethical Recommender Systems

- Wise modeling choices (e.g. use of "firstname" as feature)
- Conduct internal audits to detect fairness issues: SHAP, Integrated Gradients, fairlearn.org
- Learning representations that enforce fairness?

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Transparency

- Educate decision makers and the general public
- How to allow users to assess fairness by themselves?
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Active Area of Research

Next: Lab 3!