

# Recommendation Systems || Lecture 8

University of Washington  
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July 25, 2022

# Logistics

- ① Assignment 2 due wednesday night  
*Low not going down  
(RMSE is high)* → Tomorrow noon
- ② Project deliverables doc up on canvas - Breakdown of project to help you stay on track!  
*(syllabus)*
- ③ Assignment 3 will be assigned wednesday and you get 2 weeks

*↳ Last Assignment  
(Kaggle Contest)  
New Recs*

# Project Deliverables

- ① **Baseline Model:** For your project, try couple of baseline models such as truncated SVD, etc
  - ② **Neural Network Model:** Try at least one NN model - E.g. AutoRec (AutoEncoder for Recommendations) or DeepRec or MLP (Multi-layer perceptron), etc
  - ③ **Report:** Your report should be well formatted and organized just like a conference paper - With a) Abstract b) Introduction c) Reference to literature d) Your unique contribution in the paper e) Description of models used f) Description of data sets g) Description of metrics and key results comparing different models over the metrics (use a table for this) h) Conclusions and scope for future work
  - ④ **Code:** Publish your complete code on github and link to it in the report. Keep your code organized (modular, use of classes, etc)
  - ⑤ **Presentation:** One presentation per team (unit tests)

# Project Timeline

- ① **July 29:** Finish your 1:1 review of the project proposal

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Last Lecture

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- ⑤ **August 19:** Neurips style white paper submission (check Neurips conference page for details)

Later format for conference paper

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- ⑥ **August 19:** Final code submission and link to [github project](#).

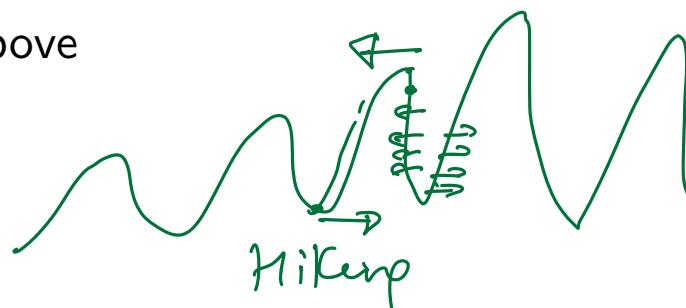
# Today!

- ① Industry Case Study on Recommendations

# ICE #1

Let's say you have a loss function  $l(X, y; \theta)$  where  $X, y$  is the data and  $\theta$  are the parameters. You want to optimize (minimize) the loss for  $\theta$ . You take the gradient of the loss  $l$  at the current pointe,  $\theta^1$ . What does the direction of the gradient point to?

- ① Direction of steepest ascent
- ② Direction of steepest descent
- ③ It's just a collection of partial derivatives. Can't really attribute meaning to it.
- ④ None of the above



# Case Study: Stocking your Pantry



# Case Study: Online Pantry

The screenshot shows the Amazon Prime Pantry homepage. At the top, there's a navigation bar with links for Departments, Browsing History, Today's Deals, Gift Cards & Registry, Sell, Help, EN, Hello, Account & Lists, Orders, Prime, and a Cart icon showing 1 box | 0 items | 0% full. A green arrow points down to the search bar. Below the navigation is a banner for "Stock up for spring" with a message: "Spend \$30, save \$5 and get free shipping". It features images of various products like laundry detergent, Listerine mouthwash, and baby items. Below the banner are buttons for EASY REORDER, NEW IN PANTRY, COUPONS, DEALS, and ABOUT PANTRY. The main content area is titled "Best Sellers in Prime Pantry" and displays eight product cards:

- Nestlé Pure Life Purified Water, 16.9-ounce plastic bottle (4.5 stars, 652 reviews, \$2.48, \$0.01/liter)
- Ritz Cracker Sandwiches, Peanut Butter, 8-1.38 oz (4.5 stars, 295 reviews, \$2.78, \$0.25/ounce)
- Heinz Tomato Original Ketchup, 32 Ounce Bottles (4.5 stars, 697 reviews, \$2.88, \$0.09/ounce)
- Dole Fruit Bowls, Mandarin Oranges in 100% Fruit Juice, 4-4.2 oz (4.5 stars, 251 reviews, \$2.42, \$0.15/ounce)
- Kraft Macaroni & Cheese Dinner Cups, Original (4.5 stars, 10,553 reviews, \$3.01, \$0.17/ounce)
- Oreo Double Stuf Chocolate Sandwich Cookies (4.5 stars, 238 reviews, \$2.98, \$0.19/ounce)
- Kleenex Ultra Soft & Strong Facial Tissues, 75 Count (4.5 stars, 451 reviews, \$6.59, \$0.02/Count)
- Ultra Downy April Fresh Liquid Fabric Softener (4.5 stars, 451 reviews, \$8.38, \$0.07/load)

Each product card includes a small image, the product name, star rating, number of reviews, price, and a note indicating how much it fills of a user's box. At the bottom of the page, there are "Add to Cart" buttons for each item.

# Discovery and Browsing



Snyder's of Hanover 100 Calorie Pretzels Variety Pack, 19.8 Ounce  
by Snyder's of Hanover

\$6<sup>53</sup> (\$0.33/Ounce) [Prime Pantry](#)

Exclusively for Prime Members

Fills 16.4% of your Pantry box [\(?\)](#)

★★★★★ [92](#)

1 [▼](#)

Add to Cart



KIND Healthy Grains Granola Bars, Oats and Honey with Toasted Coconut, Gluten Free, 1.2 oz Bars, 5 Count  
by KIND

\$3<sup>15</sup> (\$0.51/Ounce) [Prime Pantry](#)

Exclusively for Prime Members

Fills 1% of your Pantry box [\(?\)](#)

★★★★★ [79](#)

1 [▼](#)

Add to Cart



Nature Valley Biscuits, Almond Butter, Breakfast Biscuits with Nut Filling, 5 Bars - 1.4 oz  
by Nature Valley

\$2<sup>50</sup> (\$0.50/Count) [Prime Pantry](#)

Exclusively for Prime Members

Only 4 left in stock - order soon.

Fills 1.2% of your Pantry box [\(?\)](#)

★★★★★ [102](#)

1 [▼](#)

Add to Cart



Wheat Thins Crackers, Reduced Fat, 14.5-Ounce Box (Packaging may vary)  
by Wheat Thins

\$3<sup>88</sup> (\$0.27/oz) [Prime Pantry](#)

Exclusively for Prime Members

Fills 2.6% of your Pantry box [\(?\)](#)

★★★★★ [84](#)

1 [▼](#)

Add to Cart

[◀ Previous Page](#)

1 2 3 ... 37

[Next Page ▶](#)

# Recommendations are not basket oriented

Larabar Gluten Free Bar, Blueberry Muffin, 1.6 oz Bars (5 Count) by LÄRABAR

★★★★★ 154 customer reviews | 2 answered questions



Customers who bought this item also bought



Larabar Fruit & Nut Food Bar Gluten Free Non-GMO Apple Pie 1.6 oz Bar (5 Count)  
★★★★★ 129  
\$4.98 PrimePantry



Larabar Gluten Free Bar, Chocolate Chip Cookie Dough, 1.6 oz Bars (5 Count)  
★★★★★ 87  
\$4.98 PrimePantry



Larabar Gluten Free Bar, Cashew Cookie, 1.7 oz Bars (5 Count)  
★★★★★ 25  
\$4.98 PrimePantry



Larabar Gluten Free Bar, Peanut Butter Chocolate Chip, 1.6 oz Bars (5 Count)  
★★★★★ 80  
\$4.98 PrimePantry



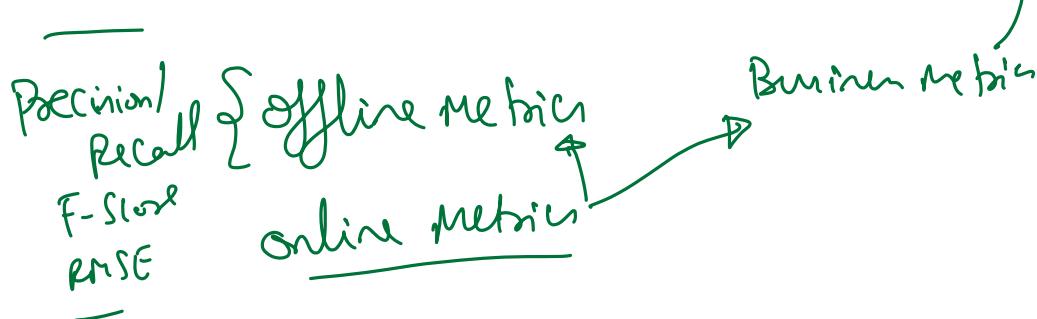
Larabar Gluten Free Bar, Peanut Butter Cookie, 1.7 oz Bars (5 Count)  
★★★★★ 61  
\$4.99 PrimePantry

# Business problem

Make it easier for a customer to fill a basket with a personalized carousel of relevant and diverse products.

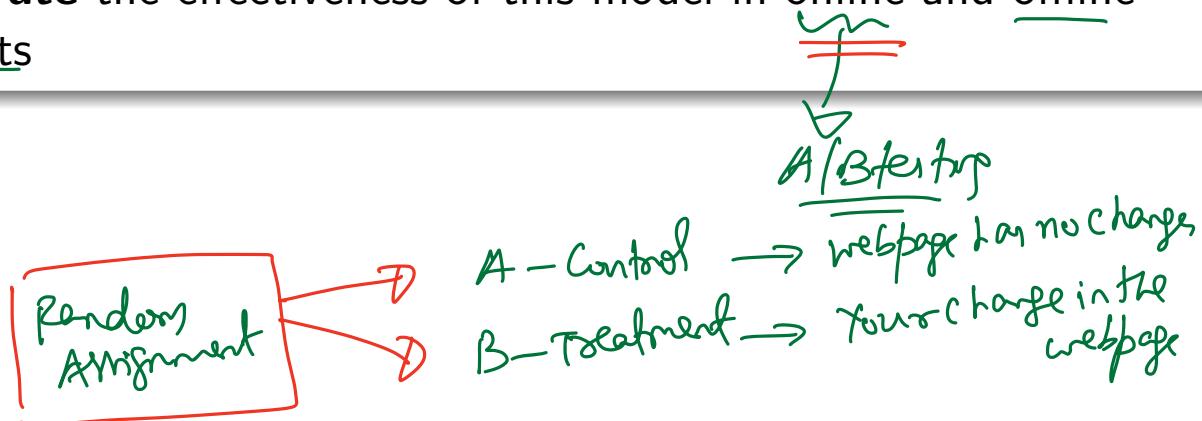
How to measure?

- Increase in units purchased per order
- Decrease in cart abandonments

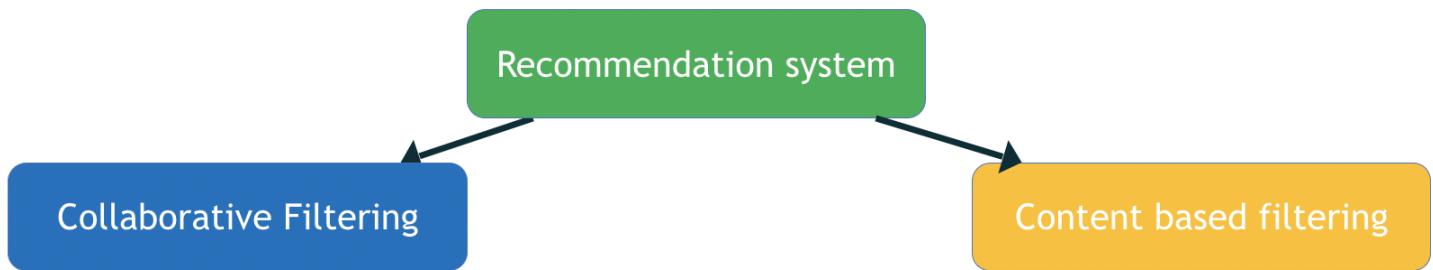


# Contributions

- **Provide** a joint relevance and diversity model for personalized basket recommendations
- **Demonstrate** the effectiveness of this model in online and offline experiments



# Traditional Recommendation Systems



# Traditional Recommendation Systems

Collaborative Filtering

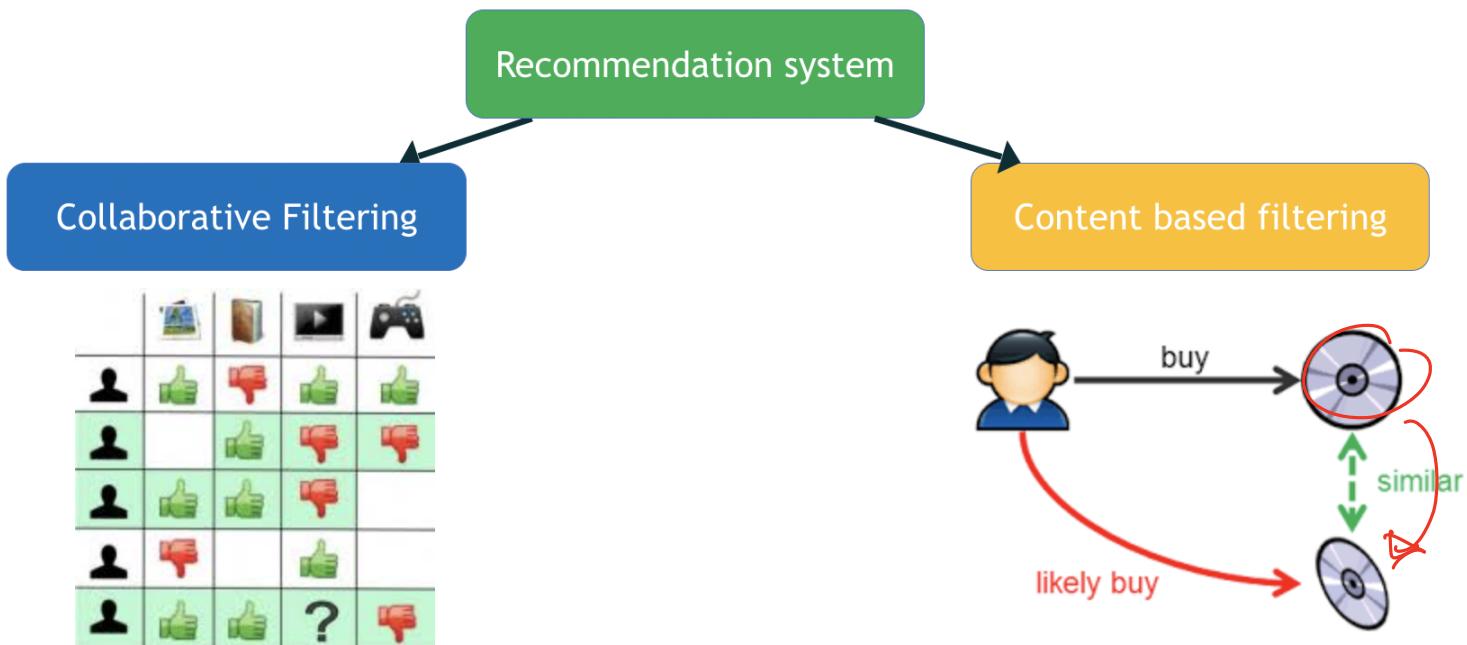
Recommendation system

Content based filtering

	Book	Book	Movie	Game
User 1	Like	Dislike	Like	Like
User 2		Like	Dislike	Dislike
User 3	Like	Like	Dislike	
User 4	Dislike		Like	
User 5	Like	Like	?	Dislike

(Behavior)

# Traditional Recommendation Systems

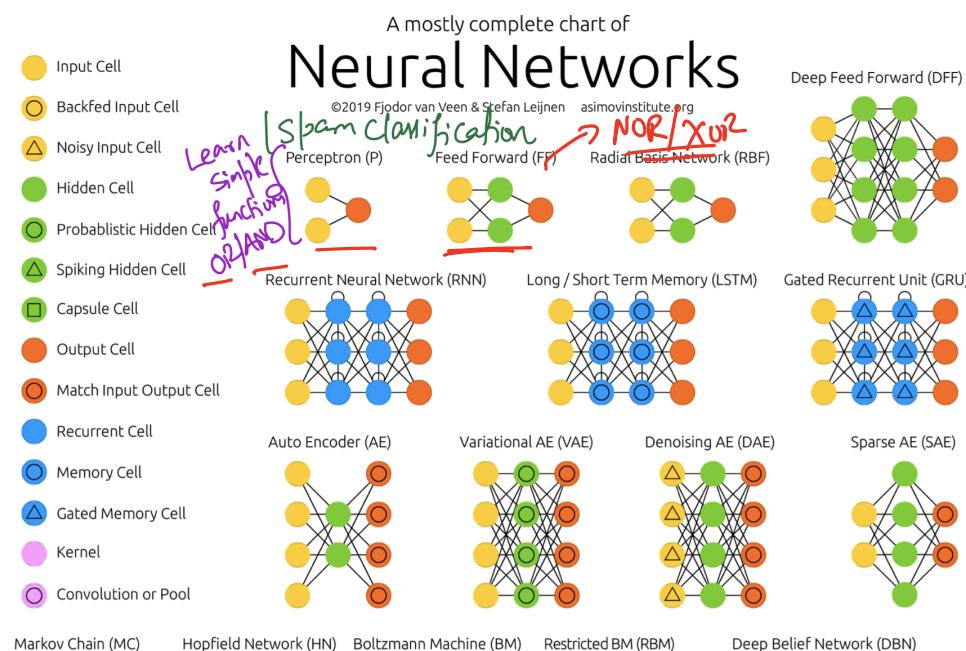


# Deep Learning for Recommendation Systems

- YouTube
- Netflix
- Yahoo News
- Amazon Videos
- Pantry Basket recommendations
- Fresh recommendations
- More!?

# Quick tour of DL Architectures

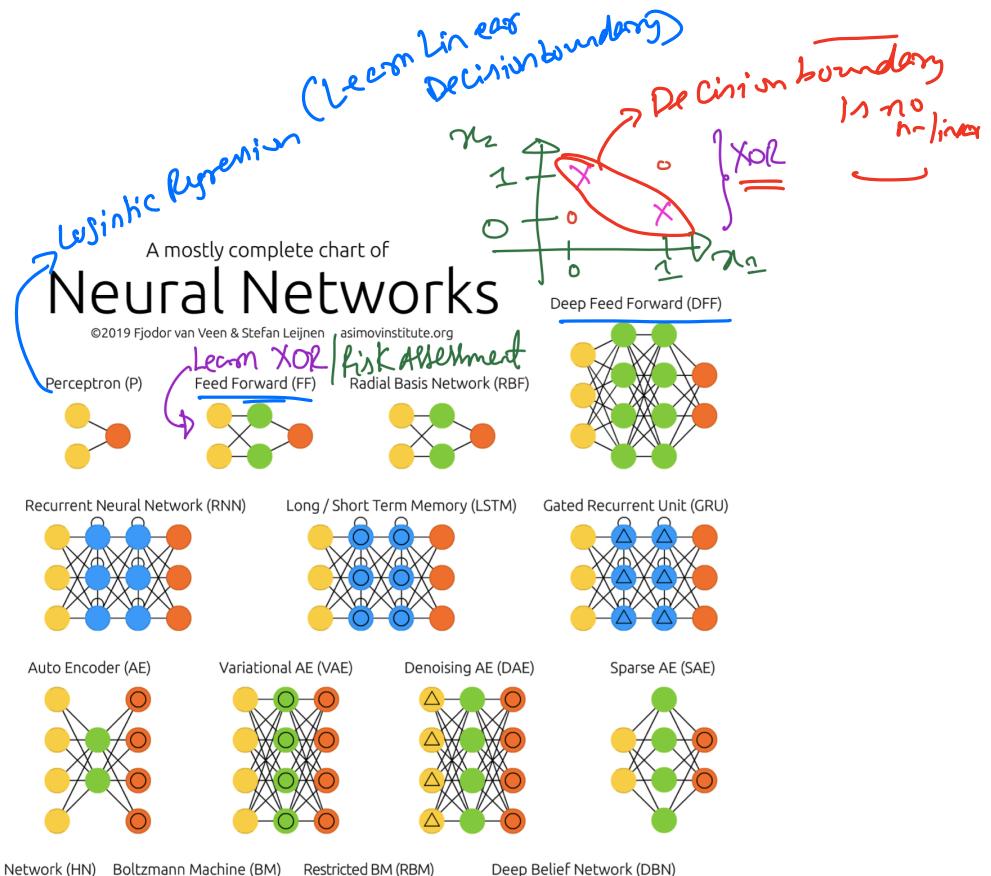
## Neural Networks Zoo



# Quick tour of DL Architectures

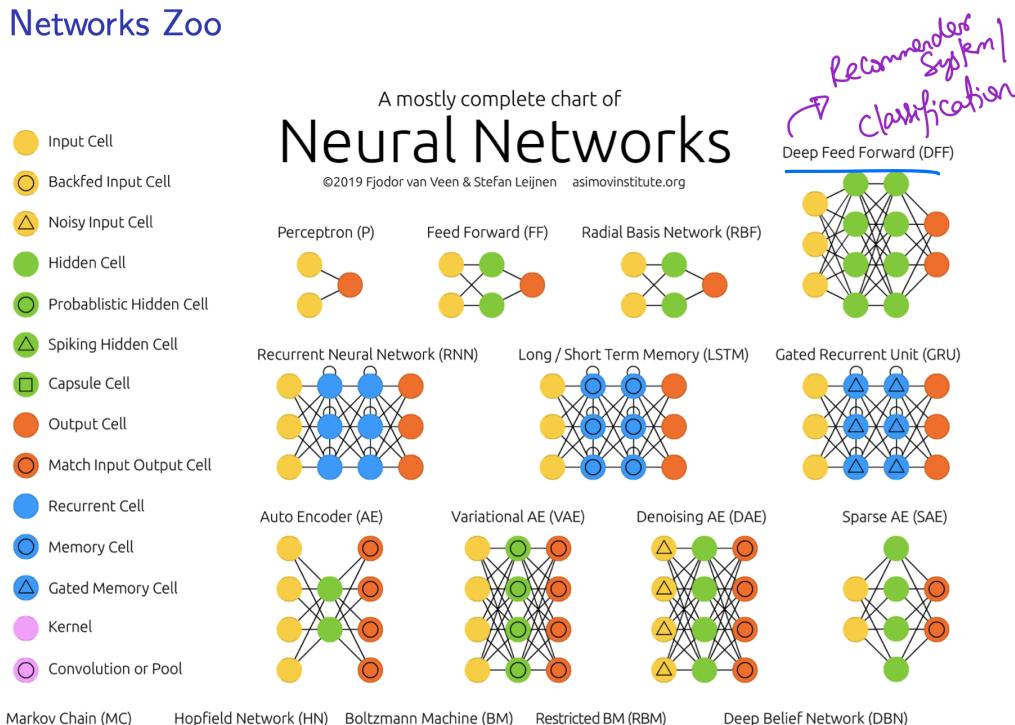
## Neural Networks Zoo

- Input Cell
- Backfed Input Cell
- △ Noisy Input Cell
- Hidden Cell
- Probabilistic Hidden Cell
- △ Spiking Hidden Cell
- Capsule Cell
- Output Cell
- Match Input Output Cell
- Recurrent Cell
- Memory Cell
- △ Gated Memory Cell
- Kernel
- Convolution or Pool



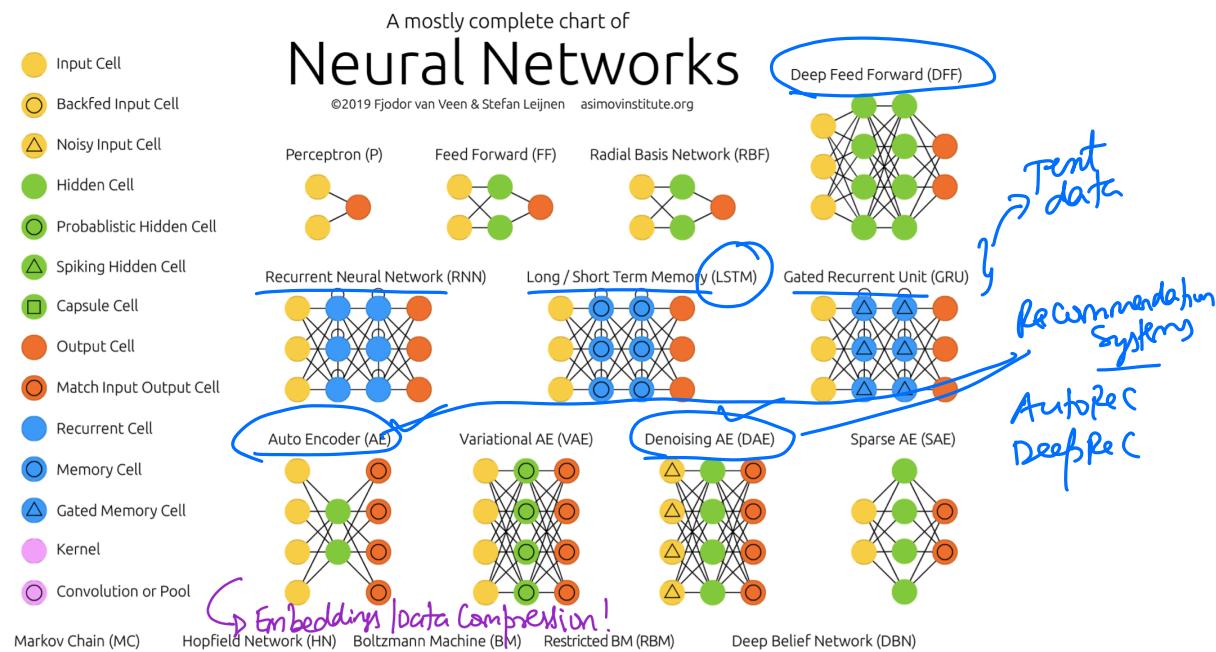
# Quick tour of DL Architectures

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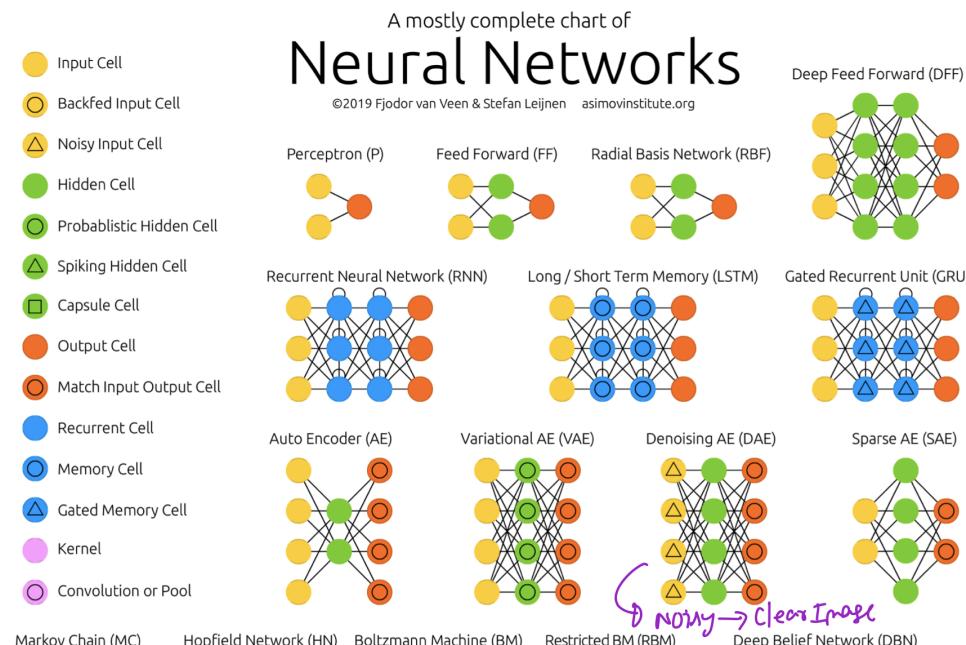
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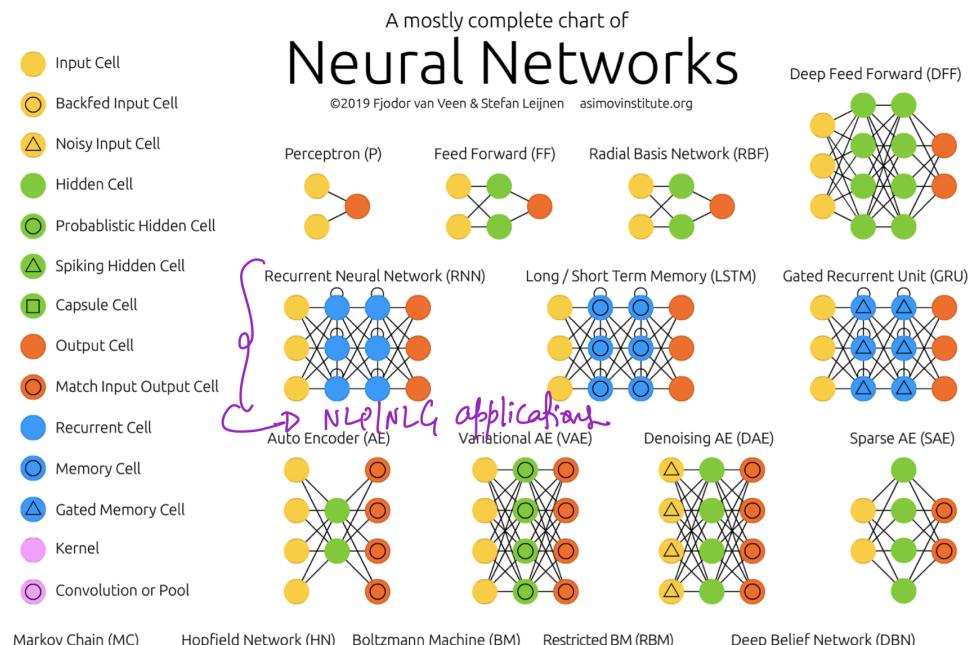
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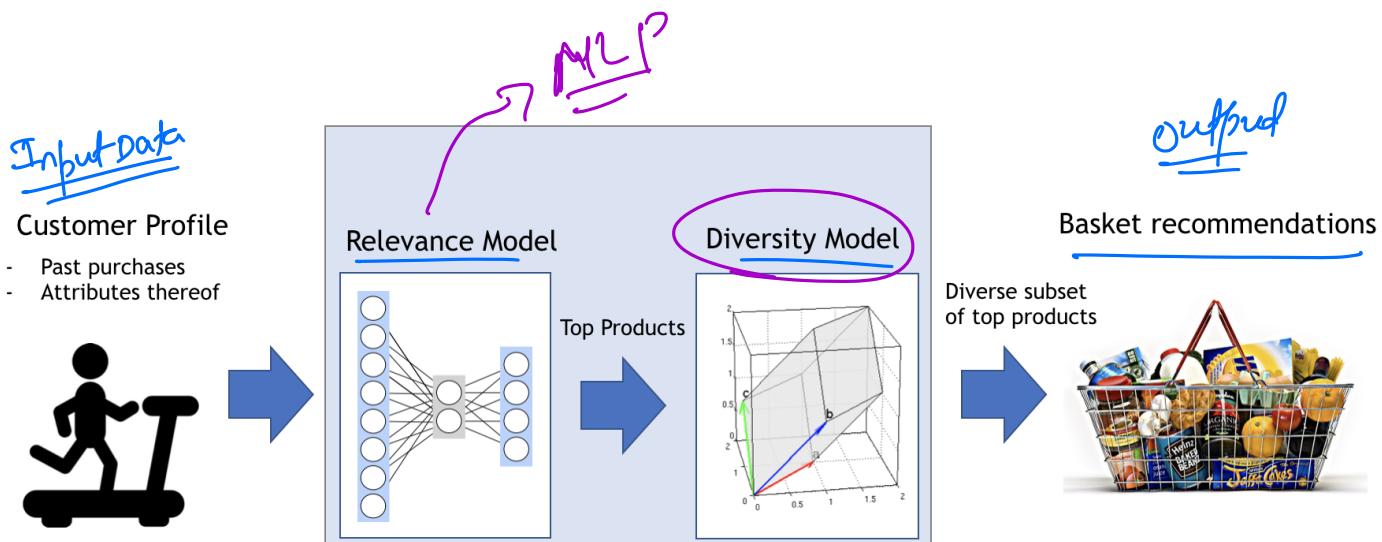
# Deep Learning for Recommendation Systems

- Auto-Encoders (Non-linear MF) ✓
- Multi-layer perceptron (MLP) [YouTube] (FFN) → Today!
- Deep semantic structured models (DSSM) (Next Lec)
- Sequence models based on RNN (recs within session) (Tent Data)
- Other models (e.g. wide and deep learning) [Google]

# Deep Learning for Recommendation Systems

- Auto-Encoders (Non-linear MF)
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- Deep semantic structured models (DSSM)
- Sequence models based on RNN (recs within session)
- Other models (e.g. wide and deep learning) [1]

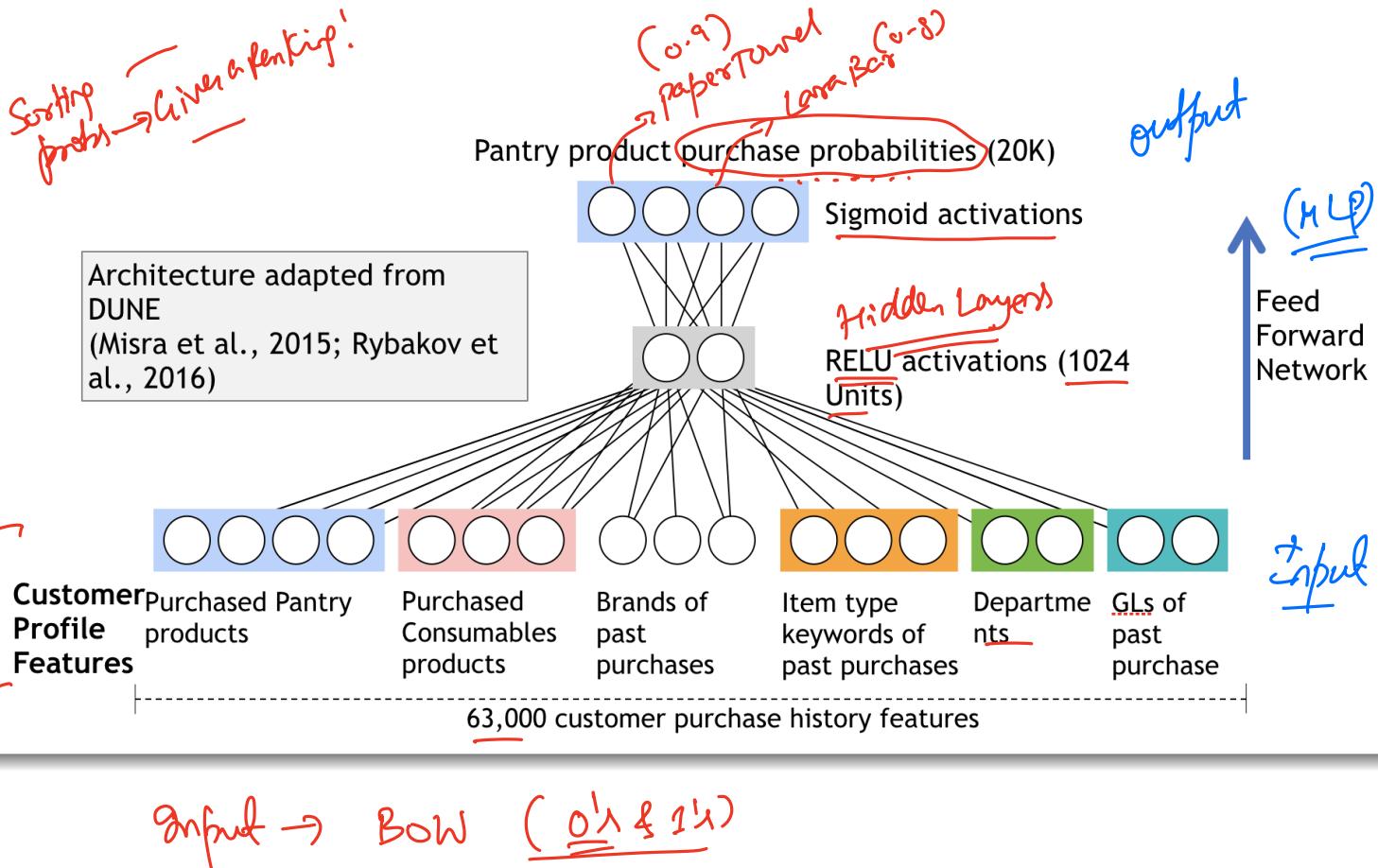
# Joint Relevance and Diversity Model for Pantry Recommendations



Balancing relevance and diversity for prime pantry recommendations. Mohan et al. AMLC 2017

# Relevance Model

# Relevance Model



## Precision @ K vs Precision

Recs                                  Purchase (Truth)  
  

  
 product IDs                              product IDs  
 $\text{Precision} = \frac{\text{Recs} \cap \text{Purchase}}{|\text{Recs}|} = \frac{2}{3}$

$$\text{Recall} = \frac{\text{Recs} \cap \text{Purchase}}{|\text{Purchase}|} = \frac{2}{4}$$

$$\text{Precision@2} = \frac{1}{2}$$

$$\text{Recall@2} = \frac{1}{4}$$

---

Precision High, Recall is Low  $\Rightarrow$  Model is not having coverage

E.g.

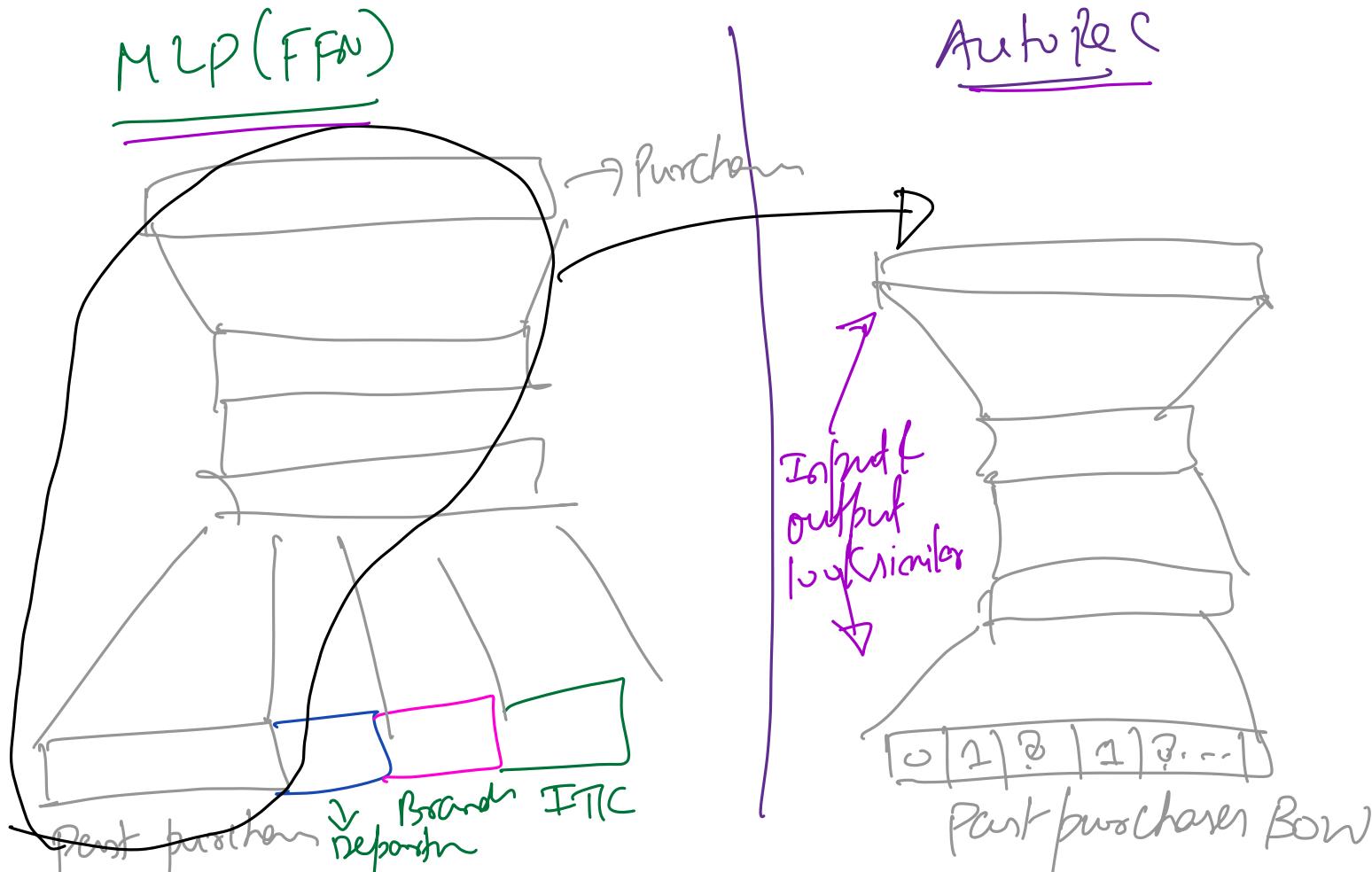
Recs                                  Purchase  
  


$$\text{Precision} = \frac{2}{2} = 100\% \quad (\text{Accuracy})$$

$$\text{Recall} = \frac{2}{8} = 25\% \quad (\text{Coverage})$$

$$F\text{-Score} = \frac{2 \cdot PR}{P+R} \quad (\text{Harmonic mean})$$

# MLP vs AutoEncoder (AutoRec)



# Diversity Model

# Embeddings for Products

2D Reproject



Represent products in product space with a large matrix of embedding coordinate vectors "L"

$$L = \begin{pmatrix} 1.5 & 1.9 & 1.8 & 1.4 & \cdots & 0.4 \\ 0.6 & 0.1 & 1.0 & 1.6 & \cdots & 1.9 \\ 0.6 & 1.6 & 1.6 & 1.6 & \cdots & 1.8 \\ 0.6 & 1.0 & 0.1 & 1.6 & \cdots & 0.6 \\ 0.8 & 1.4 & 1.9 & 0.8 & \cdots & 0.7 \end{pmatrix}$$

Go GL

We obtain these embedding vectors from the Product2Vec service [London et al, 2017]

# Diversity Subset Selection through DPP

$$S_{ij} \rightarrow \begin{matrix} \text{Similarity between} \\ \text{product } i \text{ & product } j \end{matrix}$$
$$= L_i^T L_j$$

## Similarity matrix

Let  $L$  be the Product2Vec embeddings.  $S = L^T L$  is the similarity matrix of the asins.

## Determinantal point processes (DPP)

DPP [3] is a probability distribution over subsets of a ground set.

$$\mathcal{P}(J) \propto \log(\det(S_J))$$

## Diversity and DPP

DPP favors sets that are more diverse.

[2] London et al. Product2Vec: A multi-task learning framework for cold-start product recommendation. AMLC 2016

[3] Kulesza et al. Determinantal point process for machine learning. Foundations and trends in ML, 2012

# Visualizing Determinants

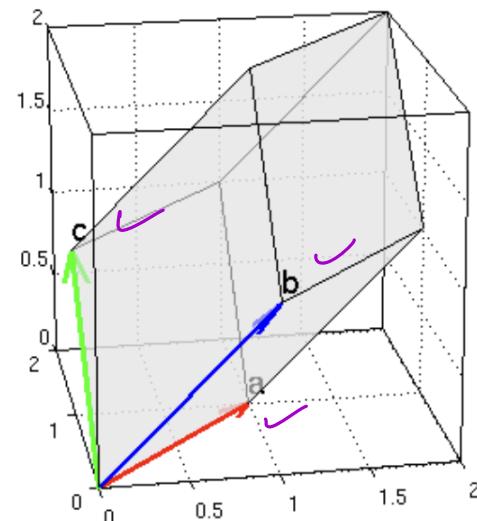
Larger the volume  $\Leftrightarrow$  more dimensionality!

Given product vectors { a, b, c } and matrix

$$L = \begin{pmatrix} | & | & | \\ a & b & c \\ | & | & | \end{pmatrix}$$

the determinant of  $LL^T$  is the squared volume of the parallelogram.

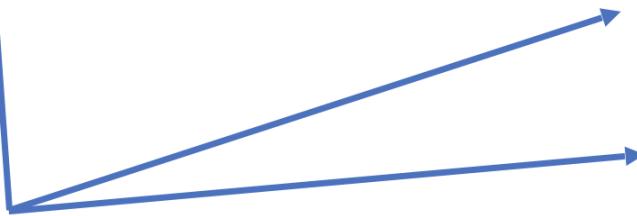
$$\det(\underline{LL^T}) = \underline{\underline{\text{Vol}}}^2$$



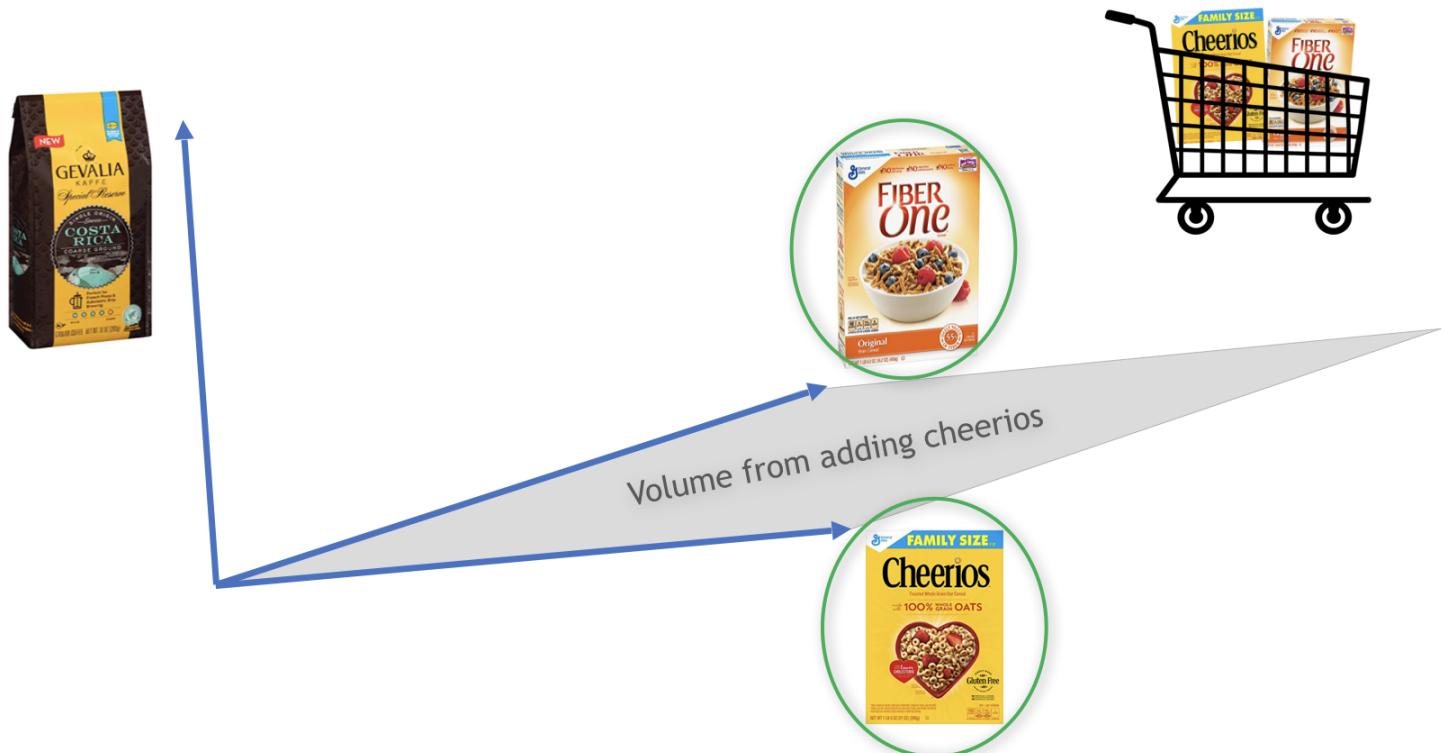
# Diversity through Determinants



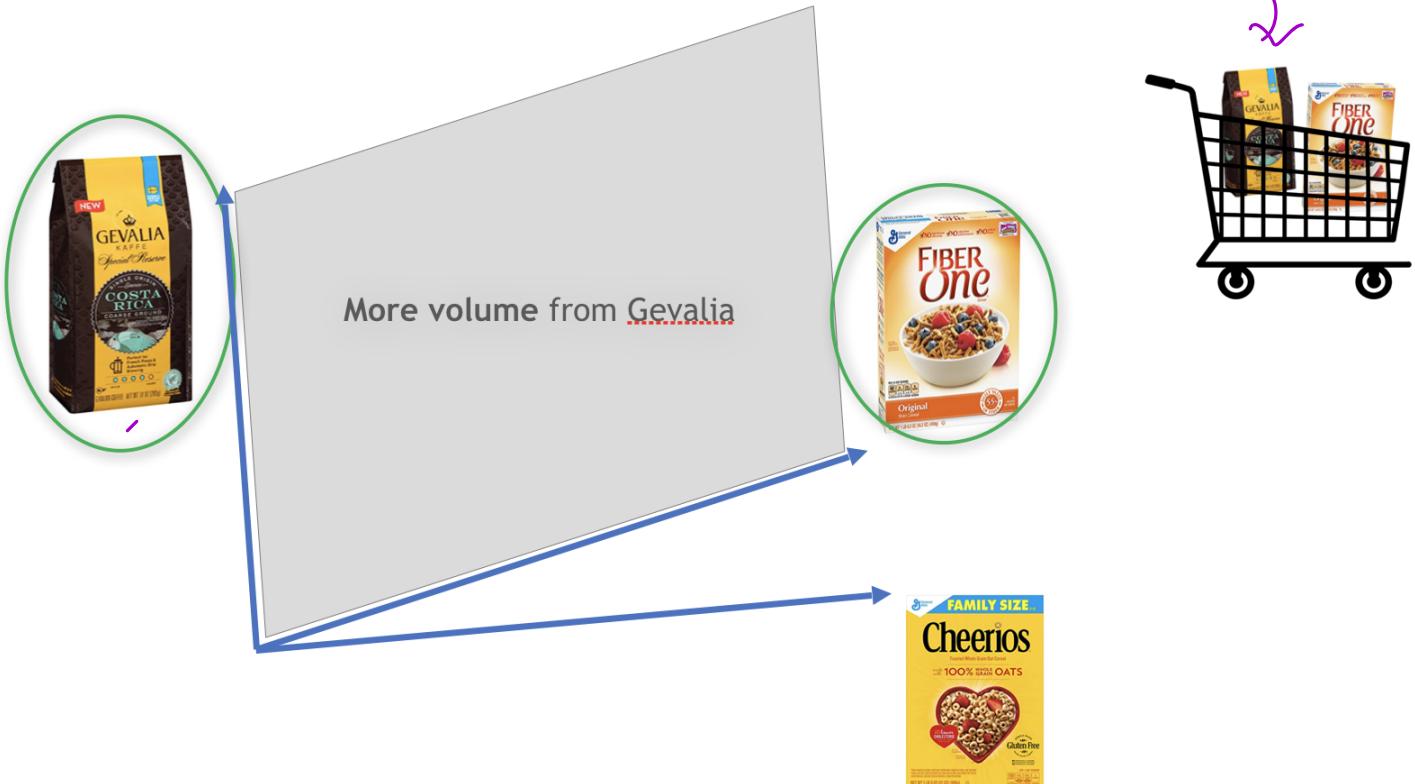
# Diversity through Determinants



# Diversity through Determinants



# Diversity through Determinants



# Trading-off Relevance and Diversity

Optimization objective  
strikes a balance

$$\max_{J:|J|=k} \sum_{j \in J} r_j$$



The  $r_j$  are scores  
from the relevance  
model

(prob, 1 score)  
====

# Trading-off Relevance and Diversity

Optimization objective  
strikes a balance

$$\max_{J: |J|=k} \sum_{j \in J} r_j + \lambda \log \det \left( \sum_{j \in J} L_j L_j^T + \gamma \mathcal{I} \right)$$

Trade-off parameter



Diversity

The  $r_j$  are scores  
from the relevance  
model

log-det measures  
diversity of the  
set

# Trading-off Relevance and Diversity

Optimization objective  
strikes a balance

$$\max_{J:|J|=k} \sum_{j \in J} r_j + \lambda \log \det \left( \sum_{j \in J} L_j L_j^T + \gamma \mathcal{I} \right)$$



Trade-off  
parameter



Smoothing  
parameter

The  $r_j$  are scores from  
the relevance model



log-det measures  
diversity of the set

Hyper-parameter

# Optimizing the trade-off

## Hardness of mode-finding

Mode-finding in DPP is NP-hard [4]. Hence, maximizing the joint relevance-diversity objective is also NP-hard.

## Approximation algorithm

We provide a  $(1 - 1/e)$ -approximation algorithm to find the optimal sub-set of the joint relevance-diversity optimization problem.

# Greedy Algorithm for Subset Selection (GDPP)

Initialize

Initialize set  $\mathbf{J}$  with the most relevant asin.

*product*

Iterate until  $|\mathbf{J}| = K$

- ▶ Pick asin  $j$  that has the appropriate balance between relevance and diversity:

$$j \leftarrow \arg \max_{k \notin \mathbf{J}} \left( r_k + \lambda \log \det(L_{\mathbf{J}} L_{\mathbf{J}}^T + L_k L_k^T + \gamma \mathcal{I}) \right)$$

- ▶ Add asin  $j$  to set  $\mathbf{J}$ .

# Greedy Algorithm for Subset Selection (GDPP)

## Initialize

Initialize set  $\mathbf{J}$  with the most relevant asin.

## Iterate until $|\mathbf{J}| = K$

- Pick asin  $j$  that has the appropriate balance between relevance and diversity:

$$j \leftarrow \arg \max_{k \notin \mathbf{J}} \left( \mathbf{r}_k + \lambda \log(1 + \mathbf{L}_k^T (\mathbf{L}_J \mathbf{L}_J^T + \gamma \mathcal{I})^{-1} \mathbf{L}_k) \right)$$

- Add asin  $j$  to set  $\mathbf{J}$ .

Relevance of ASIN  
 $k$

Efficient computation via  
rank-1 updates

# Greedy Algorithm for Subset Selection (GDPP)

## Theorem (GDPP approximation)

*GDPP enjoys a  $(1 - 1/e)$ -approximation guarantee in optimizing the joint relevance diversity objective.*

### Proof.

We note that the diversity part of the objective is submodular and monotone increasing. Since the relevance sum,  $\sum_{k \in J} r_k$  is modular and monotone increasing, the joint relevance-diversity objective is submodular and monotone increasing. The result thus follows from Nemhauser et al [4] □

Nemhauser et al. An analysis of approximation algorithms for maximizing submodular set functions. 1978.

# Diversity Algorithm Walkthrough



# Visualizing selection process



# Visualizing selection process



==

↑

most relevant  
product  
(!)

# Visualizing selection process



# Visualizing selection process



# Visualizing selection process



# Visualizing selection process



# Visualizing selection process



ShowCase to Customer  
—Relevant yet diverse!

# Free-shipping A/B test

- Prime Pantry charges \$5.99 per box ordered
- Pantry offers sponsored products which qualify customers for free shipping

*“Buy 5 Select Items Get Free Shipping”*

- Help Prime Pantry customers find qualifying products through personalized recommendations

# Control

## Control Experience

- Free ship product carousels by category
- Categories ordered by popularity
- No personalized carousels



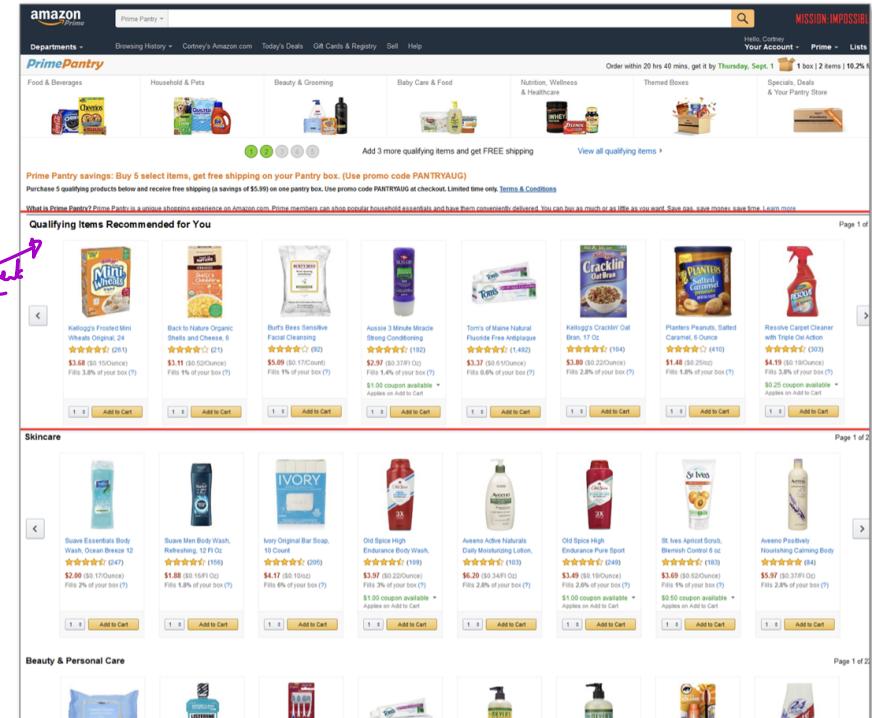
The screenshot shows the Amazon Prime Pantry interface. At the top, there's a navigation bar with links for Prime Pantry, Departments, Browsing History, Crisis... on Amazon.com, Today's Deals, Gift Cards & Registry, Sell, Help, Hello, California!, Account & Lists, Orders, Prime, and Cart. A banner at the top right says "Shop 100+ deals From Crock-Pot, FoodSaver, Graco, and more". Below the banner, there are sections for Food & Beverages, Household & Pets, Beauty & Grooming, Baby Care & Food, Nutrition, Wellness & Healthcare, and New to Pantry. A message encourages adding 5 qualifying items for free shipping. The main content area displays two rows of products under the "Household Cleaning" and "Snacks" categories, each with an "Add to Cart" button.

# Treatment

## Treatment

- Personalized carousel at the top of the page with qualifying items recommended by model

*"Qualifying Items Recommended for You"*



# A/B test outcome

Metric	Percentage change	P-value
Units metric	x% increase	0.001 *
Session metric	y% decrease	0.004 *
Pantry metric	z% increase	0.001 *

{  
Business metrics}

Statistical significant

# Summary

- MLP / FFN (Extension of AutoRec)
- Relevance & Diverse Model (jointly)
- offline Testing (Train / val / test)  
& online Testing (A/B Test)
- Improvement in offline metrics  
Precision / Recall / F-1 Score  
& business metrics

---

## Other facets

1. Training Schedule
2. Training time opt

3. Inference time optimization
4. Cold-start customers