

Natural Language Processing

Recommendation Systems

From the engineering point of view

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Readings

- Dan Jurafsky, Stanford University, CS 124, [Recommender Systems lectures](#)

What recommender systems are?

Can you think of examples?

What recommender systems are?

The most obvious example is "similar items" on shopping sites, or media platforms

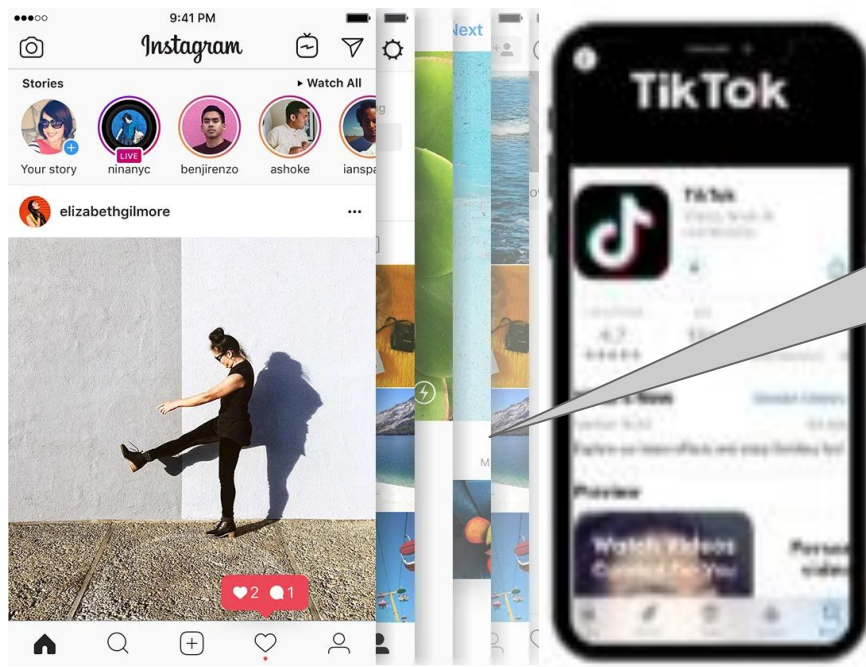


Relatively simple, in most cases not "personalized", i.e. all users see the same recommendation



What recommender systems are?

Social media feeds



Personalized for every user

What recommender systems are?

Search Ads

digital camera SafeSearch off ▾
Advanced search

About 272,000,000 results (0.21 seconds)

Lumix Digital Cameras - Capture the moments that matter Ads
www.panasonic.co.uk/Lumix_Digital
Find the complete Lumix Range here.

Digital Cameras At ASDA | ASDA.com
www.asda.com/Cameras
asda.com is rated ★★★★★ 216 reviews
Great Offers On Our Range Of **Digital Cameras**. Buy Yours Today!

Low price Digital Cameras - Get an Amazing deal on Cameras
www.moneysupermarket.com/Cameras
Compare all retailers & Save money

Compact Digital Cameras - Jessops
www.jessops.com › Cameras › Compact Digital Cameras - Cached
20+ items – Compact **Digital Cameras** - Cameras - Jessops. Buy online and ...
• Canon Powershot SX210 IS **Digital Camera** in Black – 14x Wide Zoom – 3.0 ...
• Canon Powershot S95 **Digital Camera** – 10 Megapixels – 3.8x f2 Optical Zoom
• Olympus SZ-20 **Digital Camera** in Black - only at Jessops – 12.5x Super Wide ...

Amazon.co.uk: Digital Cameras: Point & Shoot Digital Cameras...
www.amazon.co.uk/Digital-Cameras...Photography-Bundles/b?... - Cached
Results 1 - 24 of 5287 – Online shopping for **Digital Cameras** from a great selection of Electronics; Point & Shoot **Digital Cameras**. Digital SLRs, Compact System ...

What Digital Camera. digital camera reviews and photography tips...
www.whatdigitalcamera.com/ - Cached
What **Digital Camera** magazine, featuring **digital camera** reviews, **digital camera** best

Ads
1/2 Price Digital Cameras
www.littlewoods.com/DigitalCameras
Great Range of **Digital Cameras**
Buy Now and Pay Later - Littlewoods

Amazon Cameras
www.amazon.co.uk/cameras
amazon.co.uk is rated ★★★★★
Save on **Digital Cameras** and SLR.
Free UK Delivery on Amazon Orders

10 MP Digital Cameras
www.viking-direct.co.uk/10MP
viking-direct.co.uk is rated ★★★★★
Buy 10MP **Digital Cameras** at Viking
Buy Now for Next Day Delivery

Digital Camera Store
www.connscameras.ie/Digital_Cameras
Buy Compact or SLR **Digital Camera**,
Irelands Leading **Camera** Store!

Digital Cameras At Very
www.very.co.uk/DigitalCameras
Buy Now Pay Later **Digital Cameras**
at Very & Grab a Great Deal Today!

Customized for user and query
Complicated auction computation

Search ads auction

Predicted Click-Through-Rate (pCTR)

The image shows a search engine results page for the query "digital camera". The search bar at the top contains "digital camera" and a search button. Below the search bar, it says "About 272,000,000 results (0.21 seconds)". The results are divided into "Organic" and "Ads" sections. Two callout boxes are overlaid on the page, pointing to specific ads and providing their bid and predicted click-through rate (pCTR) values, along with the resulting expected revenue calculation.

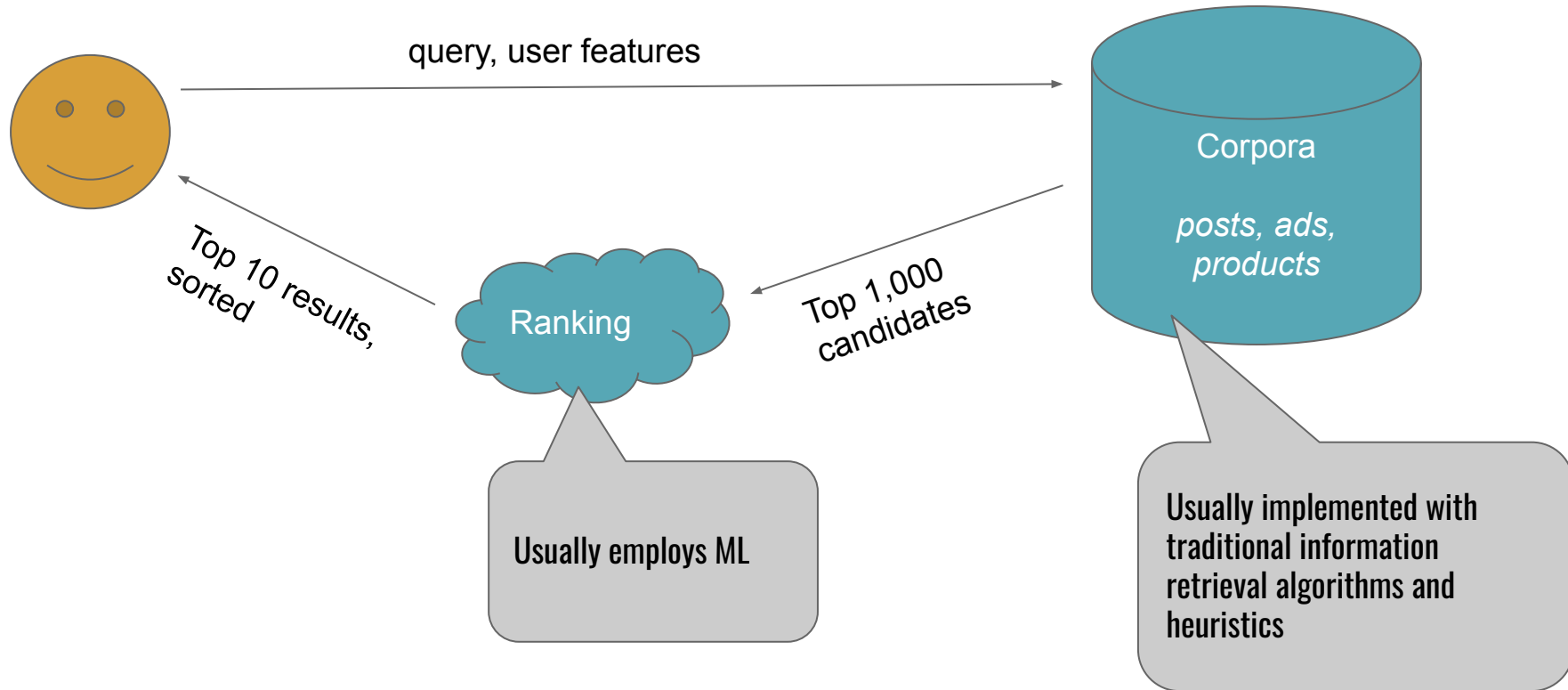
Callout 1 (pointing to the first ad):
 Bid: 10¢
 p(click): 5%
 expected revenue: $10 * 0.05 = 0.5\text{¢}$

Callout 2 (pointing to the second ad):
 Bid: 20¢
 p(click): 1%
 expected revenue: $20 * 0.01 = 0.2\text{¢}$

The ads shown include:

- 1/2 Price Digital Cameras** (wonders.com/DigitalCameras): Great Range of Digital Cameras. Buy Now and Pay Later - Littlewoods.
- Amazon Cameras** (amazon.co.uk/cameras): Save on Digital Cameras and SLR. Free UK delivery on Amazon Orders.
- 10 MP Digital Cameras** (viking-direct.co.uk/10MP): Buy 10MP Digital Cameras at Viking. Buy Now for Next Day Delivery.
- Digital Camera Store** (connscameras.ie/Digital_Cameras): Buy Compact or SLR Digital Camera. Irelands Leading Camera Store!
- Digital Cameras At Very** (very.co.uk/DigitalCameras): Buy Now Pay Later Digital Cameras at Very & Grab a Great Deal Today!

Recommender system task definition



Serving scale challenges

Typical usage stats for popular social media platforms:

- Over a billion of users
- Peaks at >500K requests per second
- Has >1,000K candidates to score for each request
- Needs to perform >500M inferences per second to serve the global user traffic

Serving infrastructure costs many millions of dollars. Must be deployed all over the world, including in countries under sanctions.

Cannot naively use big NLP models, such as BERT, GPT-3, etc.

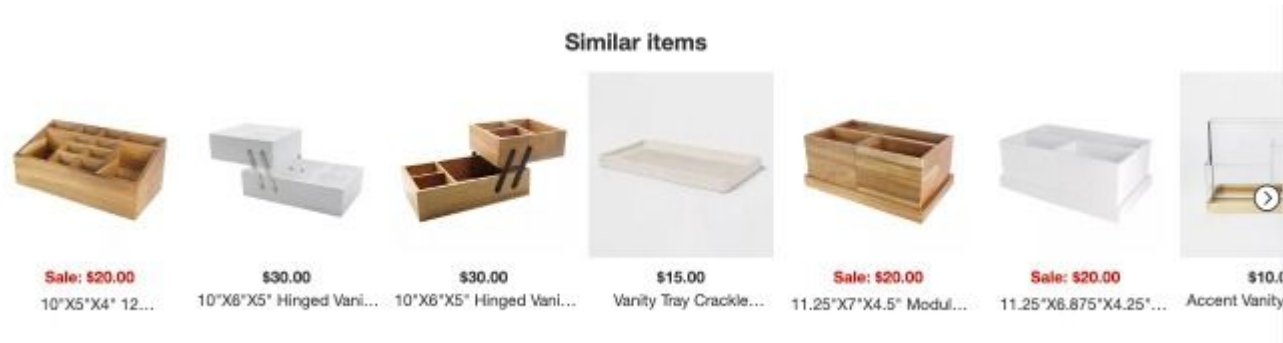


Objective function

When using ML you need to figure out the objective function

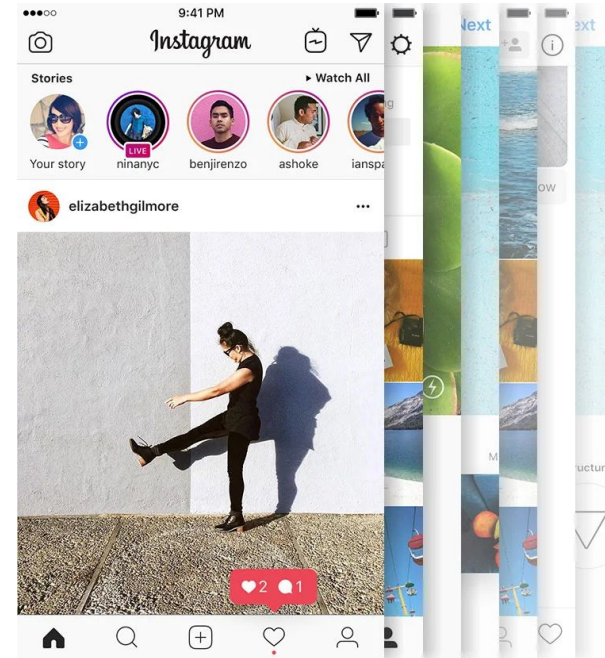
For shopping recommendations it is relatively simple:

What items are purchased after viewing this item



Objective function

How do you define the objective function for ranking social media posts?



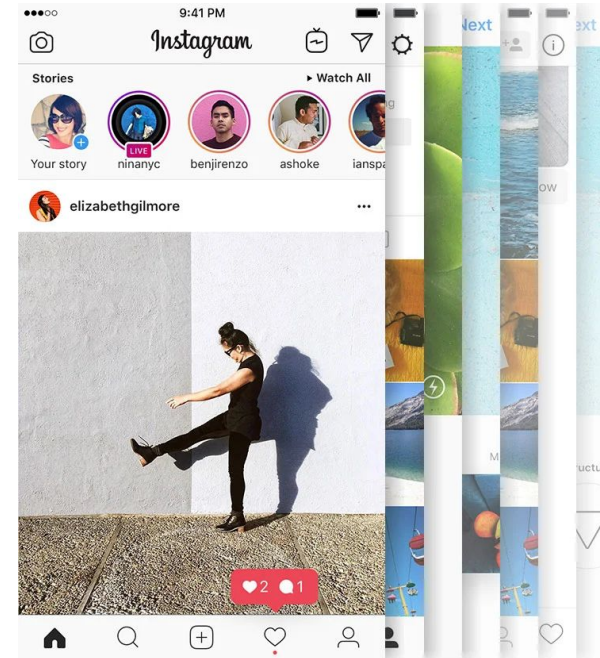
Objective function

How do you define the objective function for ranking social media posts?

What are we optimizing for?

Possible candidates

- Maximize the time spent in the app scrolling the posts
- User spent more time reading the post
- Maximize user engagement, such as "like" button clicks, comments/replies



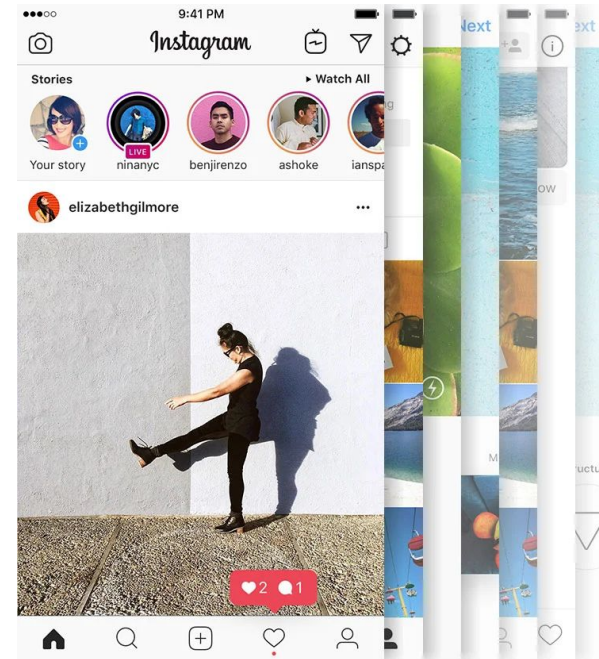
Objective function

Usually requires complicated models with lots of features and multi-objective functions, which are kept in secret.

If users spend a few minutes longer per day in the app, the company will make many billions more \$\$\$ in advertising revenues

It's important to optimize for long-term user happiness.

Companies fight hard to hire ML researchers and infrastructure people



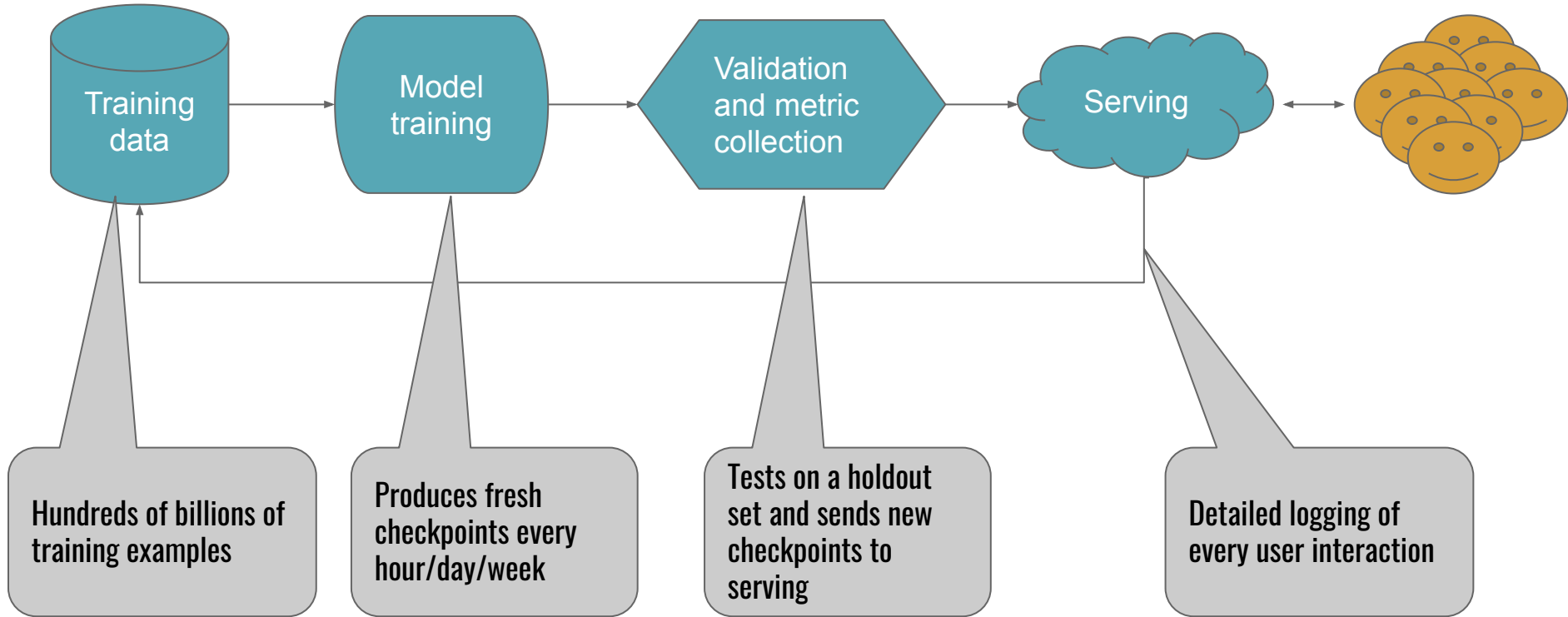
Non-stationary problem

User behavior and the meaning of keywords changes very rapidly. Model quality degrades within days

- World news
 - Science, politics, wars, pandemics, economic and social issues
- Popular events
 - Black Friday, Back-to-School, Oscars, Grammys, Worldcup, Super Bowl
- Trends
 - Fashion, Flashmobs, New art releases



Online training



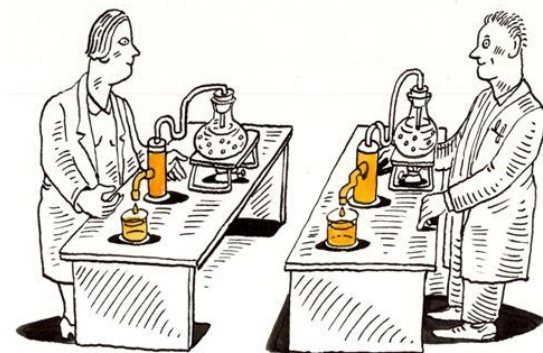
Common issues with model quality

- Model instability
 - Hyperparameters, such as learning rate, are tuned very close to the breaking point to pick up user behavior changes very quickly
 - Usually requires some form of weight normalization and gradient clipping



Common issues with model quality

- Reproducibility
 - A retrain of a model should yield the same accuracy up to 0.01%, otherwise ML researchers can't experiment with new models
 - Due to the distributed nature of training infrastructure the training sample visitation is not deterministic
 - Non-stochastic properties of Deep Neural Networks
 - See [Reproducibility in Deep Learning and Smooth Activations](#)



Common issues with model quality

- Ingestion of bad data + ripple effects
 - Happens when an upstream system misbehaves, e.g. the "buy" button gets broken for several hours, which skews the training data
 - The model starts making wrong predictions and new logs get poisoned as well
 - This creates a ripple effect that is very hard to deal with. Usually requires reverting to older checkpoints and isolating large ranges of training data.



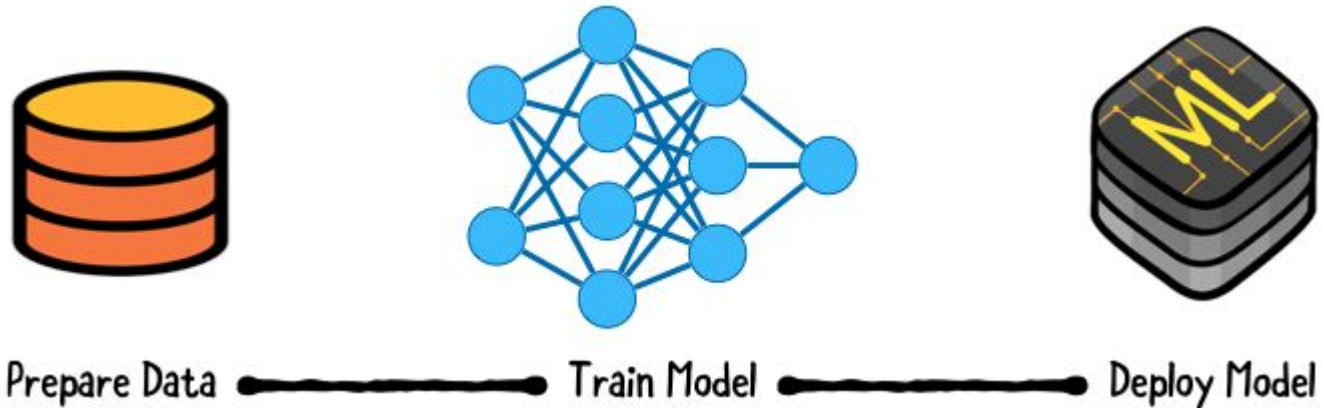
Common issues with model quality

- Feedback loop problem
 - A freshly-trained model performs poorly when it starts serving user traffic for the first time
 - It has not seen enough bad examples, because it was trained only on data that was filtered by previous iterations of the model



Part II

Model training



Training data

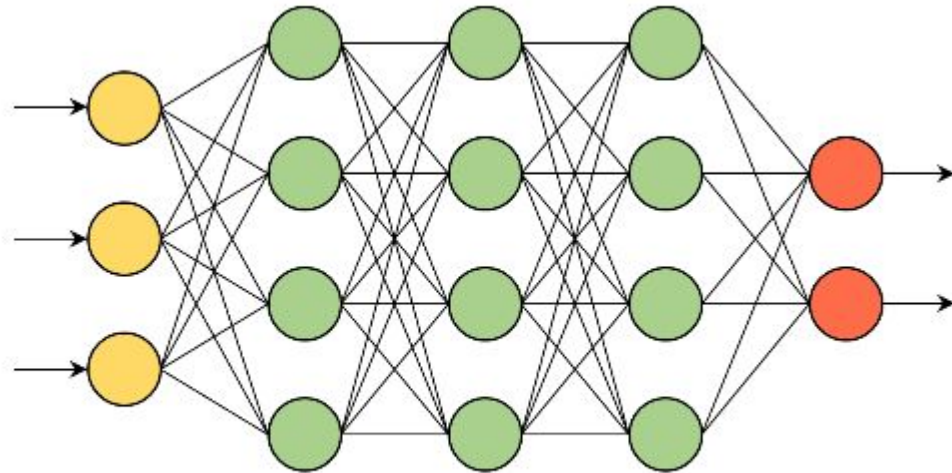
Input data

User:

*User preferences,
Language, Region,
Browser, device, ...*

Post/Ad/Product:

*Creators, title,
content, price, rating*



Input layer

Hidden layers

Output layer

Labels

User interactions:

*Post viewed
Time spent viewing
the post
Like button clicked
Comment left*

Training data

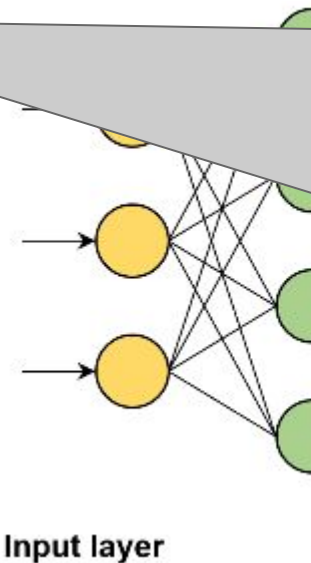
Input data

User:

*User preferences,
Language, Region,
Browser, device, ...*

Post/Ad/Product:

*Creators, title,
content, price, rating*



Hundreds of features, a lot of textual information.

Need to make sure that features are available at serving time. E.g. whether the user clicked on the post is not a good feature.

Deep Neural Networks work with vectors of floating point numbers, not with text, especially not with variable-length features

Heavy usage of embedding tables

If computation capacity allows in serving sequences can be processed using large language models, such as Bert, GPT-3

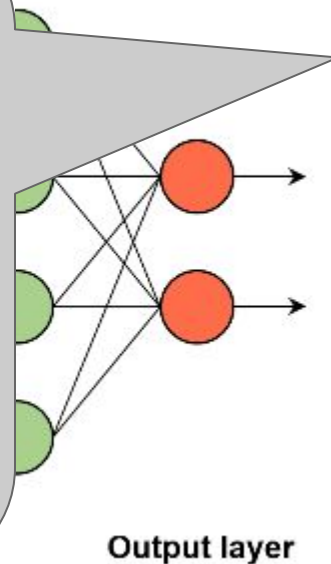
Embeddings are also useful for memorizing non-textual information

Training data

Labels are often binary indicator whether an event happened or not.
E.g. whether the user clicked on the "like" button.

However, the model outputs the probability of an event.
E.g. the probability that the user clicks on the like button is 0.0343

This means that the losses are always high, even when the model is well trained.



Labels

User interactions:

Post viewed

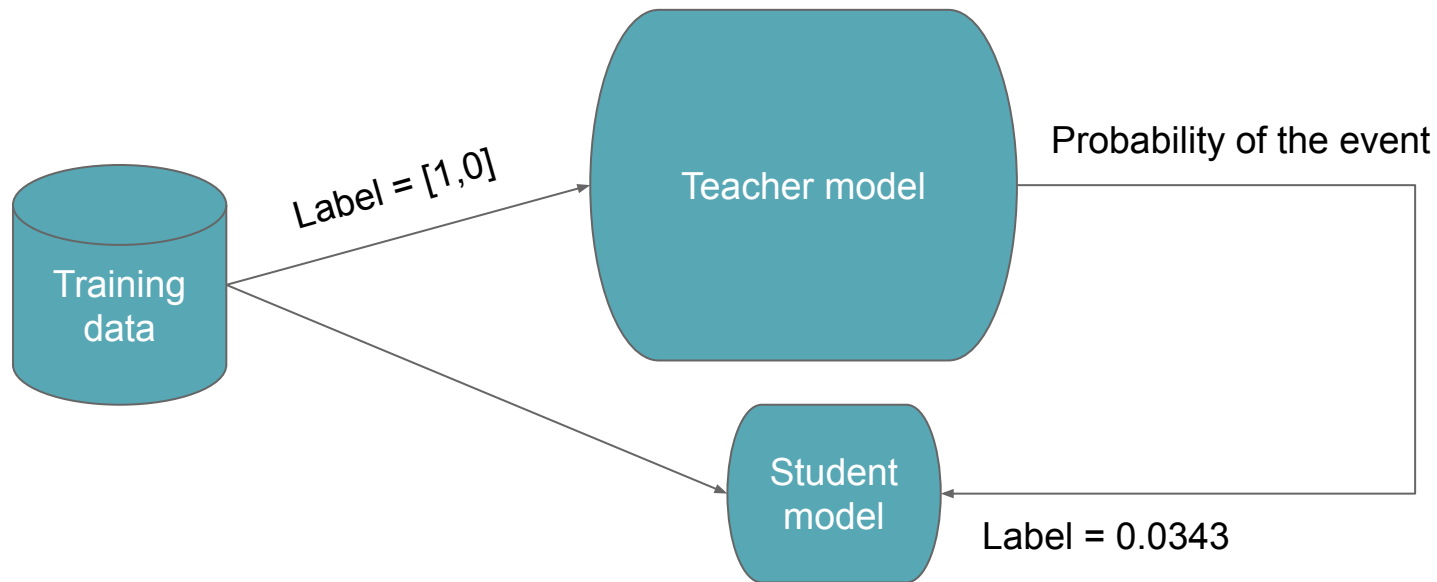
*Time spent viewing
the post*

Like button clicked

Comment left

Teacher - student

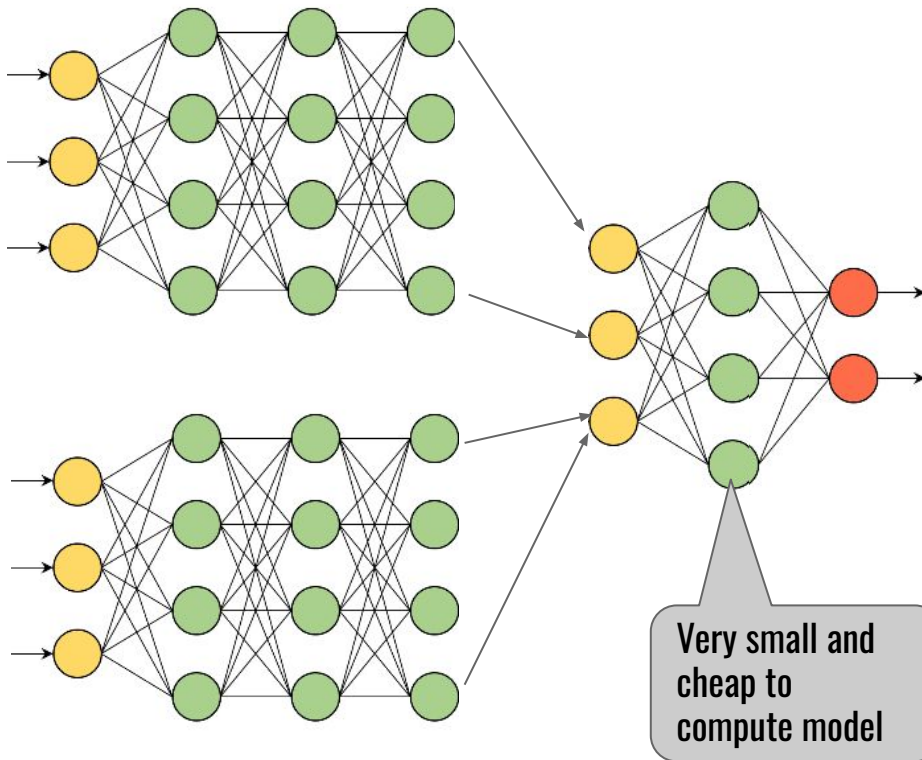
We can train a much bigger model that is unviable for serving and use it as a "teacher" for a production model.



Splitting models

User model:

*User preferences,
Language, Region,
Browser, device, ...*



Post/Ad/Product model:

*Creators, title,
content, price, rating*

Labels

User interactions:

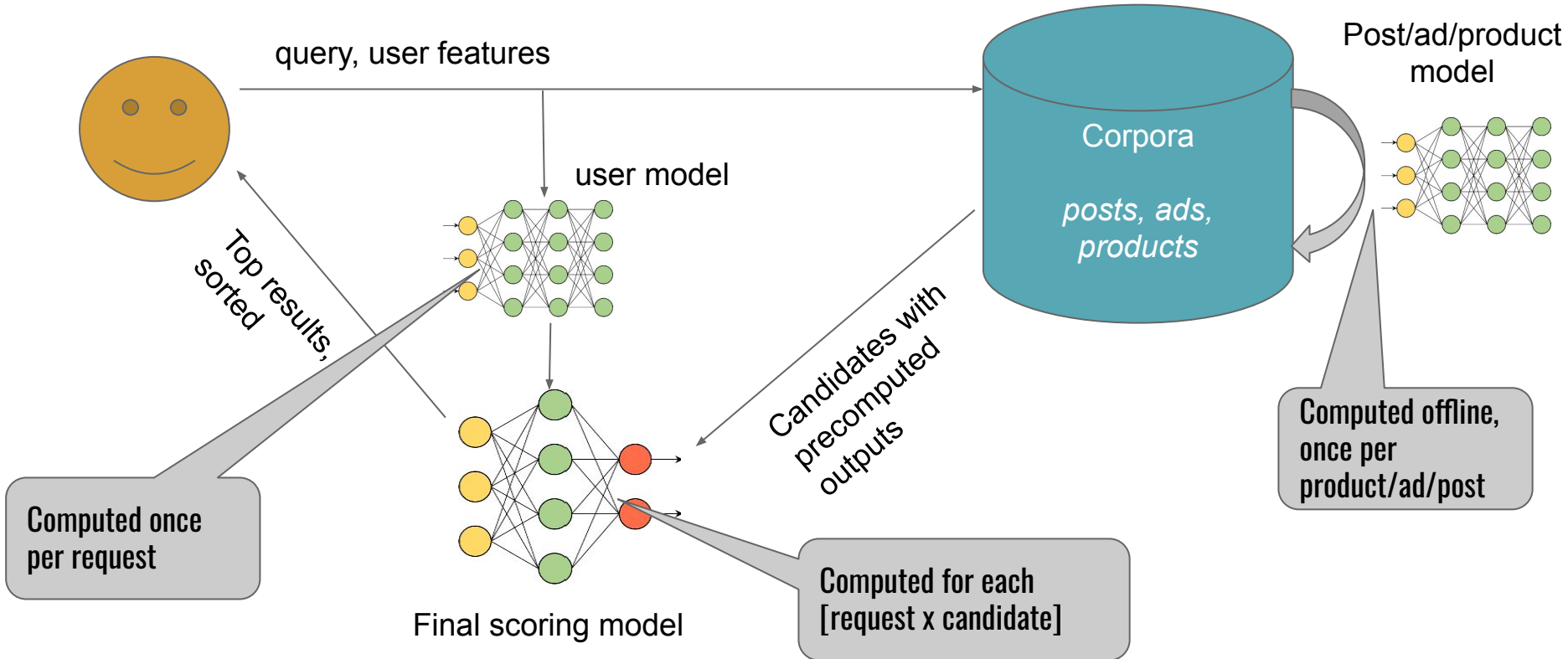
Post viewed

*Time spent viewing
the post*

Like button clicked

Comment left

Splitting models



Splitting models

- Greatly reduces serving cost
- Usually worsens the quality, because user and candidate post features aren't mixed in the neural network
- Adds a lot to system complexity

Parting words

We briefly discussed some interesting issues with building and deploying ML models

Here are some topics that we haven't talked about:

- Privacy issues and protections
- How to evaluate model quality
- Additional model distillation techniques
- Special optimizers and other techniques for asynchronous distributed training
- How to deal with late arriving data
- How to maintain models that train for months
- How to maintain feature definitions
- And many other topics

Thank you!

Questions?