

# **Machine Learning Systems Design**

## Lecture 14: Infrastructure for ML



# **Logistics**

- Demo discussion next week

# **Agenda**

1. ML infrastructure at Netflix
2. ML infrastructure at Slack
3. ML infrastructure at Spotify

# What does infrastructure mean?

A screenshot of a Slack conversation between several users. The messages are as follows:

- chiphuyen** Today at 9:31 AM  
i'm preparing a lecture on Infrastructure for ML. When you hear infrastructure for ML, what do you think of? Trying to decide what to cover.
- @chiphuyen** i'm preparing a lecture on Infrastructure for ML. When you hear infrastructure for ...  
**Justin** Today at 11:18 AM  
On-Prem vs Cloud trade-offs
- @chiphuyen** i'm preparing a lecture on Infrastructure for ML. When you hear infrastructure for ...  
**gandalf012** Today at 11:22 AM  
Cloud, CI/CD
- @chiphuyen** i'm preparing a lecture on Infrastructure for ML. When you hear infrastructure for ...  
**eggie5** Today at 12:09 PM  
data, compute and serving in same platform
- @chiphuyen** i'm preparing a lecture on Infrastructure for ML. When you hear infrastructure for ...  
**Naresh O** Today at 12:10 PM  
Additional resources/setup for explainability (edited)
- @chiphuyen** i'm preparing a lecture on Infrastructure for ML. When you hear infrastructure for ...  
**Ammar Asmro** Today at 12:19 PM  
Scale, cost, GPU's, serverless vs low level, API,

# **ML infrastructure at Netflix**

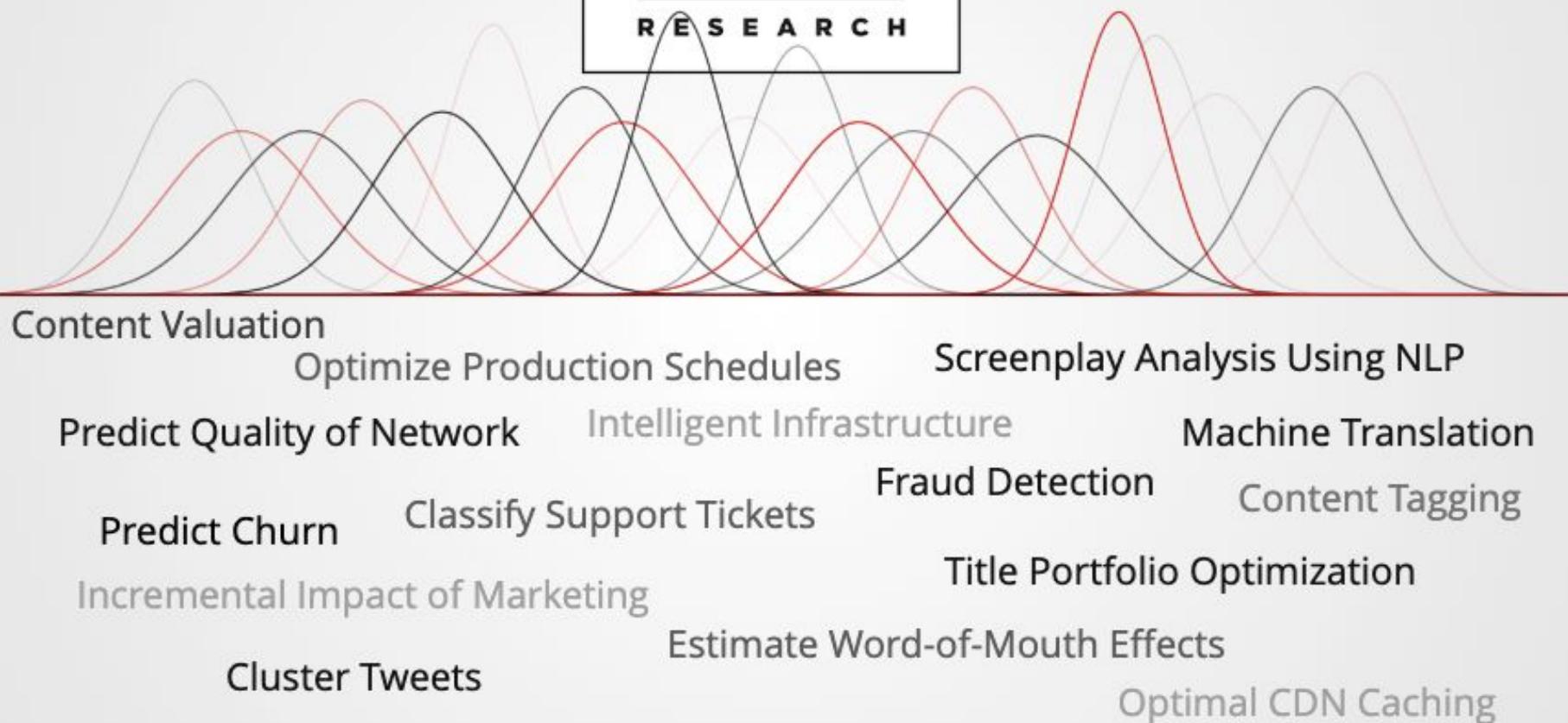


## Ville Tuulos

Manager, ML Infrastructure  
Creator of Metaflow

**NETFLIX**





Content Valuation

Optimize Production Schedules

Screenplay Analysis Using NLP

Predict Quality of Network

Intelligent Infrastructure

Machine Translation

Predict Churn

Classify Support Tickets

Fraud Detection

Content Tagging

Incremental Impact of Marketing

Title Portfolio Optimization

Cluster Tweets

Estimate Word-of-Mouth Effects

Optimal CDN Caching

# Life of a data scientist

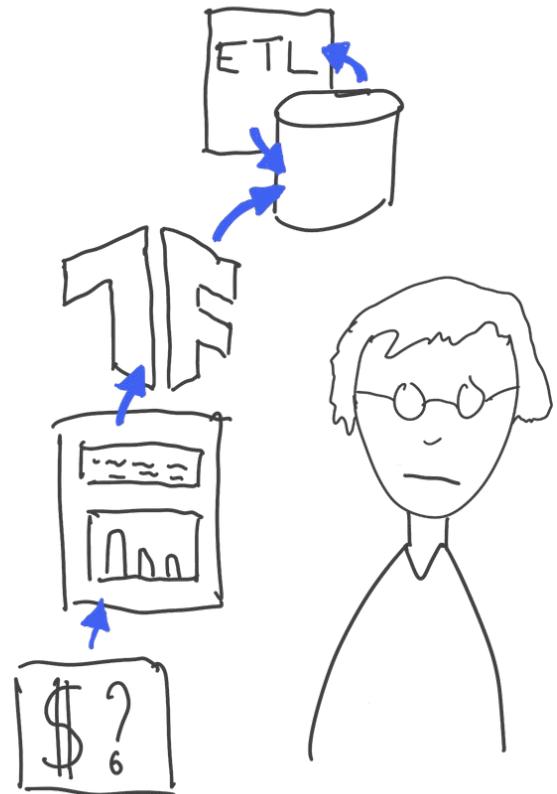














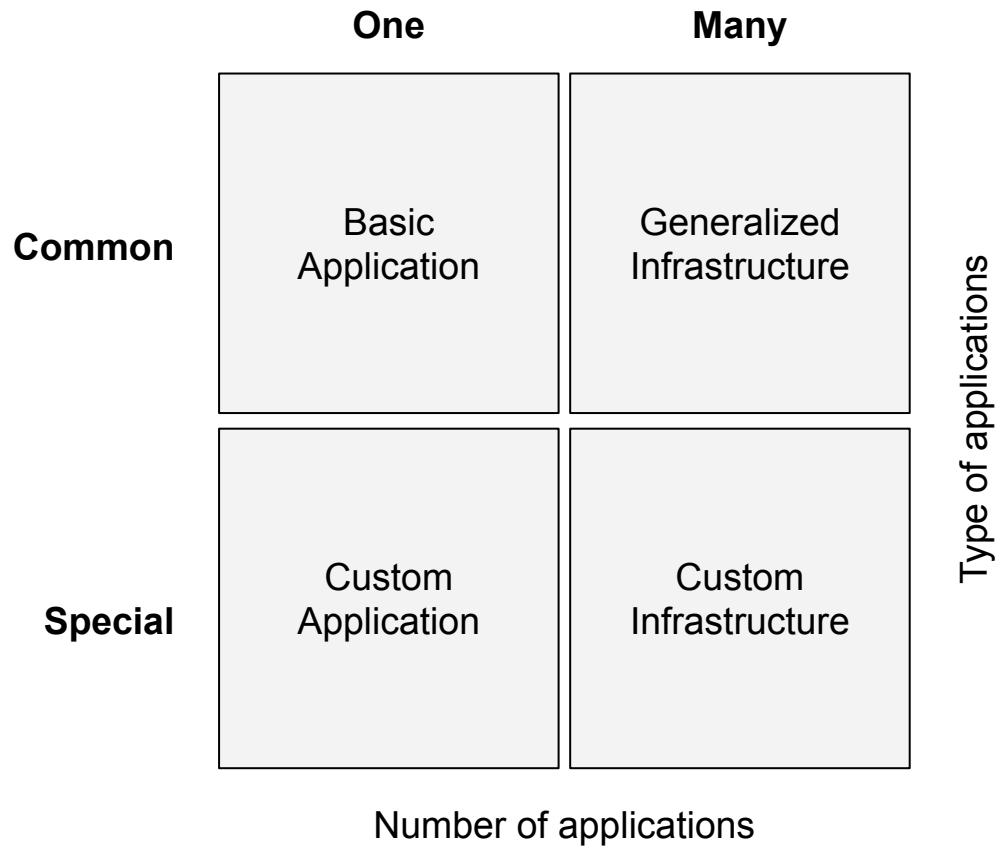


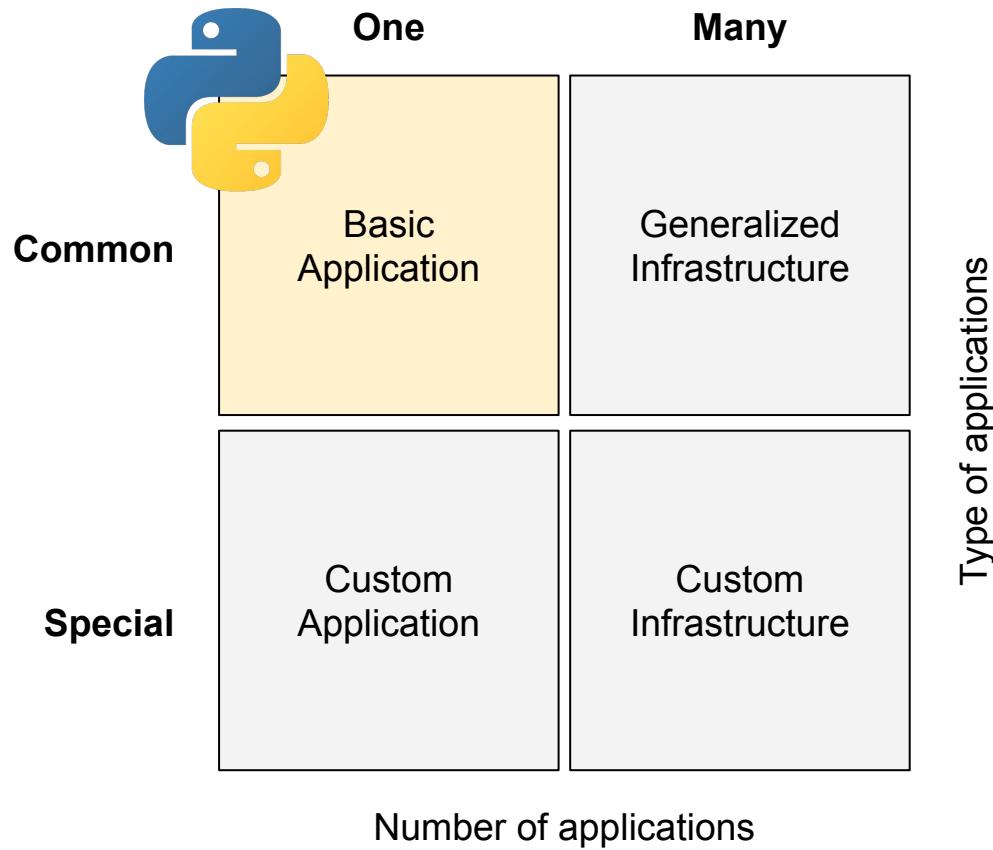


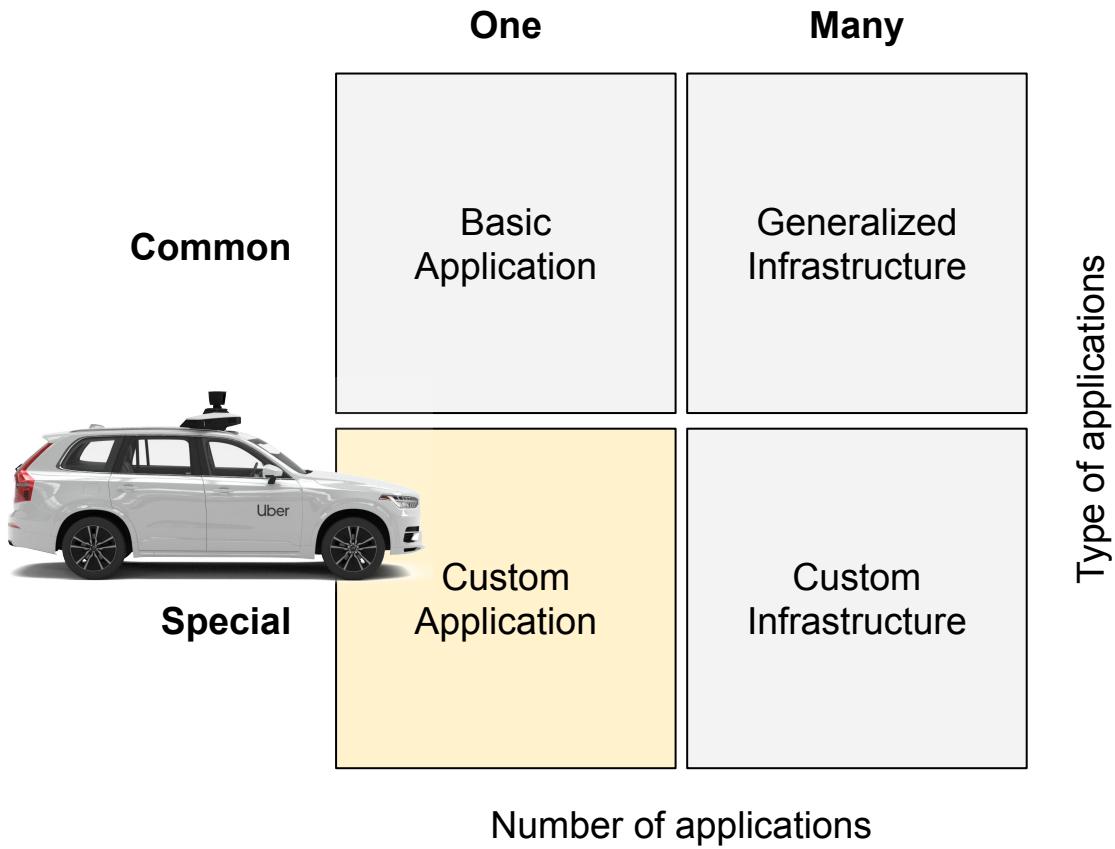


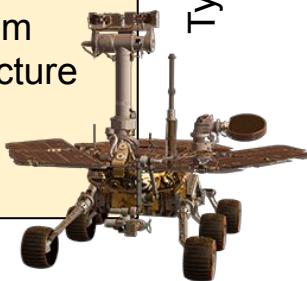
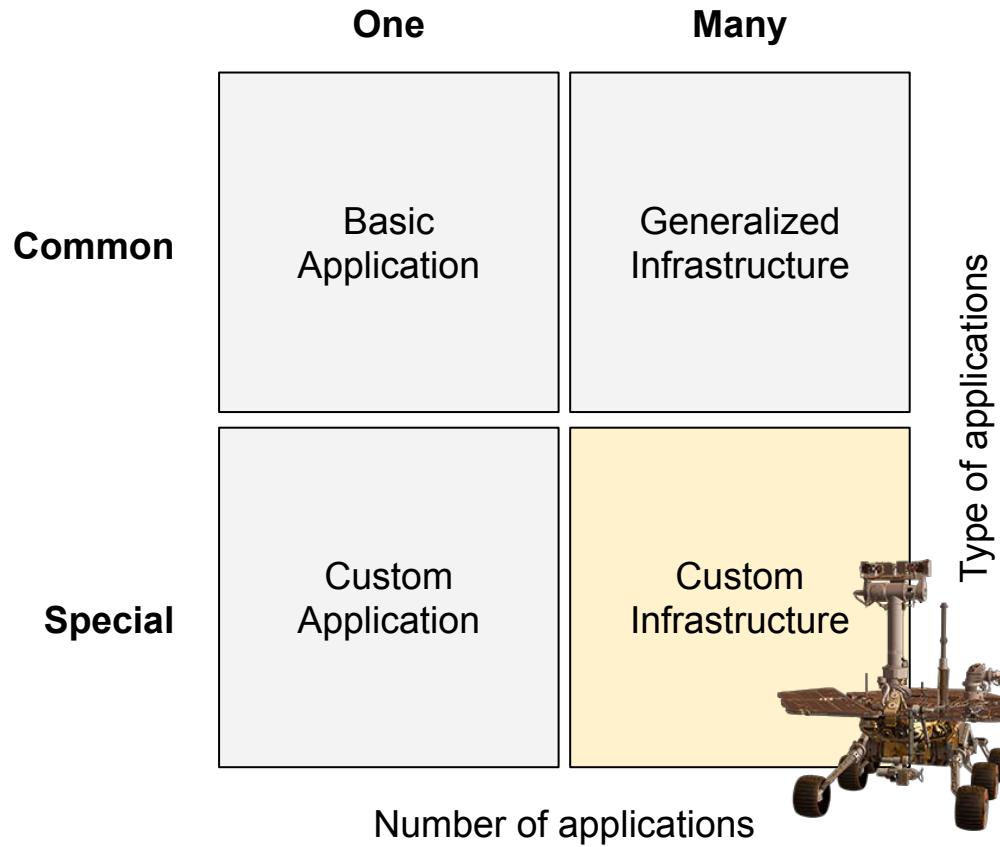


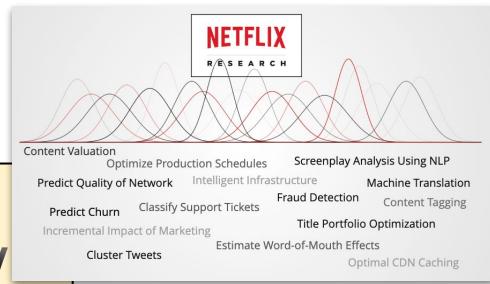
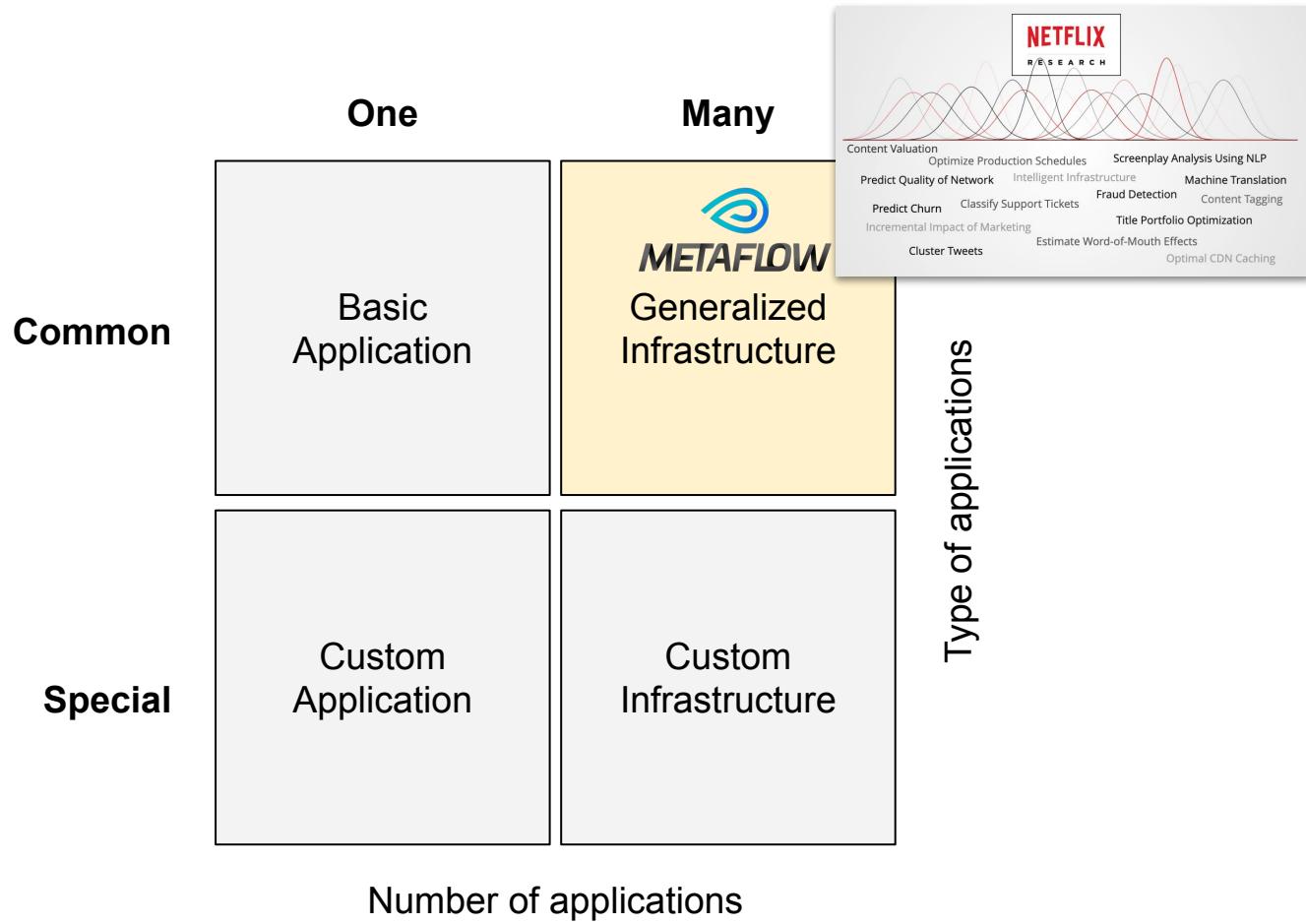
Do we need ML infrastructure?









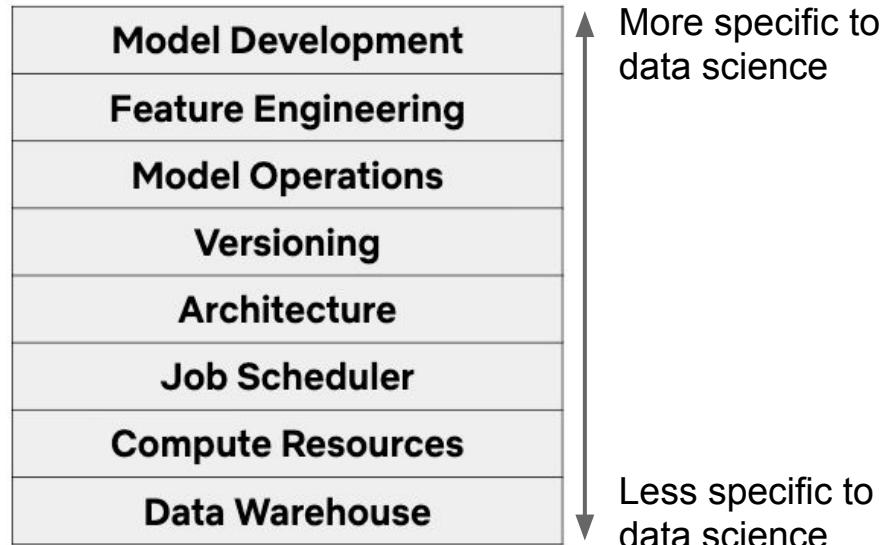


# What does ML infrastructure look like?

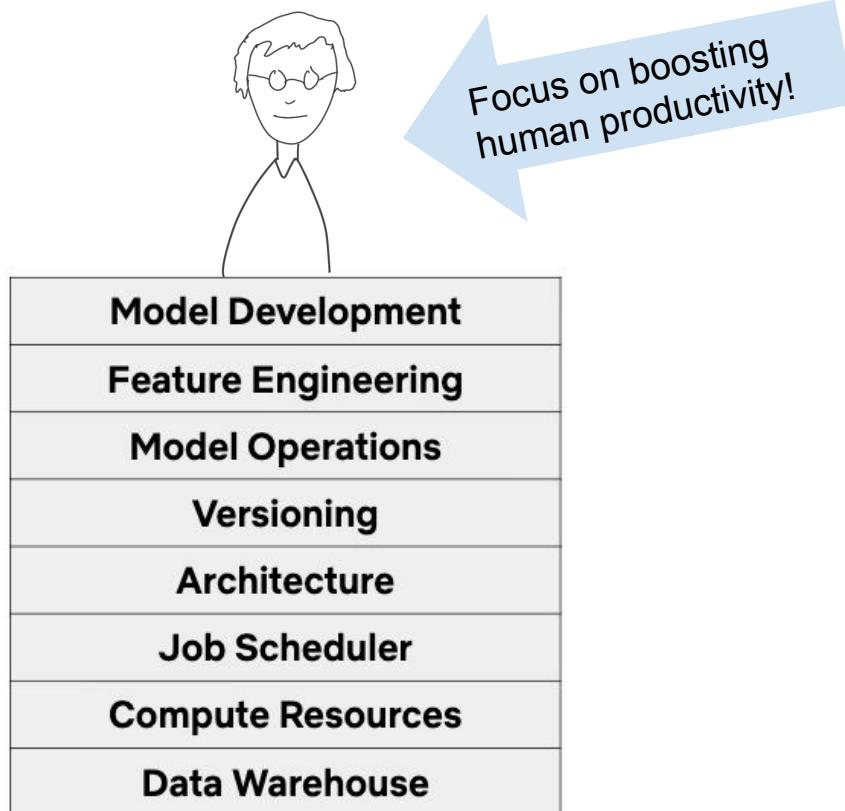
# The ML infrastructure stack



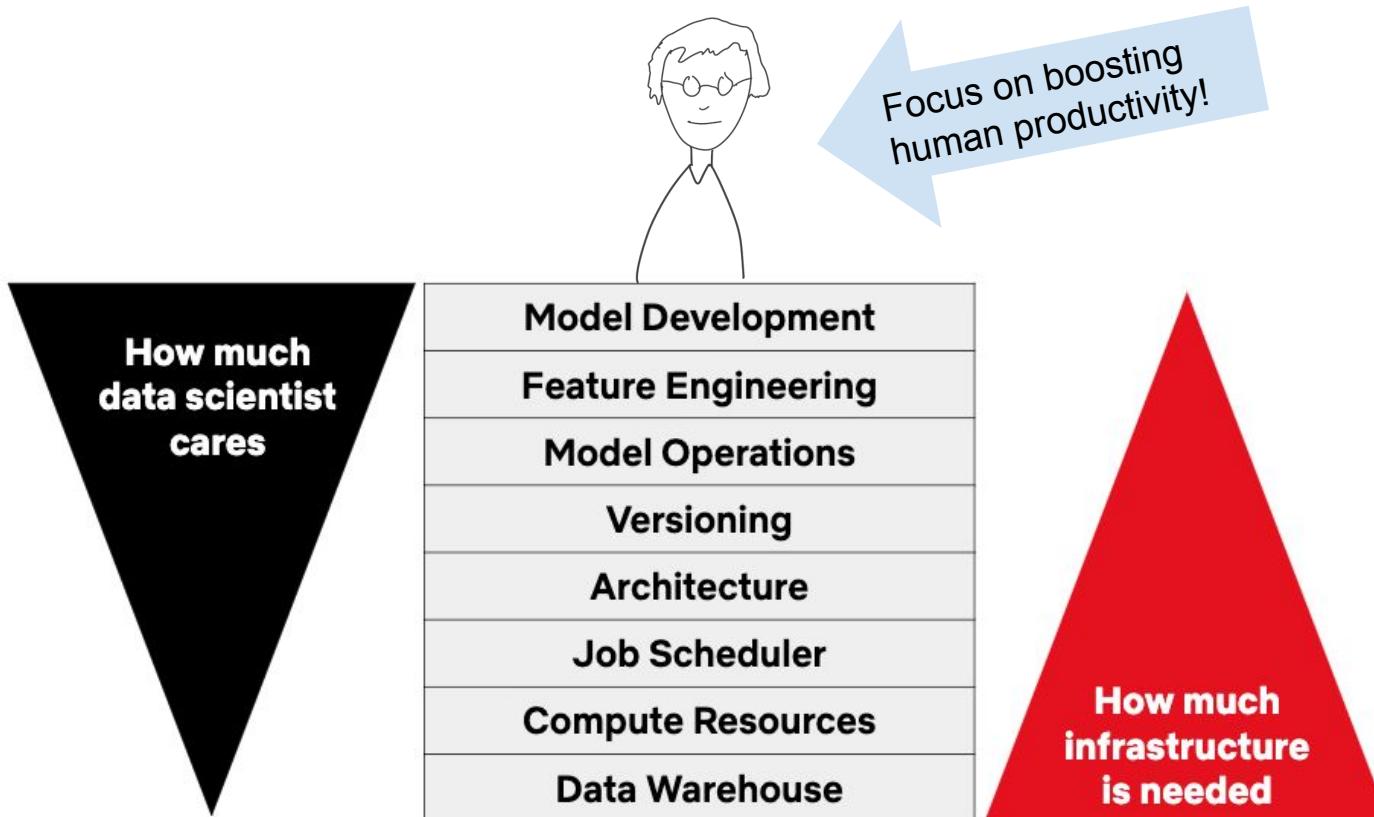
# The ML infrastructure stack



# The **human-centric** ML infrastructure stack



# The **human-centric** ML infrastructure stack





# METAFLOW

Machine Learning
Feature Engineering
Operations
Versioning
Architecture
Job Scheduler
Compute Resources
Data Warehouse

## Developing with Metaflow

- Basics of Metaflow
- Inspecting Flows and Results
- Debugging with Metaflow
- Scaling Out and Up
- Loading and Storing Data
- Managing External Libraries
- Dealing with Failures
- Organizing Results

Full stack for data science  
from prototype to production

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## Going to Production with Metaflow

- Scheduling Metaflow Flows

```
from metaflow import FlowSpec, step

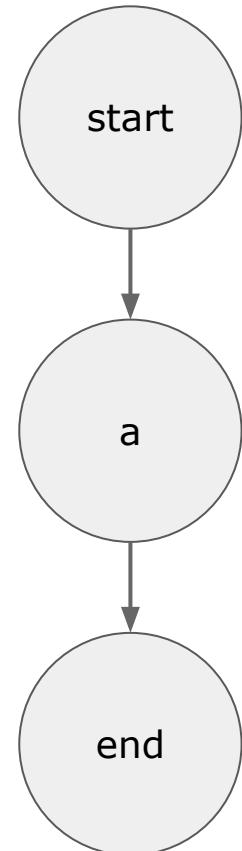
class LinearFlow(FlowSpec):

    @step
    def start(self):
        self.my_var = 'hello world'
        self.next(self.a)

    @step
    def a(self):
        print('the data artifact is: %s' % self.my_var)
        self.next(self.end)

    @step
    def end(self):
        print('the data artifact is still: %s' % self.my_var)

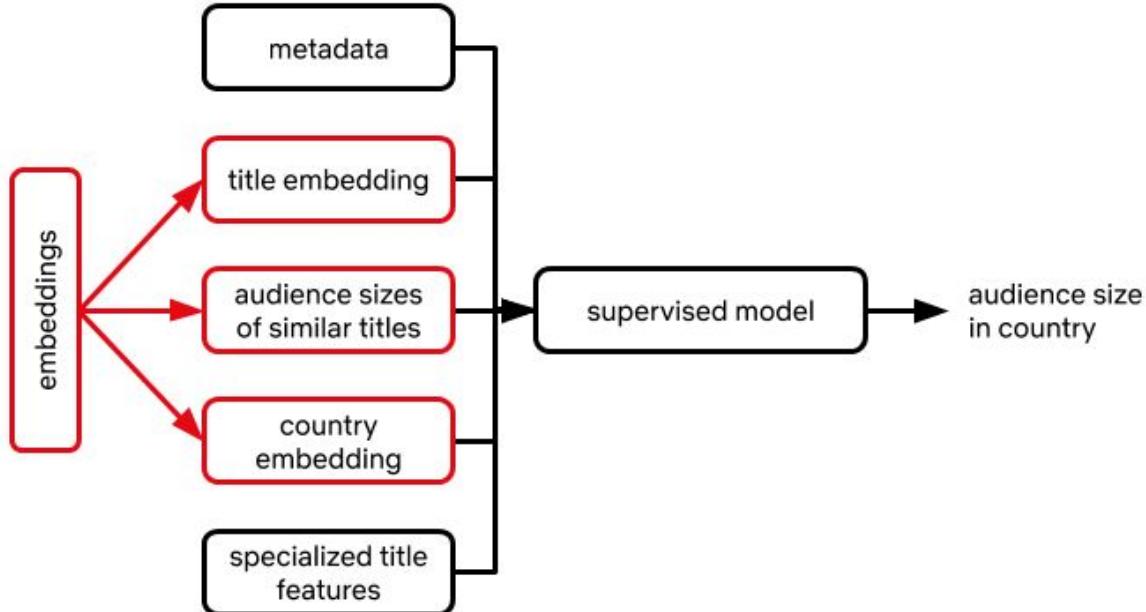
if __name__ == '__main__':
    LinearFlow()
```



# Supporting content decision makers with machine learning



by [Melody D](#)  
\* contributed



## METAFLOW



give it a try

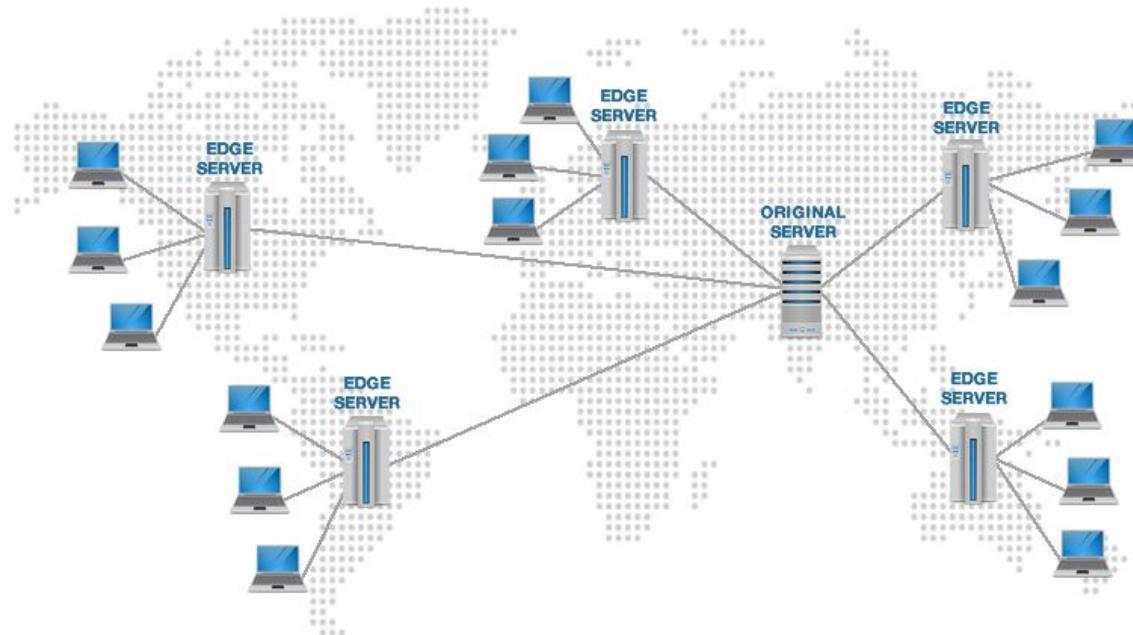
[metaflow.org](http://metaflow.org)

and give feedback

[tullos@gmail.com](mailto:tullos@gmail.com)

[@vtuulos](https://twitter.com/vtuulos)

# CDN: Content Delivery Network



# Netflix CDN: OpenConnect



# **ML infrastructure at Slack**



## **Josh Wills**

WeaveGrid, Slack, Cloudera, Google

Q world cup ad in: #team-marketing from: @Michael Chen from: @Paige Robinson Clear X

Messages Files

21 Results Most recent

Filter by

People

Paige Robinson  Michael Chen  Mani Sung

More...

Channels & Direct Messages

# team-marketing  # videos-world-cup  # brainstorming

More...

Date

Starting  Ending

Include results from:

Apps and bots  Channels I'm not a member of

@ 😊

Joosep Inc. Rose Nguyen

All Unreads Threads Starred

# announcements # design-team # core-products # product-design # team-search

Channels

# biz-metrics # brainstorming # brand-design # customer-experience # data-analytics # field-events # mobile-search # random # team-marketing # user-research # vegetarians # videos-world-cup

Direct Messages

slackbot

# team-marketing – Jun 14  
Paige Robinson 11:23 AM  
Our world cup ad ran after the first goal was scored! Heres a link to the video: <http://www.youtube.com...>

# team-marketing – Jun 11  
Michael Chen 4:07 PM  
Our world cup ads begin airing this week! We'll be featured during these games:  
 World Cup Ad Schedule Nami Taylor – June 1st, 2018

# team-marketing – May 18  
Paige Robinson 1:50 PM  
Hi team! We have the final edits for our world cup ad series. Join us at 3pm for a screening party.

# team-marketing – April 2  
Paige Robinson 10:27 AM  
Some exciting news... we just signed off on the

# Search Problems: A Comparison

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1. Corpus/queries are public.
2. Lots of head queries.
3. Web pages **want** to be found.



1. Corpus/queries are private.
2. Almost no head queries.
3. Messages **don't care** about being found.

# Delta One: Model Evaluation

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- ML Systems Are One Piece of a Complex System
- Well-defined objective functions are the exception
  - Multiple (and often conflicting) objectives are the norm
  - Weighting is fuzzy and shifts with business priorities
  - Pareto optimization is the usually the best play
- Predictive Accuracy is only useful to a point

# **Delta Two: Systems Precede Algorithms**

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- Greenfield projects hardly ever happen
  - There is always an existing system that is doing the job your model is trying to do, badly
  - Replacing it can be much harder than you think
- Bespoke ML Infrastructure Is Still Relatively Rare
  - Even if you have it for training, having it available for model serving is unlikely
  - The overriding constraint: where is the data you need stored?

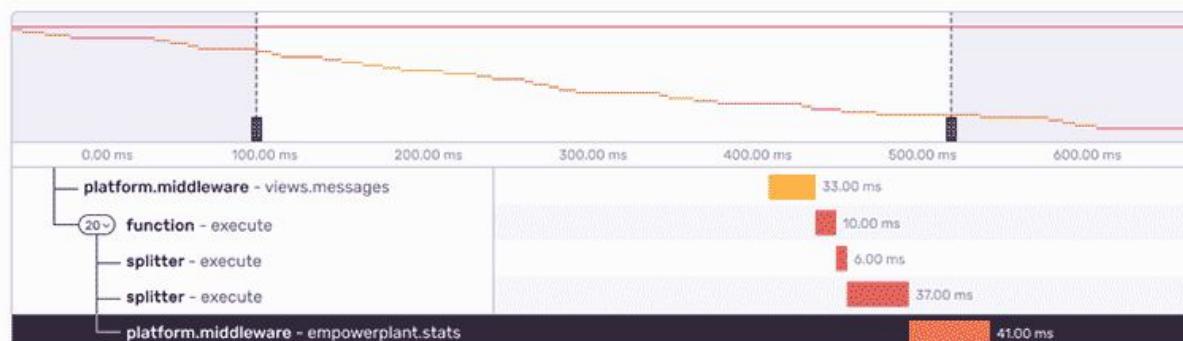
# Delta Three: Running Things in Production

Performance > Transaction Summary > Event Details

[Hide Details](#)

/api/0/projects/ep/login\_page

Search for Spans



Span ID kjstou245245345bnkbf sdf

[View Children](#)

Parent Span ID hsdgui2385402845bksidf9

[Search by Trace](#)

Trace ID osuhdg23425245245hjkjhk

## Event ID

969ad5c7f0104f35af2687aa89e

Nov 23, 2019 4:03:41 PM UTC

Plant Mood

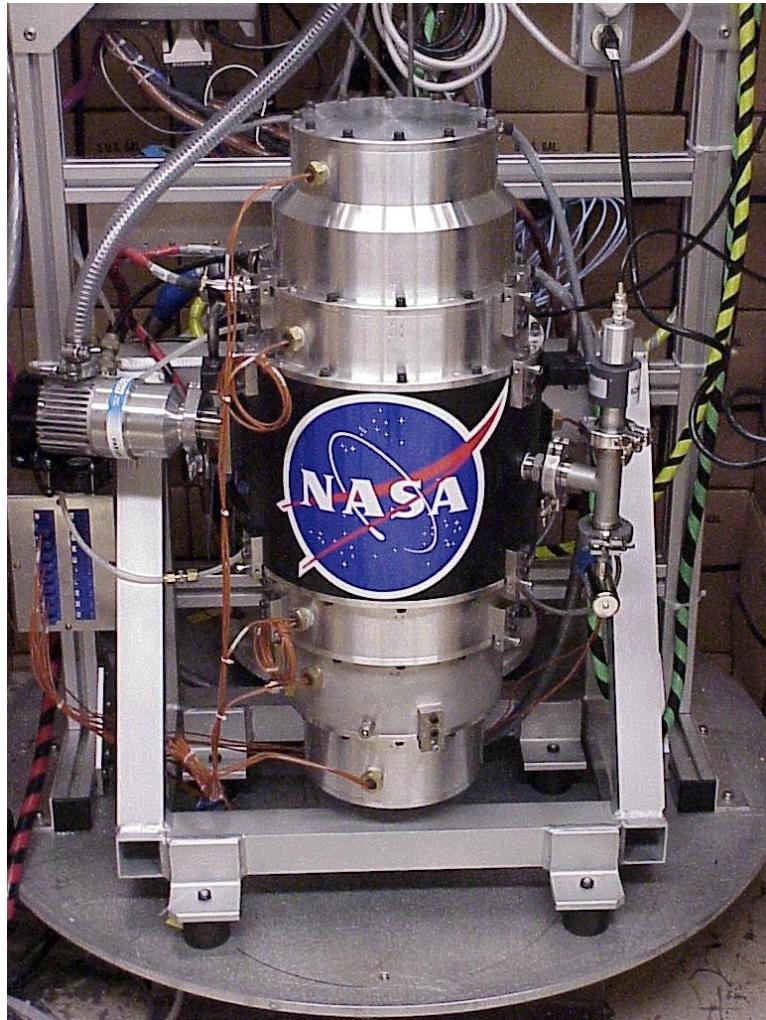
[Preview JSON \(13.8 KB\)](#)

## Ops Breakdown

● http	2.4 ms	75%
● platform	1.4 ms	10%
● db	0.4 ms	5%
● other	0.1 ms	< 1%

## Event Tag Details

ID	453463456735356
browser.name	Chrome
client_os	Mac OS X 10.15.0
client_os.name	Mac OSX



# **ML infrastructure at Spotify & Better**



**Erik Bernhardsson**  
Spotify, Better.com, creator of Luigi

# ML infra @ Spotify & Better

2021

# My background

- 2008-2015: Spotify
  - Did a lot of work on data analytics, good old Hadoop days
  - Built the first music recommendation system (still a lot of it in production)
  - Open sourced Annoy – nearest neighbors in high dimensions
  - Open sourced Luigi – workflow scheduling
- 2015-2021: Better
  - Took a team from 2 engineers to 250
  - “CTO stuff”: Did a lot of interviews, managed a lot, built a lot of processes
  - Occasionally spent some time with the data team!
- 2021-: ???
  - Planning to start something new
  - Super interested in data infrastructure!

# Joined Spotify to build a music recommendation system

Spent a few months writing my master's thesis at Spotify, then joined full-time to take it to production.

... but there was too much other stuff going on



# Managing people's data needs

- What is it that you're really trying to understand?
- Are you looking for a particular answer?
- Why does this matter to the business?

# How can you help the business make more money?

- I was analyzing ad delivery and realized a lot of our campaigns under-delivered, resulting in refunds to the advertisers
- Made a 5 line change in our ad system that added a few hundred \$k/month (and this was in 2010)

# When a hacky solution works

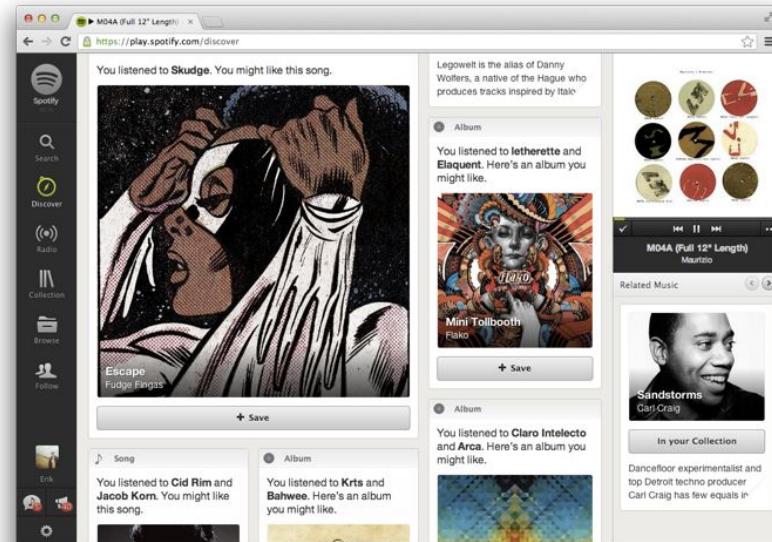
- How do you generate genre radio stations?
- Realized Spotify had 100M playlists at that point – amazing dataset of “tags”

US patent 20190138551:

*A method of selecting content items based on user interactions with provided content is performed at a server system. A subset of content items selected from a plurality of available content items is provided to a first user of the service. An amount of time that the subset of content items is provided to the first user is determined. Content item selection criteria for a second user of the service is adjusted based on the amount of time that the subset of content items is provided to the first user. In response to receiving -a request for a content item from the second user, a content item is selected items for the second user from the plurality of available content according to the adjusted content item selection criteria. The selected content item is provided to the second user.*

# Building a music recommendation system

- Collaborative filtering, lots of large-scale matrix factorization
- Initially all Hadoop, then later just local C++ code (word2vec etc)



Super quick simplistic overview of Spotify's  
system

# Step 1 – build matrix

$$M = \left( \begin{array}{cccc} c_{11} & c_{12} & \dots & c_{1n} \\ c_{21} & c_{22} & \dots & c_{2n} \\ \vdots & & & \vdots \\ c_{m1} & c_{m2} & \dots & c_{mn} \end{array} \right) \right\} 10^7 \text{ users}$$

$$N = \left( \begin{array}{ccccc} & \boxed{\text{Never gonna give}} & & & \\ & \boxed{\text{you up}} & & & \\ \downarrow & & & & \\ \begin{matrix} 0 & \boxed{7} & 21 & 0 \\ 5 & 0 & 0 & 1 \\ 4 & 0 & 13 & 9 \\ 0 & 0 & 0 & 7 \\ \boxed{19} & 1 & 0 & 13 \\ 0 & 3 & 0 & 0 \end{matrix} & & & & \end{array} \right)$$

*Never gonna give  
you up*

Erik

Erik listened to *Never  
gonna give you up* 1  
times

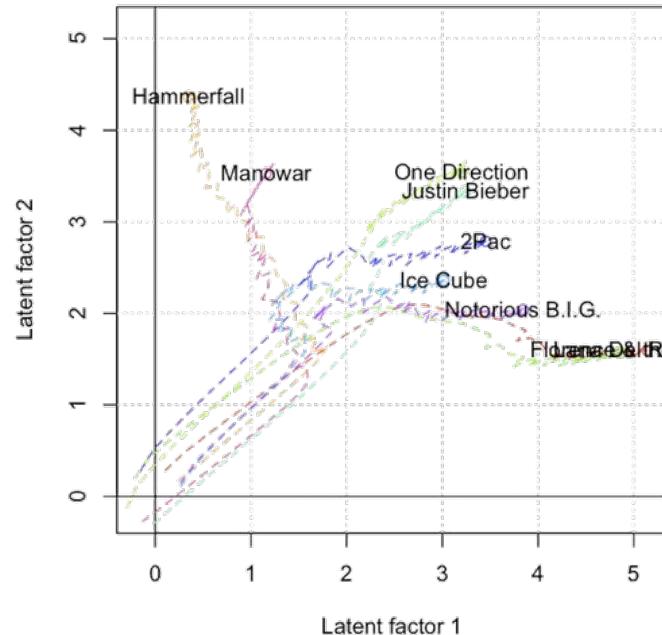
## Step 2 – factorize the matrix

$$\underbrace{\begin{pmatrix} \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \end{pmatrix}}_{P(u,i) = \sum_z P(u|z)P(i,z)} \approx \underbrace{\begin{pmatrix} \cdot & \cdot \\ \cdot & \cdot \end{pmatrix}}_{P(u|z)} \underbrace{\begin{pmatrix} \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \end{pmatrix}}_{P(i,z)}$$

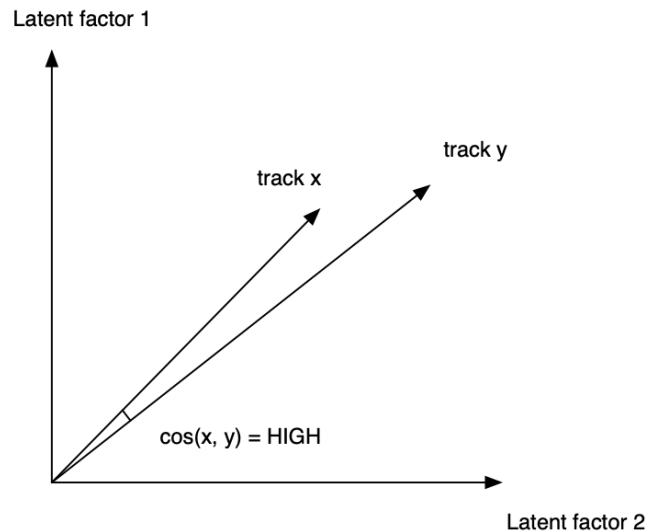
# Step 3 – run for n iterations

Start with random vectors around the origin.

Then run alternating least squares, gradient descent, or something like that.



## Step 4 – use vector similarity



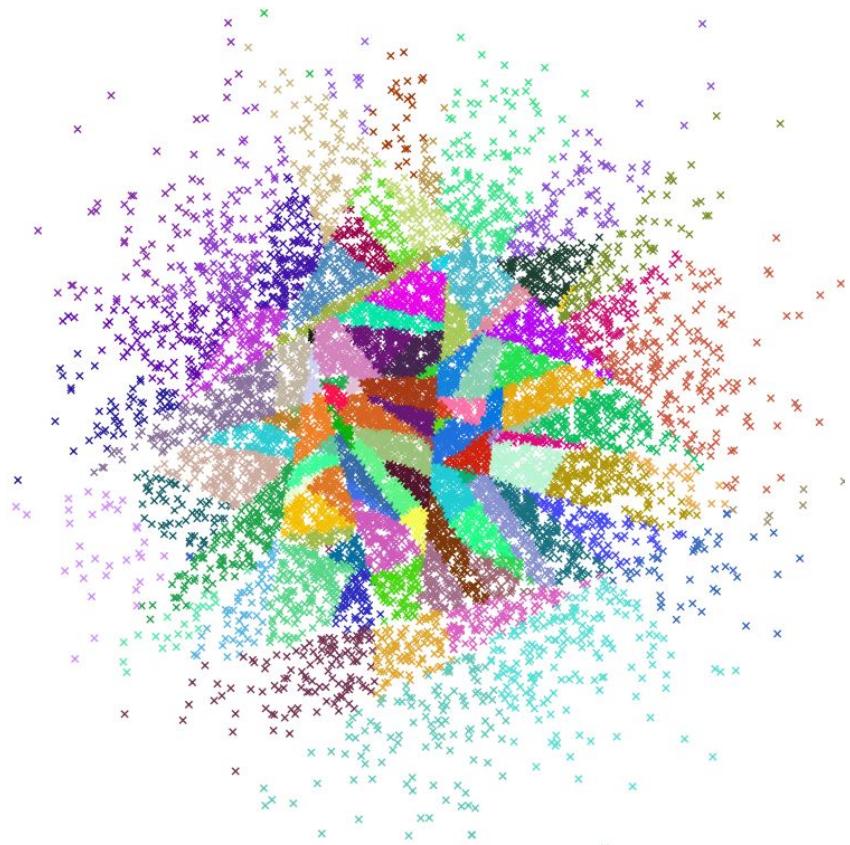
$$sim_{ij} = \cos(\mathbf{b}_i, \mathbf{b}_j) = \frac{\mathbf{b}_i^T \mathbf{b}_j}{\|\mathbf{b}_i\| \|\mathbf{b}_j\|}$$

$i$	$j$	$sim_{i,j}$
2pac	2pac	1.0
2pac	Notorious B.I.G.	0.91
2pac	Dr. Dre	0.87
2pac	Florence + the Machine	0.26
Florence + the Machine	Lana Del Rey	0.81

# Vector models

<https://github.com/spotify/annoy>

Library in C++ to do fast lookup of nearest neighbors in high-dimensional spaces



# Why Luigi? Why workflow management?

When you have 1000s of jobs running all kinds of different things, with complicated dependencies, you need something to manage the dependency graph.

Luigi isn't super well maintained and other things are a lot more popular these days (eg Airflow).



# Are you using the right tools?

If people spend more time waiting for queries to run or models to fit or anything else – it's highly likely you're not using the right tools.



Spotify's Hadoop cluster, summer of 2009

Better.com (2015-now)

# What do you need data for?

Super early stage company:

- Understanding the health of the business.

Mid-stage startup:

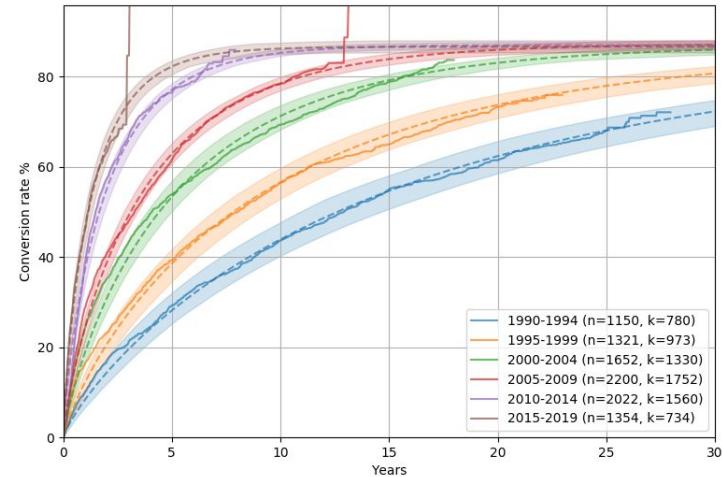
- Powering the product team to make data-driven decisions
- Measure marketing ROI and optimize

Later stage:

- Data-driven products (recommendations, personalization)

# Fitting cohort models using Gamma distributions

- Helps us allocate millions of dollars in monthly marketing spend



# What are some questions we might work on?

- What does the customer support team spend time on? How can we optimize it?
- Can we match people with real estate agents based on what they are looking for?
- What changed in this A/B test?

# Some open problems in ML/data infra (super opinionated)

# Big gap between local & prod

- Frontend development sort of trivial problem (WYSIWYG)
- Backend development:
  - Test locally using synthetic data (unit tests etc)
  - Commit and deploy
- Data development
  - Prototype code in notebooks and random scripts
  - Automation often a chore once you're done, not a tool to iterate quicker
  - Hard if you can't download the data and run on it locally

# Massive fragmentation

- Lots of point solutions, companies trying to build widget 2.0 to replace widget 1.0
- 5,000,000 blog posts about “the new data stack”, all different

# Lots of things built for scale/automation but not productivity

- Complicated configuration files
- Hard to use web interfaces
- Long iteration cycles when you build and debug stuff to make it work
- Example: AWS is amazing but I've wasted years trying to figure out their services

# After 10+ years in the cloud we're still not cloud native

- Why do I have to provision a cluster? Why can't things just scale with usage? (and charge for it)
- Lots of things still to run in your own environment (or hybrid), not full SaaS/IaaS

# Big gap between SQL and Python

- The SQL landscape has exploded recently (Snowflake, dbt)
- SQL great for preprocessing structured relational datasets
  - Lots of Pandas operations are basically the same type of processing too
- Are we putting too much logic in SQL?
- I think most companies will end up with both, but there's no great bridge

# Notebooks are nice but also kind of not?

- Incremental state, trial and error development
- Visuals inline with code
- No modularity in code
- Reproducibility not guaranteed

# Some interesting gaps

- Workflow scheduling
  - Still seems largely lacking, done right can be a hub for so many other things
- Feature stores
  - Real time updates + get historical values for training
- Execution environments
  - Kubernetes maybe a better fit for backend and not for data

# Questions?



1



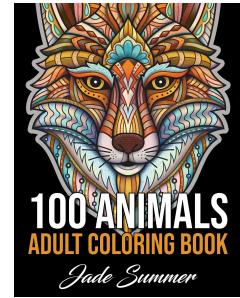
2



9



4



5



3



6



7



8



10

# **Machine Learning Systems Design**

Next class: Integrating machine learning into business