

# TOWARD A SYSTEM-WIDE AND INTERDISCIPLINARY PERSPECTIVE ON ML SYSTEM PERFORMANCE

Christian Kaestner

Carnegie Mellon University

@ FASTPATH 2021

A portrait photograph of Christian Kästner, a man with light brown hair, wearing a red button-down shirt, standing outdoors in front of a large, light-colored building with a tower.

# CHRISTIAN KÄSTNER

@p0nk

[kaestner@cs.cmu.edu](mailto:kaestner@cs.cmu.edu)

Associate Professor @ CMU

Interests:

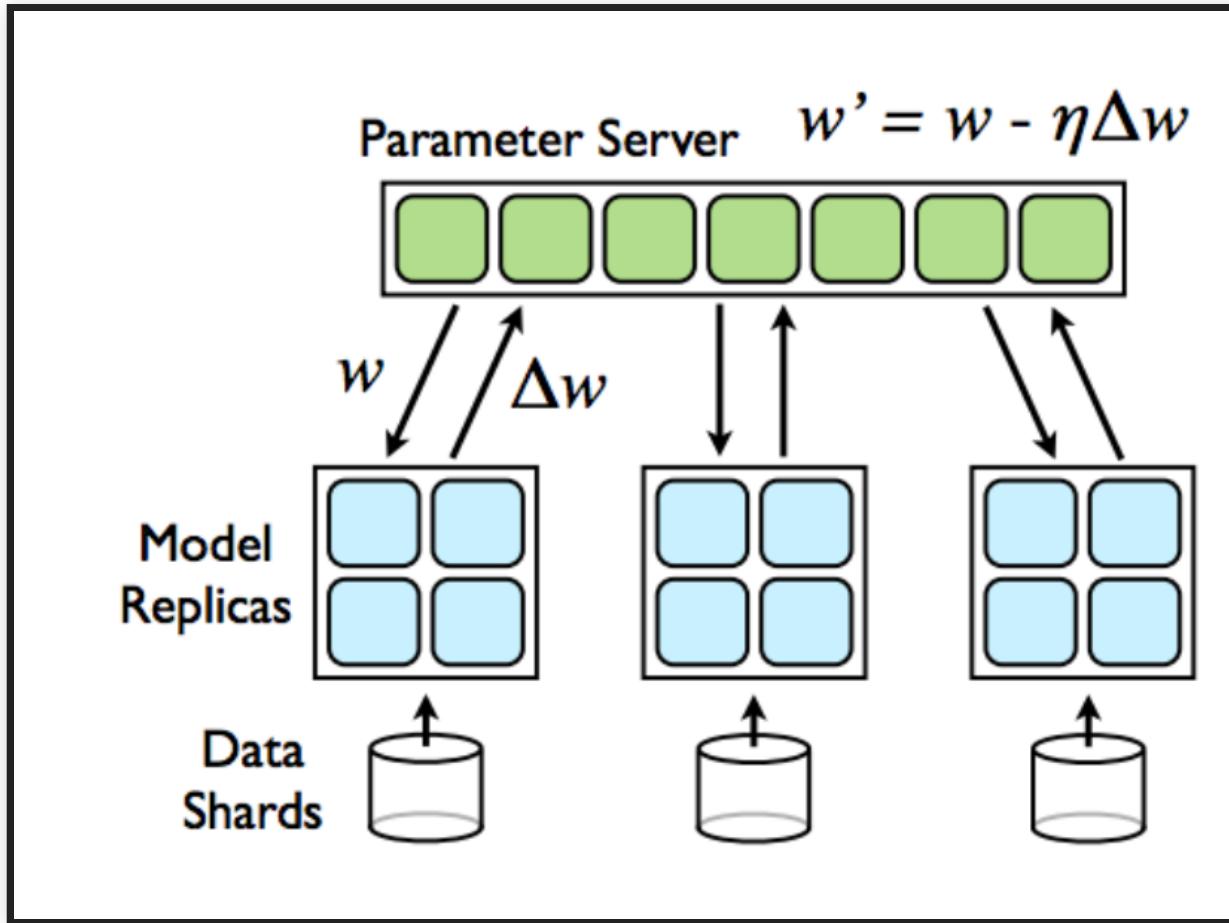
- Software Engineering for ML-Enabled Systems
- Highly-Configurable Systems (incl. performance analysis)
- Sustainability and Stress in Open Source

# SOFTWARE ENGINEERING FOR ML-ENABLED SYSTEMS

*Building, operating, and maintaining software systems  
with machine-learned components*

*with interdisciplinary collaborative teams of **data  
scientists, software engineers, operators, ...***

# SE FOR ML-ENABLED SYSTEMS != DEVELOPING ML FRAMEWORKS



# SE FOR ML-ENABLED SYSTEMS

The screenshot shows a Microsoft Word document window. The ribbon menu is visible at the top, with 'Design' selected. Below the ribbon, there are sections for 'Themes' and 'Designer'. The 'Designer' section includes 'Variants' and 'Customize' buttons, and a 'Design Ideas' button which is currently active, indicated by a red border.

The main content area displays a slide with the title 'Measuring Progress?'. The slide contains a bulleted list:

- "I'm almost done with the app. The frontend is almost fully implemented. The backend is fully finished except for the one stupid bug that keeps crashing the server. I only need to find the one stupid bug, but that can probably be done in an afternoon. We should be ready to release next week."

On the right side of the slide, there is a 'Design Ideas' sidebar. It features a large image of a person's face with the text 'Measuring Progress?' overlaid. Below this image is a quote:

• "I'm almost done with the app. The frontend is almost fully implemented. The backend is fully finished except for the one stupid bug that keeps crashing the server. I only need to find the one stupid bug, but that can probably be done in an afternoon. We should be ready to release next week."

The sidebar also includes a small 'Close' button in the top right corner.

55



Tap to add notes

56



Slide 47 of 74



Notes



15-313 Software Engineering

6

- + 29%



# SE FOR ML-ENABLED SYSTEMS

the-changelog-318 Last saved a few seconds ago ... Share

← Dashboard Quality: High ⓘ

00:00 ⚡ Offset 00:00 01:31:27

Play Back 5s 1x Volume

NOTES  
Write your notes here

**Speaker 5 ► 07:44**

Yeah. So there's a slight story behind that. So back when I was in, uh, Undergrad, I wrote a program for myself to measure a, the amount of time I did data entry from my father's business and I was on windows at the time and there wasn't a function called time dot [inaudible] time, uh, which I needed to parse dates to get back to time, top of representation, uh, I figured out a way to do it and I gave it to what's called the python cookbook because it just seemed like something other people could use. So it was just trying to be helpful. Uh, subsequently I had to figure out how to make it work because I didn't really have to. Basically, it bothered me that you had to input all the locale information and I figured out how to do it over the subsequent months. And actually as a graduation gift from my Undergrad, the week following, I solved it and wrote it all out.

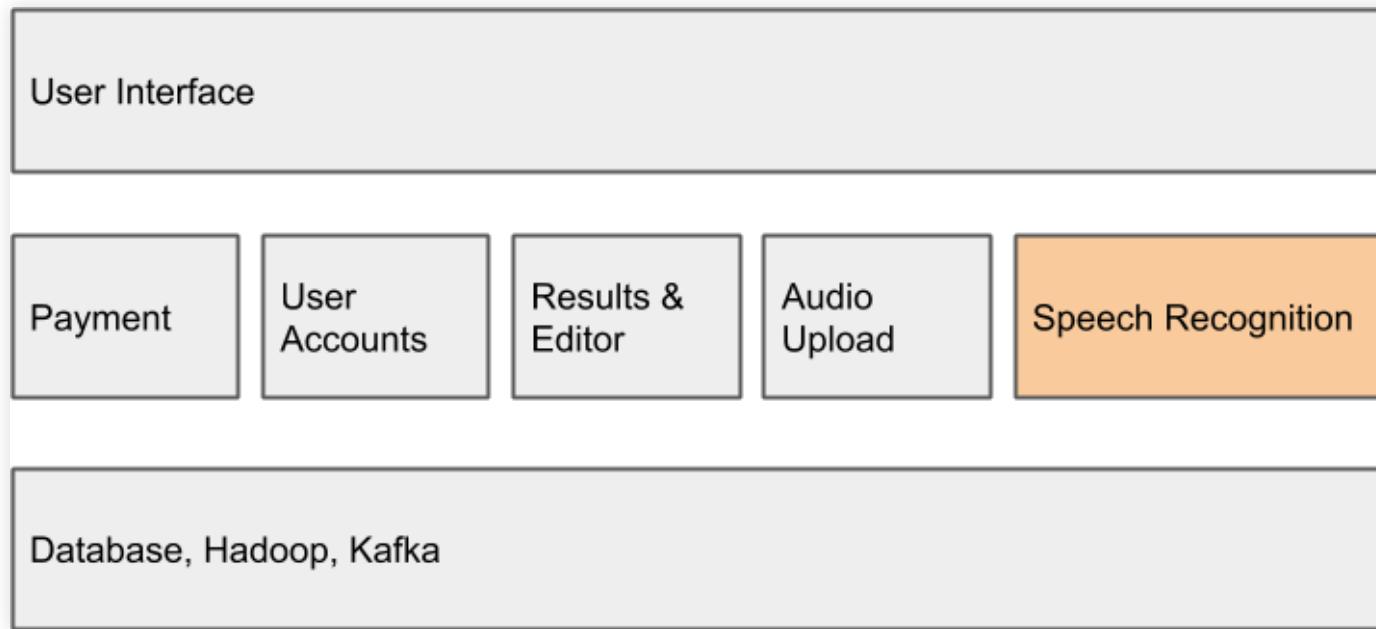
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How did we do on your transcript? ☆☆☆☆☆



# SYSTEM = ML + NON-ML COMPONENTS



# SYSTEM DESIGN MATTERS

# MOST ML COURSES

Focus narrowly on modeling techniques or building models

Using notebooks, static datasets, evaluating accuracy

The screenshot shows a Jupyter Notebook interface with the following details:

- Title:** G4 playground.ipynb
- File Menu:** File, Edit, View, Insert, Runtime, Tools, Help
- Last edited:** April 4
- Comment and Share buttons:** Comment, Share
- Code Cell Output:** Displays two rows of data and their counts:

	1096	4	12	26	3	2	0
[ ]	1096	4	12	26	3	2	0
<>	235	4	4	23	1	2	0

525 rows × 6 columns
- Code Block:**

```
[ ] # learning a classifier whether the result will be nonZero
from sklearn import tree

classifier=tree.DecisionTreeClassifier(max_depth=8)
classifier=classifier.fit(Xtrain, ynztrain)

print(classifier.score(Xtrain, ynztrain))
print(classifier.score(Xtest, ynztest))
```
- Output:** Shows the classifier's scores:

0.8266666666666667  
0.7295238095238096

```
[ ] # learning a regression model only on the nonZero data (test is on all data and somewhat  
from sklearn import tree  
  
predictor=tree.DecisionTreeRegressor(max_depth=8)  
predictor=predictor.fit(XnzTrain,YnzTrain)  
  
print(predictor.score(XnzTrain, YnzTrain))  
print(predictor.score(Xtest, ytest))
```



0.9376379365613154  
-2.437397740412892

# SE FOR ML-ENABLED SYSTEMS

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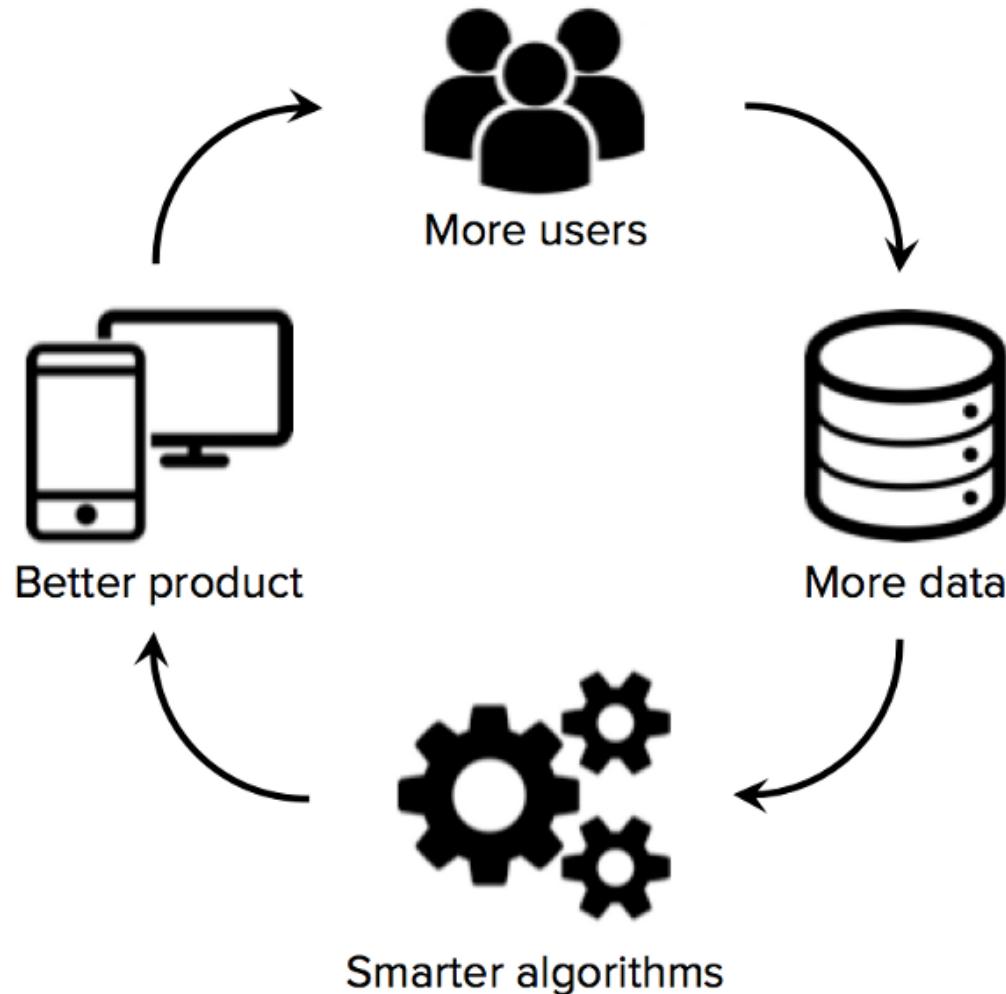
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# THE FLYWHEEL



# TELEMETRY DESIGN

the-changelog-318  
← Dashboard | Quality: High ⓘ

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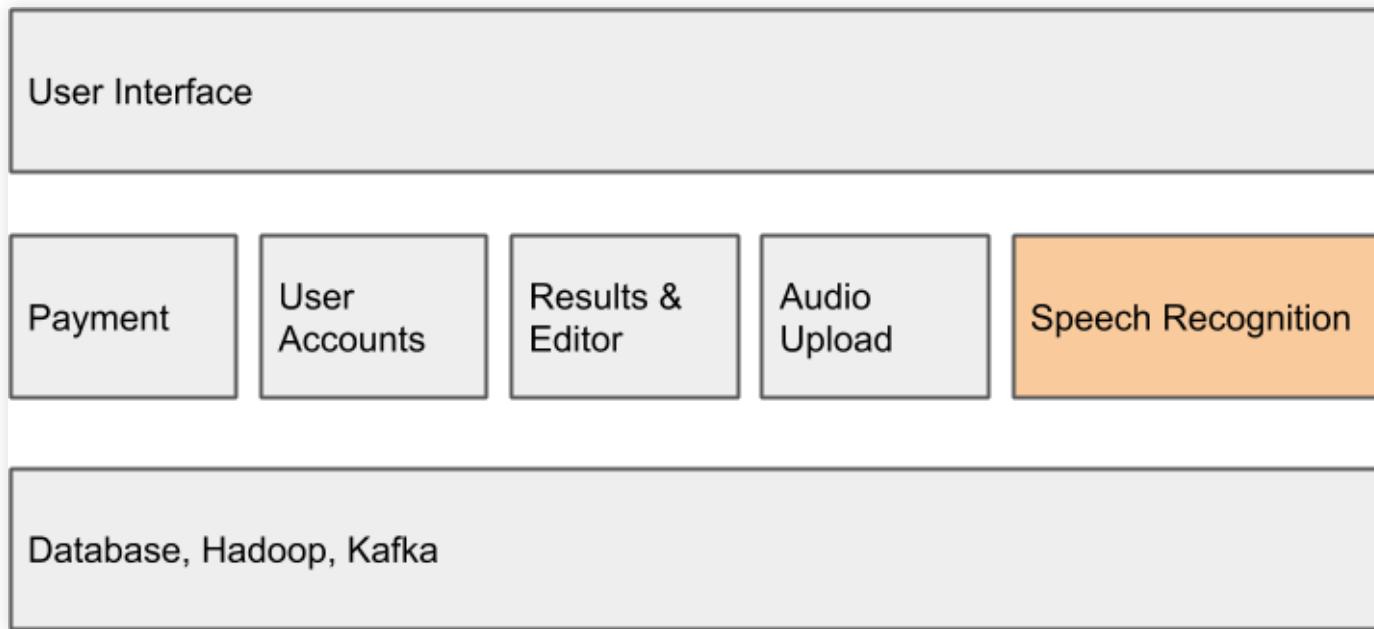
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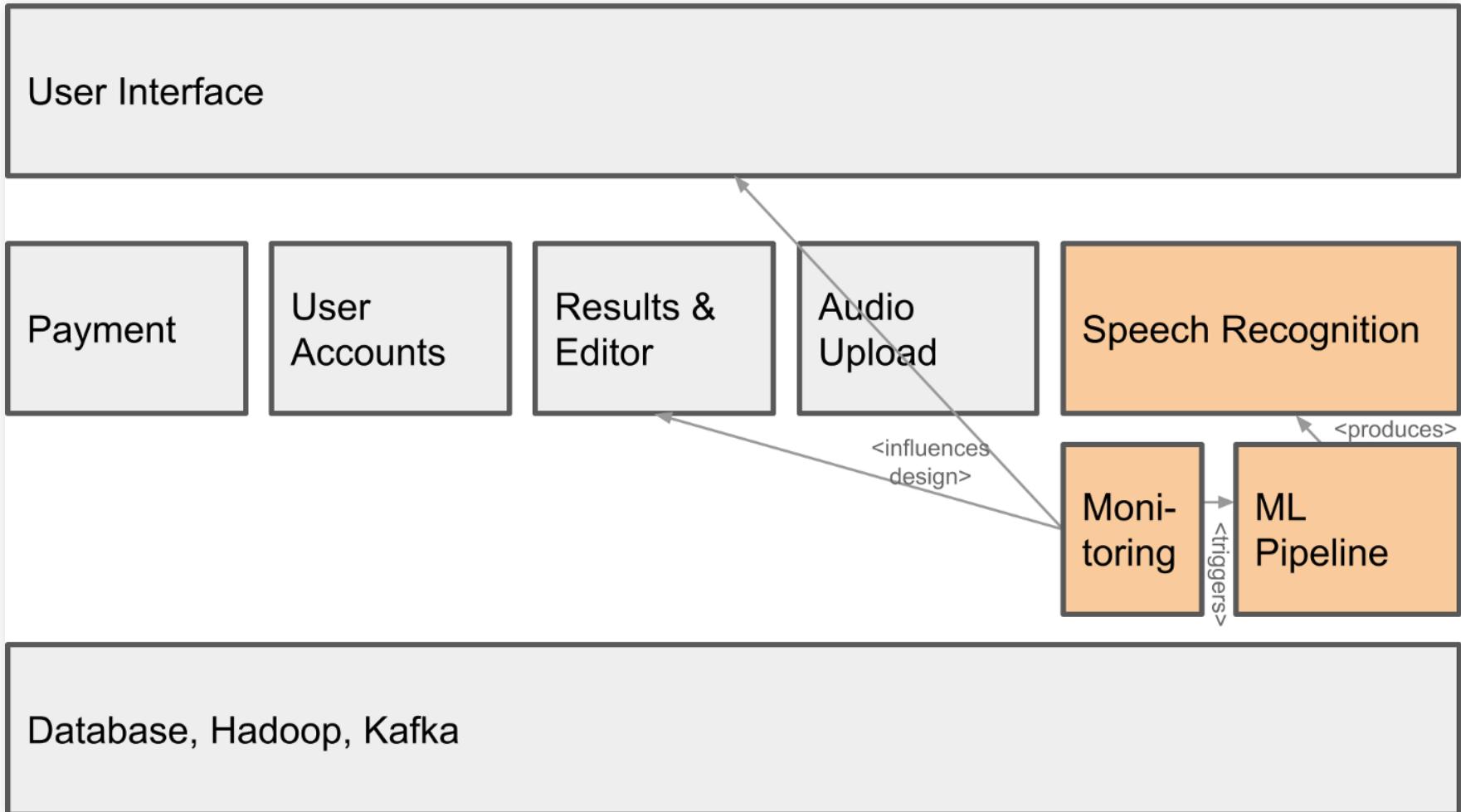
How did we do on your transcript? ☆☆☆☆☆



# ML IS A COMPONENT IN A SYSTEM



# SYSTEM DESIGN TO SUPPORT ML



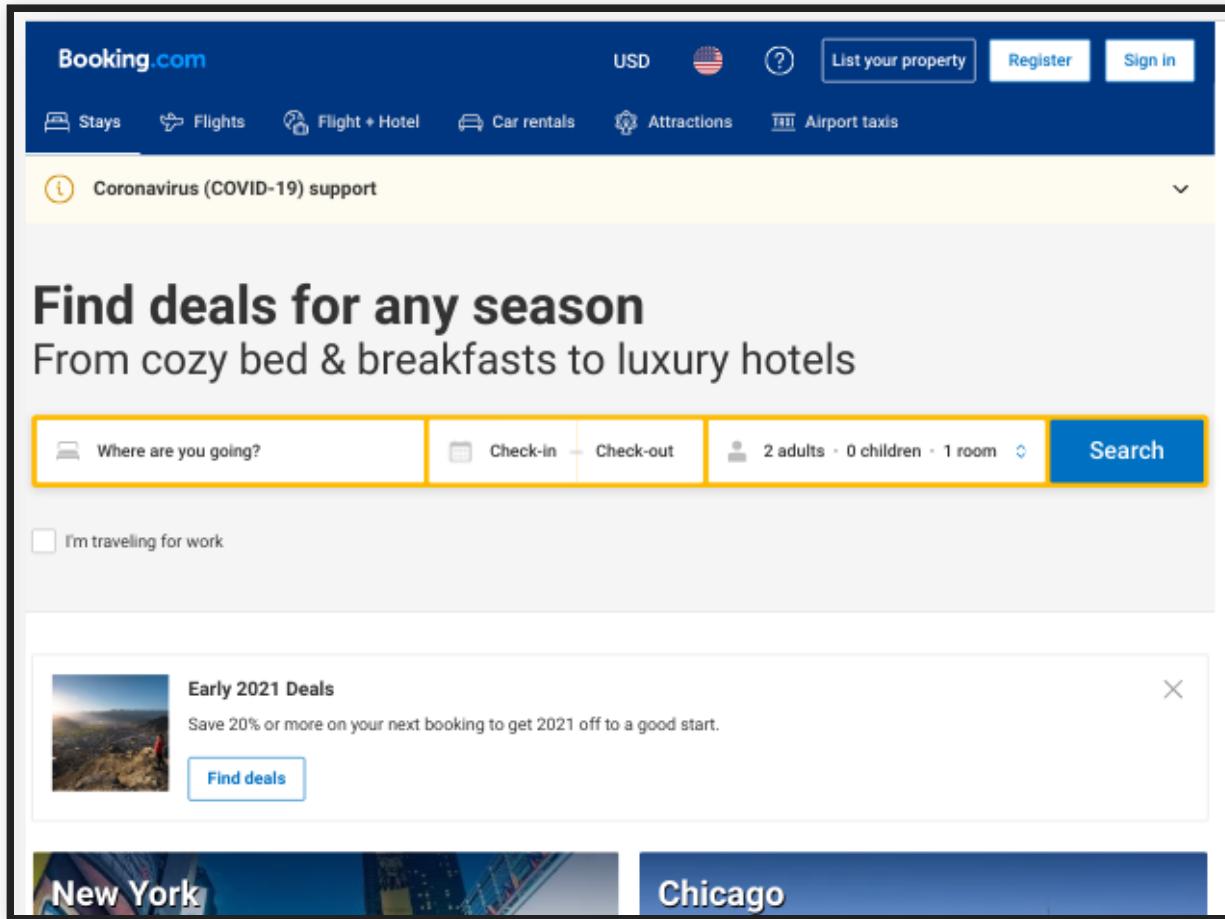
# **EVERYTHING IS A TRADEOFF**

“It Depends.”

# MANY QUALITIES OF INTEREST

- Accuracy
- Inference latency, throughput, energy consumption
- Learning time, incremental learning, scalability, resources needed
- Simplicity, maintainability, extensibility,
- Interpretability/explainability, fairness
- Robustness, reproducibility, stability
  
- Usability, trust, accountability
- User satisfaction
- Dealing with mistakes
- Safety, security, privacy
- Development velocity, predictability
- Profit
- ...

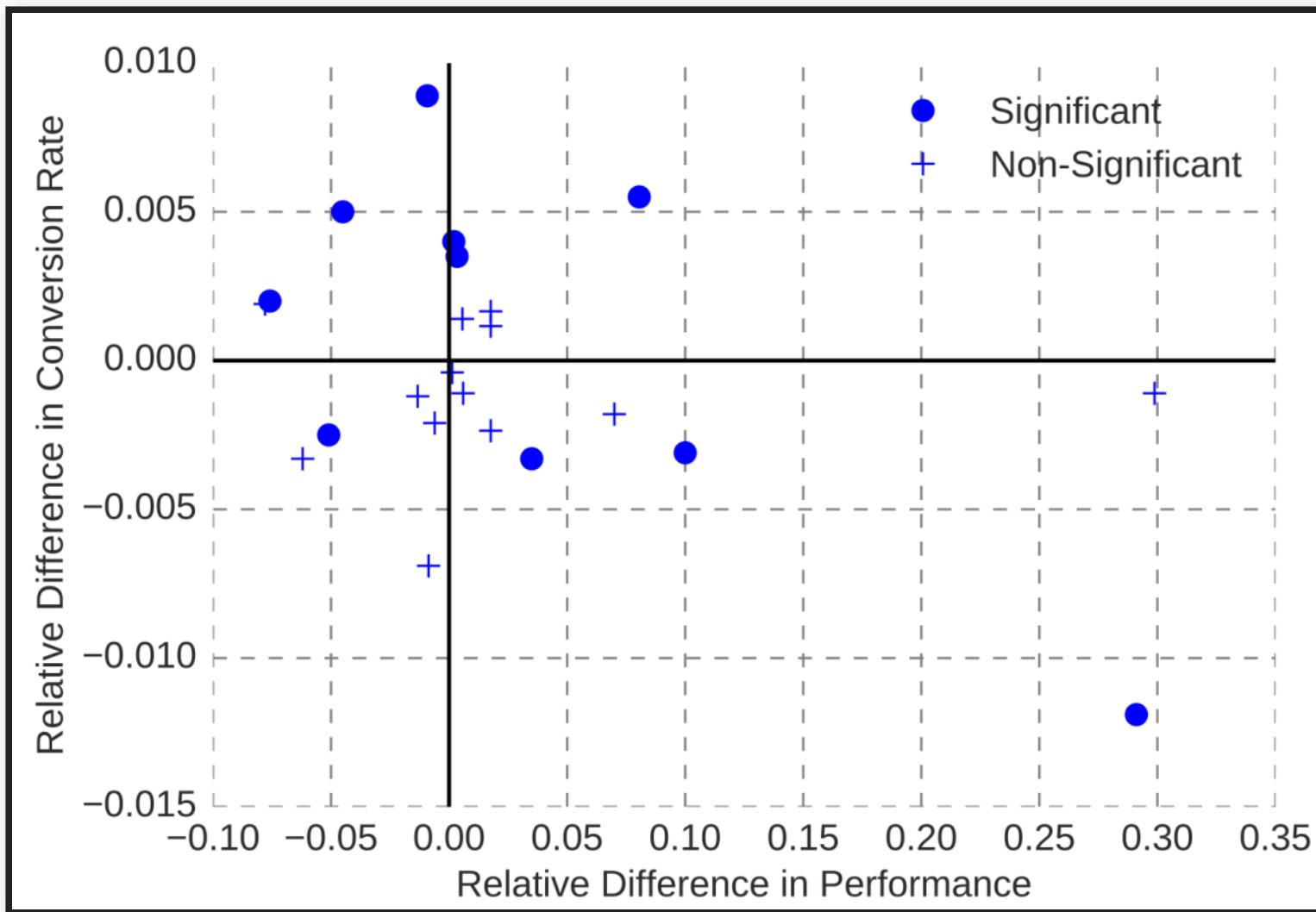
# MODEL QUALITY VS SYSTEM QUALITY



Bernardi, Lucas, Themistoklis Mavridis, and Pablo Estevez. "150 successful machine learning models: 6 lessons learned at Booking.com." In Proc. International Conference on Knowledge Discovery & Data Mining, 2019.



# MODEL QUALITY VS SYSTEM QUALITY



# MANY QUALITIES OF INTEREST

- Accuracy
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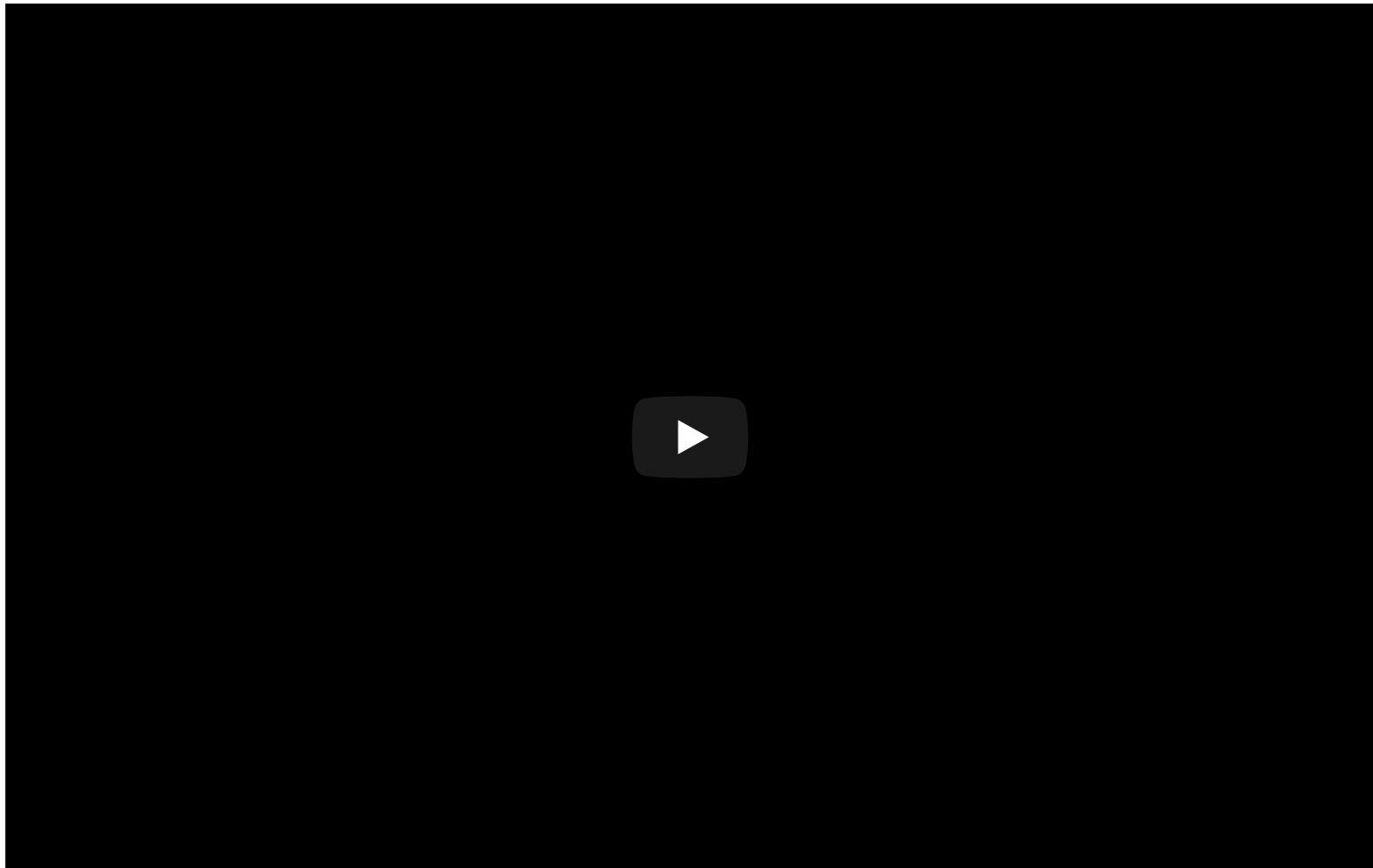
# EXAMPLE: AR INSTANT TRANSLATION



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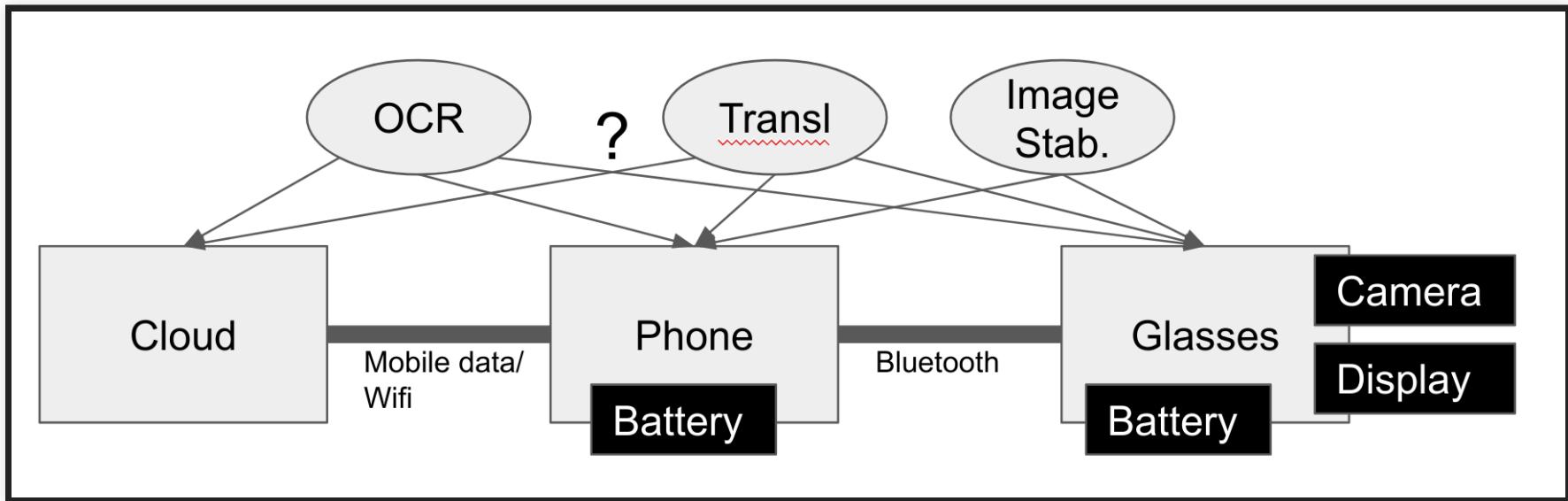
# EXAMPLE: AR INSTANT TRANSLATION



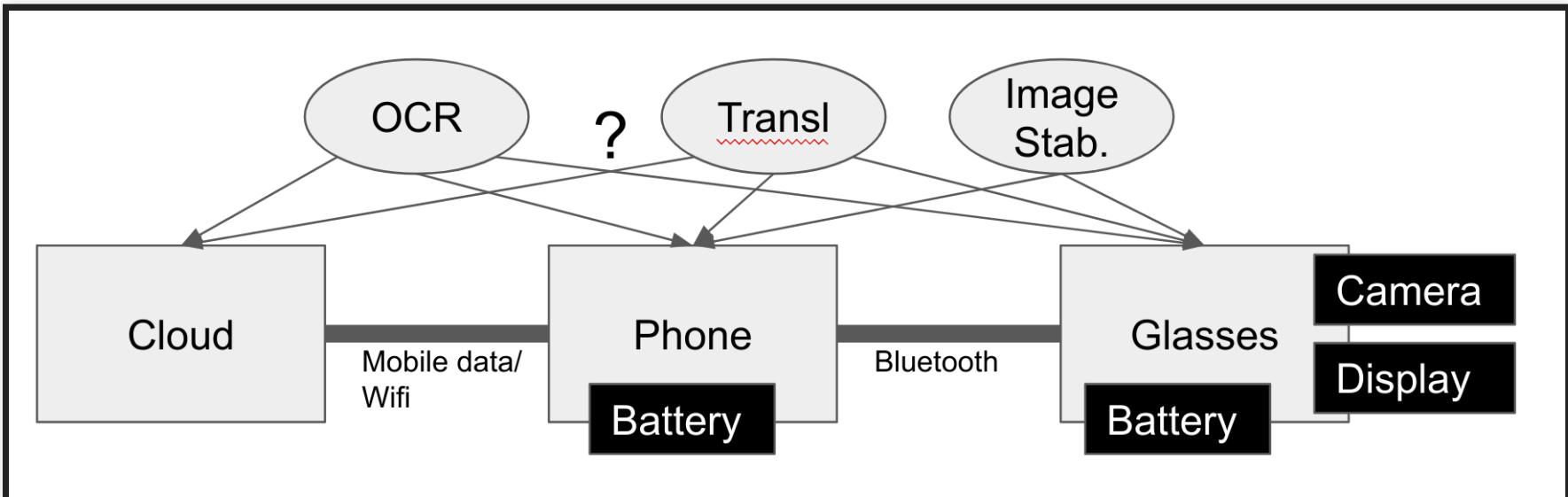
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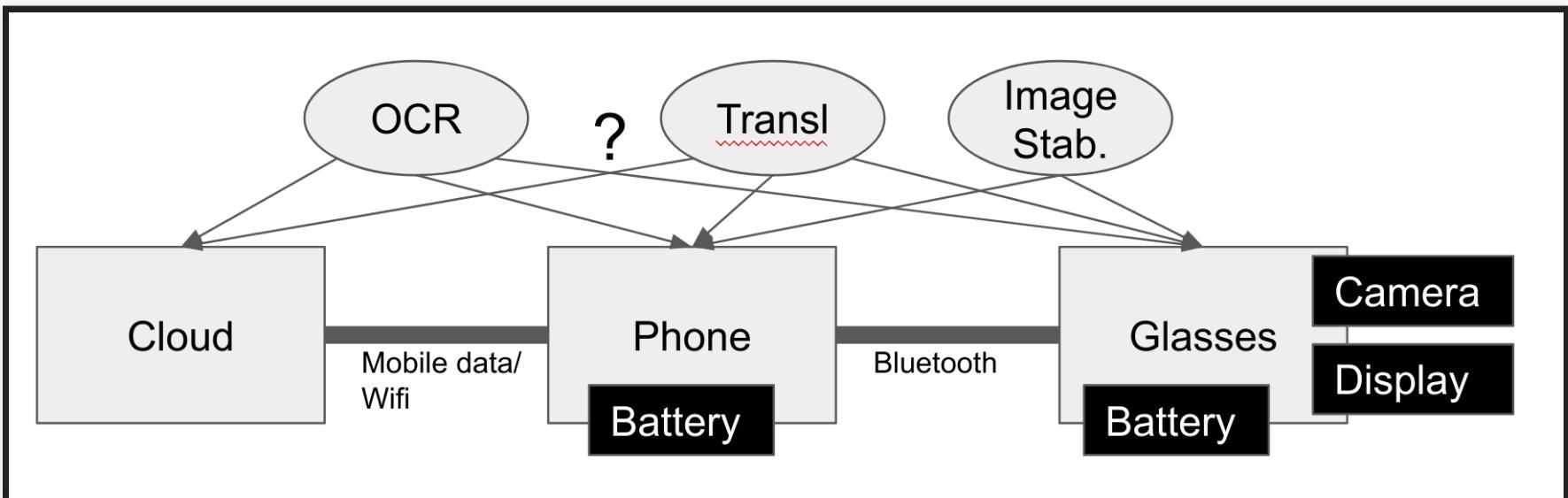
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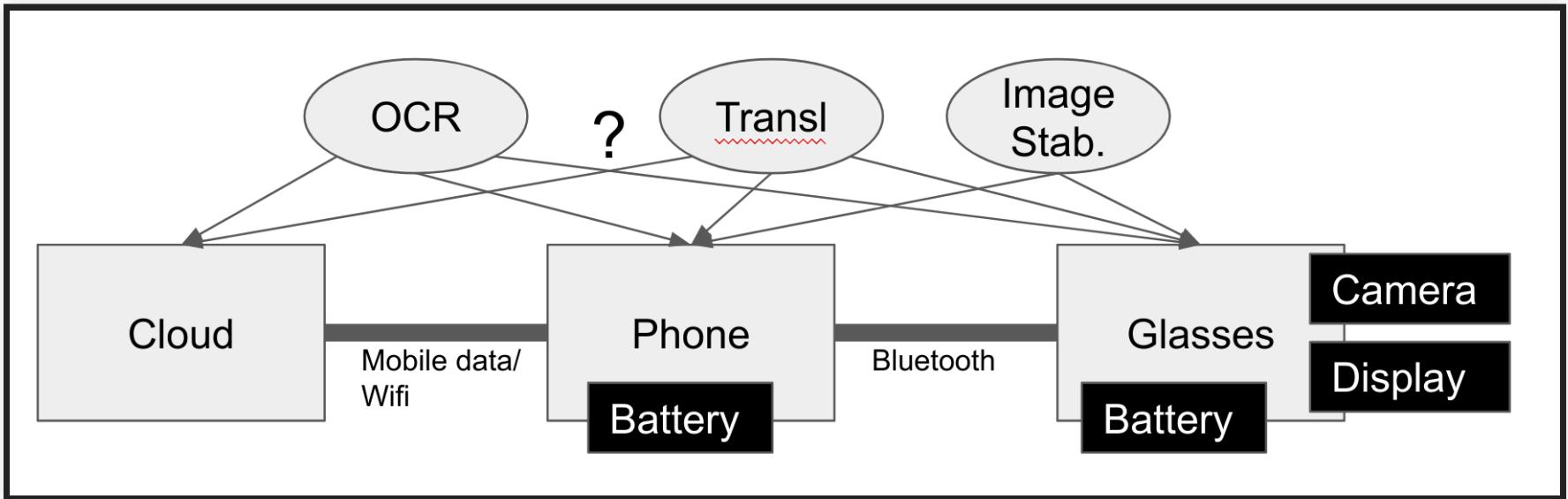
# TRADEOFF: ACCURACY VS LATENCY + ENERGY + MODEL SIZE



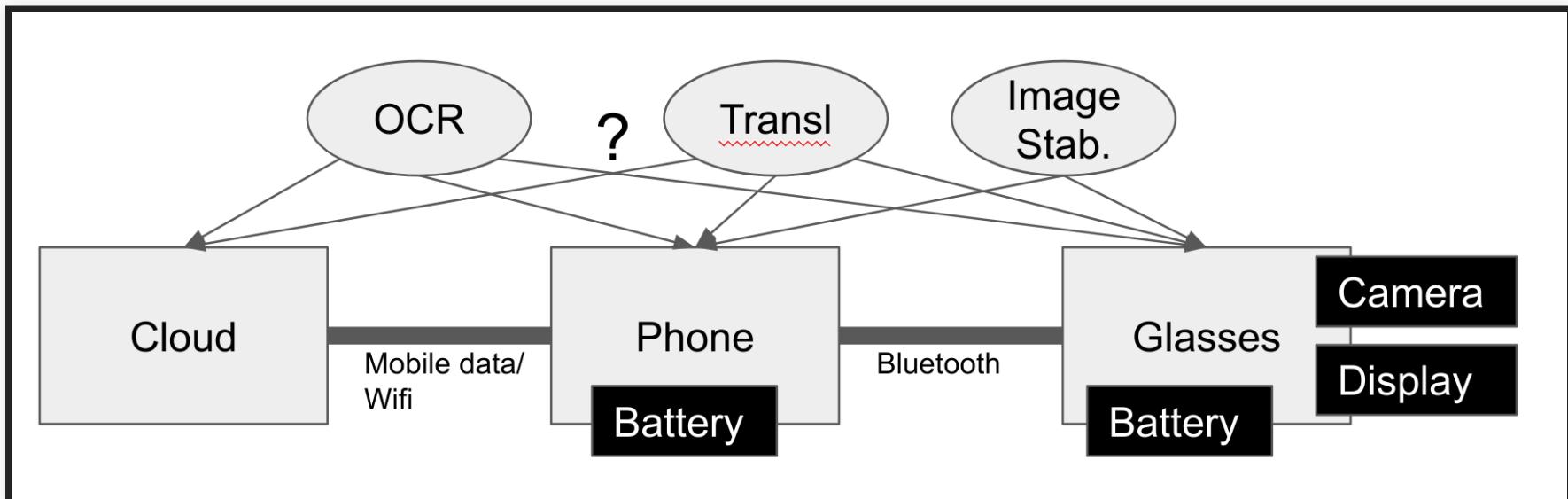
# TRADEOFF: LATENCY VS ENERGY CONSUMPTION VS BANDWIDTH



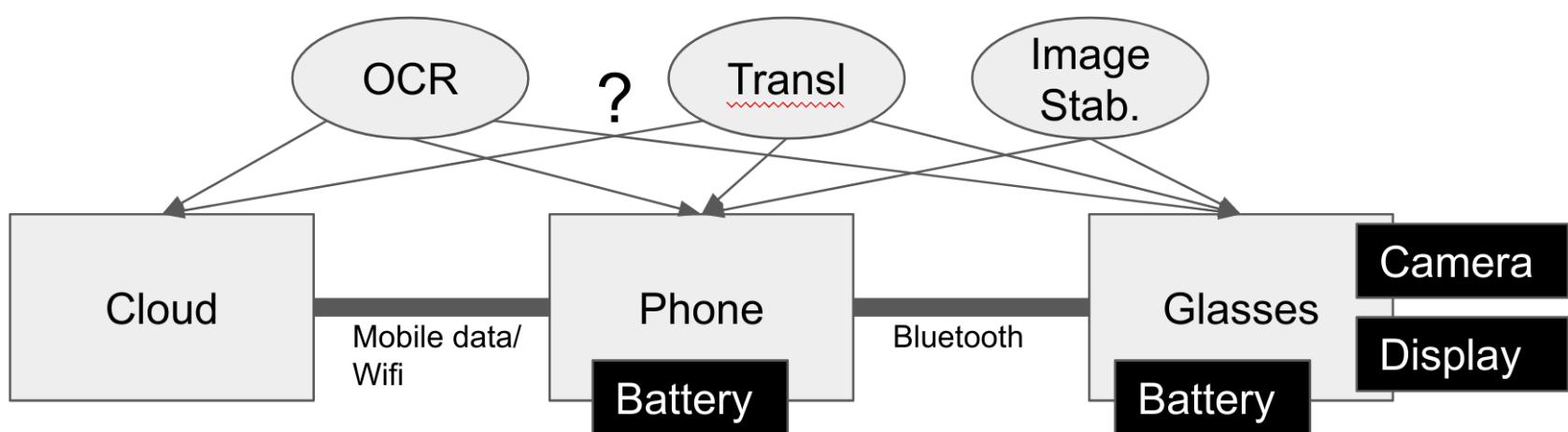
# TRADEOFF: PRIVACY VS TELEMETRY



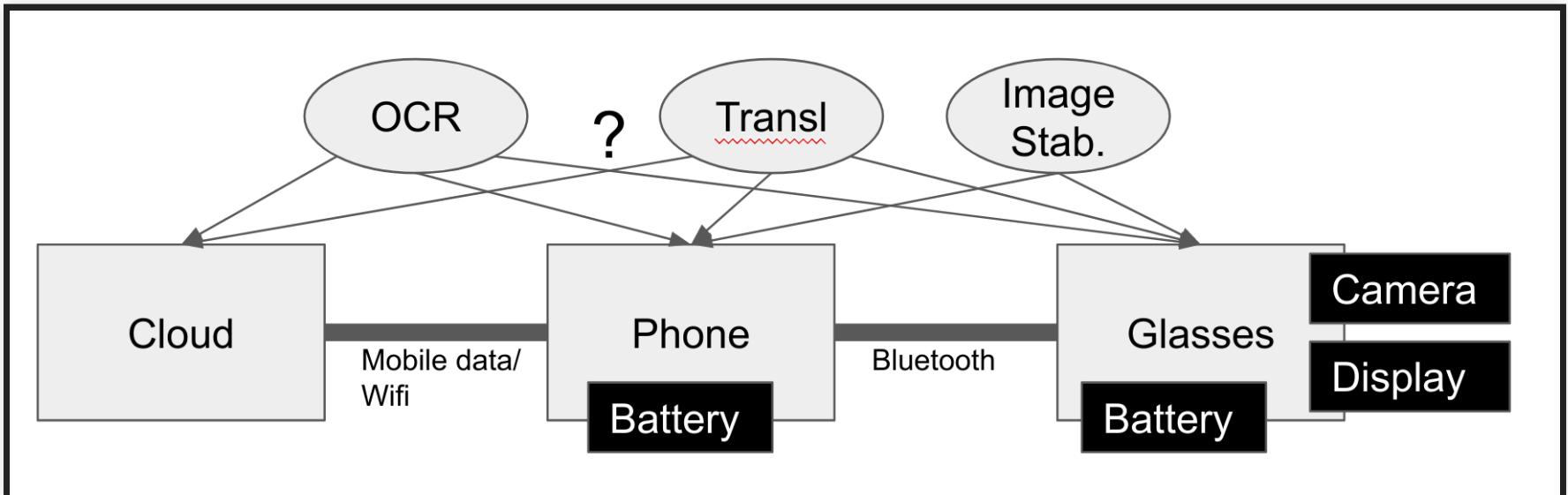
# TRADEOFF: TELEMETRY BENEFITS VS TELEMETRY COSTS



# TRADEOFF: UPDATE LATENCY VS OFFLINE USE

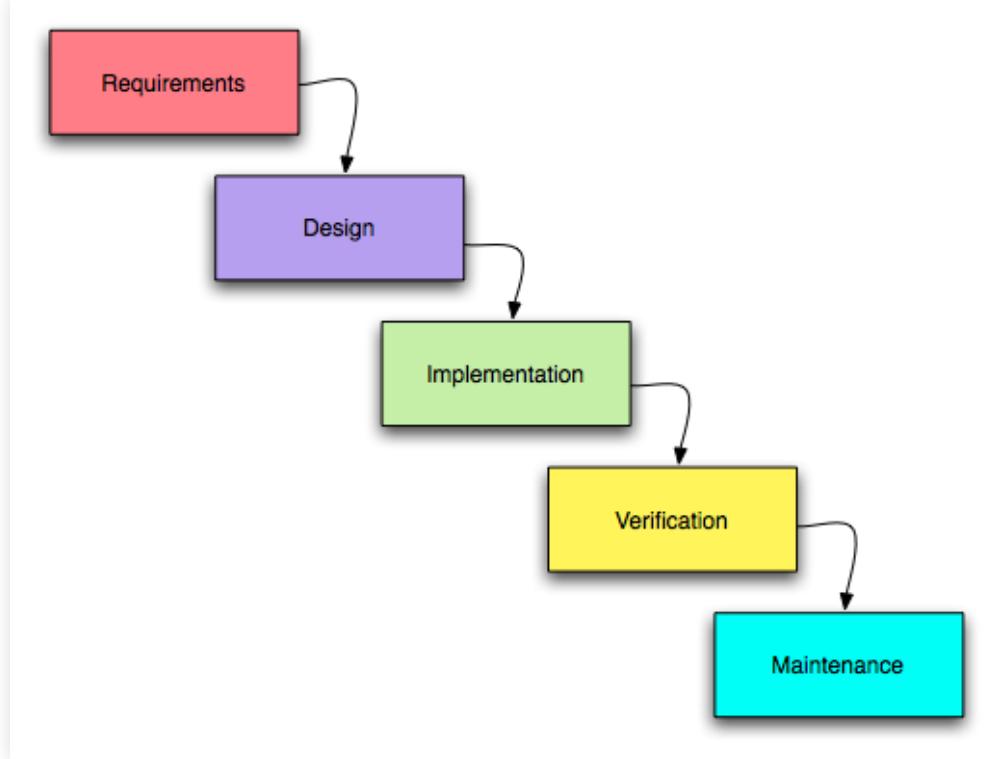


# TRADEOFF: TRAINING COST VS UPDATE FREQUENCY



“It Depends.”

# **THINK LIKE A SOFTWARE ARCHITECT**

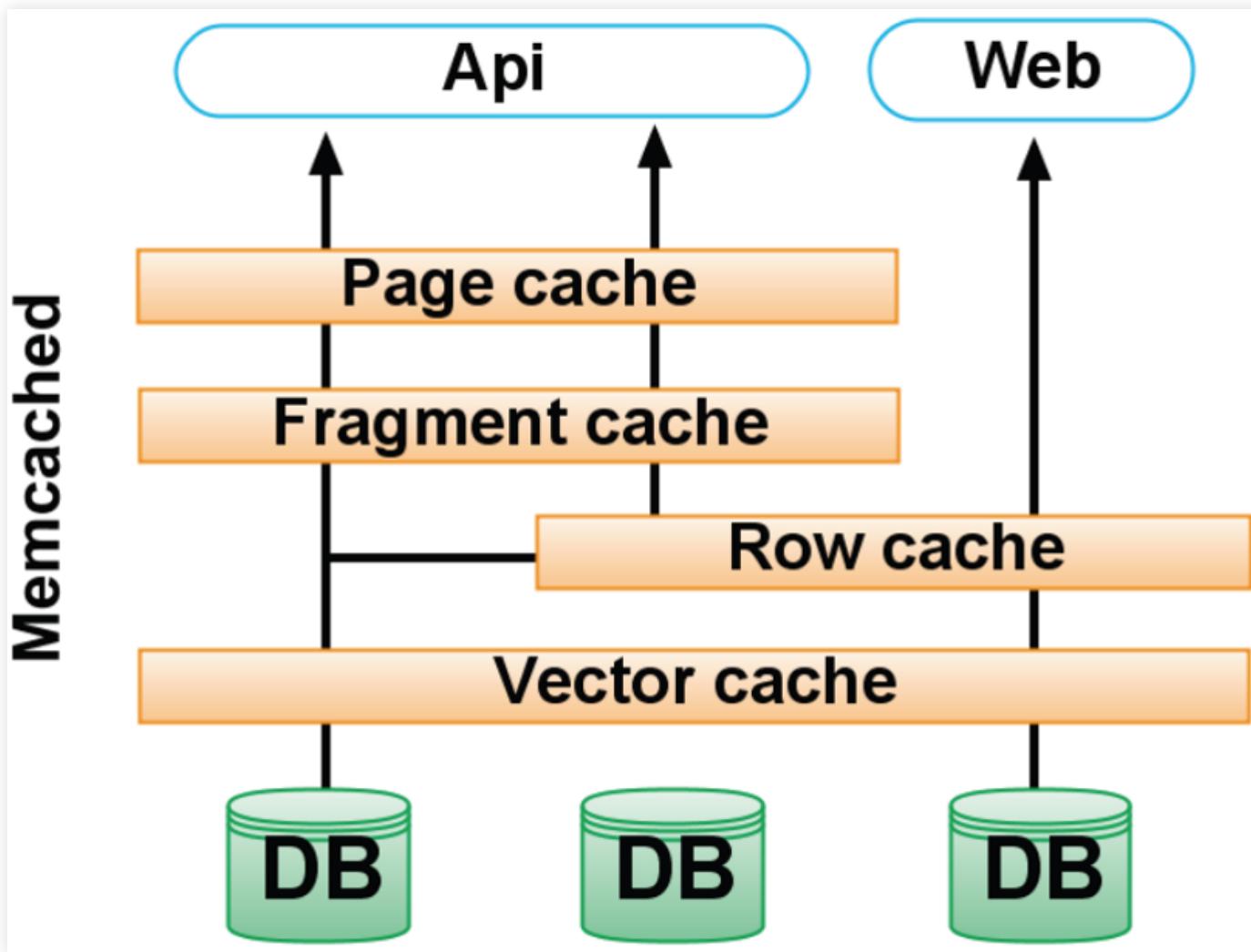


# EXCURSION: TWITTER



Raffi. [New Tweets per second record, and how!](#) Twitter Blog, 2013

# TWITTER - CACHING ARCHITECTURE



## Speaker notes

- Running one of the world's largest Ruby on Rails installations
- 200 engineers
- Monolithic: managing raw database, memcache, rendering the site, and \* presenting the public APIs in one codebase
- Increasingly difficult to understand system; organizationally challenging to manage and parallelize engineering teams
- Reached the limit of throughput on our storage systems (MySQL); read and write hot spots throughout our databases
- Throwing machines at the problem; low throughput per machine (CPU + RAM limit, network not saturated)
- Optimization corner: trading off code readability vs performance

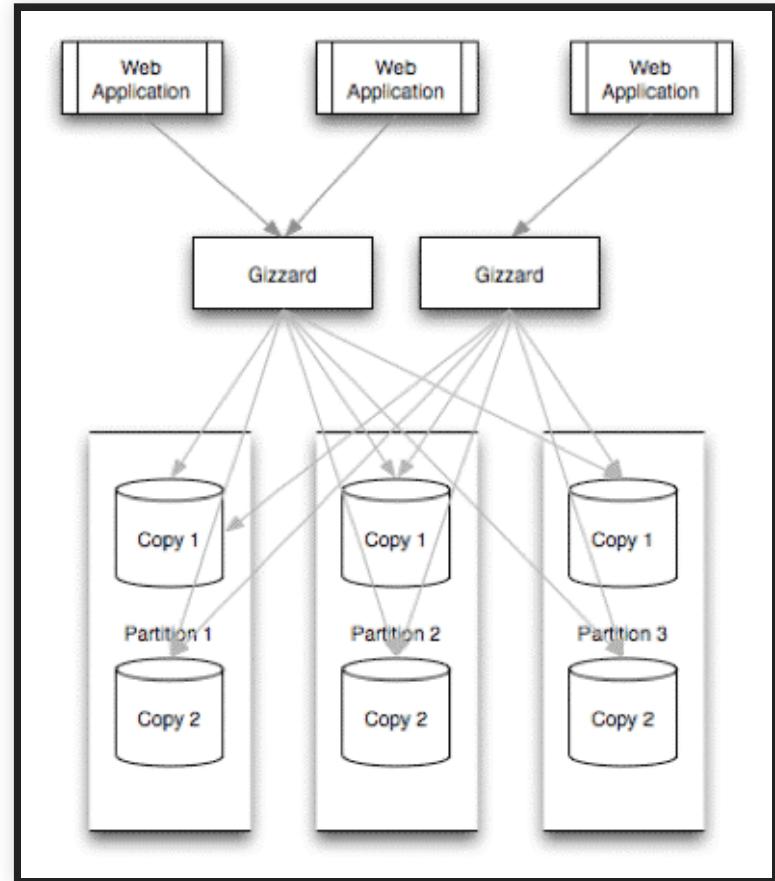
# TWITTER'S REDESIGN GOALS

- Performance
  - Improve median latency; lower outliers
  - Reduce number of machines 10x
- Reliability
  - Isolate failures
- Maintainability
  - "We wanted cleaner boundaries with “related” logic being in one place": encapsulation and modularity at the systems level (rather than at the class, module, or package level)
- Modifiability
  - Quicker release of new features: "run small and empowered engineering teams that could make local decisions and ship user-facing changes, independent of other teams"

Raffi. [New Tweets per second record, and how!](#) Twitter Blog, 2013

# TWITTER: REDESIGN DECISIONS

- Ruby on Rails -> JVM/Scala
- Monolith -> Microservices
- RPC framework with monitoring, connection pooling, failover strategies, loadbalancing, ... built in
- New storage solution, temporal clustering, "roughly sortable ids"
- Data driven decision making

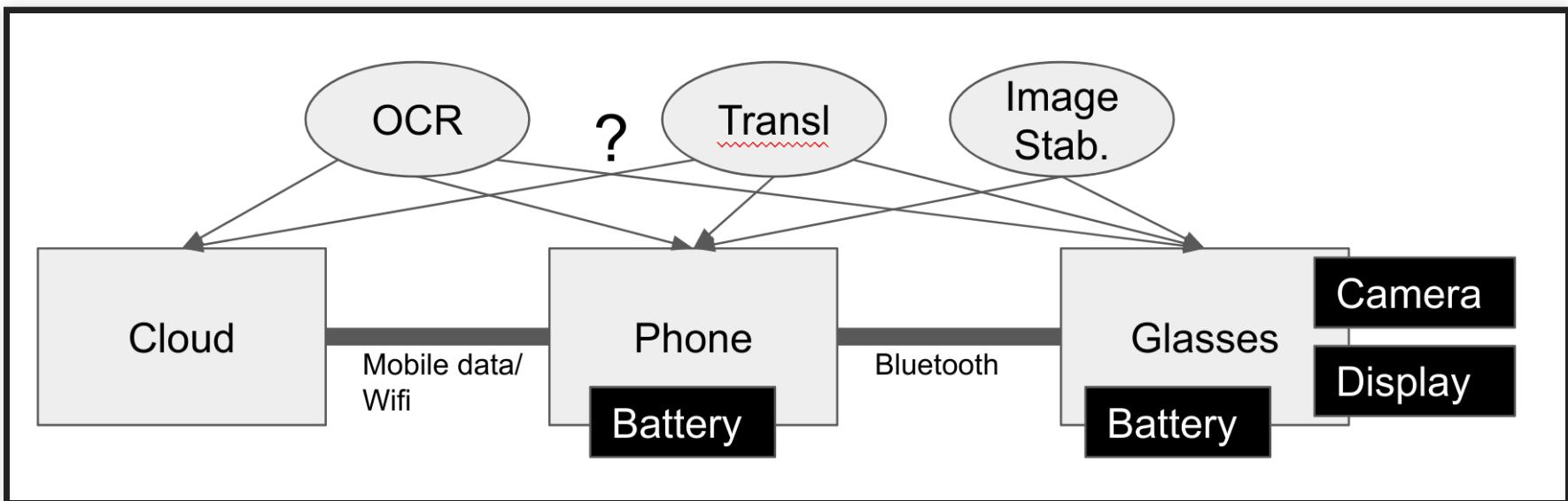


# TWITTER CASE STUDY: KEY INSIGHTS

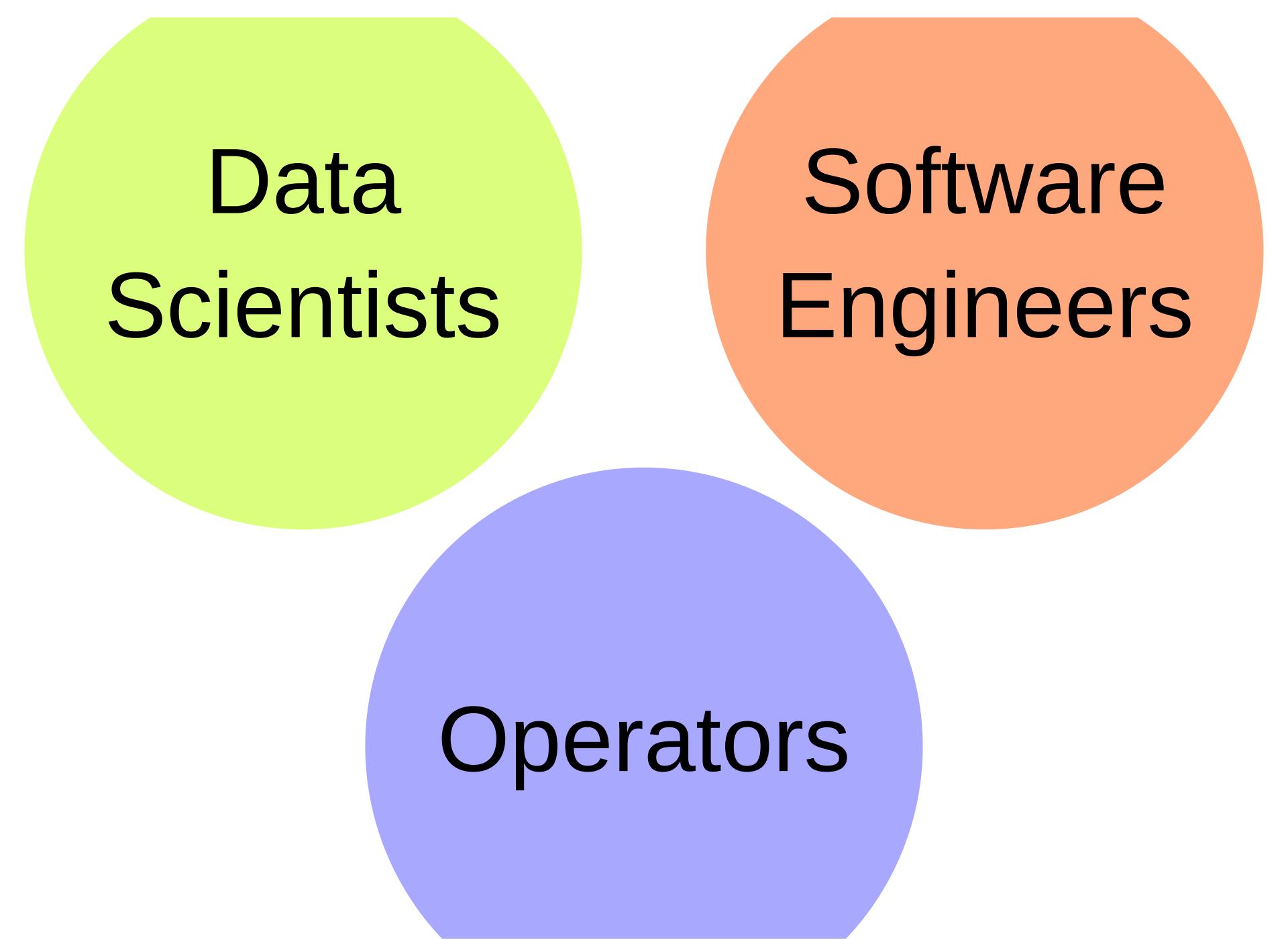
- Architectural decisions affect entire systems, not only individual modules
- Abstract, different abstractions for different scenarios
- Reason about quality attributes early
- Make architectural decisions explicit

# ARCHITECTURAL PLANNING

- Identify and prioritize relevant qualities
- Identify system structure and relevant interactions
- Understand constraints and tradeoffs
- Conduct research into requirements and constraints
- Explore alternatives
- Set obligations for components



# TEAMS AND PROCESS



A diagram consisting of three overlapping circles. The top-left circle is light green and contains the text "Data Scientists". The top-right circle is light orange and contains the text "Software Engineers". The bottom circle is light blue and contains the text "Operators". The circles overlap in the center, suggesting a shared or interconnected nature of the roles.

**Data  
Scientists**

**Software  
Engineers**

**Operators**

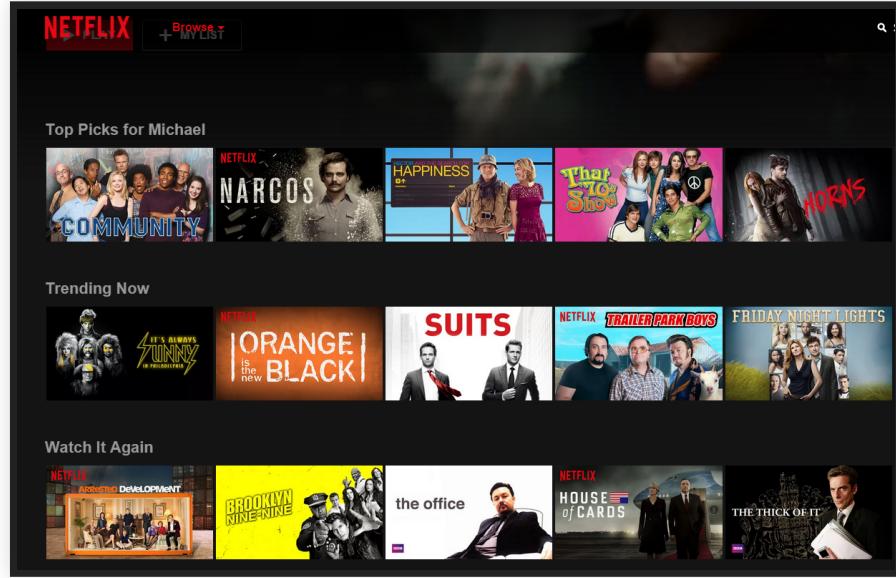


# DATA SCIENTIST

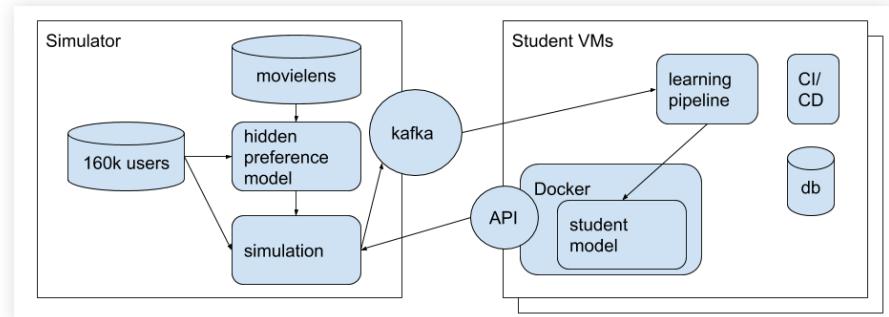
- Often fixed dataset for training and evaluation (e.g., PBS interviews)
- Focused on accuracy
- Prototyping, often Jupyter notebooks or similar
- Expert in modeling techniques and feature engineering
- Model size, updateability, implementation stability typically does not matter
- Starting to worry about fairness, robustness, ...

# SOFTWARE ENGINEER

- Builds a product
- Concerned about cost, performance, stability, release time
- Identify quality through customer satisfaction
- Must scale solution, handle large amounts of data
- Plan for mistakes and safeguards
- Maintain, evolve, and extend the product over long periods
- Consider requirements for security, safety, fairness



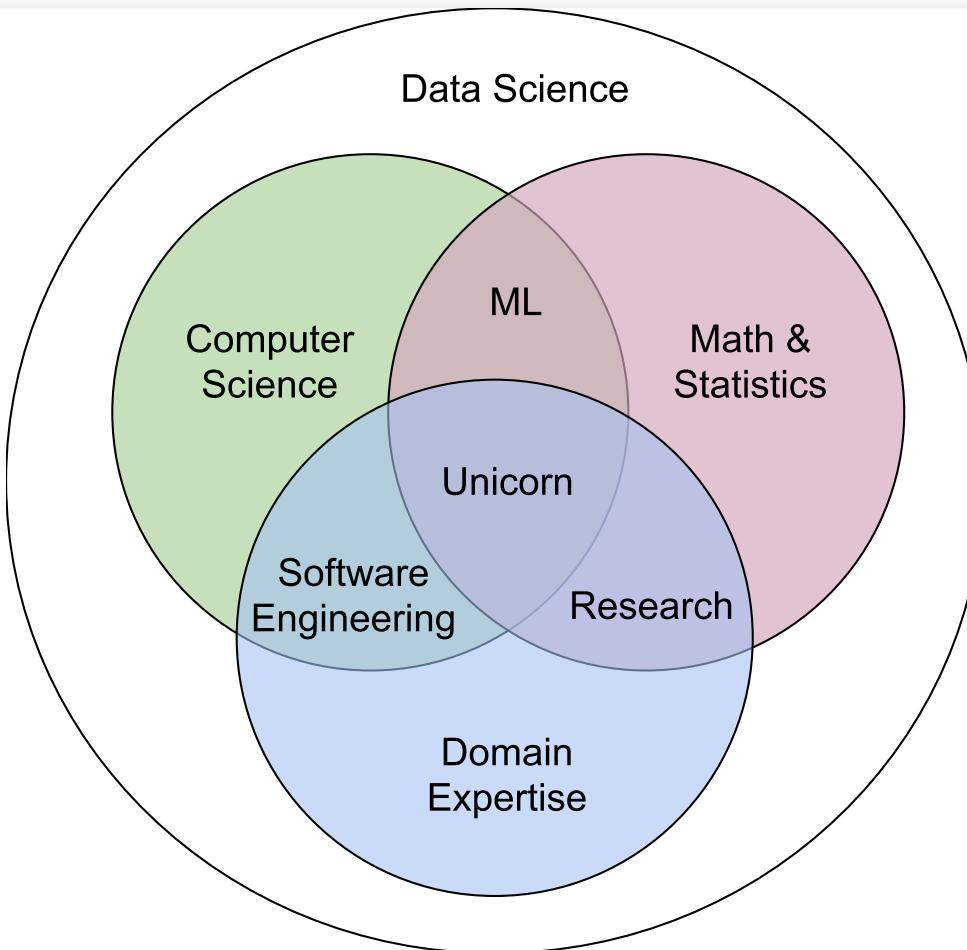
# CMU 17-445 Class Project



# DATA SCIENCE PRACTICES BY SOFTWARE ENGINEERS

- Many software engineers get involved in data science without explicit training
- Copying from public examples, little reading of documentation
- Lack of data visualization/exploration/understanding, no focus on data quality
- Strong preference for code editors, non-GUI tools
- Try improving model by adding more data or using deep learning, rarely feature engineering or debugging
- Lack of awareness about overfitting/bias problems, single focus on accuracy, no monitoring





By Steven Geringer, via Ryan Orban. [Bridging the Gap Between Data Science & Engineer: Building High-Performance Teams](#). 2016

# T-SHAPED PEOPLE

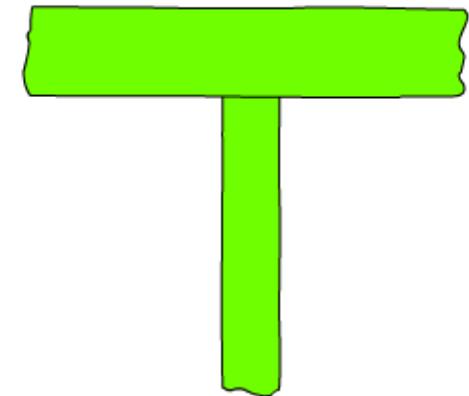
*Broad-range generalist + Deep expertise*



"I-shaped"  
Expert at one thing



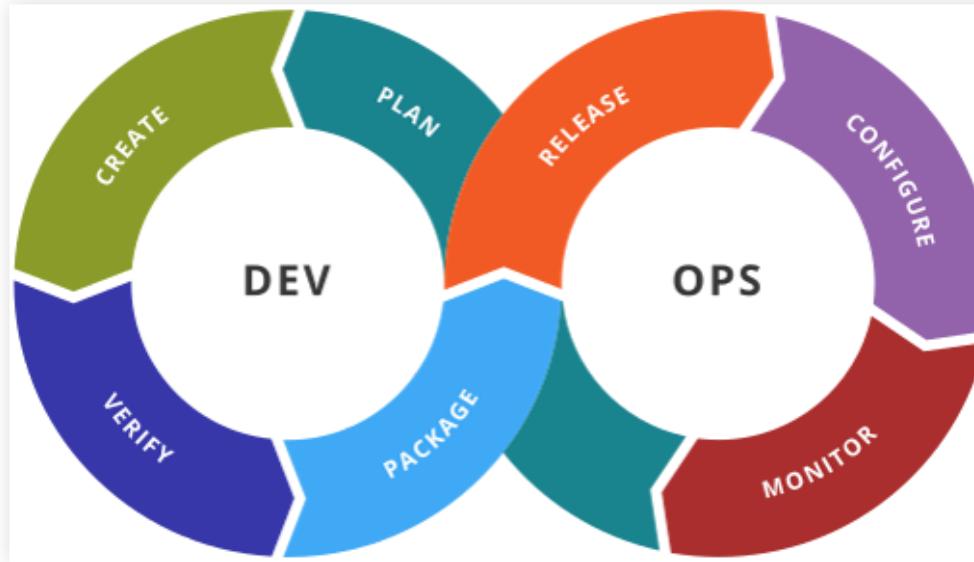
Generalist  
Capable in a lot of things  
but not expert in any



"T-shaped"  
Capable in a lot of things  
and expert in one of them

Figure: Jason Yip. [Why T-shaped people?](#). 2018

# DEVOPS AS INSPIRATION



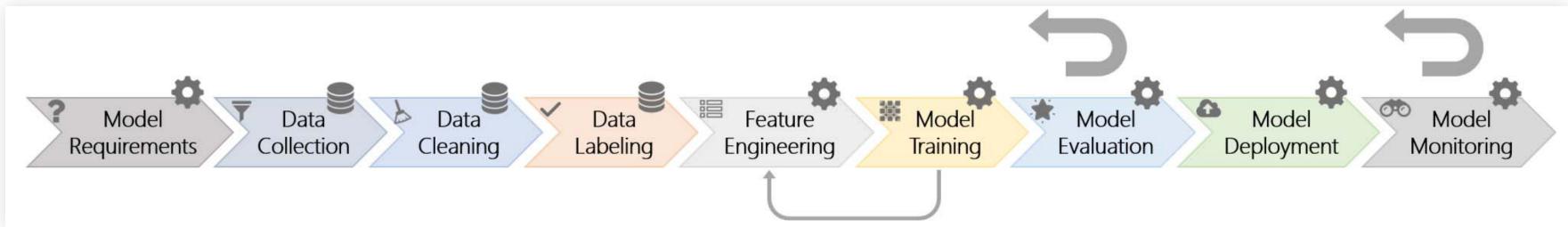
Distinct roles and expertise, but joint responsibilities, joint tooling

Interdisciplinary teams, split expertise, but joint responsibilities

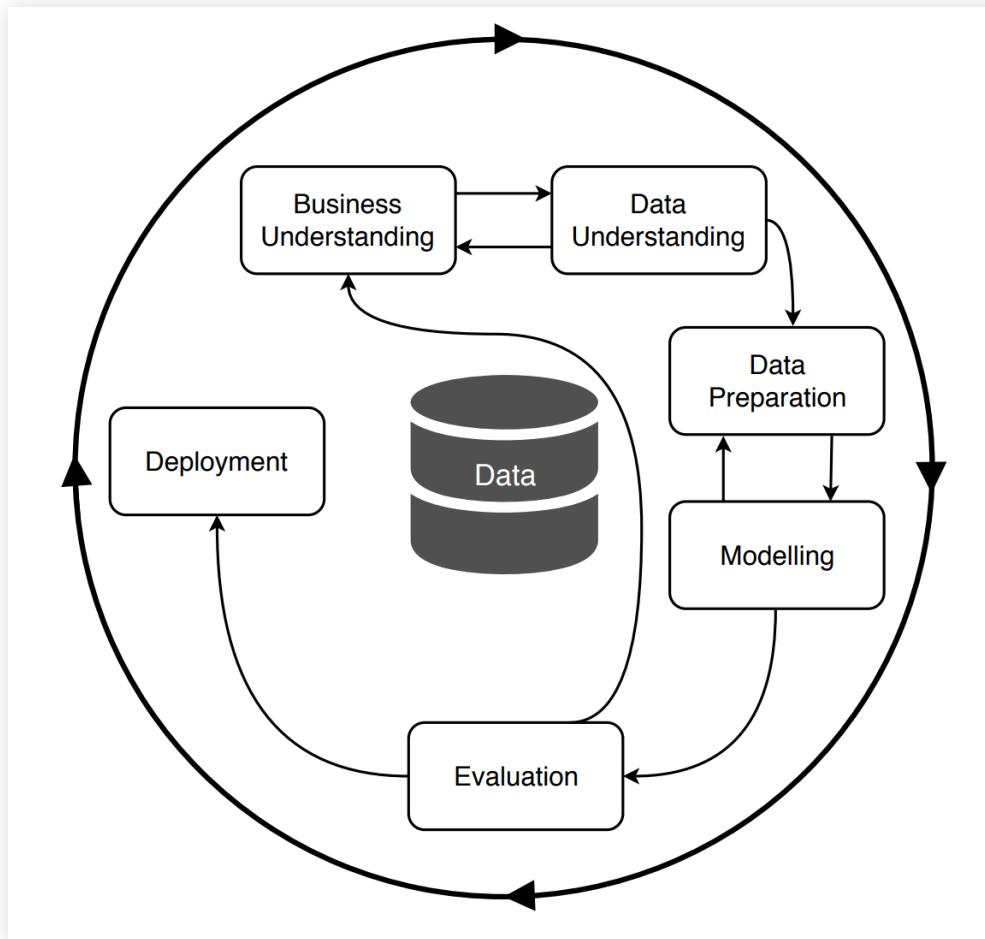
Joint vocabulary and tools

Foster system thinking

# PROCESS MODELS

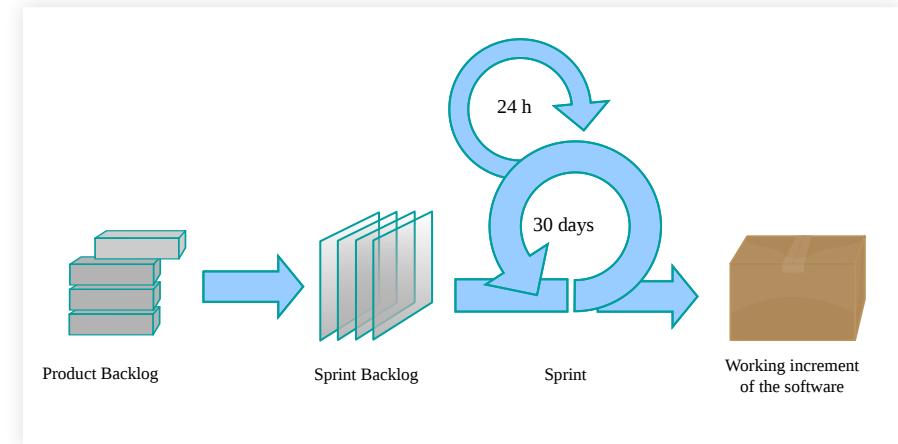
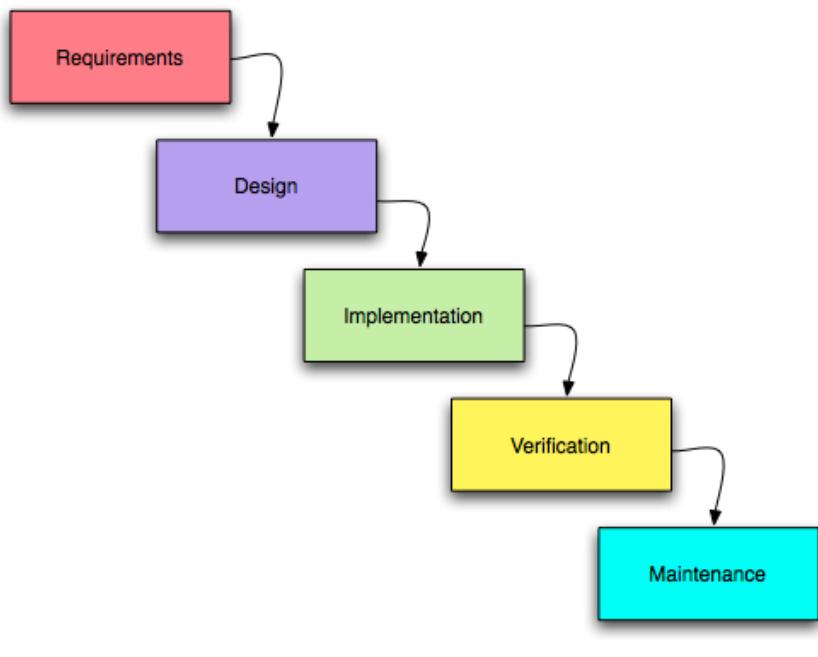


# PROCESS MODELS

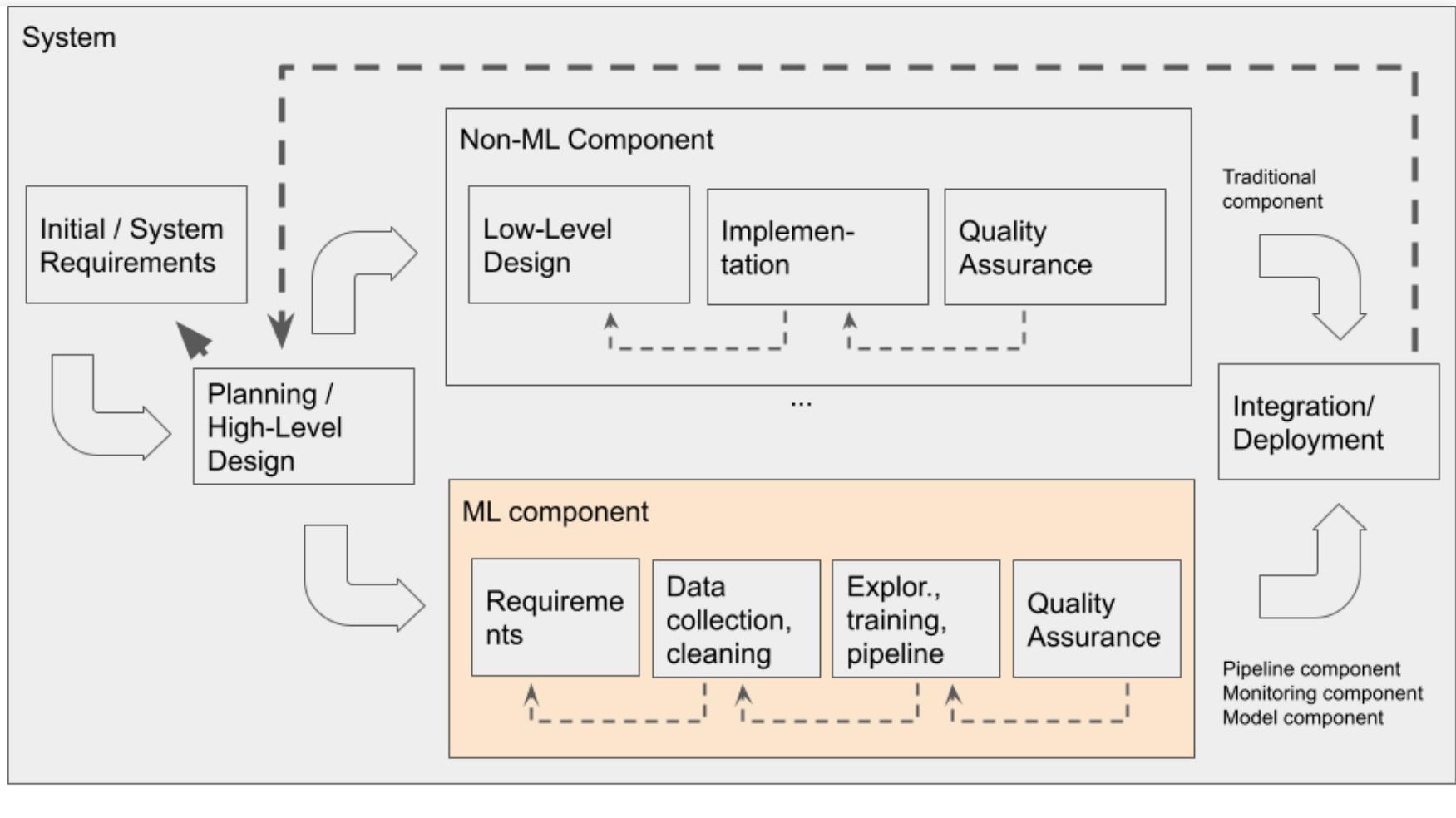


(CRISP-DM)

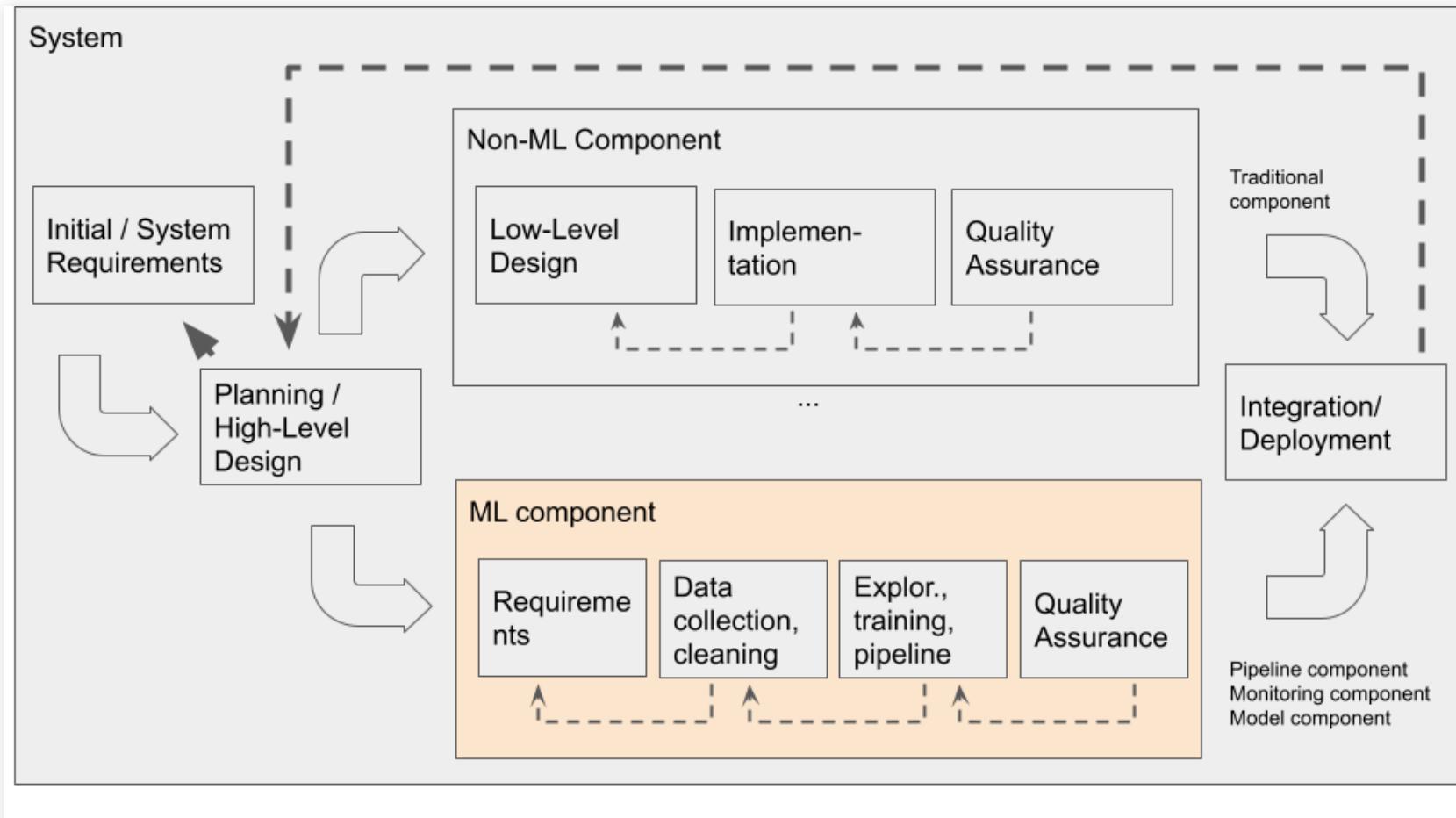
# PROCESS MODELS



# INTEGRATED ML/NON-ML PROCESS



# DEVELOPMENT TRAJECTORIES



Upfront design? ML first? Non-ML system first? Incremental refinement?

# SUMMARY

- Adopt a whole-system perspective on ML in production
- Design for quality, don't patch it in later
- Understand qualities and tradeoffs, including performance
- Consider implications of qualities on non-ML components
- Build interdisciplinary teams, integrative process

Interested in talking about your experiences in interdisciplinary ML teams? Contact us.

# TRADEOFF: MODEL IMPROVEMENT VS SYSTEM SAFEGUARDS

