



Machine Learning in Production

From Models to Systems

Administrativa

- CATME survey for team assignment
- Team assignments announced next Wednesday
- Homework 1 due in one week
- Reminder on grading rubrics
- Reminder on collaboration policy
- #assignments channel on Slack

4: Q4: Lessons ▾

0 OF 3 GRADED

TOTAL POINTS
0.0 / 10.0 pts ⚙️ Rubric Settings

[Collapse View ▲](#)

1	+10.0	Meets requirements as the solution identifies and describes two engineering lessons learned in the project. The lessons generalize from the case study and make specific recommendations for other projects. The lessons relate to engineering concerns of the production system, not data-science concerns in the initial model development.
2	+0.0	Doesn't meet requirements. No lessons were identified and described from the projects.

Learning goals

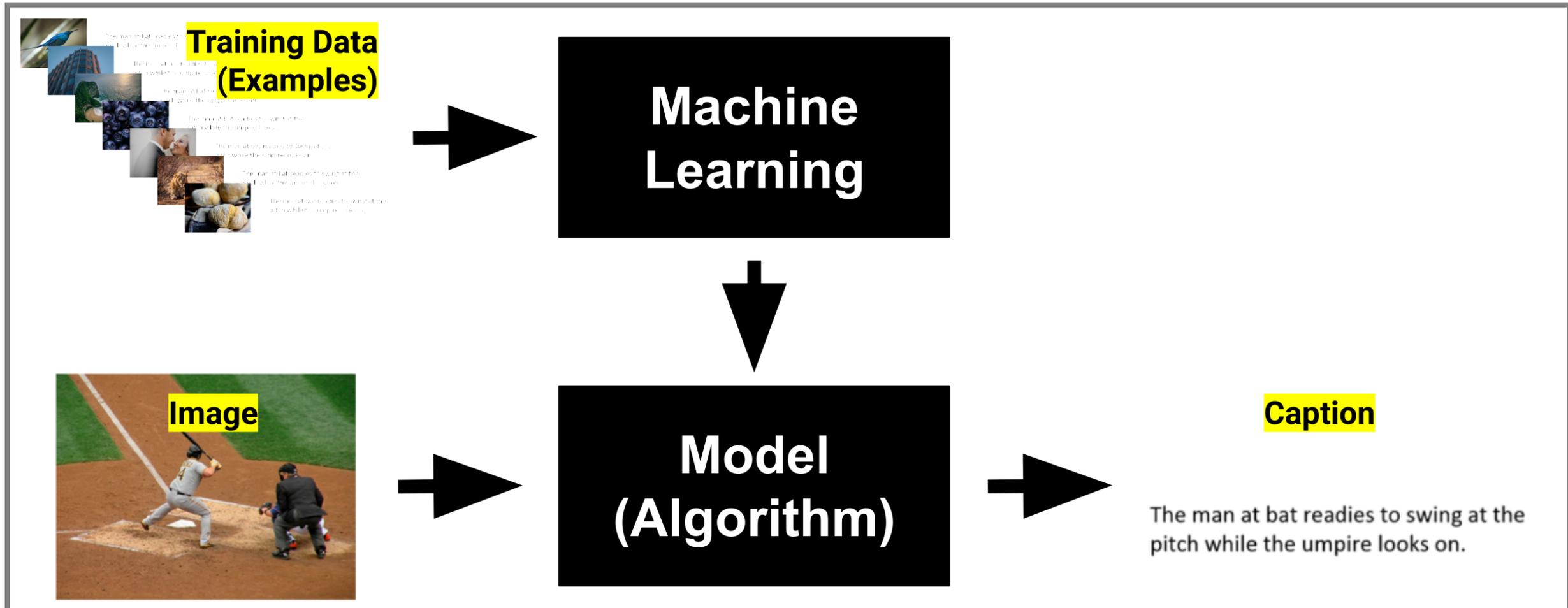
- Explain how machine learning fits into the larger picture of building and maintaining production systems
- Explain the consequences of the shift from deductive to inductive reasoning for abstraction and composition
- Explain the modularity implications of having machine-learning components without specifications
- Describe the typical components relating to AI in an AI-enabled system and typical design decisions to be made

ML Models as Part of a System

Example: Image Captioning Problem



Example: Image Captioning Problem



Why do we care about image captioning?



Machine learning as (small) component in a system

Your Audit Risk Results

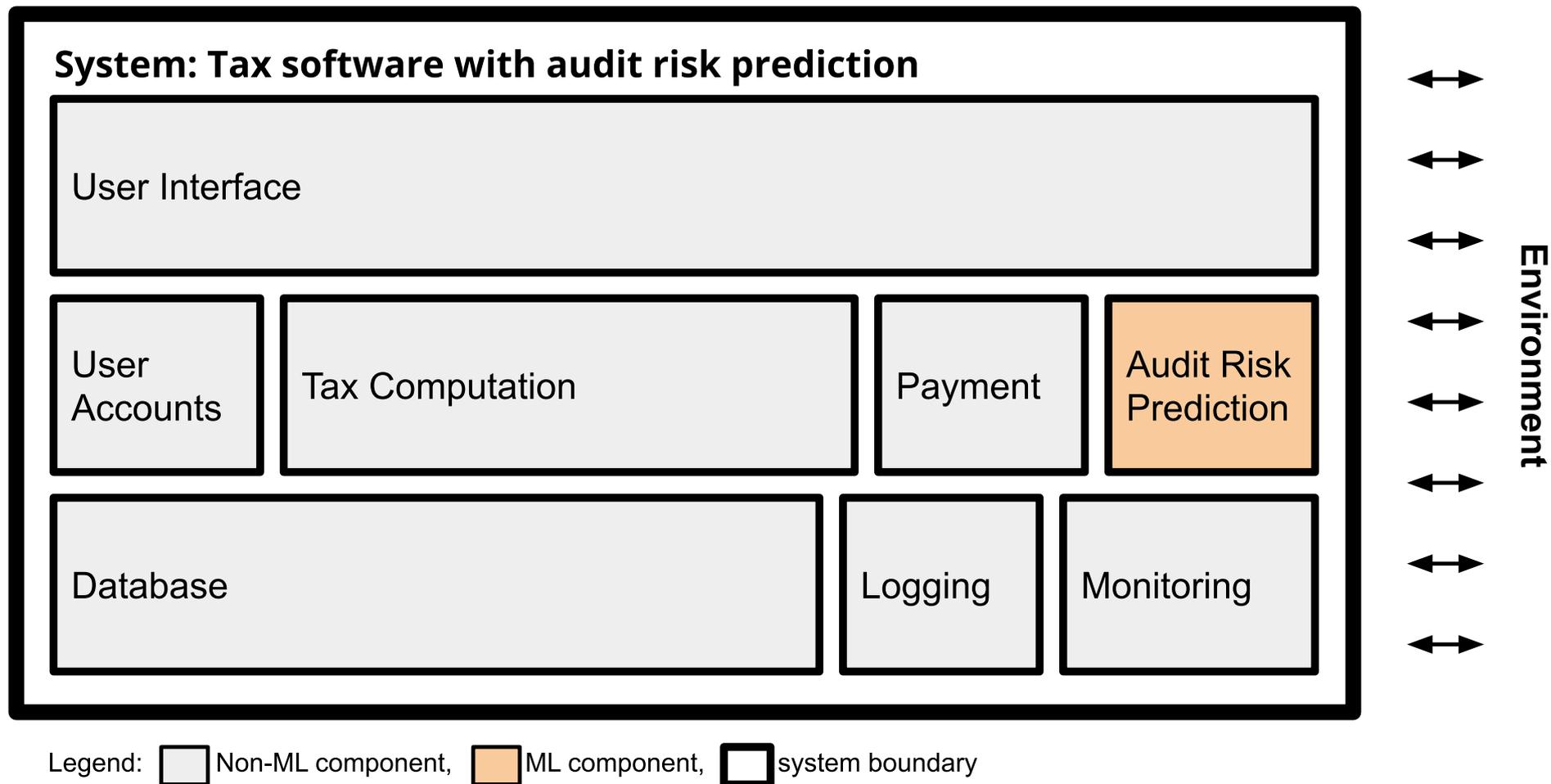


Great news! There's nothing to worry about. We didn't find anything in your return that we consider a typical audit trigger, which means you're in good shape. Plus, we've also got you covered with our [free Audit Support Guarantee](#).

Traditional non-ML tax software, with an added ML component for audit risk estimation



Machine learning as (small) component in a system



Machine learning as (core) component in a system

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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.

Speaker 5 ▶ 08:38

And I asked, **uh**, Alex Martelli, the editor of the Python Cookbook, which had published my original recipe, **a**, how do I get this into python? I think **it** might help

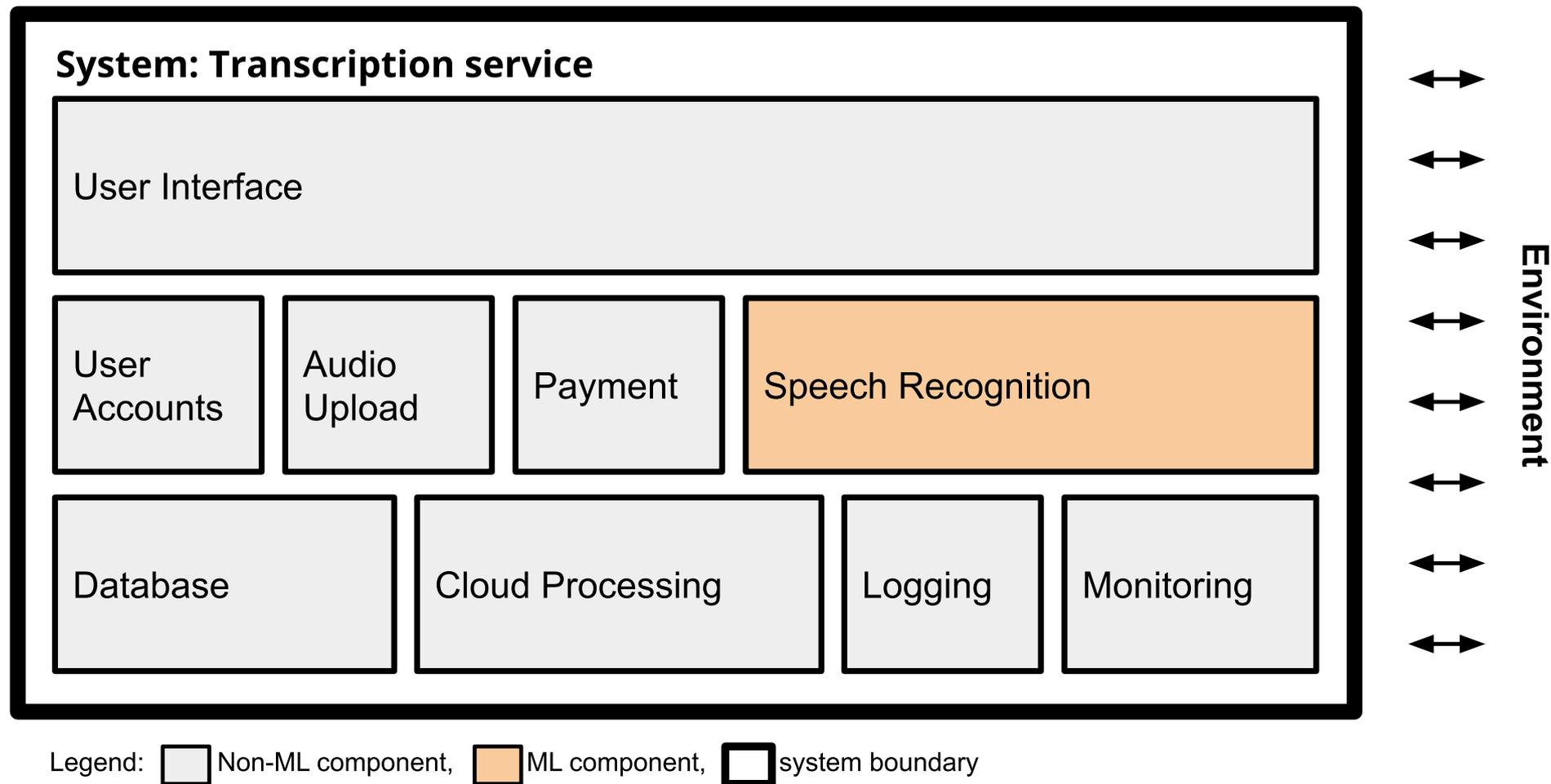
How did we do on your transcript? ☆☆☆☆☆

Speaker notes

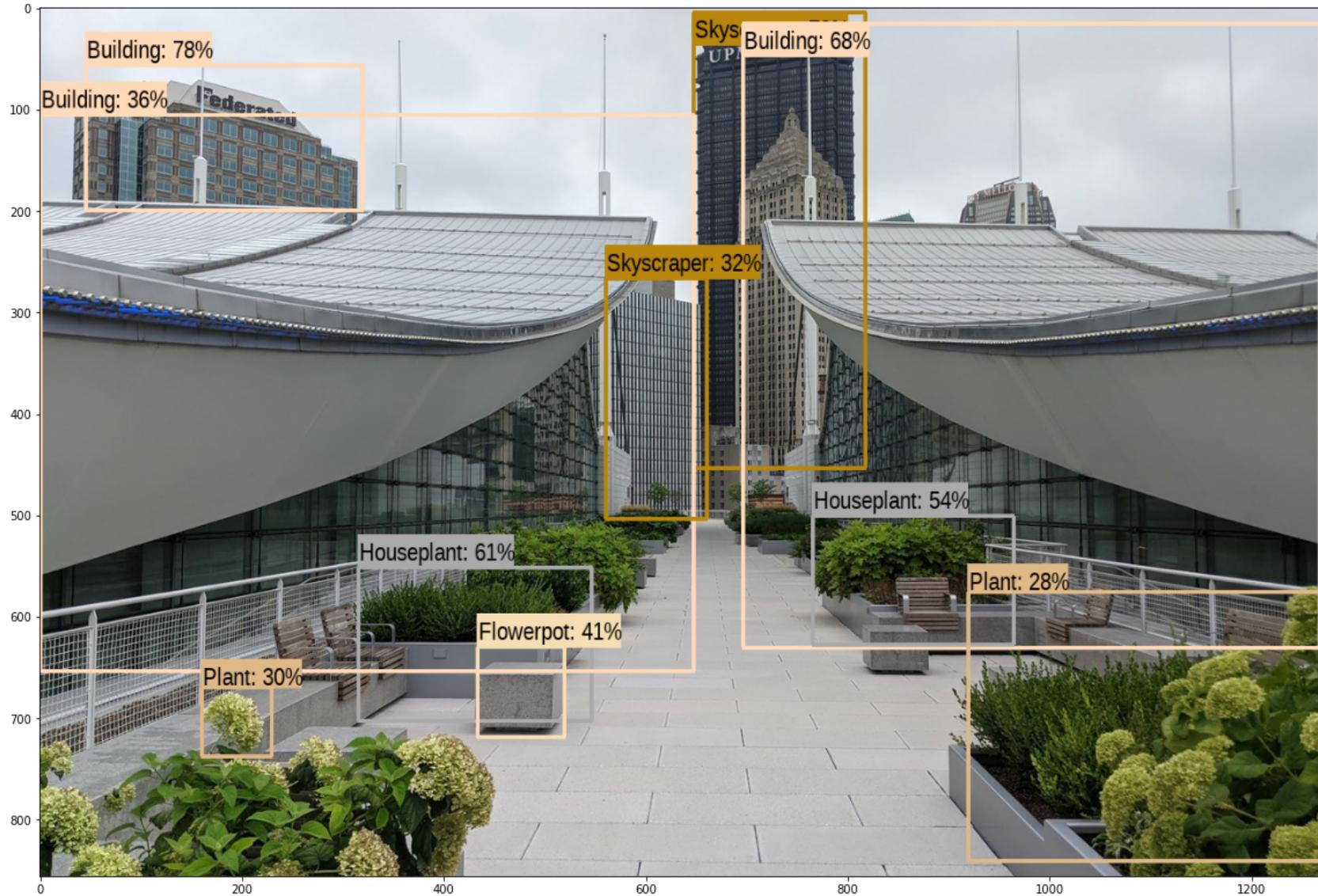
Transcription service, where interface is all built around an ML component



Machine learning as (core) component in a system



Products using Object Detection?





juggling cmu

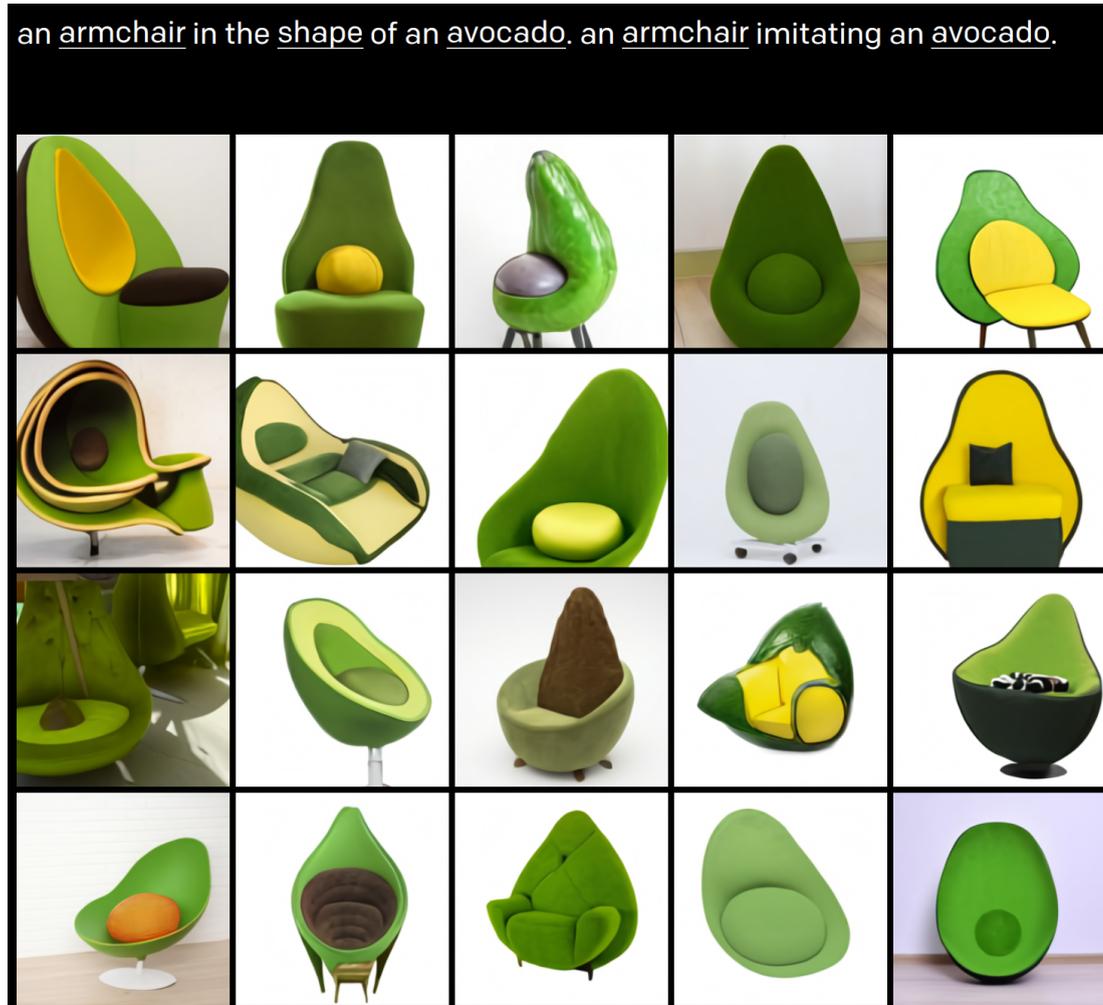
Thu, Sep 21, 2017



Sun, Aug 20, 2017



Products using Image Synthesis?



From <https://openai.com/blog/dall-e/>

Products using ... a Juggling Robot?

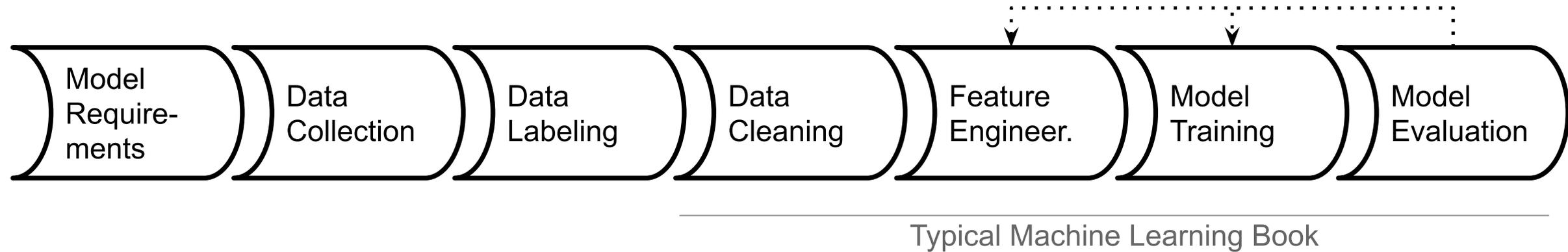


Many more examples of ML in products:

- Product recommendations on Amazon
 - Surge price calculation for Uber
 - Inventory planning in Walmart
 - Search for new oil fields by Shell
 - Adaptive cruise control in a car
 - Smart app suggestion in Android
 - Fashion trends prediction with social media data
 - Suggesting whom to talk to in a presidential campaign
 - Tracking and predicting infections in a pandemic
 - Adaptively reacting to network issues by a cell phone provider
 - Matching players in a computer game by skill
 - ...
-
- Some for end users, some for employees, some for expert users
 - Big and small components of a larger system
 - More or less non-ML code around the model

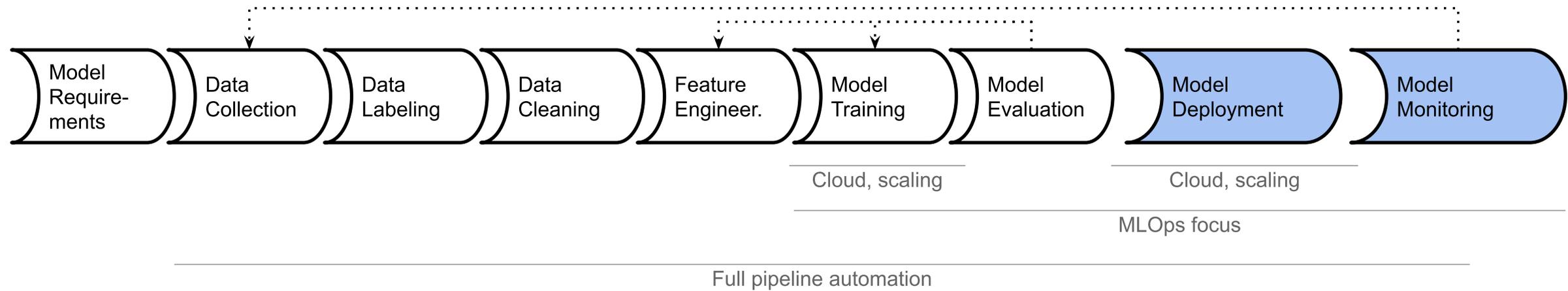
Model-Centric vs System-Wide Focus

Traditional Model Focus (Data Science)



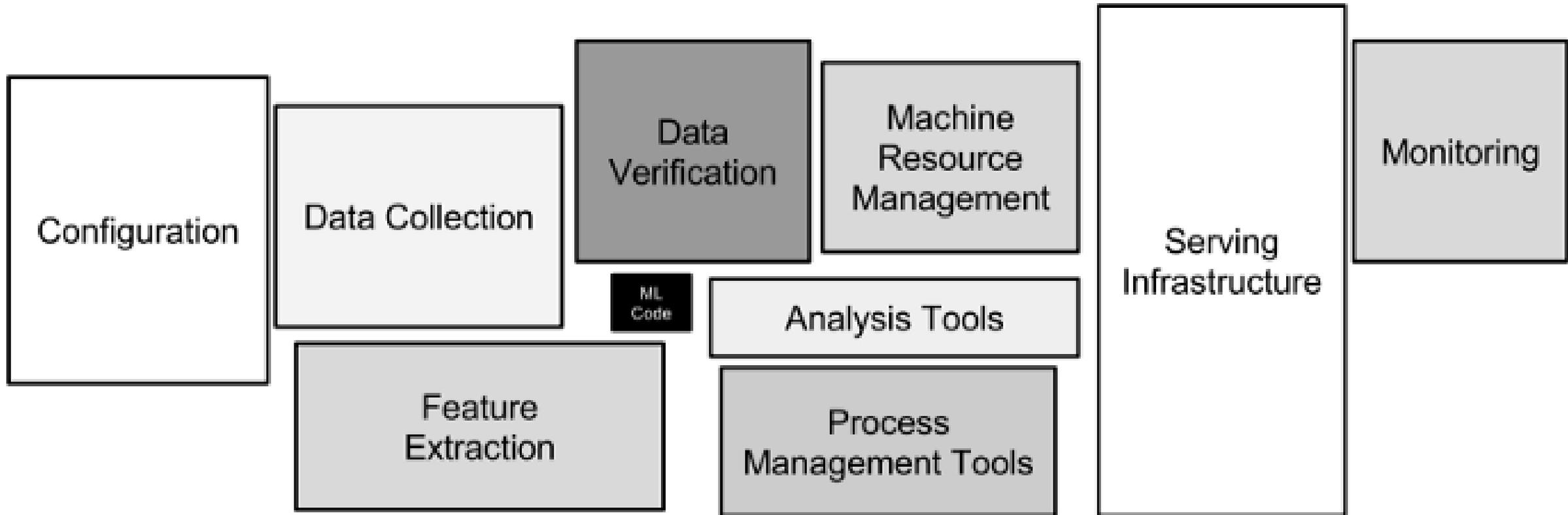
Focus: building models from given data, evaluating accuracy

Automating Pipelines and MLOps (ML Engineering)



Focus: experimenting, deploying, scaling training and serving, model monitoring and updating

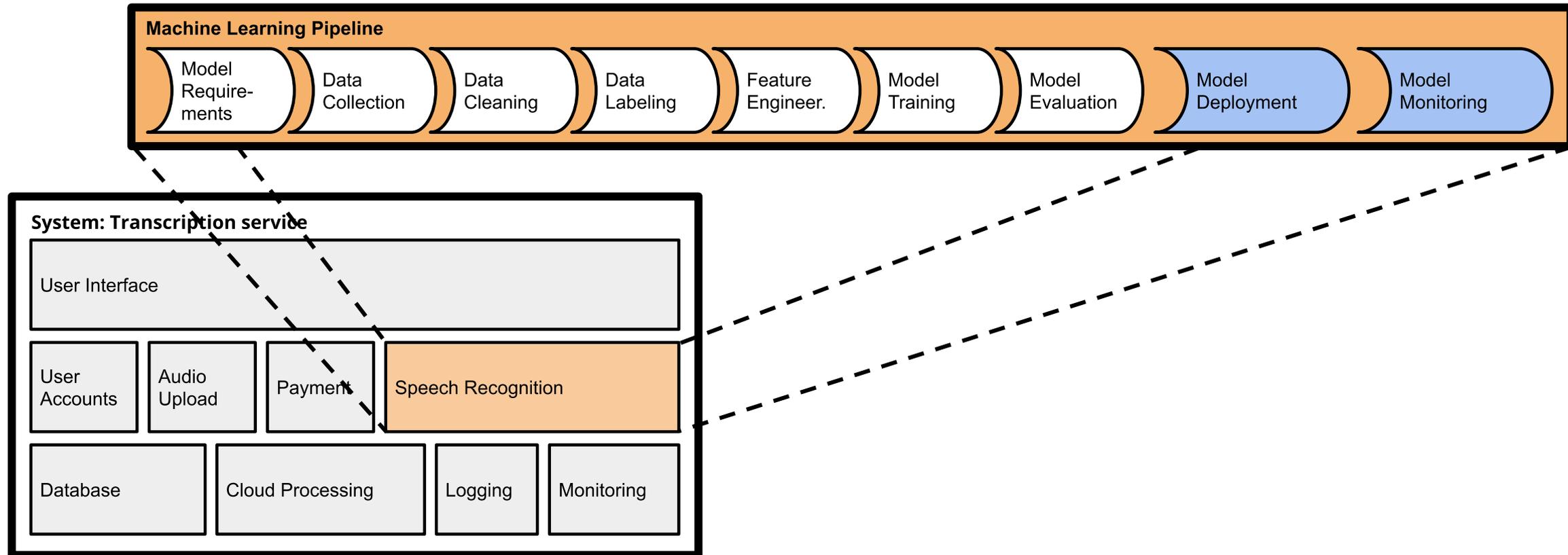
MLOps Infrastructure



From: Sculley, David, et al. "Hidden technical debt in machine learning systems." NIPS 28 (2015).

Figure from Google's 2015 technical debt paper, indicating that the amount of code for actual model training is comparably small compared to lots of infrastructure code needed to automate model training, serving, and monitoring. These days, much of this infrastructure is readily available through competing MLOps tools (e.g., serving infrastructure, feature stores, cloud resource management, monitoring).

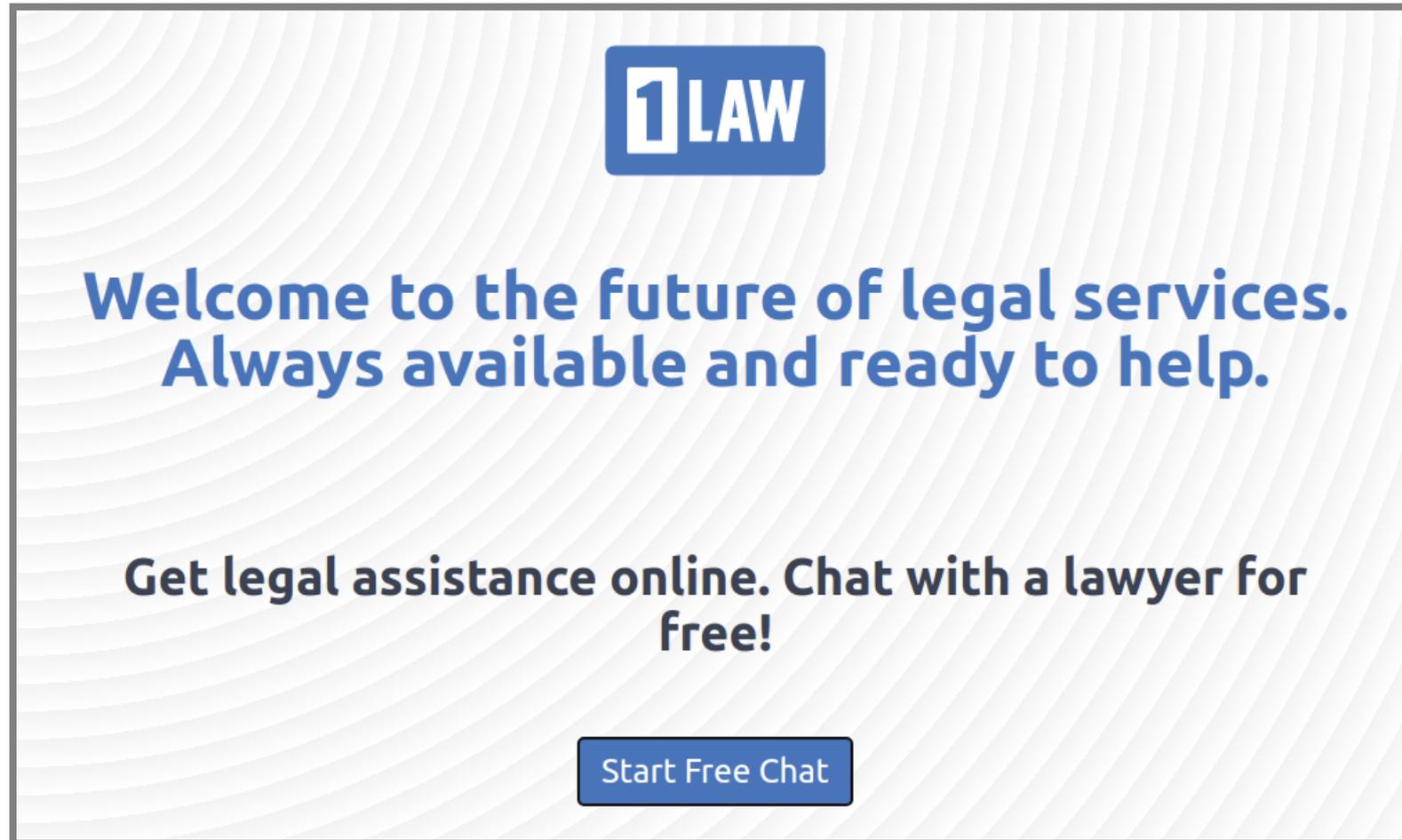
ML-Enabled Systems (ML in Production)



Interaction of ML and non-ML components, system requirements, user interactions, safety, collaboration, delivering products

Model vs System Goals

Case Study: Self-help legal chatbot

A screenshot of a chatbot interface for '1LAW'. The background is a light gray with a subtle, wavy pattern. At the top center is the '1LAW' logo, which consists of a blue square containing a white '1' followed by the word 'LAW' in white capital letters. Below the logo, the text 'Welcome to the future of legal services. Always available and ready to help.' is displayed in a bold, blue font. Further down, the text 'Get legal assistance online. Chat with a lawyer for free!' is shown in a bold, dark gray font. At the bottom center, there is a blue rectangular button with the text 'Start Free Chat' in white.

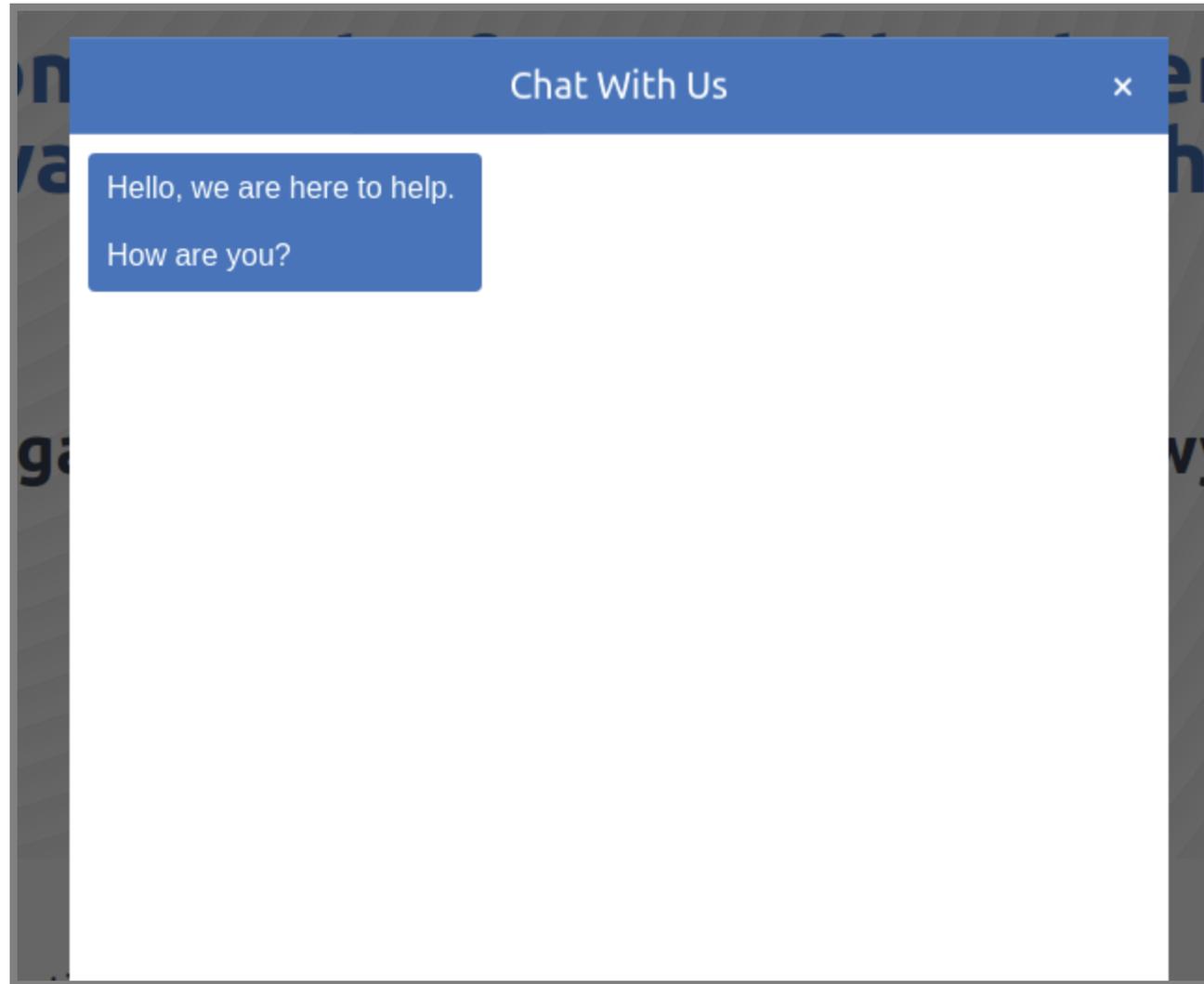
Based on the excellent paper: Passi, S., & Sengers, P. (2020). [Making data science systems work](#). *Big Data & Society*, 7(2).

Speaker notes

Screenshots for illustration purposes, not the actual system studied



Case Study: Self-help legal chatbot



Previous System: Guided Chat

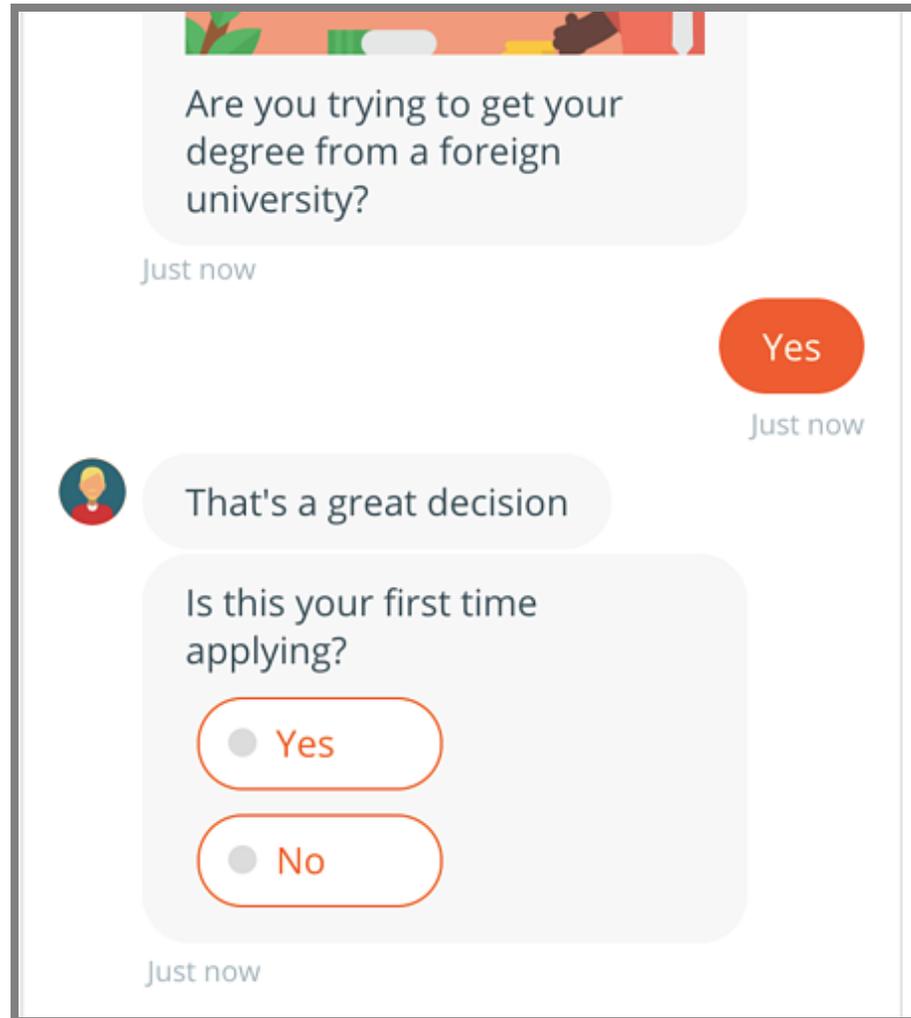


Image source: <https://www.streamcreative.com/chatbot-scripts-examples-templates>

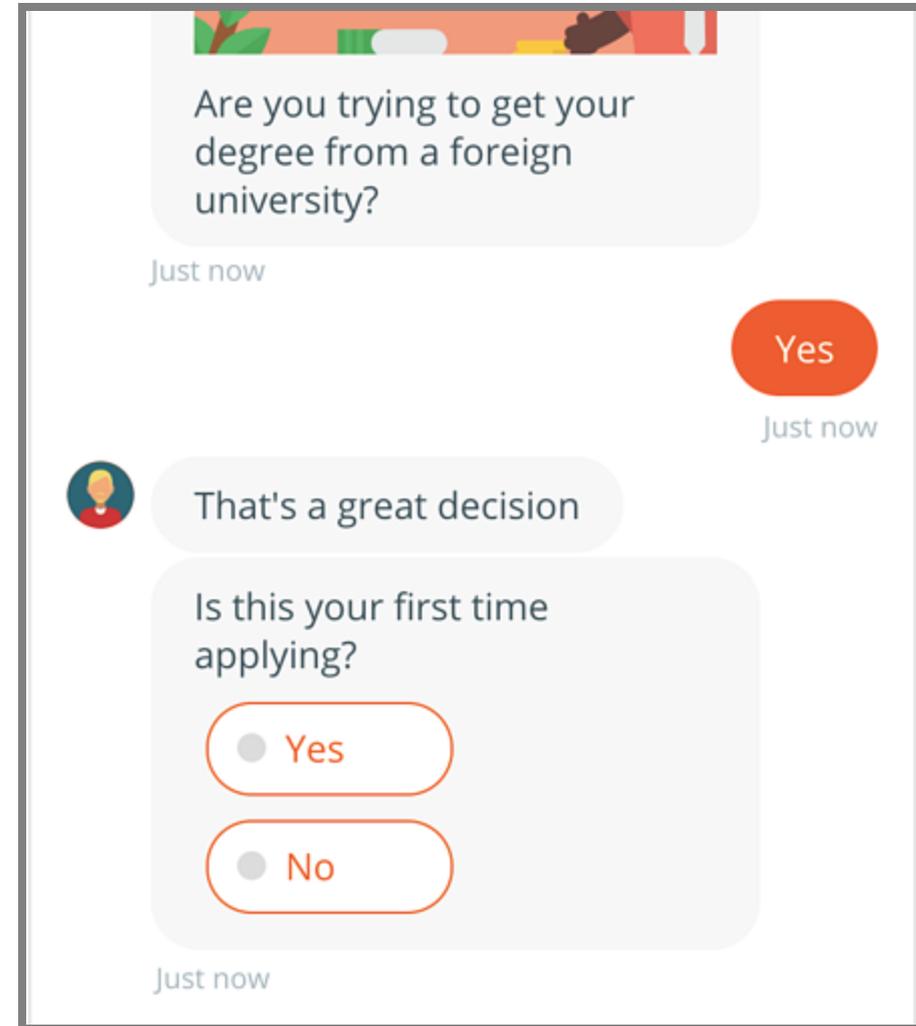
Problems with Guided Chats

Non-AI guided chat was too limited

- Cannot enumerate problems
- Hard to match against open entries ("I want to file for bankruptcy" vs "I have no money")

Involving human operators very expensive

Old-fashioned



Initial Goal: Better Chatbot

Help users with simple task

Connect them with lawyers when needed

Modernize appearance; "future of digital marketing"

Buy or Build?

Botsify Products ▾ Partner ▾ Resources ▾ Pricing Features Sign in **Signup**

Update Instagram Chatbots are available on Botsify now

Premium Chatbot Platform For Everyone

Botsify is a managed chatbot platform that provide unified chat automation for your business. Get omnichannel live-chat service connected with multiple platforms to set autoresponses

1K Chatbots
20K Bot Responses
9K Hours Saved

Get Free Trial →
Explore Platform Now

Book Demo Now 🗣️
Free 1-1 Product Tour

+307 trials started in last 7 days

9:45 TamimiMarkets Active Now
Hi
Hello 🇸🇦, This is Tamimi Market's chatbot, please choose your preferred language to use the services.
1 Arabic
2 English
2
Select your country by replying number
1 Saudi Arabia
2 Bahrain
2
Select the required service by replying number:
1 Weekly Offers
2 Rewards Program
3 Store locations and timings
4 Complaints / Feedback
3
We're open 7 AM – 11 PM, Everyday.
Click Here - <https://tinyurl.com/yjnu7vhd>

One of many commercial frameworks for building AI chatbots



Data scientists' challenges

Infrastructure: Understand chat bot infrastructure and its capabilities

Knowing topics: Identify what users talk about, train/test concepts with past chat logs

- *"We fed VocabX a line deliberately trying to confuse it. We wrote, 'I am thinking about chapter 13 in Boston divorce filing.' VocabX figured out the two topics: (1) business and industrial/company/bankruptcy (2) society/social institution/divorce."*

Guiding conversations: Supporting open-ended conversations requires detecting what's on topic and finding a good response; intent-topic modeling

- *Is talk about parents and children on topic when discussing divorce?*
- Data gathering/labeling very challenging -- too many corner cases

Stepping Back: What are the goals of the system?



Status meeting with (inhouse) Customer

The chatbot performed better than before but was far from ready for deployment. There were “too many edge cases” in which conversations did not go as planned.

Customer: *"Maybe we need to think about it like an 80/20 rule. In some cases, it works well, but for some, it is harder. 80% everything is fine, and in the remaining 20%, we try to do our best."*

Data science lead: *The trouble is how to automatically recognize what is 80 and what is 20.*

Data scientist: *It is harder than it sounds. One of the models is a matching model trained on pairs of legal questions and answers. 60,000 of them. It seems large but is small for ML.*

Customer: *That's a lot. Can it answer a question about say visa renewal?*

Data scientist: *If there exists a question like that in training data, then yes. But with just 60,000, the model can easily overfit, and then for anything outside, it would just fail.*

Customer: *I see what you are saying. Edge cases are interesting from an academic perspective, but for a business the first and foremost thing is value. You are trying to solve an interesting problem. I get it. But I feel that you may have already solved it enough to gain business value.*

Adapted from Passi, S., & Sengers, P. (2020). [Making data science systems work](#). *Big Data & Society*, 7(2).



System Goal for Chatbot

- Collect user data to sell to lawyers
- Signal technical competency to lawyers
- Acceptable to fail: Too complicated for self-help, connect with lawyer
- Solving edge cases not important

"Edge cases are important, but the end goal is user information, monetizing user data. We are building a legal self-help chatbot, but a major business use case is to tell people: 'here, talk to this lawyer.' We do want to connect them with a lawyer. Even for 20%, when our bot fails, we tell users that the problem cannot be done through self-help. Let us get you a lawyer, right? That is what we wanted in the first place."

See Passi, S., & Sengers, P. (2020). [Making data science systems work](#). *Big Data & Society*, 7(2).



Model vs System Goal?



Model vs System Goal?

Your Audit Risk Results



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Model vs System Goal?

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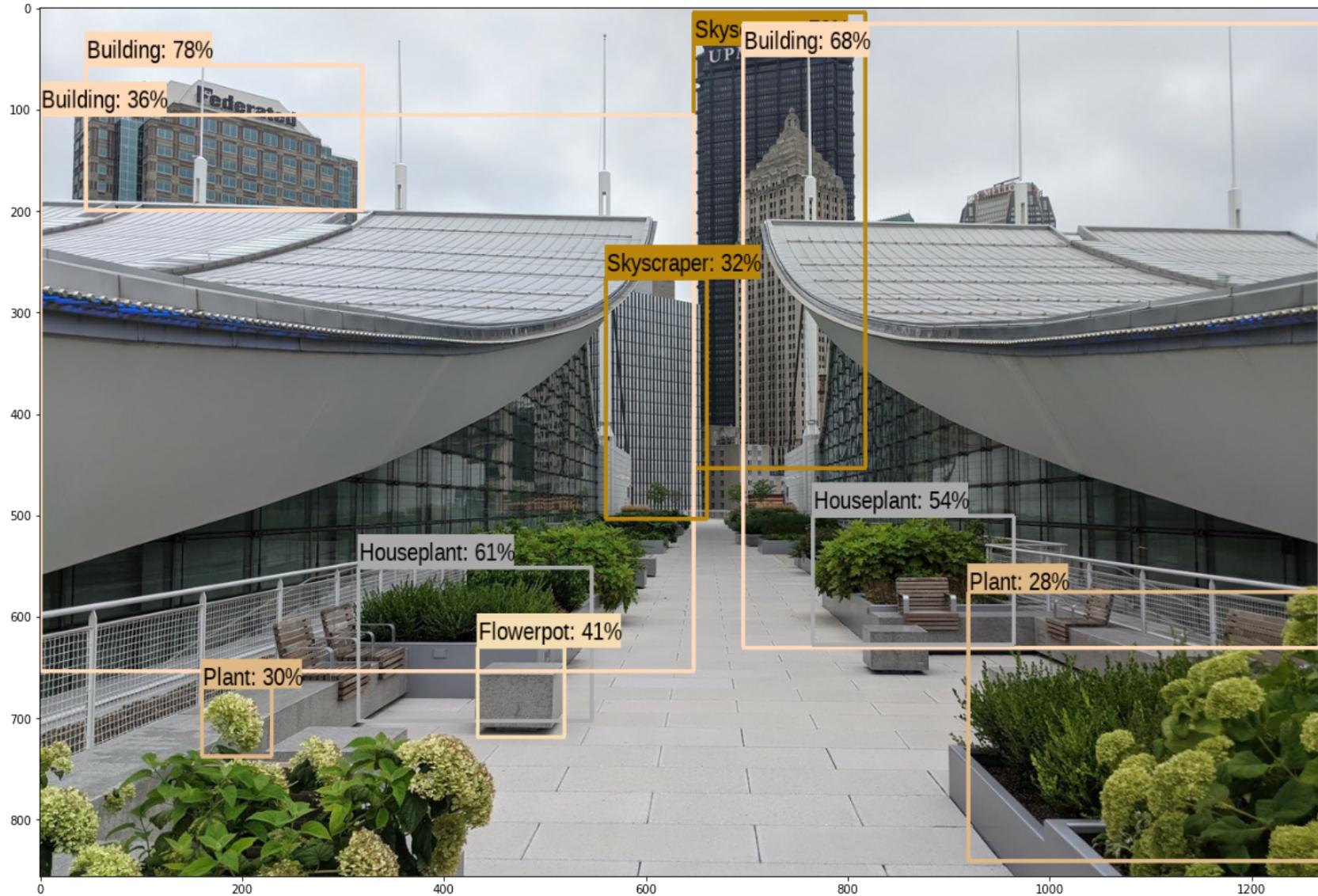
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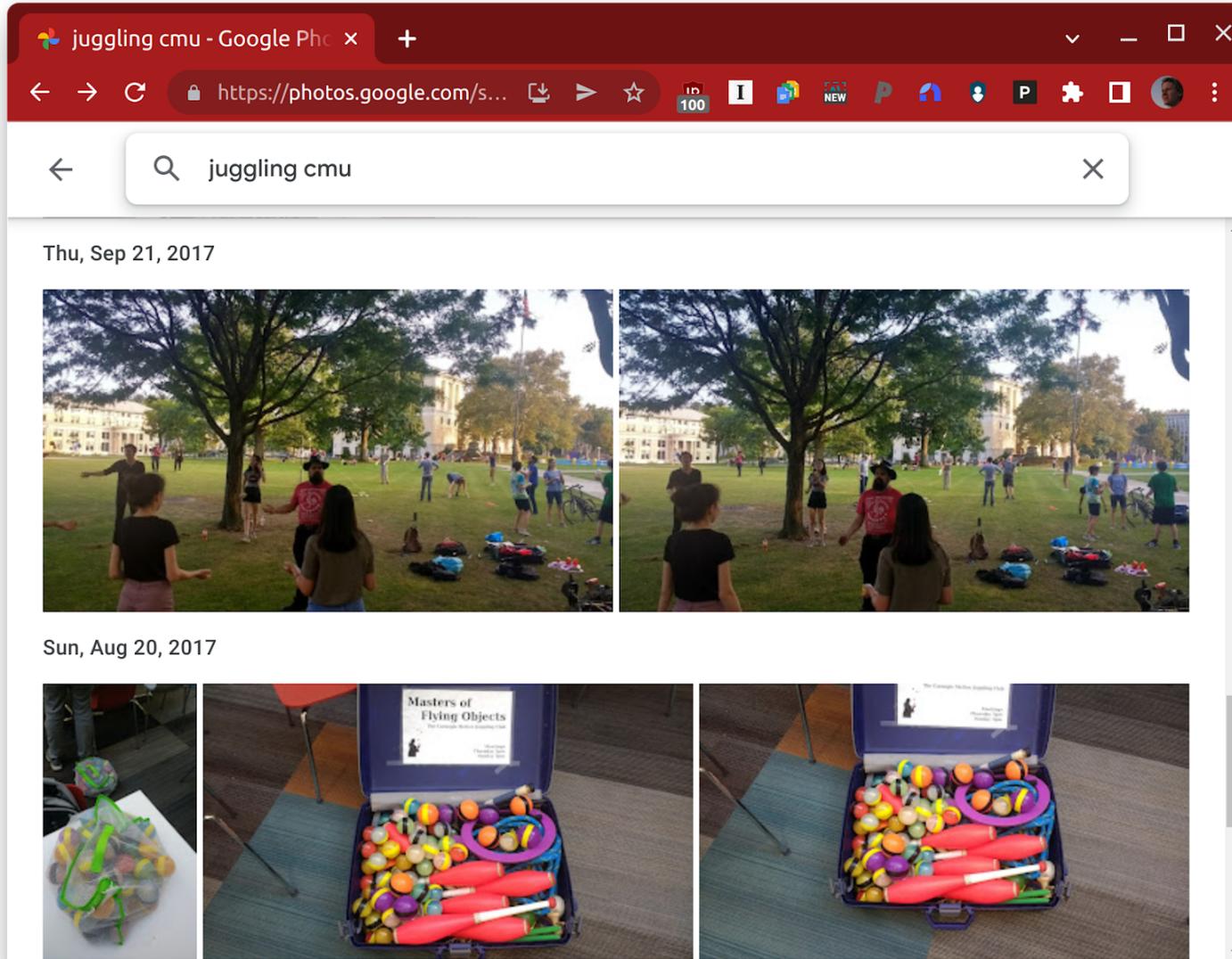
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How did we do on your transcript? ☆☆☆☆☆

Model vs System Goal?



Model vs System Goal?



Model vs System Goal?

an armchair in the shape of an avocado. an armchair imitating an avocado.



Model vs System Goal?



More Accurate Predictions may not be THAT Important

- "Good enough" may be good enough
- Prediction critical for system success or just an gimmick?
- Better predictions may come at excessive costs
 - need way more data, much longer training times
 - privacy concerns
- Better user interface ("experience") may mitigate many problems
 - e.g. explain decisions to users
- Use only high-confidence predictions?

Machine learning that matters

- 2012(!) essay lamenting focus on algorithmic improvements and benchmarks
 - focus on standard benchmark sets, not engaging with problem: Iris classification, digit recognition, ...
 - focus on abstract metrics, not measuring real-world impact: accuracy, ROC
 - distant from real-world concerns
 - lack of follow-through, no deployment, no impact
- Failure to *reproduce* and *productionize* paper contributions common
- Ignoring design choices in how to collect data, what problem to solve, how to design human-AI interface, measuring impact, ...
- *Argues: Should focus on making impact -- requires building systems*

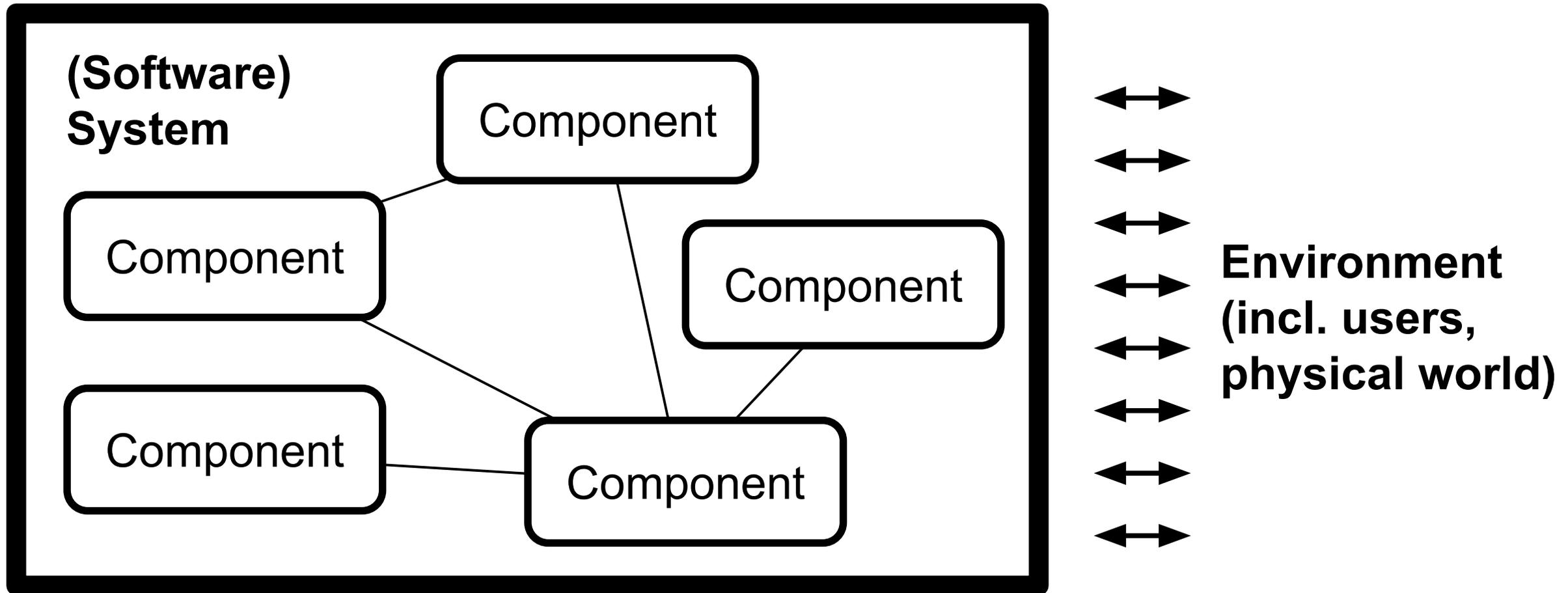
Wagstaff, Kiri. "Machine learning that matters." In Proceedings of the 29 th International Conference on Machine Learning, (2012).

On Terminology

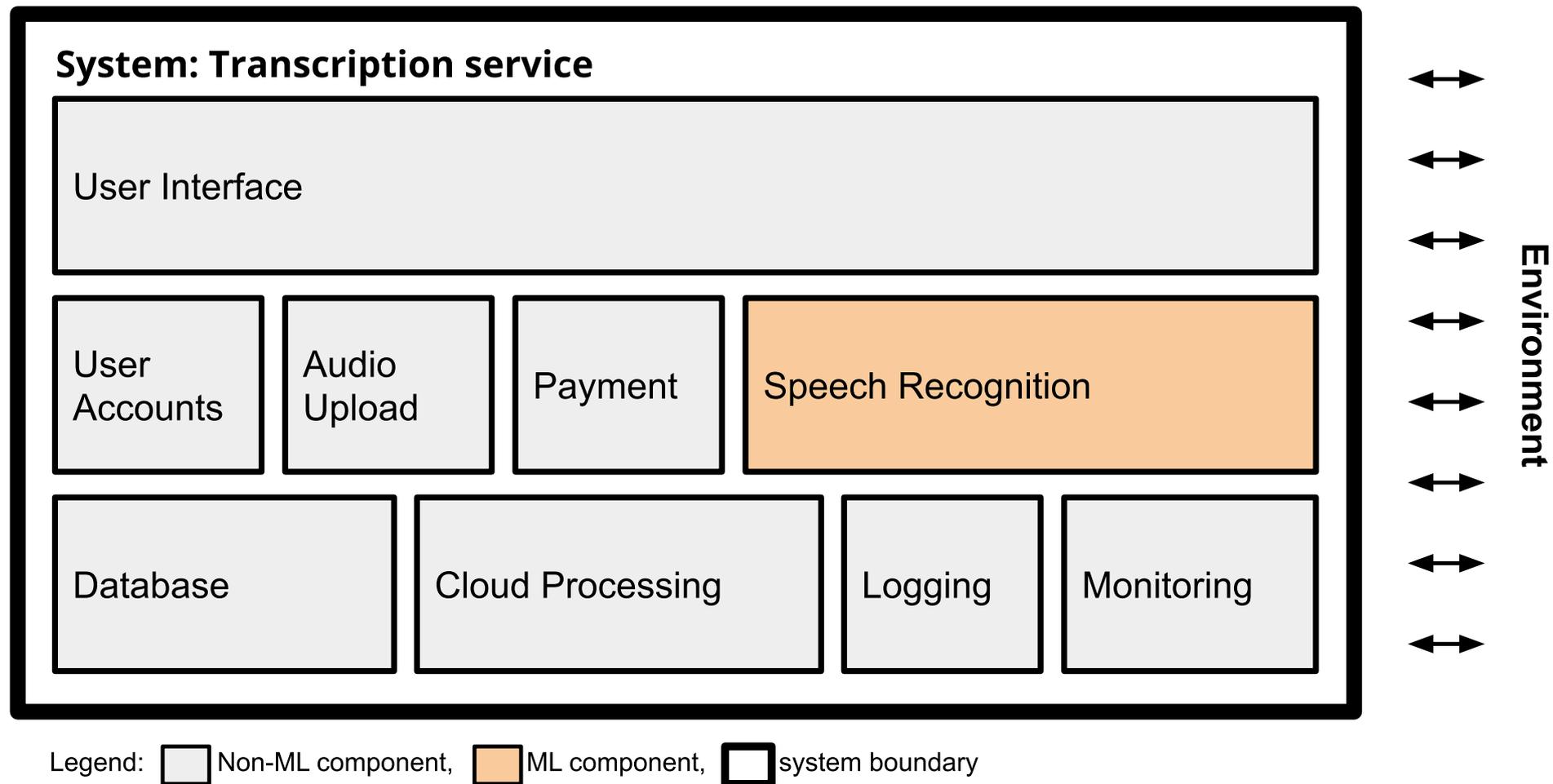


- There is no standard term for referring to building systems with AI components
- **ML-Enabled Systems**, *Production ML Systems*, *AI-Enabled Systems*, or *ML-Infused Systems*; *SE4AI*, *SE4ML*
- sometimes **AI Engineering** / **ML Engineering** -- but usually used with a ML-pipeline focus
- **MLOps** ~ technical infrastructure automating ML pipelines
- sometimes **ML Systems Engineering** -- but often this refers to building distributed and scalable ML and data storage platforms
- "AIOps" ~ using AI to make automated decisions in operations; "DataOps" ~ use of agile methods and automation in business data analytics
- My preference: **Production Systems with Machine-Learning Components**

Systems Thinking



Repeat: Machine learning as component in a system



The System Interacts with Users

Your Audit Risk Results



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Speaker notes

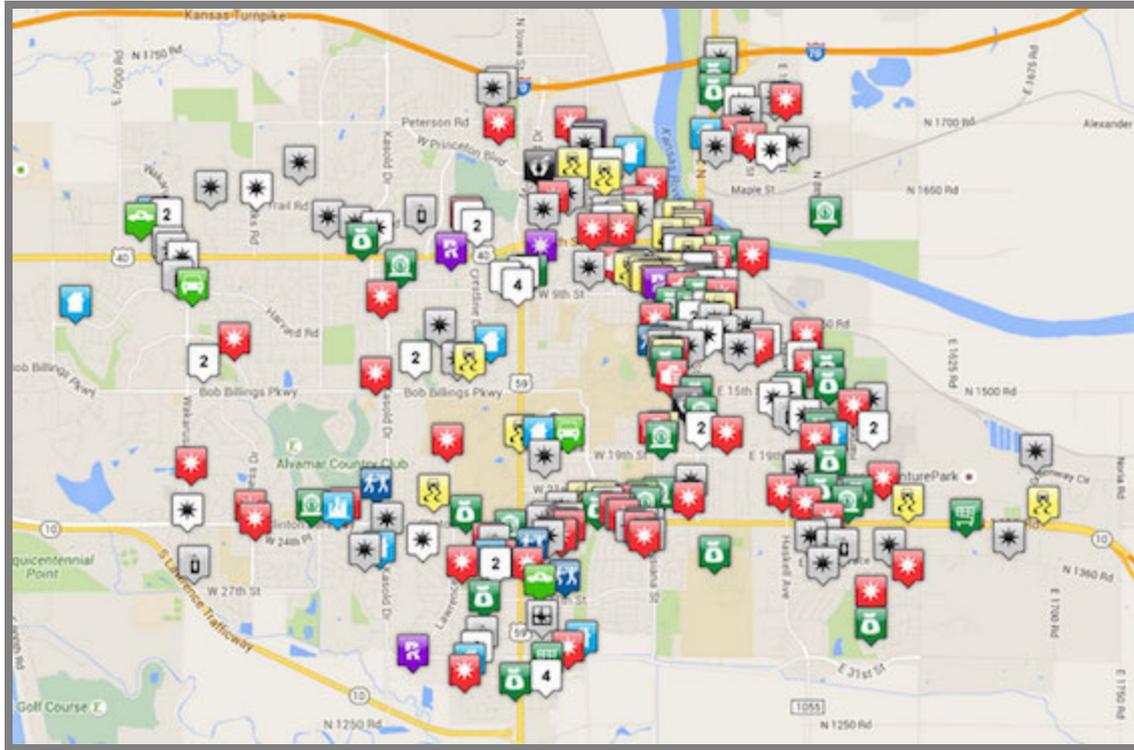
Audit risk meter from Turbo-Tax



The System Interacts with the World

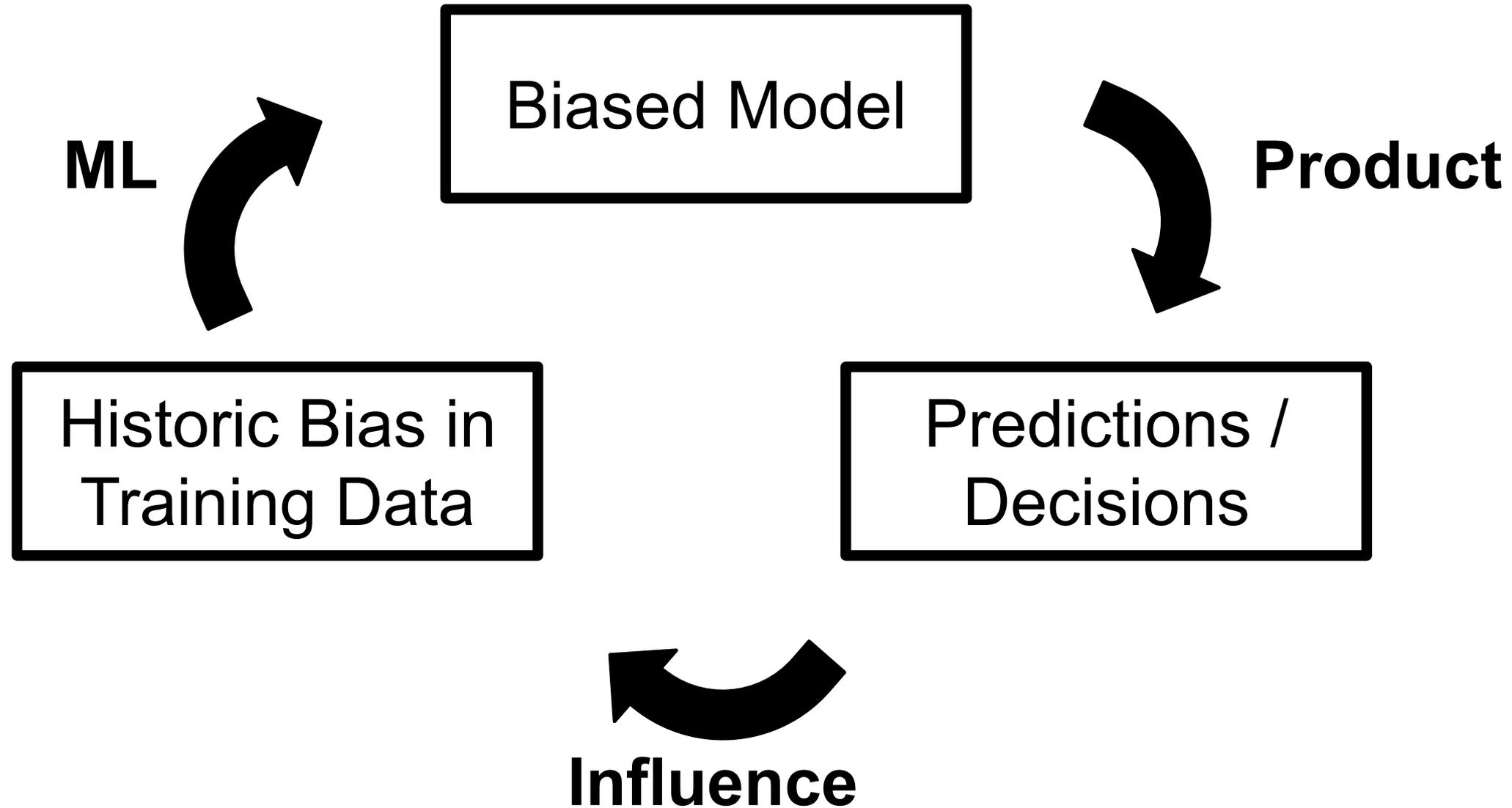


The System Interacts with the World



- Model: Use historical data to predict crime rates by neighborhoods
- Used for predictive policing: Decide where to allocate police patrol

Feedback Loops



The System Interacts with the World

MIT Technology ReviewTopics

Artificial intelligence

Predictive policing algorithms are racist. They need to be dismantled.

Lack of transparency and biased training data mean these tools are not fit for purpose. If we can't fix them, we should ditch them.

by **Will Douglas Heaven**

July 17, 2020

ML Predictions have Consequences

Assistance, productivity, creativity

Manipulation, polarization, discrimination

Feedback loops

➤ Need for **responsible engineering**

Safety is a System Property

- Code/models are not unsafe, cannot harm people
- Systems can interact with the environment in ways that are unsafe



Safety Assurance in/outside the Model

Goal: Ensure smart toaster does not burn the kitchen



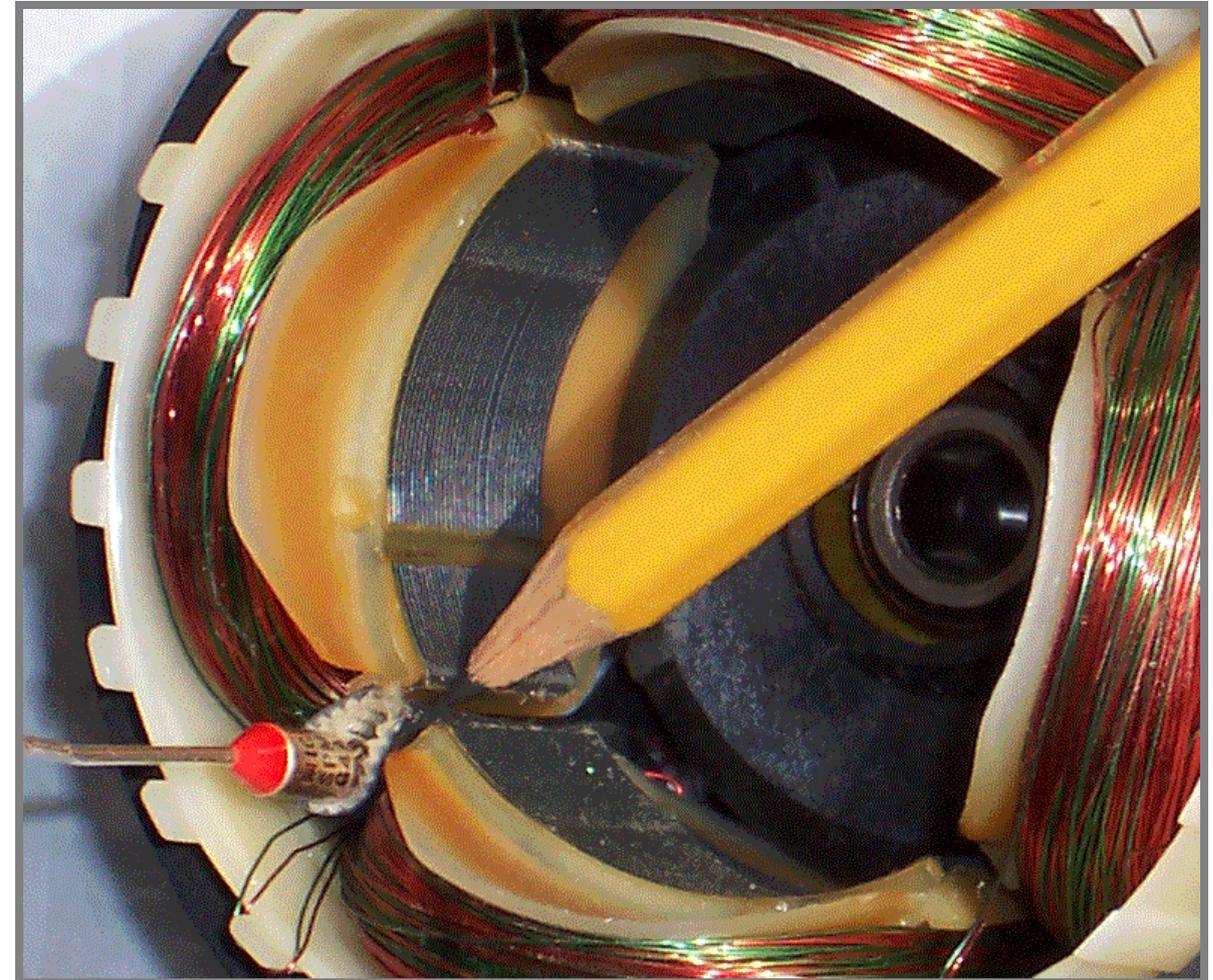
Safety Assurance in/outside the Model

In the model

- Ensure maximum toasting time
- Use heat sensor and past outputs for prediction
- Hard to make guarantees

Outside the model (e.g., "guardrails")

- Simple code check for max toasting time
- Non-ML rule to shut down if too hot
- Hardware solution: thermal fuse



(Image CC BY-SA 4.0, C J Cowie)

Model vs System Properties

Similar to safety, many other qualities should be discussed at model and system level

- Fairness
- Security
- Privacy
- Transparency, accountability
- Maintainability
- Scalability, energy consumption
- Impact on system goals
- ...

Thinking about Systems

- Holistic approach, looking at the larger picture, involving all stakeholders
- Looking at relationships and interactions among components and environments
 - Everything is interconnected
 - Combining parts creates something new with emergent behavior
 - Understand dynamics, be aware of feedback loops, actions have effects
- Understand how humans interact with the system

A system is a set of inter-related components that work together in a particular environment to perform whatever functions are required to achieve the system's objective -- Donella Meadows

Leyla Acaroglu. "[Tools for Systems Thinkers: The 6 Fundamental Concepts of Systems Thinking.](#)"
Blogpost 2017

System-Level Challenges for AI-Enabled Systems

- Getting and updating data, concept drift, changing requirements
- Handling massive amounts of data
- Interactions with the real world, feedback loops
- Lack of modularity, lack of specifications, nonlocal effects
- Deployment and maintenance
- Versioning, debugging and incremental improvement
- Keeping training and operating cost manageable
- Interdisciplinary teams
- Setting system goals, balancing stakeholders and requirements
- ...

Designing Intelligent Experiences

(Human-AI Interaction)



Gerd Eist

@erdgeist · [Follow](#)



Datenpunkt Stand der Technik im Auto: Spurassistent erkennt in der Lücke des Schattens eine Fahrbahnmarkierung und drückt mich konstant nach rechts 🤖



5:54 PM · Aug 14, 2022



🍷 2.3K

💬 Reply

🔗 Copy link

Speaker notes

Lane assistant feature recognizes gap in shadow as line marking and constantly tries to steer the car to the right



AI predictions should influence the world

- Smart toaster
- Automated slide design
- Product or music recommendations
- Feed curation in social media or news
- Recidivism prediction
- Health monitoring
- Transcription services
- Image search engine
- Smart home

Interact with the world through actuators or by influencing people

Designing Intelligent Experiences

How to use the output of a model's prediction (for a objective)?

Design considerations:

- How to present prediction to a user? Suggestions or automatically take actions?
- How to effectively influence the user's behavior toward the system's goal?
- How to minimize the consequences of flawed predictions?
- How to collect data to continue to learn from users and mistakes?

Balancing at least three **system-level** outcomes:

- Achieving objectives
- Protection from mistakes
- Collecting data for training

Presenting Intelligence

Automate: Take action on user's behalf

Prompt: Ask the user if an action should be taken

Organize/Annotate/Augment: Add information to a display

Hybrids of these

Factors to Consider

Forcefulness: How strongly to encourage taking an action (or even automate it)?

Frequency: How often to interact with the user?

Value: How much does a user (think to) benefit from the prediction?

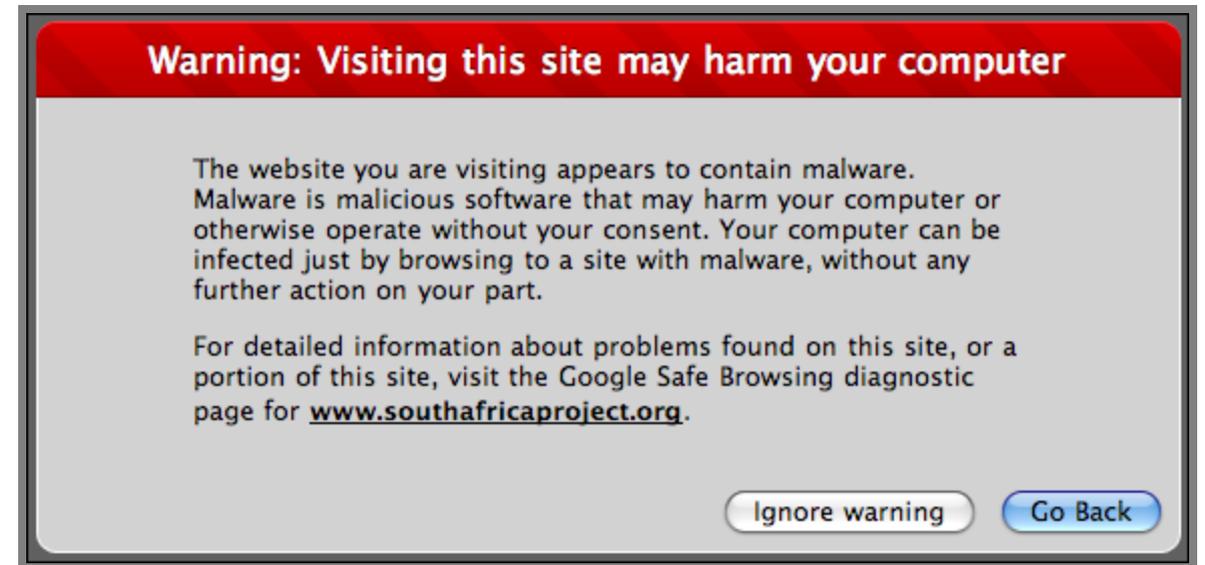
Cost: What is the damage of a wrong prediction?

Breakout Discussion: Experience Design

Fall detection for elderly people:



Safe browsing: Blocking malicious web pages



Discuss in group and post to #lecture tagging all members: (1) How do we present the intelligence to the user? (2) Justify in terms of system goals, forcefulness, frequency, value of correct and cost of wrong predictions

Speaker notes

Devices for older adults to detect falls and alert caretaker or emergency responders automatically or after interaction. Uses various inputs to detect falls. Read more: [How fall detection is moving beyond the pendant](#), MobiHealthNews, 2019



Collecting Feedback

Report Incorrect Phishing Warning

If you received a phishing warning but believe that this is actually a legitimate page, please complete the form below to report the error to Google. Information about your report will be maintained in accordance with Google's [privacy policy](#).

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Comments:
(Optional)

Submit Report



Operating Production ML Systems

(deployment, updates)

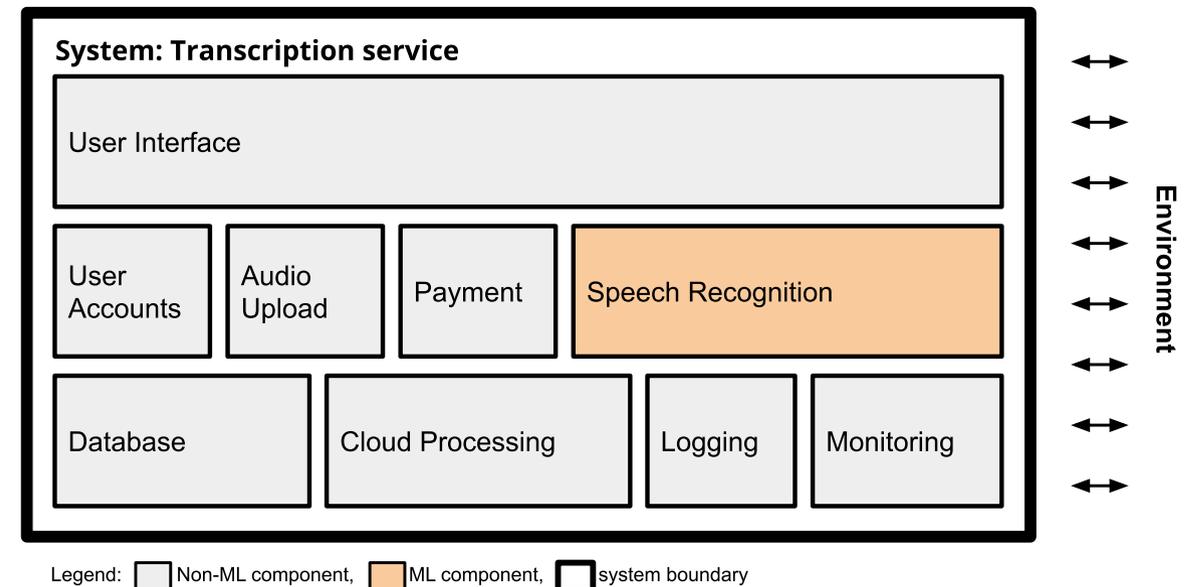
Things change...

Newer better models released
(better model architectures, more training data, ...)

Goals and scope change (more domains, handling dialects, ...)

The world changes (new products, names, slang, ...)

Online experimentation



Things change...

Reasons for change in audit risk prediction model?

Your Audit Risk Results



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Monitoring in Production

Design for telemetry

Report Incorrect Phishing Warning

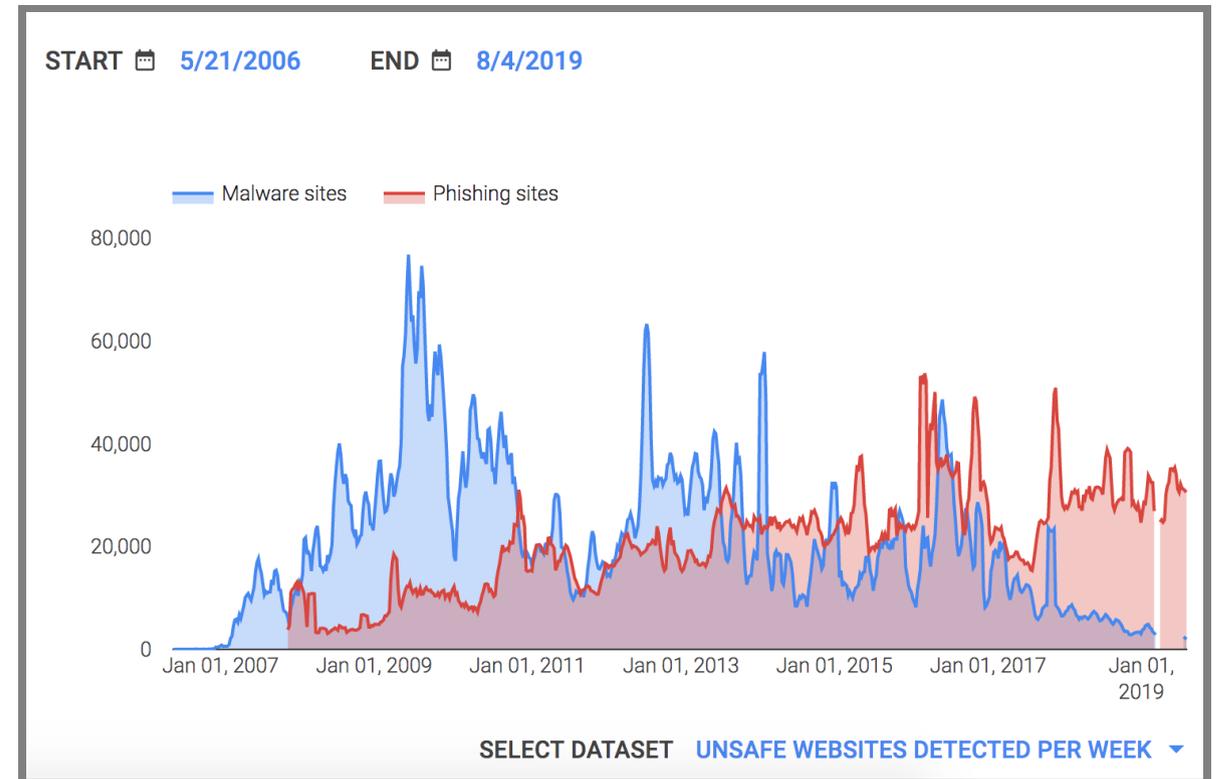
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Monitoring in Production

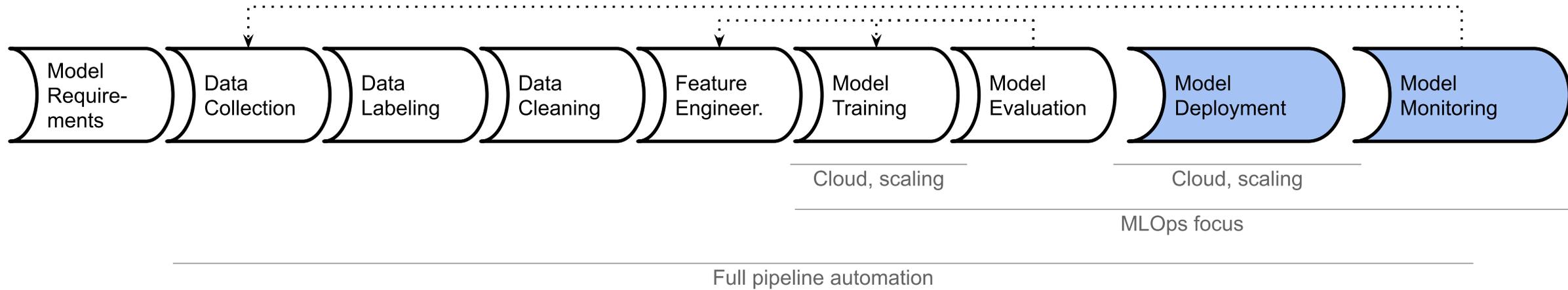
What and how to monitor in audit risk prediction?

Your Audit Risk Results

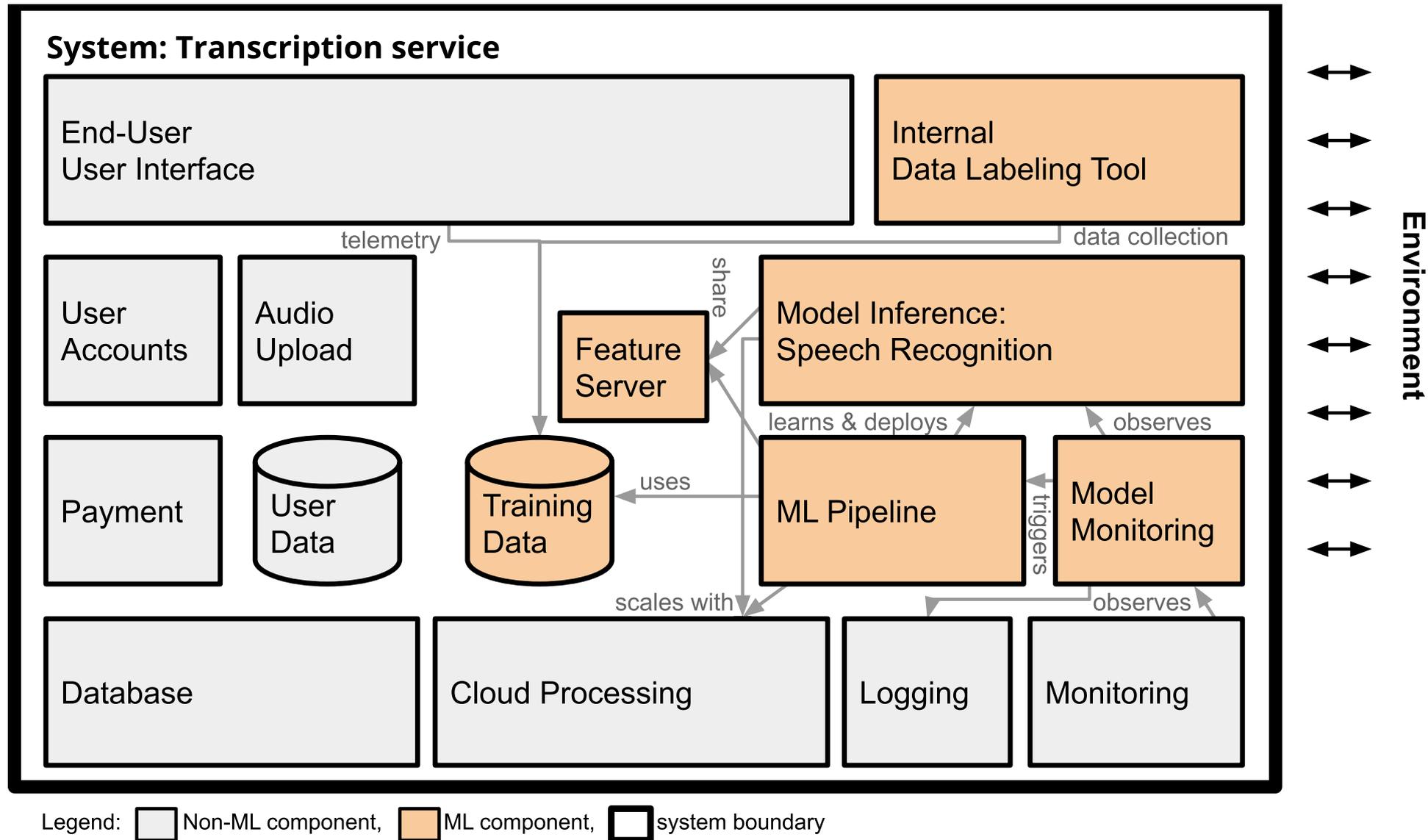


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Pipeline Thinking



Design with Pipeline and Monitoring



Pipelines Thinking is Challenging

In enterprise ML teams:

- Data scientists often focus on modeling in local environment, model-centric workflow
- Rarely robust infrastructure, often monolithic and tangled
- Challenges in deploying systems and integration with monitoring, streams etc

Shifting to pipeline-centric workflow challenging

- Requires writing robust programs, slower, less exploratory
- Standardized, modular infrastructure
- Big conceptual leap, major hurdle to adoption

Summary

Production AI-enabled systems require a *whole system perspective*, beyond just the model or the pipeline

Distinguish system goals from model goals

Quality at a *system* level: safety beyond the model, beyond accuracy

Plan for operations (telemetry, updates)

Large design space for user interface (intelligent experience):
forcefulness, frequency, telemetry

Recommended Readings

- Passi, S., & Sengers, P. (2020). [Making data science systems work](#). *Big Data & Society*, 7(2).
- Wagstaff, Kiri. "[Machine learning that matters](#)." In Proceedings of the 29th International Conference on Machine Learning, (2012).
- Sculley, David, Gary Holt, Daniel Golovin, Eugene Davydov, Todd Phillips, Dietmar Ebner, Vinay Chaudhary, Michael Young, Jean-Francois Crespo, and Dan Dennison. "[Hidden technical debt in machine learning systems](#)." In *Advances in neural information processing systems*, pp. 2503-2511. 2015.
- O'Leary, Katie, and Makoto Uchida. "[Common problems with Creating Machine Learning Pipelines from Existing Code](#)." Proc. Third Conference on Machine Learning and Systems (MLSys) (2020).
- Nushi, Besmira, Ece Kamar, Eric Horvitz, and Donald Kossmann. "[On human intellect and machine failures: troubleshooting integrative machine learning systems](#)." In *Proceedings of the Thirty-First AAAI Conference on Artificial Intelligence*, pp. 1017-1025. 2017.
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