



# 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

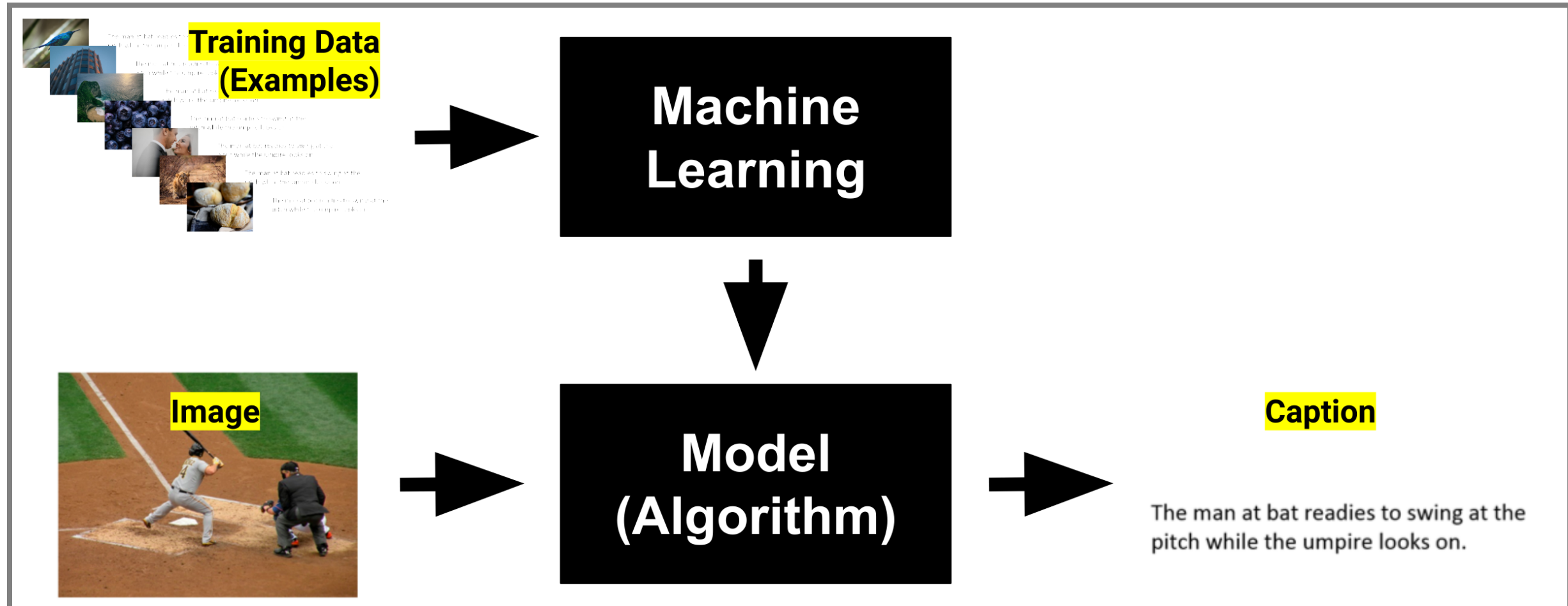
# ML Models as Part of a System



# 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

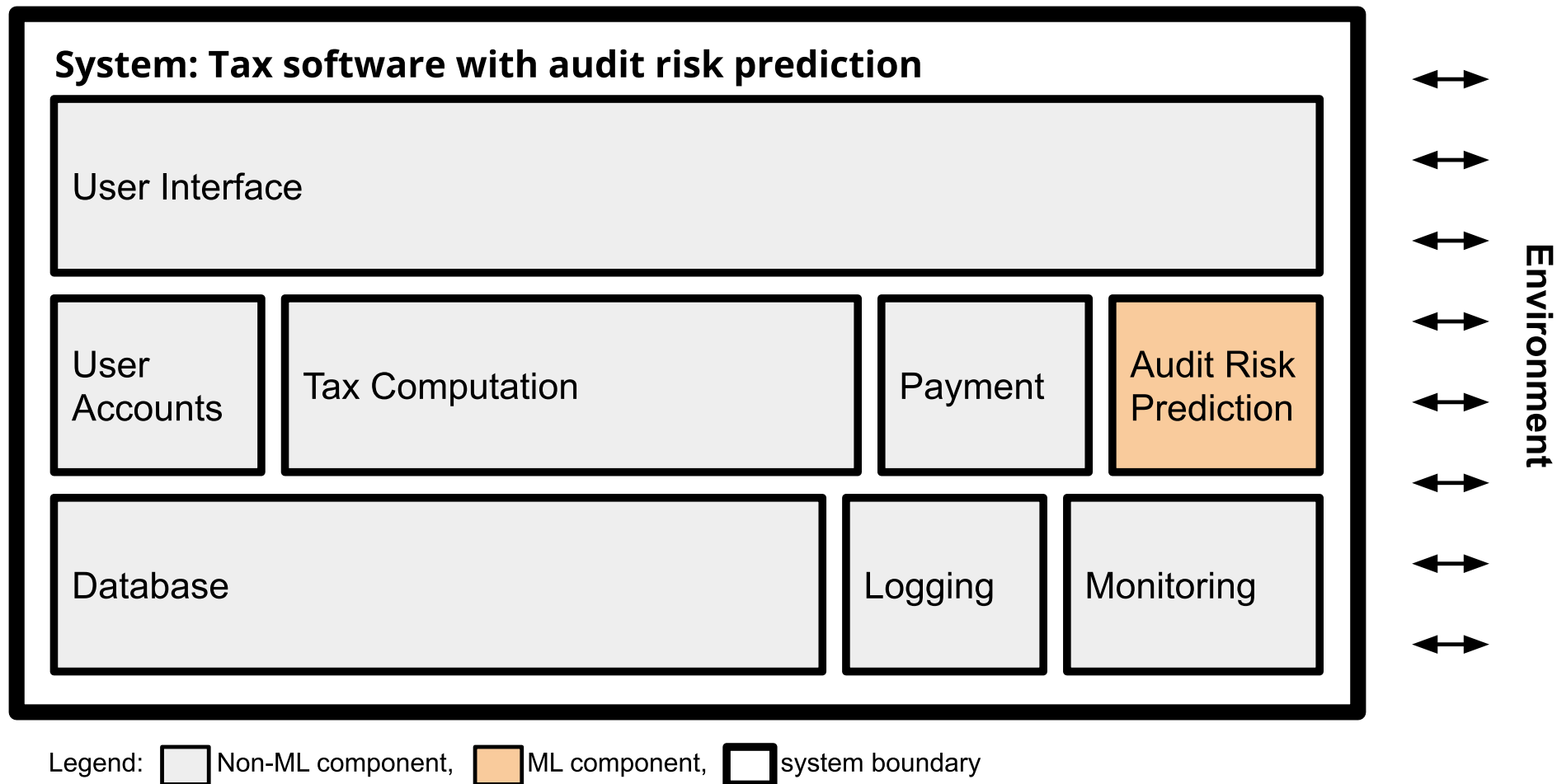


**Great news!** There's nothing to worry about. We didn't find anything in your return that we consider a typical audit trigger, which means you're in good shape. Plus, we've also got you covered with our [free Audit Support Guarantee](#).



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

the-changelog-318

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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

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

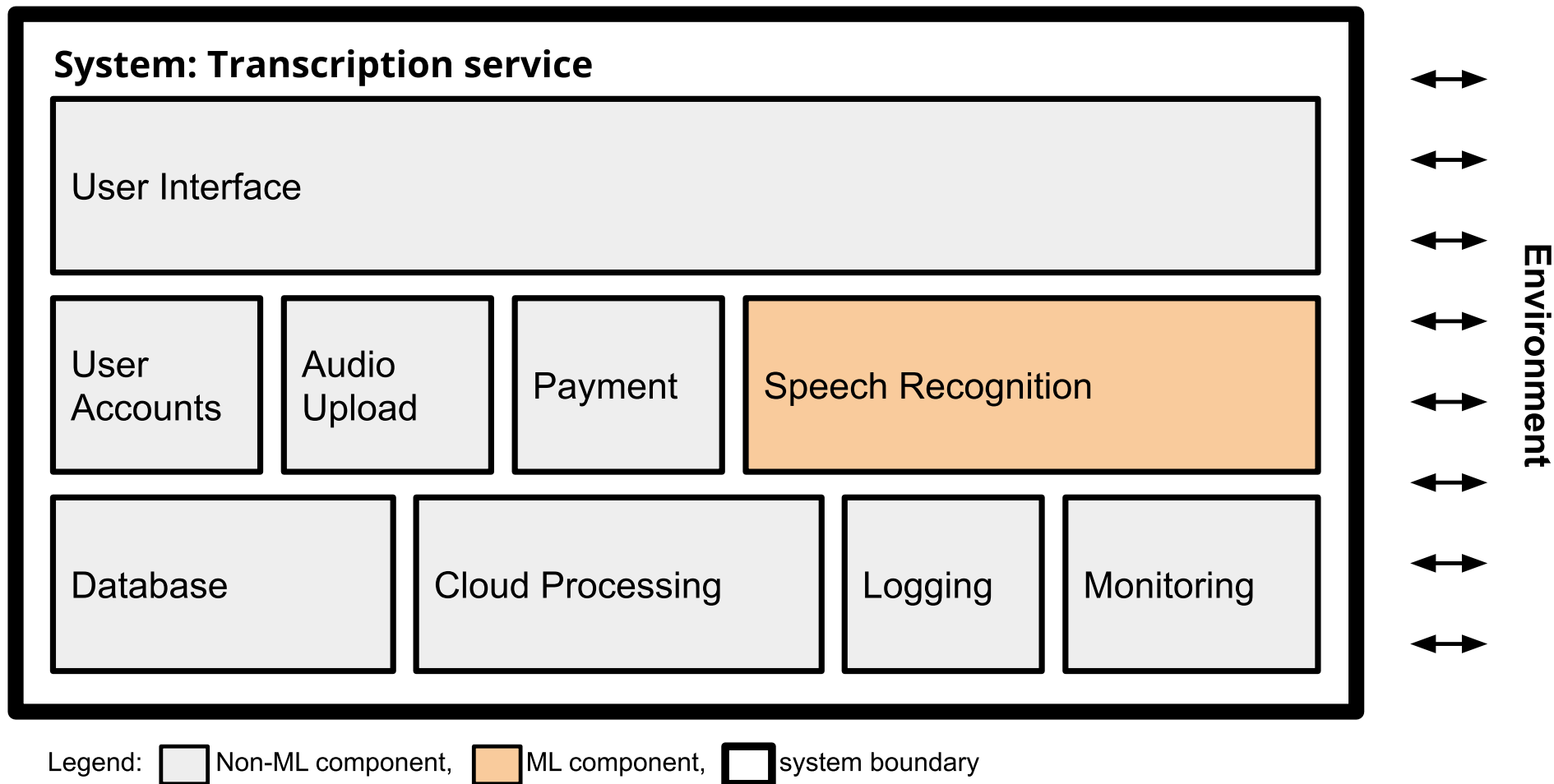
Speaker notes

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

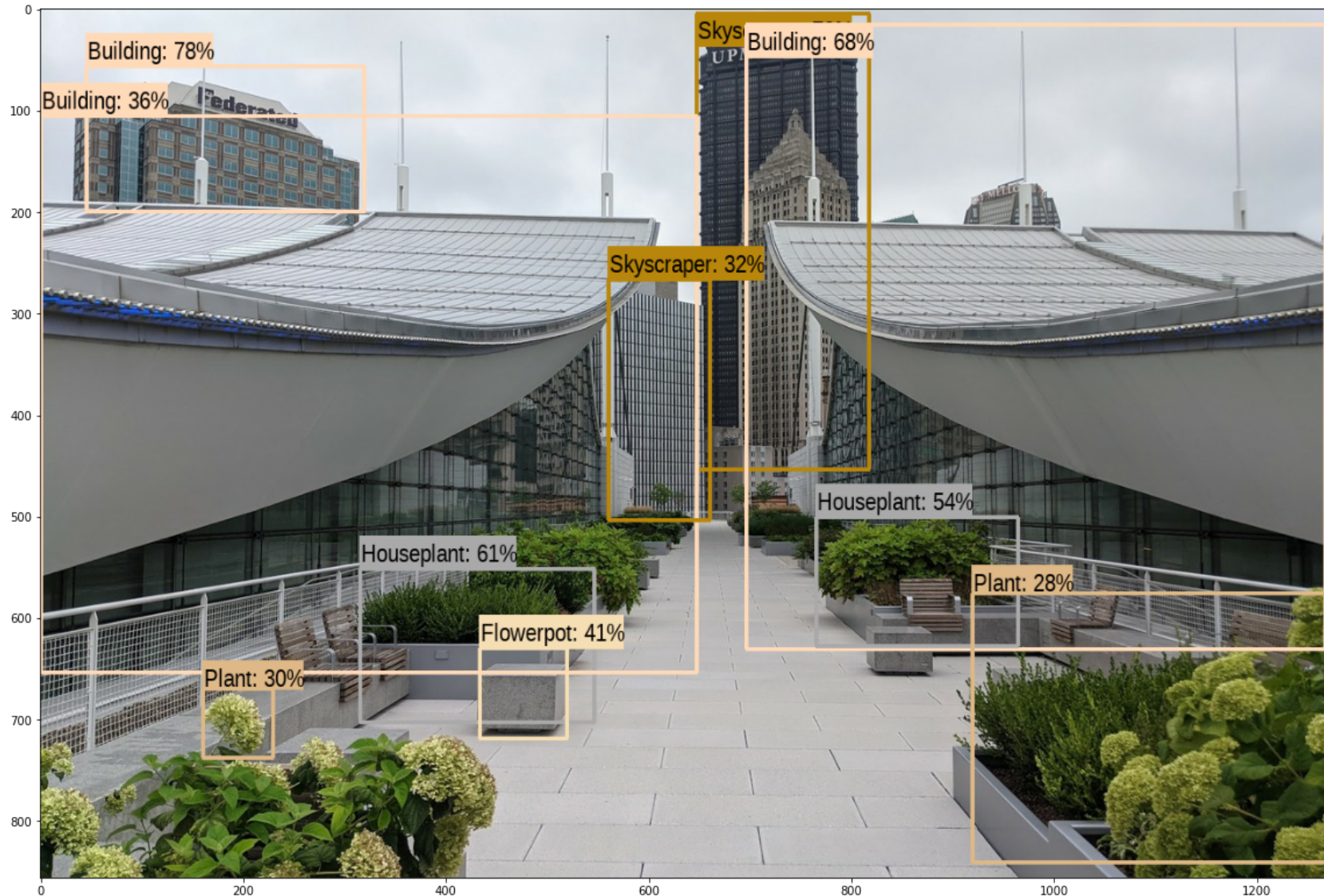




# Machine learning as (core) component in a system



# Products using Object Detection?









juggling cmu

Thu, Sep 21, 2017

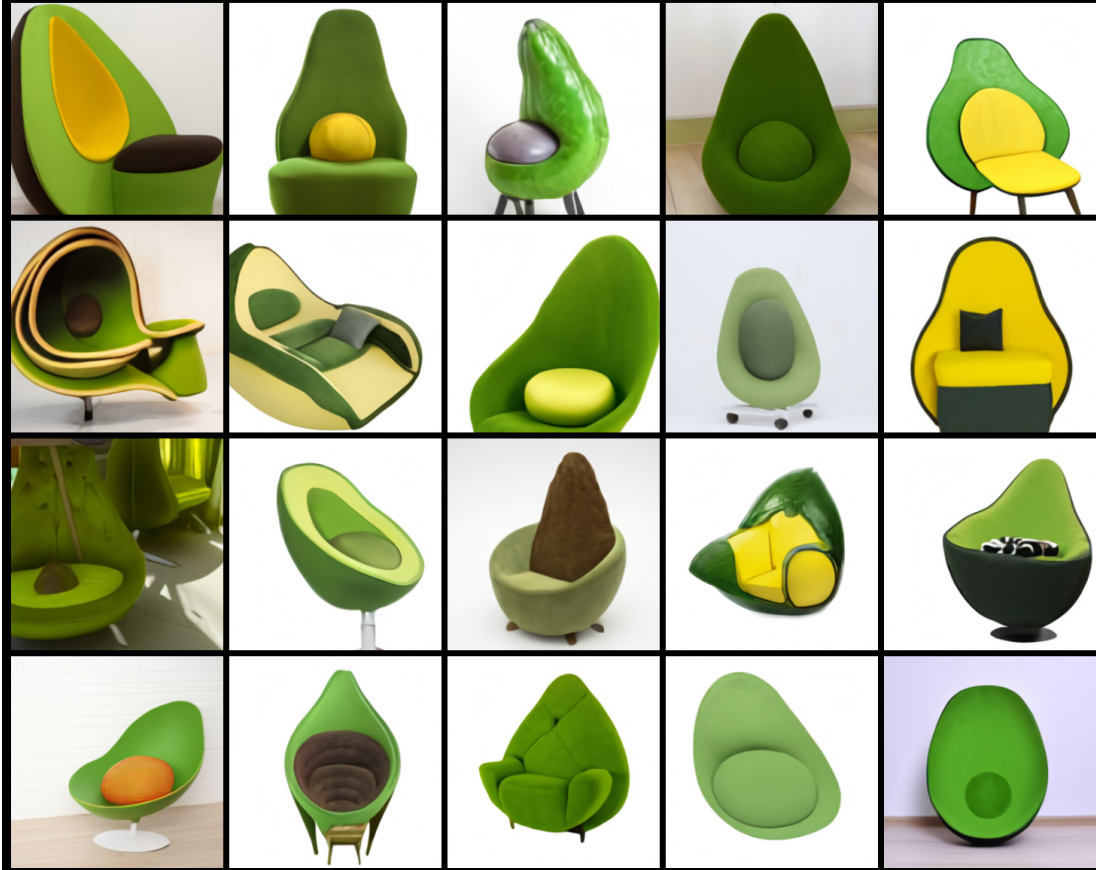


Sun, Aug 20, 2017



# Products using Image Synthesis?

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



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

# Products using ... a Juggling Robot?



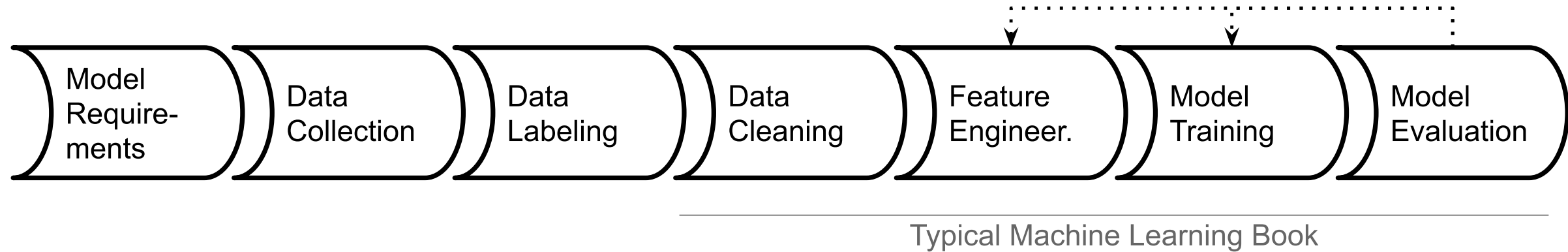
# Many more examples of ML in products:

- 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



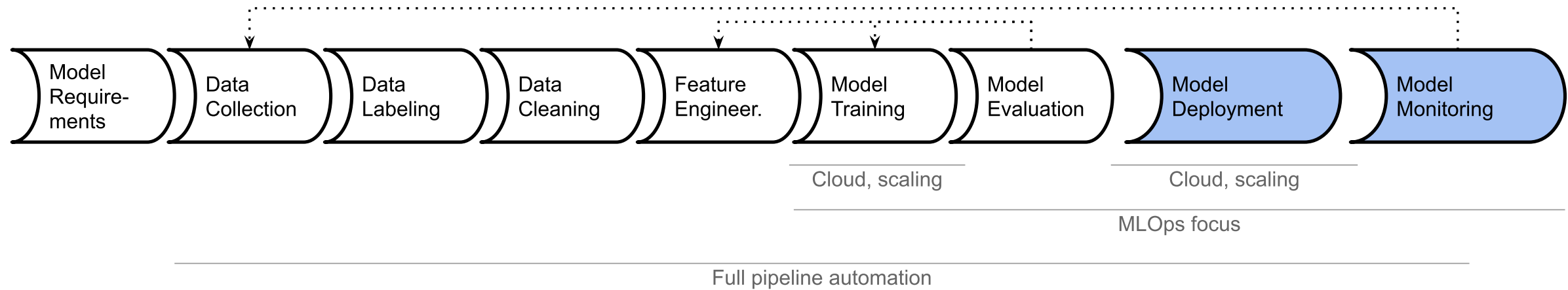
# Model-Centric vs System-Wide Focus

# Traditional Model Focus (Data Science)



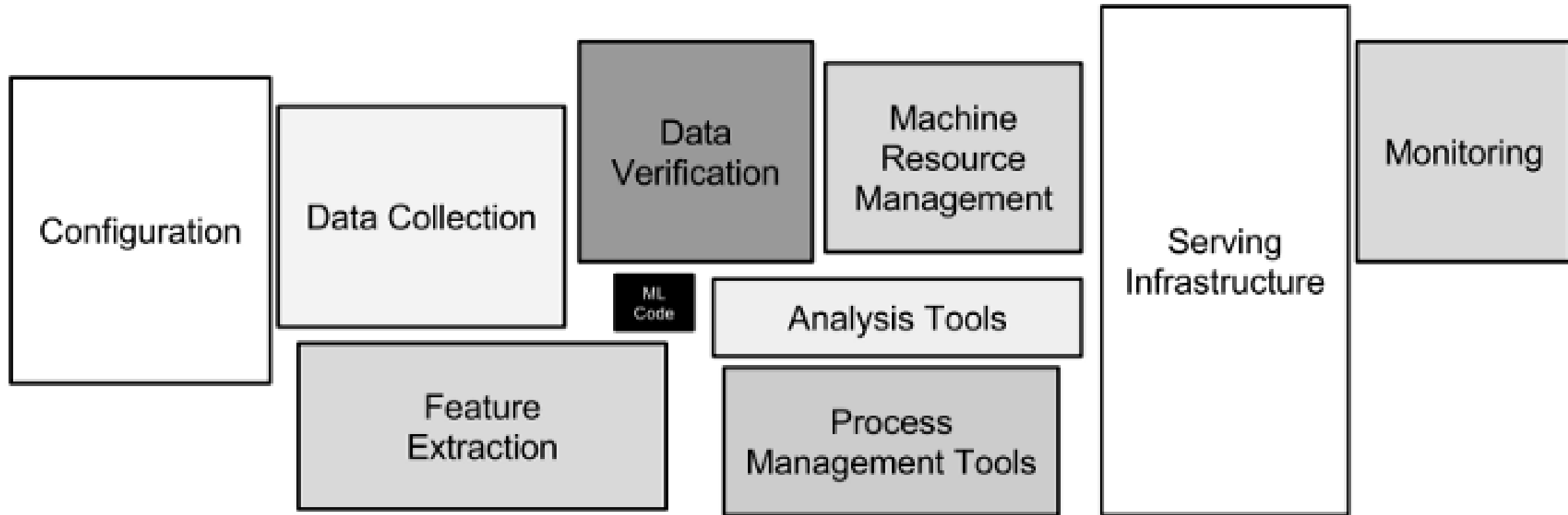
Focus: building models from given data, evaluating accuracy

# Automating Pipelines and MLOps (ML Engineering)



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

# MLOps Infrastructure

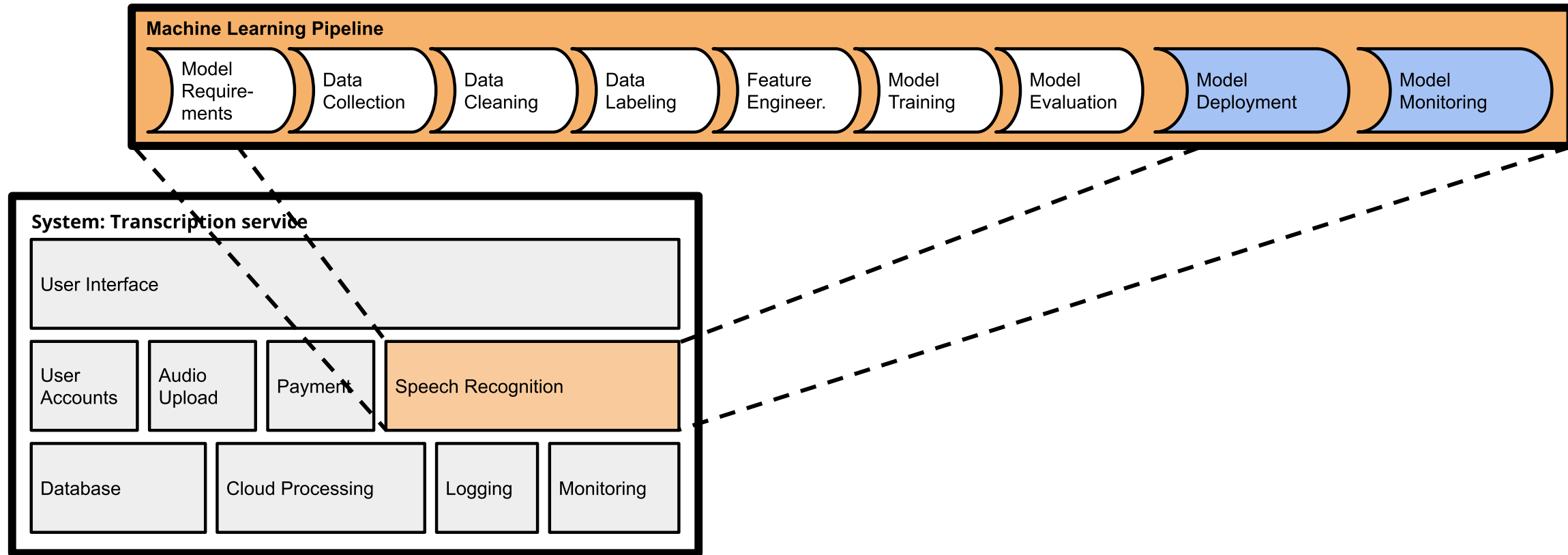


From: Sculley, David, et al. "Hidden technical debt in machine learning systems." NIPS 28 (2015).

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).



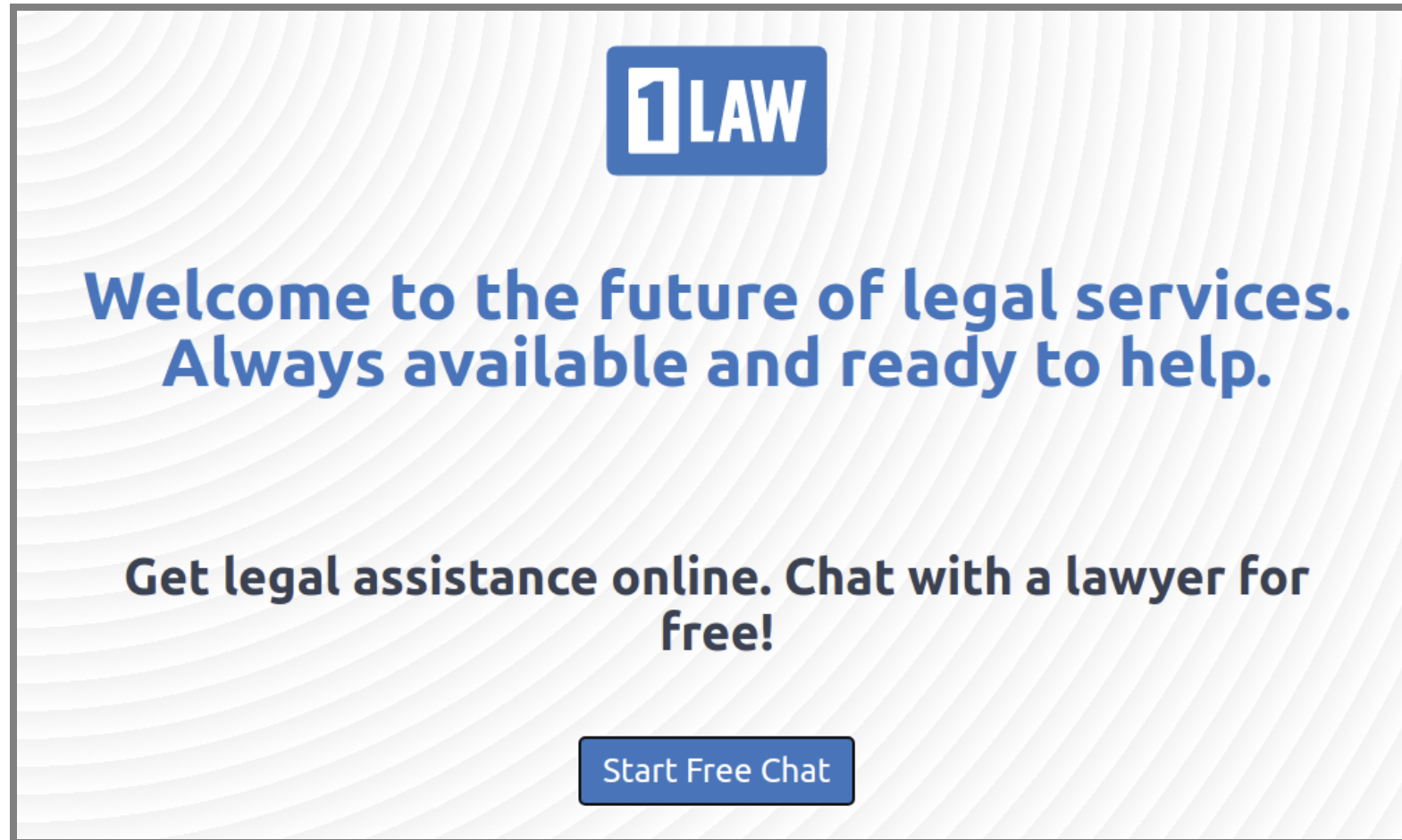
# ML-Enabled Systems (ML in Production)



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



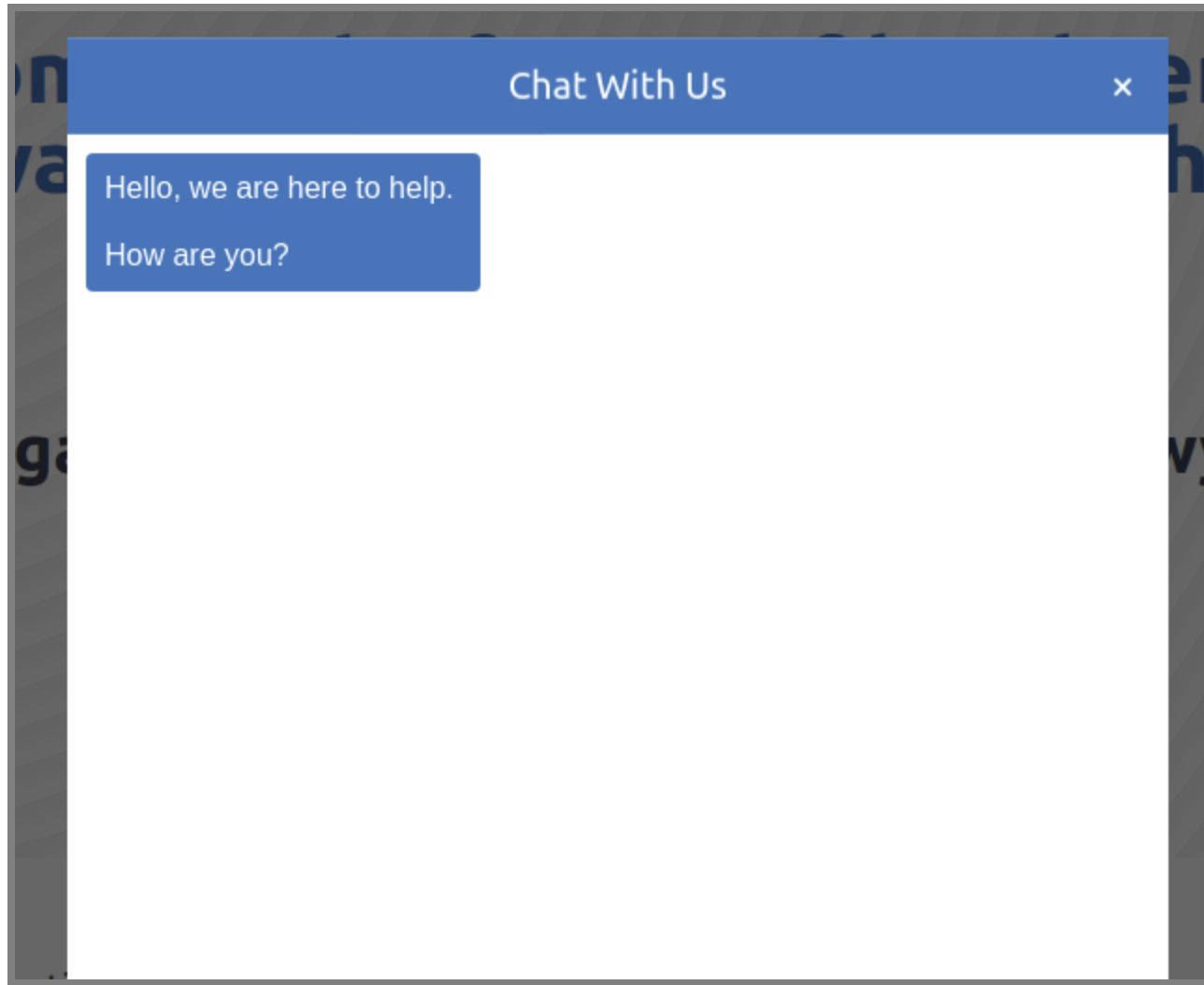
Based on the excellent paper: Passi, S., & Sengers, P. (2020). [Making data science systems work](#). Big Data & Society, 7(2).

Speaker notes

Screenshots for illustration purposes, not the actual system studied



# Case Study: Self-help legal chatbot





# Previous System: Guided Chat

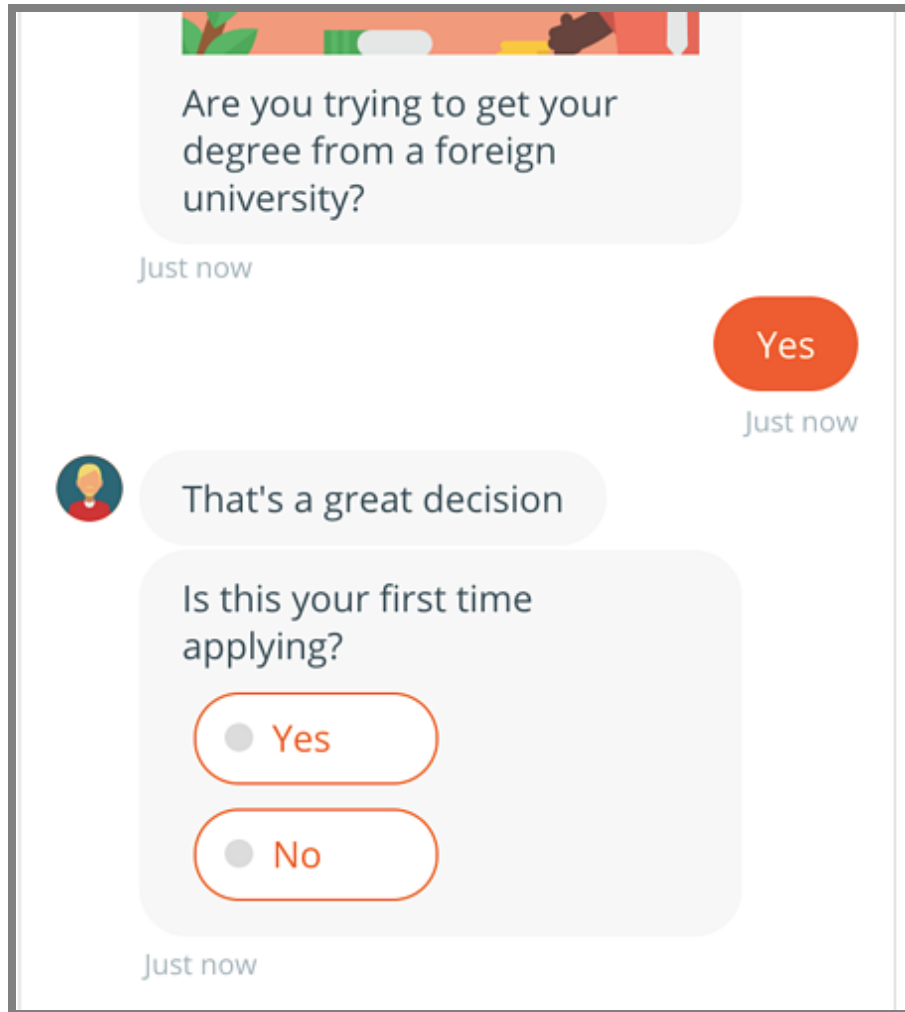


Image source: <https://www.streamcreative.com/chatbot-scripts-examples-templates>

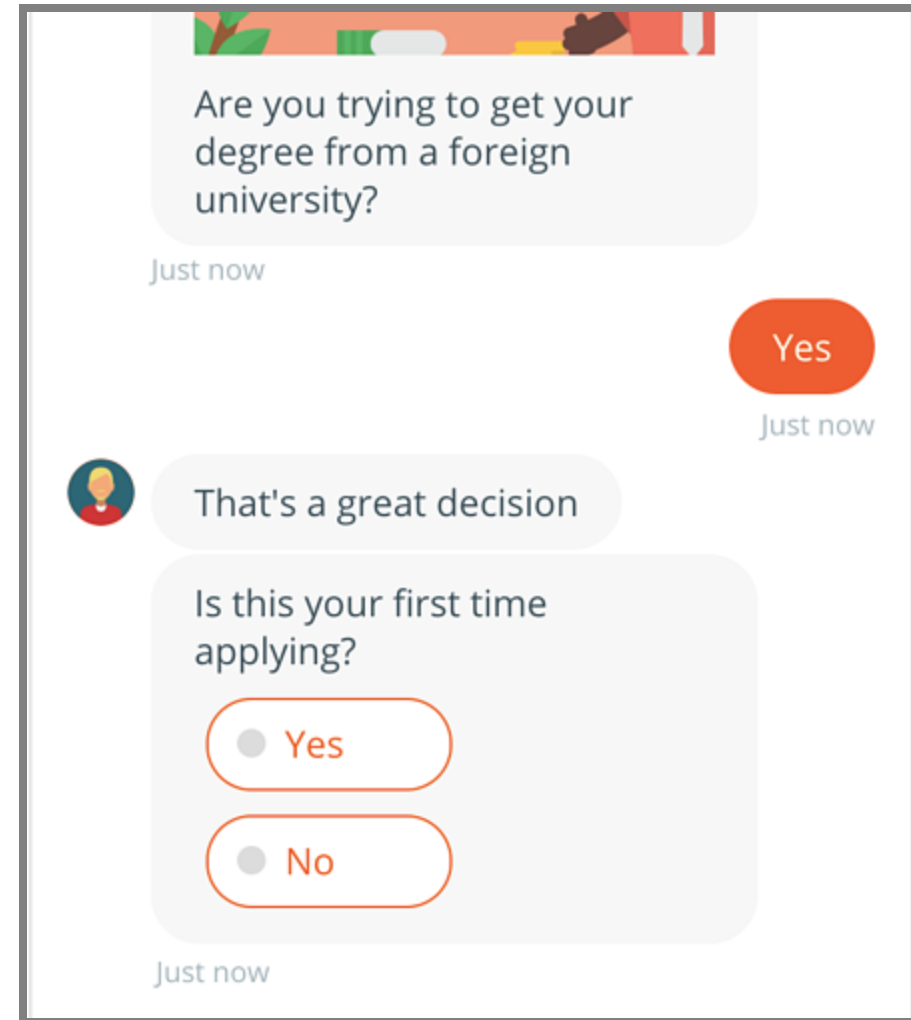
# Problems with Guided Chats

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?

Products ▾Partner ▾Resources ▾PricingFeaturesSign 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

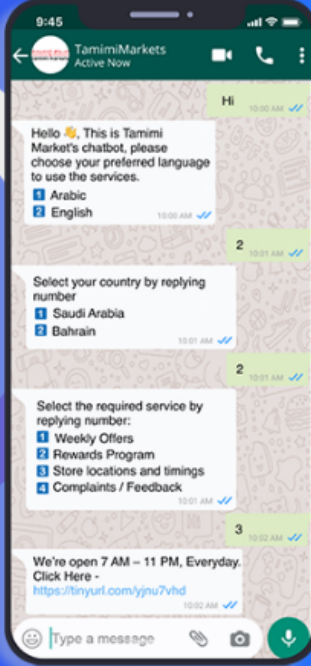
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Free 1-1 Product Tour

1K  
Chatbots

20K  
Bot Responses

9K  
Hours Saved



**+307** trials started in last 7 days



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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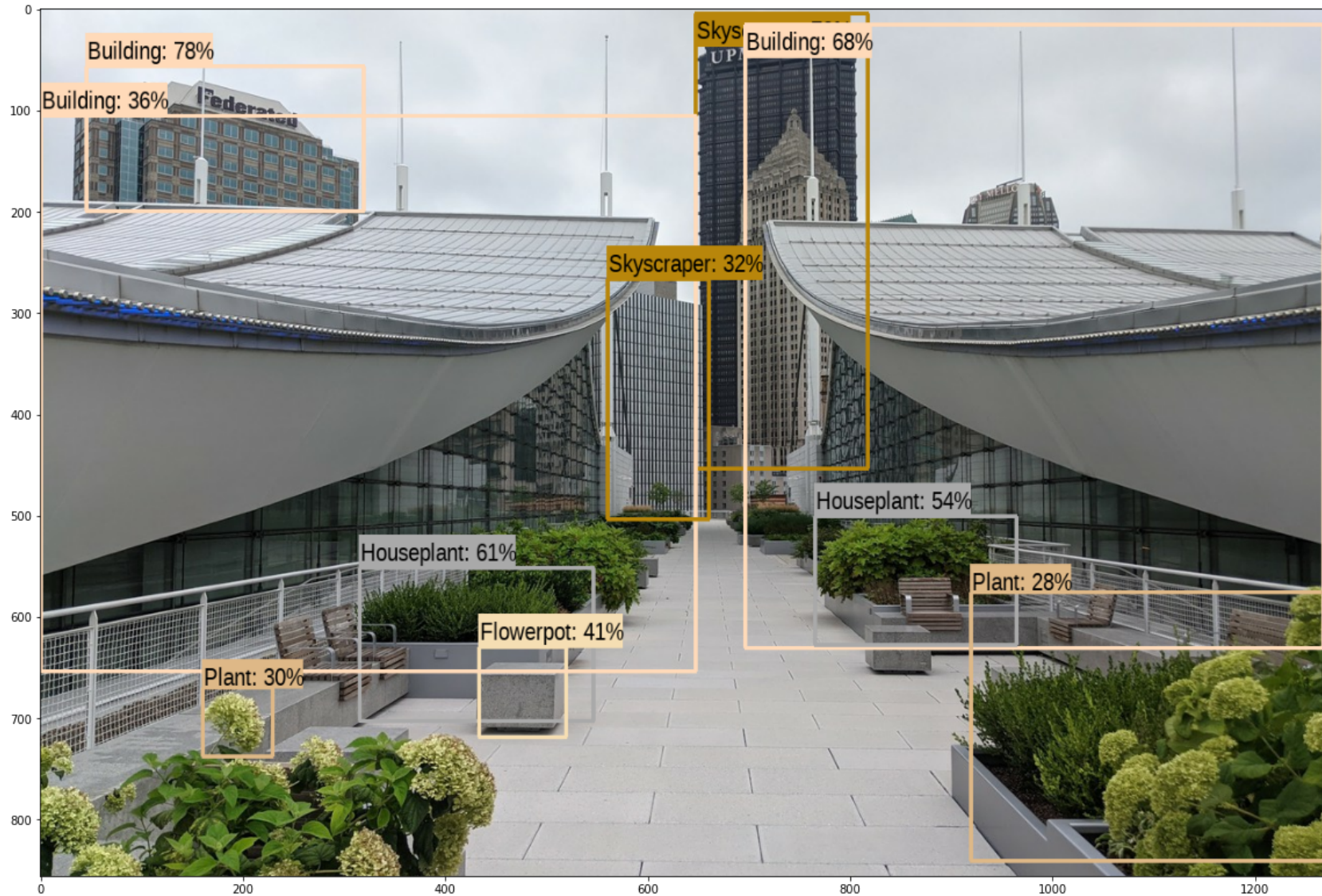
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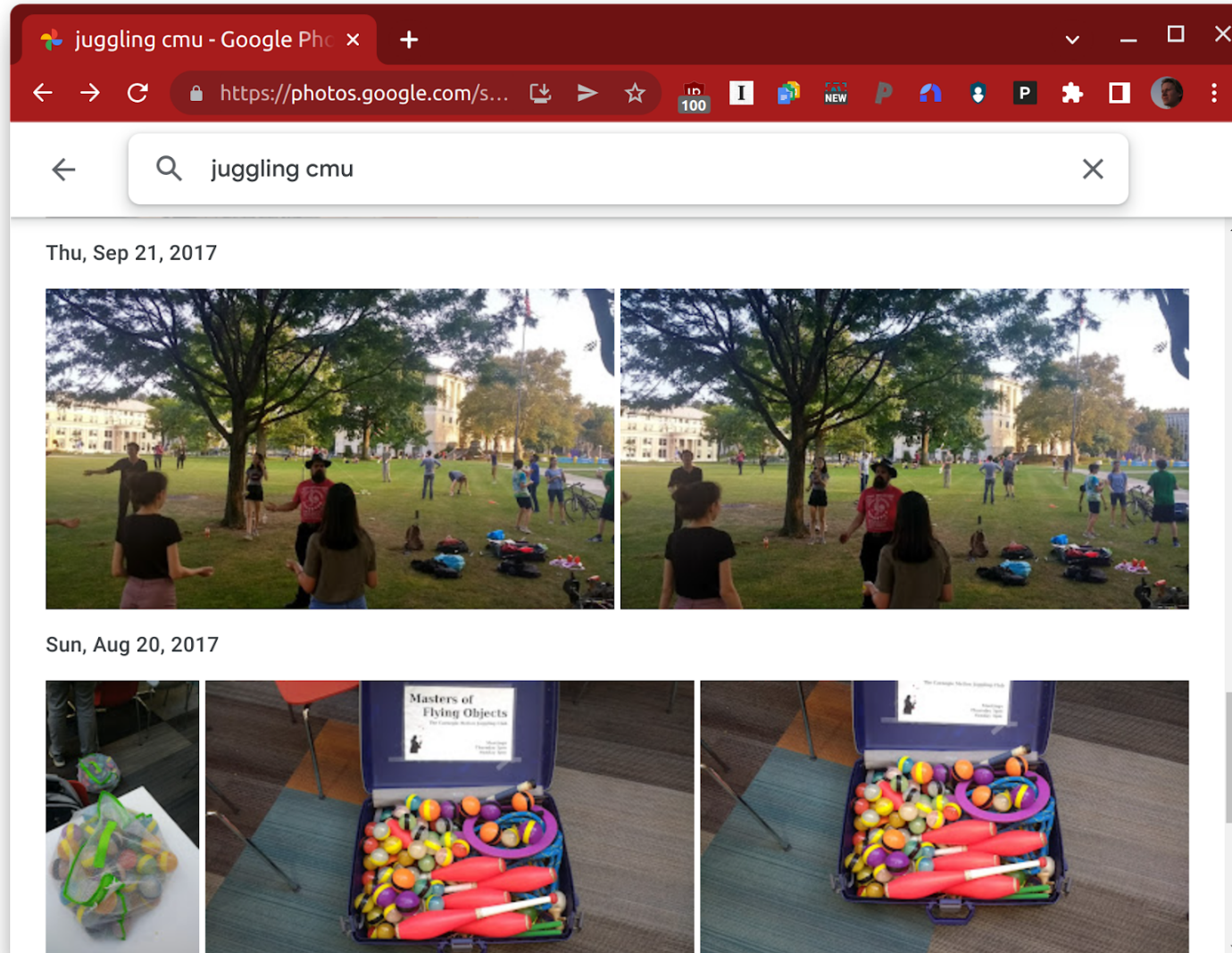
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# Model vs System Goal?



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# 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*

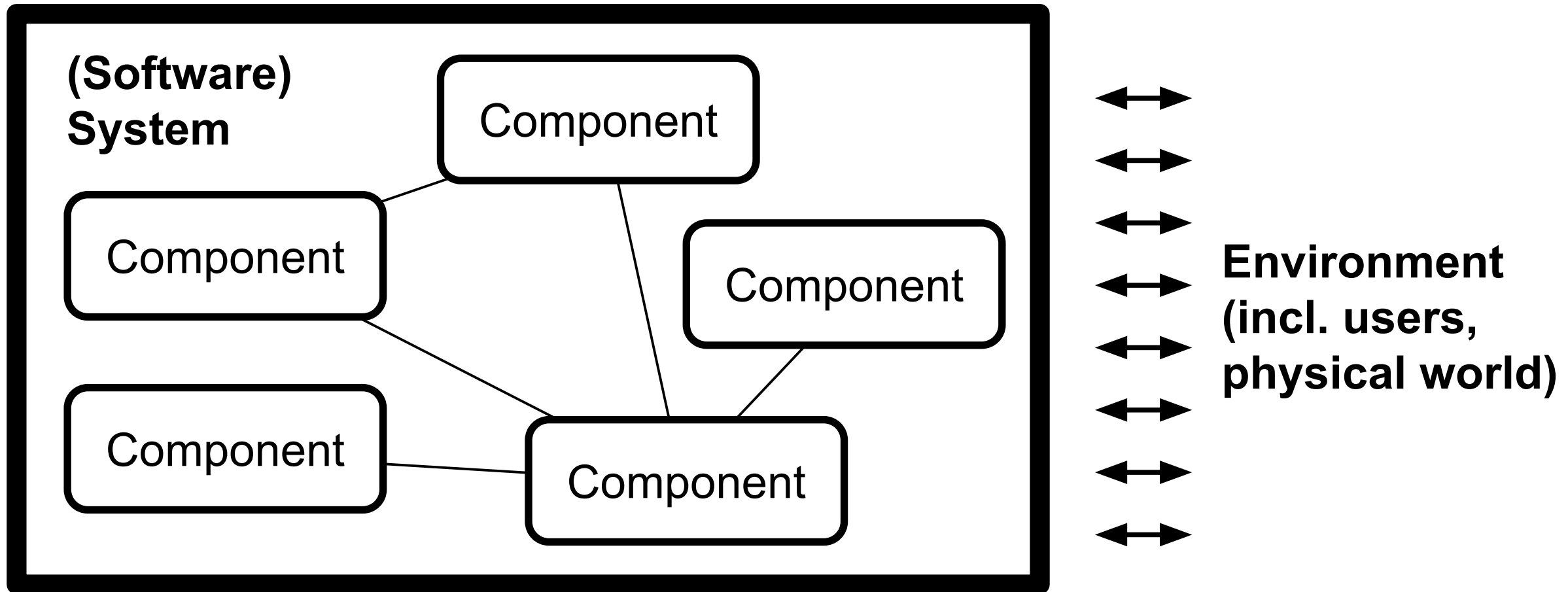
Wagstaff, Kiri. "Machine learning that matters." In Proceedings of the 29 th International Conference on Machine Learning, (2012).

# On Terminology

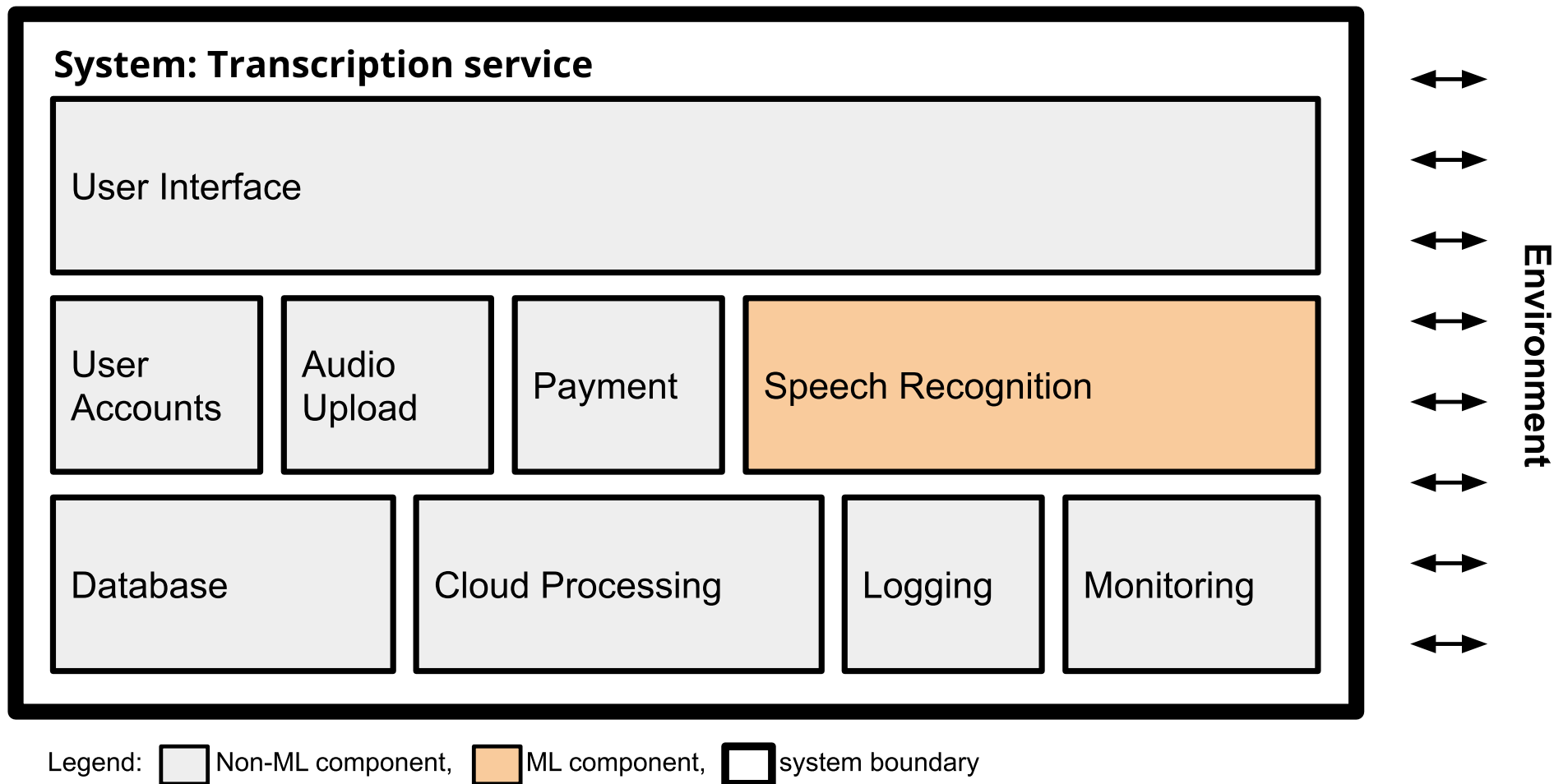


- There is no standard term for referring to building systems with AI components
- **ML-Enabled Systems**, *Production ML Systems*, *AI-Enabled Systems*, or *ML-Infused Systems*; *SE4AI*, *SE4ML*
- sometimes **AI Engineering** / **ML Engineering** -- but usually used with a ML-pipeline focus
- **MLOps** ~ 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

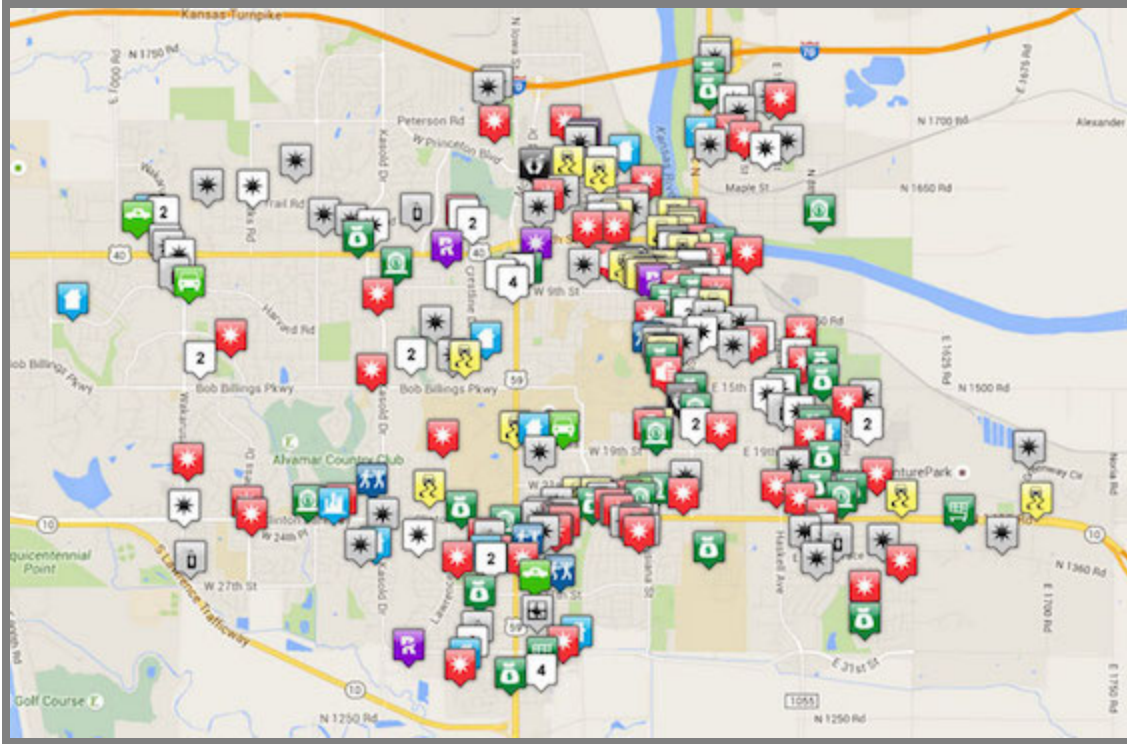




# The System Interacts with the World

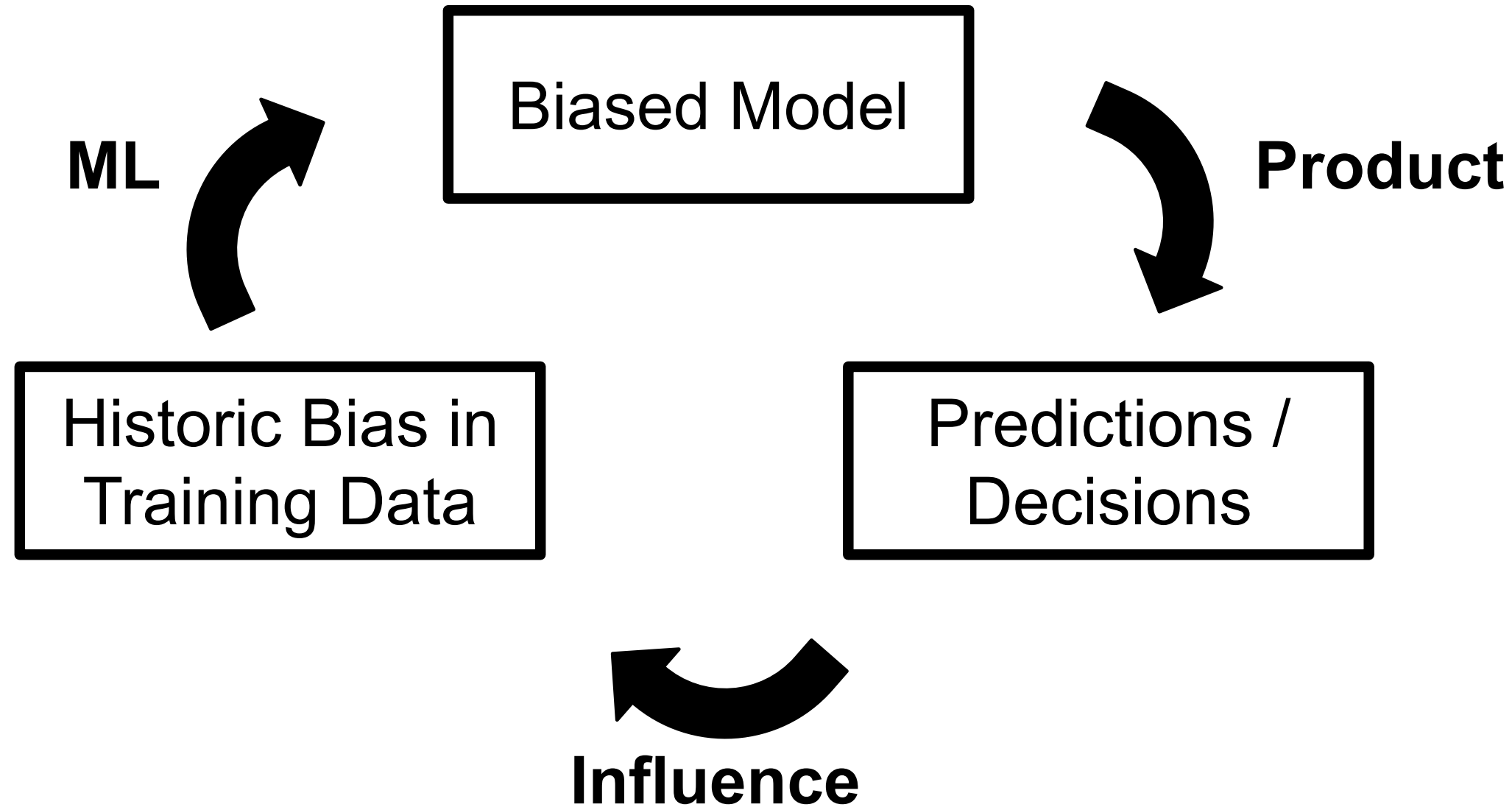


# The System Interacts with the World




- 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*





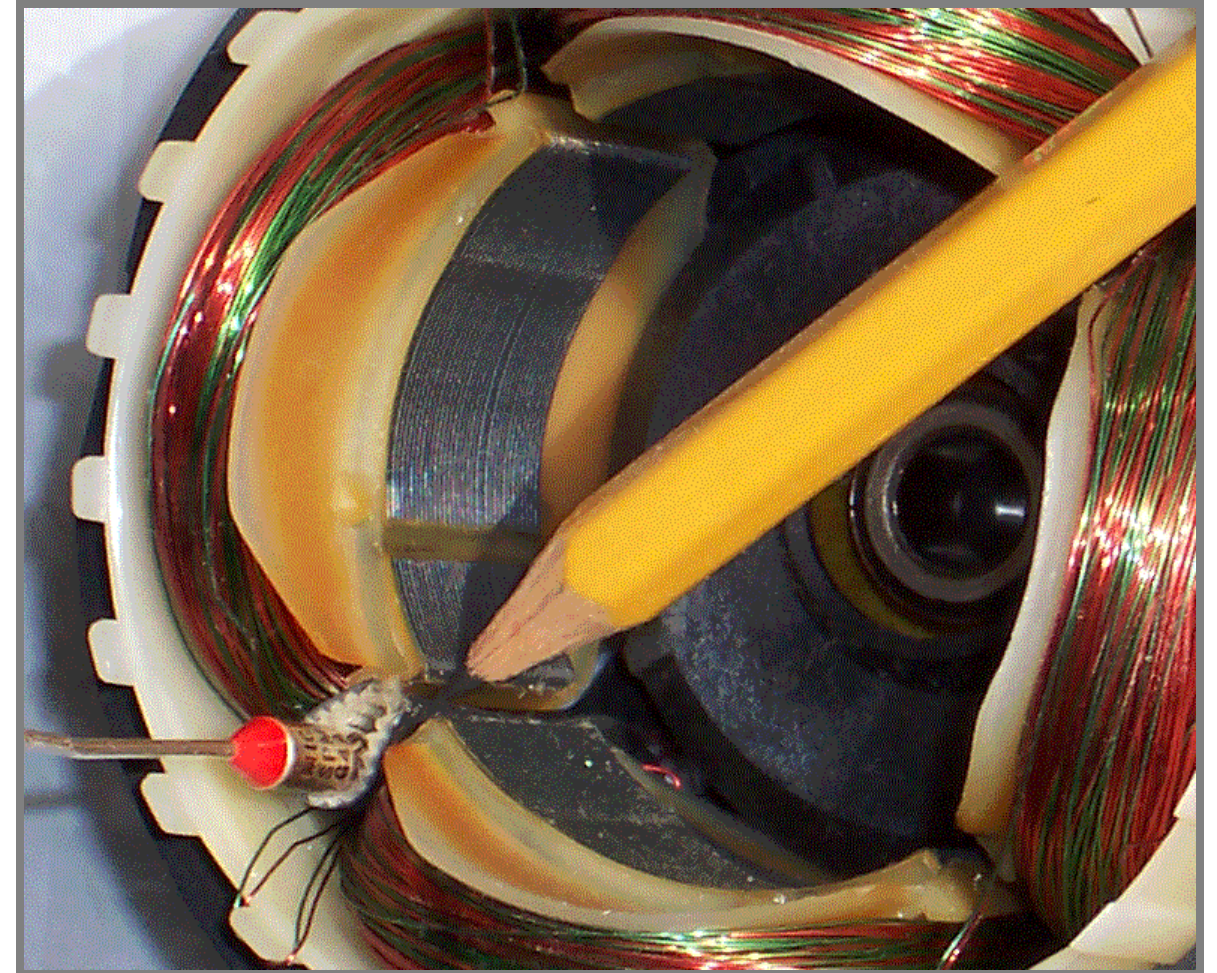
# Safety Assurance in/outside the Model

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?

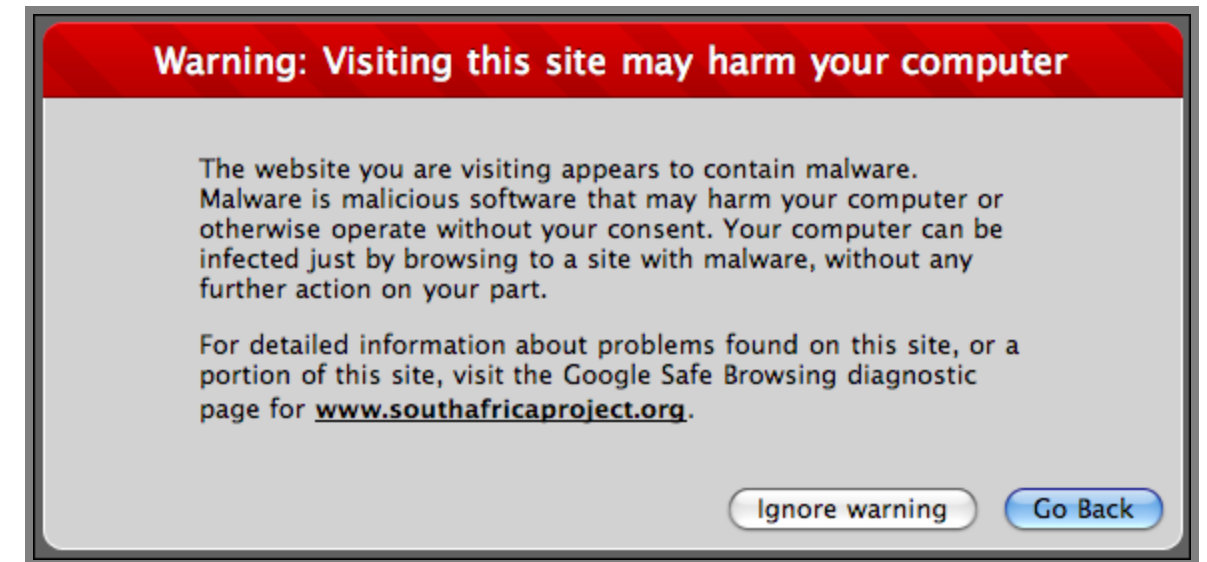
**Cost:** What is the damage of a wrong prediction?

# Breakout Discussion: Experience Design

Fall detection for elderly people:



Safe browsing: Blocking malicious web pages



Discuss in group and post to #1ecture 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

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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Privacy - Terms

Comments:  
(Optional)

Submit Report





# Operating Production ML Systems

(deployment, updates)

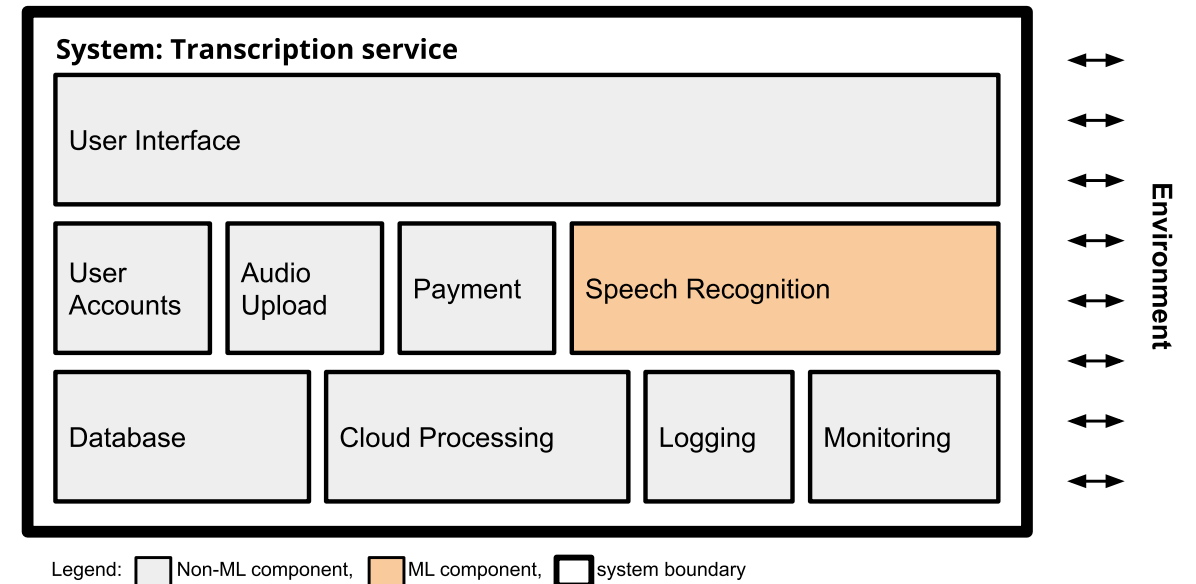
# Things change...

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



**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](#).


# Monitoring in Production

## Design for telemetry


### Report Incorrect Phishing Warning

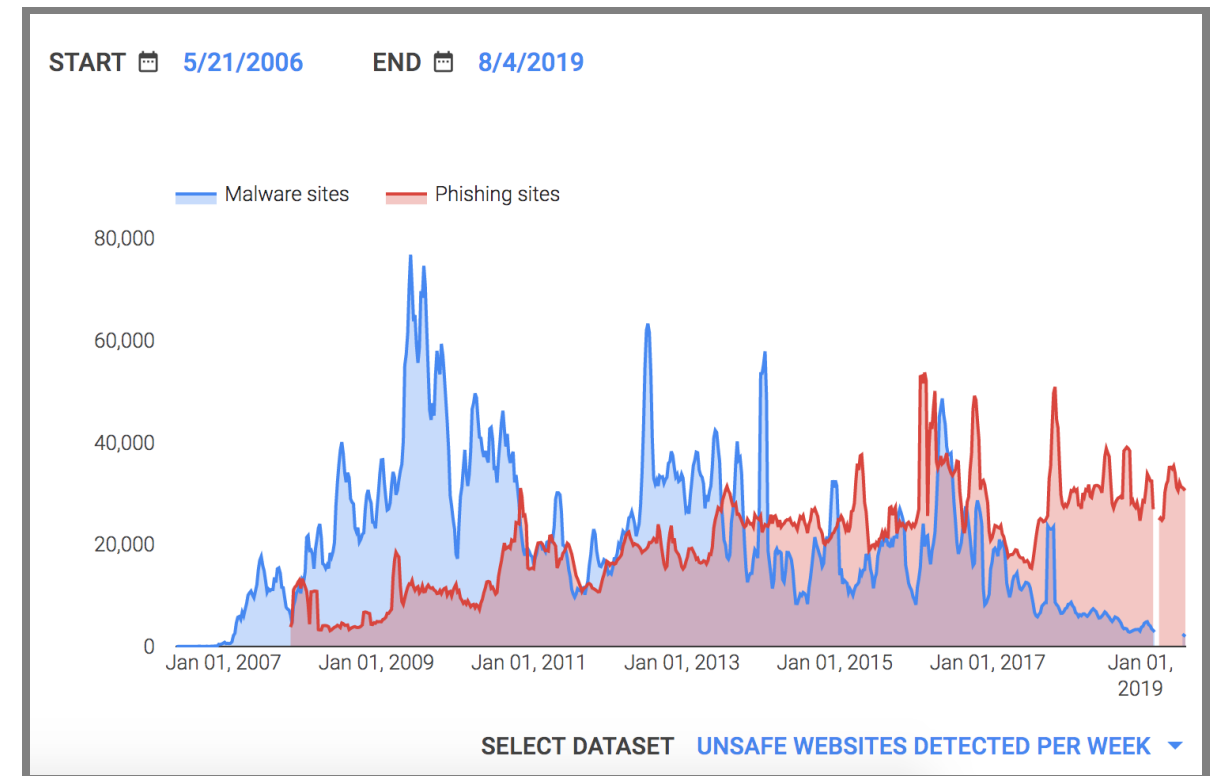
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Comments:   
(Optional)





# Monitoring in Production

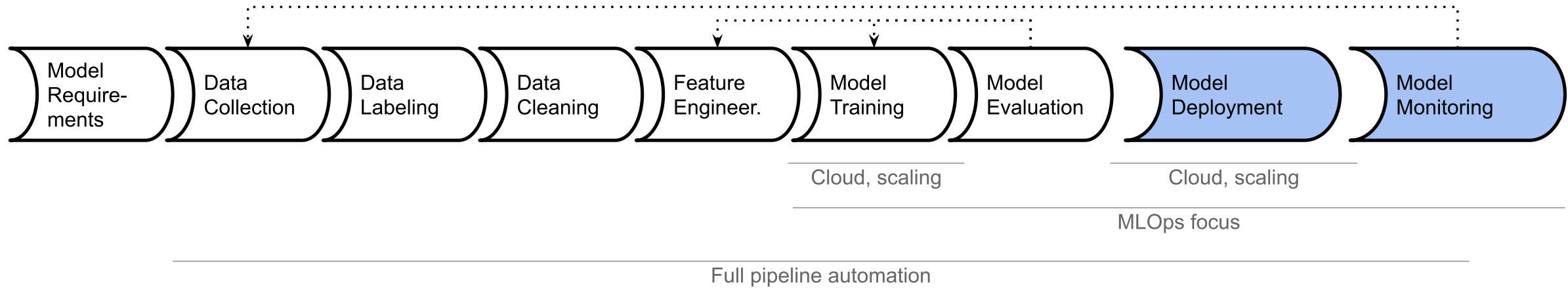
*What and how to monitor in audit risk prediction?*

## Your Audit Risk Results

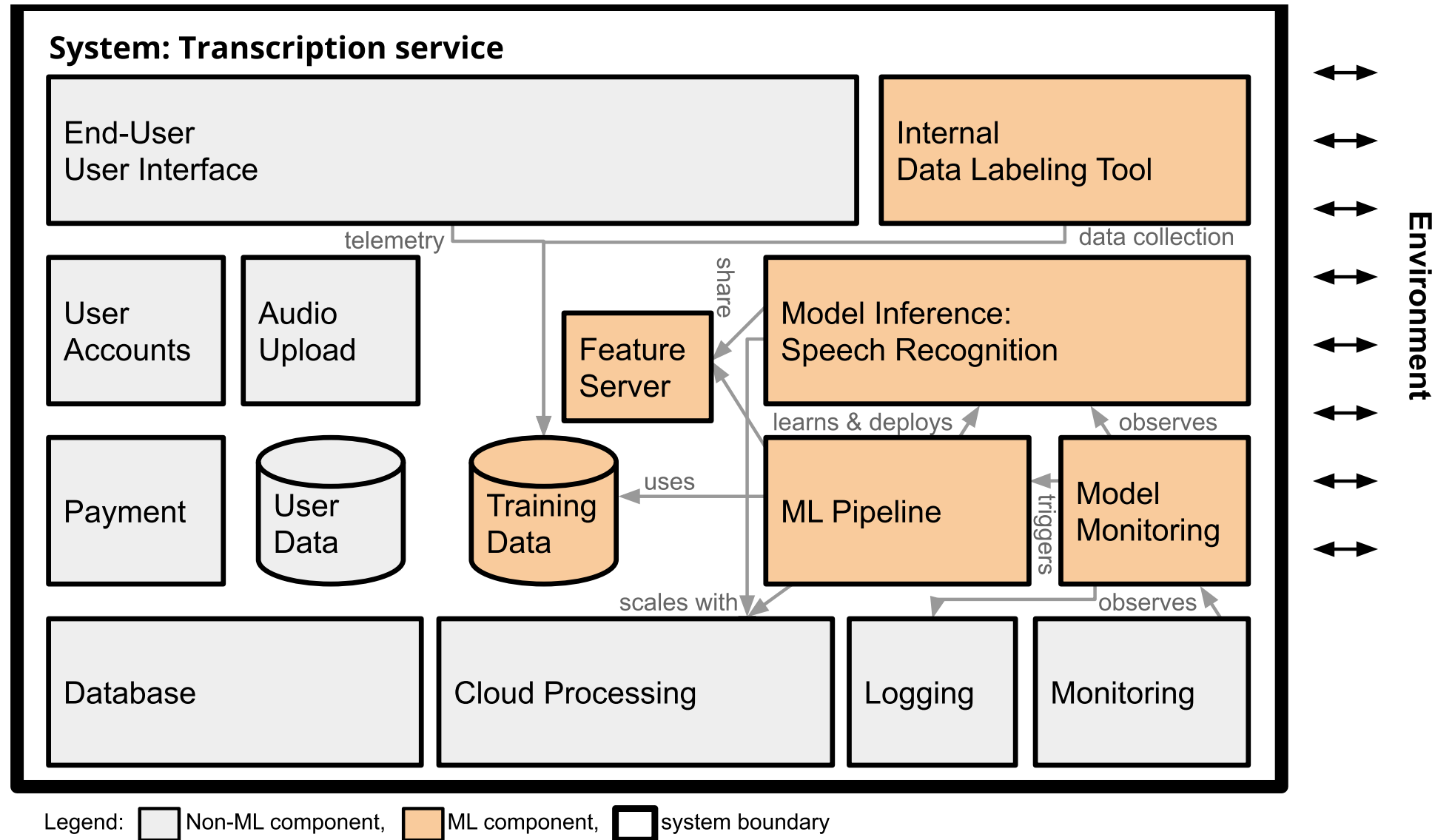


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# Pipeline Thinking



# 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.
- Nahar, Nadia, Shurui Zhou, Grace Lewis, and Christian Kästner. "[Collaboration Challenges in Building ML-Enabled Systems: Communication, Documentation, Engineering, and Process](#)." In Proceedings of the 44th International Conference on Software Engineering (ICSE), May 2022.
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