

Machine Learning Operations (MLOps)

Usage of Pipelines in the ML Lifecycle with
Tensor Flow Extended (TFX) and Kubeflow

Prof. Dr. Jan Kirenz
HdM Stuttgart

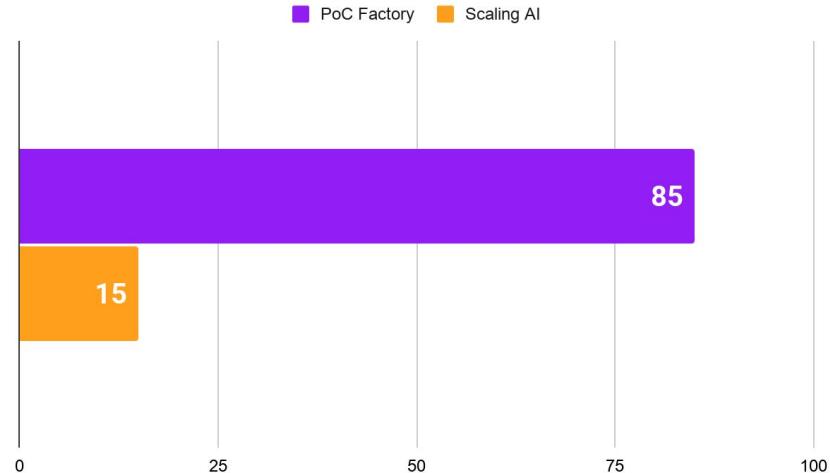
The Proof of Concept Factory

80-85% PoC Factory

Most companies...

- ... conduct AI experiments and pilots but achieve a low scaling success rate
- ... have significant under investment, yielding low returns

accenture



Gartner Top 10 Data and Analytics Trends, 2021



gartner.com/SmarterWithGartner

Source: Gartner
© 2021 Gartner, Inc. All rights reserved. CTMKT_1164473

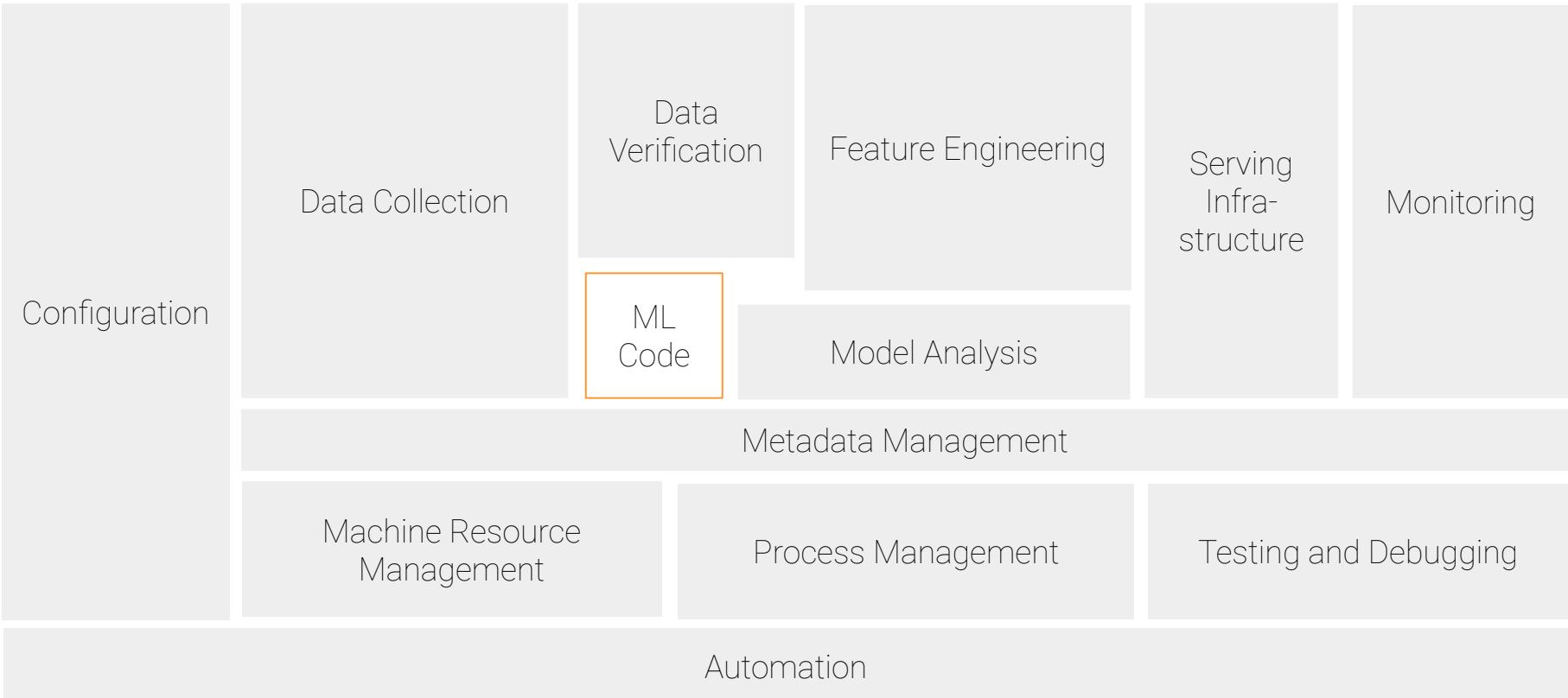
Gartner[®]

The problem with scaling AI

ML code is only a fraction of a production-ready ML project code

ML Project Code

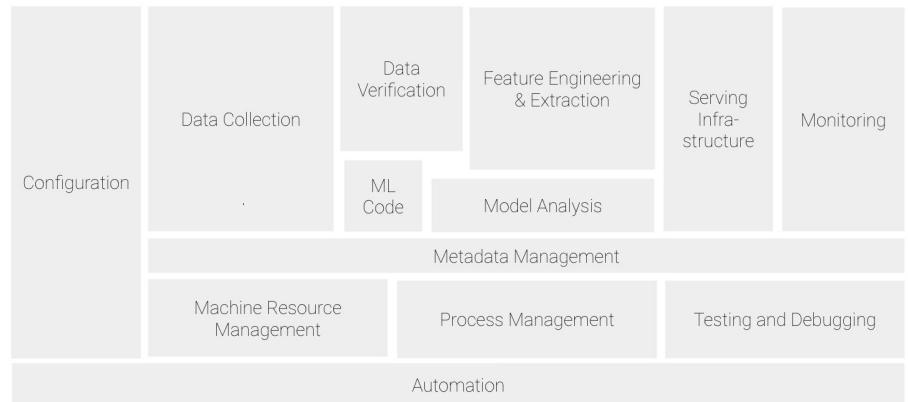




Hidden technical debt in machine learning systems

Machine learning operations (MLOps)

- ML Engineering culture and practice that aims at **unifying** ML System **development** (Dev) and ML system **operations** (Ops)
- Tools and principles to support workflow **standardization** and **automation** through the ML system lifecycle (e.g. with *pipelines*)

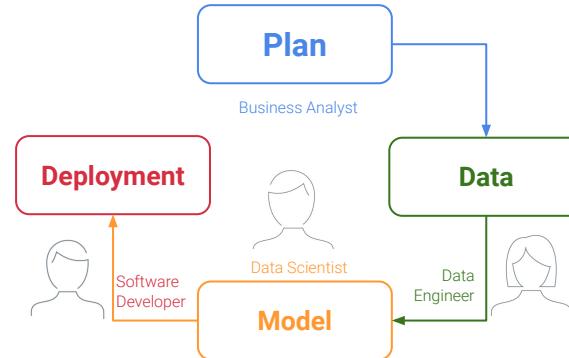


Machine learning **lifecycle**

Lifecycle

of an ML System

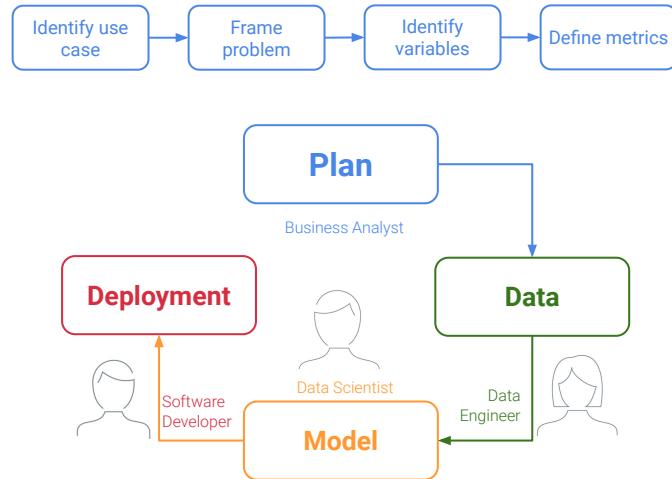
Plan | Data | Model | Deployment



Lifecycle

of an ML System

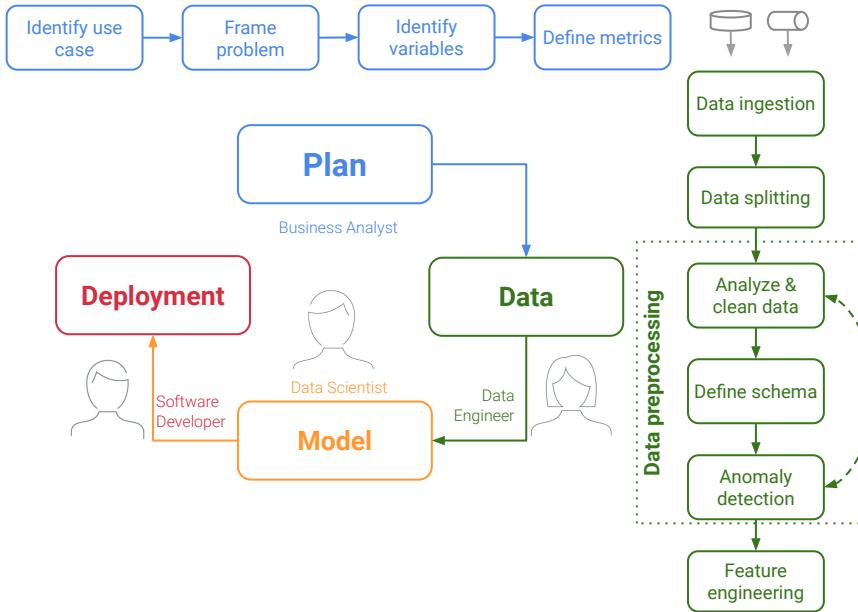
Plan | Data | Model | Deployment



Lifecycle

of an ML System

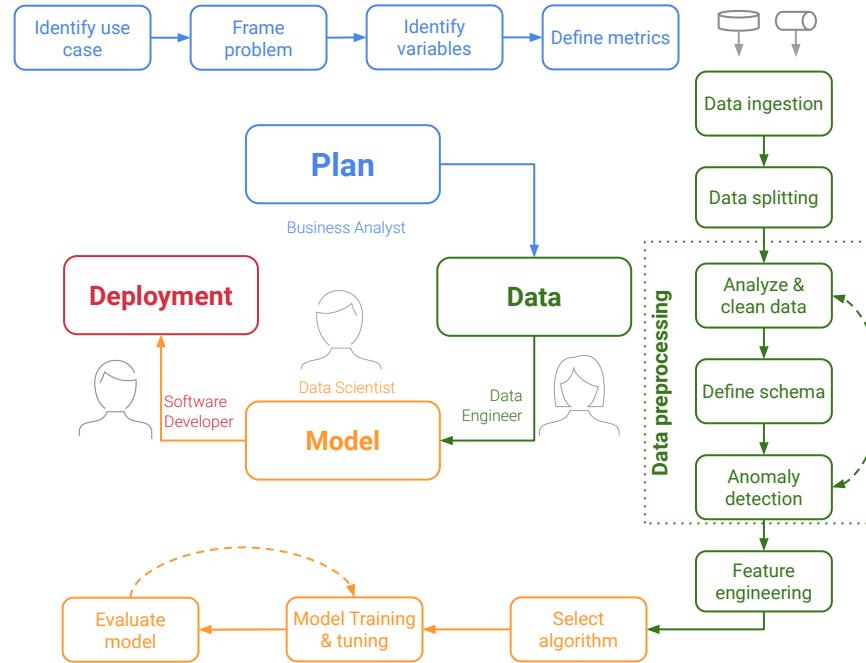
Plan | Data | Model | Deployment



Lifecycle

of an ML System

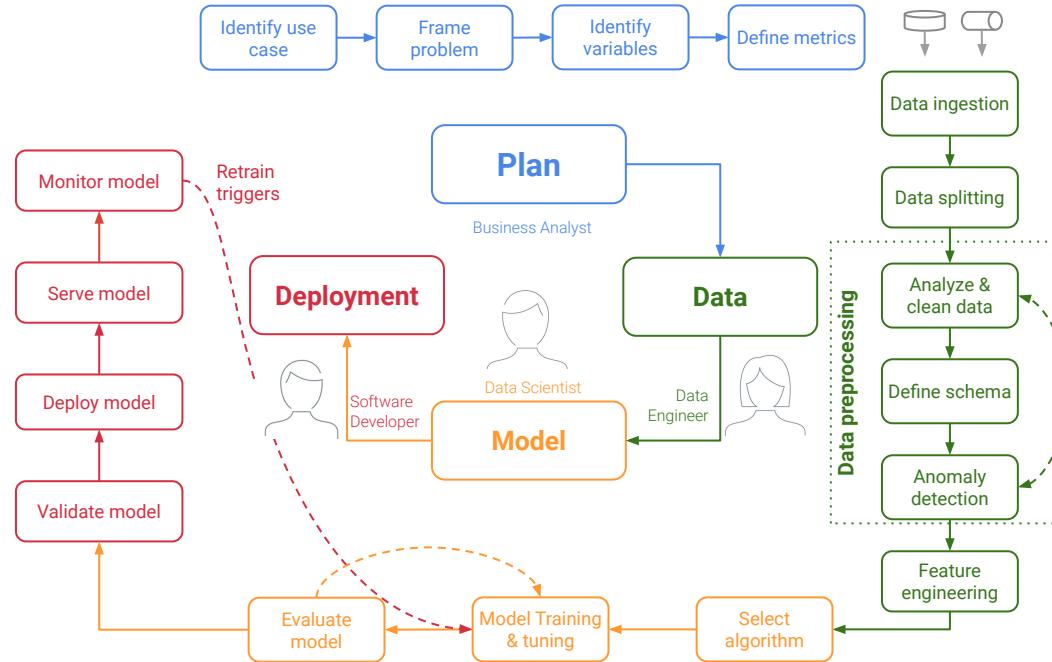
Plan | Data | **Model** | Deployment



Lifecycle

of an ML System

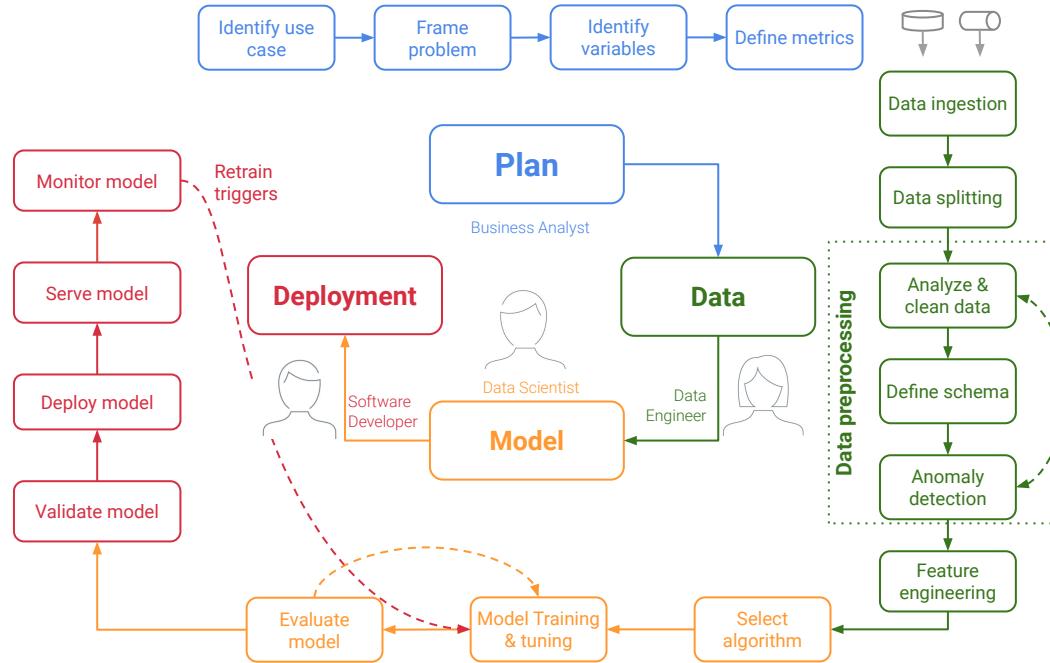
Plan | Data | Model | **Deployment**



Lifecycle

of an ML System

Plan | Data | Model | Deployment



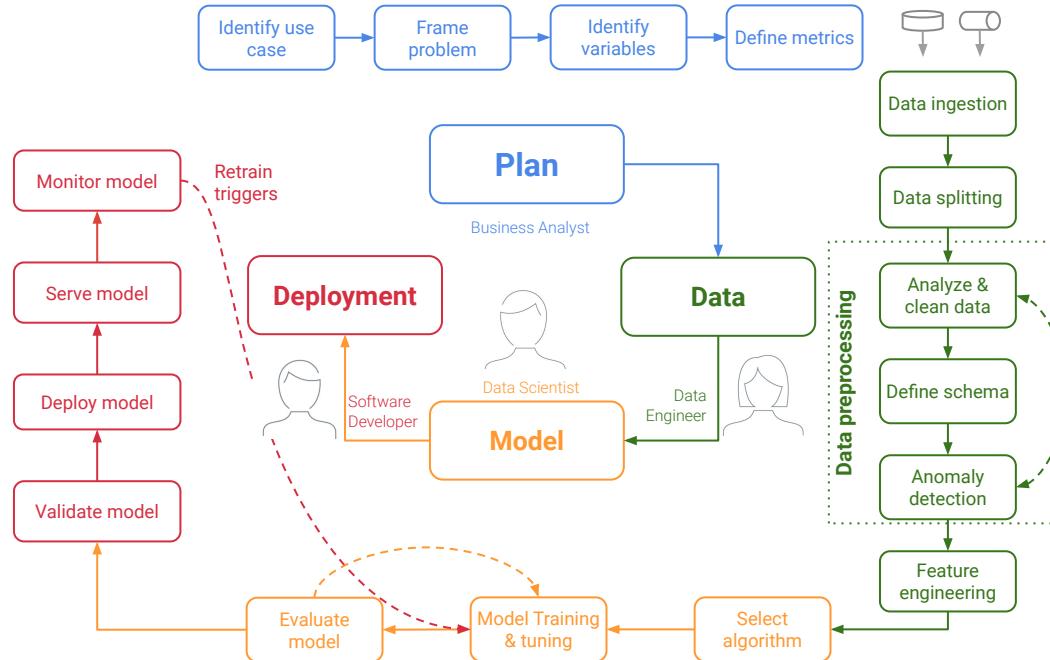
Common issues which lead to a PoC to production gap

- Lack of reuse and duplication
- Inconsistency (data, code, models)
- Manual and slow transition from PoC to production

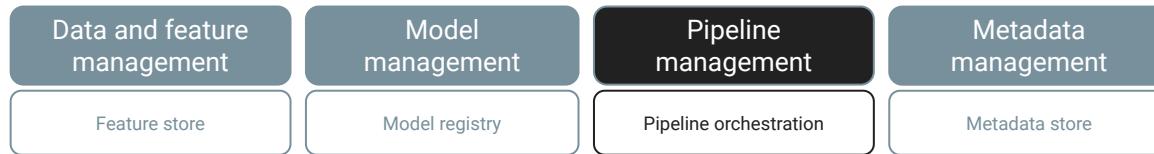
Lifecycle

of an ML System

Plan | Data | Model | Deployment

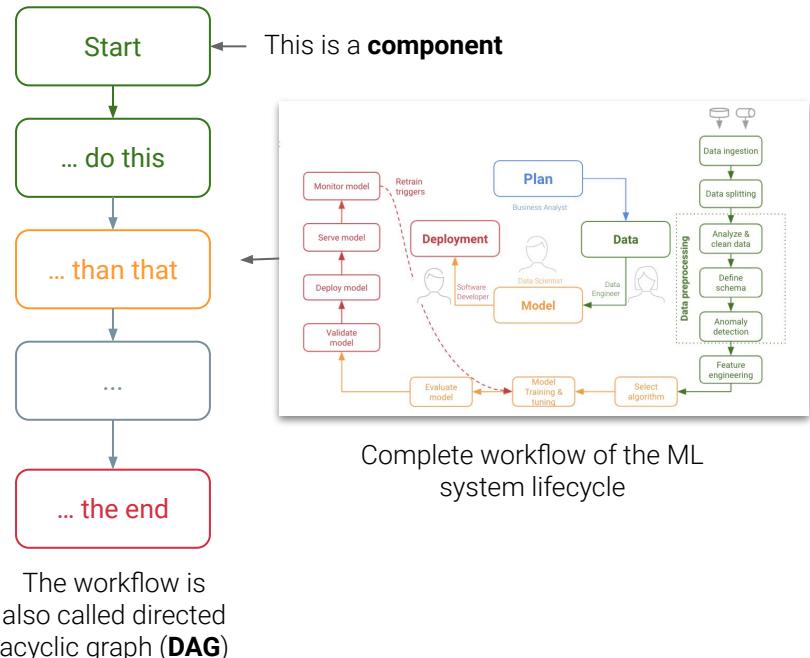


MLOps components



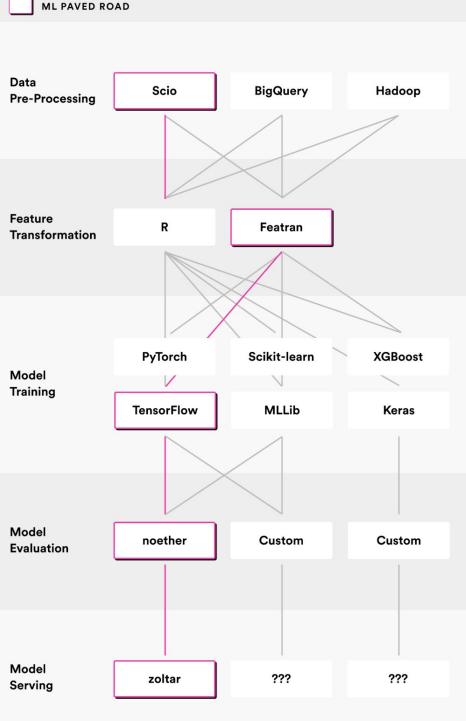
What is a pipeline?

- Description of an ML **workflow**
- A pipeline **component** is a self-contained set of user code that performs one step in the pipeline
- Includes the definition of the **configuration** and **inputs** required to run the pipeline (e.g. model hyperparameters)

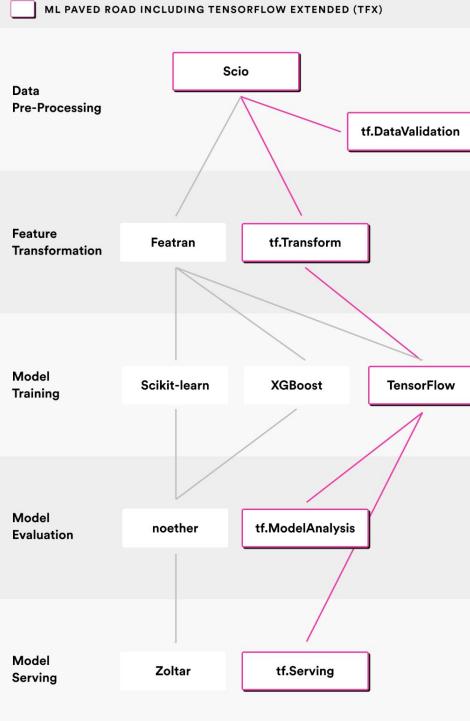




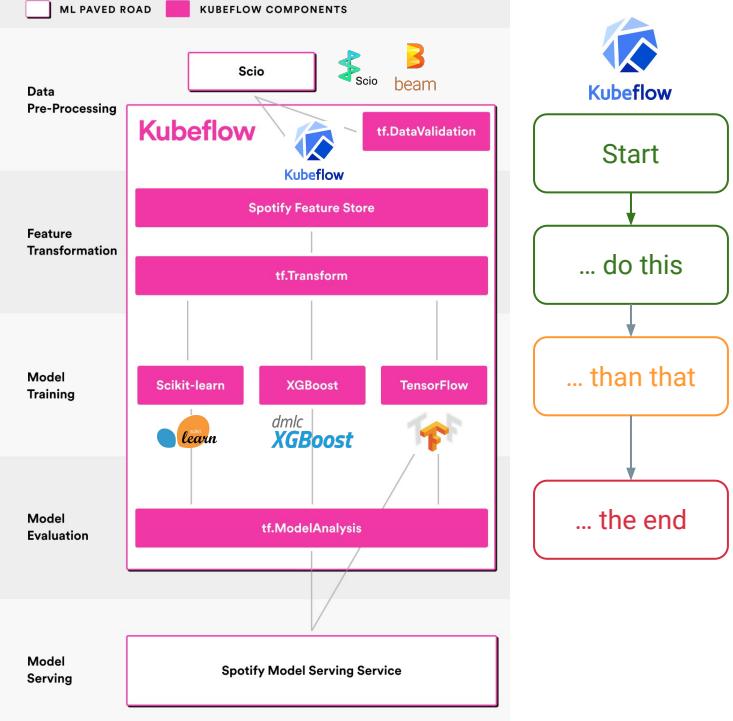
ML Platform 2018



ML Platform 2019



ML Platform 2020



TensorFlow Extended (TFX)

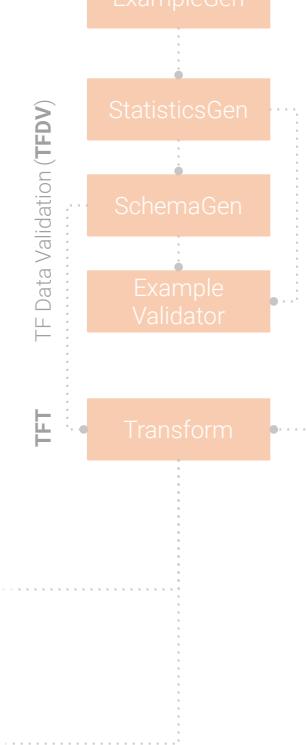
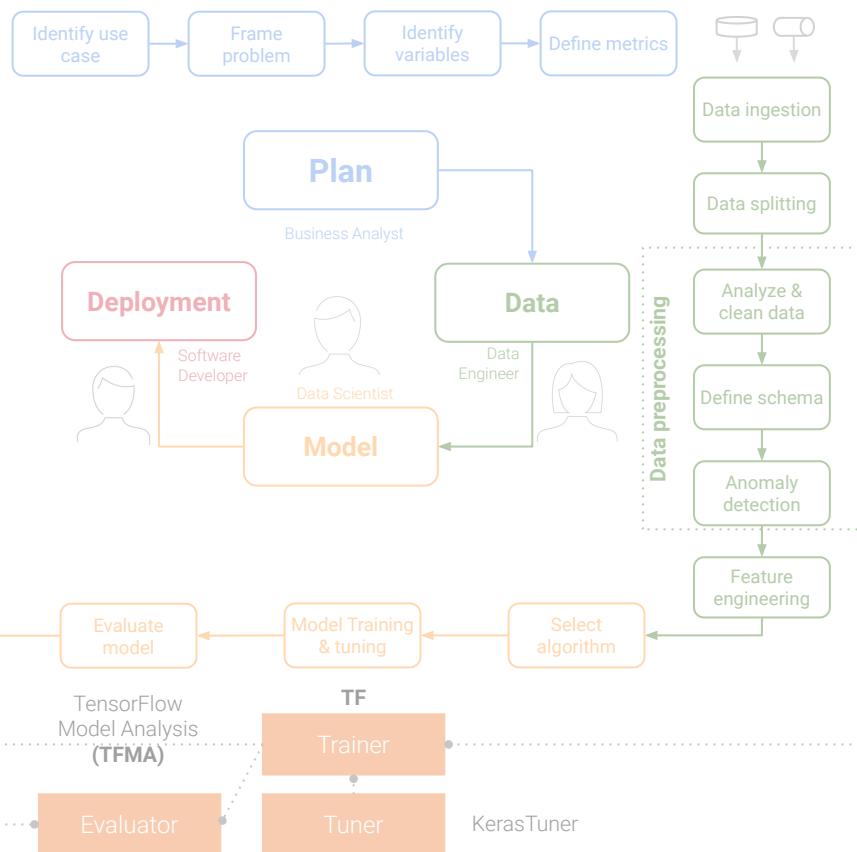
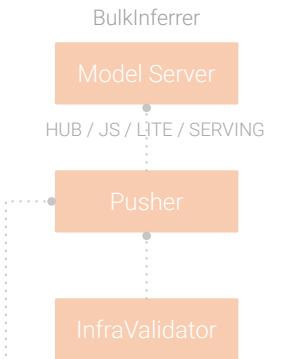
- Google-production-scale machine learning (ML) platform based on TensorFlow
- Portable to multiple environments (Azure, AWS, Google Cloud, IBM, ...)
- Python based toolkit; can be used with notebooks
- Helps you orchestrate your ML process: Apache Airflow, Apache Beam or Kubeflow pipelines



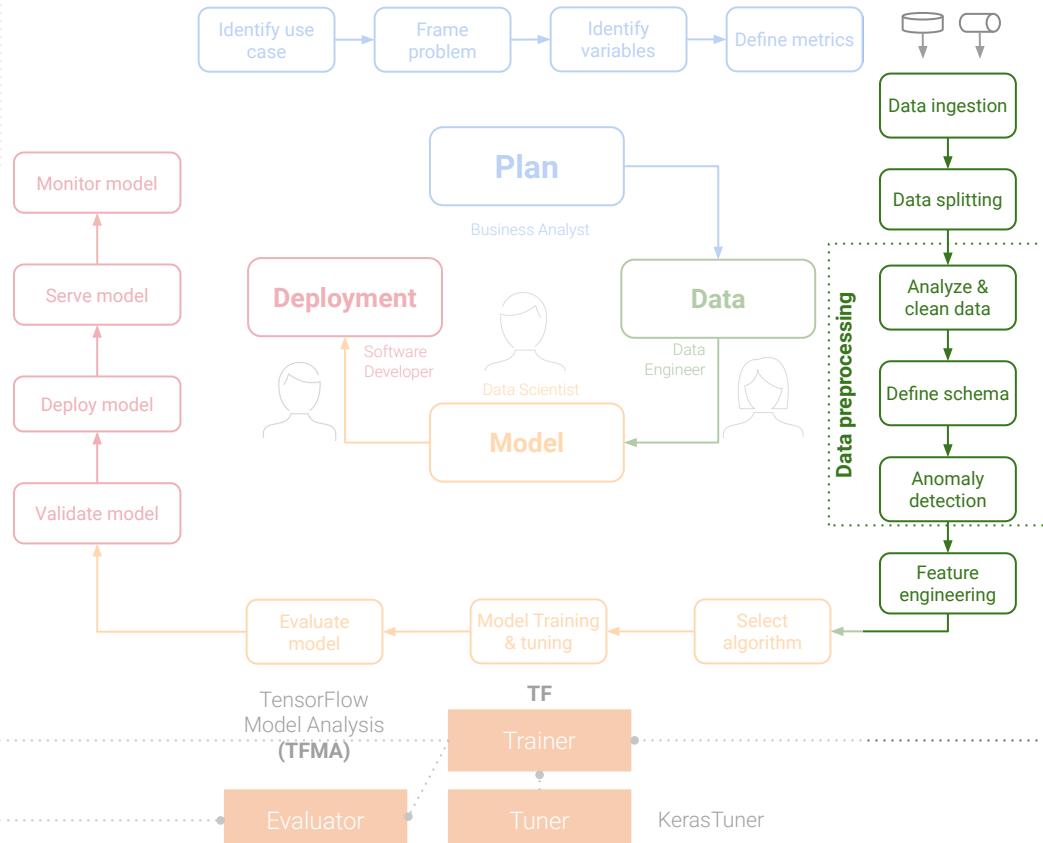
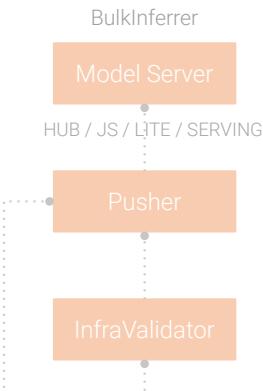
TFX 1.0 (19.05.21)

- Enterprise-grade support
- Security patches and select bug fixes for up to three years
- Guaranteed API & Artifact backward compatibility

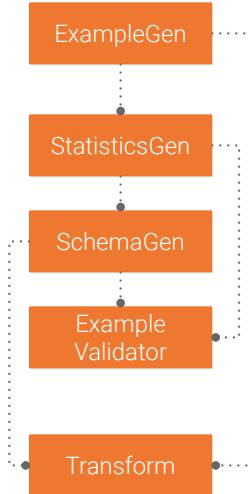




TFX Options for Pipeline Orchestration



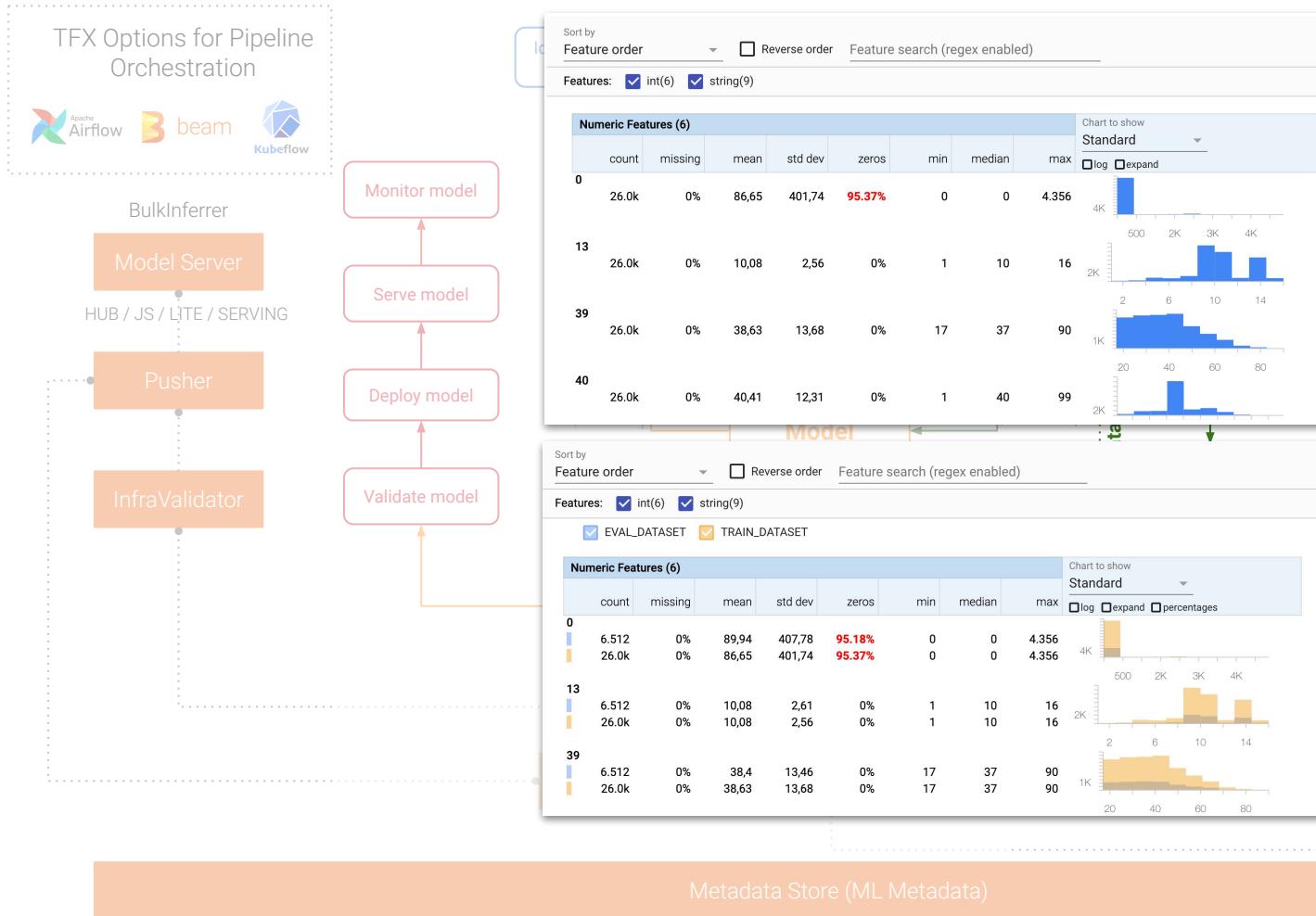
TF Data Validation (TFDV)



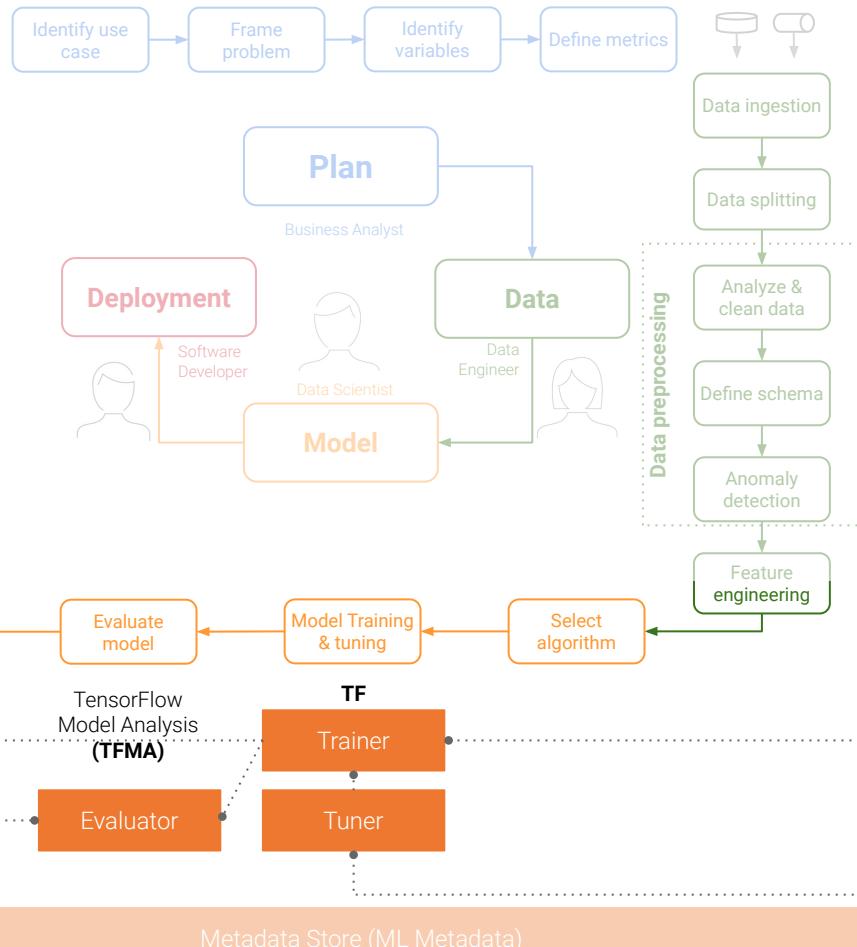
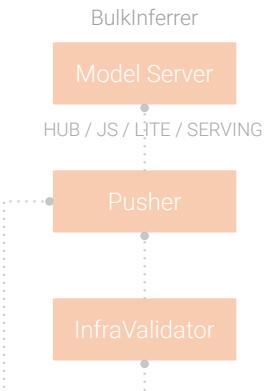
Metadata Store (ML Metadata)



TensorFlow Extended



TFX Options for Pipeline Orchestration



Metadata Store (ML Metadata)

TensorBoard.dev

SCALARS

- Show data download links
 Ignore outliers in chart scaling

Tooltip sorting method: default

Smoothing

Horizontal Axis

STEP RELATIVE WALL

Runs

Write a regex to filter runs

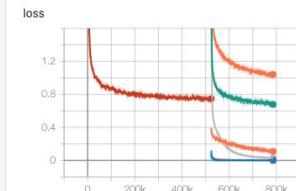
- cnn_dailymail_v002
- glue_v002_proportional
- pretrain
- squad_v010_allanswers
- super_glue_v102_proportional
- wmt15_enfr_v003
- wmt16_enro_v003
- wmt_t2t_ende_v003

TOGGLE ALL RUNS

experiment EvNO346lT0lYbmeaWmoNCQ

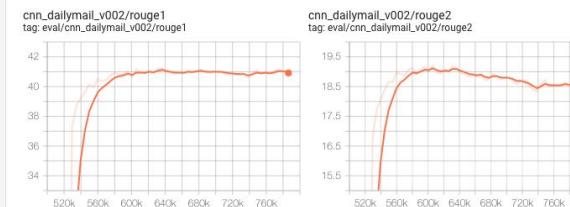
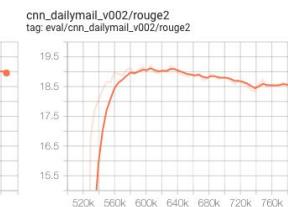
loss

Tags matching /loss/



eval

PREVIOUS PAGE

cnn_dailymail_v002/rouge1
tag: eval/cnn_dailymail_v002/rouge1cnn_dailymail_v002/rouge2
tag: eval/cnn_dailymail_v002/rouge2TensorFlow
Model Analysis
(TFMA)

Evaluator

Trainer

Tuner

Metadata Store (ML Metadata)

Model Card for Census Income Classifier

Model Details

Overview

This is a wide and deep Keras model which aims to classify whether or not an individual has an income of over \$50,000 based on various demographic features. The model is trained on the UCI Census Income Dataset. This is not a production model, and this dataset has traditionally only been used for research purposes. In this Model Card, we review quantitative components of the model's performance and data, as well as information about the model's intended uses, limitations, and ethical considerations.

Version

name: 36dea2e860670aa74691b5695587afe7

Owners

• Model Cards Team, model-cards@google.com

References

• interactive-2020-07-28T20_17_47.911887

Considerations

Use Cases

- This dataset that this model was trained on was originally created to support the machine learning community in conducting empirical analysis of ML algorithms. The Adult Data Set can be used in fairness-related studies that compare inequalities across sex and race, based on people's annual incomes.

Limitations

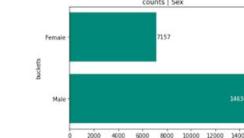
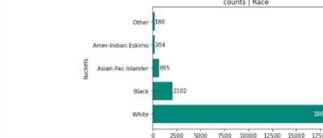
- This is a class-imbalanced dataset across a variety of protected classes. The ratio of male-to-female examples is about 2:1 and there are more examples with the "White" attribute than the "Other" attribute compared to the "Asian-Pac-Islander" or "Amer-Indian-Eskimo" groups. At a threshold of \$50,000 less than or equal to \$50,000, most elements is just over 5:1. Due to the imbalance across income levels, we can see that our true negative rate seems quite high, while our true positive rate seems quite low. This is true to an even greater degree when we only look at the "Female" subgroup. We can't make any claims about the fairness of this model without further investigation and effort to overturn these examples. To avoid this, we can try various remediation strategies in future iterations (e.g. undersampling, hyperparameter tuning, etc), but we may not be able to fix all of the fairness issues.

Ethical Considerations

- Risk: We risk expressing the viewpoint that the attributes in this dataset are the only ones that are predictive of someone's income, even though we know this is not the case.
- Mitigation Strategy: As mentioned, some interventions may need to be performed to address the class imbalances in the dataset.

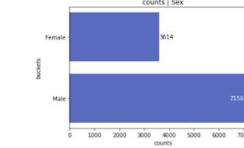
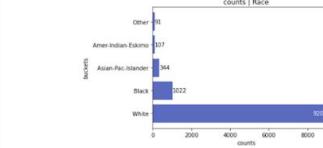
Train Set

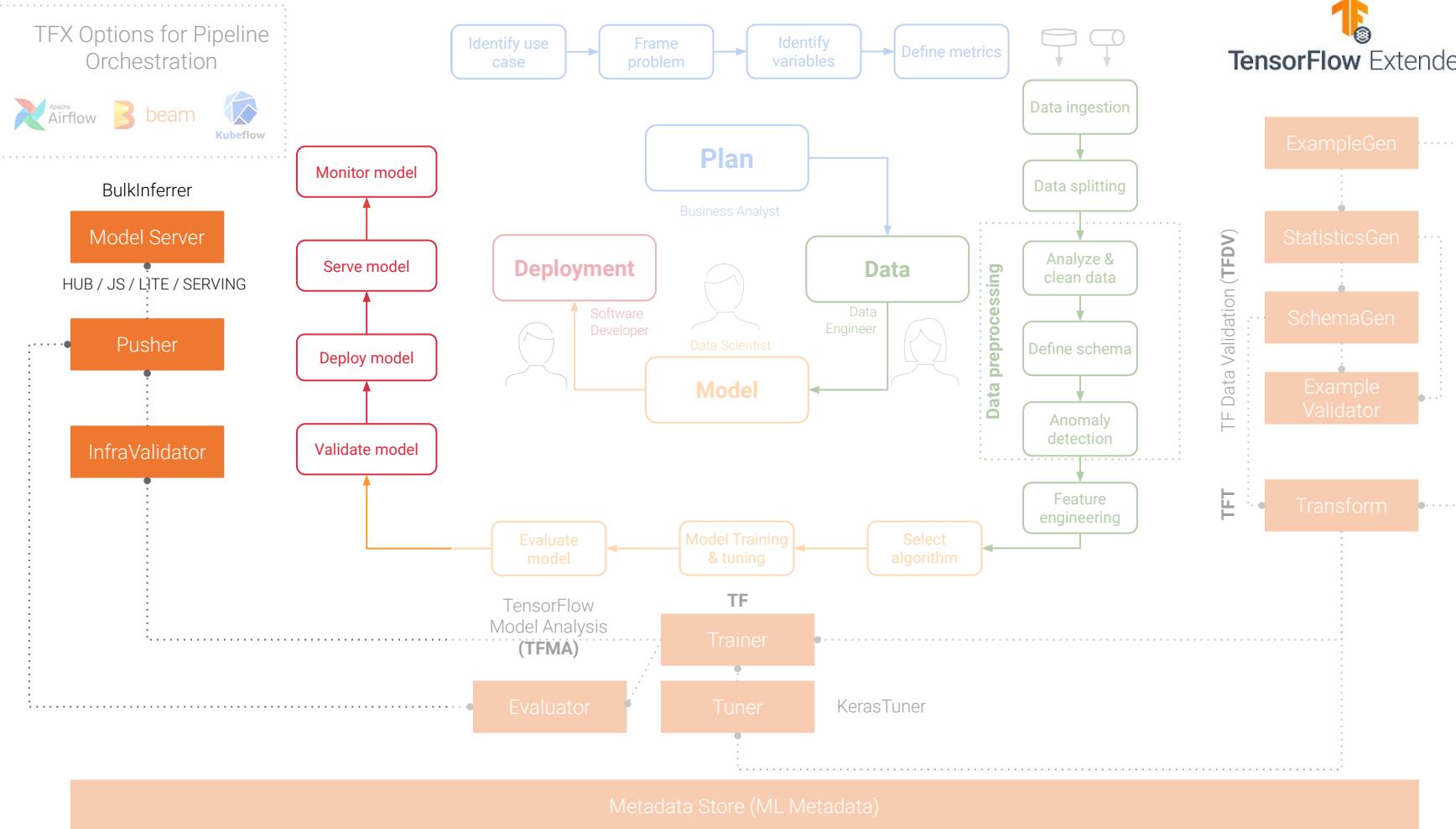
This section includes graphs displaying the class distribution for the "Race" and "Sex" attributes in our training dataset. We chose to show these graphs in particular because we felt it was important that users see the class imbalance.



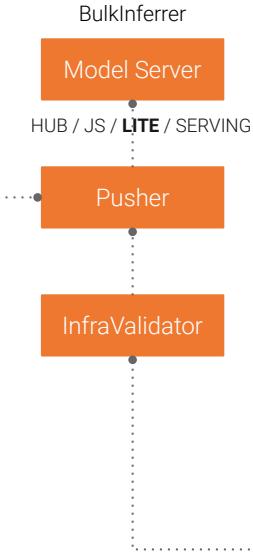
Eval Set

Like the training set, we provide graphs showing the class distribution of the data we used to evaluate our model's performance.

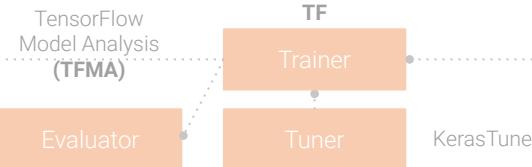




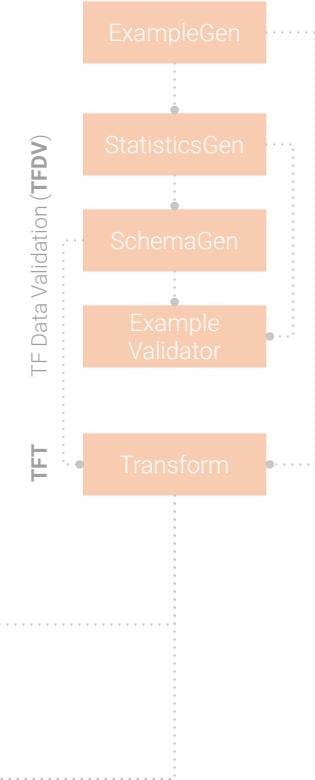
TFX Options for Pipeline Orchestration



TensorFlow Lite is a set of tools that enables on-device machine learning by helping developers run their models on mobile, embedded, and IoT devices.



Metadata Store (ML Metadata)



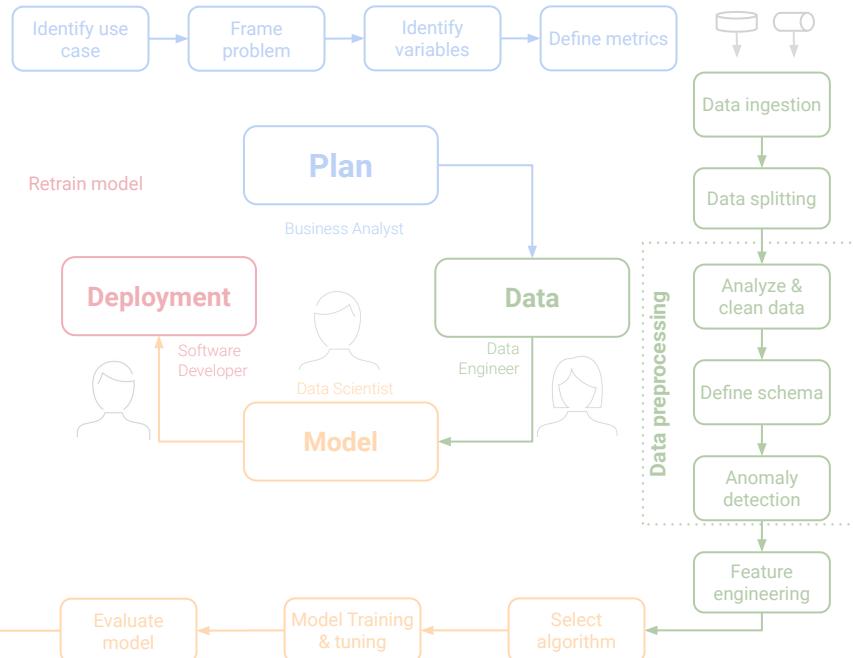


TFX Options for Pipeline Orchestration



Production phase:

automate the execution of the ML pipeline based on a schedule or certain triggering conditions.



Development phase: run the ML experiment, instead of manually executing each step.

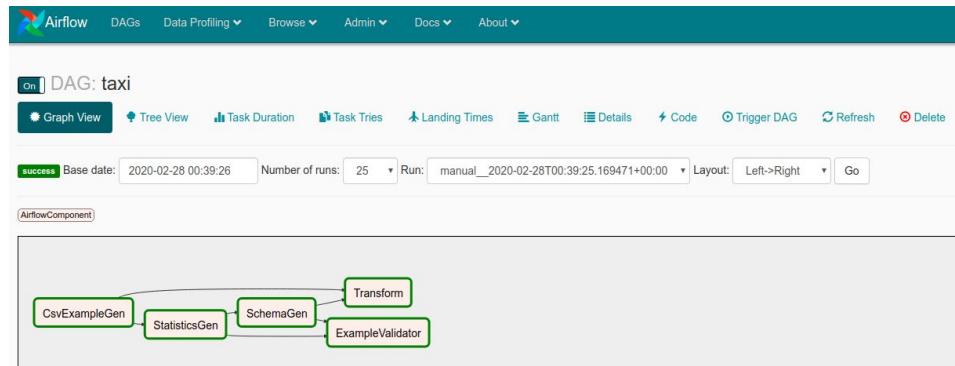


Pipeline orchestration

TFX & Apache Airflow



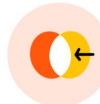
- Programmatically author, schedule and monitor workflows with **Python** code.
- **User interface** to visualize pipelines running in production, monitor progress, and troubleshoot issues.



TFX & Apache Beam



- Provides a framework for running **batch** and **streaming** data processing jobs that run on a variety of runners (Spark, Flink, ...).
- Beam provides an abstraction layer which enables TFX to run on any supported runner without code modifications
- TFX only uses the Beam **Python API**



Unified

Use a single programming model for both batch and streaming use cases.



Extensible

Write and share new SDKs, IO connectors, and transformation libraries.



Portable

Execute pipelines on multiple execution environments.



Open Source

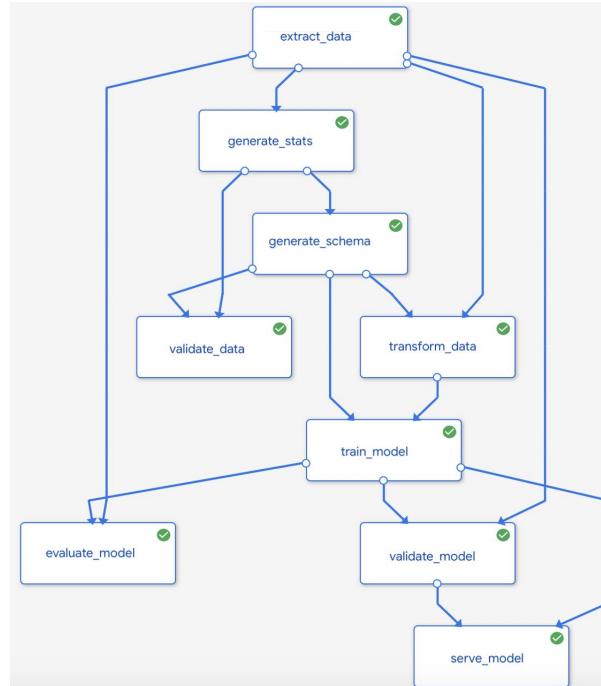
Community-based development and support to help evolve your application and use cases.

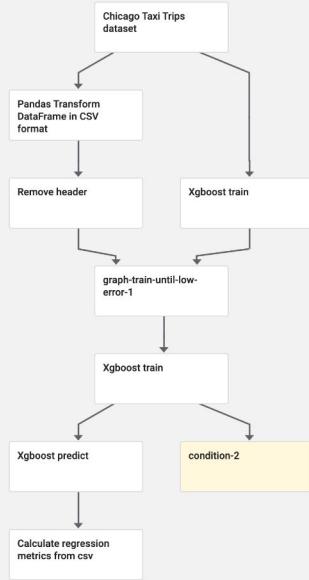
TFX & Kubeflow pipelines

The Kubeflow Pipelines platform consists of:

- An engine for scheduling multi-step ML workflows (using **Kubernetes**).
- **User interface** (UI) for managing and tracking experiments, jobs, and runs.
- **Python SDK** for defining and manipulating pipelines and components.
- **Notebooks** for interacting with the system using the SDK

Kubeflow Pipelines is available as a core component of Kubeflow or as a standalone installation.





Summary

Hide

ID
2a56d15a-7680-4c01-a4fb-1b8a52a8de94Version
[Demo] XGBoost - Iterative model training ▾

Version source

Uploaded on
1.7.2021, 08:36:13Description
source code This sample demonstrates iterative training using a train-eval-check recursive loop. The main pipeline trains the initial model and then gradually trains the model some more until the model evaluation metrics are good enough.

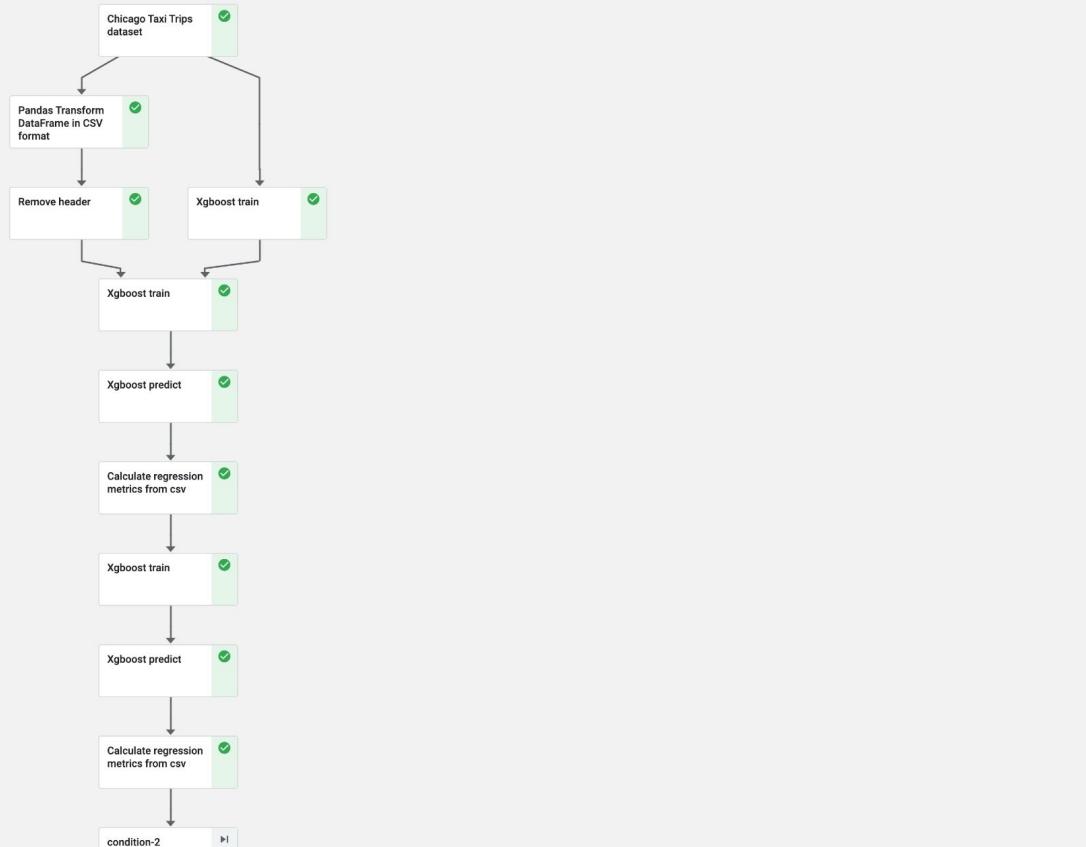
Static pipeline graph

Experiments > XGBoost-Kirenz-210701
← ✓ Run of [Demo] XGBoost - Iterative model training (025a6)

Retry Clone run Terminate Archive

Graph Run output Config

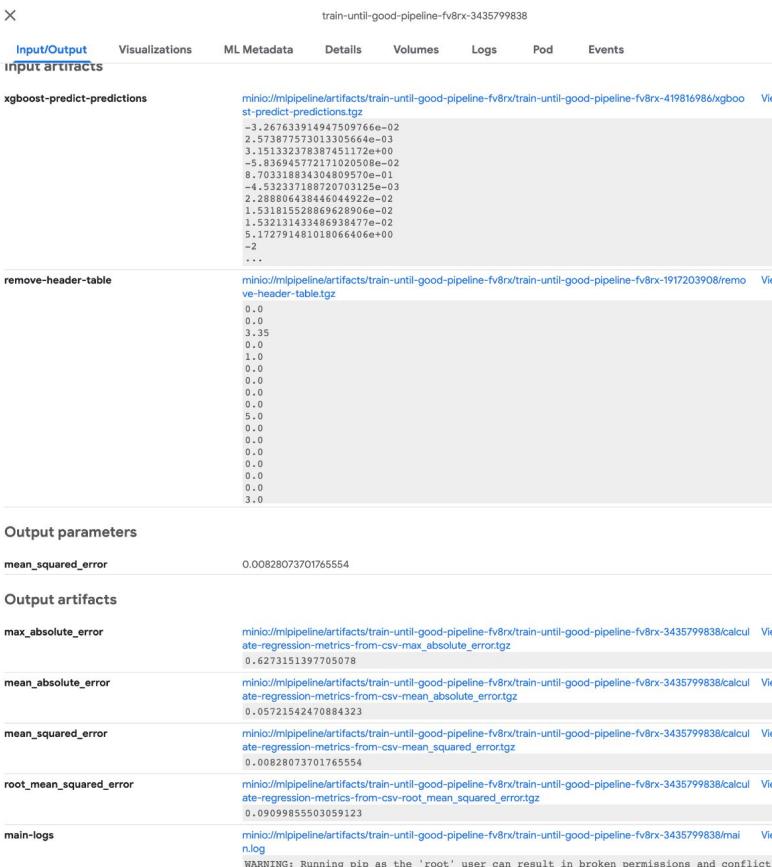
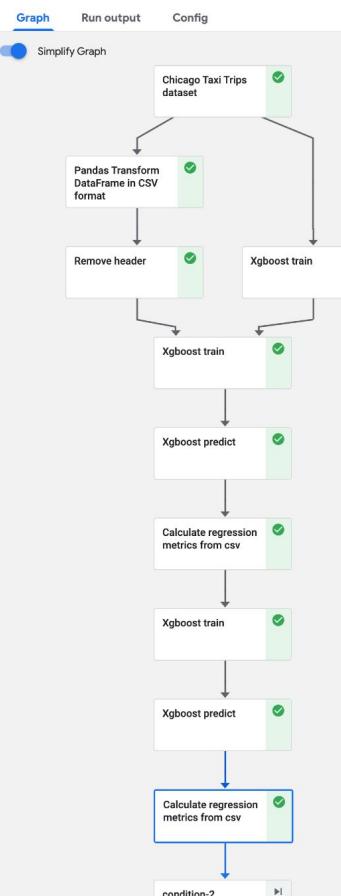
Simplify Graph



ⓘ Runtime execution graph. Only steps that are currently running or have already completed are shown.

Page 657 - 3408

[Retry](#) **Clone run** [Terminate](#) [Archiv](#)





Kubeflow

KubeFlow



TensorFlow
Extended



[Kubeflow on AWS](#)
[Kubeflow on Azure](#)
[Kubeflow on GCP](#)
[Kubeflow on IBM Cloud](#)
[Kubeflow Operator](#)
[Kubeflow on OpenShift](#)

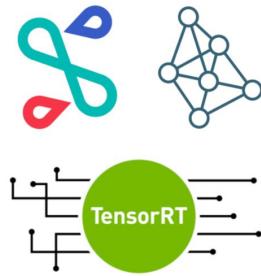
ML toolkit for Kubernetes



Notebooks



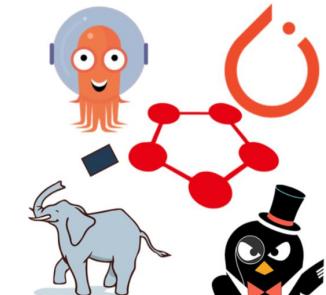
TensorFlow model training



Model serving



Pipelines



Multi-framework

Google's Vertex AI

Launched in May 2021



Google Cloud

Google Cloud Platform strikepose Search products and resources

Vertex AI

- Dashboard
- Datasets
- Features
- Labeling tasks
- Notebooks
- Pipelines
- Training
- Experiments
- Models
- Endpoints
- Batch predictions
- Metadata

Get started with Vertex AI

Vertex AI empowers machine learning developers, data scientists, and data engineers to take their projects from ideation to deployment, quickly and cost-effectively. [Learn more](#)

Region: us-central1 (Iowa)

Recent datasets:

- yogaposes (13 days ago)

+ CREATE DATASET

Recent models:

- yogaposes_202142173741 (12 days ago, Average precision: 0.9)

+ TRAIN NEW MODEL

Recent endpoints:

ONLINE TRAFFIC REQUESTS ERROR RATE

No data is available for the selected time frame.



ML Pipelines | wrap-up

By using a ML pipeline, you can:

- Automate your ML process, which lets you regularly retrain, evaluate, and deploy your model.
- Utilize distributed compute resources for processing large datasets and workloads.
- Increase the velocity of experimentation by running a pipeline with different sets of hyperparameters.

To learn more visit the following tutorials @:

<https://kirenz.github.io/>



MLOps tutorials on how to:

- Install TF and TFX
- Build your first TFX pipeline
- Install Kubeflow
- Build your first Kubeflow pipeline

Jan Kirenz

www.kirenz.com



Backup

Continuous Integration
and Continuous Delivery
pipeline for an ML/AI
project in Microsoft Azure



Azure DevOps



Azure Machine Learning

Continuous Integration
and Continuous Delivery
pipeline for an ML/AI
project in Microsoft Azure



Azure DevOps



Azure Boards



Azure Repos



Azure Pipelines



Azure Test Plans



Azure Artifacts

Plan, track, and discuss work across teams, deliver value to your users faster.

Unlimited cloud-hosted private Git repos. Collaborative pull requests. Advanced file management, and more.

CI/CD that works with any language, platform, and cloud. Connect to GitHub, GitLab, and any provider and deploy continuously to any cloud.

The test management and exploratory testing tool that lets you ship with confidence.

Create, host, and share packages. Easily add artifacts to CI/CD pipelines.



Timetracker



Docker Integration



Slack Integration



Sentry

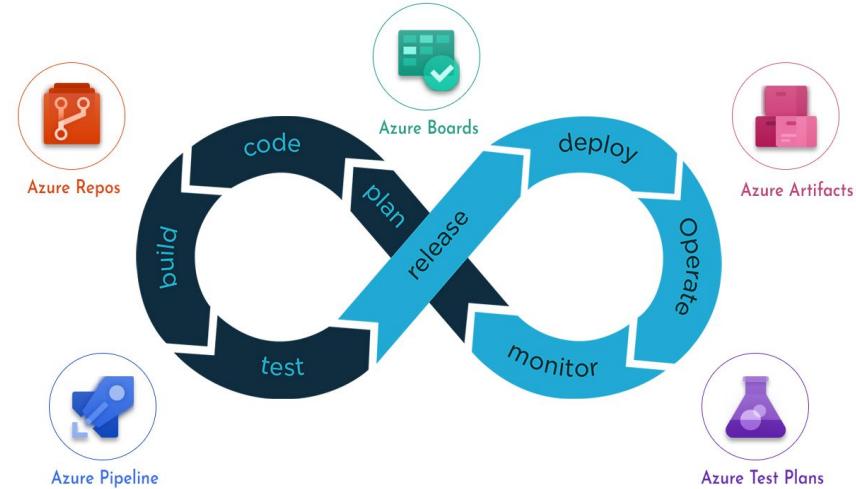


Github Integration

Extensions Marketplace

Access 1,000+ extensions or create your own.

[View all extensions >](#)



CI/CD and source code management



Azure Machine Learning

Microsoft Azure Machine Learning

milprod > Home

Azure Machine Learning studio

+ Create new

Notebooks Start now

Automated ML Start now

Designer Start now

My recent resources

Runs

Run	Run ID	Experiment	Status	Submitted time	Submitted by
Run 1	893f2c6e...	logging-a...	Completed		

Compute

Name: gpu-cluster

Navigation sidebar:

- New
- Home
- Author
- Notebooks
- Automated ML
- Designer
- Assets
- Datasets
- Experiments
- Pipelines
- Models
- Endpoints
- Manage
- Compute
- Datastores
- Data Labeling

Development tools



Languages



Frameworks



mlflow



Machine Learning for all skill levels

Productivity for all skill levels, with Jupyter notebooks, drag-and-drop [designer](#), and [automated machine learning](#).



End-to-end MLOps

Robust [MLOps](#) capabilities that enable creation and deployments of models at scale using automated and reproducible machine learning workflows.



Responsible machine learning innovation

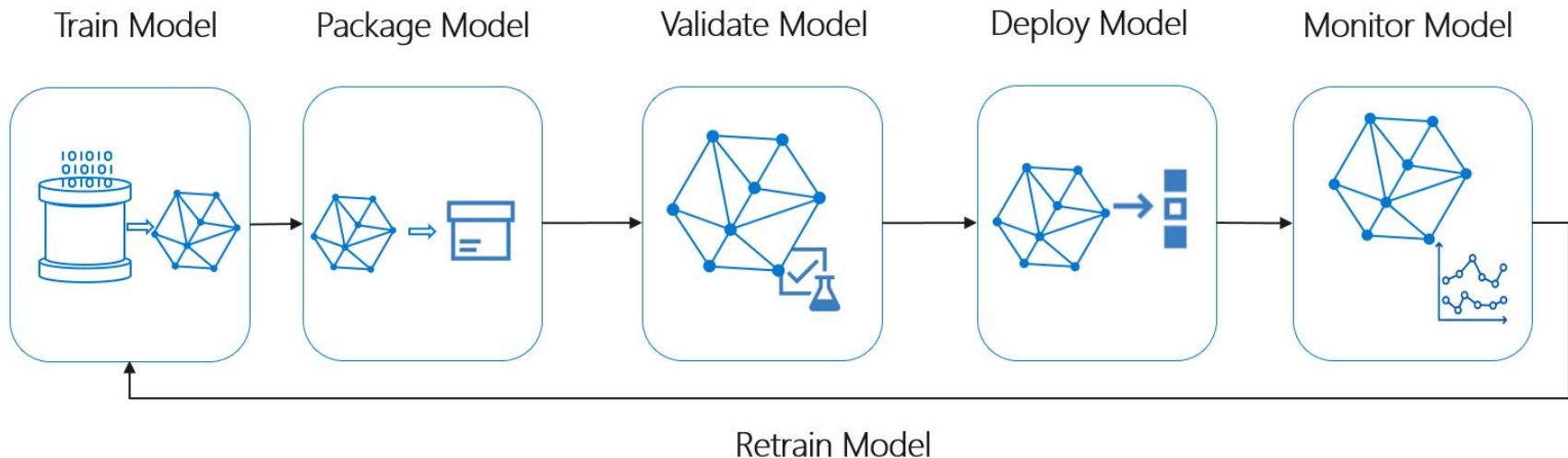
Rich set of built-in [responsible](#) capabilities to understand, protect, and control data, models and processes.

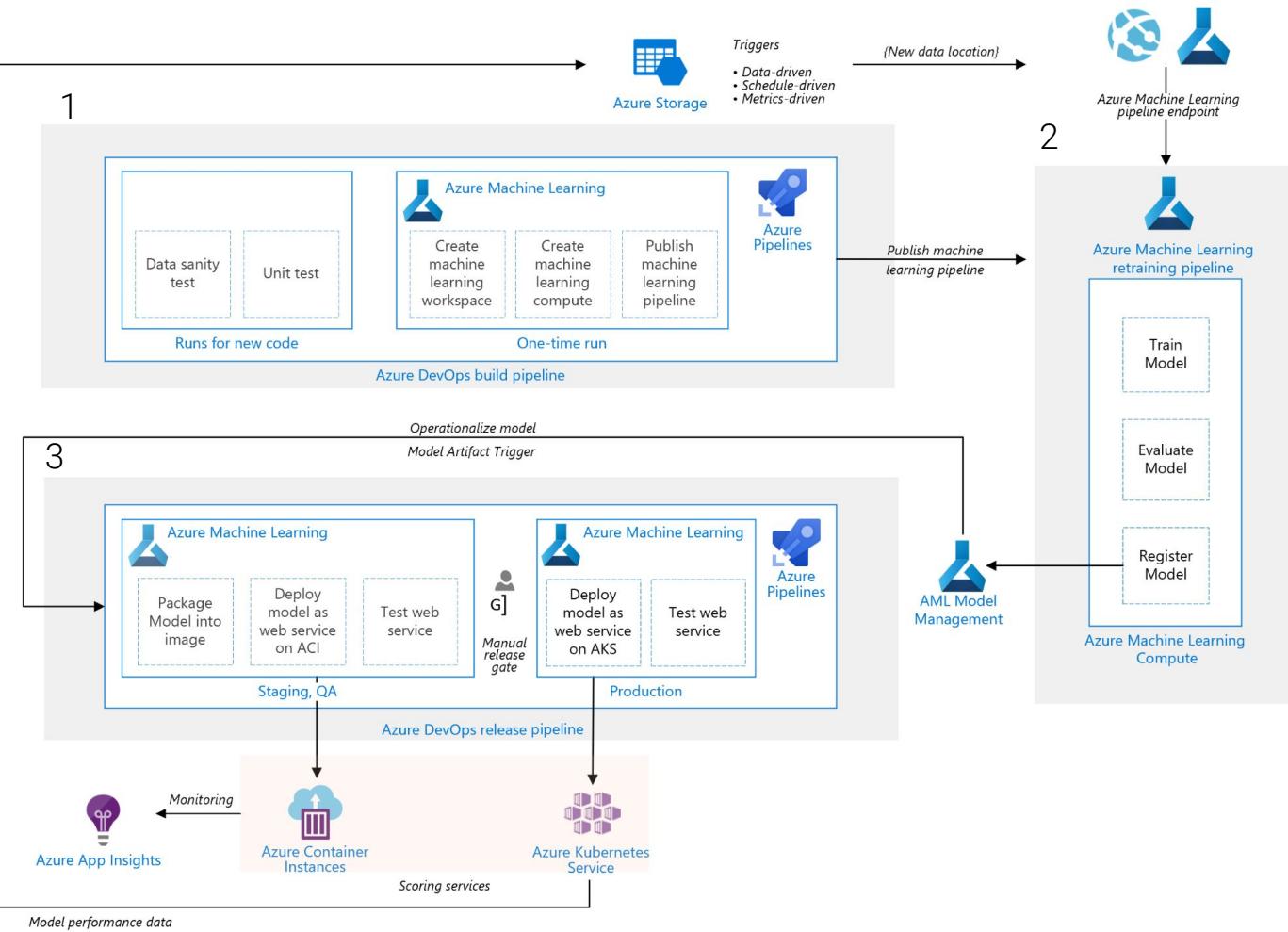


Open and interoperable

Best-in-class support for open-source frameworks and languages including MLflow, Kubeflow, ONNX, PyTorch, TensorFlow, Python, and R.

Cloud based machine learning service





Search or jump to... Watch 55 Unstar 561 Fork 581

[microsoft / MLOpsPython](#) Template

Code Issues 32 Pull requests 3 Actions Projects Wiki Security Insights

master 28 branches 115 tags Go to file Add file Code Use this template

j-so Pin AzureML SDK > 1.18.0 for pyyaml fix (#356) 2892688 on 11 Mar 421 commits

.pipelines Fix CD deployment break (#305) 10 months ago

bootstrap Update docs and pipeline status badge (#303) 10 months ago

charts Canary pipeline fixes (#224) 14 months ago

data Fix Batch Scoring docs (#333) 7 months ago

diabetes_regression Pin AzureML SDK > 1.18.0 for pyyaml fix (#356) 2 months ago

docs Added AKS compute name details (#355) 2 months ago

environment_setup Update docs and pipeline status badge (#303) 10 months ago

experimentation Making changes to experiment notebook based on changes to tutorial... 13 months ago

ml_service Fix default parameters to batch scoring pipeline + doc fixes (#310) 10 months ago

.env.example fix TRAIN_SCRIPT_PATH value in .env.example (#348) 3 months ago

.gitignore Manage environments in conda YAML files (#158) 15 months ago

LICENSE Initial commit 2 years ago

README.md Update docs and pipeline status badge (#303) 10 months ago

README.md

page_type	languages	products	description
sample	python	azure azure-machine-learning-service azure-devops	Code which demonstrates how to set up and operationalize an MLops flow leveraging Azure Machine Learning and Azure DevOps.

MLOps with Azure ML

Ci: Azure Pipelines Succeeded!

<https://github.com/Microsoft/MLOpsPython>

Prof. Dr. Jan Kirenz

MLOpsPython + Pipelines in your region may be impacted by a live site incident, resulting in possible pipeline delays. Check the status here.

Model CI Pipeline

← Jobs in run #20210406.1
kirenz.MLOpsPython (1)

Model CI

- Model CI Pipeline 2m 54s
 - Initialize job 3s
 - Initialize containers 1m 25s
 - Checkout kirenz/MLO... 1s
 - Run lint tests <1s
 - Run unit tests 1s
 - Publish test results 2s
 - Publish coverage report 2s
 - Publish Azure Ma... 1m 14s
 - Post-job: Checkout k... <1s
 - Stop Containers <1s
 - Finalize Job <1s

Train and evaluate model

- > Get Pipeline ID for e... 1m 31s
- > Trigger ML Trainin... 10m 13s
- ✓ Publish artifact if ne... 3m 2s
 - Initialize job 2s
 - Initialize containers 1m 57s
 - Checkout kirenz/MLO... 2s
 - Install AzureML CLI 30s

Project settings <

View raw log

MLOpsPython +

⚠ Pipelines in your region may be impacted by a live site incident, resulting in possible pipeline delays. Check the status here.

← Jobs in run #20210406.1

> Model CI Pipeline 2m 54s

Train and evaluate model

> Get Pipeline ID for e... 1m 31s

- Initialize job 2s
- Initialize containers 1m 13s
- Checkout kirenz/MLO... 2s
- Get Pipeline ID 11s
- Post-job: Checkout k... <1s
- Stop Containers <1s
- Finalize Job <1s

> Trigger ML Trainin... 10m 13s

- Invoke ML pipeli... 10m 13s

> Publish artifact if ne... 3m 2s

- Initialize job 2s
- Initialize containers 1m 57s
- Checkout kirenz/MLO... 2s
- Install AzureML CLI 30s
- Determine if evaluati... 20s
- PublishPipelineArtifact 7s
- Post-job: Checkout k... <1s
- Stop Containers 1s
- Finalize Job <1s

View raw log

```
1 Pool: Azure_Pipelines
2 Image: ubuntu-latest
3 Queued: Today at 10:34 [manage_parallel_jobs]
4 Agent: Hosted Agent
5 Started: Today at 10:34
6 Duration: 3m 2s
7
8 The agent request is already running or has already completed.
9 ▶ Job preparation parameters
10 □ 1 artifact produced
11 Job live console data:
12 Starting: Publish artifact if new model was registered
13 Finishing: Publish artifact if new model was registered
```

MLOpsPython



 Pipelines in your region may be impacted by a live site incident, resulting in possible pipeline delays. [Check the status here.](#)

Pipelines

[New pipeline](#)[Recent](#) [All](#) [Runs](#)[Filter pipelines](#)

Recently run pipelines

Pipeline

Last run

 Model-Train-Register-CI

#20210406.1 • Changed auto trigger

Manually triggered for  master

21m ago

18m 35s

 kirenz.MLOpsPython

#20210406.1 • Changed auto trigger

Manually triggered for  master

31m ago

1m 20s

- [!\[\]\(f64a028788a6d989618d1ecb1bb253f4_img.jpg\) Overview](#)
- [!\[\]\(561876cb256cadcfc61e02908072fd37_img.jpg\) Boards](#)
- [!\[\]\(3959dfa218288369ccf53b6d91b9de9b_img.jpg\) Repos](#)
- [!\[\]\(b2c847b99a1f91ef1c4f89f662aba1d9_img.jpg\) Pipelines](#)
- [!\[\]\(2a1910638c19ec6e4bbee6b5afcbcb36_img.jpg\) Environments](#)
- [!\[\]\(9f6c7928d98e1f9a723e8328eb2c75ff_img.jpg\) Releases](#)
- [!\[\]\(f413fde5b41b180a56bb821431876218_img.jpg\) Library](#)
- [!\[\]\(bacd88bac16f22670a236faf4088eb38_img.jpg\) Task groups](#)
- [!\[\]\(7e842447eb7289d47c6c07c7e082bf5a_img.jpg\) Deployment groups](#)
- [!\[\]\(9260b23c8df0131af4b428ed1ca21eb1_img.jpg\) Test Plans](#)
- [!\[\]\(35b7568f0cac88c8e4134c35a65c647a_img.jpg\) Artifacts](#)

- [MLOpsPython](#)
- [Overview](#)
- [Boards](#)
- [Repos](#)
- [Pipelines](#)
- [Pipelines](#)
- [Environments](#)
- [Releases](#)
- [Library](#)
- [Task groups](#)
- [Deployment groups](#)
- [Test Plans](#)
- [Artifacts](#)

Project settings Back

⚠ Pipelines in your region may be impacted by a live site incident, resulting in possible pipeline delays. [Check the status here.](#)

#20210406.1 Changed auto trigger

on Model-Train-Register-CI ✘ Retained

[Run new](#)

⋮

[Summary](#) [Tests](#) [Code Coverage](#)

Manually run by Jan Kirenz

[View change](#)

Repository and version

kirenz/MLOpsPython
master → c9d5976

Time started and elapsed

Today at 10:18
 18m 35s

Related

0 work items
 2 published

Tests and coverage

100% passed
 47.44% covered

Warnings 1

Please install dotnet core to enable automatic generation of Html report.
Model CI - Model CI Pipeline - Publish coverage report

[Stages](#) [Jobs](#)

Model CI

1 job completed 2m 57s
 100% tests passed
 1 artifact

Train and evaluate ...

3 jobs completed 15m 17s
 1 artifact
 Get Pipeline ID for exe...
 Trigger ML Training P...
 Publish artifact if new m...

[Rerun stage](#)



Home > Pipelines



Pipelines



Pipeline runs

Pipeline endpoints

Pipeline drafts



New pipeline

Refresh



Add filter



Run	Run ID	Experiment	Status	Description	Submitted time ↓
Run 1	f8ea2919-0b2b-4864-8550-fcd0b4b37ce9	mlopspython	Completed		Apr 6, 2021 10:23 AM



Microsoft Azure Machine Learning

Kostenlose Testversion mlops-AML-WS

Home > Modelle

Modellliste

+ Modell registrieren Löschen Bereitstellen Aktualisieren

+ Filter hinzufügen

Name	Version	Experiment	Ausführungs-ID	Erstellt am	Tags
diabetes_regression_model.pkl	1	--		6. Apr. 2021 10:33	area : diabetes_regression ...



M MLOpsPython +

- Overview
- Boards
- Repos
- Pipelines
- Pipelines
- Environments
- Releases
- Library
- Task groups
- Deployment groups
- Test Plans
- Artifacts

⚠ Pipelines in your region may be impacted by a live site incident, resulting in possible pipeline delays. [Check the status here.](#)

← Jobs in run #2021...

kirenz.MLOpsPython (1)

✓ Deploy to ACI



[View raw log](#)

Deploy to ACI

✓ [Deploy to ACI] 5m 25s

- ✓ Initialize job 2s
- ✓ Initialize co... 1m 20s
- ✓ Checkout kirenz.MLOpsPython 3s
- ✓ Download Pipeline 6s
- ✓ Parse Json for ... <1s
- ✓ Install AzureM... 30s
- ✓ Deploy to ACI 2m 57s
- ✓ Smoke test 21s
- ✓ Post-job: Check... <1s
- ✓ Stop Containers <1s
- ✓ Finalize Job <1s

1 Pool: [Azure Pipelines](#)

2 Image: Ubuntu16

3 Agent: Hosted Agent

4 Started: Today at 10:45

5 Duration: 5m 25s

6

7 ► Job preparation parameters

8 Job live console data:

9 Finishing: Deploy to ACI

MLOpsPython +

Overview

Boards

Repos

Pipelines

Pipelines

Environments

Releases

Library

Task groups

Deployment groups

Test Plans

Artifacts

Pipelines in your region may be impacted by a live site incident, resulting in possible pipeline delays. [Check the status here.](#)

#20210406.1 Changed auto trigger

on kirenz.MLOpsPython (1) ✘ Retained

[Run new](#)

Summary

Manually run by Jan Kirenz

[View 2 changes](#)

Repository and version

 kirenz/MLOpsPython
master ✘ c9d5976

Time started and elapsed

 Today at 10:45
 5m 32s

Related

 0 work items
 2 consumed

Tests and coverage

Warnings 1

Please use Download Build Artifact task for downloading Build Artifact type artifact. <https://docs.microsoft.com/en-us/azure/devops/pipelines/tasks/utility/download-build-artifacts?view=azure-devops&tabs=classic>
Deploy to ACI · Deploy to ACI · Download Pipeline Artifacts

Stages

Jobs

Deploy to ACI

1 job completed

5m 28s

Deploy to AKS

Skipped

Deploy to Webapp

Skipped

[Rerun stage](#)



End of Demo

Continuous Integration
and Continuous Delivery
pipeline for an ML/AI
project in Microsoft Azure