movie_data_eda_final

August 4, 2025

[13]:
```
# Cell 1: Import Libraries and Set Up Logging
import logging
import os
import time
import gzip
import requests
from dotenv import load_dotenv
import pandas as pd
from pyspark.sql import SparkSession
from pyspark.sql.functions import col, log, when, median, to_date, coalesce,␣
 ↪concat, lit
from pyspark.sql.types import StructType, StructField, IntegerType, StringType,␣
 ↪FloatType, TimestampType
from pyspark.ml.recommendation import ALS
from pyspark.ml.evaluation import RegressionEvaluator, RankingEvaluator
import tensorflow as tf
from tensorflow.keras.models import Model
from tensorflow.keras.layers import Input, Embedding, Flatten, Concatenate,␣
 ↪Dense, Dropout
import numpy as np
from datetime import datetime
```

[14]:
```
# Configure logging
logging.basicConfig(
    filename='recommendation_pipeline.log',
    level=logging.INFO,
    format='%(asctime)s - %(levelname)s - %(message)s',
    datefmt='%Y-%m-%d %H:%M:%S'
)
console = logging.StreamHandler()
console.setLevel(logging.INFO)
console.setFormatter(logging.Formatter(
    '%(asctime)s - %(levelname)s - %(message)s'))
logging.getLogger().addHandler(console)

# Load environment variables
load_dotenv()
```

```
TMDB_API_KEY = os.getenv('TMDB_API_KEY')
TMDB_API_READ_ACCESS_TOKEN = os.getenv('TMDB_API_READ_ACCESS_TOKEN')

# Set HADOOP_HOME for Windows
os.environ["HADOOP_HOME"] = "C:\\hadoop-3.3.6"
os.environ["hadoop.home.dir"] = "C:\\hadoop-3.3.6"

# Stop any existing Spark sessions
spark = SparkSession.getActiveSession()
if spark:
    spark.stop()
    logging.info("Stopped existing Spark session")

# Initialize Spark session
os.environ["PYSPARK_PYTHON"] = os.path.abspath(".venv/Scripts/python.exe")

spark = SparkSession.builder \
    .appName("CostAwareRecommendation") \
    .master("local[*]") \
    .config("spark.driver.memory", "8g") \
    .config("spark.pyspark.python", os.environ["PYSPARK_PYTHON"]) \
    .config("spark.driver.bindAddress", "127.0.0.1") \
    .config("spark.driver.host", "127.0.0.1") \
    .config("spark.driver.port", "25334") \
    .config("spark.ui.showConsoleProgress", "false") \
    .config("spark.driver.extraJavaOptions", "-Xss4m") \
    .config("spark.executor.extraJavaOptions", "-Xss4m") \
    .getOrCreate()
logging.info(f"Created Spark session: {spark.sparkContext.uiWebUrl}")

logging.info(
    "Spark session initialized, logging configured, and TMDb credentials loaded.
 ↪")
```

```
2025-08-04 12:34:25,625 - INFO - Created Spark session: http://127.0.0.1:4040
2025-08-04 12:34:25,625 - INFO - Created Spark session: http://127.0.0.1:4040
2025-08-04 12:34:25,628 - INFO - Spark session initialized, logging configured,
and TMDb credentials loaded.
2025-08-04 12:34:25,628 - INFO - Spark session initialized, logging configured,
and TMDb credentials loaded.
2025-08-04 12:34:25,625 - INFO - Created Spark session: http://127.0.0.1:4040
2025-08-04 12:34:25,628 - INFO - Spark session initialized, logging configured,
and TMDb credentials loaded.
2025-08-04 12:34:25,628 - INFO - Spark session initialized, logging configured,
and TMDb credentials loaded.
```

[4]:
```python
# Cell 2: Fetch Budget Data from TMDb API
def fetch_tmdb_budgets(links_df):
    try:
        # Convert links to Pandas for API calls
        links_pd = links_df.select("movieId", "tmdbId").toPandas()
        links_pd = links_pd[links_pd['tmdbId'].notnull()]

        budgets = []
        base_url = "https://api.themoviedb.org/3/movie/"
        headers = {"Authorization": f"Bearer {TMDB_API_READ_ACCESS_TOKEN}"}

        logging.info(
            f"Fetching budgets for {len(links_pd)} movies from TMDb...")
        for idx, row in links_pd.iterrows():
            tmdb_id = str(int(row['tmdbId']))
            url = f"{base_url}{tmdb_id}?api_key={TMDB_API_KEY}"
            response = requests.get(url, headers=headers)

            if response.status_code == 200:
                data = response.json()
                budgets.append({
                    'movieId': row['movieId'],
                    'tmdbId': tmdb_id,
                    'budget': data.get('budget', 0),
                    'release_date': data.get('release_date', '')
                })
            else:
                logging.warning(
                    f"Failed to fetch budget for tmdbId {tmdb_id}: {response.
 ↪status_code}")

            # Respect rate limit (50 requests/sec < 0.03 sec/request)
            time.sleep(0.03)

            if (idx + 1) % 100 == 0:
                logging.info(f"Processed {idx + 1} movies...")

        # Save budgets as CSV
        budgets_df = pd.DataFrame(budgets)
        budgets_df.to_csv("tmdb_budgets.csv", index=False)

        # Convert to Spark DataFrame
        budgets_spark = spark.createDataFrame(budgets_df)
        logging.info(f"Fetched and saved {len(budgets)} budgets from TMDb.")
        return budgets_spark
    except Exception as e:
        logging.error(f"Failed to fetch TMDb budgets: {str(e)}")
```

```
        raise
```

[5]:
```
def load_data_and_budgets():
    try:
        # Define schemas
        ratings_schema = StructType([
            StructField("userId", IntegerType(), False),
            StructField("movieId", IntegerType(), False),
            StructField("rating", FloatType(), False),
            StructField("timestamp", IntegerType(), False)
        ])
        movies_schema = StructType([
            StructField("movieId", IntegerType(), False),
            StructField("title", StringType(), False),
            StructField("genres", StringType(), True)
        ])
        links_schema = StructType([
            StructField("movieId", IntegerType(), False),
            StructField("imdbId", StringType(), True),
            StructField("tmdbId", StringType(), True)
        ])
        title_basics_schema = StructType([
            StructField("tconst", StringType(), False),
            StructField("titleType", StringType(), True),
            StructField("primaryTitle", StringType(), True),
            StructField("originalTitle", StringType(), True),
            StructField("isAdult", StringType(), True),
            StructField("startYear", StringType(), True),
            StructField("endYear", StringType(), True),
            StructField("runtimeMinutes", StringType(), True),
            StructField("genres", StringType(), True)
        ])

        # Load MovieLens data
        ratings_df = spark.read.schema(ratings_schema).csv(
            "ml-25m/ratings.csv", header=True)
        movies_df = spark.read.schema(movies_schema).csv(
            "ml-25m/movies.csv", header=True)
        links_df = spark.read.schema(links_schema).csv(
            "ml-25m/links.csv", header=True)

        # Load IMDb data
        basics_df = spark.read.schema(title_basics_schema).option(
            "delimiter", "\t").csv("imdb/title.basics.tsv.gz", header=True)

        # Check if budgets CSV exists
        budgets_path = os.path.abspath("tmdb_budgets.csv")
```

```
        if os.path.exists(budgets_path):
            logging.info("Loading budgets from existing CSV...")
            budgets_df = spark.read.csv(
                budgets_path, header=True, inferSchema=True)
        else:
            # Fetch TMDb budgets
            budgets_df = fetch_tmdb_budgets(links_df)
            # Ensure output directory exists
            os.makedirs(os.path.dirname(budgets_path), exist_ok=True)
            # Save budgets as CSV
            budgets_df.write.mode("overwrite").csv(budgets_path)

        # Format imdbId to match tconst (add 'tt' prefix)
        links_df = links_df.withColumn(
            "imdbId", concat(lit("tt"), col("imdbId")))

        logging.info("Loaded all datasets and budgets.")
        return ratings_df, movies_df, links_df, basics_df, budgets_df
    except Exception as e:
        logging.error(f"Failed to load data and budgets: {str(e)}")
        raise


# Check if DataFrames are already defined to avoid re-running
if 'ratings_df' not in globals() or 'movies_df' not in globals() or \
   'links_df' not in globals() or 'basics_df' not in globals() or \
   'budgets_df' not in globals():
    ratings_df, movies_df, links_df, basics_df, budgets_df =␣
 ↪load_data_and_budgets()
else:
    logging.info("DataFrames already loaded, skipping load_data_and_budgets.")
```

```
2025-08-04 00:51:16,636 - INFO - Loading budgets from existing CSV…
2025-08-04 00:51:22,036 - INFO - Loaded all datasets and budgets.
```

[6]:
```
def preprocess_data(ratings_df, movies_df, links_df, basics_df, budgets_df):
    try:
        # Log start of preprocessing
        logging.info(f"Starting preprocess_data at {time.time()}")

        # Validate input DataFrames
        logging.info("Validating input DataFrames...")
        for df, name in [(ratings_df, "ratings_df"), (movies_df, "movies_df"),
                         (links_df, "links_df"), (basics_df, "basics_df"),
                         (budgets_df, "budgets_df")]:
            if df is None:
                raise ValueError(f"{name} is None")
```

```
            df_count = df.count()
            logging.info(f"{name} has {df_count} rows")

        # Clean startYear by replacing '\N' with null in basics_df
        basics_df = basics_df.withColumn(
            "startYear",
            when(col("startYear") != "\\N", col("startYear")).otherwise(None)
        )

        # Merge datasets
        movies_df = (
            movies_df
            .join(links_df, "movieId", "inner")
            .join(
                basics_df.select(
                    col("tconst"),
                    col("primaryTitle"),
                    col("startYear"),
                    col("genres").alias("basics_genres")
                ),
                col("imdbId") == col("tconst"),
                "left"
            )
            .join(budgets_df, "movieId", "left")
            .filter(
                (col("startYear").isNotNull() & col("startYear").cast("int").
↪between(2000, 2025)) |
                (col("release_date").isNotNull() & to_date(
                    col("release_date")).cast("string").like("20[0-2][0-5]%"))
            )
            .select(
                col("movieId"),
                col("primaryTitle").alias("title"),
                coalesce(col("basics_genres"), col("genres")).alias("genres"),
                col("budget").cast("float"),
                to_date(col("release_date")).alias("release_date")
            )
        )

        # Remove sparse ratings
        movie_counts = ratings_df.groupBy(
            "movieId").count().filter(col("count") >= 10)
        ratings_df = ratings_df.join(movie_counts, "movieId")

        # Clean genres for consistent format
        movies_df = movies_df.withColumn(
            "genres",
```

```
            when(col("genres").isNotNull(), col(
                "genres")).otherwise(lit("Unknown"))
        )

        # Impute missing budgets
        genre_medians = movies_df.filter(col("budget") > 0).groupBy(
            "genres").agg(median("budget").alias("median_budget"))
        movies_df = movies_df.join(genre_medians, "genres", "left") \
            .withColumn("budget", coalesce(col("budget"), col("median_budget"),␣
↪lit(1))) \
            .drop("median_budget")

        # Normalize budgets
        movies_df = movies_df.withColumn(
            "budget_normalized",
            log(when(col("budget") > 0, col("budget")).otherwise(1))
        )

        # Save preprocessed data
        try:
            # Use absolute paths for Parquet files
            ratings_path = os.path.abspath("preprocessed_ratings")
            movies_path = os.path.abspath("preprocessed_movies")
            os.makedirs(ratings_path, exist_ok=True)
            os.makedirs(movies_path, exist_ok=True)

            # Validate DataFrames before writing
            logging.info(f"ratings_df schema: {ratings_df.schema}")
            logging.info(f"ratings_df sample: {ratings_df.show(5)}")
            logging.info(f"movies_df schema: {movies_df.schema}")
            logging.info(f"movies_df sample: {movies_df.show(5)}")

            # ratings_df.write.mode("overwrite").parquet(ratings_path)
            # movies_df.write.mode("overwrite").parquet(movies_path)
        except Exception as e:
            logging.error(f"Failed to save preprocessed data: {str(e)}")
            raise

        logging.info(
            f"Preprocessed {ratings_df.count()} ratings and {movies_df.count()}␣
↪movies.")
        return ratings_df, movies_df
    except Exception as e:
        logging.error(f"Failed to preprocess data: {str(e)}")
        raise
```

```
# Call the function
ratings_df, movies_df = preprocess_data(
    ratings_df, movies_df, links_df, basics_df, budgets_df)
```

```
2025-08-04 00:51:25,458 - INFO - Starting preprocess_data at 1754286685.4580612
2025-08-04 00:51:25,458 - INFO - Validating input DataFrames…

2025-08-04 00:51:29,203 - INFO - ratings_df has 33832162 rows
2025-08-04 00:51:29,563 - INFO - movies_df has 86537 rows
2025-08-04 00:51:29,776 - INFO - links_df has 86537 rows
2025-08-04 00:51:38,487 - INFO - basics_df has 11771649 rows
2025-08-04 00:51:38,699 - INFO - budgets_df has 85305 rows
2025-08-04 00:51:39,594 - INFO - ratings_df schema:
StructType([StructField('movieId', IntegerType(), True), StructField('userId',
IntegerType(), True), StructField('rating', FloatType(), True),
StructField('timestamp', IntegerType(), True), StructField('count', LongType(),
False)])
2025-08-04 00:52:13,003 - INFO - ratings_df sample: None
2025-08-04 00:52:13,004 - INFO - movies_df schema:
StructType([StructField('genres', StringType(), True), StructField('movieId',
IntegerType(), True), StructField('title', StringType(), True),
StructField('budget', DoubleType(), False), StructField('release_date',
DateType(), True), StructField('budget_normalized', DoubleType(), True)])

+-------+------+------+----------+-----+
|movieId|userId|rating| timestamp|count|
+-------+------+------+----------+-----+
|     28|   175|   5.0| 939073272| 3497|
|     28|   221|   4.0| 852284529| 3497|
|     28|   224|   3.0|1123310812| 3497|
|     28|   298|   4.0|1236927876| 3497|
|     28|   347|   3.0| 837372429| 3497|
+-------+------+------+----------+-----+
only showing top 5 rows

2025-08-04 00:53:06,361 - INFO - movies_df sample: None

+--------------------+-------+--------------------+---------+-----------+------
------------+
|              genres|movieId|               title|   budget|release_date|
budget_normalized|
+--------------------+-------+--------------------+---------+-----------+------
------------+
|       Drama,Fantasy| 167420|  Master i Margarita|      0.0|  1994-06-06|
0.0|
|Adventure,Animati…|   3751|         Chicken Run|    4.5E7|
2000-06-23|17.622173047734595|
|Biography,Drama,R…|   5791|               Frida|    1.2E7|
2002-08-29|16.300417207752275|
|Action,Adventure,…|  33493|Star Wars: Episod…|   1.13E8|
```

```
2005-05-17|18.542898376676614|
|Drama,Mystery,Rom…|   3457|     Waking the Dead|8500000.0|
2000-03-24|15.955576721460545|
+--------------------+-------+--------------------+---------+------------+------
------------+
only showing top 5 rows

2025-08-04 00:54:25,178 - INFO - Preprocessed 33677092 ratings and 50888 movies.
```

[7]:
```python
 # Split ratings into train (80%) and test (20%)
train_df, test_df = ratings_df.randomSplit([0.8, 0.2], seed=42)
train_count = train_df.count()
test_count = test_df.count()
print(f"Train set size: {train_count} rows")
print(f"Test set size: {test_count} rows")
```

```
Train set size: 26940320 rows
Test set size: 6736772 rows
```

[8]:
```python
# Cell 5: Build Matrix Factorization Model (ALS with Budget Weights)
def build_als_model(train_df, movies_df):
    try:
        # Merge budget with ratings
        ratings_with_budget = train_df.join(
            movies_df.select("movieId", "budget_normalized"), "movieId")

        # Train ALS model
        als = ALS(
            maxIter=10,
            regParam=0.1,
            userCol="userId",
            itemCol="movieId",
            ratingCol="rating",
            coldStartStrategy="drop",
            nonnegative=True
        )
        model = als.fit(ratings_with_budget)

        # Save model
        model.write().overwrite().save("als_model")
        logging.info("ALS model trained and saved.")
        return model
    except Exception as e:
        logging.error(f"Failed to build ALS model: {str(e)}")
        raise


als_model = build_als_model(train_df, movies_df)
```

```
2025-07-24 18:35:52,529 - INFO - ALS model trained and saved.
```

[9]:
```python
from pyspark.ml.tuning import CrossValidator, ParamGridBuilder
from pyspark.ml.evaluation import RegressionEvaluator
import logging


def build_als_model_with_cv(train_df, movies_df, num_folds=3):
    try:
        # Merge budget with ratings
        ratings_with_budget = train_df.join(
            movies_df.select("movieId", "budget_normalized"), "movieId")

        # Define ALS model
        als = ALS(
            userCol="userId",
            itemCol="movieId",
            ratingCol="rating",
            coldStartStrategy="drop",
            nonnegative=True
        )

        # Define evaluator (RMSE for regression)
        evaluator = RegressionEvaluator(
            metricName="rmse",
            labelCol="rating",
            predictionCol="prediction"
        )

        # Define parameter grid for hyperparameter tuning
        param_grid = ParamGridBuilder() \
            .addGrid(als.maxIter, [5, 10, 15]) \
            .addGrid(als.regParam, [0.01, 0.1, 0.5]) \
            .build()

        # Set up CrossValidator
        crossval = CrossValidator(
            estimator=als,
            estimatorParamMaps=param_grid,
            evaluator=evaluator,
            numFolds=num_folds,
            collectSubModels=True
        )

        # Train model with cross-validation
        cv_model = crossval.fit(ratings_with_budget)
```

```
        # Get the best model
        best_model = cv_model.bestModel

        # Log best parameters
        logging.info(
            f"Best maxIter: {best_model._java_obj.parent().getMaxIter()}")
        logging.info(
            f"Best regParam: {best_model._java_obj.parent().getRegParam()}")

        # Save best model
        best_model.write().overwrite().save("als_model_cv")
        logging.info("Best ALS model trained and saved.")
        return best_model
    except Exception as e:
        logging.error(f"Failed to build ALS model with CV: {str(e)}")
        raise


# Call the function
als_model_cv = build_als_model_with_cv(train_df, movies_df, num_folds=3)
```

```
2025-07-24 19:18:20,133 - INFO - Closing down clientserver connection
2025-07-24 19:18:20,234 - INFO - Best maxIter: 15
2025-07-24 19:18:20,281 - INFO - Best regParam: 0.1
2025-07-24 19:18:22,585 - INFO - Best ALS model trained and saved.
```

[10]:
```
# Cell 6: Build Neural Collaborative Filtering (NCF) Model
def build_ncf_model(train_df, movies_df):
    try:
        # Convert to Pandas for TensorFlow
        ratings_pd = train_df.join(movies_df.select(
            "movieId", "budget_normalized"), "movieId").toPandas()

        # Prepare data
        user_ids = ratings_pd["userId"].unique()
        movie_ids = ratings_pd["movieId"].unique()
        user_map = {id: idx for idx, id in enumerate(user_ids)}
        movie_map = {id: idx for idx, id in enumerate(movie_ids)}
        ratings_pd["user_idx"] = ratings_pd["userId"].map(user_map)
        ratings_pd["movie_idx"] = ratings_pd["movieId"].map(movie_map)
        max_budget = ratings_pd["budget_normalized"].max()

        # Define NCF model
        user_input = Input(shape=(1,), name="user")
        movie_input = Input(shape=(1,), name="movie")
        budget_input = Input(shape=(1,), name="budget")
```

```
        user_embedding = Embedding(len(user_ids), 50)(user_input)
        movie_embedding = Embedding(len(movie_ids), 50)(movie_input)
        budget_dense = Dense(10, activation="relu")(budget_input)

        user_flat = Flatten()(user_embedding)
        movie_flat = Flatten()(movie_embedding)
        concat = Concatenate()([user_flat, movie_flat, budget_dense])

        dense = Dense(128, activation="relu")(concat)
        dense = Dropout(0.2)(dense)
        output = Dense(1, activation="sigmoid")(dense)

        model = Model(inputs=[user_input, movie_input,
                              budget_input], outputs=output)
        model.compile(optimizer="adam", loss="mse")

        # Train model
        model.fit(
            [ratings_pd["user_idx"], ratings_pd["movie_idx"],
                ratings_pd["budget_normalized"] / max_budget],
            ratings_pd["rating"] / 5.0,
            epochs=10,
            batch_size=256,
            validation_split=0.2
        )

        # Save model
        model.save("ncf_model.h5")
        logging.info("NCF model trained and saved.")
        return model, user_map, movie_map
    except Exception as e:
        logging.error(f"Failed to build NCF model: {str(e)}")
        raise


ncf_model, user_map, movie_map = build_ncf_model(train_df, movies_df)
```

```
Epoch 1/10
35344/35344             1796s
51ms/step - loss: 0.0312 - val_loss: 0.0375
Epoch 2/10
35344/35344             1776s
50ms/step - loss: 0.0259 - val_loss: 0.0384
Epoch 3/10
35344/35344             1709s
48ms/step - loss: 0.0241 - val_loss: 0.0401
Epoch 4/10
35344/35344             1613s
```

```
46ms/step - loss: 0.0226 - val_loss: 0.0404
Epoch 5/10
35344/35344             2162s
61ms/step - loss: 0.0214 - val_loss: 0.0419
Epoch 6/10
35344/35344             2062s
58ms/step - loss: 0.0205 - val_loss: 0.0425
Epoch 7/10
35344/35344             1652s
47ms/step - loss: 0.0197 - val_loss: 0.0434
Epoch 8/10
35344/35344             1666s
47ms/step - loss: 0.0191 - val_loss: 0.0433
Epoch 9/10
35344/35344             1670s
47ms/step - loss: 0.0185 - val_loss: 0.0440
Epoch 10/10
35344/35344             1666s
47ms/step - loss: 0.0181 - val_loss: 0.0449

2025-07-25 00:30:50,706 - WARNING - You are saving your model as an HDF5 file
via `model.save()` or `keras.saving.save_model(model)`. This file format is
considered legacy. We recommend using instead the native Keras format, e.g.
`model.save('my_model.keras')` or `keras.saving.save_model(model,
'my_model.keras')`.
2025-07-25 00:30:51,189 - INFO - NCF model trained and saved.
```

[11]:
```python
def build_als_baseline_model(train_df, save_path="als_baseline_model"):
    """
    Train and save a baseline ALS model without budget information.

    Args:
        train_df: Spark DataFrame with userId, movieId, rating columns
        save_path: Path to save the trained model
    Returns:
        Trained ALS model
    """
    try:
        logging.info("Starting ALS baseline model training...")

        # Select relevant columns
        ratings_baseline = train_df.select("userId", "movieId", "rating")
        logging.info(f"Input data size: {ratings_baseline.count()} ratings")

        # Define ALS model
        als_baseline = ALS(
            maxIter=10,
            regParam=0.1,
```

```
            userCol="userId",
            itemCol="movieId",
            ratingCol="rating",
            coldStartStrategy="drop",
            nonnegative=True
        )

        # Train model
        logging.info("Fitting ALS baseline model...")
        als_baseline_model = als_baseline.fit(ratings_baseline)

        # Save model
        if os.path.exists(save_path):
            logging.warning(
                f"Model path {save_path} already exists, overwriting...")
        als_baseline_model.write().overwrite().save(save_path)
        logging.info(f"ALS baseline model saved to {save_path}")

        return als_baseline_model

    except Exception as e:
        logging.error(f"Failed to build ALS baseline model: {str(e)}")
        raise


# Call the function
als_baseline_model = build_als_baseline_model(train_df)
```

```
2025-07-25 00:30:51,242 - INFO - Starting ALS baseline model training…
2025-07-25 00:31:30,107 - INFO - Input data size: 26940320 ratings
2025-07-25 00:31:30,184 - INFO - Fitting ALS baseline model…
2025-07-25 00:33:35,221 - WARNING - Model path als_baseline_model already
exists, overwriting…
2025-07-25 00:33:36,534 - INFO - ALS baseline model saved to als_baseline_model
```

[12]:
```
def build_ncf_baseline_model(train_df, save_path="ncf_baseline_model.h5"):
    """
    Train and save a baseline NCF model without budget information.

    Args:
        train_df: Spark DataFrame with userId, movieId, rating columns
        save_path: Path to save the trained model
    Returns:
        Trained NCF model, user_map, movie_map
    """
    try:
        logging.info("Starting NCF baseline model training...")
```

```
        # Convert to Pandas
        ratings_pd = train_df.toPandas()
        logging.info(f"Input data size: {len(ratings_pd)} ratings")

        # Prepare data
        user_ids = ratings_pd["userId"].unique()
        movie_ids = ratings_pd["movieId"].unique()
        user_map = {id: idx for idx, id in enumerate(user_ids)}
        movie_map = {id: idx for idx, id in enumerate(movie_ids)}
        ratings_pd["user_idx"] = ratings_pd["userId"].map(user_map)
        ratings_pd["movie_idx"] = ratings_pd["movieId"].map(movie_map)
        logging.info(
            f"Number of unique users: {len(user_ids)}, movies:␣
↪{len(movie_ids)}")

        # Define NCF model
        user_input = Input(shape=(1,), name="user")
        movie_input = Input(shape=(1,), name="movie")
        user_embedding = Embedding(len(user_ids), 50)(user_input)
        movie_embedding = Embedding(len(movie_ids), 50)(movie_input)
        user_flat = Flatten()(user_embedding)
        movie_flat = Flatten()(movie_embedding)
        concat = Concatenate()([user_flat, movie_flat])
        dense = Dense(128, activation="relu")(concat)
        dense = Dropout(0.2)(dense)
        output = Dense(1, activation="sigmoid")(dense)

        model = Model(inputs=[user_input, movie_input], outputs=output)
        model.compile(optimizer="adam", loss="mse")
        logging.info("NCF baseline model architecture defined")

        # Train model
        logging.info("Fitting NCF baseline model...")
        model.fit(
            [ratings_pd["user_idx"], ratings_pd["movie_idx"]],
            ratings_pd["rating"] / 5.0,
            epochs=10,
            batch_size=256,
            validation_split=0.2,
            verbose=1
        )


        return model, user_map, movie_map

    except Exception as e:
```

```
        logging.error(f"Failed to build NCF baseline model: {str(e)}")
        raise


# Call the function
ncf_baseline_model, user_map_baseline, movie_map_baseline =␣
 ↪build_ncf_baseline_model(
    train_df)
```

```
2025-07-25 00:33:36,697 - INFO - Starting NCF baseline model training…
2025-07-25 00:38:36,269 - INFO - Input data size: 26940320 ratings
2025-07-25 00:38:38,017 - INFO - Number of unique users: 328892, movies: 32021
2025-07-25 00:38:38,887 - INFO - NCF baseline model architecture defined
2025-07-25 00:38:38,887 - INFO - Fitting NCF baseline model…

Epoch 1/10
84189/84189             5690s
68ms/step - loss: 0.0317 - val_loss: 0.0400
Epoch 2/10
84189/84189             5606s
67ms/step - loss: 0.0268 - val_loss: 0.0431
Epoch 3/10
84189/84189             5787s
69ms/step - loss: 0.0249 - val_loss: 0.0437
Epoch 4/10
84189/84189             5718s
68ms/step - loss: 0.0235 - val_loss: 0.0472
Epoch 5/10
84189/84189             5699s
68ms/step - loss: 0.0225 - val_loss: 0.0462
Epoch 6/10
84189/84189             6550s
78ms/step - loss: 0.0217 - val_loss: 0.0468
Epoch 7/10
84189/84189             6503s
77ms/step - loss: 0.0211 - val_loss: 0.0484
Epoch 8/10
84189/84189             5655s
67ms/step - loss: 0.0206 - val_loss: 0.0486
Epoch 9/10
84189/84189             5601s
67ms/step - loss: 0.0201 - val_loss: 0.0493
Epoch 10/10
84189/84189             5592s
66ms/step - loss: 0.0198 - val_loss: 0.0493
```

[14]:
```
# Save model
if os.path.exists("ncf_baseline_model.h5"):
```

```
    logging.warning(
        "Model path ncf_baseline_model.h5 already exists, overwriting...")
ncf_baseline_model.save("ncf_baseline_model.h5")
logging.info("NCF baseline model saved to ncf_baseline_model.h5")
```

```
2025-07-25 17:09:00,969 - WARNING - You are saving your model as an HDF5 file
via `model.save()` or `keras.saving.save_model(model)`. This file format is
considered legacy. We recommend using instead the native Keras format, e.g.
`model.save('my_model.keras')` or `keras.saving.save_model(model,
'my_model.keras')`.

2025-07-25 17:09:01,649 - INFO - NCF baseline model saved to
ncf_baseline_model.h5
```

[ ]:
```
from pyspark.sql import Window
from pyspark.sql.functions import col, row_number, collect_list, array_sort,␣
 ↪desc, expr

def evaluate_als_models(als_model, als_model_cv, als_baseline_model, test_df,␣
 ↪k=10, results_file="als_evaluation_results.txt"):
    """
    Evaluate ALS models (budget-aware, CV, and baseline) using RMSE,␣
 ↪precision@k, recall@k, and NDCG@k.

    Args:
        als_model_path: Path to saved budget-aware ALS model
        als_model_cv_path: Path to saved CV ALS model
        als_baseline_model: Trained baseline ALS model
        test_df: Spark DataFrame with test data
        k: Value for ranking metrics (default: 10)
        results_file: Path to save evaluation results
    """
    try:
        logging.info("Starting ALS models evaluation...")

        # Initialize evaluators
        rmse_evaluator = RegressionEvaluator(
            metricName="rmse", labelCol="rating", predictionCol="prediction"
        )
        ranking_evaluator = RankingEvaluator(
            predictionCol="prediction", labelCol="rating", k=k
        )

        # Compute ranking metrics function
        def compute_ranking_metrics(predictions, k=10):
            window = Window.partitionBy("userId").orderBy(col("prediction").
 ↪desc())
```

```
            pred_top_k = predictions.withColumn("rank", row_number().
↪over(window)) \
                .where(col("rank") <= k) \
                .groupBy("userId") \
                .agg(collect_list("movieId").alias("predicted_movies"))

            actual_top_k = predictions.where(col("rating") >= 4.0) \
                .groupBy("userId") \
                .agg(collect_list("movieId").alias("actual_movies"))

            ranking_df = pred_top_k.join(actual_top_k, on="userId",␣
↪how="inner") \
                .select(
                    expr("transform(predicted_movies, x -> cast(x as double))").
↪alias("prediction"),
                    expr("transform(actual_movies, x -> cast(x as double))").
↪alias("rating")
                )

            ranking_evaluator = RankingEvaluator(predictionCol="prediction",␣
↪labelCol="rating", k=k)
            precision_k = ranking_evaluator.setMetricName("precisionAtK").
↪evaluate(ranking_df)
            recall_k = ranking_evaluator.setMetricName("recallAtK").
↪evaluate(ranking_df)
            ndcg_k = ranking_evaluator.setMetricName("ndcgAtK").
↪evaluate(ranking_df)
            return precision_k, recall_k, ndcg_k

        # Evaluate ALS (budget-aware)
        logging.info("Evaluating budget-aware ALS model...")
        als_predictions = als_model.transform(test_df)
        als_rmse = rmse_evaluator.evaluate(als_predictions)
        als_precision, als_recall, als_ndcg = compute_ranking_metrics(
            als_predictions)
        logging.info(
            f"ALS RMSE: {als_rmse}, Precision@{k}: {als_precision}, Recall@{k}:␣
↪{als_recall}, NDCG@{k}: {als_ndcg}")

        # Evaluate ALS CV
        logging.info("Evaluating ALS CV model...")
        als_cv_predictions = als_model_cv.transform(test_df)
        als_cv_rmse = rmse_evaluator.evaluate(als_cv_predictions)
        als_cv_precision, als_cv_recall, als_cv_ndcg = compute_ranking_metrics(
            als_cv_predictions)
        logging.info(
```

```
            f"ALS CV RMSE: {als_cv_rmse}, Precision@{k}: {als_cv_precision},␣
↪Recall@{k}: {als_cv_recall}, NDCG@{k}: {als_cv_ndcg}")

        # Evaluate ALS baseline
        logging.info("Evaluating ALS baseline model...")
        als_baseline_predictions = als_baseline_model.transform(test_df)
        als_baseline_rmse = rmse_evaluator.evaluate(als_baseline_predictions)
        als_baseline_precision, als_baseline_recall, als_baseline_ndcg =␣
↪compute_ranking_metrics(
            als_baseline_predictions)
        logging.info(
            f"ALS Baseline RMSE: {als_baseline_rmse}, Precision@{k}:␣
↪{als_baseline_precision}, Recall@{k}: {als_baseline_recall}, NDCG@{k}:␣
↪{als_baseline_ndcg}")

        # Save results
        with open(results_file, "w") as f:
            f.write(
                f"ALS RMSE: {als_rmse}\nPrecision@{k}:␣
↪{als_precision}\nRecall@{k}: {als_recall}\nNDCG@{k}: {als_ndcg}\n")
            f.write(
                f"ALS CV RMSE: {als_cv_rmse}\nPrecision@{k}:␣
↪{als_cv_precision}\nRecall@{k}: {als_cv_recall}\nNDCG@{k}: {als_cv_ndcg}\n")
            f.write(
                f"ALS Baseline RMSE: {als_baseline_rmse}\nPrecision@{k}:␣
↪{als_baseline_precision}\nRecall@{k}: {als_baseline_recall}\nNDCG@{k}:␣
↪{als_baseline_ndcg}\n")
        logging.info(f"ALS evaluation results saved to {results_file}")

    except Exception as e:
        logging.error(f"Failed to evaluate ALS models: {str(e)}")
        raise


# Call the function
evaluate_als_models(
    als_model,
    als_model_cv,
    als_baseline_model,
    test_df=test_df
)
```

```
2025-07-25 19:15:42,629 - INFO - Starting ALS models evaluation…

2025-07-25 19:15:42,651 - INFO - Evaluating budget-aware ALS model…
2025-07-25 19:20:07,117 - INFO - ALS RMSE: 0.8027380664203994, Precision@10:
0.4434385788632965, Recall@10: 0.8338646700175392, NDCG@10: 0.8836108559971472
2025-07-25 19:20:07,369 - INFO - Evaluating ALS CV model…
```

```
2025-07-25 19:25:01,769 - INFO - ALS CV RMSE: 0.7986708117672686, Precision@10:
0.4438688359870148, Recall@10: 0.8341365775660732, NDCG@10: 0.8842670488375413
2025-07-25 19:25:01,860 - INFO - Evaluating ALS baseline model…
2025-07-25 19:30:23,919 - INFO - ALS Baseline RMSE: 0.818098461609045,
Precision@10: 0.4994386689880877, Recall@10: 0.7854035140796781, NDCG@10:
0.8788548384043531
2025-07-25 19:30:24,026 - INFO - ALS evaluation results saved to
als_evaluation_results.txt
```

[ ]:
```python
import pickle

# Save
with open("user_map.pkl", "wb") as f:
    pickle.dump(user_map, f)
with open("movie_map.pkl", "wb") as f:
    pickle.dump(movie_map, f)
with open("user_map_baseline.pkl", "wb") as f:
    pickle.dump(user_map_baseline, f)
with open("movie_map_baseline.pkl", "wb") as f:
    pickle.dump(movie_map_baseline, f)
```

[ ]:
```python
# Save
train_df.write.mode("overwrite").parquet("train_df.parquet")
test_df.write.mode("overwrite").parquet("test_df.parquet")
movies_df.write.mode("overwrite").parquet("movies_df.parquet")
```

[1]:
```python
import pickle
with open("user_map.pkl", "rb") as f:
    user_map = pickle.load(f)
with open("movie_map.pkl", "rb") as f:
    movie_map = pickle.load(f)
with open("user_map_baseline.pkl", "rb") as f:
    user_map_baseline = pickle.load(f)
with open("movie_map_baseline.pkl", "rb") as f:
    movie_map_baseline = pickle.load(f)

print(f"user_map length: {len(user_map)}")
print(f"movie_map length: {len(movie_map)}")
print(f"user_map_baseline length: {len(user_map_baseline)}")
print(f"movie_map_baseline length: {len(movie_map_baseline)}")
```

```
user_map length: 221652
movie_map length: 19108
user_map_baseline length: 328892
movie_map_baseline length: 32021
```

[7]:
```python
import logging
import pandas as pd
```

```
import numpy as np
from tensorflow.keras.models import load_model
from sklearn.metrics import mean_squared_error
from pyspark.sql.functions import col
from pyspark.ml.evaluation import RankingEvaluator
import os
from pyspark.sql import Window
from pyspark.sql.functions import col, row_number, collect_list, array_sort,␣
 ↪desc, expr

import pickle
ncf_model = load_model("ncf_model.h5", compile =False)
ncf_baseline_model = load_model("ncf_baseline_model.h5", compile=False)

with open("user_map.pkl", "rb") as f:
    user_map = pickle.load(f)
with open("movie_map.pkl", "rb") as f:
    movie_map = pickle.load(f)
with open("user_map_baseline.pkl", "rb") as f:
    user_map_baseline = pickle.load(f)
with open("movie_map_baseline.pkl", "rb") as f:
    movie_map_baseline = pickle.load(f)
test_df = test_df.repartition(50)

def evaluate_ncf_models(ncf_model, ncf_baseline_model, user_map, movie_map,␣
 ↪user_map_baseline, movie_map_baseline, test_df, movies_df, k=10,␣
 ↪results_file="ncf_evaluation_results.txt"):
    """
    Evaluate NCF models (budget-aware and baseline) using RMSE, precision@k,␣
 ↪recall@k, and NDCG@k.

    Args:
        ncf_model_path: Path to saved budget-aware NCF model0
        ncf_baseline_model: Trained baseline NCF model
        user_map: Mapping for budget-aware model user IDs
        movie_map: Mapping for budget-aware model movie IDs
        user_map_baseline: Mapping for baseline model user IDs
        movie_map_baseline: Mapping for baseline model movie IDs
        test_df: Spark DataFrame with test data
        movies_df: Spark DataFrame with movie data
        k: Value for ranking metrics (default: 10)
        results_file: Path to save evaluation results
    """
    try:
        logging.info("Starting NCF models evaluation...")
        # Load models
```

```
        # Convert test data to Pandas
        test_pd = test_df.join(movies_df.select(
            "movieId", "budget_normalized"), "movieId").toPandas()
        logging.info(f"Test data size: {len(test_pd)} ratings")
        test_pd["user_idx"] = test_pd["userId"].map(user_map)
        test_pd["movie_idx"] = test_pd["movieId"].map(movie_map)
        test_pd["user_idx_baseline"] = test_pd["userId"].map(user_map_baseline)
        test_pd["movie_idx_baseline"] = test_pd["movieId"].map(
            movie_map_baseline)


        # Filter out rows with missing indices
        test_pd = test_pd.dropna(subset=["user_idx", "movie_idx",␣
↪"user_idx_baseline", "movie_idx_baseline"])

        # Convert indices to int for TensorFlow compatibility
        test_pd["user_idx"] = test_pd["user_idx"].astype(int)
        test_pd["movie_idx"] = test_pd["movie_idx"].astype(int)
        test_pd["user_idx_baseline"] = test_pd["user_idx_baseline"].astype(int)
        test_pd["movie_idx_baseline"] = test_pd["movie_idx_baseline"].
↪astype(int)


        # Evaluate NCF (budget-aware)
        logging.info("Evaluating budget-aware NCF model...")
        ncf_predictions = ncf_model.predict(
            [test_pd["user_idx"], test_pd["movie_idx"],
                test_pd["budget_normalized"] / test_pd["budget_normalized"].
↪max()],
            batch_size=256,
            verbose=1
        )
        ncf_rmse = np.sqrt(mean_squared_error(
            test_pd["rating"], ncf_predictions.flatten() * 5.0))

        # Evaluate NCF baseline
        logging.info("Evaluating NCF baseline model...")
        ncf_baseline_predictions = ncf_baseline_model.predict(
            [test_pd["user_idx_baseline"], test_pd["movie_idx_baseline"]],
            batch_size=256,
            verbose=1
        )
        ncf_baseline_rmse = np.sqrt(mean_squared_error(
            test_pd["rating"], ncf_baseline_predictions.flatten() * 5.0))

        # Compute ranking metrics
        def compute_ncf_ranking_metrics(predictions, test_pd, spark, k=k):
```

```
            # Create DataFrame with predictions
            pred_df = pd.DataFrame({
                "userId": test_pd["userId"],
                "movieId": test_pd["movieId"],
                "rating": test_pd["rating"],
                "prediction": predictions.flatten() * 5.0
            })
            spark_pred_df = spark.createDataFrame(pred_df)

            # Get top-k predicted movies per user
            window = Window.partitionBy("userId").orderBy(col("prediction").
↪desc())
            pred_top_k = spark_pred_df.withColumn("rank", row_number().
↪over(window)) \
                .where(col("rank") <= k) \
                .groupBy("userId") \
                .agg(collect_list("movieId").alias("predicted_movies"))

            # Get actual relevant movies per user (e.g., rating >= 4.0)
            actual_top_k = spark_pred_df.where(col("rating") >= 4.0) \
                .groupBy("userId") \
                .agg(collect_list("movieId").alias("actual_movies"))

            # Join and cast to array<double>
            ranking_df = pred_top_k.join(actual_top_k, on="userId",␣
↪how="inner") \
                .select(
                    expr("transform(predicted_movies, x -> cast(x as double))").
↪alias("prediction"),
                    expr("transform(actual_movies, x -> cast(x as double))").
↪alias("rating")
                )

            ranking_evaluator = RankingEvaluator(predictionCol="prediction",␣
↪labelCol="rating", k=k)
            precision_k = ranking_evaluator.setMetricName("precisionAtK").
↪evaluate(ranking_df)
            recall_k = ranking_evaluator.setMetricName("recallAtK").
↪evaluate(ranking_df)
            ndcg_k = ranking_evaluator.setMetricName("ndcgAtK").
↪evaluate(ranking_df)
            return precision_k, recall_k, ndcg_k

        logging.info("Computing ranking metrics for NCF...")
        ncf_precision, ncf_recall, ncf_ndcg = compute_ncf_ranking_metrics(
            ncf_predictions, test_pd, test_df.sparkSession)
```

```
        logging.info(
            f"NCF RMSE: {ncf_rmse}, Precision@{k}: {ncf_precision}, Recall@{k}:␣
↪{ncf_recall}, NDCG@{k}: {ncf_ndcg}")

        logging.info("Computing ranking metrics for NCF baseline...")
        ncf_baseline_precision, ncf_baseline_recall, ncf_baseline_ndcg =␣
↪compute_ncf_ranking_metrics(
            ncf_baseline_predictions, test_pd, test_df.sparkSession)
        logging.info(
            f"NCF Baseline RMSE: {ncf_baseline_rmse}, Precision@{k}:␣
↪{ncf_baseline_precision}, Recall@{k}: {ncf_baseline_recall}, NDCG@{k}:␣
↪{ncf_baseline_ndcg}")

        # Save results
        with open(results_file, "w") as f:
            f.write(
                f"NCF RMSE: {ncf_rmse}\nPrecision@{k}:␣
↪{ncf_precision}\nRecall@{k}: {ncf_recall}\nNDCG@{k}: {ncf_ndcg}\n")
            f.write(
                f"NCF Baseline RMSE: {ncf_baseline_rmse}\nPrecision@{k}:␣
↪{ncf_baseline_precision}\nRecall@{k}: {ncf_baseline_recall}\nNDCG@{k}:␣
↪{ncf_baseline_ndcg}\n")
        logging.info(f"NCF evaluation results saved to {results_file}")

    except Exception as e:
        logging.error(f"Failed to evaluate NCF models: {str(e)}")
        raise


# Call the function
evaluate_ncf_models(
    ncf_model,
    ncf_baseline_model,
    user_map,
    movie_map,
    user_map_baseline,
    movie_map_baseline,
    test_df,
    movies_df
)
```

```
2025-08-02 19:58:51,018 - INFO - Starting NCF models evaluation…
2025-08-02 20:00:20,622 - INFO - Test data size: 2828066 ratings
2025-08-02 20:00:21,650 - INFO - Evaluating budget-aware NCF model…
```

```
11024/11024             21s 2ms/step
```

```
2025-08-02 20:00:48,235 - INFO - Evaluating NCF baseline model…
```

```
11024/11024             32s 3ms/step

2025-08-02 20:01:28,894 - INFO - Computing ranking metrics for NCF…
2025-08-02 20:06:38,186 - INFO - NCF RMSE: 0.8467916130875904, Precision@10:
0.4350195805637138, Recall@10: 0.8241554161915556, NDCG@10: 0.8673054665417687
2025-08-02 20:06:38,186 - INFO - Computing ranking metrics for NCF baseline…
2025-08-02 20:09:15,163 - INFO - NCF Baseline RMSE: 0.8458766979382569,
Precision@10: 0.4363805585613429, Recall@10: 0.8252542085592518, NDCG@10:
0.8713218084278783
2025-08-02 20:09:15,165 - INFO - NCF evaluation results saved to
ncf_evaluation_results.txt
```

[9]:
```
test_df.show(5)
movies_df.show(5)
```

```
+-------+------+------+----------+-----+
|movieId|userId|rating| timestamp|count|
+-------+------+------+----------+-----+
|     28|   224|   3.0|1123310812| 3497|
|     28|   388|   4.0| 950162252| 3497|
|     28|   663|   4.0|1120519874| 3497|
|     28|  1617|   4.5|1505372662| 3497|
|     28|  1821|   4.0| 943907496| 3497|
+-------+------+------+----------+-----+
only showing top 5 rows
+--------------------+-------+--------------------+---------+------------+------
------------+
|              genres|movieId|               title|   budget|release_date|
budget_normalized|
+--------------------+-------+--------------------+---------+------------+------
------------+
|       Drama,Fantasy| 167420|  Master i Margarita|      0.0|  1994-06-06|
0.0|
|Adventure,Animati…|   3751|         Chicken Run|    4.5E7|
2000-06-23|17.622173047734595|
|Biography,Drama,R…|   5791|               Frida|    1.2E7|
2002-08-29|16.300417207752275|
|Action,Adventure,…|  33493|Star Wars: Episod…|   1.13E8|
2005-05-17|18.542898376676614|
|Drama,Mystery,Rom…|   3457|     Waking the Dead|8500000.0|
2000-03-24|15.955576721460545|
+--------------------+-------+--------------------+---------+------------+------
------------+
only showing top 5 rows
```

[11]:
```
import logging
import pandas as pd
import numpy as np
```

```
from tensorflow.keras.models import load_model
from scipy.stats import ttest_rel
from pyspark.sql.functions import col, when
import os
from pyspark.ml.recommendation import ALSModel

import pickle
ncf_model = load_model("ncf_model.h5", compile=False)
ncf_baseline_model = load_model("ncf_baseline_model.h5", compile=False)
# Load the ALS models
als_model = ALSModel.load("als_model")
als_baseline_model = ALSModel.load("als_baseline_model")
als_model_cv = ALSModel.load("als_model_cv")


with open("user_map.pkl", "rb") as f:
    user_map = pickle.load(f)
with open("movie_map.pkl", "rb") as f:
    movie_map = pickle.load(f)
with open("user_map_baseline.pkl", "rb") as f:
    user_map_baseline = pickle.load(f)
with open("movie_map_baseline.pkl", "rb") as f:
    movie_map_baseline = pickle.load(f)
test_df = test_df.repartition(50)

def statistical_and_fairness_analysis(
    als_model, als_model_cv, als_baseline_model, ncf_model, ncf_baseline_model,
    user_map, movie_map, user_map_baseline, movie_map_baseline,
    test_df, movies_df, sample_size=1000,␣
 ↪results_file="statistical_fairness_results.txt"
):
    try:
        logging.info("Starting statistical and fairness analysis...")

        als_predictions = als_model.transform(test_df)
        als_cv_predictions = als_model_cv.transform(test_df)
        als_baseline_predictions = als_baseline_model.transform(test_df)

        test_pd = test_df.join(movies_df.select(
            "movieId", "budget_normalized"), "movieId").toPandas()
        test_pd["user_idx"] = test_pd["userId"].map(user_map)
        test_pd["movie_idx"] = test_pd["movieId"].map(movie_map)
        test_pd["user_idx_baseline"] = test_pd["userId"].map(user_map_baseline)
        test_pd["movie_idx_baseline"] = test_pd["movieId"].map(
            movie_map_baseline)
```

```
        # Drop any rows where mapping failed
        test_pd = test_pd.dropna(subset=[
        "user_idx", "movie_idx", "user_idx_baseline", "movie_idx_baseline"
        ])

        # Ensure integer indices for embedding layers
        test_pd["user_idx"] = test_pd["user_idx"].astype(int)
        test_pd["movie_idx"] = test_pd["movie_idx"].astype(int)
        test_pd["user_idx_baseline"] = test_pd["user_idx_baseline"].astype(int)
        test_pd["movie_idx_baseline"] = test_pd["movie_idx_baseline"].
↪astype(int)

        ncf_predictions = ncf_model.predict(
            [test_pd["user_idx"], test_pd["movie_idx"],
             test_pd["budget_normalized"] / test_pd["budget_normalized"].max()],
            batch_size=256,
            verbose=1
        )
        ncf_baseline_predictions = ncf_baseline_model.predict(
            [test_pd["user_idx_baseline"], test_pd["movie_idx_baseline"]],
            batch_size=256,
            verbose=1
        )

        logging.info(
            f"Performing paired t-tests with sample size {sample_size}...")
        als_errors = als_predictions.select(
            (col("rating") - col("prediction")).alias("error")).rdd.map(lambda␣
↪x: x.error).collect()
        als_cv_errors = als_cv_predictions.select(
            (col("rating") - col("prediction")).alias("error")).rdd.map(lambda␣
↪x: x.error).collect()
        als_baseline_errors = als_baseline_predictions.select(
            (col("rating") - col("prediction")).alias("error")).rdd.map(lambda␣
↪x: x.error).collect()
        ncf_errors = (test_pd["rating"] -
                      ncf_predictions.flatten() * 5.0).tolist()
        ncf_baseline_errors = (
            test_pd["rating"] - ncf_baseline_predictions.flatten() * 5.0).
↪tolist()

        sample_size = min(sample_size, len(als_errors), len(als_cv_errors), len(
            als_baseline_errors), len(ncf_errors), len(ncf_baseline_errors))
        als_errors = als_errors[:sample_size]
        als_cv_errors = als_cv_errors[:sample_size]
        als_baseline_errors = als_baseline_errors[:sample_size]
        ncf_errors = ncf_errors[:sample_size]
```

```
        ncf_baseline_errors = ncf_baseline_errors[:sample_size]

        comparisons = [
            ("ALS vs ALS CV", als_errors, als_cv_errors),
            ("ALS vs ALS Baseline", als_errors, als_baseline_errors),
            ("ALS vs NCF", als_errors, ncf_errors),
            ("ALS CV vs ALS Baseline", als_cv_errors, als_baseline_errors),
            ("ALS CV vs NCF", als_cv_errors, ncf_errors),
            ("ALS Baseline vs NCF", als_baseline_errors, ncf_errors),
            ("NCF vs NCF Baseline", ncf_errors, ncf_baseline_errors)
        ]
        t_test_results = []
        for name, errors1, errors2 in comparisons:
            t_stat, p_value = ttest_rel(errors1, errors2)
            t_test_results.append((name, t_stat, p_value))
            logging.info(f"{name} t-test: t={t_stat:.4f}, p={p_value:.4f}")

        logging.info(
            "Performing fairness analysis (diversity across budget tiers)...")
        # Filter movies_df to exclude zero or negative budgets
        movies_with_budget_df = movies_df.filter(col("budget") > 0)
        # Compute budget quartiles from valid budgets only
        budget_quartiles = movies_with_budget_df.approxQuantile(
            "budget", [0.25, 0.5, 0.75], 0.05
        )
        logging.info(f"Budget quartiles (budget > 0): {budget_quartiles}")

        # Redefine compute_diversity to use filtered movies_with_budget_df
        def compute_diversity(predictions, model_name, k=10):
            diversity = predictions.orderBy(col("prediction").desc()).limit(k).
↪join(
                movies_with_budget_df, "movieId"
            ).groupBy(
                when(col("budget") <= budget_quartiles[0], "Low")
                .when(col("budget") <= budget_quartiles[1], "Medium")
                .otherwise("High")
            ).count()
            diversity_result = diversity.collect()
            logging.info(f"{model_name} Diversity by budget tier:␣
↪{diversity_result}")
            return diversity_result

        als_diversity = compute_diversity(als_predictions, "ALS")
        als_cv_diversity = compute_diversity(als_cv_predictions, "ALS CV")
        als_baseline_diversity = compute_diversity(
            als_baseline_predictions, "ALS Baseline")
```

```
        ncf_pred_df = pd.DataFrame({
            "userId": test_pd["userId"],
            "movieId": test_pd["movieId"],
            "rating": test_pd["rating"],
            "prediction": ncf_predictions.flatten() * 5.0
        })
        ncf_spark_pred_df = test_df.sparkSession.createDataFrame(ncf_pred_df)
        ncf_diversity = compute_diversity(ncf_spark_pred_df, "NCF")

        ncf_baseline_pred_df = pd.DataFrame({
            "userId": test_pd["userId"],
            "movieId": test_pd["movieId"],
            "rating": test_pd["rating"],
            "prediction": ncf_baseline_predictions.flatten() * 5.0
        })
        ncf_baseline_spark_pred_df = test_df.sparkSession.createDataFrame(
            ncf_baseline_pred_df)
        ncf_baseline_diversity = compute_diversity(
            ncf_baseline_spark_pred_df, "NCF Baseline")

        with open(results_file, "w") as f:
            f.write("Statistical Tests (Paired t-tests):\n")
            for name, t_stat, p_value in t_test_results:
                f.write(f"{name}: t={t_stat:.4f}, p={p_value:.4f}\n")
            f.write("\nFairness Analysis (Diversity by Budget Tier):\n")
            f.write(f"ALS: {als_diversity}\n")
            f.write(f"ALS CV: {als_cv_diversity}\n")
            f.write(f"ALS Baseline: {als_baseline_diversity}\n")
            f.write(f"NCF: {ncf_diversity}\n")
            f.write(f"NCF Baseline: {ncf_baseline_diversity}\n")

        logging.info(
            f"Statistical and fairness analysis results saved to␣
 ↪{results_file}")

    except Exception as e:
        logging.error(
            f"Failed to perform statistical and fairness analysis: {str(e)}")
        raise


# Call the function
statistical_and_fairness_analysis(
    als_model,
    als_model_cv,
    als_baseline_model,
    ncf_model,
```

```
    ncf_baseline_model,
    user_map=user_map,
    movie_map=movie_map,
    user_map_baseline=user_map_baseline,
    movie_map_baseline=movie_map_baseline,
    test_df=test_df,
    movies_df=movies_df
)
```

```
2025-08-04 01:09:29,131 - INFO - Starting statistical and fairness analysis…

11024/11024             36s 3ms/step
11024/11024             33s 3ms/step

2025-08-04 01:12:48,114 - INFO - Performing paired t-tests with sample size
1000…
2025-08-04 01:18:54,974 - INFO - ALS vs ALS CV t-test: t=27.1396, p=0.0000
2025-08-04 01:18:55,013 - INFO - ALS vs ALS Baseline t-test: t=-0.1304, p=0.8963
2025-08-04 01:18:55,023 - INFO - ALS vs NCF t-test: t=4.9065, p=0.0000
2025-08-04 01:18:55,023 - INFO - ALS CV vs ALS Baseline t-test: t=-0.6582,
p=0.5106
2025-08-04 01:18:55,037 - INFO - ALS CV vs NCF t-test: t=4.4087, p=0.0000
2025-08-04 01:18:55,037 - INFO - ALS Baseline vs NCF t-test: t=5.0701, p=0.0000
2025-08-04 01:18:55,037 - INFO - NCF vs NCF Baseline t-test: t=1.6081, p=0.1081
2025-08-04 01:18:55,037 - INFO - Performing fairness analysis (diversity across
budget tiers)…
2025-08-04 01:20:22,911 - INFO - Budget quartiles (budget > 0): [1300000.0,
5150000.0, 17000000.0]
2025-08-04 01:21:41,218 - INFO - ALS Diversity by budget tier: [Row(CASE WHEN
(budget <= 1300000.0) THEN Low WHEN (budget <= 5150000.0) THEN Medium ELSE High
END='High', count=1), Row(CASE WHEN (budget <= 1300000.0) THEN Low WHEN (budget
<= 5150000.0) THEN Medium ELSE High END='Medium', count=2)]
2025-08-04 01:22:52,729 - INFO - ALS CV Diversity by budget tier: [Row(CASE WHEN
(budget <= 1300000.0) THEN Low WHEN (budget <= 5150000.0) THEN Medium ELSE High
END='High', count=2), Row(CASE WHEN (budget <= 1300000.0) THEN Low WHEN (budget
<= 5150000.0) THEN Medium ELSE High END='Medium', count=1)]
2025-08-04 01:24:19,858 - INFO - ALS Baseline Diversity by budget tier:
[Row(CASE WHEN (budget <= 1300000.0) THEN Low WHEN (budget <= 5150000.0) THEN
Medium ELSE High END='High', count=1)]
2025-08-04 01:26:28,646 - INFO - NCF Diversity by budget tier: [Row(CASE WHEN
(budget <= 1300000.0) THEN Low WHEN (budget <= 5150000.0) THEN Medium ELSE High
END='High', count=9)]
2025-08-04 01:30:30,566 - INFO - NCF Baseline Diversity by budget tier:
[Row(CASE WHEN (budget <= 1300000.0) THEN Low WHEN (budget <= 5150000.0) THEN
Medium ELSE High END='High', count=3), Row(CASE WHEN (budget <= 1300000.0) THEN
Low WHEN (budget <= 5150000.0) THEN Medium ELSE High END='Low', count=2),
Row(CASE WHEN (budget <= 1300000.0) THEN Low WHEN (budget <= 5150000.0) THEN
Medium ELSE High END='Medium', count=1)]
2025-08-04 01:30:30,578 - INFO - Statistical and fairness analysis results saved
```

```
to statistical_fairness_results.txt
```

[15]:
```python
# Cell 8: Visualize Results
import re
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
import numpy as np


def parse_evaluation_results(file_path, model_name):
    metrics = {}
    with open(file_path, 'r') as f:
        content = f.read()
        for metric in ['RMSE', 'Precision@10', 'Recall@10', 'NDCG@10']:
            match = re.search(rf"{model_name}\s*{metric}:\s*([\d.]+)", content)
            if match:
                metrics[metric] = float(match.group(1))
    return metrics


def parse_statistical_fairness(file_path):
    stats = {}
    fairness = {}
    current_section = None
    with open(file_path, 'r') as f:
        for line in f:
            line = line.strip()
            if line.startswith("Statistical Tests"):
                current_section = "stats"
                continue
            elif line.startswith("Fairness Analysis"):
                current_section = "fairness"
                continue
            if current_section == "stats" and line.startswith("ALS") or line.
 ↪startswith("NCF"):
                match = re.search(
                    r"(\w+\s*(?:CV|Baseline)?)\s*vs\s*(\w+\s*(?:CV|Baseline)?):
 ↪\s*t=([\d.-]+),\s*p=([\d.e-]+)", line)
                if match:
                    key = f"{match.group(1)} vs {match.group(2)}"
                    stats[key] = {'t': float(match.group(
                        3)), 'p': float(match.group(4))}
            elif current_section == "fairness" and line.startswith("ALS") or␣
 ↪line.startswith("NCF"):
                match = re.search(
                    r"(\w+\s*(?:CV|Baseline)?):\s*\[(.*?)\]", line)
```

```
                if match:
                    model = match.group(1)
                    rows = re.findall(
                        r"Row\(.*?='(\w+)',\s*count=(\d+)\)", match.group(2))
                    fairness[model] = {tier: int(count)
                                       for tier, count in rows}
    return stats, fairness


def visualize_results():
    try:
        # Parse evaluation results
        als_metrics = parse_evaluation_results(
            "als_evaluation_results.txt", "ALS")
        als_cv_metrics = parse_evaluation_results(
            "als_evaluation_results.txt", "ALS CV")
        als_baseline_metrics = parse_evaluation_results(
            "als_evaluation_results.txt", "ALS Baseline")
        ncf_metrics = parse_evaluation_results(
            "ncf_evaluation_results.txt", "NCF")
        ncf_baseline_metrics = parse_evaluation_results(
            "ncf_evaluation_results.txt", "NCF Baseline")

        # Parse statistical and fairness results
        stats_results, fairness_results = parse_statistical_fairness(
            "statistical_fairness_results.txt")

        # Combine metrics into a DataFrame
        metrics_df = pd.DataFrame({
            "Model": ["ALS", "ALS CV", "ALS Baseline", "NCF", "NCF Baseline"],
            "RMSE": [als_metrics.get("RMSE", 0), als_cv_metrics.get("RMSE", 0),␣
 ↪als_baseline_metrics.get("RMSE", 0),
                     ncf_metrics.get("RMSE", 0), ncf_baseline_metrics.
 ↪get("RMSE", 0)],
            "Precision@10": [als_metrics.get("Precision@10", 0), als_cv_metrics.
 ↪get("Precision@10", 0),
                             als_baseline_metrics.get(
                                 "Precision@10", 0), ncf_metrics.
 ↪get("Precision@10", 0),
                             ncf_baseline_metrics.get("Precision@10", 0)],
            "Recall@10": [als_metrics.get("Recall@10", 0), als_cv_metrics.
 ↪get("Recall@10", 0),
                          als_baseline_metrics.get(
                              "Recall@10", 0), ncf_metrics.get("Recall@10", 0),
                          ncf_baseline_metrics.get("Recall@10", 0)],
            "NDCG@10": [als_metrics.get("NDCG@10", 0), als_cv_metrics.
 ↪get("NDCG@10", 0),
```

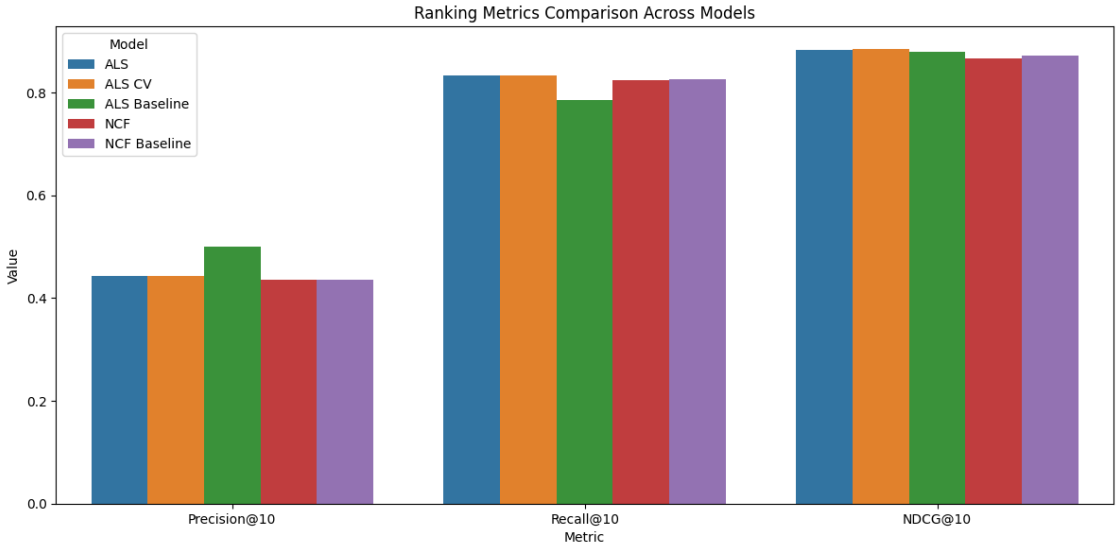
```
                    als_baseline_metrics.get(
                        "NDCG@10", 0), ncf_metrics.get("NDCG@10", 0),
                    ncf_baseline_metrics.get("NDCG@10", 0)]
        })

        # Plot RMSE comparison
        plt.figure(figsize=(10, 6))
        sns.barplot(x="Model", y="RMSE", data=metrics_df)
        plt.title("RMSE Comparison: Budget-Aware vs. Baseline Models")
        plt.ylabel("RMSE")
        plt.savefig("rmse_comparison.png")
        plt.close()

        # Plot ranking metrics
        ranking_metrics = metrics_df.melt(id_vars=["Model"],␣
↪value_vars=["Precision@10", "Recall@10", "NDCG@10"],
                                          var_name="Metric", value_name="Value")
        plt.figure(figsize=(12, 6))
        sns.barplot(x="Metric", y="Value", hue="Model", data=ranking_metrics)
        plt.title("Ranking Metrics Comparison Across Models")
        plt.savefig("ranking_metrics.png")
        plt.close()

        # Plot statistical tests
        stats_df = pd.DataFrame([
            {"Comparison": k, "t-statistic": v["t"], "p-value": v["p"]} for k,␣
↪v in stats_results.items()
        ])
        plt.figure(figsize=(12, 6))
        bars = sns.barplot(x="Comparison", y="t-statistic", data=stats_df)
        for i, bar in enumerate(bars.patches):
            p_val = stats_df.iloc[i]["p-value"]
            bars.annotate(f"p={p_val:.4f}",
                          (bar.get_x() + bar.get_width() / 2, bar.get_height()),
                          ha="center", va="bottom", fontsize=10)
        plt.title("Statistical Tests (t-statistics with p-values)")
        plt.xticks(rotation=45, ha="right")
        plt.tight_layout()
        plt.savefig("statistical_tests.png")
        plt.close()

        # Plot fairness (budget tier diversity)
        fairness_df = []
        for model, tiers in fairness_results.items():
            for tier, count in tiers.items():
                fairness_df.append(
                    {"Model": model, "Budget Tier": tier, "Count": count})
```

```
        fairness_df = pd.DataFrame(fairness_df)
        plt.figure(figsize=(10, 6))
        sns.barplot(x="Budget Tier", y="Count", hue="Model", data=fairness_df)
        plt.title("Diversity by Budget Tier Across Models")
        plt.savefig("diversity_comparison.png")
        plt.close()

        # Log visualization completion
        logging.info(
            "Visualizations saved: rmse_comparison.png, ranking_metrics.png,␣
 ↪statistical_tests.png, diversity_comparison.png")
    except Exception as e:
        logging.error(f"Failed to visualize results: {str(e)}")
        raise


visualize_results()
```

```
2025-08-04 12:37:17,973 - INFO - Visualizations saved: rmse_comparison.png,
ranking_metrics.png, statistical_tests.png, diversity_comparison.png
2025-08-04 12:37:17,973 - INFO - Visualizations saved: rmse_comparison.png,
ranking_metrics.png, statistical_tests.png, diversity_comparison.png
2025-08-04 12:37:17,973 - INFO - Visualizations saved: rmse_comparison.png,
ranking_metrics.png, statistical_tests.png, diversity_comparison.png
```

[16]:
```
import re
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns


def parse_all_ranking_metrics(file_paths):
    """Parse ranking metrics for all models from provided text files."""
    model_metrics = {}
    metric_names = ["Precision@10", "Recall@10", "NDCG@10"]

    for file_path in file_paths:
        with open(file_path, "r") as f:
            lines = f.readlines()
            current_model = None
            for line in lines:
                line = line.strip()
                model_match = re.match(r"^([\w\s]+)RMSE:", line)
                if model_match:
                    current_model = model_match.group(1).strip()
                    if current_model not in model_metrics:
                        model_metrics[current_model] = {}
```

```
                for metric in metric_names:
                    if f"{metric}:" in line and current_model:
                        val_match = re.search(rf"{metric}:\s*([\d.]+)", line)
                        if val_match:
                            model_metrics[current_model][metric] = float(
                                val_match.group(1))
    return model_metrics


def plot_ranking_metrics(metrics_dict):
    """Create a barplot from parsed ranking metrics."""
    df = pd.DataFrame([
        {"Model": model, "Metric": metric, "Value": value}
        for model, metrics in metrics_dict.items()
        for metric, value in metrics.items()
    ])

    plt.figure(figsize=(12, 6))
    sns.barplot(data=df, x="Metric", y="Value", hue="Model")
    plt.title("Ranking Metrics Comparison Across Models")
    plt.ylabel("Value")
    plt.tight_layout()
    plt.savefig("fixed_ranking_metrics.png")
    plt.show()


# Usage
ranking_metrics = parse_all_ranking_metrics([
    "als_evaluation_results.txt",
    "ncf_evaluation_results.txt"
])
plot_ranking_metrics(ranking_metrics)
```



[17]:
```python
# Cell 8: Clean Up
def cleanup():
    try:
        spark.stop()
        logging.info("Spark session closed.")
    except Exception as e:
        logging.error(f"Cleanup failed: {str(e)}")
        raise


cleanup()
```

```
2025-08-04 12:47:26,133 - INFO - Spark session closed.
2025-08-04 12:47:26,133 - INFO - Spark session closed.
2025-08-04 12:47:26,133 - INFO - Spark session closed.
```