

Lessons learnt in optimizing a large-scale pandas application using Polars, FireDucks and cuDF: Go Smart and Save More!

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Sourav Saha

Quick Introduction!



SOURAV SAHA – Senior Research Engineer @ NEC Corporation (Japan)

A software professional with 12+ years of working experience at NEC Corporation across diverse areas of **HPC, Vector Supercomputing, Distributed Programming, Big Data and Machine Learning**.

Key area of interest:

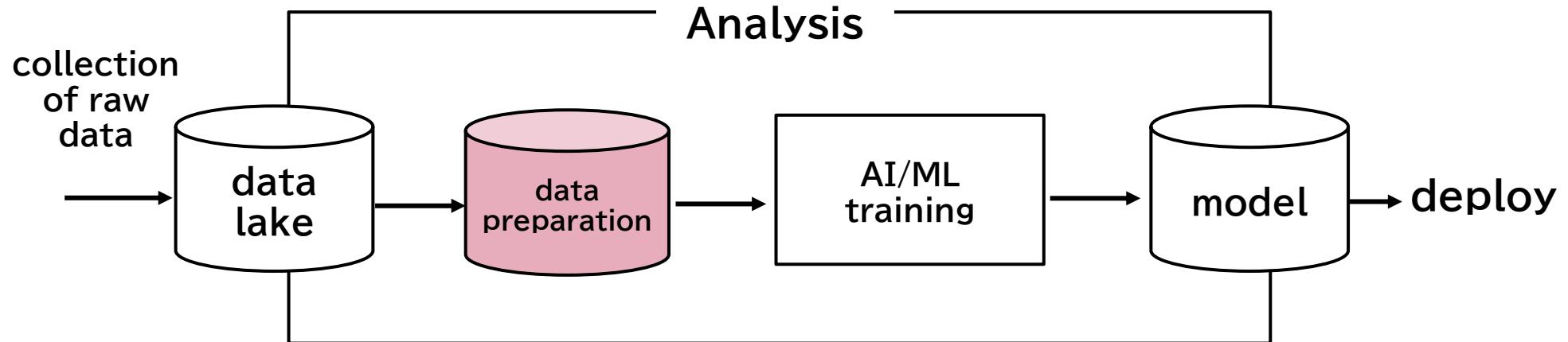
Optimization of Data Processing, AI/ML related workflow

Who is this talk for?

- You are a researcher, algorithm developer, system developer who works with data in python almost everyday.
- You are working with large-scale data in pandas.
- The data is related to Financial transactions.
- You are experiencing performance issue (probably related to cloud cost, runtime memory, etc.)
- You are looking for different high-performance pandas alternatives.
- You have already invested in GPU and want to use it for data preparation.

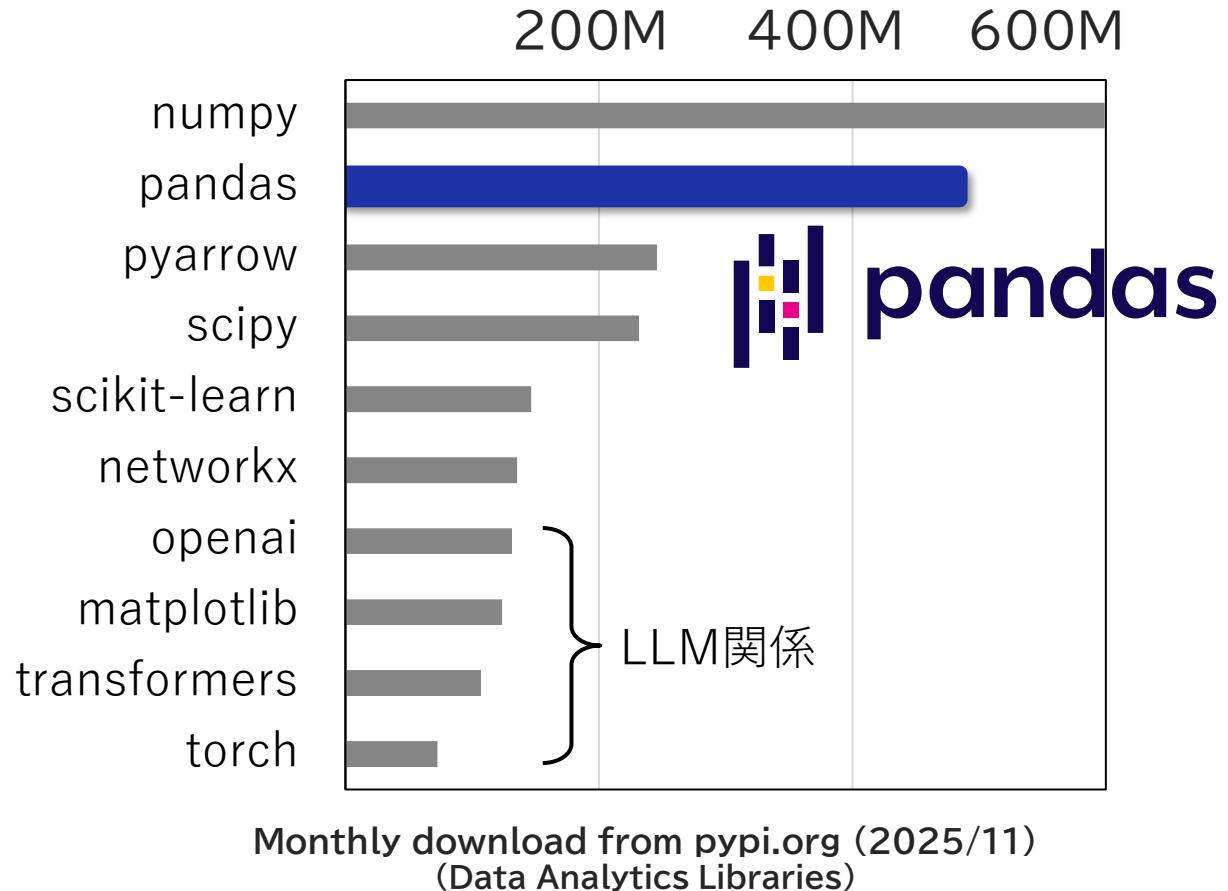
Overview of the Application

- **Application Overview:**
 - Transactional Data Analysis and Feature creation: using pandas
 - **Extremely Slow: Target of today's discussion**
 - I will be using [online retail analysis dataset](#) for the sample queries in the upcoming slides.
 - Machine Learning: Market Basket Analysis, Neural Collaborative Filtering etc.



Pandas: the de-facto toolkit for analyzing structured data in Python

The standard Python library for data analysis, downloaded over 400 million times per month

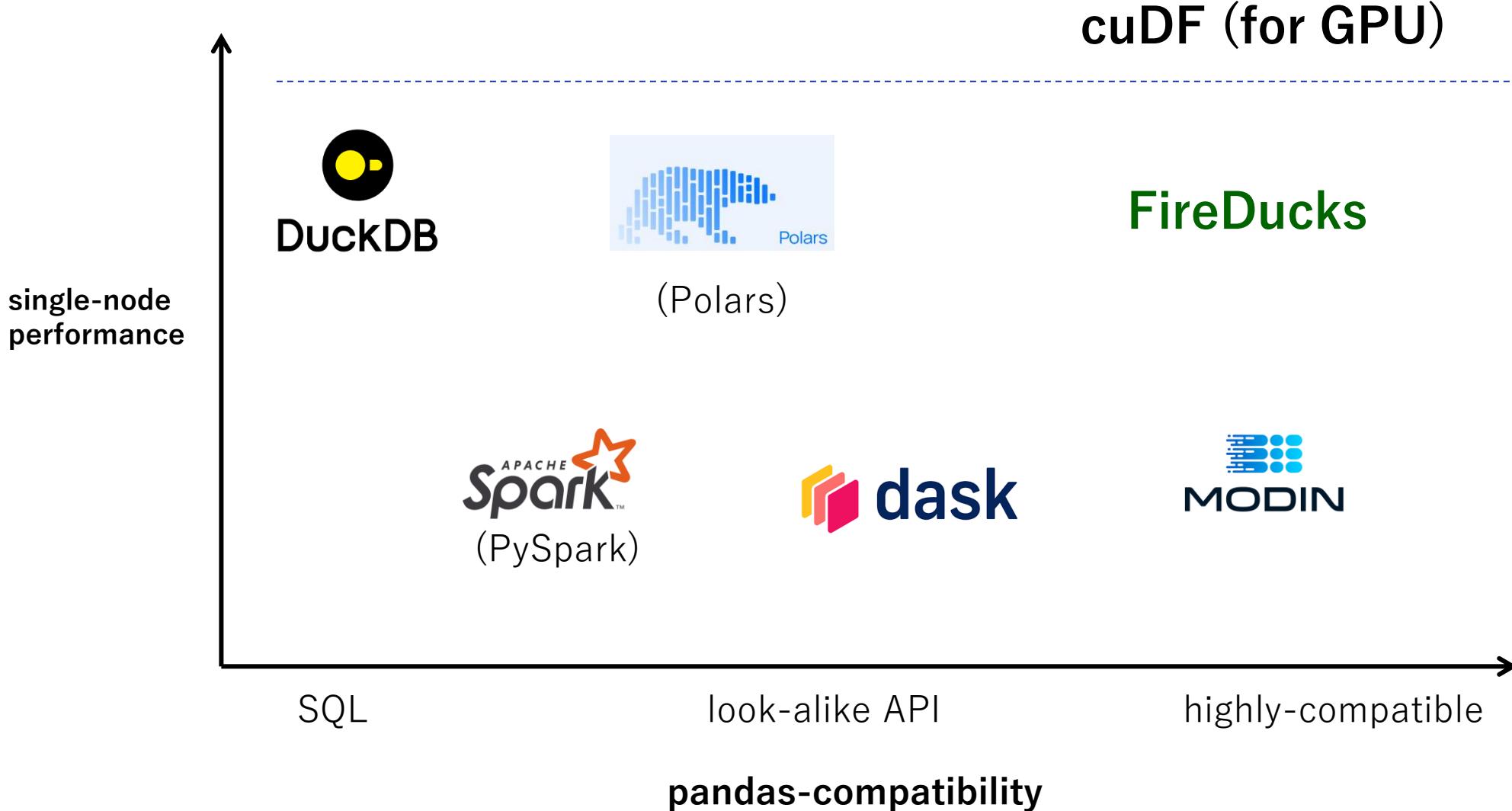


With the increase in data volume and complexity, a user starts experiencing performance issues with pandas

<https://www.amazon.co.jp/s?k=pandas>

<https://www.udemy.com/ja/topic/pandas/>

Exploring High-performance Pandas Alternatives

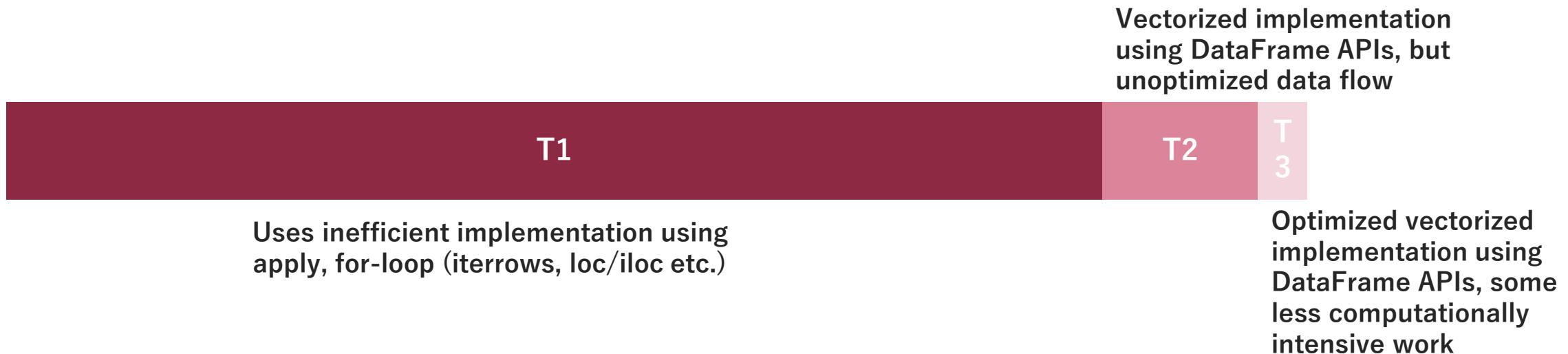


Comparison among Chosen Libraries

	Polars	FireDucks	cuDF
Primary Language	Rust (with Python API)	C++ (with Python API)	C++/CUDA (with Python API)
Execution Model	Lazy + Eager modes	Lazy + Eager modes	Eager only
Query Optimization	Yes	Yes	No
Pandas Compatibility	Not Compatible	Very High	High
Main Strength	Fast CPU analytics, low memory use, intuitive APIs	No code migration, Fast CPU analytics, Low memory use	No code migration, massive speedups for large datasets using GPU parallelism
Hardware Target	CPU (single/multi-threaded), NVIDIA GPU	CPU (single/multi-threaded), NVIDIA GPU (limited to enterprise edition)	NVIDIA GPU
Supported OS	OS Independent	Linux, macOS (Windows via WSL)	Linux Only (Windows via WSL)
License	MIT	3-Clause BSD	Apache 2.0

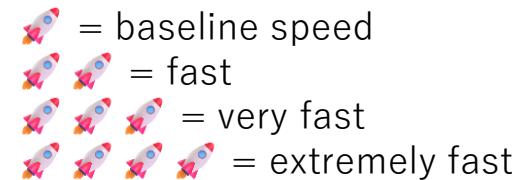
Bottleneck Analysis

- During the initial investigation, we found following three bottleneck categories involve in a typical pandas application:
 - ◆ **Loop-based implementation (T1)**: Primary bottlenecks covering almost 94% of the total processing time
 - ◆ **DataFrame API-based implementation without optimized data flow (T2)**: Secondary bottlenecks covering almost 5% of the total processing time
 - ◆ **DataFrame API-based implementation with optimized data flow (T3)**: Not-critical (1%), but encounters performance issue with high-volume data



Bottleneck Analysis

Categories	pandas	FireDucks	cuDF	Polars
Loop-based (T1)	Slow	Slower	Slower	Slower
DataFrame API-based without optimized data-flow (T2)	🚀	🚀🚀🚀🚀	🚀🚀	🚀🚀🚀🚀
DataFrame API-based with optimized data-flow (T3)	🚀🚀	🚀🚀🚀🚀	🚀🚀🚀🚀	🚀🚀🚀🚀



- **T1: Primary bottlenecks covering almost 94% of the total processing time**
 - Due to very inefficient implementation using iterrows, apply etc., the execution is slow in pandas
 - Such implementation hinders parallelism, query optimization etc., adds extra overheads. Therefore, further performance degradation is observed even from high-performance pandas alternatives.
- **T2: Secondary bottlenecks covering almost 5% of the total processing time**
 - Although implemented using vectorized dataframe APIs, the unoptimized data flow causes a lot of unnecessary computation overhead. Therefore, libraries with eager execution model, like pandas, cuDF are slower.
 - Whereas, libraries with query optimization support, like FireDucks, Polars excel in these areas.
- **T3: Not-critical (1%), but encounters performance issue with high-volume data**
 - Pandas works well for these cases, but experiences performance issue with high-volume data (due to its single-threaded execution model)
 - All other alternatives: cuDF, Polars, FireDucks work extremely well for such cases even with high-volume data

Exploring Type-1 Bottlenecks (Loop-based implementation)

Query 01: Problem Statement

- Fill missing values of “Description” column using the most frequent description of the specific “StockCode”.

InvoiceNo	StockCode	Description	Quantity	InvoiceDate	UnitPrice	CustomerID	Country
536414	22139	<NA>	56	2010-12-01 11:52:00	0.0	NaN	United Kingdom
536545	21134	<NA>	1	2010-12-01 14:32:00	0.0	NaN	United Kingdom
536546	22145	<NA>	1	2010-12-01 14:33:00	0.0	NaN	United Kingdom
536547	37509	<NA>	1	2010-12-01 14:33:00	0.0	NaN	United Kingdom
536549	85226A	<NA>	1	2010-12-01 14:34:00	0.0	NaN	United Kingdom
...
581199	84581	<NA>	-2	2011-12-07 18:26:00	0.0	NaN	United Kingdom
581203	23406	<NA>	15	2011-12-07 18:31:00	0.0	NaN	United Kingdom
581209	21620	<NA>	6	2011-12-07 18:35:00	0.0	NaN	United Kingdom
581234	72817	<NA>	27	2011-12-08 10:33:00	0.0	NaN	United Kingdom
581408	85175	<NA>	20	2011-12-08 14:06:00	0.0	NaN	United Kingdom



```
>>> df[df["StockCode"] == "22139"]["Description"].value_counts()
Description
RETROSPOT TEA SET CERAMIC 11 PC    988
amazon                                1
Name: count, dtype: Int64
>>> df[df["StockCode"] == "21134"]["Description"].value_counts()
Series([], Name: count, dtype: Int64)
>>> df[df["StockCode"] == "22145"]["Description"].value_counts()
Description
CHRISTMAS CRAFT HEART STOCKING     1
Name: count, dtype: Int64
```

InvoiceNo	StockCode	Description	Quantity	InvoiceDate	UnitPrice	CustomerID	Country
536414	22139	RETROSPOT TEA SET CERAMIC 11 PC	56	2010-12-01 11:52:00	0.0	NaN	United Kingdom
536545	21134	<NA>	1	2010-12-01 14:32:00	0.0	NaN	United Kingdom
536546	22145	CHRISTMAS CRAFT HEART STOCKING	1	2010-12-01 14:33:00	0.0	NaN	United Kingdom
536547	37509	NEW ENGLAND MUG W GIFT BOX	1	2010-12-01 14:33:00	0.0	NaN	United Kingdom
536549	85226A	<NA>	1	2010-12-01 14:34:00	0.0	NaN	United Kingdom
...
581199	84581	DOG TOY WITH PINK CROCHET SKIRT	-2	2011-12-07 18:26:00	0.0	NaN	United Kingdom
581203	23406	HOME SWEET HOME KEY HOLDER	15	2011-12-07 18:31:00	0.0	NaN	United Kingdom
581209	21620	SET OF 4 ROSE BOTANICAL CANDLES	6	2011-12-07 18:35:00	0.0	NaN	United Kingdom
581234	72817	SET OF 2 CHRISTMAS DECOUPAGE CANDLE	27	2011-12-08 10:33:00	0.0	NaN	United Kingdom
581408	85175	CACTI T-LIGHT CANDLES	20	2011-12-08 14:06:00	0.0	NaN	United Kingdom

Query 01: implementation using iterrows

```
df_descr_null = df[df["Description"].isnull()]

for index, row in df_descr_null.iterrows():
    stock_code = row["StockCode"]
    # Find the most frequent description for this StockCode
    most_frequent_description = df[df["StockCode"] == stock_code]["Description"].mode()
    if not most_frequent_description.empty:
        df.at[index, "Description"] = most_frequent_description[0]
```

Loop-based traditional approach

index	StockCode	Description
622	22139	RETROSPOT TEA SET CERAMIC 11 PC
1970	21134	NA
1971	22145	CHRISTMAS CRAFT HEART STOCKING
1972	37509	NEW ENGLAND MUG W GIFT BOX
1987	85226A	NA
:	:	
538554	85175	CACTI T-LIGHT CANDLES

For a sample data with 7270 null descriptions, pandas took ~930 sec.

Query 01: modified implementation using vectorized APIs

```
# Find "StockCode" wise most-frequent element of "Description"
```

```
most_freq = (  
    df[["StockCode", "Description"]]  
    .value_counts()  
    .reset_index()  
    .groupby("StockCode")  
    .head(1)  
)
```

```
most_freq.columns = ["StockCode", "FreqDescription", "frequency"]
```

```
# transform the "Description" column with the most-frequent description
```

```
tmp = df.merge(most_freq, on="StockCode", how="left")
```

```
# fill nulls with the most-frequent description
```

```
df["Description"] = df["Description"].fillna(tmp["FreqDescription"])
```

vectorized approach

For a sample data with
7270 null descriptions

	pandas	cuDF	polars	FireDucks
	1.4s	2.4s	0.6s	0.5s

group-wise count of unique descriptions

StockCode	Description	
10002	INFLATABLE POLITICAL GLOBE	71
10080	GROOVY CACTUS INFLATABLE	22
	check	1
10120	DOGGY RUBBER	30
10123C	HEARTS WRAPPING TAPE	3
10124A	SPOTS ON RED BOOKCOVER TAPE	5
10124G	ARMY CAMO BOOKCOVER TAPE	4
10125	MINI FUNKY DESIGN TAPES	94
10133	COLOURING PENCILS BROWN TUBE	199
	damaged	1

group-wise most frequent description

StockCode	Description	
10002	INFLATABLE POLITICAL GLOBE	71
10080	GROOVY CACTUS INFLATABLE	22
10120	DOGGY RUBBER	30
10123C	HEARTS WRAPPING TAPE	3
10124A	SPOTS ON RED BOOKCOVER TAPE	5
10124G	ARMY CAMO BOOKCOVER TAPE	4
10125	MINI FUNKY DESIGN TAPES	94
10133	COLOURING PENCILS BROWN TUBE	199

merge with most frequent description

StockCode	Description	FreqDescription
10002	<NA>	INFLATABLE POLITICAL GLOBE
10002	<NA>	INFLATABLE POLITICAL GLOBE
10123C	<NA>	HEARTS WRAPPING TAPE
10080	<NA>	GROOVY CACTUS INFLATABLE

Query 02: Problem Statement

- Find the number of transactions a user performed within the N days (e.g., 90) of the current transaction

CustomerID	InvoiceNo	InvoiceDate
12347.0	537626	2010-12-07 14:57:00
12347.0	542237	2011-01-26 14:30:00
12347.0	549222	2011-04-07 10:43:00
12347.0	556201	2011-06-09 13:01:00
12347.0	562032	2011-08-02 08:48:00
12347.0	573511	2011-10-31 12:25:00
12347.0	581180	2011-12-07 15:52:00



CustomerID	InvoiceNo	InvoiceDate	count
12347.0	537626	2010-12-07 14:57:00	2
12347.0	542237	2011-01-26 14:30:00	3
12347.0	549222	2011-04-07 10:43:00	3
12347.0	556201	2011-06-09 13:01:00	3
12347.0	562032	2011-08-02 08:48:00	2
12347.0	573511	2011-10-31 12:25:00	2
12347.0	581180	2011-12-07 15:52:00	2

Query 02: implementation using row-wise apply

```
def helper(x, offset=90):
    fdf = df[
        (df["CustomerID"] == x["CustomerID"]) &
        (abs(df["InvoiceDate"] - x["InvoiceDate"]) <= timedelta(days=offset))
    ]
    return len(fdf)

ret = df.assign(count=lambda data: data.apply(helper, axis=1))[
    ["CustomerID", "InvoiceDate", "count"]
]
```

apply-based
traditional
approach

For a sample data with 110950 unique transactions made by 4372 unique customers, pandas took ~134 sec.

CustomerID	InvoiceNo	InvoiceDate
12347.0	537626	2010-12-07 14:57:00
12347.0	542237	2011-01-26 14:30:00
12347.0	549222	2011-04-07 10:43:00
12347.0	556201	2011-06-09 13:01:00
12347.0	562032	2011-08-02 08:48:00
12347.0	573511	2011-10-31 12:25:00
12347.0	581180	2011-12-07 15:52:00

InvoiceDate	TimeDiff	Count
2010-12-07 14:57:00	237 days 17:51:00	
2011-01-26 14:30:00	187 days 18:18:00	
2011-04-07 10:43:00	116 days 22:05:00	
2011-06-09 13:01:00	53 days 19:47:00	
2011-08-02 08:48:00	0 days 00:00:00	
2011-10-31 12:25:00	90 days 03:37:00	
2011-12-07 15:52:00	127 days 07:04:00	2

Query 02: implementation using merge+filter

Vectorized approach

```
# self-join for pair-wise comparison
m = df.merge(df, on="CustomerID")
delta = timedelta(days=offset)

# filter the target pairs
m["TimeDiff"] =
    abs(m["InvoiceDate_x"] - m["InvoiceDate_y"])
)

# perform groupby-aggregate
ret = (
    m[m["TimeDiff"] <= delta]
        .groupby(["CustomerID", "InvoiceDate_x"])
            ["InvoiceNo_y"].count().reset_index()
)
ret.columns = ["CustomerID", "InvoiceDate", "count"]
```

pandas	cuDF	polars	FireDucks
0.9s	3.5s	0.3s	0.4s

pair construction

CustomerID	InvoiceNo_x	InvoiceDate_x	InvoiceNo_y	InvoiceDate_y
12347.0	537626	2010-12-07 14:57:00	537626	2010-12-07 14:57:00
12347.0	537626	2010-12-07 14:57:00	542237	2011-01-26 14:30:00
12347.0	537626	2010-12-07 14:57:00	549222	2011-04-07 10:43:00
12347.0	537626	2010-12-07 14:57:00	556201	2011-06-09 13:01:00
12347.0	537626	2010-12-07 14:57:00	562032	2011-08-02 08:48:00
12347.0	537626	2010-12-07 14:57:00	573511	2011-10-31 12:25:00
12347.0	537626	2010-12-07 14:57:00	581180	2011-12-07 15:52:00
12347.0	542237	2011-01-26 14:30:00	537626	2010-12-07 14:57:00
12347.0	542237	2011-01-26 14:30:00	542237	2011-01-26 14:30:00
12347.0	542237	2011-01-26 14:30:00	549222	2011-04-07 10:43:00
12347.0	542237	2011-01-26 14:30:00	556201	2011-06-09 13:01:00
12347.0	542237	2011-01-26 14:30:00	562032	2011-08-02 08:48:00

pair-wise diff calculation

CustomerID	InvoiceNo_x	InvoiceDate_x	InvoiceNo_y	InvoiceDate_y	TimeDiff
12347.0	537626	2010-12-07 14:57:00	537626	2010-12-07 14:57:00	0 days 00:00:00
12347.0	537626	2010-12-07 14:57:00	542237	2011-01-26 14:30:00	49 days 23:33:00
12347.0	537626	2010-12-07 14:57:00	549222	2011-04-07 10:43:00	120 days 19:46:00
12347.0	537626	2010-12-07 14:57:00	556201	2011-06-09 13:01:00	183 days 22:04:00
12347.0	537626	2010-12-07 14:57:00	562032	2011-08-02 08:48:00	237 days 17:51:00
12347.0	537626	2010-12-07 14:57:00	573511	2011-10-31 12:25:00	327 days 21:28:00
12347.0	537626	2010-12-07 14:57:00	581180	2011-12-07 15:52:00	365 days 00:55:00
12347.0	542237	2011-01-26 14:30:00	537626	2010-12-07 14:57:00	49 days 23:33:00
12347.0	542237	2011-01-26 14:30:00	542237	2011-01-26 14:30:00	0 days 00:00:00
12347.0	542237	2011-01-26 14:30:00	549222	2011-04-07 10:43:00	70 days 20:13:00
12347.0	542237	2011-01-26 14:30:00	556201	2011-06-09 13:01:00	133 days 22:31:00
12347.0	542237	2011-01-26 14:30:00	562032	2011-08-02 08:48:00	187 days 18:18:00

Filtration of target pairs

CustomerID	InvoiceNo_x	InvoiceDate_x	InvoiceNo_y	InvoiceDate_y	TimeDiff
12347.0	537626	2010-12-07 14:57:00	537626	2010-12-07 14:57:00	0 days 00:00:00
12347.0	537626	2010-12-07 14:57:00	542237	2011-01-26 14:30:00	49 days 23:33:00
12347.0	542237	2011-01-26 14:30:00	537626	2010-12-07 14:57:00	49 days 23:33:00
12347.0	542237	2011-01-26 14:30:00	542237	2011-01-26 14:30:00	0 days 00:00:00
12347.0	542237	2011-01-26 14:30:00	549222	2011-04-07 10:43:00	70 days 20:13:00

Query 03: Problem Statement

- Calculate the total sales per Invoice for each Customer.

CustomerID	InvoiceNo	StockCode	Quantity	UnitPrice
17850.0	536365	85123A	6	2.55
17850.0	536365	71053	6	3.39
17850.0	536365	84406B	8	2.75
17850.0	536365	84029G	6	3.39
17850.0	536365	84029E	6	3.39
...
12680.0	581587	22613	12	0.85
12680.0	581587	22899	6	2.10
12680.0	581587	23254	4	4.15
12680.0	581587	23255	4	4.15
12680.0	581587	22138	3	4.95



CustomerID	InvoiceNo	
12346.0	541431	385918.00
	C541433	-385918.00
12347.0	537626	3558.95
	542237	2376.95
	549222	3181.25

18283.0	579673	1118.05
	580872	1040.00
18287.0	554065	3826.40
	570715	5006.60
	573167	353.40

Query 03: apply-based vs vectorized implementation

apply-based
approach

```
ret = df.groupby(["CustomerID", "InvoiceNo"]).apply(  
    lambda x: (x["Quantity"] * x["UnitPrice"]).sum()  
)
```

For a sample data with
2709545 transactions made
by 4372 unique customers,
pandas took ~3.4 sec.

vectorized
approach

```
ret = (  
    df.assign(revenue=lambda x: x["Quantity"] * x["UnitPrice"])  
    .groupby(["CustomerID", "InvoiceNo"])["revenue"]  
    .sum()  
)
```

pandas	cuDF	polars	FireDucks
378 ms	29 ms	80 ms	64 ms

Exploring Type-2 Bottlenecks

(Vectorized implementation without optimized data flow)

Query 04: Problem Statement

- Find the list of customers from the “North America” (NA) region who involve in at least one refund related transaction

CustomerID	StockCode	InvoiceDate	Quantity	InvoiceDate_y	Quantity_y	region
12607.0	22551	2011-10-10 16:06:00	12	2011-10-12 16:17:00	-12	NA
12607.0	21915	2011-10-10 16:06:00	12	2011-10-12 16:17:00	-12	NA
12607.0	22619	2011-10-10 16:06:00	4	2011-10-12 16:17:00	-4	NA
12607.0	22138	2011-10-10 16:06:00	3	2011-10-12 16:17:00	-3	NA
12607.0	21524	2011-10-10 16:06:00	2	2011-10-12 16:17:00	-2	NA
...
12558.0	84828	2011-12-02 10:41:00	24	2011-12-08 10:14:00	-24	NA
12558.0	23158	2011-12-02 10:41:00	36	2011-12-08 10:14:00	-36	NA
12558.0	21507	2011-12-02 10:41:00	12	2011-12-08 10:14:00	-12	NA
12558.0	21508	2011-12-02 10:41:00	12	2011-12-08 10:14:00	-12	NA
12558.0	22027	2011-12-02 10:41:00	12	2011-12-08 10:14:00	-12	NA

Query 04: Vectorized implementation (unoptimized data flow)

```
ret = (
    left.merge(right, on=["CustomerID", "StockCode"])
        .pipe(lambda m: m[m["Quantity"] > 0])
        .pipe(lambda m: m[m["Quantity_y"] < 0])
        .pipe(lambda m: m[m["region"] == "NA"])
        .groupby("CustomerID")["InvoiceNo"]
        .nunique()
)
```

For a sample data with 2709545 transactions made by 4372 unique customers, the execution times are as follows:

pandas	cuDF	polars	FireDucks
67 s	42 s	0.15 s	0.08 s

- Vectorized DataFrame API-based implementation
- But the flow is not optimized!!
 - It combines two large tables and filters out the unrequired rows before performing the groupby.
- An optimized flow could be:
 - Filter required rows and columns from the left and right tables
 - Perform the merge, groupby, etc.
- **Library without query optimization, like pandas, cuDF suffer from performance issues.**
- **Whereas, library with query optimization, like FireDucks, Polars, etc. outperform in such cases.**

Query 04: Vectorized implementation (optimized data flow)

```
ret = (
    left.merge(right, on=["CustomerID", "StockCode"])
        .pipe(lambda m: m[m["Quantity"] > 0])
        .pipe(lambda m: m[m["Quantity_y"] < 0])
        .pipe(lambda m: m[m["region"] == "NA"])
    .groupby("CustomerID")["InvoiceNo"]
    .nunique()
)
```



```
left = left.pipe(lambda m: m[m["region"] == "NA"]).pipe(
    lambda m: m[m["Quantity"] > 0]
)[["CustomerID", "StockCode", "InvoiceNo"]]

right = right.pipe(lambda m: m[m["Quantity_y"] < 0])[
    ["CustomerID", "StockCode"]]

ret = (
    left.merge(right, on=["CustomerID", "StockCode"])
        .groupby("CustomerID")["InvoiceNo"]
        .nunique()
)
```

For a sample data with 2709545 transactions made by 4372 unique customers, the execution times are as follows:

pandas	cuDF	polars	FireDucks
67 s	42 s	0.15 s	0.08 s



significant
performance gain



Ignorable
differences

pandas	cuDF	polars	FireDucks
0.77 s	1.02 s	0.18 s	0.11 s

Exploring Type-3 Bottlenecks (Vectorized implementation with optimized data flow)

Query 05: Problem Statement

- Calculate country and month wise total revenue.

Country		InvoiceDate	Quantity	UnitPrice
United Kingdom		2010-12-01 08:26:00	6	2.55
United Kingdom		2010-12-01 08:26:00	6	3.39
United Kingdom		2010-12-01 08:26:00	8	2.75
United Kingdom		2010-12-01 08:26:00	6	3.39
United Kingdom		2010-12-01 08:26:00	6	3.39
...				
France		2011-12-09 12:50:00	12	0.85
France		2011-12-09 12:50:00	6	2.10
France		2011-12-09 12:50:00	4	4.15
France		2011-12-09 12:50:00	4	4.15
France		2011-12-09 12:50:00	3	4.95



Country	month	revenue
Australia	1	45088.55
Australia	2	73477.10
Australia	3	86119.95
Australia	4	3858.00
Australia	5	68192.05
...		
Unspecified	6	928.90
Unspecified	7	7127.05
Unspecified	8	2655.15
Unspecified	9	1434.25
Unspecified	11	4828.75

Query 05: Vectorized implementation (optimized data flow)

```
ret = (
    df.pipe(lambda x: x[x["Quantity"] > 0])
    .pipe(lambda x: x[x["UnitPrice"] > 0])
    .assign(revenue=lambda x: x["Quantity"] * x["UnitPrice"])
    .assign(month=lambda x: x["InvoiceDate"].dt.month)
    .groupby(["Country", "month"], as_index=False)[["revenue"]]
    .sum()
)
```

For a sample data with 2709545 transactions made by 38 unique countries, the execution times are as follows:

pandas	cuDF	polars	FireDucks
0.74 s	0.09 s	0.18 s	0.12 s

- Efficient Query implementation!!
 - Pandas work well for this case.
 - Polars/FireDucks perform better due to multi-threaded execution
 - **cuDF performs the best** due to GPU level parallelism.

Learning Summary

Learning #1: Breaking out of the loop

- Most of the pandas applications suffers from Type-1 bottlenecks (loop-based traditional implementation)
- If such bottleneck exists, performance gain might not be expected even from high-performance pandas alternatives, like cuDF, FireDucks etc.
- Hence before migrating to different library/execution platform, it would be better to re-implement the bottlenecks using pandas specific vectorized implementation

Query	ASIS	Type-1 Optimized
Q01	929.47	1.39
Q02	133.62	0.93
Q03	3.39	0.38
Q04	66.66	67.24
Q05	0.71	0.74
Total	1133.85	70.68

Pandas itself could be made **~16x faster** just by making efficient changes in the traditional loop-based implementation

Learning #2: Single-node processing might be enough

Query	Type-1 Optimized				
	pandas	cuDF	Polars	FireDucks	
SF=1	Q01	1.39	2.36	0.62	0.54
	Q02	0.93	3.52	0.32	0.43
	Q03	0.38	0.03	0.08	0.06
	Q04	67.24	42.24	0.15	0.08
	Q05	0.74	0.10	0.18	0.12
	Total	70.68	48.25	1.34	1.24

cuDF: ~1.5x speedup

- Only GPU parallelism, no query optimization
- Absolute zero code modification

Polars: ~50x speedup

- High migration cost: Re-writing required even for Type-2 bottlenecks (pandas -> polars)

FireDucks: ~54x speedup

- Absolute zero code modification

Query	Type-1 Optimized				
	pandas	cuDF	Polars	FireDucks	
SF=10	Q01	14.06	23.57	3.39	3.21
	Q02	67.28	mem-error	10.60	12.02
	Q03	3.48	17.57	0.48	0.17
	Q04	mem-error	mem-error	1.13	0.40
	Q05	6.76	0.77	1.22	1.06
	Total	91.58	41.90	16.83	16.87

cuDF:

- Memory error might occur due to Type-2 bottlenecks that cuDF cannot auto-optimize.

FireDucks/Polars:

- Capable of auto optimization for Type-2 bottlenecks.
- Hence, work smoothly even for high-volume data

Learning #3: FireDucks might be the one you are looking for!

- **Pandas accelerator without much code alteration**

```
$ python demo.py
```

```
Code block '[pandas] Execution time of func_1: ' took: 1.40680 s  
Code block '[pandas] Execution time of func_2: ' took: 0.96898 s  
Code block '[pandas] Execution time of func_3: ' took: 0.42458 s  
Code block '[pandas] Execution time of func_4: ' took: 66.99391 s  
Code block '[pandas] Execution time of func_5: ' took: 0.77127 s
```

```
$ python -mcudf.pandas demo.py
```

```
Code block '[cudf] Execution time of func_1: ' took: 2.32772 s  
Code block '[cudf] Execution time of func_2: ' took: 3.5178 s  
Code block '[cudf] Execution time of func_3: ' took: 0.02973 s  
Code block '[cudf] Execution time of func_4: ' took: 42.30631 s  
Code block '[cudf] Execution time of func_5: ' took: 0.09402 s
```

```
$ python -mfireducks.pandas demo.py
```

```
Code block '[fireducks] Execution time of func_1: ' took: 0.59689 s  
Code block '[fireducks] Execution time of func_2: ' took: 0.40727 s  
Code block '[fireducks] Execution time of func_3: ' took: 0.06636 s  
Code block '[fireducks] Execution time of func_4: ' took: 0.09151 s  
Code block '[fireducks] Execution time of func_5: ' took: 0.11985 s
```

- For an existing pandas based application, or the one that works with external libraries expecting pandas DataFrame as input, **FireDucks can be an excellent choice.**
- Just refrain from traditional loop-based (T1) implementation and enjoy high-performance processing speed for all your data intensive workload with FireDucks.

Thank you!



Presentation Deck



Connect me!