A Practical Approach to Device-Level Analytical Offloads

Presented by
Donpaul Stephens
Founder & CEO, AirMettle

SNIA COMPUTE, MEMORY, AND STORAGE SUMMIT
Solutions, Architectures, and Community
VIRTUAL EVENT, MAY 21-22, 2024

"Our scientific large-scale simulations can generate hundreds of petabytes of highly dimensional floating-point data ... But the data associated with a scientific feature of interest can be orders of magnitude smaller than the written data, so a key challenge is quickly and efficiently finding what's relevant in this sea of data. To optimize this process, we've been drawn towards computational storage — processing data in-place and near storage — to eliminate unnecessary data movement while maintaining parallelism and adequate data protection."

– Gary Grider, High Performance Computing division leader

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Computational Storage?

Erik Riedel's
Ph.D. Dissertation 1999:

Active Disks –
Remote Execution for Network-Attached Storage

Why didn't it take off?
How we can put it to work.

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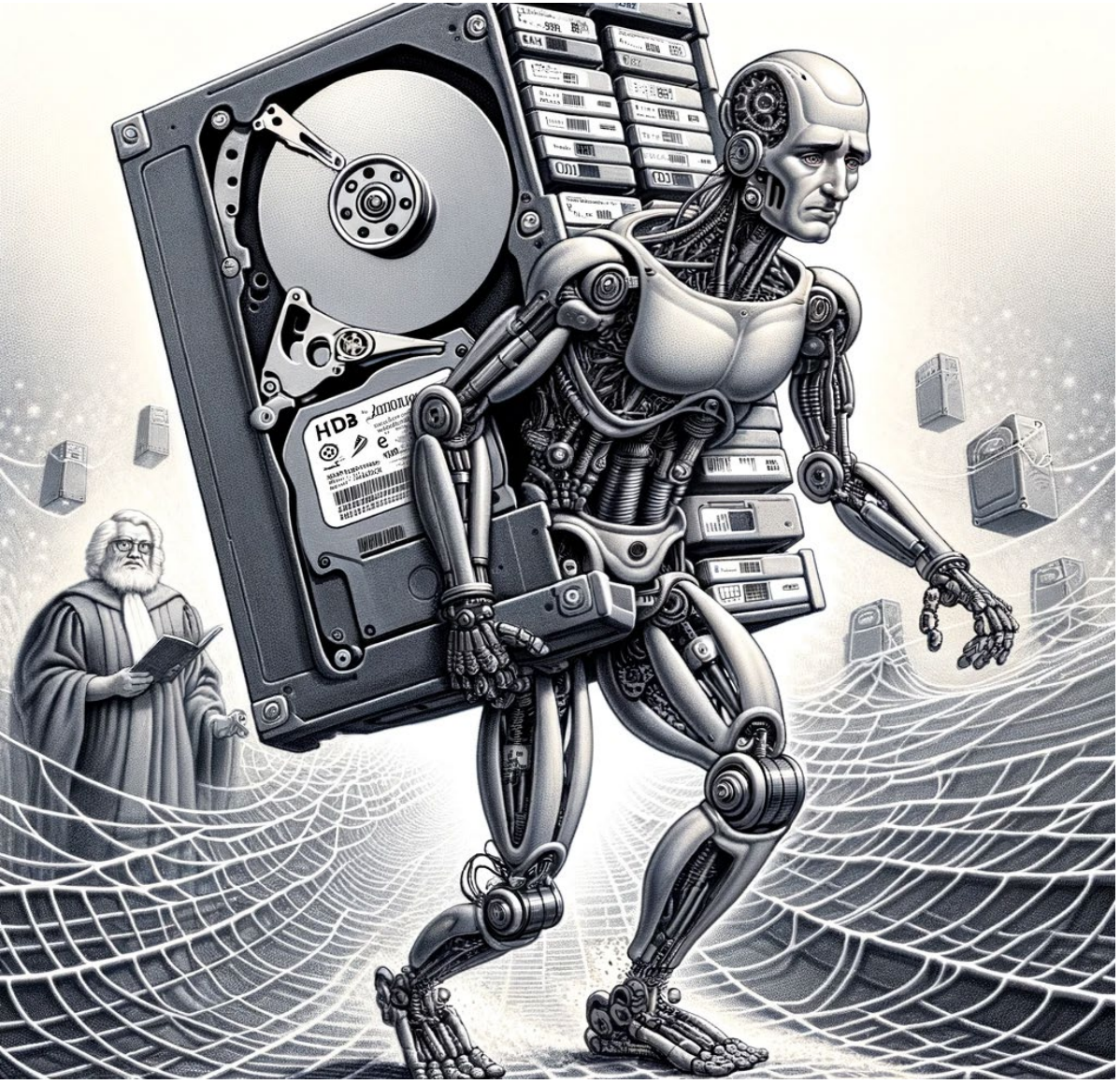
Why is Big Data so SLOW?



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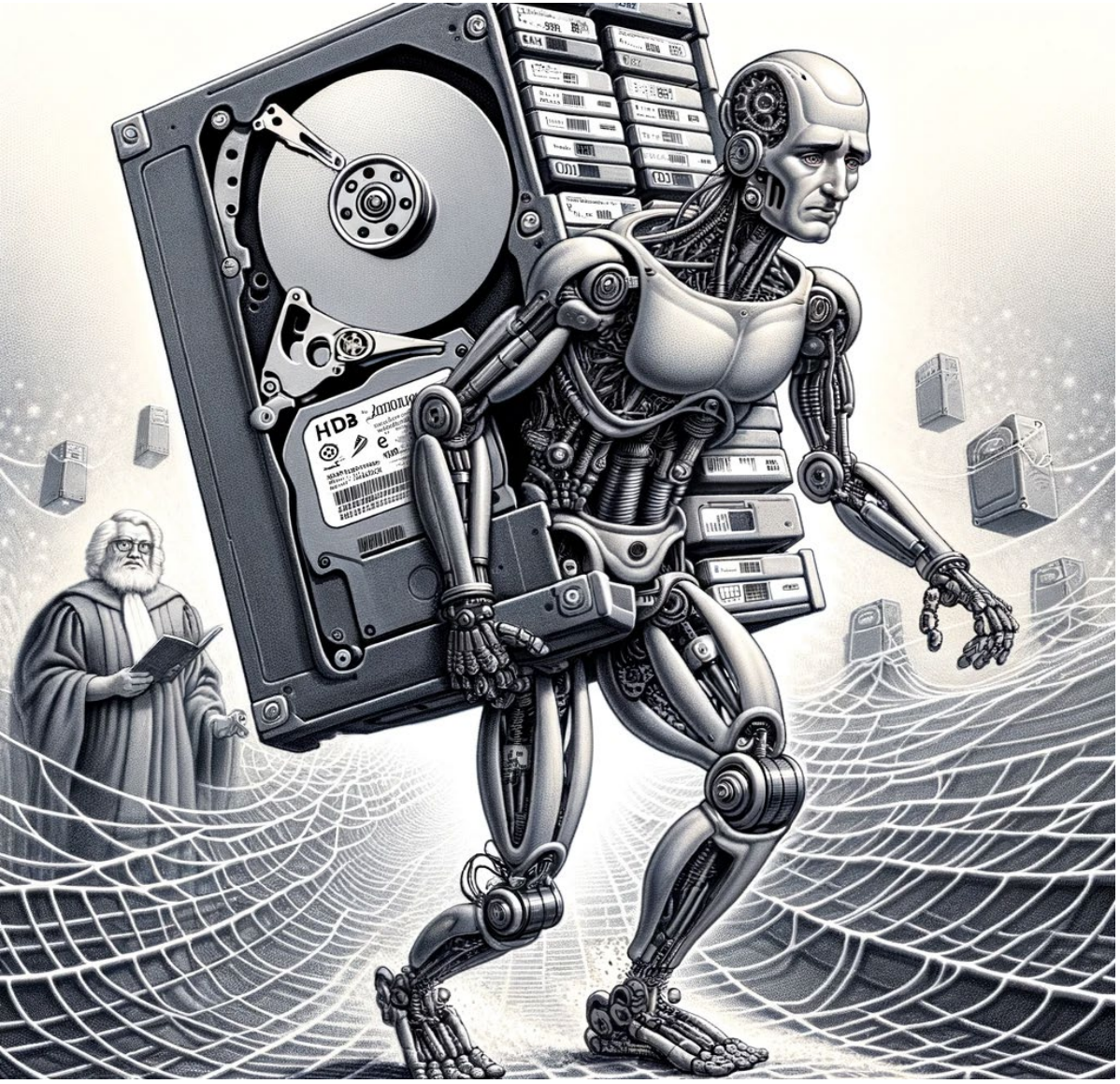
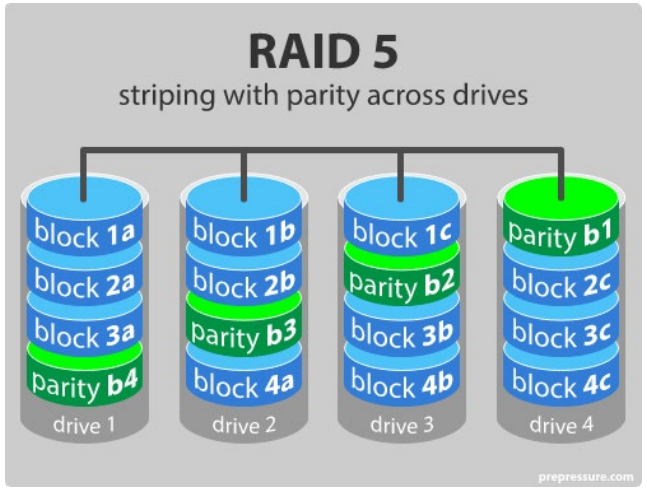
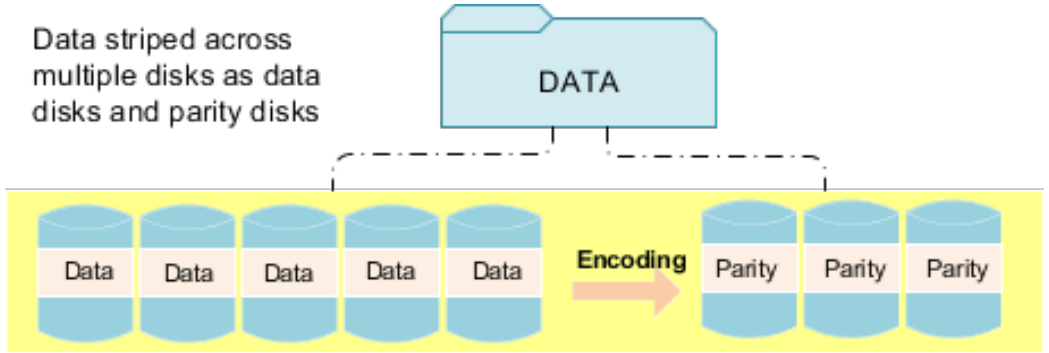
Why is Big Data so SLOW?



In part: How storage protects data



Erasure Coding:



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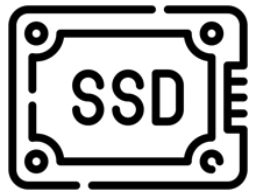
Data reliably placed in storage: First 4 devices shown…

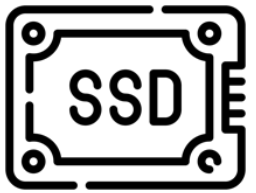
Simple Table:

1	155190	7706	1	17	21168.23	0.04	0.02	N	O	3/13/96	2/12/96	3/22/96	DELIVER_IN_PERSON	TRUCK	egular_courts_above_the
1	67310	7311	2	36	45983.16	0.09	0.06	N	O	4/12/96	2/28/96	4/20/96	TAKE_BACK_RETURN	MAIL	ly_final_dependencies:_slyly_bold_
1	63700	3701	3	8	13309.6	0.1	0.02	N	O	1/29/96	3/5/96	1/31/96	TAKE_BACK_RETURN	REG_AIR	riously._regular|_express_dep
1	2132	4633	4	28	28955.64	0.09	0.06	N	O	4/21/96	3/30/96	5/16/96	NONE	AIR	lites._fluffily_even_de
1	24027	1534	5	24	22824.48	0.1	0.04	N	O	3/30/96	3/14/96	4/1/96	NONE	FOB	_pending_foxes._slyly_re
1	15635	638	6	32	49620.16	0.07	0.02	N	O	1/30/96	2/7/96	2/3/96	DELIVER_IN_PERSON	MAIL	arefully_slyly_ex
2	106170	1191	1	38	44694.46	0	0.05	N	O	1/28/97	1/14/97	2/2/97	TAKE_BACK_RETURN	RAIL	ven_requests._deposits_breach_a

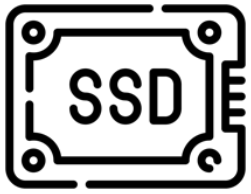
#1



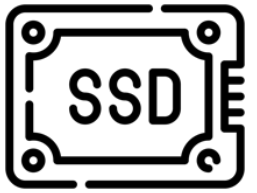
#2



#3



#4



Bytes of data divided evenly across SSDs!

Data protection and streaming performance!

Supports data protection algorithms designed for HDD!

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Byte-level partitions precludes analytics

Simple Table:

1	155190	7706	1	17	21168.23	0.04	0.02	N	O	3/13/96	2/12/96	3/22/96	DELIVER_IN_PERSON	TRUCK	egular_courts_above_the
1	67310	7311	2	36	45983.16	0.09	0.06	N	O	4/12/96	2/28/96	4/20/96	TAKE_BACK_RETURN	MAIL	ly_final_dependencies:_slyly_bold_
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1	2132	4633	4	28	28955.64	0.09	0.06	N	O	4/21/96	3/30/96	5/16/96	NONE	AIR	lites._fluffily_even_de
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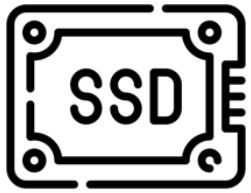
2	106170	1191	1	38	44694.46	0	0.05	N	O	1/28/97	1/14/97	2/2/97	TAKE_BACK_RETURN	RAIL	ven_requests._deposits_breach_a

#1

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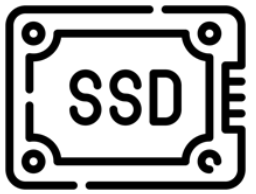
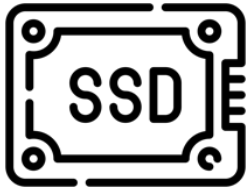
1,155190,7706,1,17,21168.23,0.04,0.02,N,O,1996-03-13
,1996-02-12,1996-03-22,DELIVER_IN_PERSON,TRUCK,egula
r_courts_above_the, 1,67310,7311,2,36,45983.16,0.09,
0.06,N,O,1996-04-12,1996-02-28,1996-04-20,TAKE_BACK_
```

#2



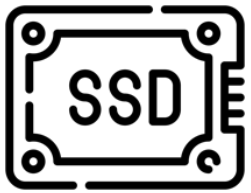

```
RETURN,MAIL,ly_final_dependencies:_slyly_bold_, 1,63
700,3701,3,8,13309.60,0.10,0.02,N,O,1996-01-29,1996-
03-05,1996-01-31,TAKE_BACK_RETURN,REG_AIR,riously._r
egular|_express_dep, 1,2132,4633,4,28,28955.64,0.09,
```

#3




```
0.06,N,O,1996-04-21,1996-03-30,1996-05-16,NONE,AIR,l
ites._fluffily_even_de, 1,24027,1534,5,24,22824.48,0
.10,0.04,N,O,1996-03-30,1996-03-14,1996-04-01,NONE,F
OB,_pending_foxes._slyly_re, 1,15635,638,6,32,49620.
```

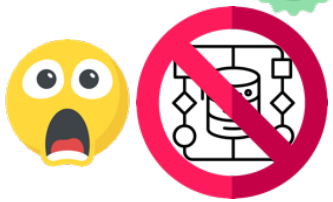
#4




```
16,0.07,0.02,N,O,1996-01-30,1996-02-07,1996-02-03,DE
LIVER_IN_PERSON,MAIL,arefully_slyly_ex, 2,106170,119
1,1,38,44694.46,0.00,0.05,N,O,1997-01-28,1997-01-14,
1997-02-02,TAKE_BACK_RETURN,RAIL,ven_requests._depos
```

Bytes of data divided evenly across SSDs!

Data protection and streaming performance!



HDD-centric RAID/Erasure Coding prevent in-storage analytics

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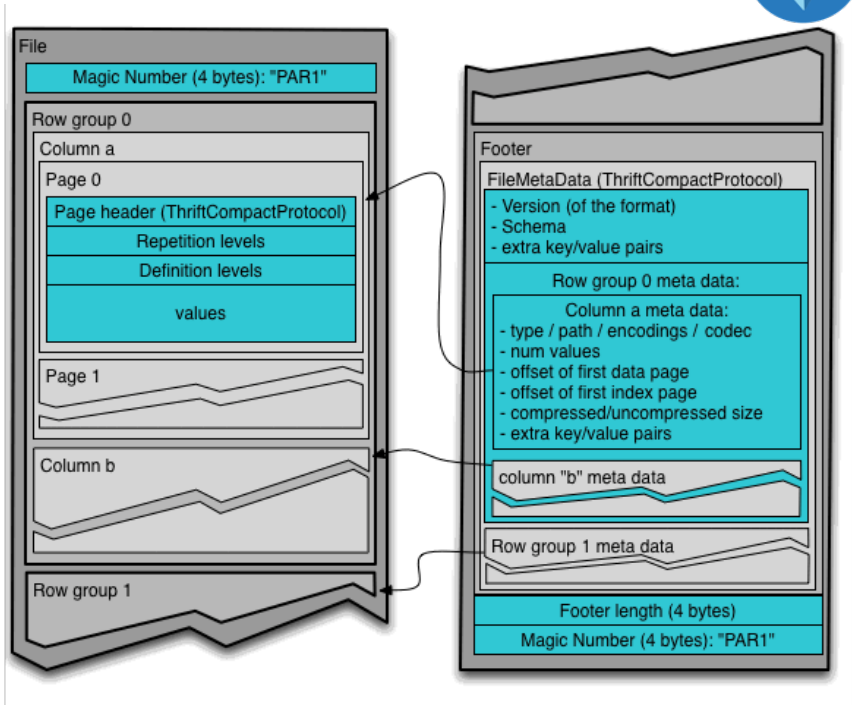
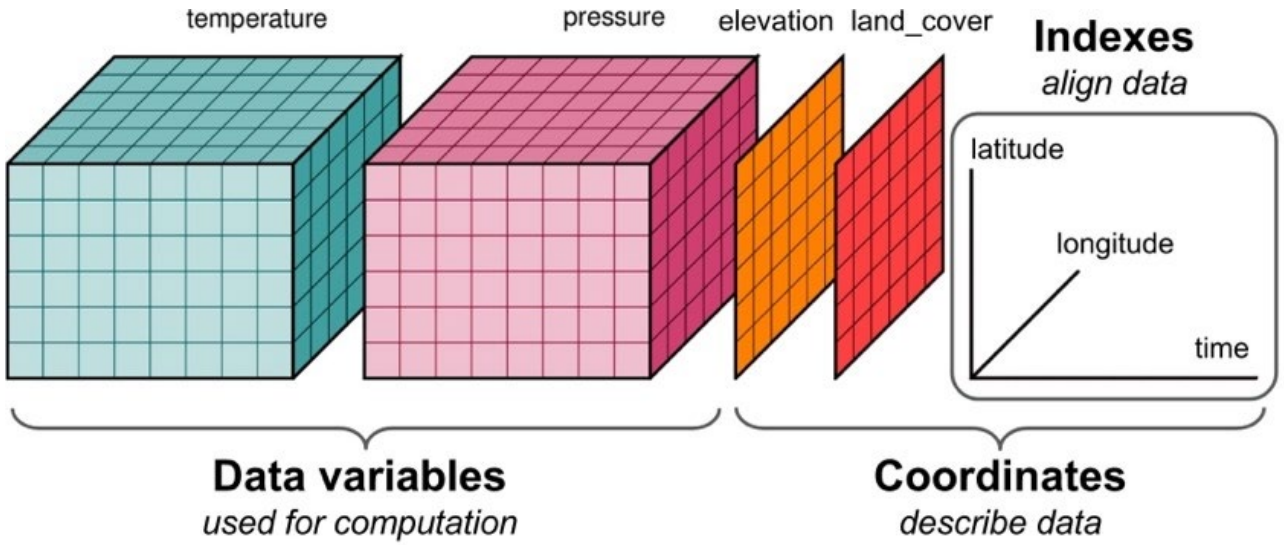
Challenge: Array based data formats

Parquet

ICEBERG



netCDF4 / HDF5



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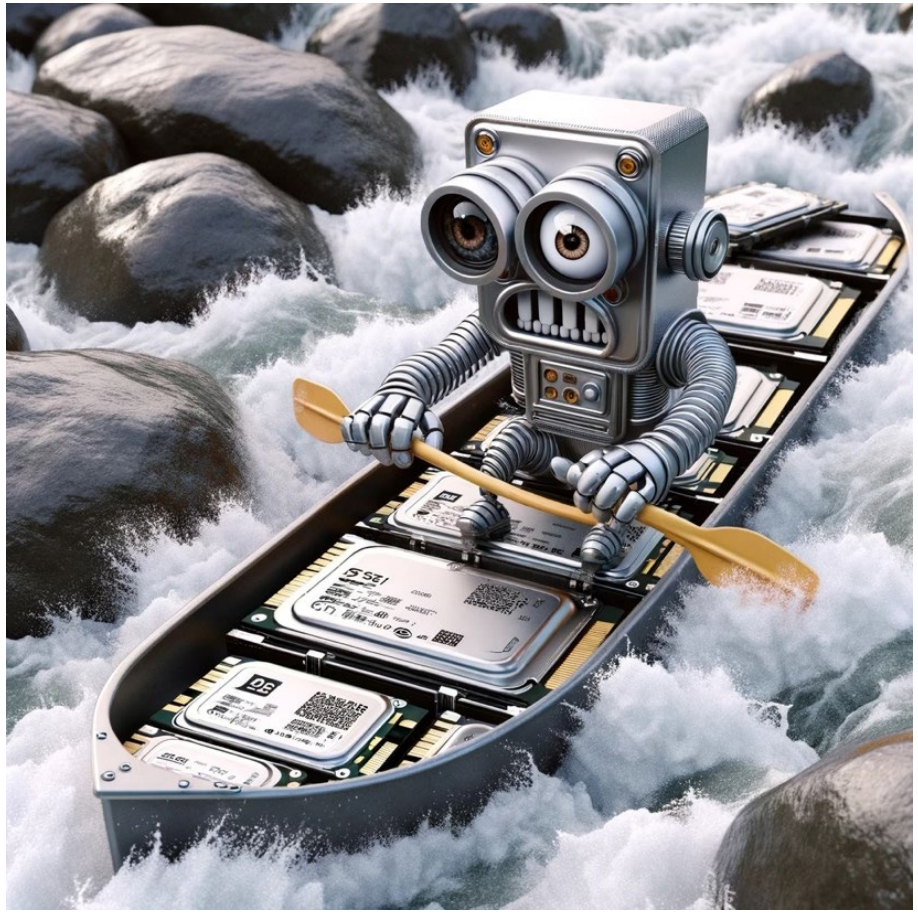
Branches are hard, complex data structures more complex



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Let’s take Occam’s Razor to the Gordian’s Knot

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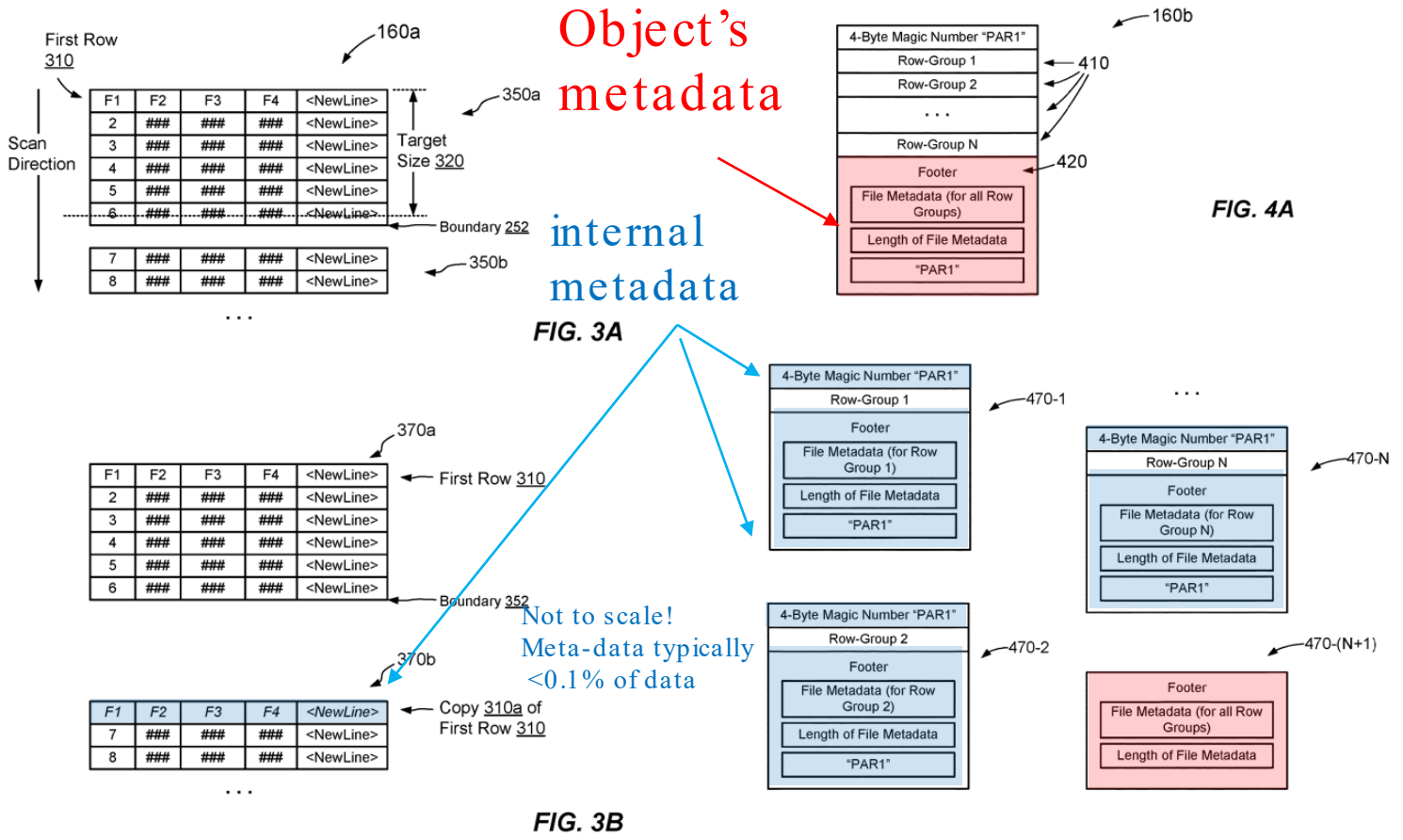
Step 1: Preserve structure of the data



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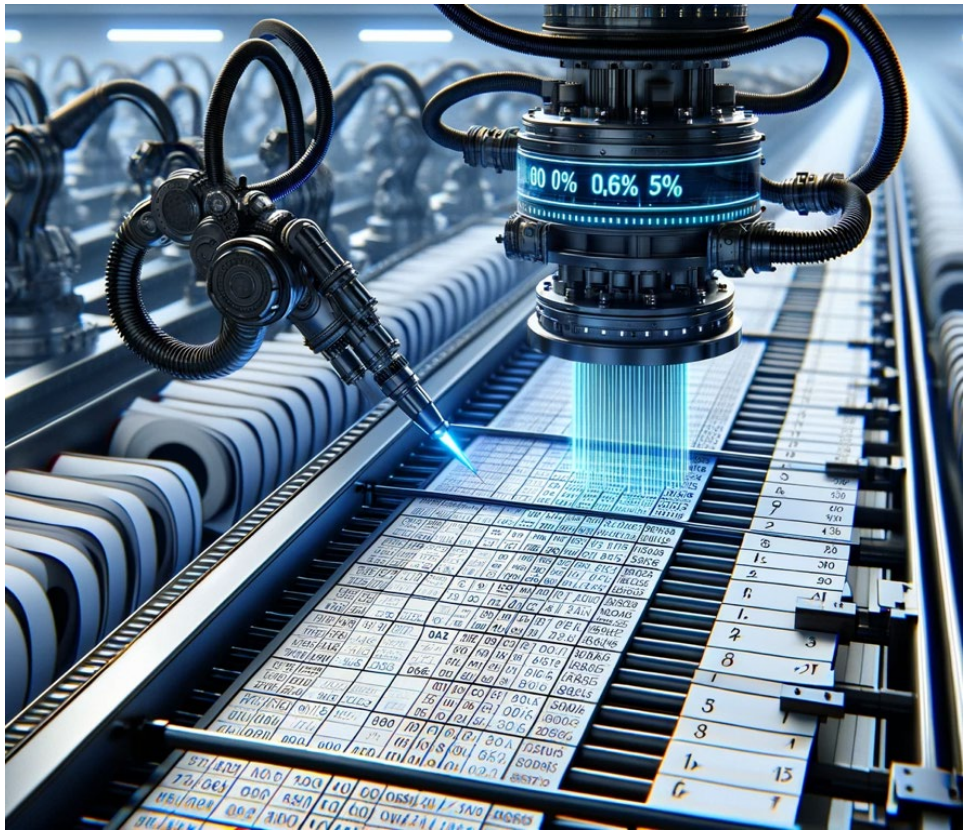
Step 2: Data path ONLY, no Control Path!

- In-device processing
  - Straightforward to implement & utilize
  - Minimal to NO cost difference or design complexity



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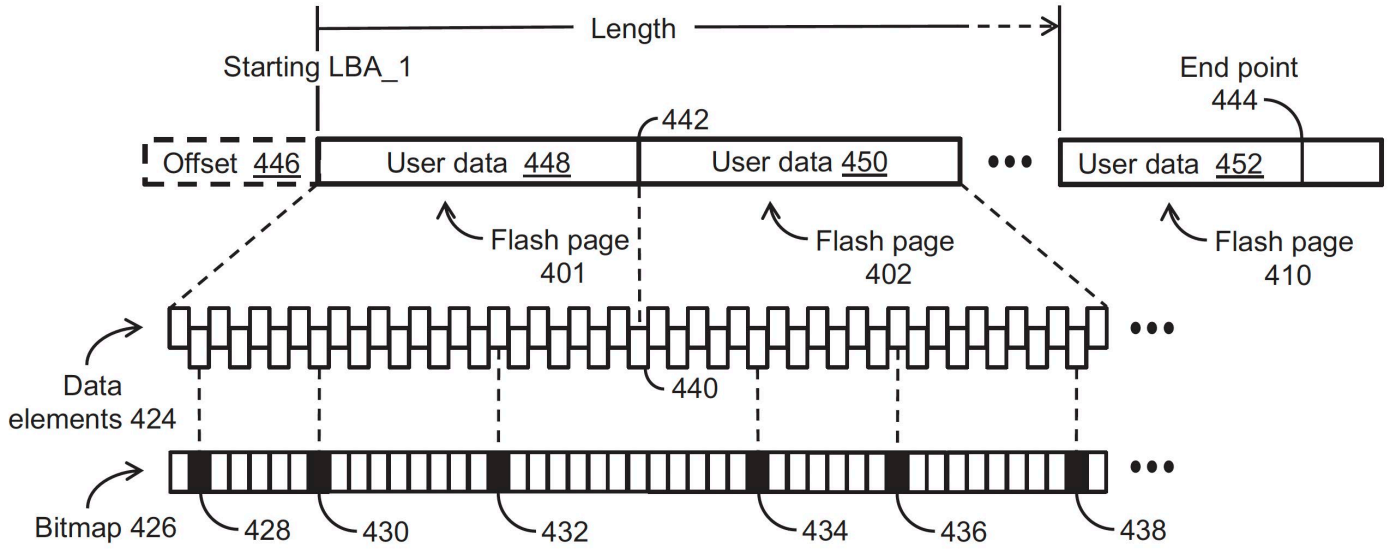
CHECK & FETCH
User-level Datapath APIs



Patent pending

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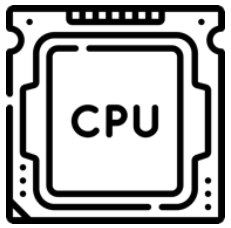
VIRTUAL EVENT, MAY 21-22, 2024

Parquet

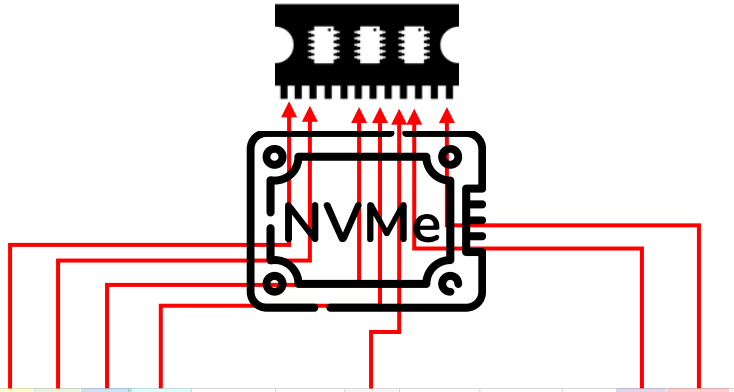
SELECT

Today

```
SELECT
    lo_custkey,
    lo_orderdate,
    lo_partkey,
    lo_revenue,
    lo_suppkey,
    lo_supplycost
FROM
    s3Object
WHERE
    (lo_quantity BETWEEN 11 AND 20)
    AND (lo_orderdate <= 20210116);
```



- Retrieve required columns
  - ~MB per column
- Process Data in CPU
- <0.1% for many queries!



LO_ ORDERKEY	LO_ LINENUMBER	LO_ CUSTKEY	LO_ PARTKEY	LO_ SUPPKEY	LO_ ORDERDATE	LO_ ORDERPRIORITY	LO_ SHIPPRIORITY	LO_ QUANTITY	LO_ EXTENDEDPRICE	LO_ ORDTOTALPRICE	LO_ DISCOUNT	LO_ REVENUE	LO_ SUPPLYCOST	LO_ TAX	LO_ COMMITDATE	LO_ SHIPMODE
685	5	68	341	349	1/1/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	2/1/21	TRUCK
560	5	979	510	942	1/2/21	2-HIGH	2	18	3482.81	13217.61	0.05	20748.27	3752.25	0.05	2/2/21	SHIP
630	7	772	515	283	1/3/21	5-LOW	4	30	6794.8	8005.41	0.03	37516.42	7694.96	0.12	2/3/21	RAIL
193	5	235	70	587	1/4/21	5-LOW	2	13	8804.42	19985.63	0.08	26818.47	3488.45	0.15	2/4/21	RAIL
836	5	717	358	821	1/5/21	5-LOW	2	47	5482.41	7102.67	0.08	24896.14	6744.53	0.05	2/5/21	AIR
764	4	999	909	434	1/6/21	1-URGENT	3	33	2898.73	14455.99	0.09	1026.75	5414.6	0.12	2/6/21	AIR
708	5	292	557	220	1/7/21	1-URGENT	0	35	399.33	12787.9	0	21844.68	5107.17	0.13	2/7/21	SHIP
360	5	727	886	820	1/8/21	3-MEDIUM	4	24	7132.33	16279.77	0.09	4114.13	9061.04	0.19	2/8/21	MAIL
10	9	702	766	740	1/9/21	1-URGENT	2	26	178.05	19526.89	0.04	11204.41	5769.13	0.16	2/9/21	AIR
724	5	710	323	874	1/10/21	4-NOT SPECIFIED	0	47	3789.52	17806.89	0.09	46687.3	8355.19	0.17	2/10/21	AIR
278	4	728	624	787	1/11/21	4-NOT SPECIFIED	0	44	5352.32	15314.78	0.07	11554.51	7392.95	0.1	2/11/21	SHIP
755	8	556	92	374	1/12/21	5-LOW	2	42	9228.9	13995.14	0.1	43058.54	866.29	0.04	2/12/21	AIR
805	6	33	342	291	1/13/21	2-HIGH	3	47	986	6776.41	0.08	40341.78	7844.55	0.2	2/13/21	SHIP
600	6	12	424	564	1/14/21	5-LOW	1	1	4118.83	3038.94	0.04	8798.17	2560.27	0.03	2/14/21	REG AIR
71	1	617	552	671	1/15/21	4-NOT SPECIFIED	3	13	340.7	1346.46	0.05	30679.89	9079.92	0.09	2/15/21	SHIP
473	2	213	972	438	1/16/21	4-NOT SPECIFIED	2	10	3491.85	4913.84	0.04	6667.43	907.78	0.01	2/16/21	AIR
601	6	139	663	827	1/17/21	4-NOT SPECIFIED	4	19	6260.09	8702.4	0.04	36666.52	3664.18	0.19	2/17/21	MAIL
397	4	695	415	940	1/18/21	5-LOW	1	5	2862.77	10487.73	0.03	32235.65	1447.46	0.19	2/18/21	TRUCK
315	1	422	658	824	1/19/21	3-MEDIUM	1	8	2176.52	15484.36	0.05	40784.99	5018.1	0.14	2/19/21	TRUCK
706	6	638	711	509	1/20/21	2-HIGH	2	4	1245.46	19178.94	0.07	24489.84	8290.21	0.07	2/20/21	SHIP
487	1	669	968	787	1/21/21	3-MEDIUM	2	49	5813.69	2434.68	0.03	45828.29	3332.78	0.05	2/21/21	MAIL
552	2	624	275	942	1/22/21	3-MEDIUM	4	13	6983.17	2229.38	0.05	3418.1	1933.88	0.05	2/22/21	TRUCK
88	3	489	861	856	1/23/21	2-HIGH	3	38	6752.38	11834.92	0.01	15351.54	3637.54	0.03	2/23/21	MAIL
175	5	771	44	450	1/24/21	4-NOT SPECIFIED	4	46	9493.72	14933.42	0.02	36037.58	8231.86	0.11	2/24/21	TRUCK
601	3	540	84	327	1/25/21	4-NOT SPECIFIED	2	49	126.76	16978.19	0	21487.35	1833.65	0.03	2/25/21	AIR
850	1	980	434	491	1/26/21	5-LOW	4	46	6507.25	18723.06	0.1	9474.62	2659.94	0.06	2/26/21	REG AIR
678	4	218	810	54	1/27/21	5-LOW	2	19	6043.88	19670.18	0	6253.33	1154.09	0.13	2/27/21	REG AIR
538	3	664	94	817	1/28/21	3-MEDIUM	1	8	5928.52	8056.05	0.02	41049.62	7204.25	0.15	2/28/21	AIR

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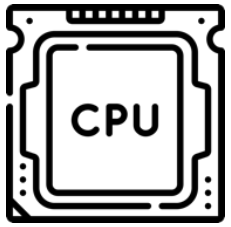
Parquet

SELECT

Today

```
SELECT
    lo_custkey,
    lo_orderdate,
    lo_partkey,
    lo_revenue,
    lo_suppkey,
    lo_supplycost
FROM
    s3Object
WHERE
    (lo_quantity BETWEEN 11 AND 20)
    AND (lo_orderdate <= 20210116);
```



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  - ~MB per column
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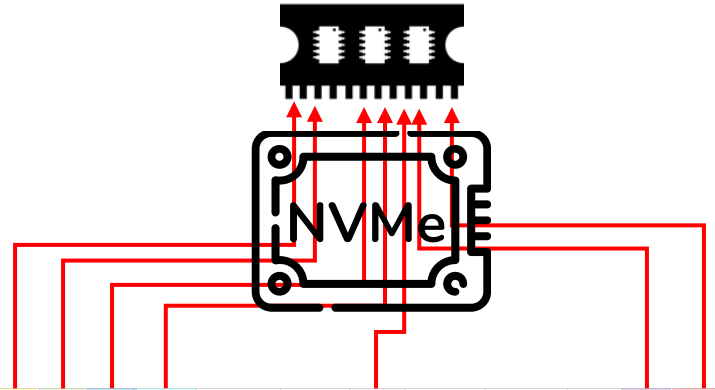

LO_ ORDERKEY	LO_ LINENUMBER	LO_ CUSTKEY	LO_ PARTKEY	LO_ SUPPKEY	LO_ ORDERDATE	LO_ ORDERPRIORITY	LO_ SHIPPRIORITY	LO_ QUANTITY	LO_ EXTENDEDPRICE	LO_ ORDTOTALPRICE	LO_ DISCOUNT	LO_ REVENUE	LO_ SUPPLYCOST	LO_ TAX	LO_ COMMITDATE	LO_ SHIPMODE
685	5	68	341	349	1/1/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	2/1/21	TRUCK
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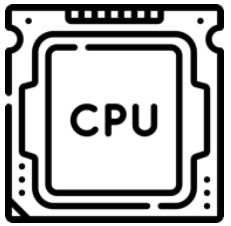
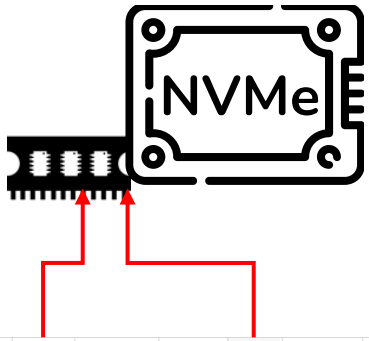
764	4	999	909	434	1/6/21	1-URGENT	3	33	2898.73	14455.99	0.09	1026.75	5414.6	0.12	2/6/21	AIR
708	5	292	557	220	1/7/21	1-URGENT	0	35	399.33	12787.9	0	21844.68	5107.17	0.13	2/7/21	SHIP
360	5	727	886	820	1/8/21	3-MEDIUM	4	24	7132.33	16279.77	0.09	4114.13	9061.04	0.19	2/8/21	MAIL
10	9	702	766	740	1/9/21	1-URGENT	2	26	178.05	19526.89	0.04	11204.41	5769.13	0.16	2/9/21	AIR
724	5	710	323	874	1/10/21	4-NOT SPECIFIED	0	47	3789.52	17806.89	0.09	46687.3	8355.19	0.17	2/10/21	AIR
278	4	728	624	787	1/11/21	4-NOT SPECIFIED	0	44	5352.32	15314.78	0.07	11554.51	7392.95	0.1	2/11/21	SHIP
755	8	556	92	374	1/12/21	5-LOW	2	42	9228.9	13995.14	0.1	43058.54	866.29	0.04	2/12/21	AIR
805	6	33	342	291	1/13/21	2-HIGH	3	47	986	6776.41	0.08	40341.78	7844.55	0.2	2/13/21	SHIP
600	6	12	424	564	1/14/21	5-LOW	1	1	4118.83	3038.94	0.04	8798.17	2560.27	0.03	2/14/21	REG AIR
71	1	617	552	671	1/15/21	4-NOT SPECIFIED	3	13	340.7	1346.46	0.05	30679.89	9079.92	0.09	2/15/21	SHIP
473	2	213	972	438	1/16/21	4-NOT SPECIFIED	2	10	3491.85	4913.84	0.04	6667.43	907.78	0.01	2/16/21	AIR
601	6	139	663	827	1/17/21	4-NOT SPECIFIED	4	19	6260.09	8702.4	0.04	36666.52	3664.18	0.19	2/17/21	MAIL
397	4	695	415	940	1/18/21	5-LOW	1	5	2862.77	10487.73	0.03	32235.65	1447.46	0.19	2/18/21	TRUCK
315	1	422	658	824	1/19/21	3-MEDIUM	1	8	2176.52	15484.36	0.05	40784.99	5018.1	0.14	2/19/21	TRUCK
706	6	638	711	509	1/20/21	2-HIGH	2	4	1245.46	19178.94	0.07	24489.84	8290.21	0.07	2/20/21	SHIP
487	1	669	968	787	1/21/21	3-MEDIUM	2	49	5813.69	2434.68	0.03	45828.29	3332.78	0.05	2/21/21	MAIL
552	2	624	275	942	1/22/21	3-MEDIUM	4	13	6983.17	2229.38	0.05	3418.1	1933.88	0.05	2/22/21	TRUCK
88	3	489	861	856	1/23/21	2-HIGH	3	38	6752.38	11834.92	0.01	15351.54	3637.54	0.03	2/23/21	MAIL
175	5	771	44	450	1/24/21	4-NOT SPECIFIED	4	46	9493.72	14933.42	0.02	36037.58	8231.86	0.11	2/24/21	TRUCK
601	3	540	84	327	1/25/21	4-NOT SPECIFIED	2	49	126.76	16978.19	0	21487.35	1833.65	0.03	2/25/21	AIR
850	1	980	434	491	1/26/21	5-LOW	4	46	6507.25	18723.06	0.1	9474.62	2659.94	0.06	2/26/21	REG AIR
678	4	218	810	54	1/27/21	5-LOW	2	19	6043.88	19670.18	0	6253.33	1154.09	0.13	2/27/21	REG AIR
538	3	664	94	817	1/28/21	3-MEDIUM	1	8	5928.52	8056.05	0.02	41049.62	7204.25	0.15	2/28/21	AIR

With CHECK-FETCH



- Perform basic filtering in device
- Scratchpad can eliminate returning intermediate results



LO_ ORDERKEY	LO_ LINENUMBER	LO_ CUSTKEY	LO_ PARTKEY	LO_ SUPPKEY	LO_ ORDERDATE	LO_ ORDERPRIORITY	LO_ SHIPPRIORITY	LO_ QUANTITY	LO_ EXTENDEDPRICE	LO_ ORDTOTALPRICE	LO_ DISCOUNT	LO_ REVENUE	LO_ SUPPLYCOST	LO_ TAX	LO_ COMMITDATE	LO_ SHIPMODE
685	5	68	341	349	1/1/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	2/1/21	TRUCK
560	5	979	510	942	1/2/21	2-HIGH	2	18	3482.81	13217.61	0.05	20748.27	3752.25	0.05	2/2/21	SHIP
630	7	772	515	283	1/3/21	5-LOW	4	30	6794.8	8005.41	0.03	37516.42	7694.96	0.12	2/3/21	RAIL
193	5	235	70	587	1/4/21	5-LOW	2	13	8804.42	19985.63	0.08	26818.47	3488.45	0.15	2/4/21	RAIL
836	5	717	358	821	1/5/21	5-LOW	2	47	5482.41	7102.67	0.08	24896.14	6744.53	0.05	2/5/21	AIR
764	4	999	909	434	1/6/21	1-URGENT	3	33	2898.73	14455.99	0.09	1026.75	5414.6	0.12	2/6/21	AIR
708	5	292	557	220	1/7/21	1-URGENT	0	35	399.33	12787.9	0	21844.68	5107.17	0.13	2/7/21	SHIP
360	5	727	886	820	1/8/21	3-MEDIUM	4	24	7132.33	16279.77	0.09	4114.13	9061.04	0.19	2/8/21	MAIL
10	9	702	766	740	1/9/21	1-URGENT	2	26	178.05	19526.89	0.04	11204.41	5769.13	0.16	2/9/21	AIR
724	5	710	323	874	1/10/21	4-NOT SPECIFIED	0	47	3789.52	17806.89	0.09	46687.3	8355.19	0.17	2/10/21	AIR
278	4	728	624	787	1/11/21	4-NOT SPECIFIED	0	44	5352.32	15314.78	0.07	11554.51	7392.95	0.1	2/11/21	SHIP
755	8	556	92	374	1/12/21	5-LOW	2	42	9228.9	13995.14	0.1	43058.54	866.29	0.04	2/12/21	AIR
805	6	33	342	291	1/13/21	2-HIGH	3	47	986	6776.41	0.08	40341.78	7844.55	0.2	2/13/21	SHIP
600	6	12	424	564	1/14/21	5-LOW	1	1	4118.83	3038.94	0.04	8798.17	2560.27	0.03	2/14/21	REG AIR
71	1	617	552	671	1/15/21	4-NOT SPECIFIED	3	13	340.7	1346.46	0.05	30679.89	9079.92	0.09	2/15/21	SHIP
473	2	213	972	438	1/16/21	4-NOT SPECIFIED	2	10	3491.85	4913.84	0.04	6667.43	907.78	0.01	2/16/21	AIR
601	6	139	663	827	1/17/21	4-NOT SPECIFIED	4	19	6260.09	8702.4	0.04	36666.52	3664.18	0.19	2/17/21	MAIL
397	4	695	415	940	1/18/21	5-LOW	1	5	2862.77	10487.73	0.03	32235.65	1447.46	0.19	2/18/21	TRUCK
315	1	422	658	824	1/19/21	3-MEDIUM	1	8	2176.52	15484.36	0.05	40784.99	5018.1	0.14	2/19/21	TRUCK
706	6	638	711	509	1/20/21	2-HIGH	2	4	1245.46	19178.94	0.07	24489.84	8290.21	0.07	2/20/21	SHIP
487	1	669	968	787	1/21/21	3-MEDIUM	2	49	5813.69	2434.68	0.03	45828.29	3332.78	0.05	2/21/21	MAIL
552	2	624	275	942	1/22/21	3-MEDIUM	4	13	6983.17	2229.38	0.05	3418.1	1933.88	0.05	2/22/21	TRUCK
88	3	489	861	856	1/23/21	2-HIGH	3	38	6752.38	11834.92	0.01	15351.54	3637.54	0.03	2/23/21	MAIL
175	5	771	44	450	1/24/21	4-NOT SPECIFIED	4	46	9493.72	14933.42	0.02	36037.58	8231.86	0.11	2/24/21	TRUCK
601	3	540	84	327	1/25/21	4-NOT SPECIFIED	2	49	126.76	16978.19	0	21487.35	1833.65	0.03	2/25/21	AIR
850	1	980	434	491	1/26/21	5-LOW	4	46	6507.25	18723.06	0.1	9474.62	2659.94	0.06	2/26/21	REG AIR
678	4	218	810	54	1/27/21	5-LOW	2	19	6043.88	19670.18	0	6253.33	1154.09	0.13	2/27/21	REG AIR
538	3	664	94	817	1/28/21	3-MEDIUM	1	8	5928.52	8056.05	0.02	41049.62	7204.25	0.15	2/28/21	AIR

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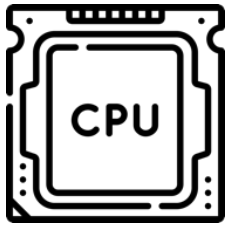
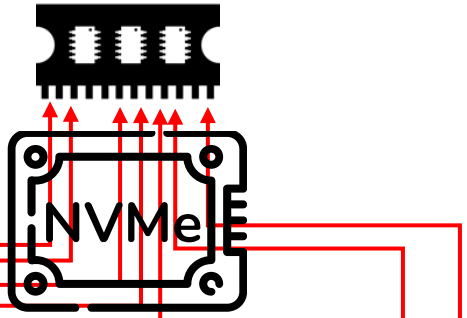
Parquet SELECT

Today

```
SELECT
    lo_custkey,
    lo_orderdate,
    lo_partkey,
    lo_revenue,
    lo_suppkey,
    lo_supplycost
FROM
    s3Object
WHERE
    (lo_quantity BETWEEN 11 AND 20)
    AND (lo_orderdate <= 20210116);
```

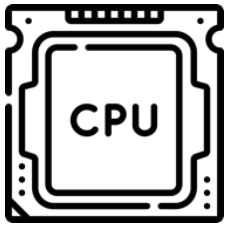


- Retrieve required columns
  - ~MB per column
- Process Data in CPU
- <0.1% for many queries!

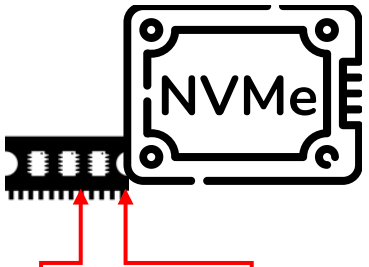


LO_ ORDERKEY	LO_ LINENUMBER	LO_ CUSTKEY	LO_ PARTKEY	LO_ SUPPKEY	LO_ ORDERDATE	LO_ ORDERPRIORITY	LO_ SHIPPRIORITY	LO_ QUANTITY	LO_ EXTENDEDPRICE	LO_ ORDTOTALPRICE	LO_ DISCOUNT	LO_ REVENUE	LO_ SUPPLYCOST	LO_ TAX	LO_ COMMITDATE	LO_ SHIPMODE
685	5	68	341	349	1/1/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	2/1/21	TRUCK
560	5	979	510	942	1/2/21	2-HIGH	2	18	3482.81	13217.61	0.05	20748.27	3752.25	0.05	2/2/21	SHIP
630	7	772	515	283	1/3/21	5-LOW	4	30	6794.8	8005.41	0.03	37516.42	7694.96	0.12	2/3/21	RAIL
193	5	235	70	587	1/4/21	5-LOW	2	13	8804.42	19985.63	0.08	26818.47	3488.45	0.15	2/4/21	RAIL
836	5	717	358	821	1/5/21	5-LOW	2	47	5482.41	7102.67	0.08	24896.14	6744.53	0.05	2/5/21	AIR
764	4	999	909	434	1/6/21	1-URGENT	3	33	2898.73	14455.99	0.09	1026.75	5414.6	0.12	2/6/21	AIR
708	5	292	557	220	1/7/21	1-URGENT	0	35	399.33	12787.9	0	21844.68	5107.17	0.13	2/7/21	SHIP
360	5	727	886	820	1/8/21	3-MEDIUM	4	24	7132.33	16279.77	0.09	4114.13	9061.04	0.19	2/8/21	MAIL
10	9	702	766	740	1/9/21	1-URGENT	2	26	178.05	19526.89	0.04	11204.41	5769.13	0.16	2/9/21	AIR
724	5	710	323	874	1/10/21	4-NOT SPECIFIED	0	47	3789.52	17806.89	0.09	46687.3	8355.19	0.17	2/10/21	AIR
278	4	728	624	787	1/11/21	4-NOT SPECIFIED	0	44	5352.32	15314.78	0.07	11554.51	7392.95	0.1	2/11/21	SHIP
755	8	556	92	374	1/12/21	5-LOW	2	42	9228.9	13995.14	0.1	43058.54	866.29	0.04	2/12/21	AIR
805	6	33	342	291	1/13/21	2-HIGH	3	47	986	6776.41	0.08	40341.78	7844.55	0.2	2/13/21	SHIP
600	6	12	424	564	1/14/21	5-LOW	1	1	4118.83	3038.94	0.04	8798.17	2560.27	0.03	2/14/21	REG AIR
71	1	617	552	671	1/15/21	4-NOT SPECIFIED	3	13	340.7	1346.46	0.05	30679.89	9079.92	0.09	2/15/21	SHIP
473	2	213	972	438	1/16/21	4-NOT SPECIFIED	2	10	3491.85	4913.84	0.04	6667.43	907.78	0.01	2/16/21	AIR
601	6	139	663	827	1/17/21	4-NOT SPECIFIED	4	19	6260.09	8702.4	0.04	36666.52	3664.18	0.19	2/17/21	MAIL
397	4	695	415	940	1/18/21	5-LOW	1	5	2862.77	10487.73	0.03	32235.65	1447.46	0.19	2/18/21	TRUCK
315	1	422	658	824	1/19/21	3-MEDIUM	1	8	2176.52	15484.36	0.05	40784.99	5018.1	0.14	2/19/21	TRUCK
706	6	638	711	509	1/20/21	2-HIGH	2	4	1245.46	19178.94	0.07	24489.84	8290.21	0.07	2/20/21	SHIP
487	1	669	968	787	1/21/21	3-MEDIUM	2	49	5813.69	2434.68	0.03	45828.29	3332.78	0.05	2/21/21	MAIL
552	2	624	275	942	1/22/21	3-MEDIUM	4	13	6983.17	2229.38	0.05	3418.1	1933.88	0.05	2/22/21	TRUCK
88	3	489	861	856	1/23/21	2-HIGH	3	38	6752.38	11834.92	0.01	15351.54	3637.54	0.03	2/23/21	MAIL
175	5	771	44	450	1/24/21	4-NOT SPECIFIED	4	46	9493.72	14933.42	0.02	36037.58	8231.86	0.11	2/24/21	TRUCK
601	3	540	84	327	1/25/21	4-NOT SPECIFIED	2	49	126.76	16978.19	0	21487.35	1833.65	0.03	2/25/21	AIR
850	1	980	434	491	1/26/21	5-LOW	4	46	6507.25	18723.06	0.1	9474.62	2659.94	0.06	2/26/21	REG AIR
678	4	218	810	54	1/27/21	5-LOW	2	19	6043.88	19670.18	0	6253.33	1154.09	0.13	2/27/21	REG AIR
538	3	664	94	817	1/28/21	3-MEDIUM	1	8	5928.52	8056.05	0.02	41049.62	7204.25	0.15	2/28/21	AIR

With CHECK-FETCH



- Perform basic filtering in device
- Scratchpad can eliminate returning intermediate results
- Bitwise operators: combine results



LO_ ORDERKEY	LO_ LINENUMBER	LO_ CUSTKEY	LO_ PARTKEY	LO_ SUPPKEY	LO_ ORDERDATE	LO_ ORDERPRIORITY	LO_ SHIPPRIORITY	LO_ QUANTITY	LO_ EXTENDEDPRICE	LO_ ORDTOTALPRICE	LO_ DISCOUNT	LO_ REVENUE	LO_ SUPPLYCOST	LO_ TAX	LO_ COMMITDATE	LO_ SHIPMODE
685	5	68	341	349	1/1/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	2/1/21	TRUCK
560	5	979	510	942	1/2/21	2-HIGH	2	18	3482.81	13217.61	0.05	20748.27	3752.25	0.05	2/2/21	SHIP
630	7	772	515	283	1/3/21	5-LOW	4	30	6794.8	8005.41	0.03	37516.42	7694.96	0.12	2/3/21	RAIL
193	5	235	70	587	1/4/21	5-LOW	2	13	8804.42	19985.63	0.08	26818.47	3488.45	0.15	2/4/21	RAIL
836	5	717	358	821	1/5/21	5-LOW	2	47	5482.41	7102.67	0.08	24896.14	6744.53	0.05	2/5/21	AIR
764	4	999	909	434	1/6/21	1-URGENT	3	33	2898.73	14455.99	0.09	1026.75	5414.6	0.12	2/6/21	AIR
708	5	292	557	220	1/7/21	1-URGENT	0	35	399.33	12787.9	0	21844.68	5107.17	0.13	2/7/21	SHIP
360	5	727	886	820	1/8/21	3-MEDIUM	4	24	7132.33	16279.77	0.09	4114.13	9061.04	0.19	2/8/21	MAIL
10	9	702	766	740	1/9/21	1-URGENT	2	26	178.05	19526.89	0.04	11204.41	5769.13	0.16	2/9/21	AIR
724	5	710	323	874	1/10/21	4-NOT SPECIFIED	0	47	3789.52	17806.89	0.09	46687.3	8355.19	0.17	2/10/21	AIR
278	4	728	624	787	1/11/21	4-NOT SPECIFIED	0	44	5352.32	15314.78	0.07	11554.51	7392.95	0.1	2/11/21	SHIP
755	8	556	92	374	1/12/21	5-LOW	2	42	9228.9	13995.14	0.1	43058.54	866.29	0.04	2/12/21	AIR
805	6	33	342	291	1/13/21	2-HIGH	3	47	986	6776.41	0.08	40341.78	7844.55	0.2	2/13/21	SHIP
600	6	12	424	564	1/14/21	5-LOW	1	1	4118.83	3038.94	0.04	8798.17	2560.27	0.03	2/14/21	REG AIR
71	1	617	552	671	1/15/21	4-NOT SPECIFIED	3	13	340.7	1346.46	0.05	30679.89	9079.92	0.09	2/15/21	SHIP
473	2	213	972	438	1/16/21	4-NOT SPECIFIED	2	10	3491.85	4913.84	0.04	6667.43	907.78	0.01	2/16/21	AIR
601	6	139	663	827	1/17/21	4-NOT SPECIFIED	4	19	6260.09	8702.4	0.04	36666.52	3664.18	0.19	2/17/21	MAIL
397	4	695	415	940	1/18/21	5-LOW	1	5	2862.77	10487.73	0.03	32235.65	1447.46	0.19	2/18/21	TRUCK
315	1	422	658	824	1/19/21	3-MEDIUM	1	8	2176.52	15484.36	0.05	40784.99	5018.1	0.14	2/19/21	TRUCK
706	6	638	711	509	1/20/21	2-HIGH	2	4	1245.46	19178.94	0.07	24489.84	8290.21	0.07	2/20/21	SHIP
487	1	669	968	787	1/21/21	3-MEDIUM	2	49	5813.69	2434.68	0.03	45828.29	3332.78	0.05	2/21/21	MAIL
552	2	624	275	942	1/22/21	3-MEDIUM	4	13	6983.17	2229.38	0.05	3418.1	1933.88	0.05	2/22/21	TRUCK
88	3	489	861	856	1/23/21	2-HIGH	3	38	6752.38	11834.92	0.01	15351.54	3637.54	0.03	2/23/21	MAIL
175	5	771	44	450	1/24/21	4-NOT SPECIFIED	4	46	9493.72	14933.42	0.02	36037.58	8231.86	0.11	2/24/21	TRUCK
601	3	540	84	327	1/25/21	4-NOT SPECIFIED	2	49	126.76	16978.19	0	21487.35	1833.65	0.03	2/25/21	AIR
850	1	980	434	491	1/26/21	5-LOW	4	46	6507.25	18723.06	0.1	9474.62	2659.94	0.06	2/26/21	REG AIR
678	4	218	810	54	1/27/21	5-LOW	2	19	6043.88	19670.18	0	6253.33	1154.09	0.13	2/27/21	REG AIR
538	3	664	94	817	1/28/21	3-MEDIUM	1	8	5928.52	8056.05	0.02	41049.62	7204.25	0.15	2/28/21	AIR

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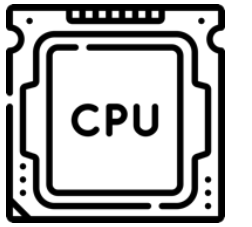
Parquet

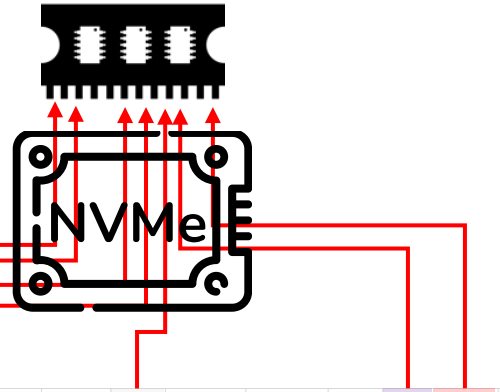
SELECT

Today

```
SELECT
    lo_custkey,
    lo_orderdate,
    lo_partkey,
    lo_revenue,
    lo_suppkey,
    lo_supplycost
FROM
    s3Object
WHERE
    (lo_quantity BETWEEN 11 AND 20)
    AND (lo_orderdate <= 20210116);
```

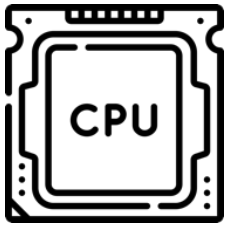


- Retrieve required columns
  - ~MB per column
- Process Data in CPU
- <0.1% for many queries!



LO_ ORDERKEY	LO_ LINENUMBER	LO_ CUSTKEY	LO_ PARTKEY	LO_ SUPPKEY	LO_ ORDERDATE	LO_ ORDERPRIORITY	LO_ SHIPPRIORITY	LO_ QUANTITY	LO_ EXTENDEDPRICE	LO_ ORDTOTALPRICE	LO_ DISCOUNT	LO_ REVENUE	LO_ SUPPLYCOST	LO_ TAX	LO_ COMMITDATE	LO_ SHIPMODE
685	5	68	341	349	1/1/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	2/1/21	TRUCK
560	5	979	510	942	1/2/21	2-HIGH	2	18	3482.81	13217.61	0.05	20748.27	3752.25	0.05	2/2/21	SHIP
630	7	772	515	283	1/3/21	5-LOW	4	30	6794.8	8005.41	0.03	37516.42	7694.96	0.12	2/3/21	RAIL
193	5	235	70	587	1/4/21	5-LOW	2	13	8804.42	19985.63	0.08	26818.47	3488.45	0.15	2/4/21	RAIL
836	5	717	358	821	1/5/21	5-LOW	2	47	5482.41	7102.67	0.08	24896.14	6744.53	0.05	2/5/21	AIR
764	4	999	909	434	1/6/21	1-URGENT	3	33	2898.73	14455.99	0.09	1026.75	5414.6	0.12	2/6/21	AIR
708	5	292	557	220	1/7/21	1-URGENT	0	35	399.33	12787.9	0	21844.68	5107.17	0.13	2/7/21	SHIP
360	5	727	886	820	1/8/21	3-MEDIUM	4	24	7132.33	16279.77	0.09	4114.13	9061.04	0.19	2/8/21	MAIL
10	9	702	766	740	1/9/21	1-URGENT	2	26	178.05	19526.89	0.04	11204.41	5769.13	0.16	2/9/21	AIR
724	5	710	323	874	1/10/21	4-NOT SPECIFIED	0	47	3789.52	17806.89	0.09	46687.3	8355.19	0.17	2/10/21	AIR
278	4	728	624	787	1/11/21	4-NOT SPECIFIED	0	44	5352.32	15314.78	0.07	11554.51	7392.95	0.1	2/11/21	SHIP
755	8	556	92	374	1/12/21	5-LOW	2	42	9228.9	13995.14	0.1	43058.54	866.29	0.04	2/12/21	AIR
805	6	33	342	291	1/13/21	2-HIGH	3	47	986	6776.41	0.08	40341.78	7844.55	0.2	2/13/21	SHIP
600	6	12	424	564	1/14/21	5-LOW	1	1	4118.83	3038.94	0.04	8798.17	2560.27	0.03	2/14/21	REG AIR
71	1	617	552	671	1/15/21	4-NOT SPECIFIED	3	13	340.7	1346.46	0.05	30679.89	9079.92	0.09	2/15/21	SHIP
473	2	213	972	438	1/16/21	4-NOT SPECIFIED	2	10	3491.85	4913.84	0.04	6667.43	907.78	0.01	2/16/21	AIR
601	6	139	663	827	1/17/21	4-NOT SPECIFIED	4	19	6260.09	8702.4	0.04	36666.52	3664.18	0.19	2/17/21	MAIL
397	4	695	415	940	1/18/21	5-LOW	1	5	2862.77	10487.73	0.03	32235.65	1447.46	0.19	2/18/21	TRUCK
315	1	422	658	824	1/19/21	3-MEDIUM	1	8	2176.52	15484.36	0.05	40784.99	5018.1	0.14	2/19/21	TRUCK
706	6	638	711	509	1/20/21	2-HIGH	2	4	1245.46	19178.94	0.07	24489.84	8290.21	0.07	2/20/21	SHIP
487	1	669	968	787	1/21/21	3-MEDIUM	2	49	5813.69	2434.68	0.03	45828.29	3332.78	0.05	2/21/21	MAIL
552	2	624	275	942	1/22/21	3-MEDIUM	4	13	6983.17	2229.38	0.05	3418.1	1933.88	0.05	2/22/21	TRUCK
88	3	489	861	856	1/23/21	2-HIGH	3	38	6752.38	11834.92	0.01	15351.54	3637.54	0.03	2/23/21	MAIL
175	5	771	44	450	1/24/21	4-NOT SPECIFIED	4	46	9493.72	14933.42	0.02	36037.58	8231.86	0.11	2/24/21	TRUCK
601	3	540	84	327	1/25/21	4-NOT SPECIFIED	2	49	126.76	16978.19	0	21487.35	1833.65	0.03	2/25/21	AIR
850	1	980	434	491	1/26/21	5-LOW	4	46	6507.25	18723.06	0.1	9474.62	2659.94	0.06	2/26/21	REG AIR
678	4	218	810	54	1/27/21	5-LOW	2	19	6043.88	19670.18	0	6253.33	1154.09	0.13	2/27/21	REG AIR
538	3	664	94	817	1/28/21	3-MEDIUM	1	8	5928.52	8056.05	0.02	41049.62	7204.25	0.15	2/28/21	AIR

With CHECK-FETCH



- Perform basic filtering in device
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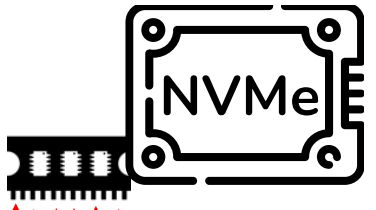
- Extract only desired data



LO_ CUSTKEY	LO_ ORDERDATE	LO_ PARTKEY	LO_ REVENUE	LO_ SUPPKEY	LO_ SUPPLYCOST
979	1/2/21	510	20748.27	942	3752.25
235	1/4/21	70	26818.47	587	3488.45
617	1/15/21	552	30679.89	671	9079.92

LO_ ORDERKEY	LO_ LINENUMBER	LO_ CUSTKEY	LO_ PARTKEY	LO_ SUPPKEY	LO_ ORDERDATE	LO_ ORDERPRIORITY	LO_ SHIPPRIORITY	LO_ QUANTITY	LO_ EXTENDEDPRICE	LO_ ORDTOTALPRICE	LO_ DISCOUNT	LO_ REVENUE	LO_ SUPPLYCOST	LO_ TAX	LO_ COMMITDATE	LO_ SHIPMODE
685	5	68	341	349	1/1/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	2/1/21	TRUCK
560	5	979	510	942	1/2/21	2-HIGH	2	18	3482.81	13217.61	0.05	20748.27	3752.25	0.05	2/2/21	SHIP
630	7	772	515	283	1/3/21	5-LOW	4	30	6794.8	8005.41	0.03	37516.42	7694.96	0.12	2/3/21	RAIL
193	5	235	70	587	1/4/21	5-LOW	2	13	8804.42	19985.63	0.08	26818.47	3488.45	0.15	2/4/21	RAIL
836	5	717	358	821	1/5/21	5-LOW	2	47	5482.41	7102.67	0.08	24896.14	6744.53	0.05	2/5/21	AIR
764	4	999	909	434	1/6/21	1-URGENT	3	33	2898.73	14455.99	0.09	1026.75	5414.6	0.12	2/6/21	AIR
708	5	292	557	220	1/7/21	1-URGENT	0	35	399.33	12787.9	0	21844.68	5107.17	0.13	2/7/21	SHIP
360	5	727	886	820	1/8/21	3-MEDIUM	4	24	7132.33	16279.77	0.09	4114.13	9061.04	0.19	2/8/21	MAIL
10	9	702	766	740	1/9/21	1-URGENT	2	26	178.05	19526.89	0.04	11204.41	5769.13	0.16	2/9/21	AIR
724	5	710	323	874	1/10/21	4-NOT SPECIFIED	0	47	3789.52	17806.89	0.09	46687.3	8355.19	0.17	2/10/21	AIR
278	4	728	624	787	1/11/21	4-NOT SPECIFIED	0	44	5352.32	15314.78	0.07	11554.51	7392.95	0.1	2/11/21	SHIP
755	8	556	92	374	1/12/21	5-LOW	2	42	9228.9	13995.14	0.1	43058.54	866.29	0.04	2/12/21	AIR
805	6	33	342	291	1/13/21	2-HIGH	3	47	986	6776.41	0.08	40341.78	7844.55	0.2	2/13/21	SHIP
600	6	12	424	564	1/14/21	5-LOW	1	1	4118.83	3038.94	0.04	8798.17	2560.27	0.03	2/14/21	REG AIR
71	1	617	552	671	1/15/21	4-NOT SPECIFIED	3	13	340.7	1346.46	0.05	30679.89	9079.92	0.09	2/15/21	SHIP
473	2	213	972	438	1/16/21	4-NOT SPECIFIED	2	10	3491.85	4913.84	0.04	6667.43	907.78	0.01	2/16/21	AIR
601	6	139	663	827	1/17/21	4-NOT SPECIFIED	4	19	6260.09	8702.4	0.04	36666.52	3664.18	0.19	2/17/21	MAIL
397	4	695	415	940	1/18/21	5-LOW	1	5	2862.77	10487.73	0.03	32235.65	1447.46	0.19	2/18/21	TRUCK
315	1	422	658	824	1/19/21	3-MEDIUM	1	8	2176.52	15484.36	0.05	40784.99	5018.1	0.14	2/19/21	TRUCK
706	6	638	711	509	1/20/21	2-HIGH	2	4	1245.46	19178.94	0.07	24489.84	8290.21	0.07	2/20/21	SHIP
487	1	669	968	787	1/21/21	3-MEDIUM	2	49	5813.69	2434.68	0.03	45828.29	3332.78	0.05	2/21/21	MAIL
552	2	624	275	942	1/22/21	3-MEDIUM	4	13	6983.17	2229.38	0.05	3418.1	1933.88	0.05	2/22/21	TRUCK
88	3	489	861	856	1/23/21	2-HIGH	3	38	6752.38	11834.92	0.01	15351.54	3637.54	0.03	2/23/21	MAIL
175	5	771	44	450	1/24/21	4-NOT SPECIFIED	4	46	9493.72	14933.42	0.02	36037.58	8231.86	0.11	2/24/21	TRUCK
601	3	540	84	327	1/25/21	4-NOT SPECIFIED	2	49	126.76	16978.19	0	21487.35	1833.65	0.03	2/25/21	AIR
850	1	980	434	491	1/26/21	5-LOW	4	46	6507.25	18723.06	0.1	9474.62	2659.94	0.06	2/26/21	REG AIR
678	4	218	810	54	1/27/21	5-LOW	2	19	6043.88	19670.18	0	6253.33	1154.09	0.13	2/27/21	REG AIR
538	3	664	94	817	1/28/21	3-MEDIUM	1	8	5928.52	8056.05	0.02	41049.62	7204.25	0.15	2/28/21	AIR

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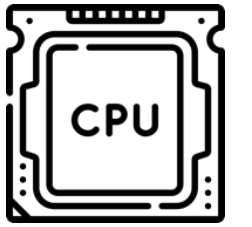
Parquet

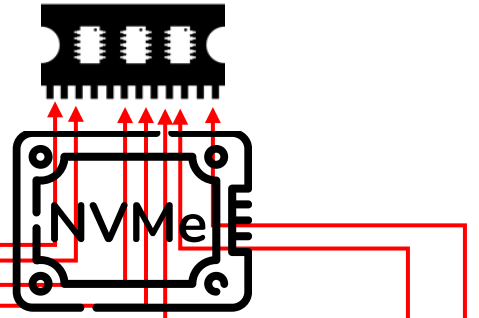
SELECT

Today

```
SELECT
    lo_custkey,
    lo_orderdate,
    lo_partkey,
    lo_revenue,
    lo_suppkey,
    lo_supplycost
FROM
    s3Object
WHERE
    (lo_quantity BETWEEN 11 AND 20)
    AND (lo_orderdate <= 20210116);
```

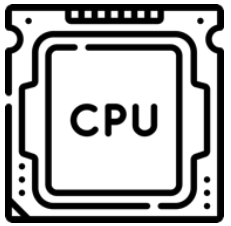


- Retrieve required columns
  - ~MB per column
- Process Data in CPU
- <0.1% for many queries!



LO_ ORDERKEY	LO_ LINENUMBER	LO_ CUSTKEY	LO_ PARTKEY	LO_ SUPPKEY	LO_ ORDERDATE	LO_ ORDERPRIORITY	LO_ SHIPPRIORITY	LO_ QUANTITY	LO_ EXTENDEDPRICE	LO_ ORDTOTALPRICE	LO_ DISCOUNT	LO_ REVENUE	LO_ SUPPLYCOST	LO_ TAX	LO_ COMMITDATE	LO_ SHIPMODE
685	5	68	341	349	1/1/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	2/1/21	TRUCK
560	5	979	510	942	1/2/21	2-HIGH	2	18	3482.81	13217.61	0.05	20748.27	3752.25	0.05	2/2/21	SHIP
630	7	772	515	283	1/3/21	5-LOW	4	30	6794.8	8005.41	0.03	37516.42	7694.96	0.12	2/3/21	RAIL
193	5	235	70	587	1/4/21	5-LOW	2	13	8804.42	19985.63	0.08	26818.47	3488.45	0.15	2/4/21	RAIL
836	5	717	358	821	1/5/21	5-LOW	2	47	5482.41	7102.67	0.08	24896.14	6744.53	0.05	2/5/21	AIR
764	4	999	909	434	1/6/21	1-URGENT	3	33	2898.73	14455.99	0.09	1026.75	5414.6	0.12	2/6/21	AIR
708	5	292	557	220	1/7/21	1-URGENT	0	35	399.33	12787.9	0	21844.68	5107.17	0.13	2/7/21	SHIP
360	5	727	886	820	1/8/21	3-MEDIUM	4	24	7132.33	16279.77	0.09	4114.13	9061.04	0.19	2/8/21	MAIL
10	9	702	766	740	1/9/21	1-URGENT	2	26	178.05	19526.89	0.04	11204.41	5769.13	0.16	2/9/21	AIR
724	5	710	323	874	1/10/21	4-NOT SPECIFIED	0	47	3789.52	17806.89	0.09	46687.3	8355.19	0.17	2/10/21	AIR
278	4	728	624	787	1/11/21	4-NOT SPECIFIED	0	44	5352.32	15314.78	0.07	11554.51	7392.95	0.1	2/11/21	SHIP
755	8	556	92	374	1/12/21	5-LOW	2	42	9228.9	13995.14	0.1	43058.54	866.29	0.04	2/12/21	AIR
805	6	33	342	291	1/13/21	2-HIGH	3	47	986	6776.41	0.08	40341.78	7844.55	0.2	2/13/21	SHIP
600	6	12	424	564	1/14/21	5-LOW	1	1	4118.83	3038.94	0.04	8798.17	2560.27	0.03	2/14/21	REG AIR
71	1	617	552	671	1/15/21	4-NOT SPECIFIED	3	13	340.7	1346.46	0.05	30679.89	9079.92	0.09	2/15/21	SHIP
473	2	213	972	438	1/16/21	4-NOT SPECIFIED	2	10	3491.85	4913.84	0.04	6667.43	907.78	0.01	2/16/21	AIR
601	6	139	663	827	1/17/21	4-NOT SPECIFIED	4	19	6260.09	8702.4	0.04	36666.52	3664.18	0.19	2/17/21	MAIL
397	4	695	415	940	1/18/21	5-LOW	1	5	2862.77	10487.73	0.03	32235.65	1447.46	0.19	2/18/21	TRUCK
315	1	422	658	824	1/19/21	3-MEDIUM	1	8	2176.52	15484.36	0.05	40784.99	5018.1	0.14	2/19/21	TRUCK
706	6	638	711	509	1/20/21	2-HIGH	2	4	1245.46	19178.94	0.07	24489.84	8290.21	0.07	2/20/21	SHIP
487	1	669	968	787	1/21/21	3-MEDIUM	2	49	5813.69	2434.68	0.03	45828.29	3332.78	0.05	2/21/21	MAIL
552	2	624	275	942	1/22/21	3-MEDIUM	4	13	6983.17	2229.38	0.05	3418.1	1933.88	0.05	2/22/21	TRUCK
88	3	489	861	856	1/23/21	2-HIGH	3	38	6752.38	11834.92	0.01	15351.54	3637.54	0.03	2/23/21	MAIL
175	5	771	44	450	1/24/21	4-NOT SPECIFIED	4	46	9493.72	14933.42	0.02	36037.58	8231.86	0.11	2/24/21	TRUCK
601	3	540	84	327	1/25/21	4-NOT SPECIFIED	2	49	126.76	16978.19	0	21487.35	1833.65	0.03	2/25/21	AIR
850	1	980	434	491	1/26/21	5-LOW	4	46	6507.25	18723.06	0.1	9474.62	2659.94	0.06	2/26/21	REG AIR
678	4	218	810	54	1/27/21	5-LOW	2	19	6043.88	19670.18	0	6253.33	1154.09	0.13	2/27/21	REG AIR
538	3	664	94	817	1/28/21	3-MEDIUM	1	8	5928.52	8056.05	0.02	41049.62	7204.25	0.15	2/28/21	AIR

With CHECK-FETCH



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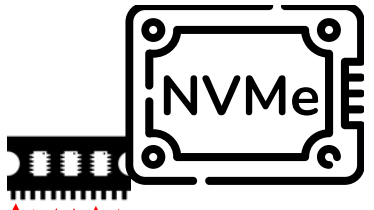

LO_ CUSTKEY	LO_ ORDERDATE	LO_ PARTKEY	LO_ REVENUE	LO_ SUPPKEY	LO_ SUPPLYCOST
979	1/2/21	510	20748.27	942	3752.25
235	1/4/21	70	26818.47	587	3488.45
617	1/15/21	552	30679.89	671	9079.92

LO_ ORDERKEY	LO_ LINENUMBER	LO_ CUSTKEY	LO_ PARTKEY	LO_ SUPPKEY	LO_ ORDERDATE	LO_ ORDERPRIORITY	LO_ SHIPPRIORITY	LO_ QUANTITY	LO_ EXTENDEDPRICE	LO_ ORDTOTALPRICE	LO_ DISCOUNT	LO_ REVENUE	LO_ SUPPLYCOST	LO_ TAX	LO_ COMMITDATE	LO_ SHIPMODE
685	5	68	341	349	1/1/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	2/1/21	TRUCK
560	5	979	510	942	1/2/21	2-HIGH	2	18	3482.81	13217.61	0.05	20748.27	3752.25	0.05	2/2/21	SHIP
630	7	772	515	283	1/3/21	5-LOW	4	30	6794.8	8005.41	0.03	37516.42	7694.96	0.12	2/3/21	RAIL
193	5	235	70	587	1/4/21	5-LOW	2	13	8804.42	19985.63	0.08	26818.47	3488.45	0.15	2/4/21	RAIL
836	5	717	358	821	1/5/21	5-LOW	2	47	5482.41	7102.67	0.08	24896.14	6744.53	0.05	2/5/21	AIR
764	4	999	909	434	1/6/21	1-URGENT	3	33	2898.73	14455.99	0.09	1026.75	5414.6	0.12	2/6/21	AIR
708	5	292	557	220	1/7/21	1-URGENT	0	35	399.33	12787.9	0	21844.68	5107.17	0.13	2/7/21	SHIP
360	5	727	886	820	1/8/21	3-MEDIUM	4	24	7132.33	16279.77	0.09	4114.13	9061.04	0.19	2/8/21	MAIL
10	9	702	766	740	1/9/21	1-URGENT	2	26	178.05	19526.89	0.04	11204.41	5769.13	0.16	2/9/21	AIR
724	5	710	323	874	1/10/21	4-NOT SPECIFIED	0	47	3789.52	17806.89	0.09	46687.3	8355.19	0.17	2/10/21	AIR
278	4	728	624	787	1/11/21	4-NOT SPECIFIED	0	44	5352.32	15314.78	0.07	11554.51	7392.95	0.1	2/11/21	SHIP
755	8	556	92	374	1/12/21	5-LOW	2	42	9228.9	13995.14	0.1	43058.54	866.29	0.04	2/12/21	AIR
805	6	33	342	291	1/13/21	2-HIGH	3	47	986	6776.41	0.08	40341.78	7844.55	0.2	2/13/21	SHIP
600	6	12	424	564	1/14/21	5-LOW	1	1	4118.83	3038.94	0.04	8798.17	2560.27	0.03	2/14/21	REG AIR
71	1	617	552	671	1/15/21	4-NOT SPECIFIED	3	13	340.7	1346.46	0.05	30679.89	9079.92	0.09	2/15/21	SHIP
473	2	213	972	438	1/16/21	4-NOT SPECIFIED	2	10	3491.85	4913.84	0.04	6667.43	907.78	0.01	2/16/21	AIR
601	6	139	663	827	1/17/21	4-NOT SPECIFIED	4	19	6260.09	8702.4	0.04	36666.52	3664.18	0.19	2/17/21	MAIL
397	4	695	415	940	1/18/21	5-LOW	1	5	2862.77	10487.73	0.03	32235.65	1447.46	0.19	2/18/21	TRUCK
315	1	422	658	824	1/19/21	3-MEDIUM	1	8	2176.52	15484.36	0.05	40784.99	5018.1	0.14	2/19/21	TRUCK
706	6	638	711	509	1/20/21	2-HIGH	2	4	1245.46	19178.94	0.07	24489.84	8290.21	0.07	2/20/21	SHIP
487	1	669	968	787	1/21/21	3-MEDIUM	2	49	5813.69	2434.68	0.03	45828.29	3332.78	0.05	2/21/21	MAIL
552	2	624	275	942	1/22/21	3-MEDIUM	4	13	6983.17	2229.38	0.05	3418.1	1933.88	0.05	2/22/21	TRUCK
88	3	489	861	856	1/23/21	2-HIGH	3	38	6752.38	11834.92	0.01	15351.54	3637.54	0.03	2/23/21	MAIL
175	5	771	44	450	1/24/21	4-NOT SPECIFIED	4	46	9493.72	14933.42	0.02	36037.58	8231.86	0.11	2/24/21	TRUCK
601	3	540	84	327	1/25/21	4-NOT SPECIFIED	2	49	126.76	16978.19	0	21487.35	1833.65	0.03	2/25/21	AIR
850	1	980	434	491	1/26/21	5-LOW	4	46	6507.25	18723.06	0.1	9474.62	2659.94	0.06	2/26/21	REG AIR
678	4	218	810	54	1/27/21	5-LOW	2	19	6043.88	19670.18	0	6253.33	1154.09	0.13	2/27/21	REG AIR
538	3	664	94	817	1/28/21	3-MEDIUM	1	8	5928.52	8056.05	0.02	41049.62	7204.25	0.15	2/28/21	AIR

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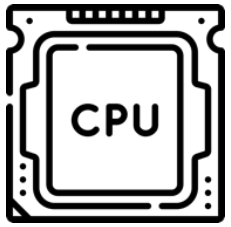
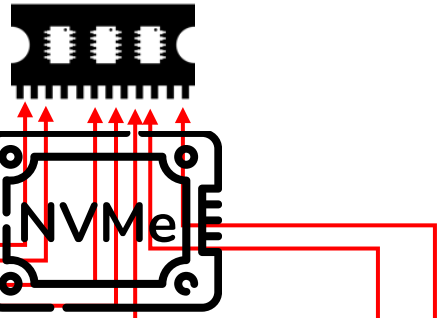
Parquet SELECT

Today

```
SELECT
    lo_custkey,
    lo_orderdate,
    lo_partkey,
    lo_revenue,
    lo_suppkey,
    lo_supplycost
FROM
    s3Object
WHERE
    (lo_quantity BETWEEN 11 AND 20)
    AND (lo_orderdate <= 20210116);
```

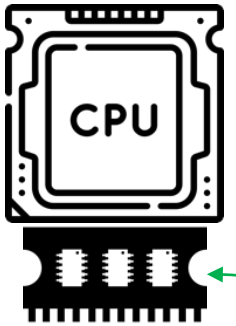


- Retrieve required columns
  - ~MB per column
- Process Data in CPU
- <0.1% for many queries!

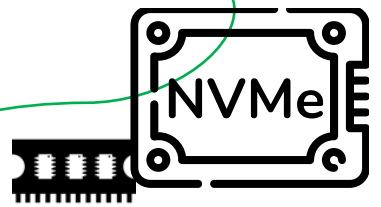


LO_ ORDERKEY	LO_ LINENUMBER	LO_ CUSTKEY	LO_ PARTKEY	LO_ SUPPKEY	LO_ ORDERDATE	LO_ ORDERPRIORITY	LO_ SHIPPRIORITY	LO_ QUANTITY	LO_ EXTENDEDPRICE	LO_ ORDTOTALPRICE	LO_ DISCOUNT	LO_ REVENUE	LO_ SUPPLYCOST	LO_ TAX	LO_ COMMITDATE	LO_ SHIPMODE
685	5	68	341	349	1/1/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	2/1/21	TRUCK
560	5	979	510	942	1/2/21	2-HIGH	2	18	3482.81	13217.61	0.05	20748.27	3752.25	0.05	2/2/21	SHIP
630	7	772	515	283	1/3/21	5-LOW	4	30	6794.8	8005.41	0.03	37516.42	7694.96	0.12	2/3/21	RAIL
193	5	235	70	587	1/4/21	5-LOW	2	13	8804.42	19985.63	0.08	26818.47	3488.45	0.15	2/4/21	RAIL
836	5	717	358	821	1/5/21	5-LOW	2	47	5482.41	7102.67	0.08	24896.14	6744.53	0.05	2/5/21	AIR
764	4	999	909	434	1/6/21	1-URGENT	3	33	2898.73	14455.99	0.09	1026.75	5414.6	0.12	2/6/21	AIR
708	5	292	557	220	1/7/21	1-URGENT	0	35	399.33	12787.9	0	21844.68	5107.17	0.13	2/7/21	SHIP
360	5	727	886	820	1/8/21	3-MEDIUM	4	24	7132.33	16279.77	0.09	4114.13	9061.04	0.19	2/8/21	MAIL
10	9	702	766	740	1/9/21	1-URGENT	2	26	178.05	19526.89	0.04	11204.41	5769.13	0.16	2/9/21	AIR
724	5	710	323	874	1/10/21	4-NOT SPECIFIED	0	47	3789.52	17806.89	0.09	46687.3	8355.19	0.17	2/10/21	AIR
278	4	728	624	787	1/11/21	4-NOT SPECIFIED	0	44	5352.32	15314.78	0.07	11554.51	7392.95	0.1	2/11/21	SHIP
755	8	556	92	374	1/12/21	5-LOW	2	42	9228.9	13995.14	0.1	43058.54	866.29	0.04	2/12/21	AIR
805	6	33	342	291	1/13/21	2-HIGH	3	47	986	6776.41	0.08	40341.78	7844.55	0.2	2/13/21	SHIP
600	6	12	424	564	1/14/21	5-LOW	1	1	4118.83	3038.94	0.04	8798.17	2560.27	0.03	2/14/21	REG AIR
71	1	617	552	671	1/15/21	4-NOT SPECIFIED	3	13	340.7	1346.46	0.05	30679.89	9079.92	0.09	2/15/21	SHIP
473	2	213	972	438	1/16/21	4-NOT SPECIFIED	2	10	3491.85	4913.84	0.04	6667.43	907.78	0.01	2/16/21	AIR
601	6	139	663	827	1/17/21	4-NOT SPECIFIED	4	19	6260.09	8702.4	0.04	36666.52	3664.18	0.19	2/17/21	MAIL
397	4	695	415	940	1/18/21	5-LOW	1	5	2862.77	10487.73	0.03	32235.65	1447.46	0.19	2/18/21	TRUCK
315	1	422	658	824	1/19/21	3-MEDIUM	1	8	2176.52	15484.36	0.05	40784.99	5018.1	0.14	2/19/21	TRUCK
706	6	638	711	509	1/20/21	2-HIGH	2	4	1245.46	19178.94	0.07	24489.84	8290.21	0.07	2/20/21	SHIP
487	1	669	968	787	1/21/21	3-MEDIUM	2	49	5813.69	2434.68	0.03	45828.29	3332.78	0.05	2/21/21	MAIL
552	2	624	275	942	1/22/21	3-MEDIUM	4	13	6983.17	2229.38	0.05	3418.1	1933.88	0.05	2/22/21	TRUCK
88	3	489	861	856	1/23/21	2-HIGH	3	38	6752.38	11834.92	0.01	15351.54	3637.54	0.03	2/23/21	MAIL
175	5	771	44	450	1/24/21	4-NOT SPECIFIED	4	46	9493.72	14933.42	0.02	36037.58	8231.86	0.11	2/24/21	TRUCK
601	3	540	84	327	1/25/21	4-NOT SPECIFIED	2	49	126.76	16978.19	0	21487.35	1833.65	0.03	2/25/21	AIR
850	1	980	434	491	1/26/21	5-LOW	4	46	6507.25	18723.06	0.1	9474.62	2659.94	0.06	2/26/21	REG AIR
678	4	218	810	54	1/27/21	5-LOW	2	19	6043.88	19670.18	0	6253.33	1154.09	0.13	2/27/21	REG AIR
538	3	664	94	817	1/28/21	3-MEDIUM	1	8	5928.52	8056.05	0.02	41049.62	7204.25	0.15	2/28/21	AIR

With CHECK-FETCH



- Perform basic filtering in device
- Scratchpad can eliminate returning intermediate results
- Bitwise operators: combine results
- Extract only desired data
- **99%+ reduction of data to host!**



LO_ CUSTKEY	LO_ ORDERDATE	LO_ PARTKEY	LO_ REVENUE	LO_ SUPPKEY	LO_ SUPPLYCOST
979	1/2/21	510	20748.27	942	3752.25
235	1/4/21	70	26818.47	587	3488.45
617	1/15/21	552	30679.89	671	9079.92

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Ask what your storage should do for YOU

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Firmware-only implementation on high volume commercial SSD demo in 2024

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Donpaul Stephens

donpaul@airmettle.com