

# A Practical Approach to Device-Level Analytical Offloads

Presented by  
Donpaul Stephens  
Founder & CEO, AirMettle



## 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

# Computational Storage?

Erik Riedel's  
Ph.D. Dissertation 1999:

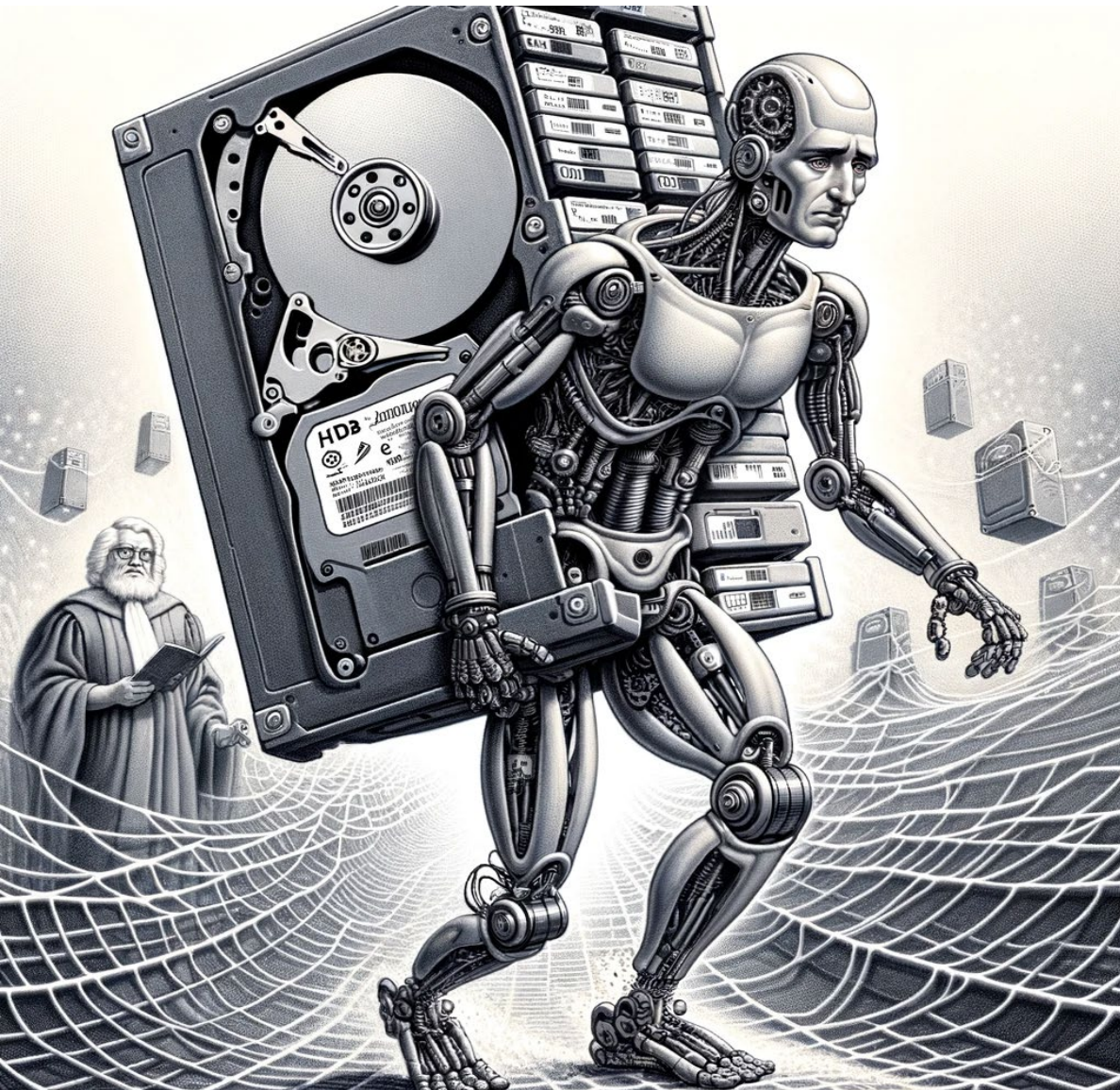
Active Disks –  
Remote Execution for Network-Attached  
Storage

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





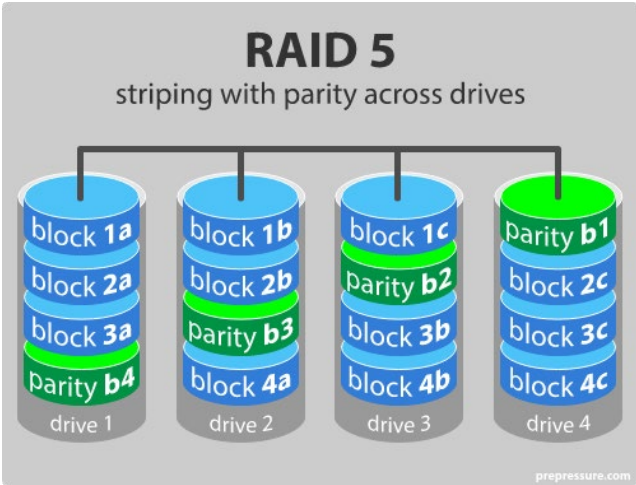
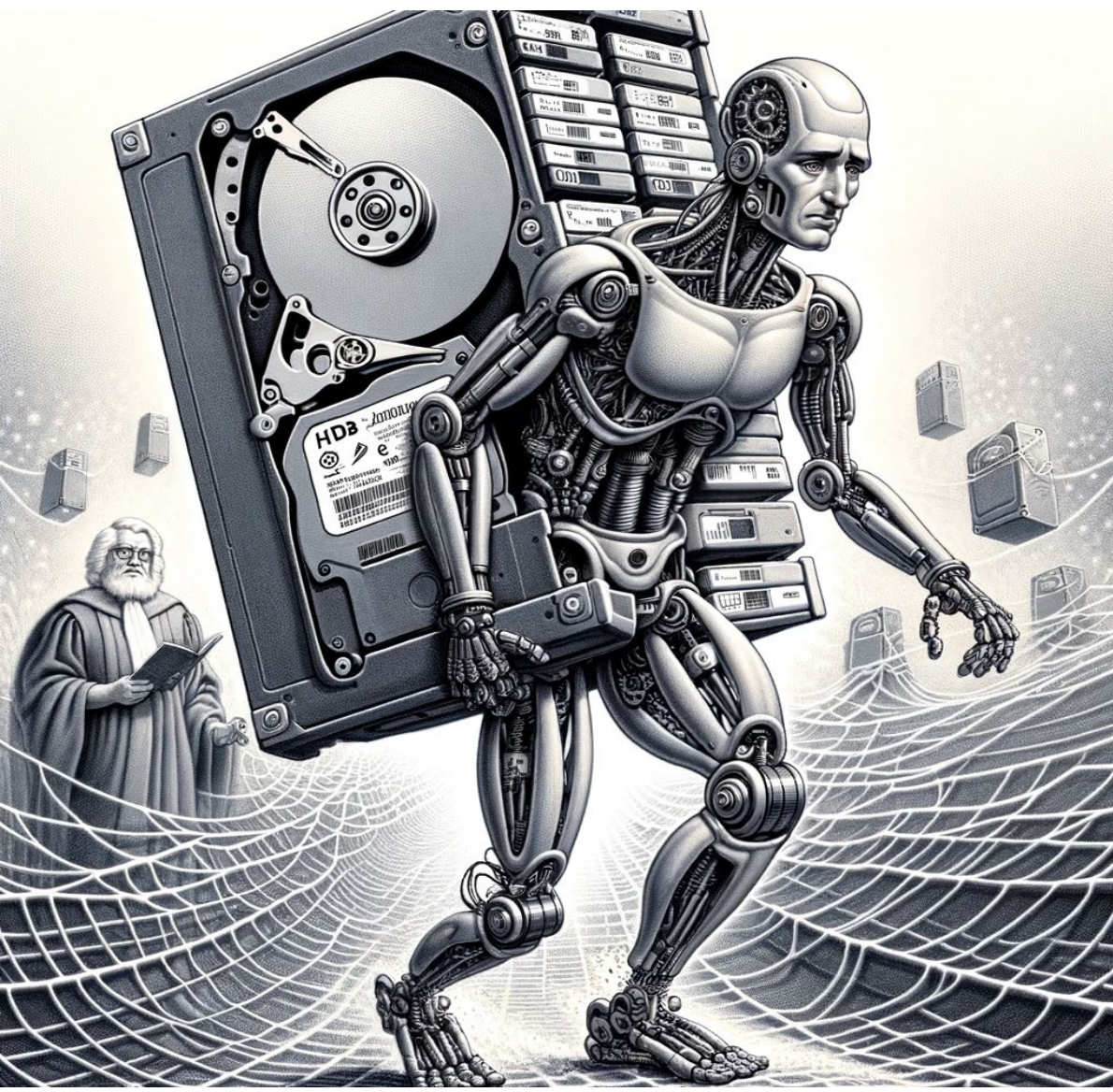
# Why is Big Data so SLOW?



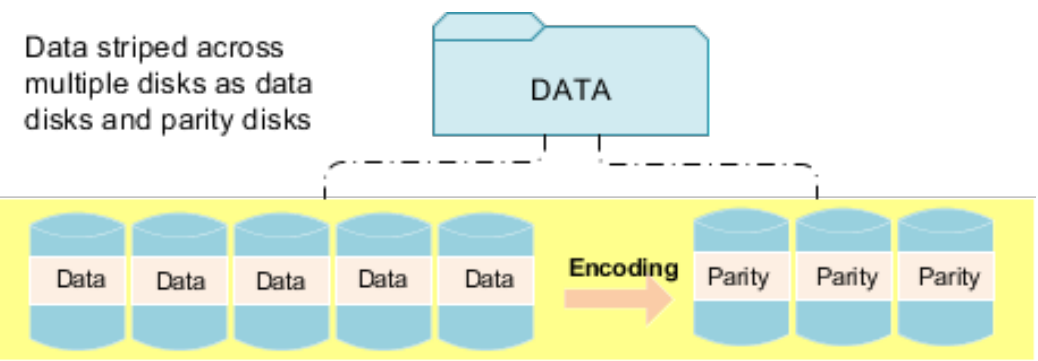


# Why is Big Data so SLOW?

In part: How storage protects data



## Erasure Coding:

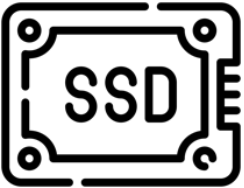


# Data reliably placed in storage: First 4 devices shown...

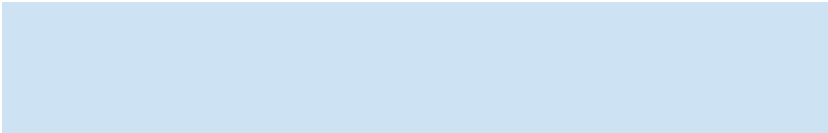
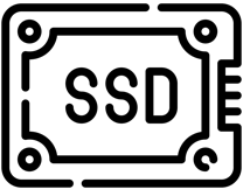
Simple Table:

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



#3

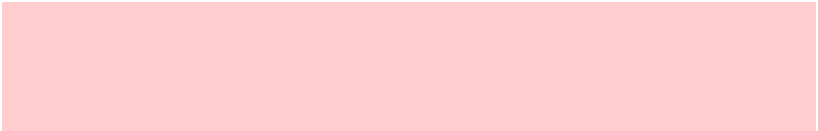


Bytes of data divided evenly across SSDs!

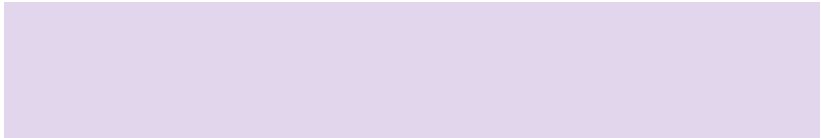
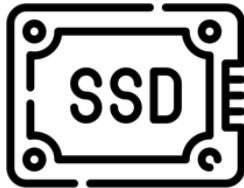


Data protection and streaming performance!

#2



#4



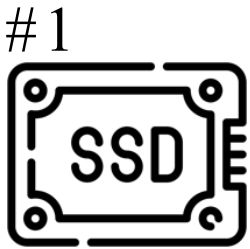
Supports data protection algorithms designed for HDD!



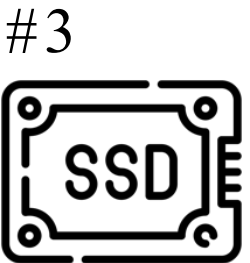
# Byte-level partitions precludes analytics

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_
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



1,155190,7706,1,17,21168.23,0.04,0.02,N,0,1996-03-13,1996-02-12,1996-03-22,DELIVER\_IN\_PERSON,TRUCK,egular\_courts\_above\_the,1,67310,7311,2,36,45983.16,0.09,0.06,N,0,1996-04-12,1996-02-28,1996-04-20,TAKE\_BACK



0.06,N,0,1996-04-21,1996-03-30,1996-05-16,NONE,AIR,1ites.\_fluffily\_even\_de,1,24027,1534,5,24,22824.48,0.10,0.04,N,0,1996-03-30,1996-03-14,1996-04-01,NONE,FOB,\_pending\_foxes.\_slyly\_re,1,15635,638,6,32,49620.

Bytes of data divided evenly across SSDs!



Data protection and streaming performance!



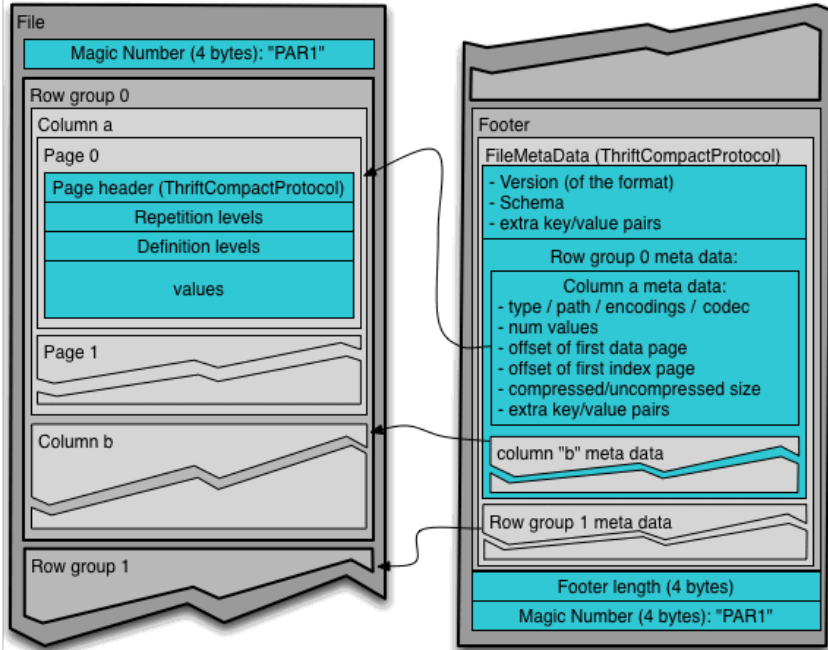
RETURN,MAIL,ly\_final\_dependencies\_slyly\_bold\_,1,63700,3701,3,8,13309.60,0.10,0.02,N,0,1996-01-29,1996-03-05,1996-01-31,TAKE\_BACK\_RETURN,REG\_AIR,riously\_rregularl\_express\_dep,1,2132,4633,4,28,28955.64,0.09




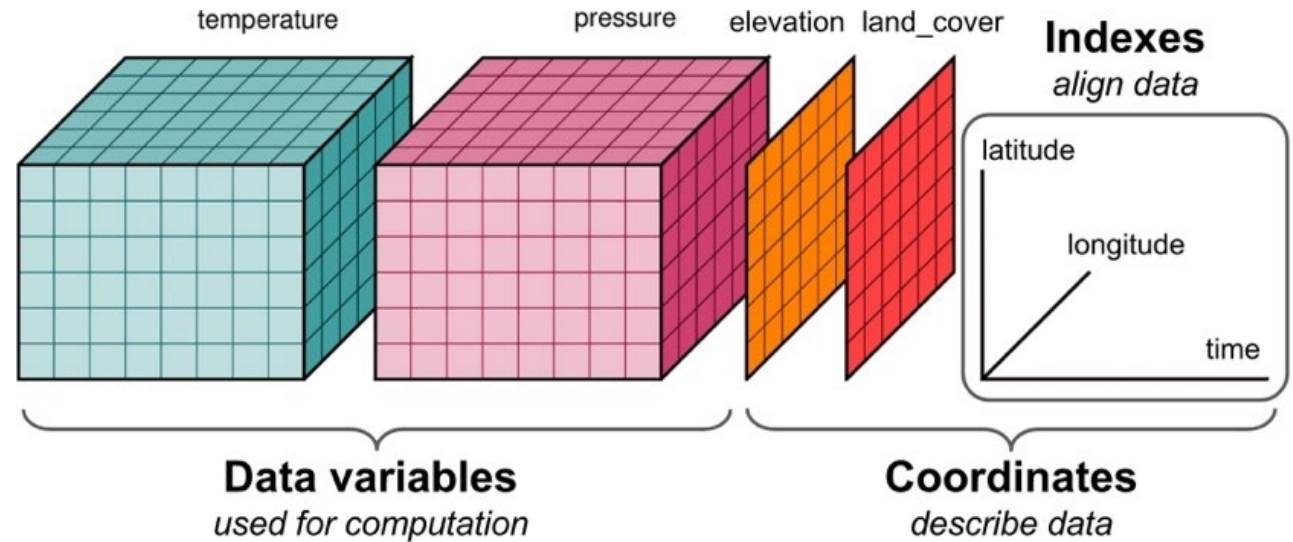
16,0.07,0.02,N,0,1996-01-30,1996-02-07,1996-02-03,DELIVER\_IN\_PERSON,MAIL,arefully\_slyly\_ex,2,106170,1191,1,38,44694.46,0.00,0.05,N,0,1997-01-28,1997-01-14,1997-02-02,TAKE\_BACK\_RETURN,RAIL,ven\_requests.\_depos

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

# Challenge: Array based data formats

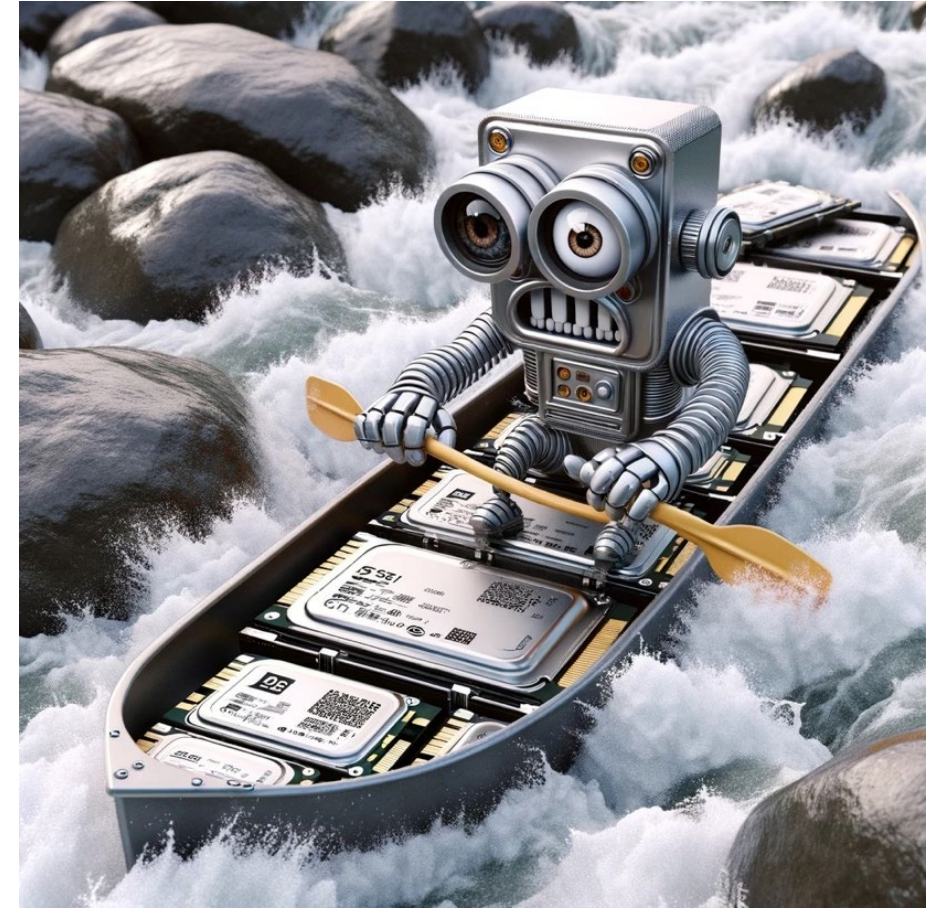


netCDF4 /  5





# Branches are hard, complex data structures more complex

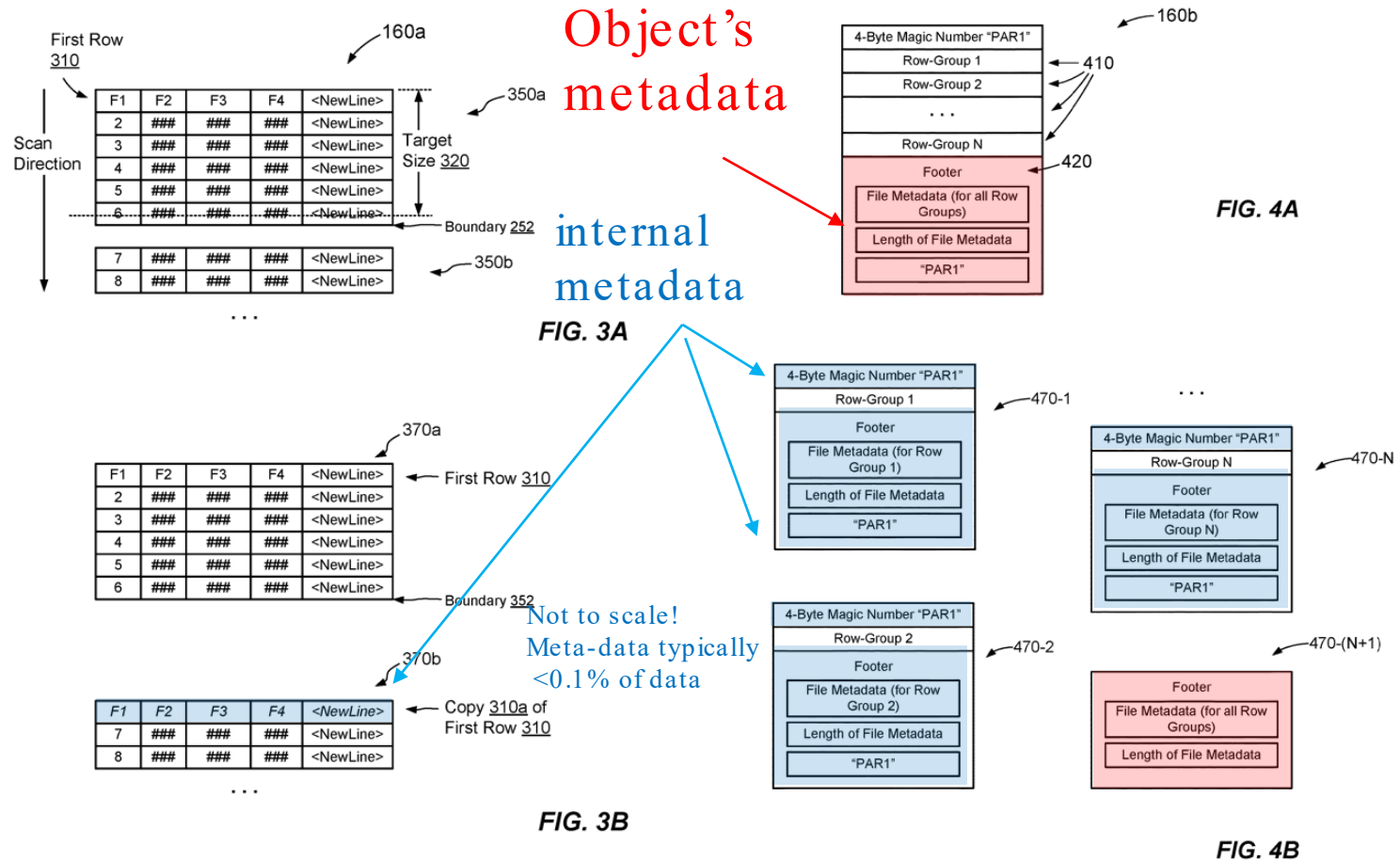


# Let's take Occam's Razor to the Gordian's Knot





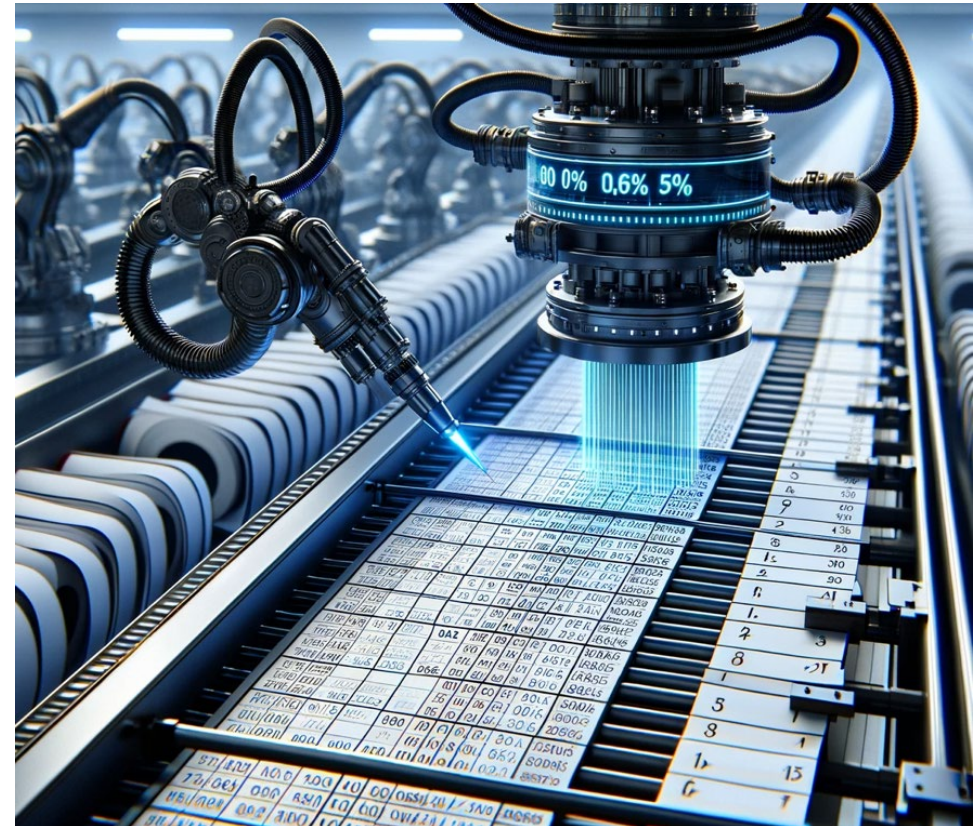
# Step 1: Preserve structure of the data





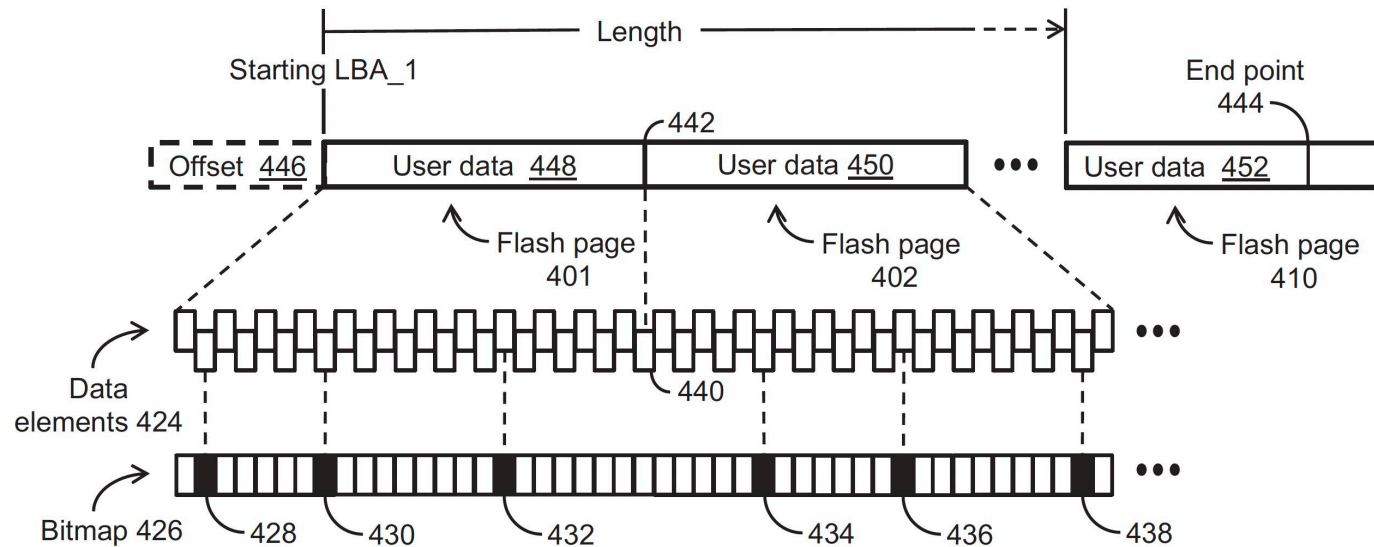
# Step 2: Data path ONLY, no Control Path!

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



# CHECK & FETCH

## User-level Datapath APIs



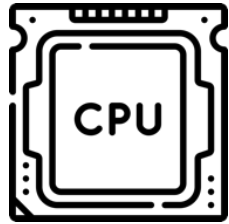
Patent pending



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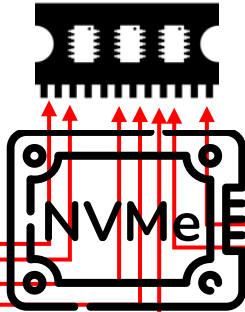
*Solutions, Architectures, and Community*  
VIRTUAL EVENT, MAY 21-22, 2024

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!

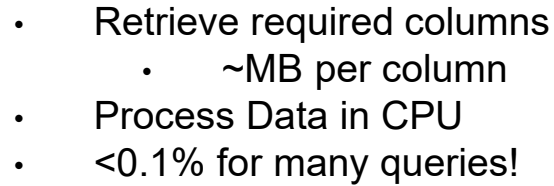


LO_ORDERKEY	LO_LINENUMBER	LO_CUSTKEY	LO_PARTKEY	LO_SUPPKEY	LO_ORDERDATE	LO_ORDERPRIORITY	LO_SHIPPRIORITY	LO_QUANTITY	LO_EXTENDEDPRICE	LO_ORDTOTALPRICE	LO_DISCOUNT	LO_REVENUE	LO_SUPPLYCOST	LO_TAX	LO_COMMITDATE	LO_SHIPMODE
685	5	68	341	349	1/1/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	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	13526.89	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	4	49	5813.69	2434.68	0.03	45828.29	3332.78	0.05	2/21/21	MAIL
552	2	634	275	942	1/22/21	3-MEDIUM	2	13	6983.17	2229.38	0.05	3418.1	1931.88	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

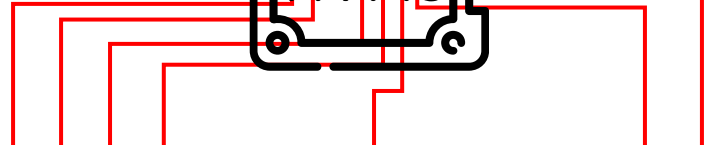




# Today

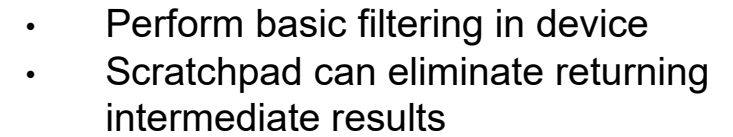


```
SELECT
    lo_custkey,
    lo_orderdate,
    lo_partkey,
    lo_revenue,
    lo_suppkey,
    lo_supplycost
FROM
    s3object
WHERE
    (lo_quantity > 1000000)
    AND (lo_orderdate < '1997-01-01')
```



LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO
ORDERKEY	LINUMBER	CUSTKEY	PARTKEY	SUPPLY	ORDERDATE	ORDERPRIORITY	SHIPPRIORITY	QUANTITY	EXTENDEDPRICE	ORDTOTALPRICE	DISCOUNT	REVENUE	SUPPLYCOST	TAX	COMMITDATE	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			
140	5	979	510	942	1/2/21 2-HIGH		2	18	3480.81	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	679.8	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	14545.99	0.09	10267.75	5414.6	0.12	2/6/21 AIR			
368	5	292	557	220	1/7/21 1-URGENT		0	35	399.33	12879.9	0	21844.68	5107.17	0.13	2/7/21 SHIP			
700	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		47		3789.52	17806.89	0.09	46687.3	8359.19	0.17	2/10/21 AIR			
4	728	624	378	171	1/11/21 4-NOT SPECIFIED		44		5352.32	15314.78	0.07	11554.51	7392.95	0.1	2/11/21 SHIP			
85	558	93	374	374	1/12/21 5-LOW		3		9228.19	13995.14	0.07	4120.54	3666.29	0.2	2/12/21 SHIP			
205	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		10		3491.85	4913.84	0.04	6667.43	907.78	0.01	2/16/21 AIR			
603	6	139	663	827	1/17/21 4-NOT SPECIFIED		4	19	6260.09	8702.4	0.04	36662.52	3664.18	0.19	2/17/21 MAIL			
397	4	695	415	940	1/18/21 5-LOW		5	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	5018.14	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			
481	1	669	968	787	1/21/21 3-MEDIUM		2	49	5813.69	2344.68	0.03	45828.29	3332.78	0.05	2/21/21 MAIL			
552	2	624	275	942	1/22/21 3-MEDIUM		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		46		9493.72	14933.42	0.02	36037.88	8231.86	0.11	2/24/21 TRUCK			
60	3	540	89	337	1/25/21 4-NOT SPECIFIED		49		126.76	10919.19	0.09	2146.35	139.76	0.03	2/25/21 SHIP			
150	1	980	434	491	1/26/21 5-LOW		4	46	6507.25	17273.06	0.1	9474.62	2659.94	0.06	2/26/21 REG AIR			
678	4	218	810	54	1/27/21 5-LOW		1	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			

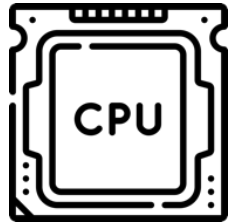
## With CHECK-FETCH



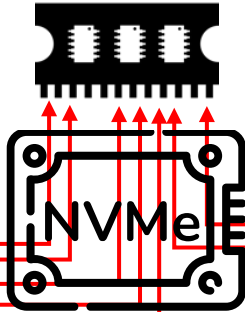
LO	ORDERKEY	LO_0	LO_1	LO_2	LO_3	LO_4	LO_5	LO_6	LO_7	LO_8	LO_9	LO_10	LO_11	LO_12	LO_13	LO_14	LO_15	LO_16	LO_17
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# Today

```
SELECT
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    lo_orderdate,
    lo_partkey,
    lo_revenue,
    lo_suppkey,
    lo_supplycost
FROM
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WHERE
    (lo_quantity > 1000)
    AND (lo_orderdate < '1997-01-01')
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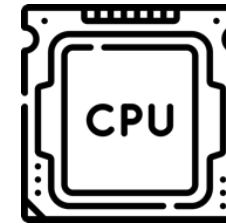


- Retrieve required columns
  - ~MB per column
- Process Data in CPU
- <0.1% for many queries!

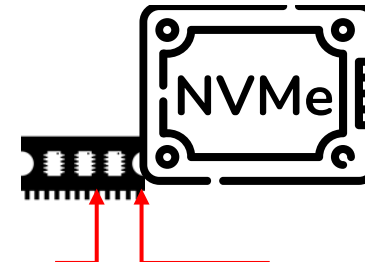


LO_ORDERKEY	LO_LO_NUMBER	LO_CUSTKEY	LO_PARTKEY	LO_SUPPKEY	LO_ORDERDATE	LO_ORDERPRIORITY	LO_SHIPPRIORITY	LO_QUANTITY	LO_EXTENDEDPRICE	LO_ORDTOTALPRICE	LO_DISCOUNT	LO_REVENUE	LO_SUPPLYCOST	LO_TAX	LO_COMMITDATE	LO_SHIPMODE
685	5	68	341	349	1/1/21 3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	2/1/21	TRUCK	
686	5	979	510	942	1/2/21 2-HIGH	2	18	3482.84	13217.61	0.05	20748.27	3752.25	0.05	2/1/21	SHIP	
630	7	772	515	283	1/3/21 5-LOW	4	30	6794.8	8005.41	0.03	37516.42	7696.94	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	10267.75	5414.6	0.12	2/6/21	RAIL	
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	8759.13	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	5365.19	0.17	2/10/21	AIR	
4	728	624	787	111	1/11/21 4-NOT SPECIFIED	0	44	5552.32	15314.48	0.07	11554.51	7392.95	0.1	2/11/21	SHIP	
8	756	8	93	374	1/12/21 5-LOW	2	46	376.29	13995.14	0	4385.4	2122.21	0.07	2/12/21	RAIL	
205	8	33	342	291	1/13/21 2-HIGH	3	47	886	6776.41	0.08	4031.78	7844.5	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	32325.65	1447.46	0.19	2/18/21	TRUCK	
135	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	
481	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	1	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	8218.86	0.11	2/24/21	TRUCK	
30	540	9	817	327	1/25/21 4-NOT SPECIFIED	4	49	126.76	1687.46	0	2143.35	2525.65	0.07	2/25/21	REG AIR	
651	1	980	434	491	1/26/21 5-LOW	4	46	6507.25	18723.06	0.1	9637.56	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	18	5928.52	10506.05	0.02	41049.62	7204.25	0.15	2/28/21	SHIP	

## With CHECK-FETCH




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

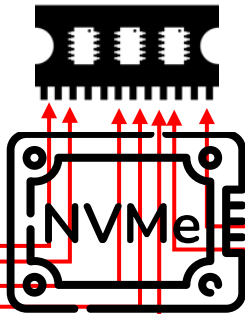


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ORDERKEY	UNENUMBER	CUSTKEY	PARTKEY	SUPPLY	ORDDATE	ORDEPRORITY	SHIPRIORITY	QUANTITY	EXTENDEDPRICE	ORDTOTALPRICE	DISCOUNT	REVENUE	SUPPLYCOST	TAX	COMMITDATE	SHIPMODE			
680	5	68	341	949	1/17/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.27	0.1	2/1/21	TRUCK			
565	5	979	510	342	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	1/13/21	5-LOW	4	30	6794.8	8005.41	0.03	37516.42	7694.96	0.12	2/17/21	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			
264	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	SHP			
360	5	727	886	820	1/8/21	3-MEDIUM	4	24	7132.33	16279.77	0.09	4114.13	9061.04	0.09	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			
778	4	728	624	787	1/11/21	4-NOT SPECIFIED	0	44	5352.32	15314.78	0.07	11554.51	895.9	0.11	2/11/21	SHP			
255	8	556	92	374	1/12/21	1-URGENT	2	42	9228.9	13995.14	0.1	40364.54	7062.9	0.2	2/12/21	AIR			
805	3	33	342	293	1/13/21	2-HIGH	3	47	986	17676.41	0.08	42034.78	7844.55	0.2	2/13/21	SHP			
600	6	12	424	564	1/14/21	5-LOW	1	1	4118.83	3038.94	0.04	8798.17	2560.27	0.2	2/14/21	REG AIR			
71	1	617	552	671	1/15/21	4-NOT SPECIFIED	3	13	340.7	1346.46	0.05	30673.89	9079.92	0.09	2/15/21	SHP			
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	2606.09	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	32325.65	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	8290.17	0.07	2/20/21	SHP			
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	350	1/24/21	4-NOT SPECIFIED	2	46	9493.72	14933.42	0.02	36037.58	8231.86	0.11	2/24/21	TRUCK			
601	3	540	84	427	1/25/21	4-NOT SPECIFIED	2	49	126.76	16978.19	0	21487.35	1833.65	0.03	2/25/21	AIR			
5	980	435	491	476	1/26/21	5-LOW	4	46	6507.25	804.6	0.1	9474.62	2263.91	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	84	817	1/28/21	3-MEDIUM	1	8	5092.52	8056.05	0.02	41049.67	7204.25	0.15	2/28/21	AIR			

# Today




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

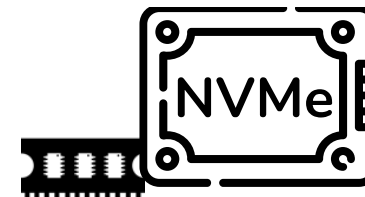


LO ORDERKEY	LO_LOINUMBER	LO_LOPARTKEY	LO_LOPARTKEY	LO_LOSUPPLY	LO_LOORDERDATE	LO_LOORDERPRIORITY	LO_LOSHIPPRIORITY	LO_LOQUANTITY	LO_LOEXTENDEDPRICE	LO_LOORDTOTALPRICE	LO_LODISCOUNT	LO_LOREVENUE	LO_LOSUPPLYCOST	LO_LOTAX	LO_LOCOMMODITY	LO_LOSHIPMODE
685	5	678	341	349	1/1/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	2/1/21	TRUCK
560	5	989	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	7618.42	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	23516.47	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	14545.99	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	8759.13	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	4667.83	5369.19	0.17	2/10/21	AIR
278	4	728	624	371	1/11/21	4-NOT SPECIFIED	4	44	5352.32	15314.78	0.07	11554.51	7392.95	0.1	2/11/21	SHIP
756	8	556	92	374	1/12/21	5-LOW	2	9228.9	3228.9	0.12	4301.94	866.39	0.04	2/12/21	RAIL	
805	6	33	342	291	1/13/21	2-HIGH	3	47	986	6776.41	0.08	4034.78	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	3666.52	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	6795.12	11834.92	0.01	15351.54	3637.54	0.03	2/23/21	MAIL
175	5	771	44	405	1/24/21	4-NOT SPECIFIED	4	46	9493.72	14933.42	0.02	36037.58	8231.86	0.11	2/24/21	RAIL
601	3	540	84	327	1/25/21	4-NOT SPECIFIED	4	9	126.76	4919.19	0.01	2144.8	1833.6	0.03	2/25/21	REG AIR
528	1	980	434	491	1/26/21	5-LOW	4	46	6507.25	18723.06	0.1	9474.62	2659.94	0.05	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




LO_ CUSTKEY	LO_ ORDERDATE	LO_ PARTKEY	LO_ REVENUE	LO_ SUPPKEY	LO_ SUPPLYCO
979	1/2/21	510	20748.27	942	3752
235	1/4/21	70	26818.47	587	3488
617	1/15/21	552	30679.89	671	9079

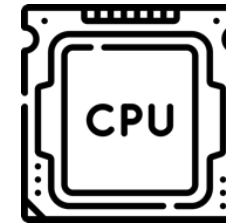
LO_ORDERKEY	LO_LO	LO_LOUNUMBER	LO_CUSTKEY	LO_PARTKEY	LO_SUPPKEY	LO_ORDERDATE	LO_ORDERPRIORITY	LO_SHIPPIRTYPE	LO_QUANTITY	LO_EXTENDEDPRICE	LO_ORDTOTALPRICE	LO_DISCOUNT	LO_REVENUE	LO_SUPPLYCOST	LO_TAX	LO_COMMODATE	LO_SHPMODE
685	5	98	341	349		1/1/21 3-MEDIUM		2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	2/1/21 TRUCK	
560	5	979	510	942		1/2/21 2-HIGH		2	18	3482.81	17321.61	0.05	20748.27	3752.25	0.05	2/2/21 SHIP	
630	7	772	515	283		1/3/21 S-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 S-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 S-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 U-URGENT		3	33	2898.73	14455.99	0.09	1026.75	5414.6	0.12	2/6/21 AIR	
708	5	292	557	220		2/7/21 U-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 U-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		4	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		4	44	5352.32	15314.78	0.07	11554.51	7392.95	0.1	2/11/21 SHIP	
756	8	556	92	374		1/12/21 S-HIGH		2	42	9228.9	13995.14	0	856.09	4309.04	0.04	2/12/21 AIR	
605	3	33	342	291		1/13/21 3-HIGH		3	47	986	6776.41	0.08	4034.78	7844.55	0.2	2/13/21 SHIP	
800	6	12	424	564		1/14/21 S-LOW		1	1	4118.83	3038.94	0.04	8738.12	2560.27	0.03	2/14/21 REG AIR	
71	1	617	552	671		1/15/21 4-NOT SPECIFIED		3	103	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	3666.52	3664.18	0.19	2/17/21 MAIL	
397	4	695	415	940		1/18/21 S-LOW		1	5	2862.77	10487.73	0.03	32323.65	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	5018.14	0.14	2/19/21 TRUCK	
706	6	638	711	509		1/20/21 2-HIGH		4	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	6752.18	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	4993.72	14933.42	0.02	36073.69	8259.86	0.11	2/24/21 SHIP	
640	3	540	94	323		1/25/21 4-NOT SPECIFIED		2	46	126.76	19473.06	0.01	1833.65	514.73	0.03	2/25/21 RAIL	
850	1	980	434	491		1/26/21 S-LOW		4	46	6507.25	18723.06	0.1	9474.62	2631.91	0.05	2/26/21 REG AIR	
678	4	218	810	54		1/27/21 S-LOW		1	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	



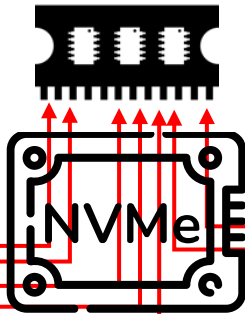
## With CHECK-FETCH



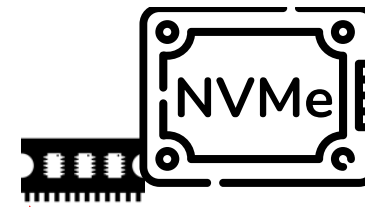
- Retrieve required columns
  - ~MB per column
- Process Data in CPU
- <0.1% for many queries!



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




LO_ORDERKEY	LO_LO_NUMBER	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	
686	5	979	510	942	1/2/21 2-HIGH	2	18	3482.81	13217.61	0.05	20748.27	3752.25	0.05	2/1/21	SHIP	
630	7	772	515	283	1/3/21 5-LOW	4	30	6794.8	8005.41	0.03	37516.42	7696.94	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	14545.99	0.09	10267.75	5414.6	0.12	2/6/21	RAIL	
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	8759.13	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	5365.19	0.17	2/10/21	AIR	
4	728	624	787	111	1/11/21 4-NOT SPECIFIED	0	44	5552.32	15314.48	0.07	11554.51	7392.95	0.1	2/11/21	SHIP	
8	756	8	93	374	1/12/21 5-LOW	2	46	376.29	13995.14	0	4385.4	2122.21	0.07	2/12/21	RAIL	
205	8	33	342	291	1/13/21 2-HIGH	3	47	886	6776.41	0.08	4031.78	7844.5	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	36079.89	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	32325.65	1447.46	0.19	2/18/21	TRUCK	
135	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	
481	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	1	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	8218.86	0.11	2/24/21	TRUCK	
30	540	98	817	327	1/25/21 4-NOT SPECIFIED	4	49	126.76	1687.66	0	2143.35	2525.65	0.07	2/25/21	REG AIR	
651	1	980	434	491	1/26/21 5-LOW	4	46	6507.25	18723.06	0.1	9637.56	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	18	5928.52	8506.05	0.02	41049.62	7204.25	0.15	2/28/21	SHIP	



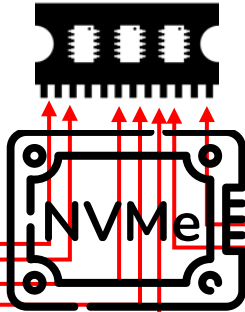
LO_ CUSTKEY	LO_ ORDERDATE	LO_ PARTKEY	LO_ REVENUE	LO_ SUPPKEY	LO_ SUPPLYCO
979	1/2/21	510	20748.27	942	3752
235	1/4/21	70	26818.47	587	3488
617	1/15/21	552	30679.89	671	9079

LO_ORDERKEY	LO_LO	LO_LINUMBER	LO_CUSTKEY	LO_PARTKEY	LO_SUPPKEY	LO_ORDERDATE	LO_ORDERPRIORITY	LO_SHIPRIORITY	LO_QUANTITY	LO_EXTENDEDPRICE	LO_ORDTOTALPRICE	LO_DISCOUNT	LO_REVENUE	LO_SUPPLYCOST	LO_TAX	LO_COMMODATE	LO_SHPMODE
680	5	98	341	349		1/1/21 3-MEDIUM			2	34	2128.74	13861.44	0.04	9968.63	3995.22	0.1	2/1/21 TRUCK
565	5	979	530	942		1/2/21 2-HIGH			2	18	3482.81	12371.61	0.05	20748.27	3752.25	0.05	2/2/21 SHIP
630	7	772	515	283		1/3/21 S-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 S-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 S-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			4	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			4	44	5352.32	15314.78	0.07	11554.51	7392.95	0.1	2/11/21 SHIP
756	8	556	92	374		1/12/21 S-HIGH			2	42	9228.9	13995.14	0	856.09	4309.04	0.04	2/12/21 AIR
605	3	33	342	291		1/13/21 3-HIGH			3	47	986	6776.41	0.08	4034.78	7844.55	0.2	2/13/21 SHIP
800	6	12	424	564		1/14/21 S-LOW			1	1	4118.83	3038.94	0.04	8738.12	2560.27	0.03	2/14/21 REG AIR
71	1	617	552	671		1/15/21 4-NOT SPECIFIED			3	103	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	3666.52	3664.18	0.19	2/17/21 MAIL
397	4	695	415	940		1/18/21 S-LOW			1	5	2862.77	10487.73	0.03	32323.65	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	5018.14	0.14	2/19/21 TRUCK
706	6	638	711	509		1/20/21 2-HIGH			4	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	6752.18	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	4993.72	14933.42	0.02	36073.69	8259.86	0.11	2/24/21 SHIP
640	3	540	94	323		1/25/21 4-NOT SPECIFIED			2	46	126.76	19178.94	0	1833.65	5147.3	0.25	2/25/21 AIR
850	1	980	434	491		1/26/21 S-LOW			4	46	6507.25	18723.06	0.1	9474.62	2631.91	0.2	2/26/21 REG AIR
678	4	218	810	54		1/27/21 S-LOW			1	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			2	8	5928.52	8056.05	0.02	41049.62	7204.25	0.15	2/28/21 AIR

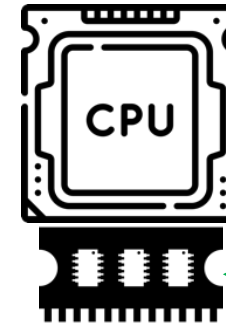
## With CHECK-FETCH



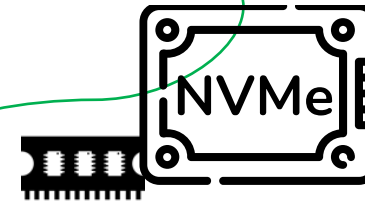
- Retrieve required columns
  - ~MB per column
- Process Data in CPU
- <0.1% for many queries!



LO_ORDERKEY	LO_LO	LO_LINUMBER	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	2182.84	11861.44	0.04	9968.63	3795.22	0.1	2/1/21	TRUCK		
560	5	979	510	942	1/2/21 2-HIGH	2	18	1327.61	13217.61	0.05	20748.27	3952.25	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	19598.63	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	14545.99	0.09	1026.75	5414.6	0.12	2/6/21	AIR		
768	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		
300	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	13599.19	0.17	2/10/21	SHIP		
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		
805	6	556	92	374	1/12/21 5-LOW	4	42	9228.8	13995.14	0.1	43009.84	8666.39	0.2	2/12/21	AIR		
405	3	33	342	291	1/13/21 2-HIGH	3	47	886	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	36665.52	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	32323.65	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		
8	3	489	861	856	1/23/21 2-HIGH	3	48	6793.28	11834.92	0.01	15351.54	3637.54	0.03	2/23/21	MAIL		
175	5	771	44	445	1/24/21 4-NOT SPECIFIED	4	46	9493.72	14933.42	0.02	36073.66	8231.86	0.11	2/24/21	TRUCK		
601	3	540	84	327	1/25/21 4-NOT SPECIFIED	4	26	126.76	1919.19	0.09	214.85	1893.65	0.03	2/25/21	SHIP		
850	1	980	434	491	1/26/21 5-LOW	1	46	6507.25	18723.06	0.1	9473.62	2659.94	0.06	2/26/21	REG AIR		
678	4	218	810	54	1/27/21 5-LOW	1	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		



- 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_ SUPPLYCO
979	1/2/21	510	20748.27	942	3752
235	1/4/21	70	26818.47	587	3488
617	1/15/21	552	30679.89	671	9079

Don't ask what you should  
do for your storage

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](mailto:donpaul@airmettle.com)



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