

SNIA DEVELOPER CONFERENCE



BY Developers FOR Developers

September 16-18, 2024
Santa Clara, CA

Computational Storage Service

Analytical Data Platform with Intelligent Analytics Offload

Donpaul Stephens
AirMettle, Inc.

Computational Storage

Let's start with the devices...

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.



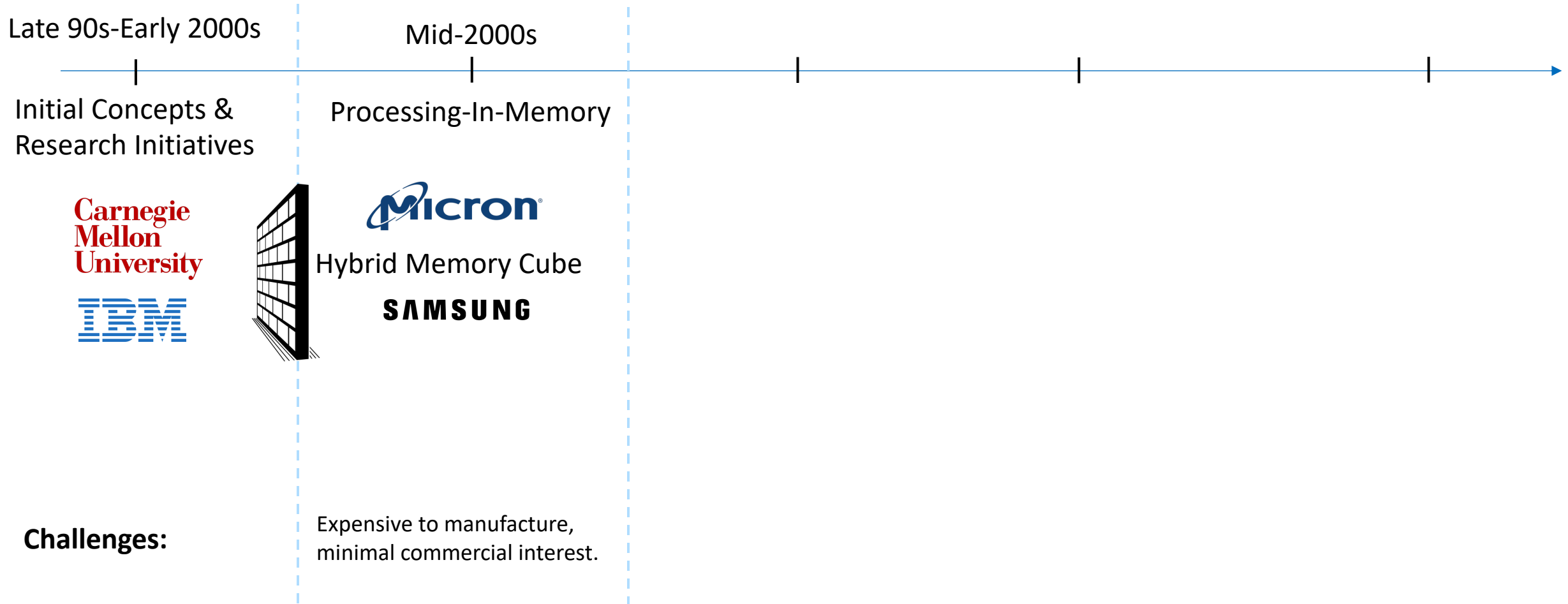
Computational Storage... through the years

Late 90s-Early 2000s

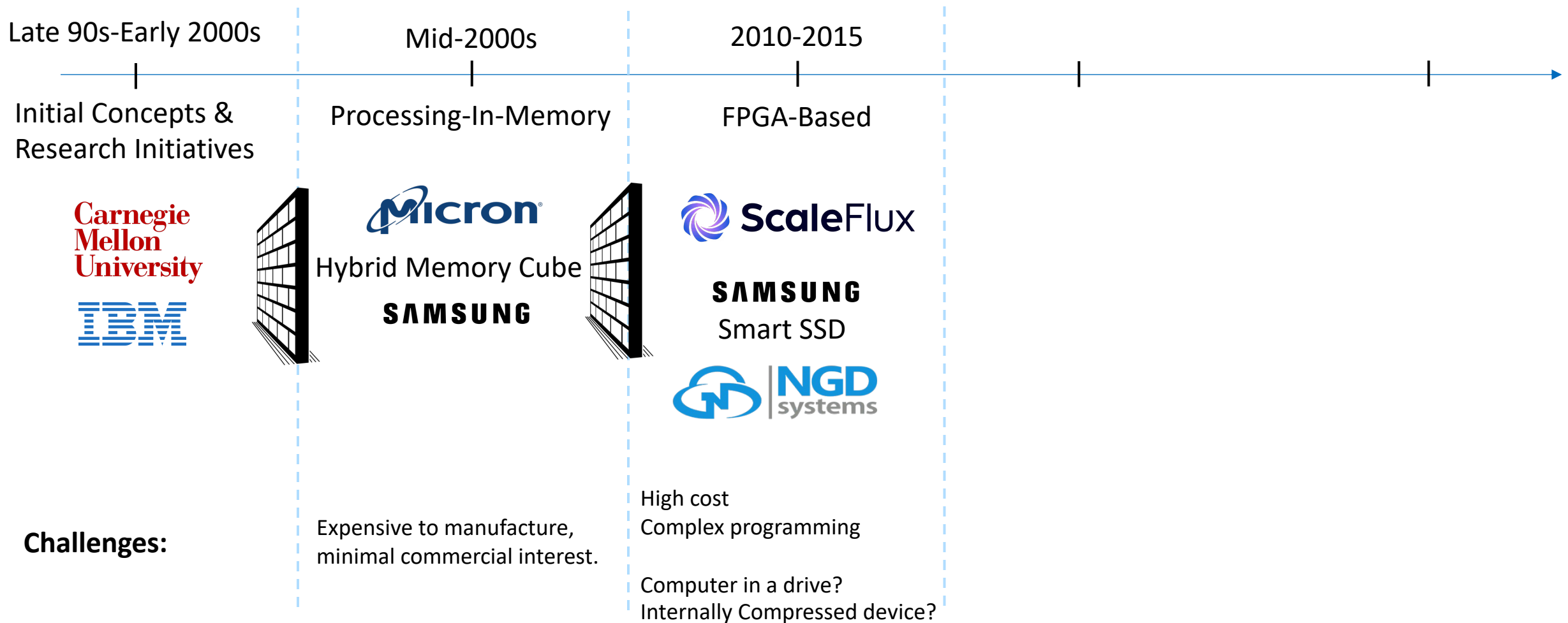
Initial Concepts &
Research Initiatives

**Carnegie
Mellon
University**
IBM

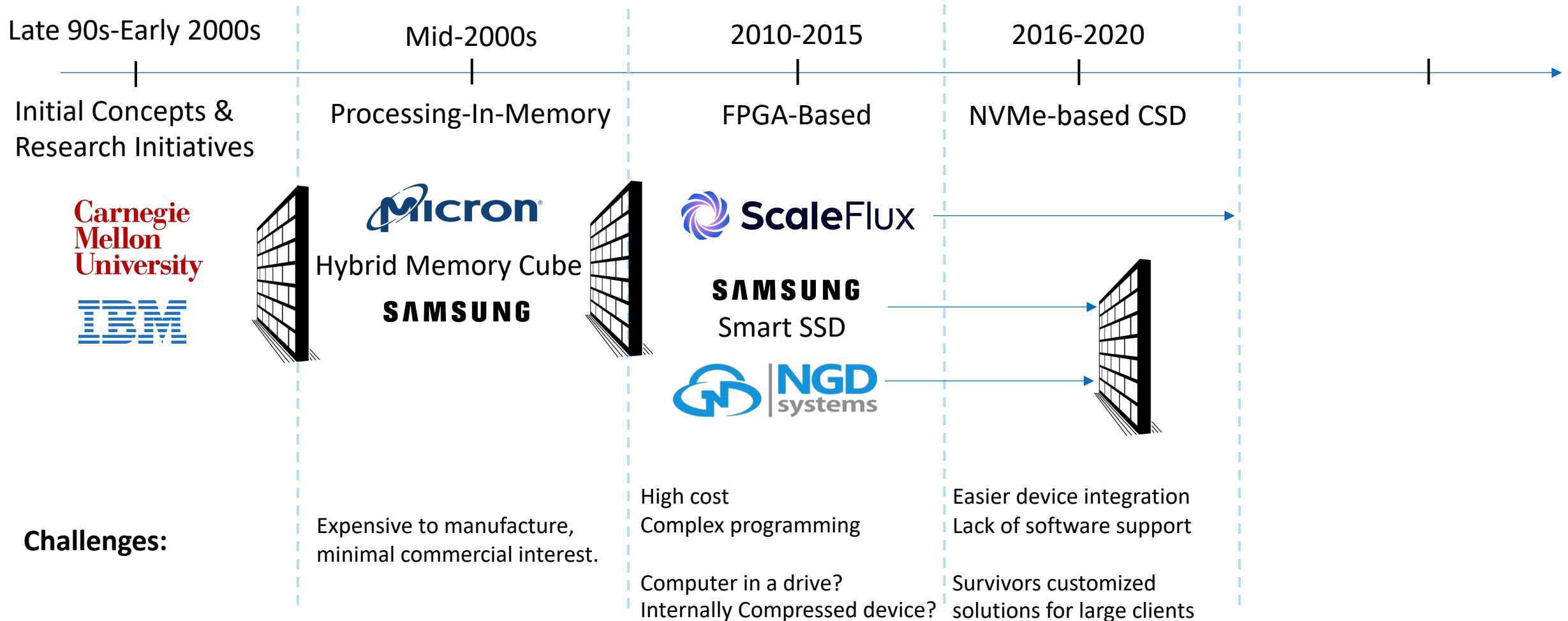
Computational Storage... through the years



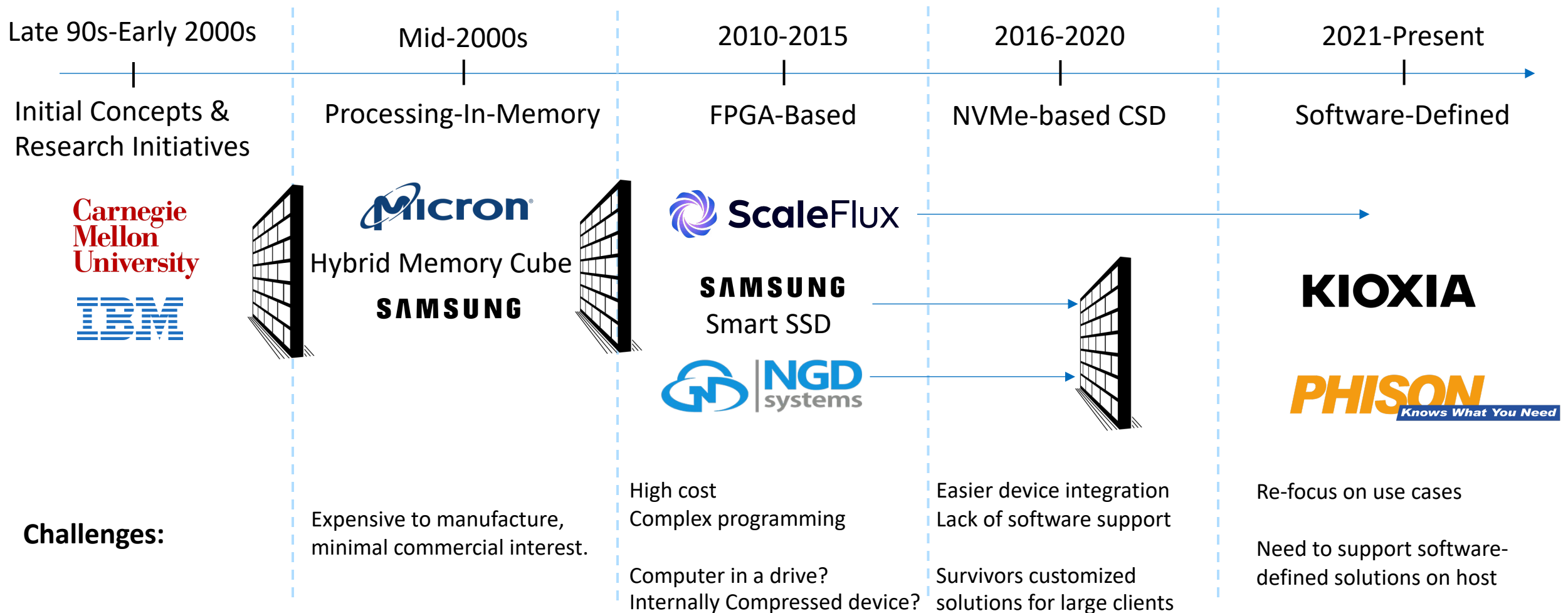
Computational Storage... through the years



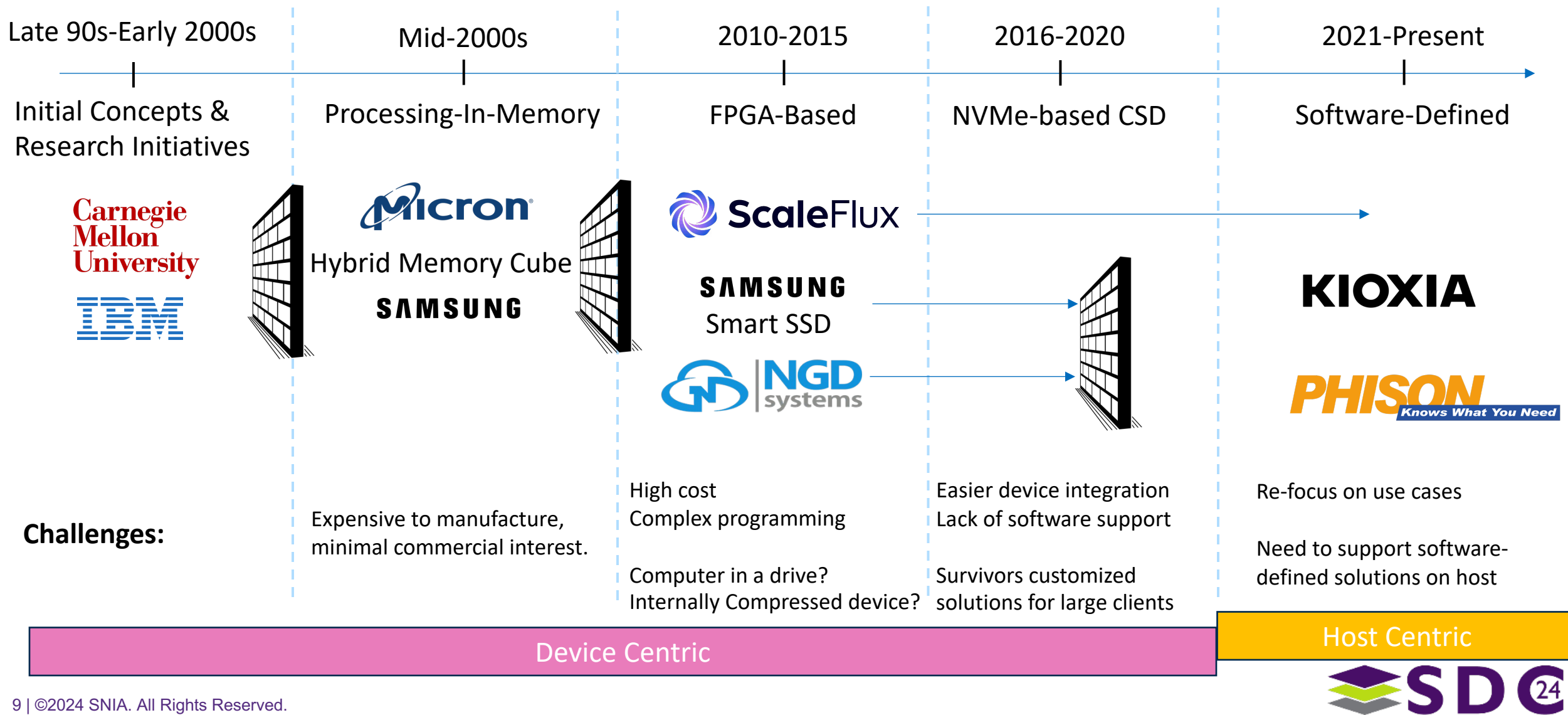
Computational Storage... through the years



Computational Storage... through the years



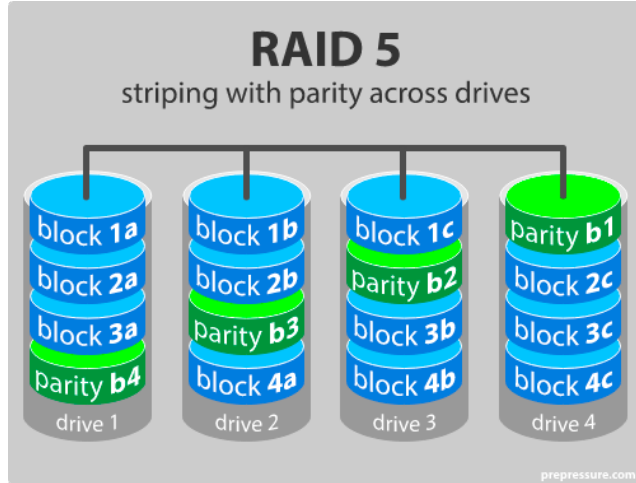
Computational Storage... through the years



Host-level Approach

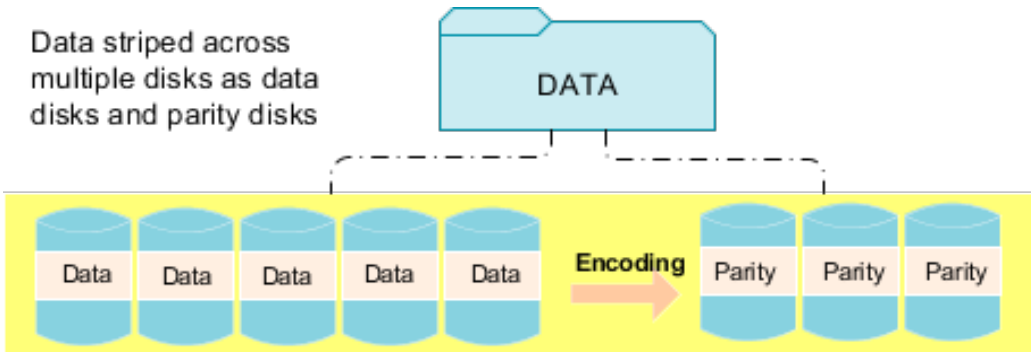
Applications, with limitations

How storage protects data



Erasure Coding:

Data striped across multiple disks as data disks and parity disks



Designed way back... Then:

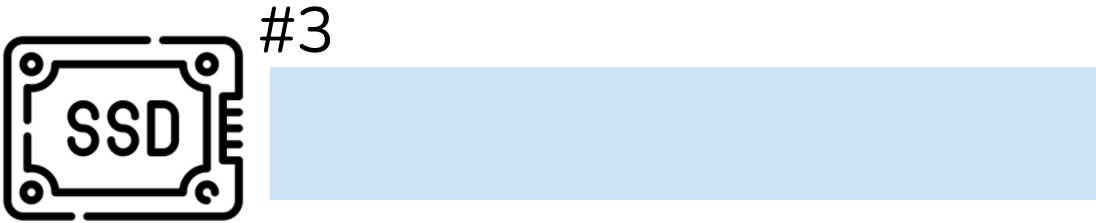
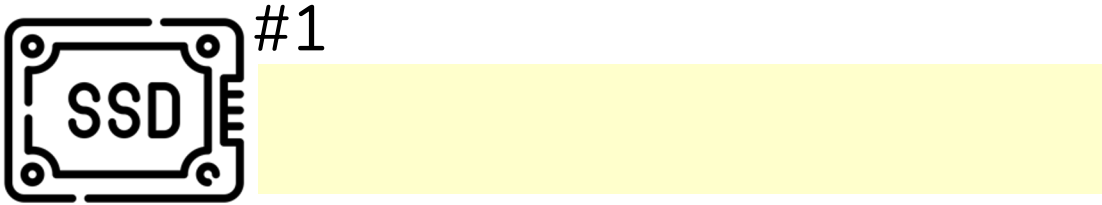
(logic was expensive, interconnect was relatively cheap



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



Bytes of data divided evenly across SSDs!



Data protection and streaming performance!

Supports data protection algorithms designed for HDD!

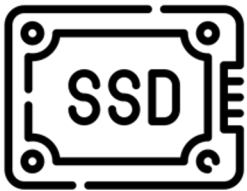
KIOXIA Talk this afternoon!



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

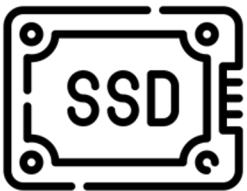
Simple Table:

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
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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

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



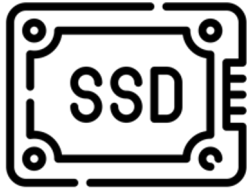
#3

0.06,N,0,1996-04-21,1996-03-30,1996-05-16,NONE,AIR,lites._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.



#2

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._regular|_express_dep, 1,2132,4633,4,28,28955.64,0.09,



#4

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

Bytes of data divided evenly across SSDs!

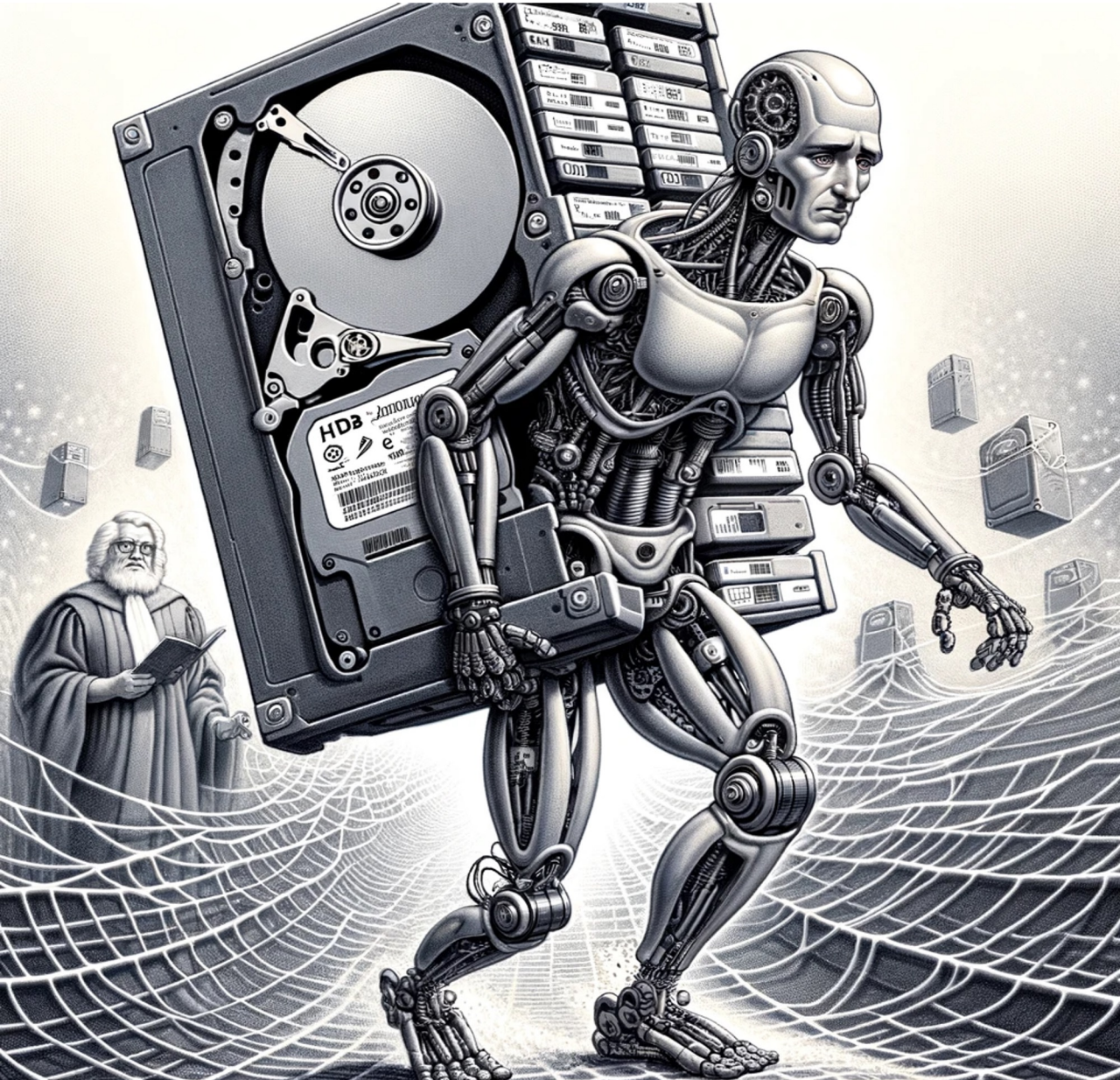


Data protection and streaming performance!



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

Is Big Data just doomed to be SLOW?



Systems-level Approach

Fast & Efficient Distributed Analytical Processing

Took Occam's Razor to the Gordian's Knot of in-place analytics Computational Storage Service



Divide (transparently) to conquer common analytical needs

U.S. Patent

Jun. 6, 2023

Sheet 3 of 11

US 11,669,505 B2



U.S. Patent

Jun. 6, 2023

Sheet 4 of 11

US 11,669,505 B2



- Data file formats unchanged
- Each internal component can be processed separately in parallel in storage
- Overhead is typically <0.2%

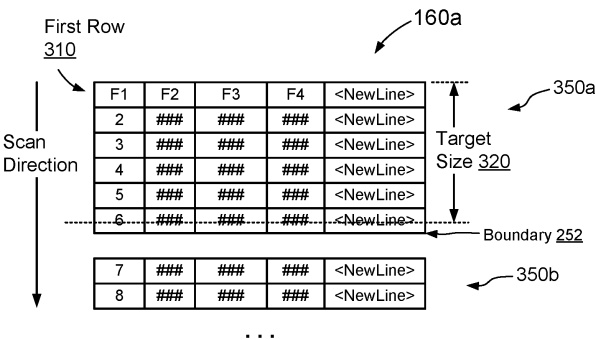


FIG. 3A

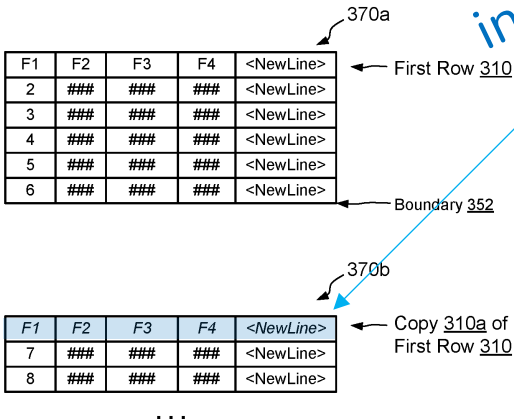


FIG. 3B

Object's own metadata

internal metadata

Not to scale!
Meta-data typically
<0.1% of data

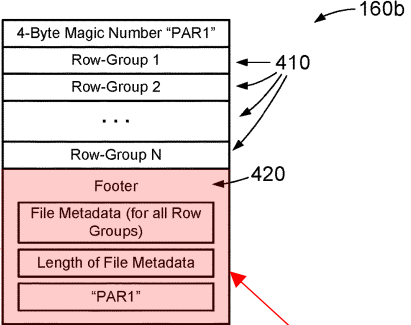


FIG. 4A

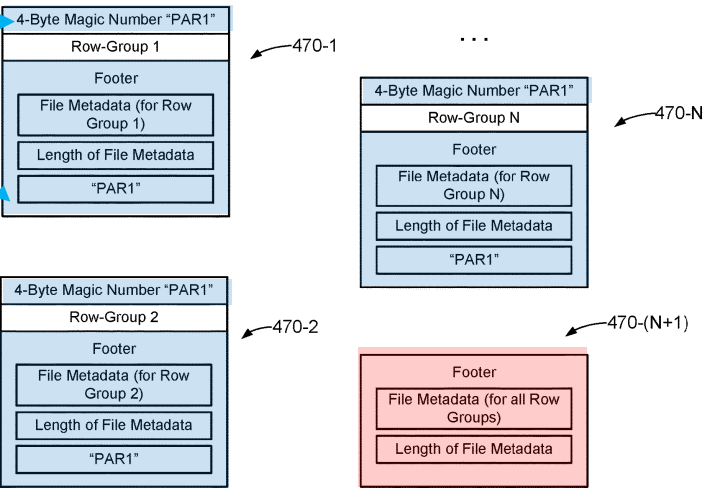


FIG. 4B

AirMettle internal metadata enables parallel in-storage analytics

Components are not fixed sized: fixed via smarter Erasure Coding



U.S. Patent Jun. 6, 2023 Sheet 7 of 11 US 11,669,505 B2

U.S. Patent Jun. 6, 2023 Sheet 8 of 11 US 11,669,505 B2

Erasure coding
For non-uniform
data segments

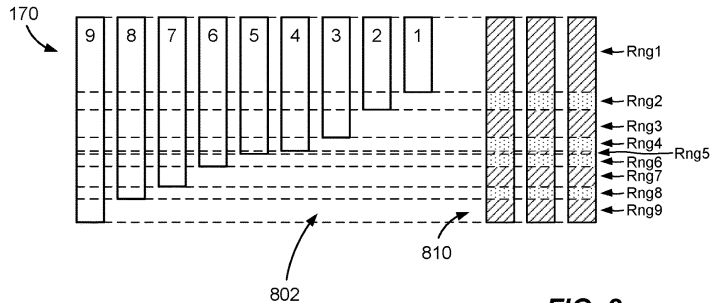
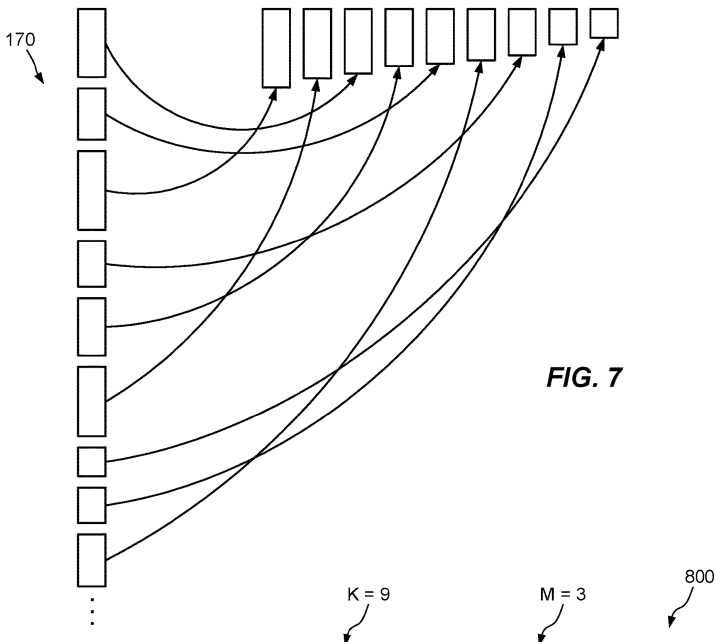


FIG. 8

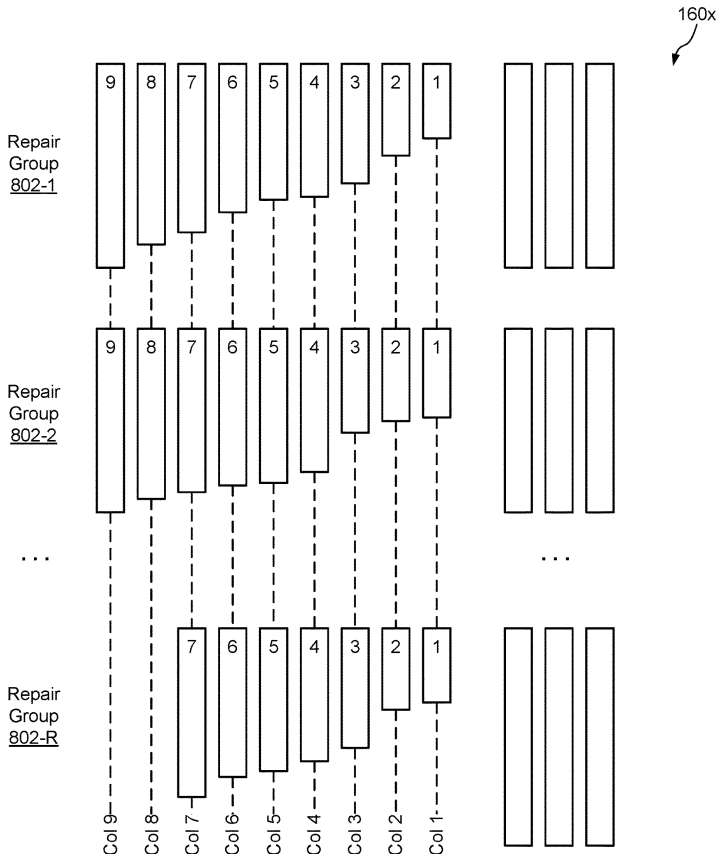
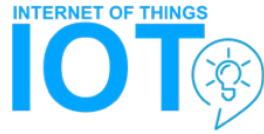


FIG. 9



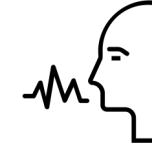
Accelerated analytics of classic tabular data (S3 Select API)

Security Information & Event Management



- Scan historical data to diagnose current events
 - Determine how many records might be relevant before retrieving any

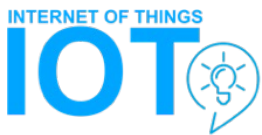
Natural Language Processing



- Search for key-words
 - Gather statistics of usage
 - Extract text if required for further analysis

Accelerated analytics of classic tabular data (S3 Select API)

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Natural Language Processing



- Search for key-words
 - Gather statistics of usage
 - Extract text if required for further analysis

Validated with



Star Schema Benchmark

Utilized 223 Select queries to Object Storage:



100 X faster

Under a minute vs. 1 hour 45min

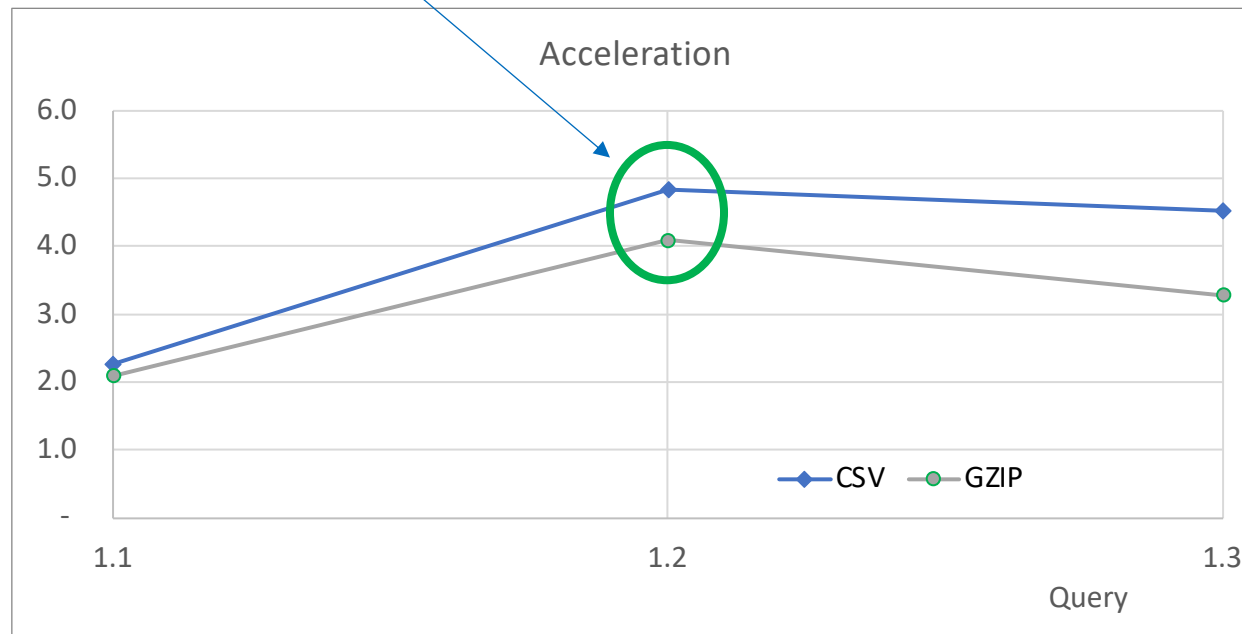
Unprecedented speed of analysis: Directly from storage

No data warehouse required



AirMettle Accelerates

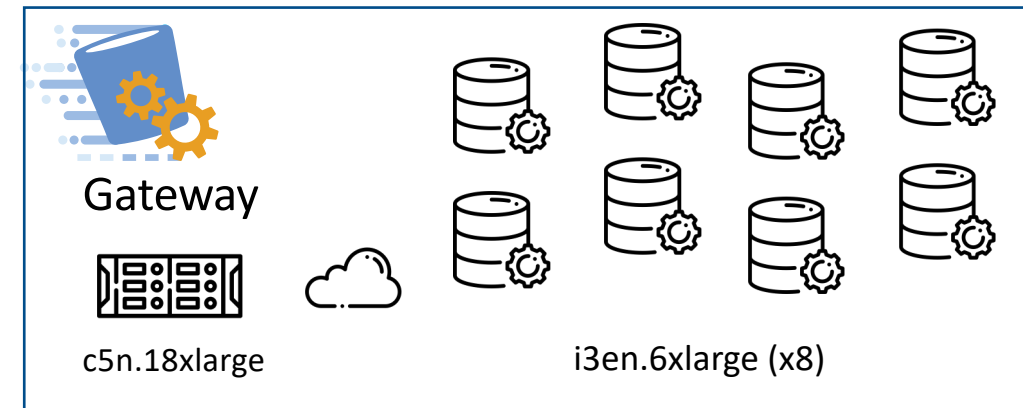
5x Acceleration on Complete Queries,
today... just by using a different storage



Star Schema Benchmark, Scale Factor 1 with 1 object per table



c5n.18xlarge



S3 Select API
enables comparison vs.
major cloud's object storage

AirMettle: SQL needed for ad-hoc analysis of large objects well beyond “S3 Select”, and with superior APIs to access it:

E.g., Security Information & Event Management

Collects sample measurements with certain flags and arguments and groups them by minute.

Returns the number of samples, average duration, and standard deviation of duration for each group.

```
SELECT
  TO_STRING(event_ts, 'yyyy-MM-dd HH24:mi') AS interval,
  COUNT(*) AS event_count,
  AVG(CAST(event_dur AS INT)) AS avg_event_duration,
  STDDEV_SAMP(CAST(event_dur AS INT)) AS event_duration_stddev
FROM
  events
WHERE
  flgs LIKE 'C__'
  AND REGEXP_CONTAINS(args, 'JY.')
  AND event_ts BETWEEN TO_TIMESTAMP('2000-01-01 00') AND TO_TIMESTAMP('2000-01-01 01')
GROUP BY
  interval;
```

- Data organization:
 - Aggregates within groups!
- Data characterization:

GROUP BY

STDDEV_SAMP

Ad hoc
Fully parallel
In-place

Device-level Processing?

But what about the SSD?!?!?
How do we go from This:



But what about the SSD?!?!?
How do we go from This:



to This:



Target Use Cases: For whom



Security Information & Event Management &
Network Operations Management









Weather/climate









Semiconductor manufacturing







Real-time Analytics (Security, e-commerce)
Massive Multi-player On-line Games (MMOG)





Significant amount of Flash used in Public Cloud
“object / Blob” storage is Array-based data formats



Target Use Cases: Analytics → which we CAN address



Security Information & Event Management &
Network Operations Management

✓



Weather/climate

✓



Semiconductor manufacturing

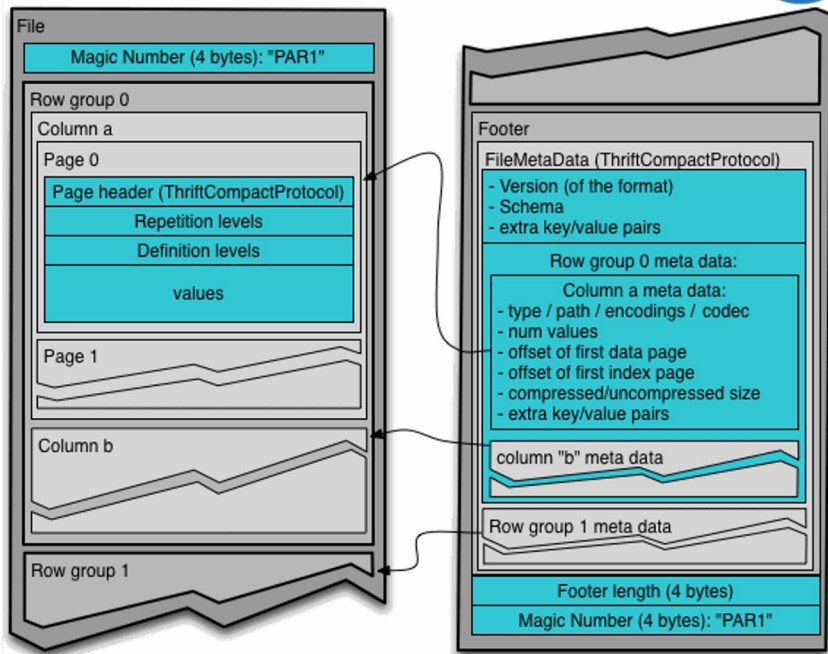
✓




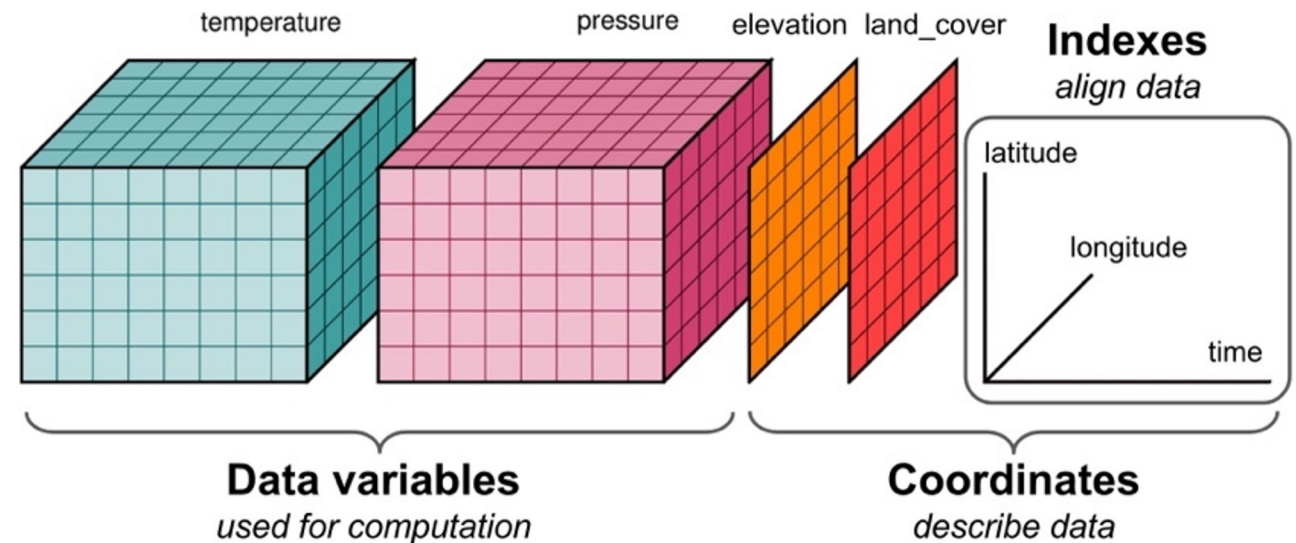
Real-time Analytics (Security, e-commerce)
Massive Multi-player On-line Games (MMOG)

✓

Challenge: Array based data formats



netCDF4 /  5



- There many public data formats, which are complex & evolving

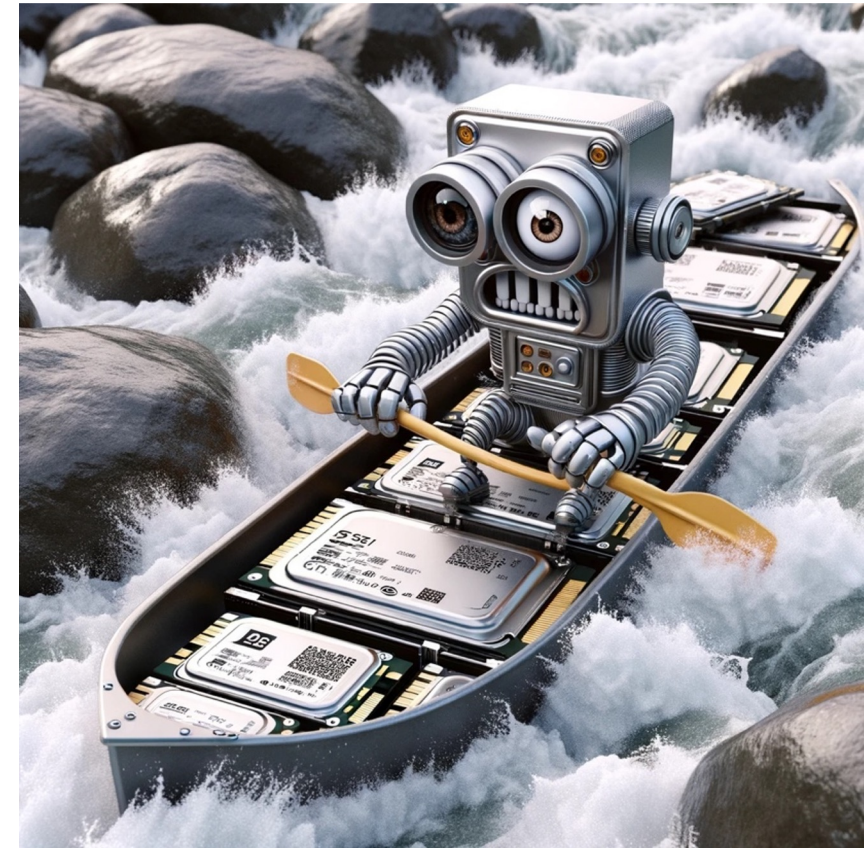
Cram a modern processor & OS Into a hard real-time embedded controller?



Branches
(prediction, memory management)
Are HARD



Complex terrain
(data formats)



Seemingly
unbounded complexity

Henry Youngman's classic

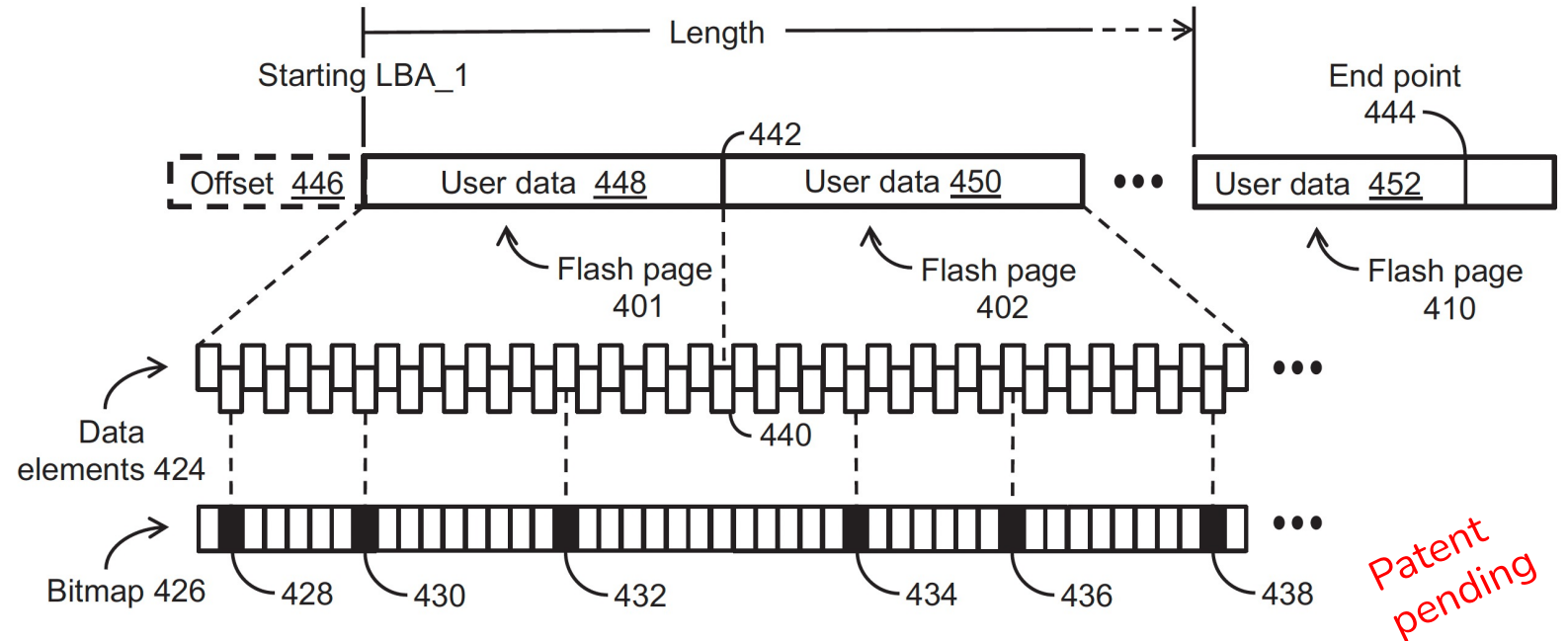
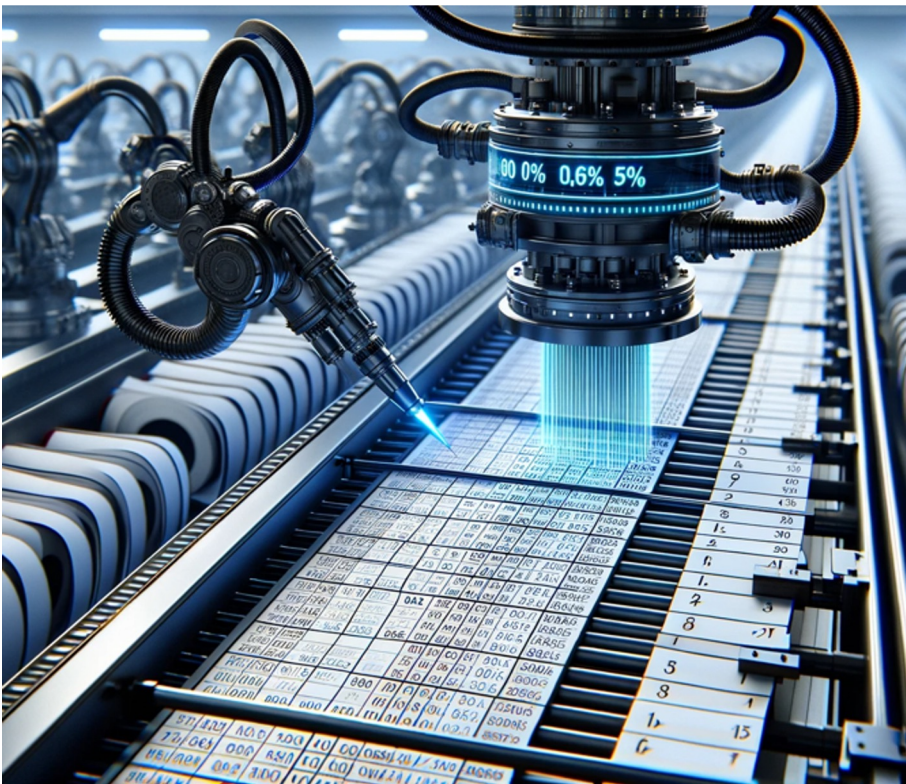
The Patient says,
“Doctor, it hurts when I do this.”

“Then don’t do that.”



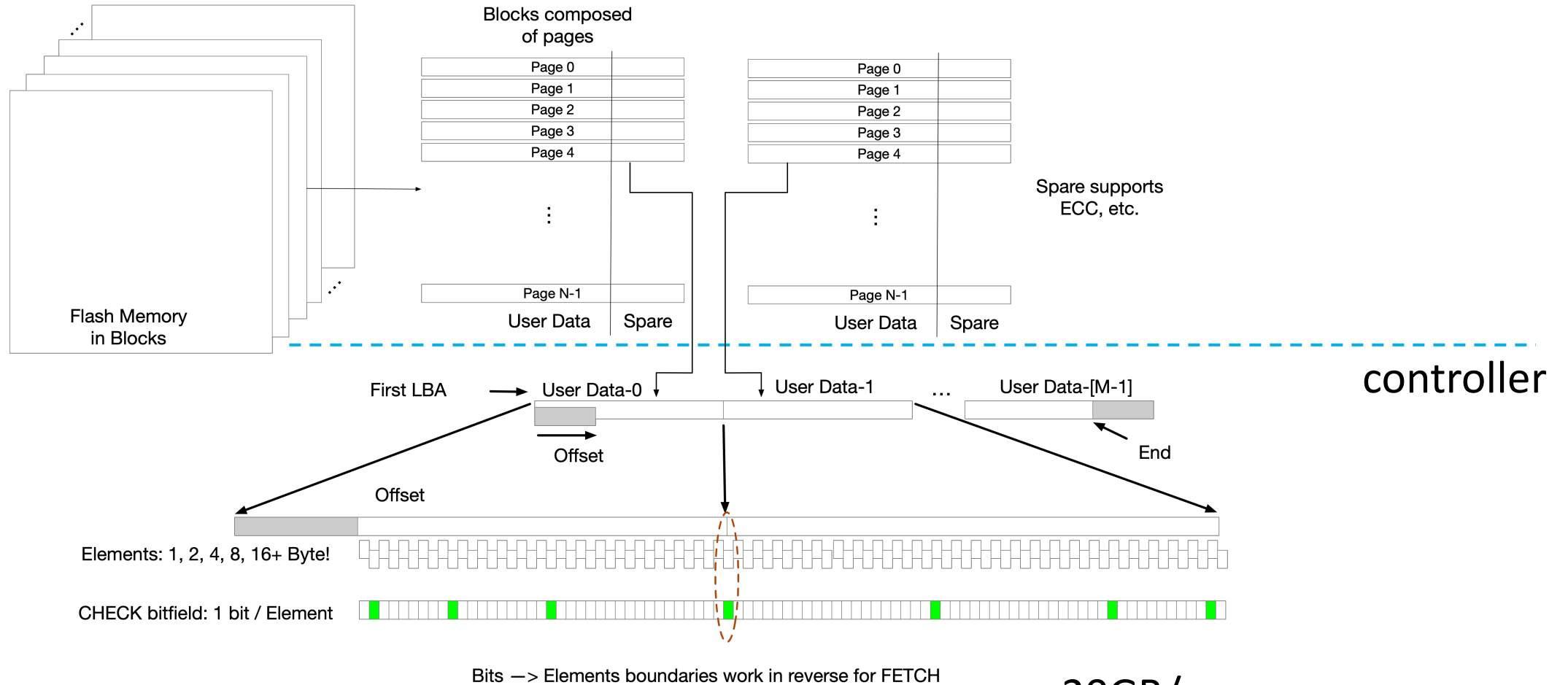
New Paradigm: CHECK & FETCH

User commands, NO administrative, NO Branches




“Inspection process”

MASSIVELY Parallelizable: choice up to controller

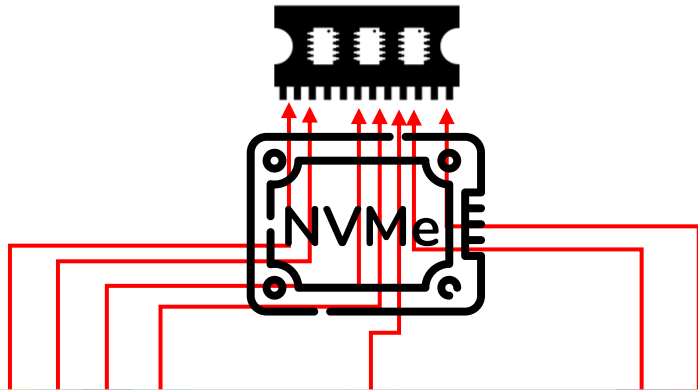


How wide? 4KB feasible on controller..

$$\frac{20\text{GB/s}}{4\text{KB}} = 5\text{MHz}$$



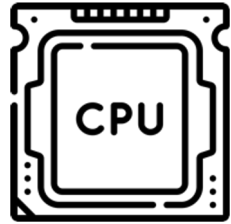
- Retrieve required columns
 - ~MB per column
- Process Data in CPU
- <0.1% for many queries!



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	LO_18
ORDERKEY	LINE NUMBER	CUSTOMER	PARTNER	SUPPLIER	ORDERRATE	ORDERPRIORITY	SHIPPRIORITY	QUANTITY	EXTENDEDPRICE	ORDTOTALPRICE	DISCOUNT	REVENUE	SUPPLYCOST	TAX	COMMODITY	SHIPMODE			
680	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				
565	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	14555.99	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	4114.3	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	11260.41	8759.13	0.16	2/9/21 AIR				
724	5	710	323	874	1/10/21 4-NOT SPECIFIED		47	3789.52	17806.89	0.09	46667.3	5369.19	0.17	2/10/21 AIR					
4	738	634	487	624	1/11/21 4-NOT SPECIFIED		44	5352.32	15314.78	0.02	1151.34	7392.95	0.12	2/11/21 SHIP					
755	8	556	92	374	1/12/21 5-LOW		2	42	9399.14	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	784.55	0.2	2/13/21 SHIP				
700	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				
61	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				
395	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				
317	1	422	658	824	1/19/21 3-MEDIUM		1	8	2176.52	15484.36	0.05	40784.99	5018.14	0.2	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		3	18	6983.17	2229.38	0.05	3481.1	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				
5	771	4	545	450	1/24/21 4-NOT SPECIFIED		4	26	9493.72	19313.42	0.02	3601.38	8231.86	0.11	2/24/21 TRUCK				
301	3	540	84	327	1/25/21 4-NOT SPECIFIED		4	16	126.76	16978.19	0.0	21485	1835.61	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	2659.06	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		2	8	5928.52	8056.05	0.02	10469.62	7204.25	0.15	2/28/21 AIR				



Today

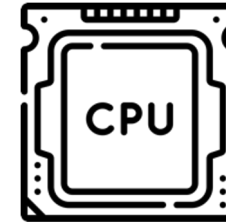


```
SELECT
  lo_custkey,
  lo_orderdate,
  lo_partkey,
  lo_revenue,
  lo_suppkey,
  lo_supplycost
FROM
  s3object
WHERE
  (lo_quantity BETWEEN 11 AND 20)
  AND (lo_orderdate <= 20210116);
```

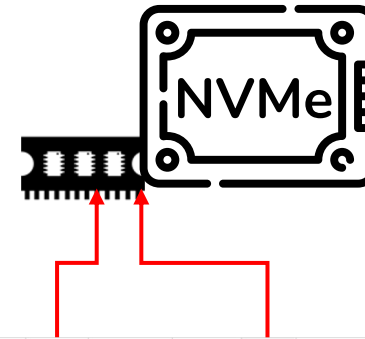
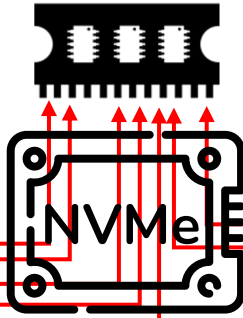
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- <0.1% for many queries!

SELECT

With CHECK-FETCH



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

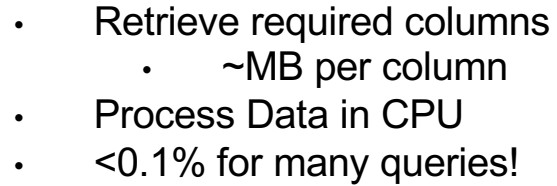


LO_ORDERKEY	LO_LINENUMBER	LO_CUSTKEY	LO_PARTKEY	LO_SUPPKEY	LO_ORDERDATE	LO_ORDERPRIORITY	LO_SHIPPRIORITY	LO_QUANTITY	LO_EXTENDEDPRICE	LO_ORDTOTALPRICE	LO_DISCOUNT	LO_REVENUE	LO_SUPPLYCOST	LO_TAX	LO_COMMITDATE	LO_SHIPMODE
685	5	68	341	349	1/1/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	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	6753.38	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

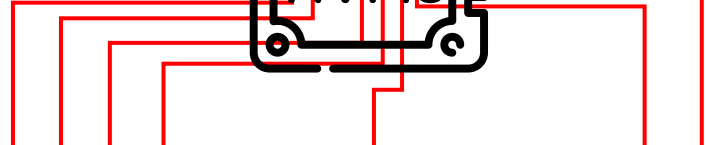
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685	5	68	341	349	1/1/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	2/1/21	TRUCK
560	5	979	510	942	1/2/21	2-HIGH	2	18	3482.81	13217.61	0.05	20748.27	3752.25	0.05	2/2/21	SHIP
630	7	772	515	283	1/3/21	5-LOW	4	30	6794.8	8005.41	0.03	37516.42	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	6753.38	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

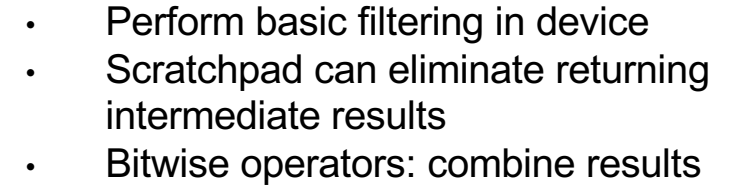


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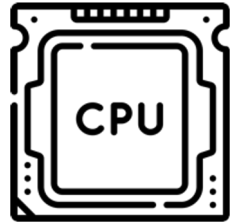
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685	5	68	341	349	1/1/21 3-MEDIUM		2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	2/1/21	TRUCK
560	7	599	510	942	1/2/21 2-HIGH		2	18	3482.81	13217.61	0.05	20748.27	3752.25	0.05	2/2/21	SHIP
630	7	772	515	283	1/3/21 5-LOW		4	30	6794.8	8005.41	0.03	37516.42	7694.96	0.12	2/3/21	RAIL
193	5	235	70	587	1/4/21 5-LOW		4	13	8804.42	19589.63	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	102.75	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	8355.19	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
856	5	556	92	574	1/12/21 5-LOW		4	47	9228.49	13995.14	0.1	43054.4	8566.29	0.12	2/12/21	SHIP
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	5018.14	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
487	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		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	9493.72	14933.42	0.07	9607.58	8251.86	0.11	2/24/21	TRUCK
3	540	94	84	437	1/26/21 4-NOT SPECIFIED		4	46	126.76	49	0	2144.85	1843.65	0.03	2/26/21	SHIP
850	940	434	491	491	1/28/21 5-LOW		46	46	6507.25	18723.06	0.1	34734.62	2659.94	0.06	2/28/21	REG AIR
678	4	218	810	54	1/27/21 5-LOW		19	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



ORDER	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO	LO
ORDER	LINUMBER	CUSTKEY	PARTKEY	SUPPLY	ORDATE	ORDERPRIORITY	SHIPPRIORITY	QUANTITY	EXTENDEDPRICE	ORDTOTALPRICE	DISCOUNT	REVENUE	SUPPLYCOST	TAX	COMMITDATE	SHIPMODE			
685	5	68	341	949	1/1/21 3-MEDIUM		2	34	7128.74	11861.44	0.04	9968.63	3995.22	0.1	2/1/21 SHIP				
560	5	979	510	942	1/2/21 2-HIGH		3	18	3482.81	13217.61	0.05	20748.27	3752.25	0.05	2/2/21 TRUCK				
630	7	727	515	283	1/3/21 5-LOW		4	30	6794.8	8005.41	0.03	37516.42	7624.96	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		4	44	5352.32	15314.78	0.07	11554.51	7392.95	0.1	2/11/21 SHIP				
755	8	336	92	334	1/12/21 5-LOW		2	92	9228.9	13995.14	0.05	3009.58	866.9	0.12	2/12/21 AIR				
805	6	33	342	291	1/13/21 2-HIGH		4	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	32335.65	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	8390.21	0.07	2/20/21 SHIP				
487	1	669	968	787	1/21/21 3-MEDIUM		2	49	5813.69	2344.68	0.03	45828.29	3327.78	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	23	6752.38	11834.92	0.01	13551.54	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				
880	4	434	488	426	1/26/21 5-LOW		4	46	6507.46	18723.06	0.1	9417.6	2616.94	0.1	2/26/21 SHIP				
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	96	817	1/28/21 3-MEDIUM		2	8	5928.52	8056.05	0.02	104949.2	7204.25	0.15	2/28/21 AIR				

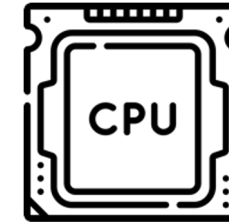
Today



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

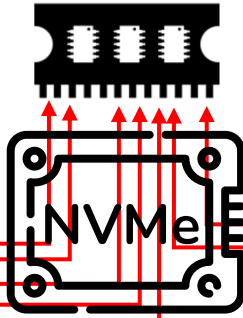
- Retrieve required columns
 - ~MB per column
- Process Data in CPU
- <0.1% for many queries!

SELECT



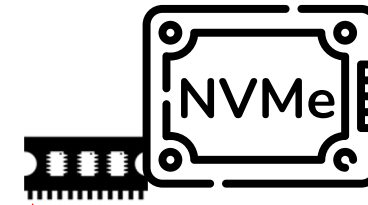
With CHECK-FETCH

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



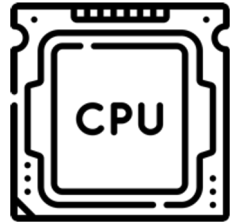
LO_ORDERKEY	LO_LINENUMBER	LO_CUSTKEY	LO_PARTKEY	LO_SUPPKEY	LO_ORDERDATE	LO_ORDERPRIORITY	LO_SHIPPRIORITY	LO_QUANTITY	LO_EXTENDEDPRICE	LO_ORDTOTALPRICE	LO_DISCOUNT	LO_REVENUE	LO_SUPPLYCOST	LO_TAX	LO_COMMITDATE	LO_SHIPMODE
685	5	68	341	349	1/1/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	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	4	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

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



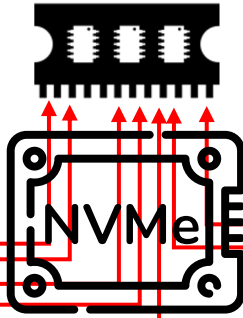
LO_ORDERKEY	LO_LINENUMBER	LO_CUSTKEY	LO_PARTKEY	LO_SUPPKEY	LO_ORDERDATE	LO_ORDERPRIORITY	LO_SHIPPRIORITY	LO_QUANTITY	LO_EXTENDEDPRICE	LO_ORDTOTALPRICE	LO_DISCOUNT	LO_REVENUE	LO_SUPPLYCOST	LO_TAX	LO_COMMITDATE	LO_SHIPMODE
685	5	68	341	349	1/1/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	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

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);
```

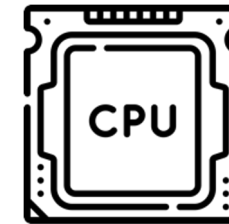
- Retrieve required columns
 - ~MB per column
- Process Data in CPU
- <0.1% for many queries!



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

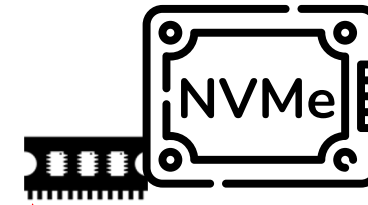
SELECT

With CHECK-FETCH



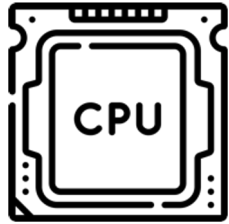
- Perform basic filtering in device
- Scratchpad can eliminate returning intermediate results
- Bitwise operators: combine results
- Extract only desired data

LO_CUSTKEY	LO_ORDERDATE	LO_PARTKEY	LO_REVENUE	LO_SUPPKEY	LO_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



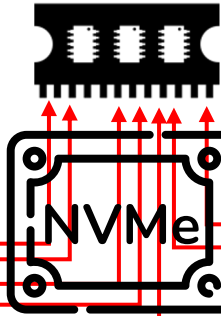
LO_ORDERKEY	LO_LINENUMBER	LO_CUSTKEY	LO_PARTKEY	LO_SUPPKEY	LO_ORDERDATE	LO_ORDERPRIORITY	LO_SHIPPRIORITY	LO_QUANTITY	LO_EXTENDEDPRICE	LO_ORDTOTALPRICE	LO_DISCOUNT	LO_REVENUE	LO_SUPPLYCOST	LO_TAX	LO_COMMITDATE	LO_SHIPMODE
685	5	68	341	349	1/1/21	3-MEDIUM	2	34	2128.74	11861.44	0.04	9968.63	3995.22	0.1	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

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);
```

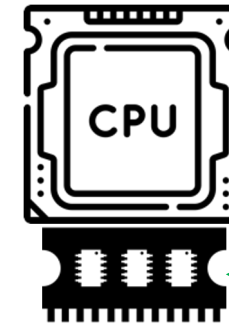
- Retrieve required columns
 - ~MB per column
- Process Data in CPU
- <0.1% for many queries!



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		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		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		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		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		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		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		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		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		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	8355.19	0.17	2/10/21	AIR
278	4	728	624	787	1/11/21	4-NOT SPECIFIED		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		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		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	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		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
601	6	139	663	827	1/17/21	4-NOT SPECIFIED		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		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		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		4	1245.46	19178.94	0.07	24489.84	8290.21	0.07	2/20/21	SHIP
487	1	669	908	787	1/21/21	3-MEDIUM		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		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		38	6752.38	11834.92	0.01	15351.54	3637.54	0.03	2/23/21	MAIL
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678	4	218	810	54	1/27/21	5-LOW		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		8	5928.52	8056.05	0.02	41049.62	7204.25	0.15	2/28/21	AIR

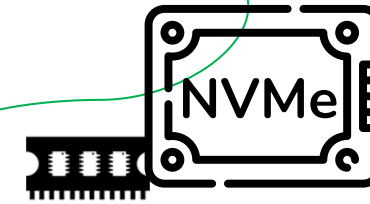
SELECT

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



AirMettle's methodology for enabling in-device analytical offloads can be implemented in both the firmware and the hardware of our commercial enterprise SSDs.

- Sebastien Jean , CTO



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Computational Storage Service

Analytical Data Platform with Intelligent Analytics Offload

Donpaul Stephens

AirMettle, Inc.

donpaul@airmettle.com



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