LayoutBench: Performance Benchmarking of Cloud Storage Layouts for Multimedia Data

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No benchmark for multimedia retrieval on cloud storage!

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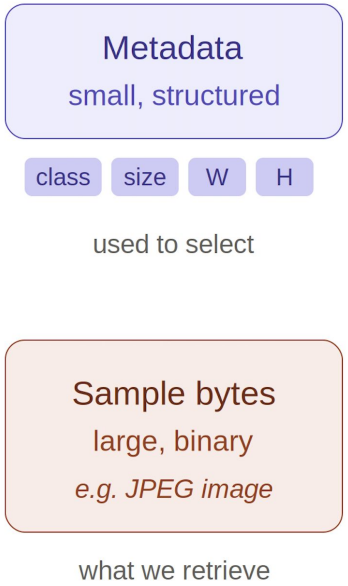

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- Every layout manages two things:
  - Metadata — class, size, width, height (used to select)
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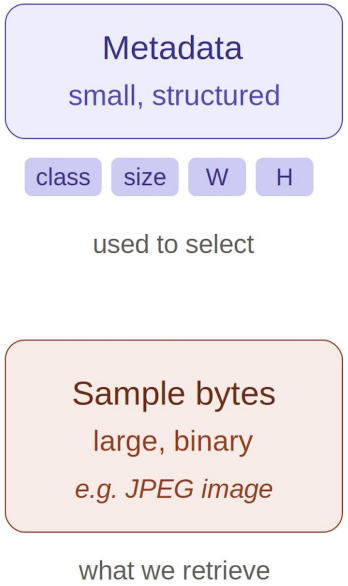

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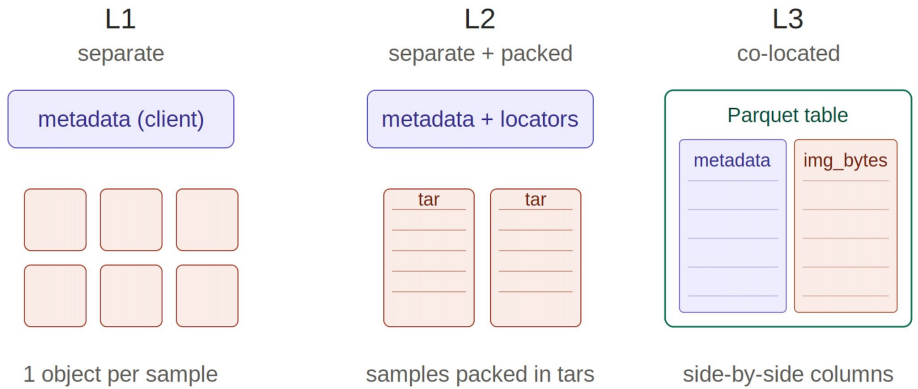

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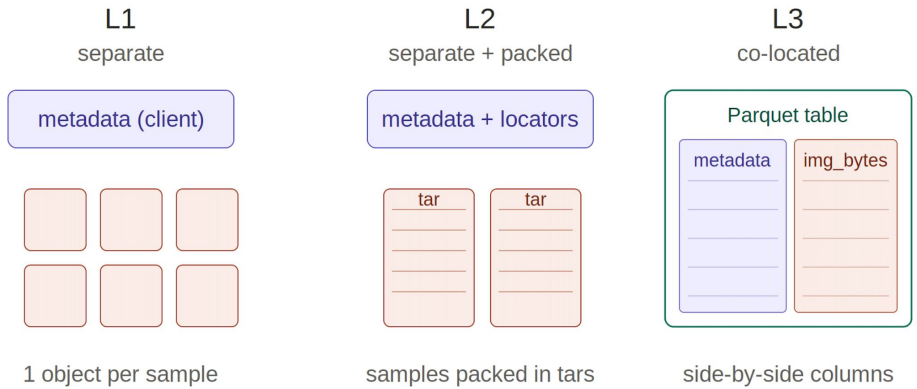
- Layouts differ in how they co-locate or separate these



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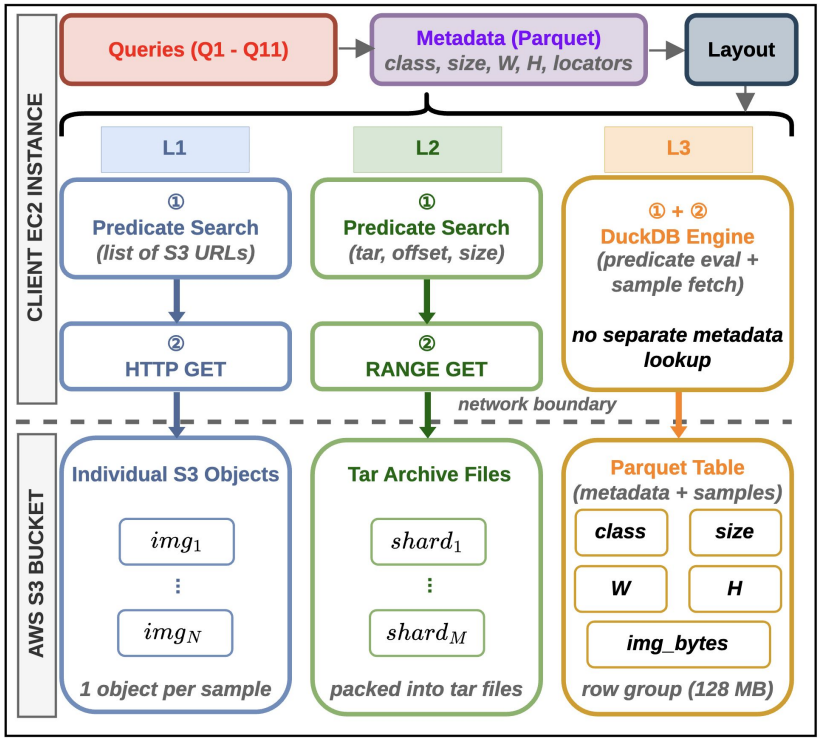

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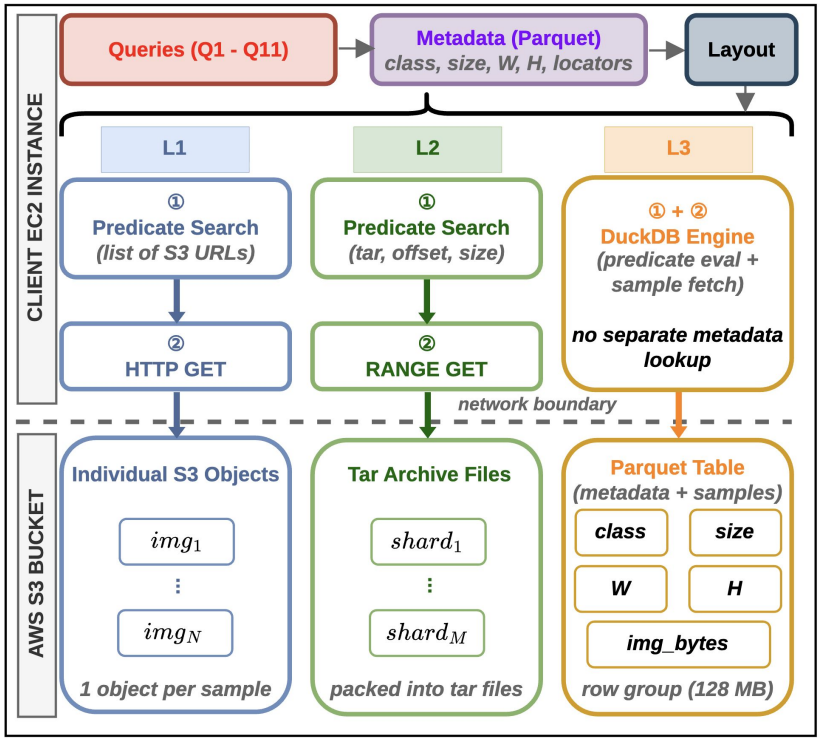
- L1: One sample → one S3 object



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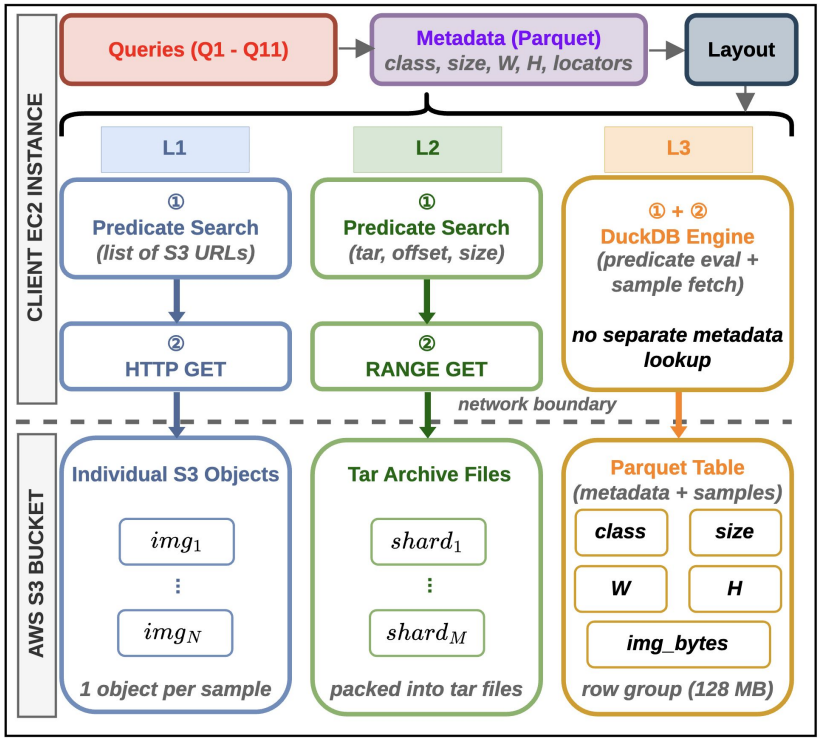

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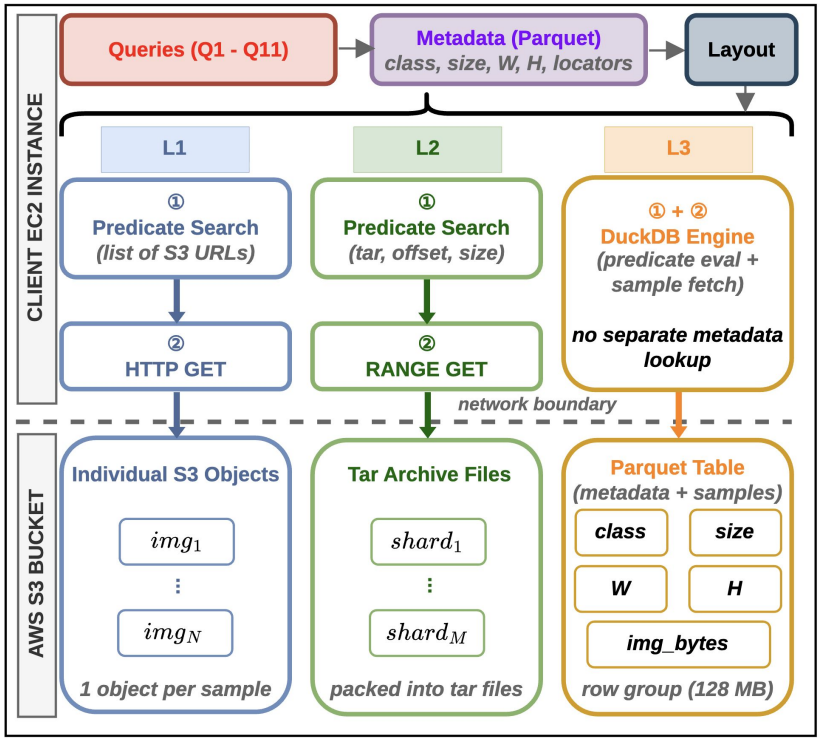
- L1: One sample → one S3 object
- L2: Samples packed into tar archives (byte-range GETs)
- L3: Samples as BLOBs in Parquet columns (DuckDB queries)



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- 11 queries: atomic (Q1–Q6) + composite (Q7–Q11)
- 6 EC2 instances: 3 bandwidth tiers + 3 memory tiers
- Metrics: retrieval time T, data transferred D, cost C

Dataset statistics at the storage server and client

Table 1: Dataset statistics at the storage server and client.

Dataset	Location	Attribute	Storage Layout Plan		
			L1	L2	L3
mini	Server	Number of Files	12,756	23	22
		File Size	1.39 GB	1.38 GB	1.36 GB
	Client	Index File Size	553 KB	810 KB	0
medium	Server	Number of Files	128,066	28	28
		File Size	13.91 GB	13.76 GB	13.57 GB
	Client	Index File Size	4.4 MB	6.8 MB	0
full	Server	Number of Files	1,281,167	276	274
		File Size	139.25 GB	137.73 GB	135.85 GB
	Client	Index File Size	35.6 MB	54.7 MB	0

Summary of the queries

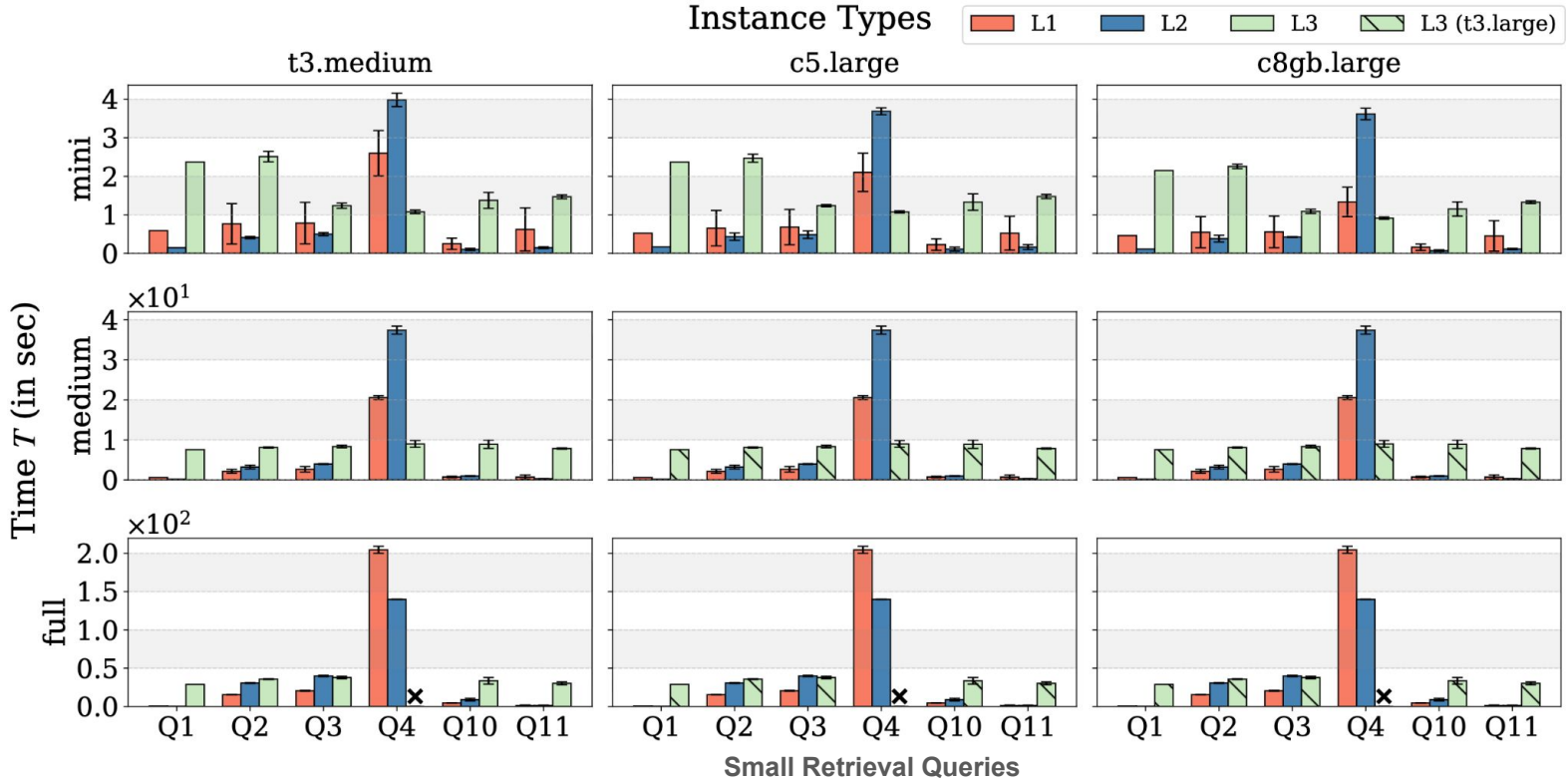
Q.	Type	Predicate				Query Description	Retrieval – Num. of Files		
		C	S	W	H		mini	medium	full
Q1	One Sample	✓				one image of *streetcar*	1	1	1
Q2	Batch Fetch	✓				N images of *lemon* ($N = 10(mini), 100(medium), 1000(full)$)	10	100	1,000
Q3	One Class	✓				images of *cello*	13	130	1,300
Q4	Regex Match	✓				images whose labels are prefixed with snake, i.e., LIKE *%snake*	130	1,300	13,000
Q5	Fan-out	✓				images of *Old_English_sheepdog*, *giant_panda*, and *water_buffalo*	39	390	3,900
Q6	File size Filter		✓			images that are at least 500 KB	86	801	7,837
Q7	Resolution Filter			✓	✓	images whose width and height are both at least 1024 pixels	133	1,309	12,635
Q8	Cross-column			✓	✓	images whose width / height ratio is greater than 1.5	2,311	23,006	229,710
Q9	Multi-label Filter	✓	✓			images of *canoe* and *starfish* that are smaller than 100 KB	6	47	575
Q10	Selective Filter	✓	✓			images of *tiger_cat* that are smaller than 100 KB	1	27	294
Q11	All-column Filter	✓	✓	✓	✓	images of *bagel* under 200 KB with width and height at least 512 pixels	1	6	32

Comparison of client EC2 instance types

API Name	Network	Memory	vCPUs	Hourly Cost
t3.medium	Up to 5 Gigabit	4 GiB	2 vCPUs	$0.0416
c5.large	Up to 10 Gigabit	4 GiB	2 vCPUs	$0.0850
c8gb.large	Up to 20 Gigabit	4 GiB	2 vCPUs	$0.1185
t3.large	Up to 5 Gigabit	8 GiB	2 vCPUs	$0.0832
t3.xlarge	Up to 5 Gigabit	16 GiB	4 vCPUs	$0.1664
t3.2xlarge	Up to 5 Gigabit	32 GiB	8 vCPUs	$0.3328

Finding #1: Latency Crossover (L1 vs L2); L3's Baseline Overhead

End-to-end retrieval time (Q1-Q4 & Q10-Q11) [Finding #1]



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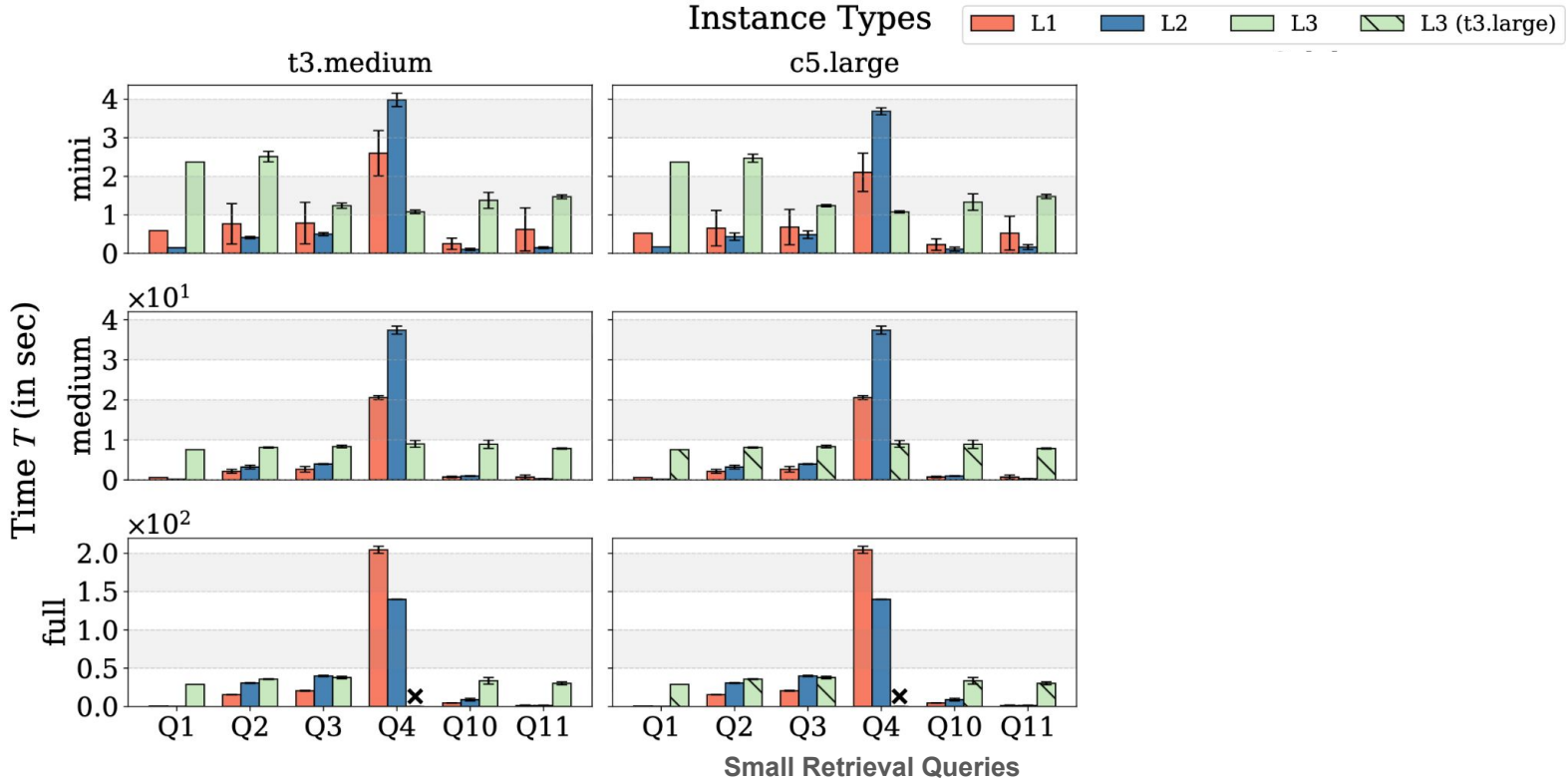

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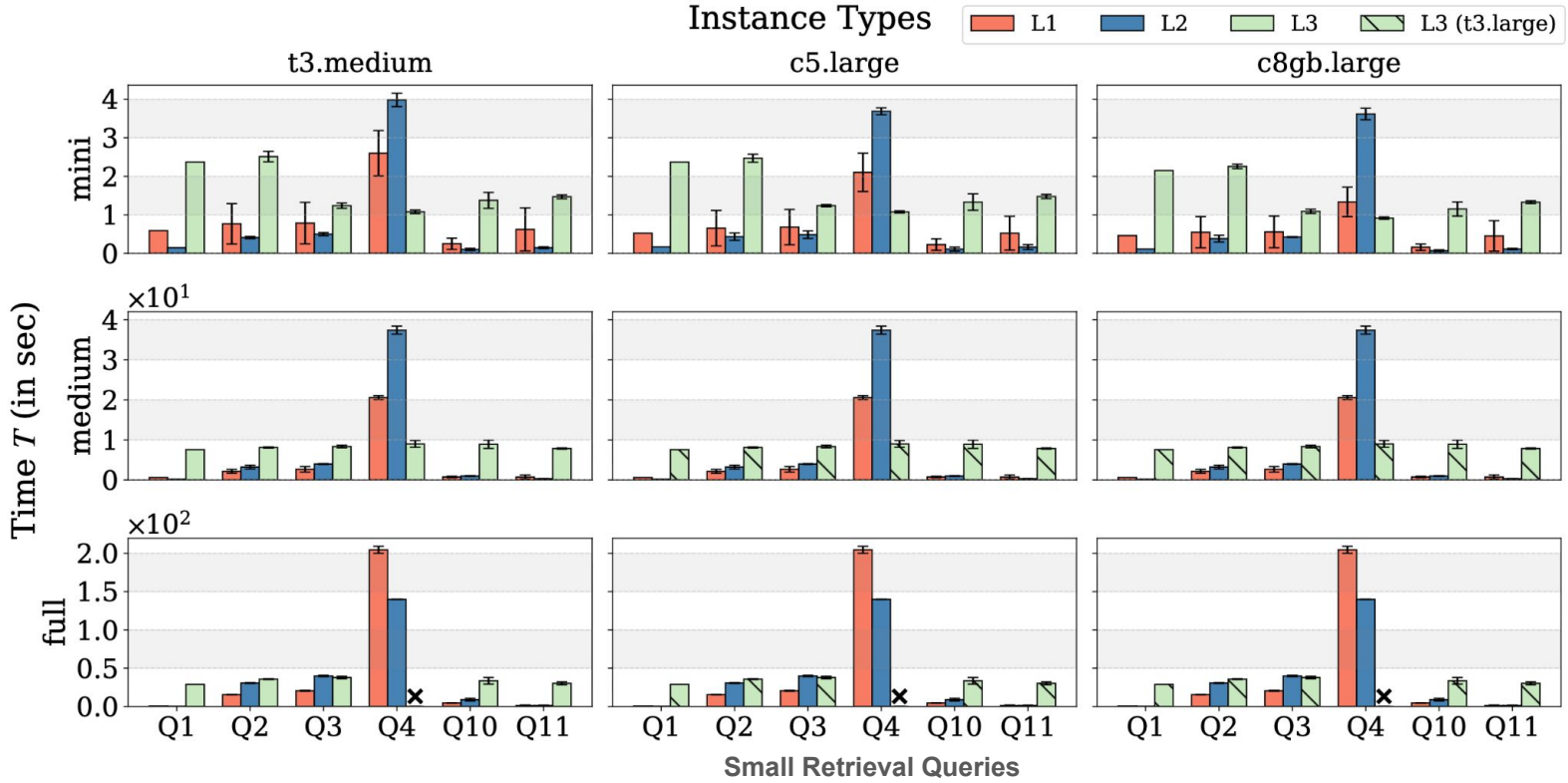
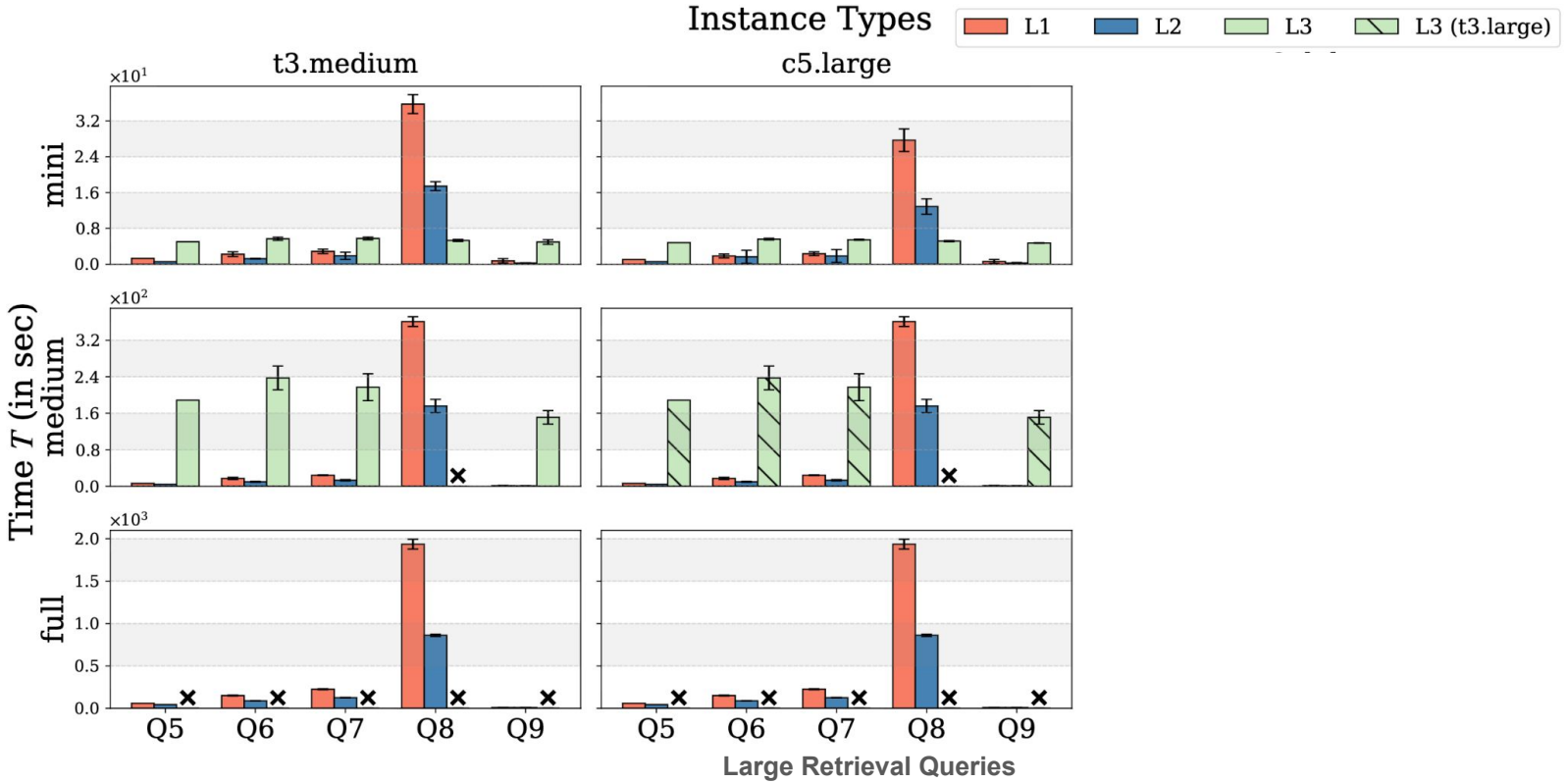


End-to-end retrieval time (Q5-Q9) [Finding #1]



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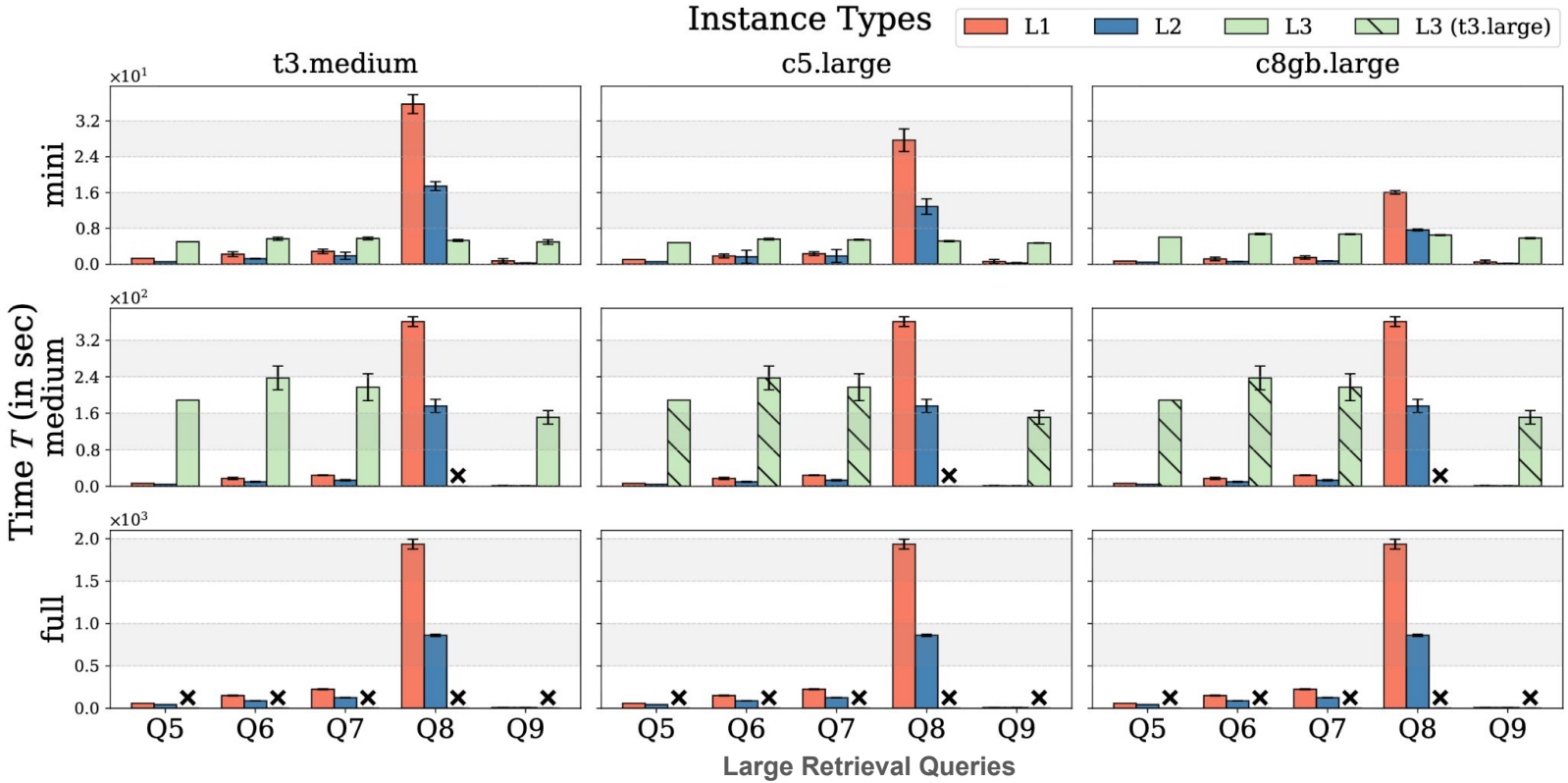

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- L3 is slow for small & mid retrievals (DuckDB init overhead)
- L3 is fastest for very large retrievals (row-group reads win)
- L3 cannot run on small instances at full scale (✗ marks)

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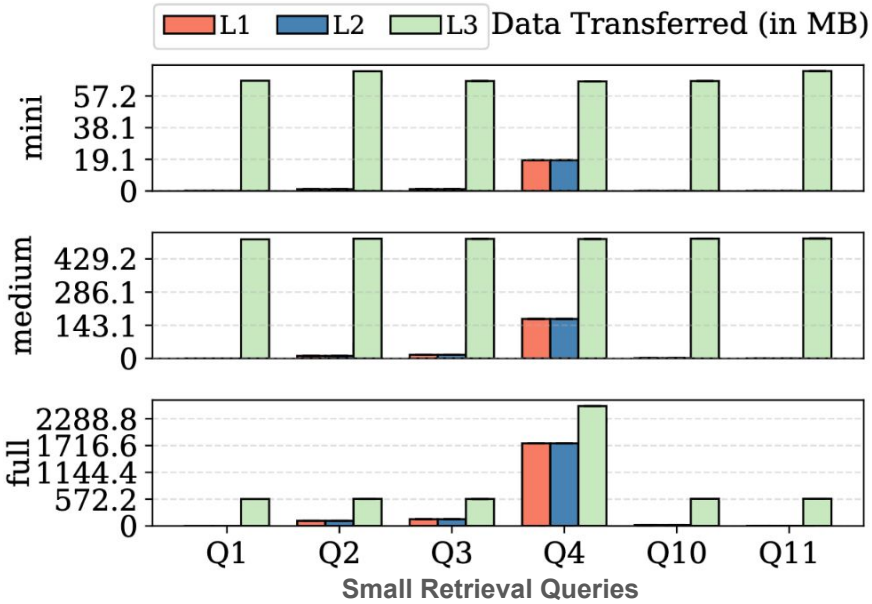

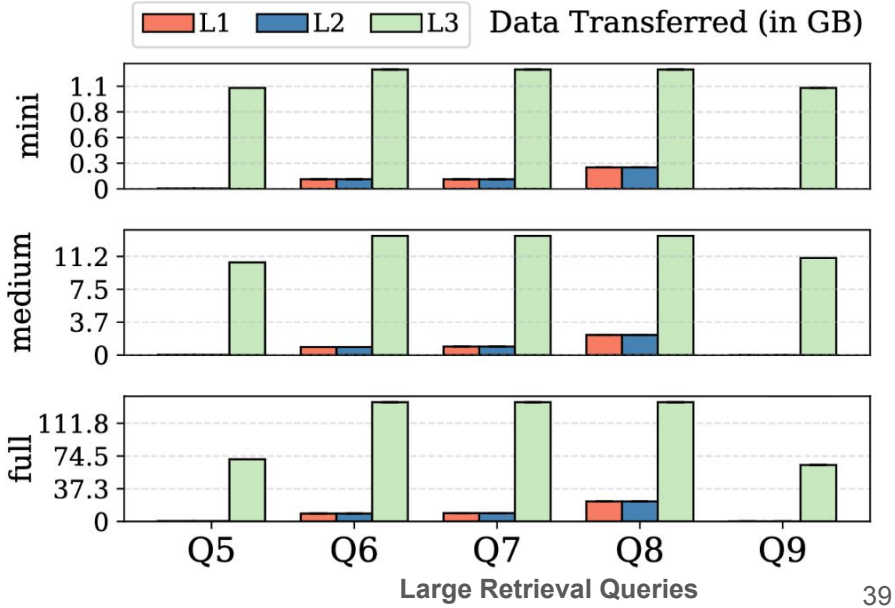

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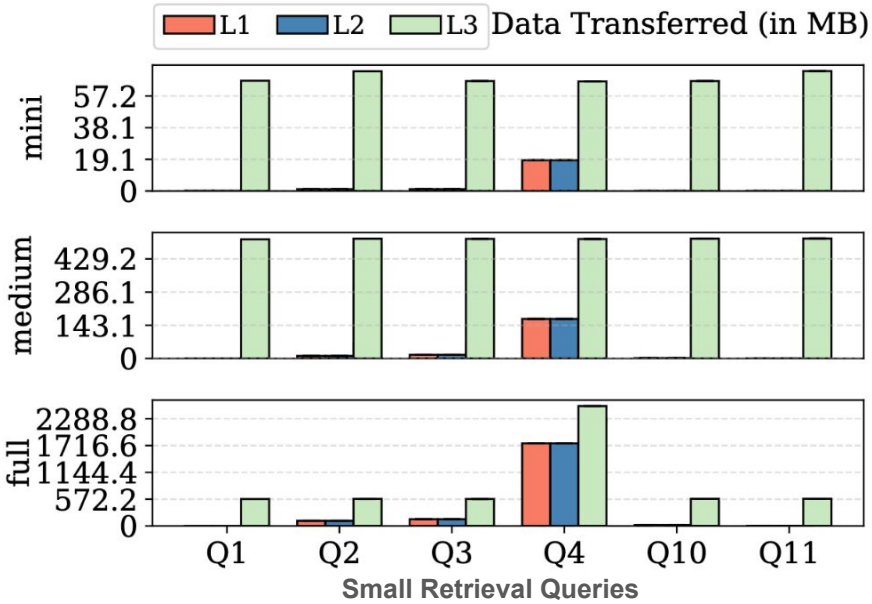

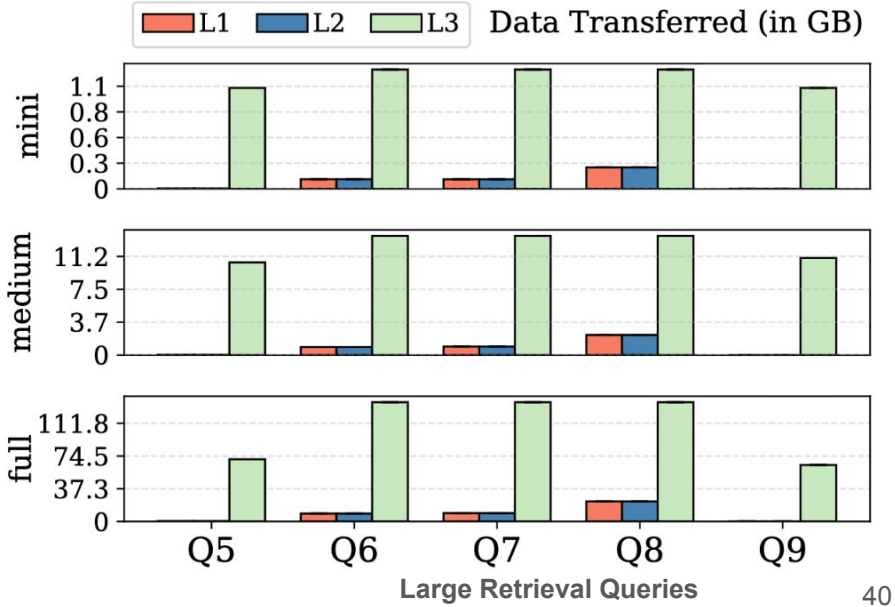

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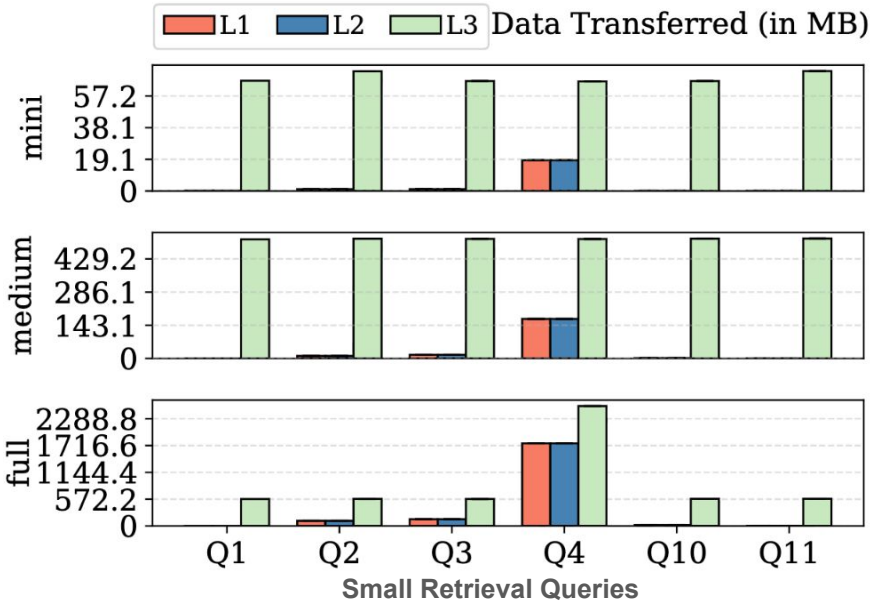
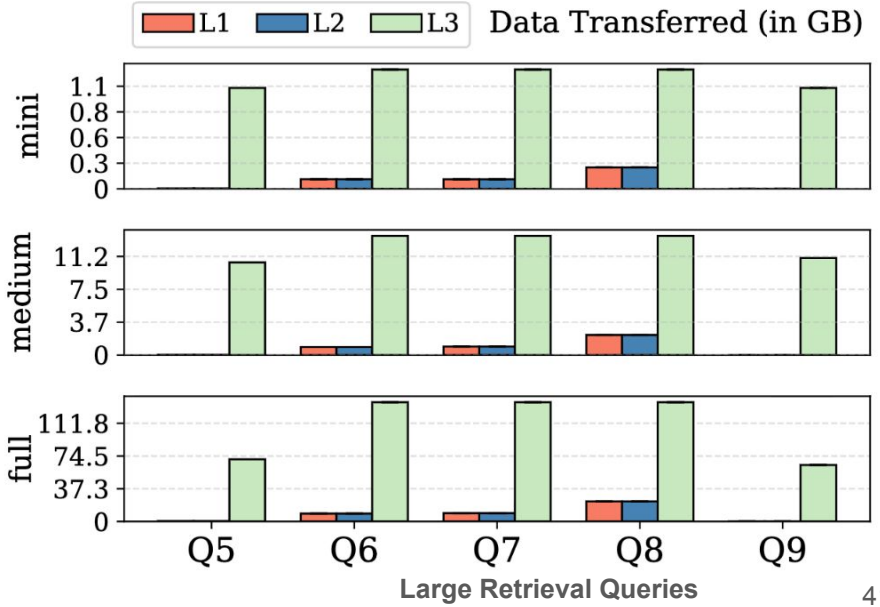
- L3: fetches entire row groups → big overhead on selective queries





Finding #3: Each Layout Has a Different Bottleneck

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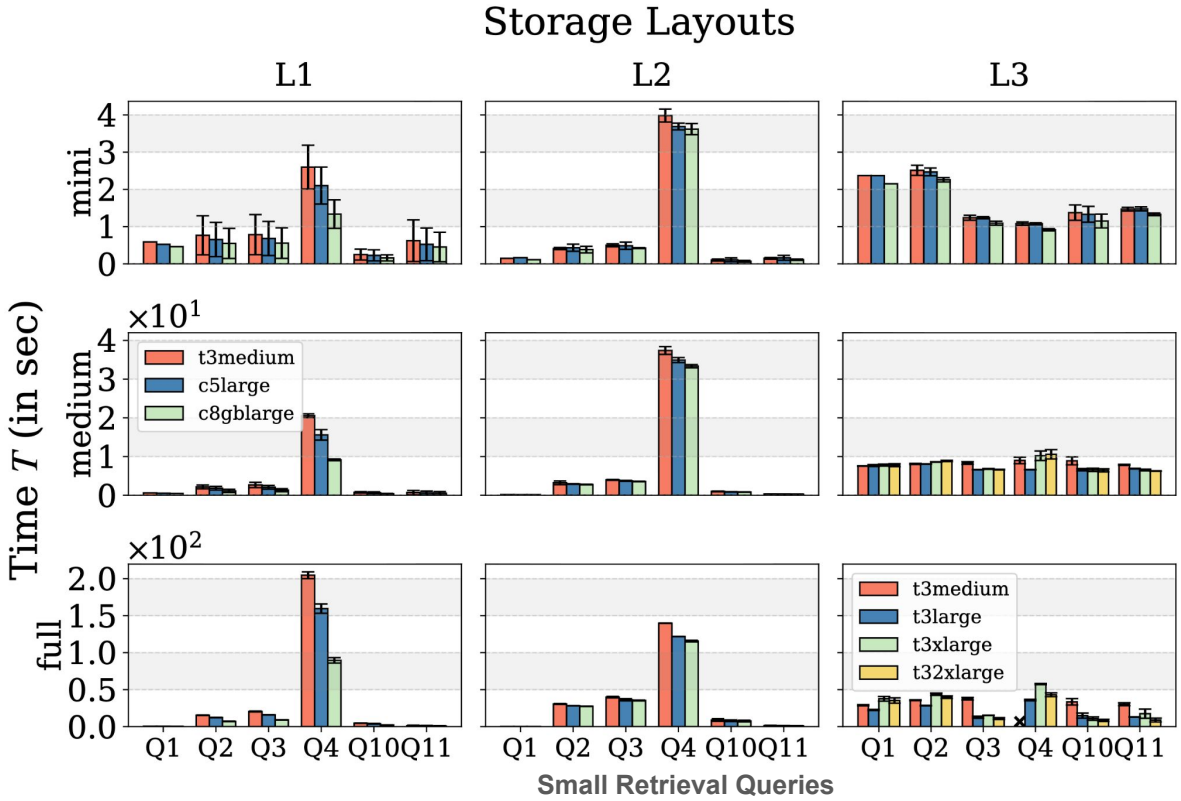

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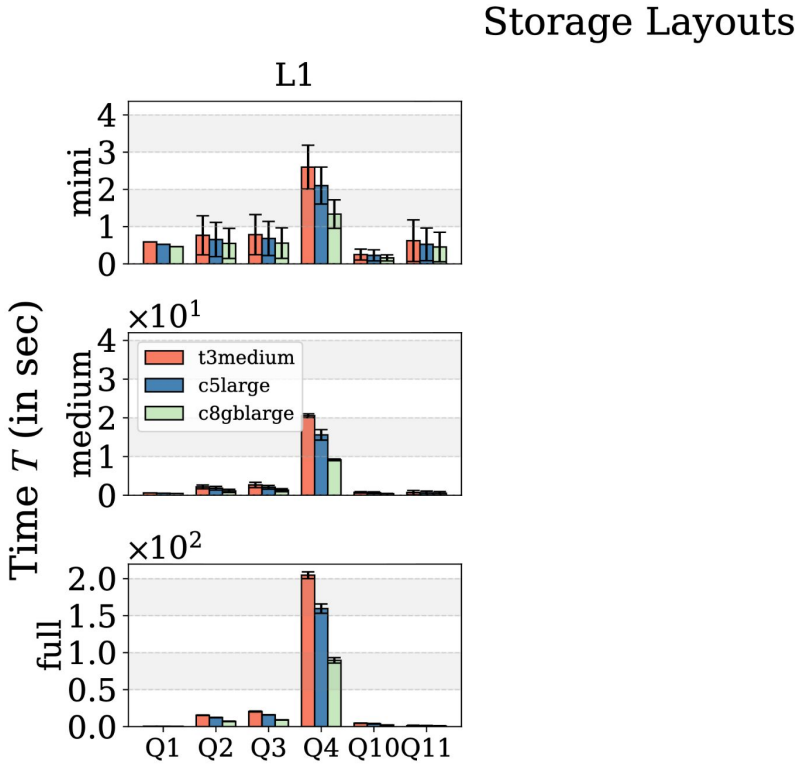

Small Retrieval Queries

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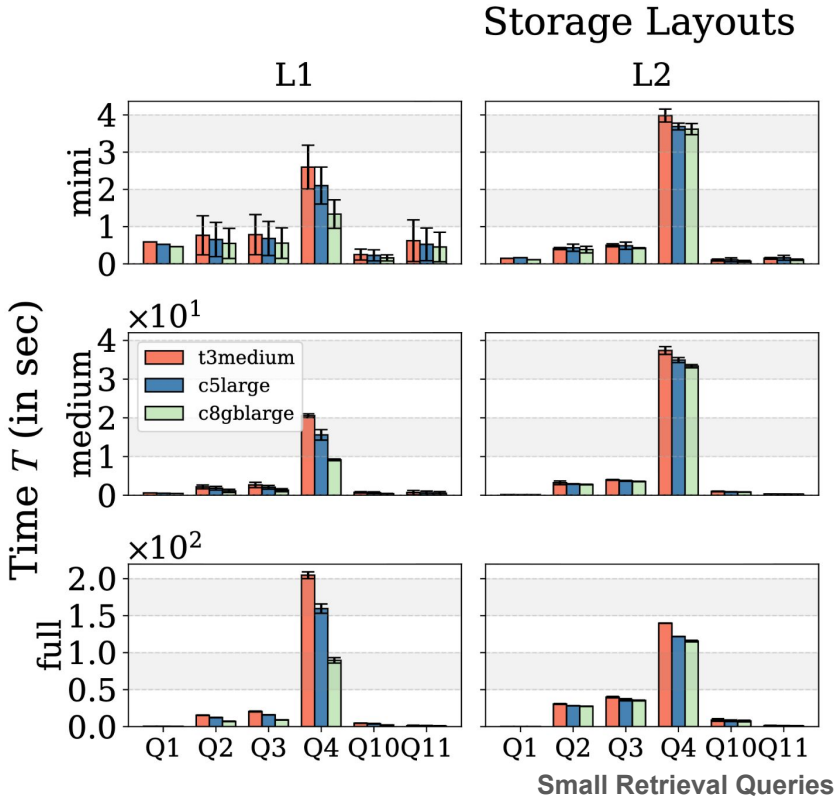

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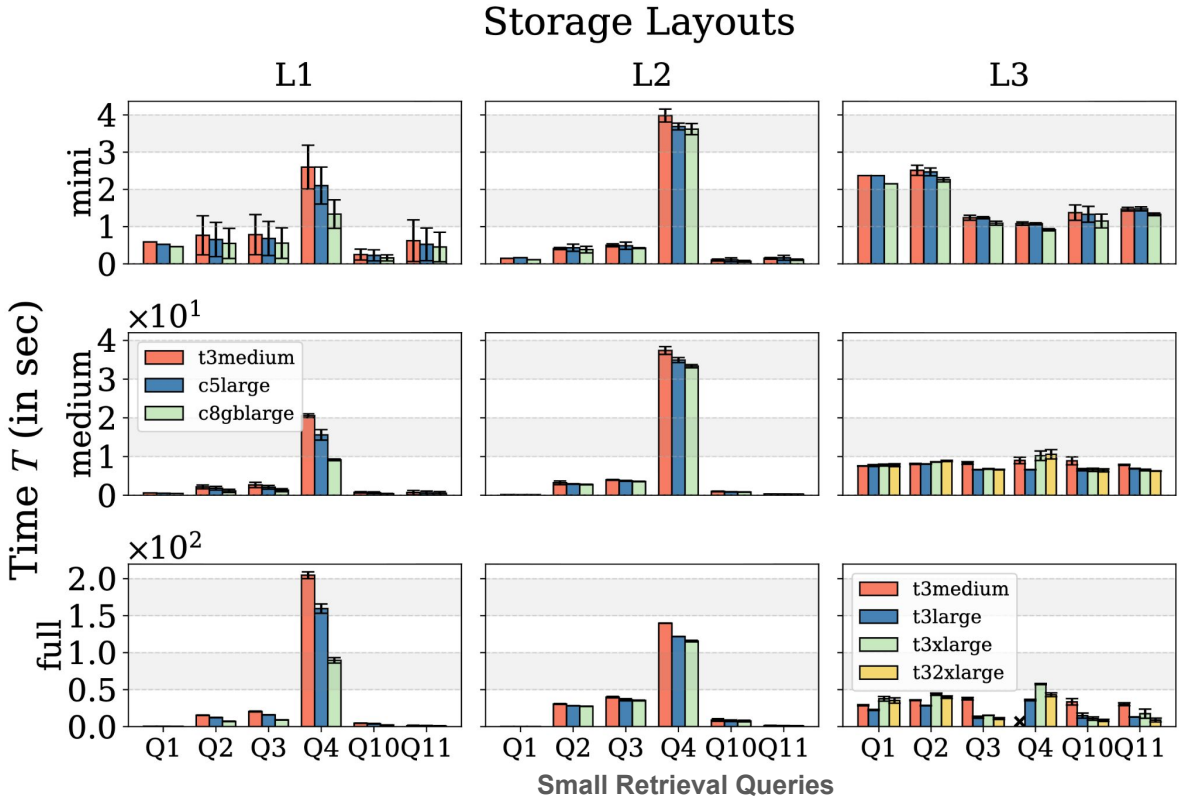

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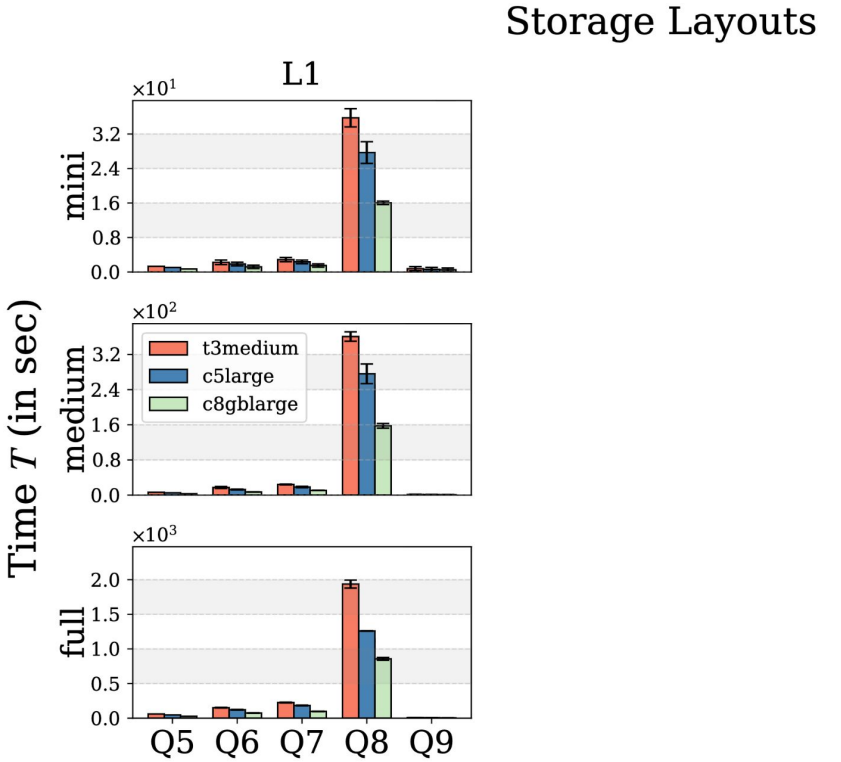

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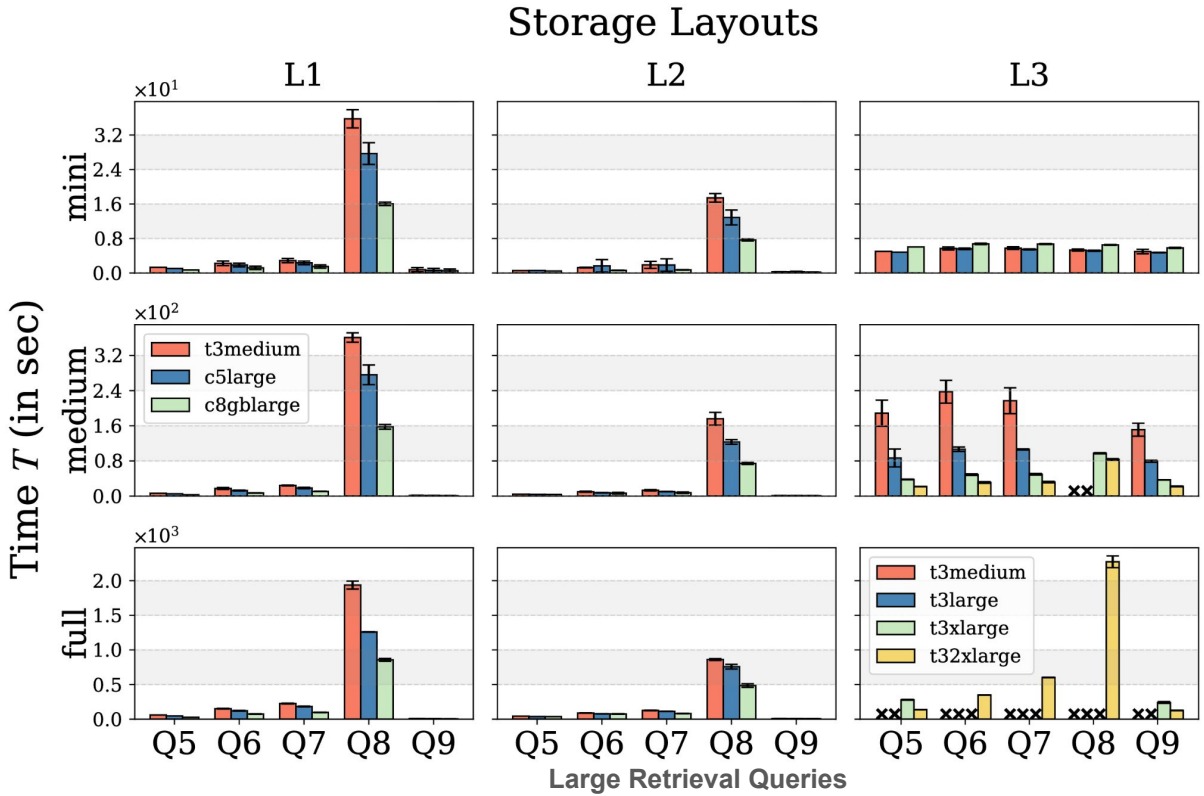

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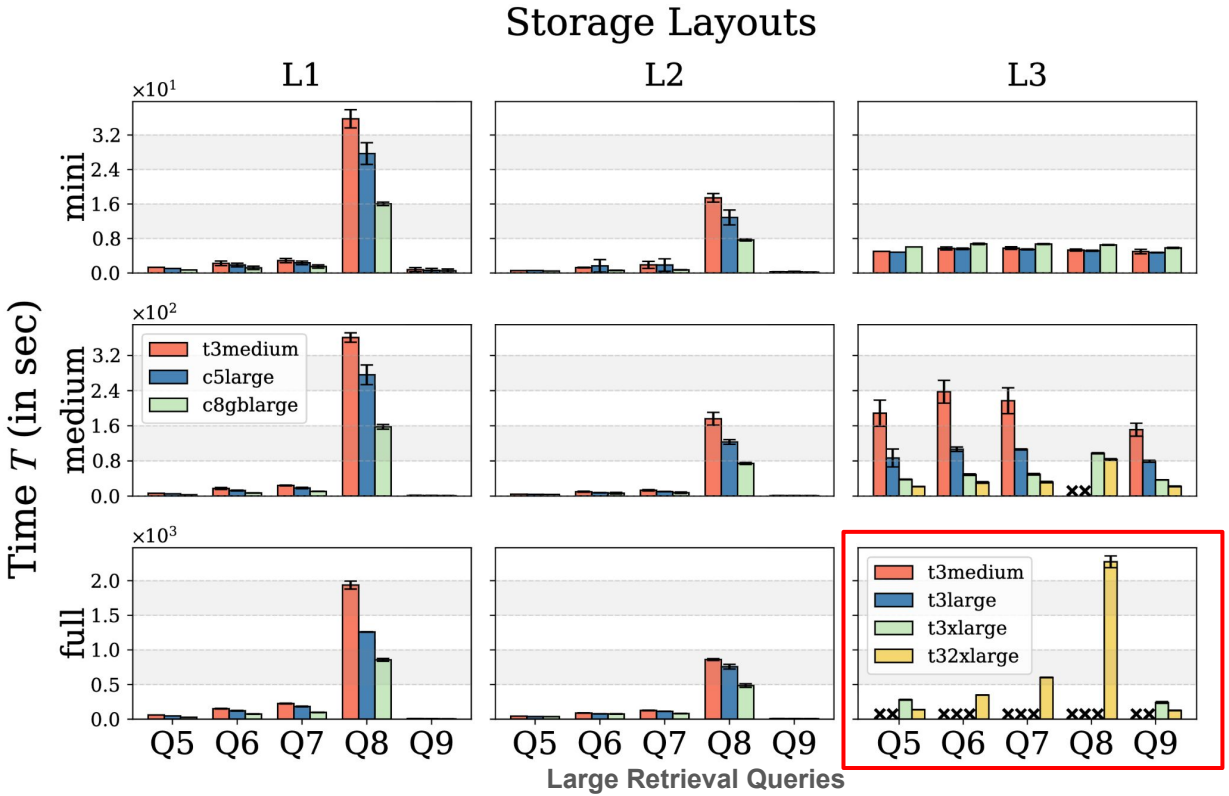

Finding #3: Each Layout Has a Different Bottleneck

Layout	**Bottleneck**	**Fixed by**
L1	Per-request latency and network bandwidth	Can't easily fix
L2	Network bandwidth	More bandwidth
L3	Memory	Bigger instance (💰)

Finding #4: The Cost Story

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- Cost breakdown on *t3.medium*

	L1	L2	L3
C_{network}	\$0.795	\$0.795	\$9.183
C_{compute}	\$0.010	\$0.005	\$0.019
$C(total)$	\$0.805	**\$0.800**	\$9.202

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Primary bottleneck	Latency	Bandwidth	Memory
Connection overhead	High	Low	N/A
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Recommendation: L2 for images – best latency-cost balance for image workloads