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Data Storage Technology Overview

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Agenda

- History and Trends of Automotive Storage
- Data Storage Types and Data Recording Scenarios
- Considerations of Storage

A Powerful Platform

Western Digital

Data Center | Auto | Compute | Mobile | Home | Industrial

PORTFOLIO BREADTH

TECHNOLOGY ENGINE

~14,000 active patents

GLOBAL SCALE

62,000+ employees worldwide

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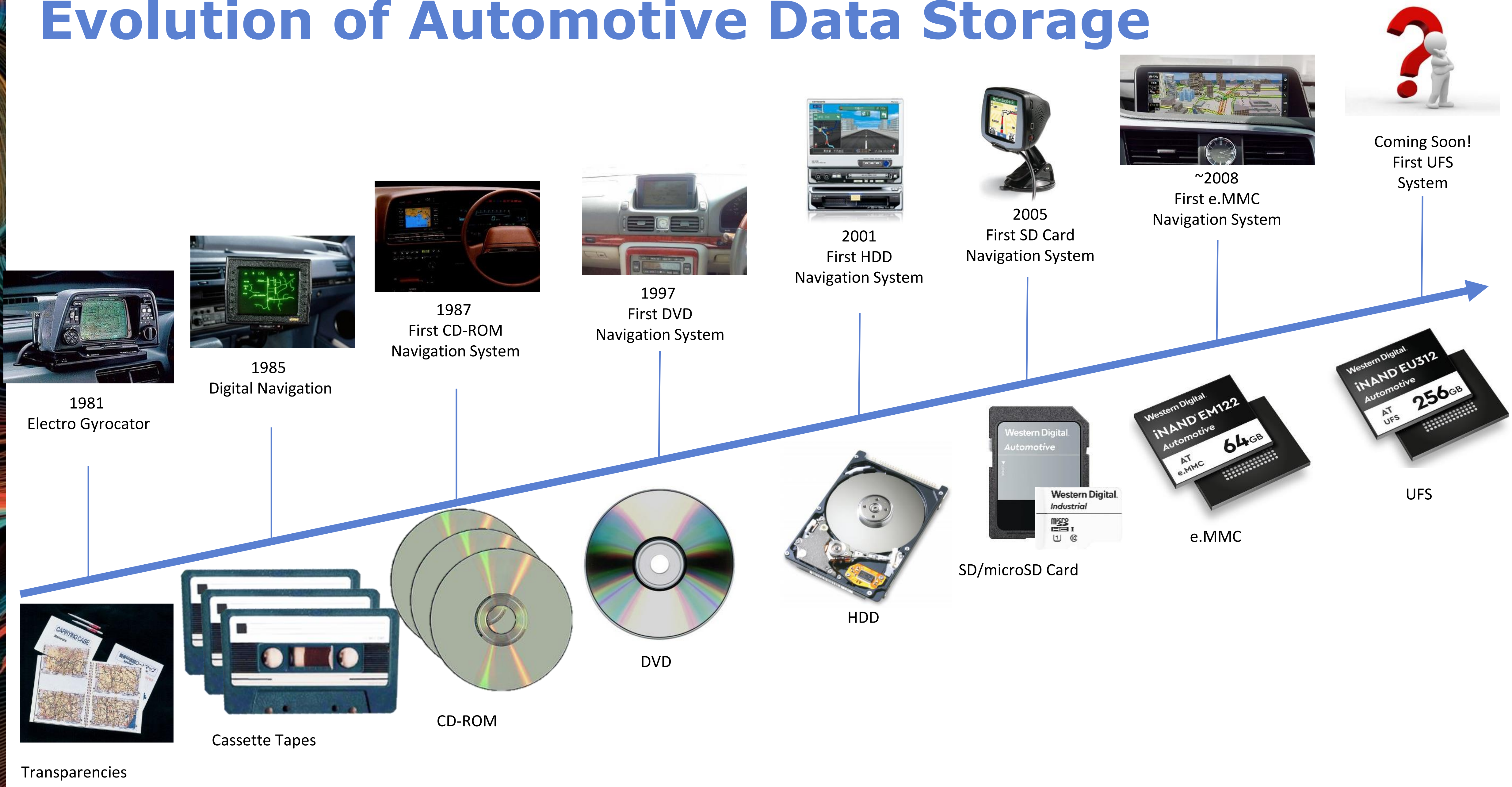
Evolution of Automotive Data Storage



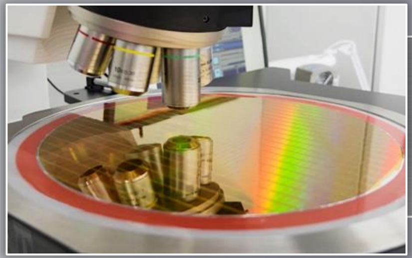
Automotive Data Storage Today

Automotive Storage Trends

DENSITY needs increasing

SPEED of data increasing

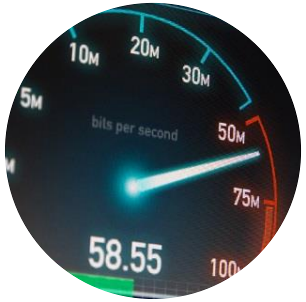
USAGE models changing



QUALITY targets are still ZERO dppm!

Data Storage Enabling the Car of the Future

Changing Storage Usage Models



Faster Boot and Read Speeds

Operating systems and applications are getting more complex

Wider Temperature Environments

More powerful processors

New Write-intensive Workloads

Multi-camera recording, autonomous drive, data telematics

Automotive Data Storage Tomorrow

F U T U R E

VIRTUAL MACHINES

Comput
combi

AI Database

Stores
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BODY CONTROLS

Controls
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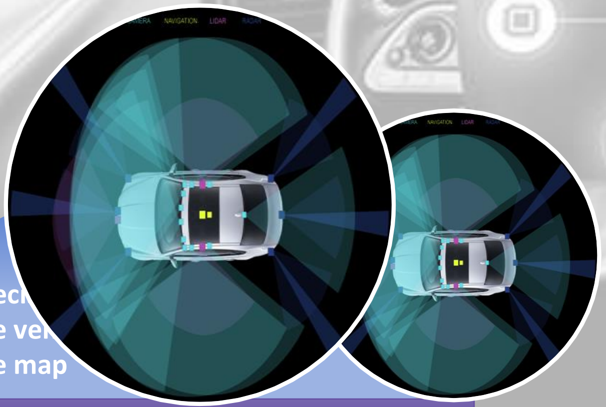

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LOCATOR/SENSOR FUSION

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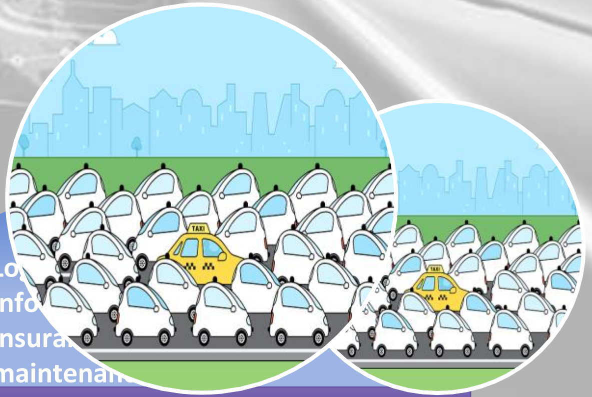
AUTONOMOUS DRIVE



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Fleet TaaS/MaaS

Growth of Data Storage in Vehicles

3D/HD Mapping • Infotainment/Navigation • Digital Clusters • Telematics Gateways • V2V/V2I Comms • Autonomous Drive • Data Recorders

Application stack + HMI (voice, gesture, etc)

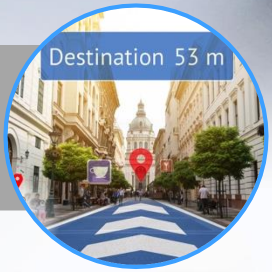
32GB

Maps (3D/HD)

64-128GB+

Augmented Reality

16-128GB+



Hypervisor + multiple OS

8-64GB

Autonomous drive OS + App Stack

32-512GB

Drive Recorder

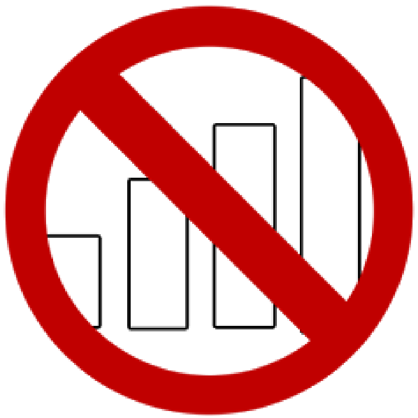
32GB-2TB+

DashCams, Cluster, Telematics/V2X,Body control

8-64GB

In Car Storage v. Cloud Storage

Connectivity



Latency

Cost

Automotive Data Storage Types and Scenarios for Data Recording

Types of Data Storage Technology

Each storage technology has a different role

Volatile Storage

- DRAM – Used for storing data that the processor is using. Very fast read/write capabilities

Non-volatile Storage

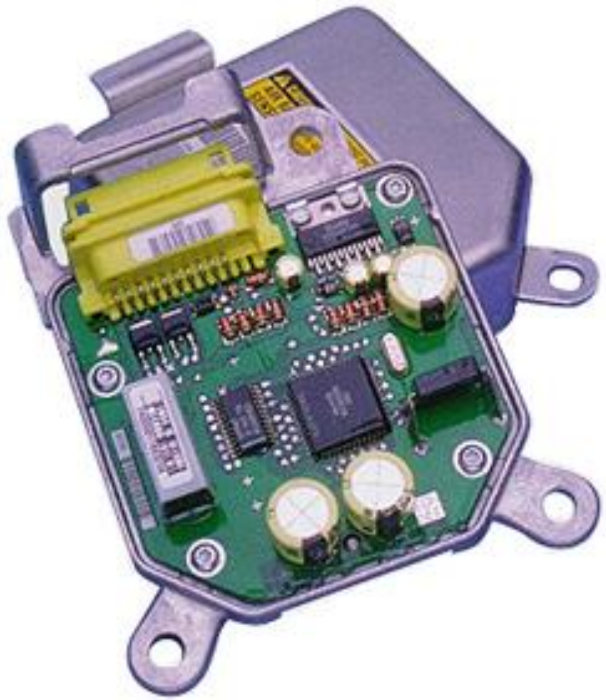
- Magnetic
  - HDD – High data storage capacity, but not suited to applications with shock/vibe
  - Tape – High data storage capacity, but not suited to applications with shock/vibe
- Flash
  - NOR – Low storage capacity and resilient to shock/vibe
  - NAND – High storage capacity and resilient to shock/vibe

Used in automotive today
No longer used in automotive

Other data storage products exist but are not commercially viable today

What is Used Today for Event Data Recorders

- DRAM + NOR flash
  - Very limited amount of data (kilobytes-megabytes)
  - Data is constantly written into DRAM but only transferred to NOR when there is an Event



Estimated Data Generation by SAE Level

	Cameras	Radar Sensors	Ultrasound Sensors	LiDAR	Gigabytes Generated per hour (Low)	Gigabytes Generated per hour (High)
Level 0	0–1	0	0-4	0	0	280
Level 1	1–4	3–5	4–8	0	520	2,220
Level 2	4–8	5–8	8–12	0–2	1,700	6,000
Level 3	7–10	6–9	8–12	1–3	4,700	7,800
Level 4	9–16	11–21	8–12	3–5	6,700	16,700
Level 5	9–17	11–23	8–16	3–6	6,700	17,300

Note: Data assumes 24bpp.

Source: IDC, November 2019

Cameras will be the biggest driver of Data

Higher resolution (4K/8K), higher frame rate will drive this even more.

Data Generated

Running Autopilot 2.5

	H-Pixel	V-Pixel	Frames per Second	Megabits per Second	Gigabytes Generated per Hour
Front narrow, max distance: 820ft, 35-degree field of view	1,280	960	30	885.00	398
Front main, max distance: 260ft, 50-degree field of view	1,280	960	30	885.00	398
Front fisheye, max distance: 195ft, 150-degree field of view	1,280	960	30	885.00	398
Left pillar, 195ft, 80-degree field of view	640	480	30	221.00	100
Right pillar, 195ft, 80-degree field of view	640	480	30	221.00	100
Left repeater, 325ft, 60-degree field of view	640	480	30	221.00	100
Right repeater, 325ft, 60-degree field of view	640	480	30	221.00	100
Rear, max distance: 160ft, 140-degree field of view	1,160	720	30	601.00	271
Long-range radar				15.00	7
Long-range ultrasound x 12				0.12	0
Total				4,155.12	1,872

Note: Data assumes 24bpp.

Source: IDC, November 2019

Scenario1: Data Written to DRAM First

Data Recorder- TB Written

Write Amplification Factor:	1.5
Memory	X3
P/E Cycles	3000

15 years +
10 years +
5 years +
Less than 5 years

			Card Capacity (GB)					
			16	32	64	128	256	512
TB Writes			31	63	125	250	500	1000
GB Writes			32000	64000	128000	256000	512000	1024000

Data Recorder - Expected Life (Years)

	Recording Bit Rate (Mbps)	Recorded time per incident (seconds)	Number of incidents a year	Device Capacity (GB)					
				16	32	64	128	256	512
Level 2	4.155	30	100	21030	42061	84122	168243	336486	672973
	4.155	60	100	10515	21030	42061	84122	168243	336486
	4.155	90	100	7010	14020	28041	56081	112162	224324
	4.155	30	300	7010	14020	28041	56081	112162	224324
	4.155	60	300	3505	7010	14020	28041	56081	112162
	4.155	90	300	2337	4673	9347	18694	37387	74775
	4.155	30	600	3505	7010	14020	28041	56081	112162
	4.155	60	600	1753	3505	7010	14020	28041	56081
	4.155	90	600	1168	2337	4673	9347	18694	37387
Level 5	50	120	3000	15	29	58	117	233	466

Scenario 1:
- Data written to DRAM and then non-volatile storage when event occurs
- NAND Flash endurance exceeds Level 5 estimate data rate and supports over 3000 incidents a year recorded 2 minutes each for >15 years

Scenario 2: Continual Recording to NAND Flash

Data Recorder - TB Written

Write Amplification Factor:	1.5	15 years +	
Memory	X3	10 years +	
P/E Cycles	100000	5 years +	
		Less than 5 years	

	Card Capacity (GB)						
	5	10	19	39	78	155	303
TB Writes	316	631	1263	2525	5051	10101	19729
GB Writes	323232	646465	1292929	2585859	5171717	10343434	20202020

Data Recorder - Expected Life (Years)

	Recording Bit Rate (Mbps)	**Device Capacity (GB)**						
		5	**10**	**19**	**39**	**78**	**155**	**303**
Level 2	4	21.0	42.0	84.0	167.9	335.9	671.7	1312.0
	10	8.4	16.8	33.6	67.2	134.3	268.7	524.8
	20	4.2	8.4	16.8	33.6	67.2	134.3	262.4
	30	2.8	5.6	11.2	22.4	44.8	89.6	174.9
	40	2.1	4.2	8.4	16.8	33.6	67.2	131.2
Level 5	50	1.7	3.4	6.7	13.4	26.9	53.7	105.0
	60	1.4	2.8	5.6	11.2	22.4	44.8	87.5
	70	1.2	2.4	4.8	9.6	19.2	38.4	75.0
	80	1.0	2.1	4.2	8.4	16.8	33.6	65.6
	90	0.9	1.9	3.7	7.5	14.9	29.9	58.3

Scenario 2:
- Data written continuously directly to NAND flash storage
- NAND Flash endurance exceeds Level 5 estimate data rate and can support over 50Mbps for over 15 years

Considerations for Storage

- What type of data is stored
- What is the data stream bit rate
  - Cameras the largest drivers with higher resolution frame rates increasing
- What frequencies and length of events if only events recorded (Scenario 1)
- How long events need to be available in on-board storage
  - 1 week, 1 month, 6 months?

<u>Use cases matter</u>

Questions

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Embedded Storage Interface Evolution

Increasing read/write speeds to storage

eMMC v4.41
104 MB/s

eMMC v4.5
200 MB/s

eMMC v5.0
400 MB/s

UFS v1.1
720 MB/s

UFS v2.1
1,440 MB/s

PCIe NVMe

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Overall Storage Requirements Changing

- Read/Write Intensive
- High Data retention
- Low to mid capacities
- Temperature not extreme
- Low performance

- Read/Write Intensive
- High data retention
- **Mid to high capacities**
- **Extreme temperature**
- **High performance**