Big Data

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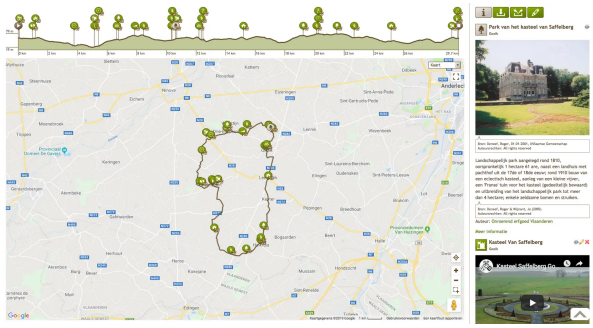
Inhoudsopgave

1 Understanding Data Intensive Applications

1.1 Why Big Data?

1.1.1 Use case: data intensive application RouteYou



Figuur 1: RouteYou

- Routes - user preferences & interests
- Searcheable Text data
- Geospatial data
- Community driven
  - Exponential user growth is necessary to make the application posssible
  - Server power/bills should grow linearly

1.2 Data Intensive Application: RAMS!

- **Reliable**
  - tolerating human mistakes
- **Available**
- **Maintainable**
  - Easy to adapt (evolvability)
  - Easy to deploy & operate (operations/sys admins)
- **Scalable**
  - User growth while maintaining low response times

1.2.1 Common similar abbreviations

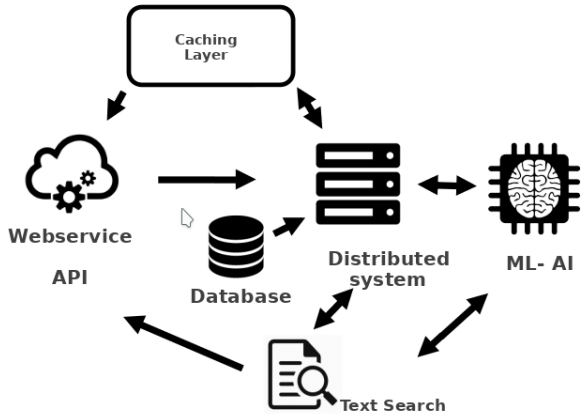
- Infrastructure: RAS (Reliable, Available, Serviceable)
- Developer: RMS (Reliable, Maintainable, Scalable)

1.2.2 Methods to improve Maintainability

- Github
- Error handling
- Relative paths (not absolute)
- Abstraction (REST API, . . .)
- Documentation

1.2.3 RAMS applied to RouteYou application

- Geospatial data (longitude, latitude)
- Available & scalable
- Scalable & low response time
- Community driven - unstructured text
- Maintainable: automatic classification of community input (ML)



Figuur 2: To support many users, you need a caching layer

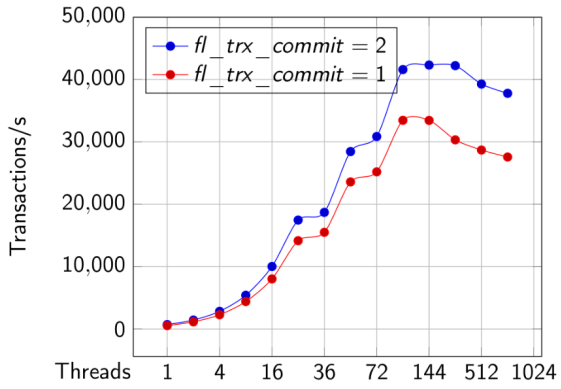
1.3 Learning outcome for this module

Being able to make infrastructure & software choices to build a Reliable, Available, Maintainable & Scalable (RAMS) data intensive application.

- Deep insights into database technology & cloud services
- Connecting with Machine Learning & AI
- Configuring a data back-end (in the cloud or locally)

1.4 Scaling

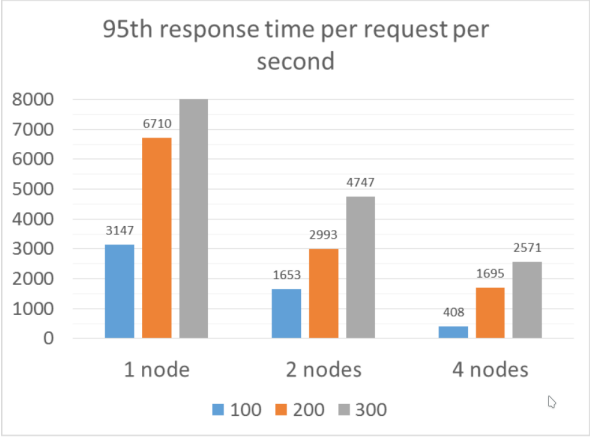
1.4.1 MySQL scaling



Figuur 3: Transactions/sec

- Processing power of 16-64 = slightly less then 4x
- Real performance: 2.3x
- = scaling up: add more processing power to the system

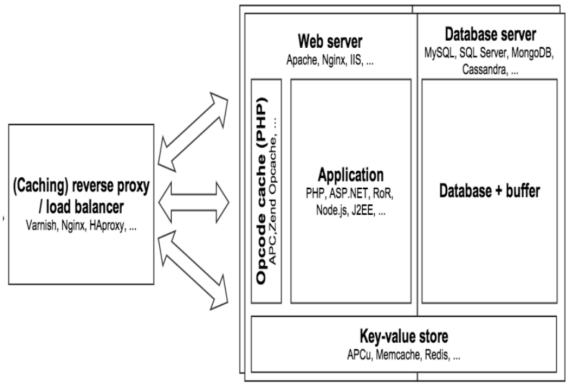
1.4.2 ElasticSearch Scaling: distributed system



Figuur 4: Response time per request

- Scaling out: add more servers to your data system

1.4.3 Professional architecture (Dev oriented)



Figuur 5: Professional architecture diagram

- **Reverse proxy** / **Load balancer:** improves scalability
- **Opcode/app/Webserver:** webservice + API
- **Key-value store:** 'caching layer'
- **Database server:** distributed storage system + relational database

1.4.4 Time series Distributed database (OpenTSDB, InfluxDB)

Location	DateTime	maxTemp	minTemp	prcp	dewpoint	gust	seaLevelPres	windSpeed
3927	2011-09-16T00:00:00	82	80.1	0	75.9		1015.9	5.9
3864	2011-09-16T00:00:00	82.4	71.6	0	70.2			4.2
3860	2011-09-16T00:00:00	86	75	0	68.7	22	1019	12
3858	2011-09-16T00:00:00	84	79	0	71.4		1018.5	4.9
3855	2011-09-16T00:00:00	84.9	78.1	0	70		1019.1	9.8
3853	2011-09-16T00:00:00	82	62.1	0	69.8	25.1	1014.9	12.5
3847	2011-09-16T00:00:00	87.1	78.1	0	56.6		1013	5.3
3846	2011-09-16T00:00:00	93.9	81	0	55.2		1006.4	2.9
3845	2011-09-16T00:00:00	91	78.1	0	62.4			3.3
3843	2011-09-16T00:00:00	59	52	0.05	39.2		1024.1	5.9
3837	2011-09-16T00:00:00	54	42.1	0.07	40.3	20	1017.7	5.3
3835	2011-09-16T00:00:00	57.9	53.1	0	40.9	28	1017.9	13.5
3833	2011-09-16T00:00:00	55.9	52	0.01	38.8	24.1	1019.5	14
3830	2011-09-16T00:00:00	57.2	48.9	0.04	42	20	1016.7	10.1
3827	2011-09-16T00:00:00	63	46.9	0	41.8	22	1010.8	13

Figuur 6: Data from windmill sensors. Most sensors log about every second

- Losing data is not that big a problem
- Massive amount of data to write

1.5 Scalability & application performance management

Response times and percentiles rule the web

1.5.1 The need for speed: some insights from Google

- Speed is a ranking factor
- When your site has high response times, less URLs will be crawled from your site
- 53% of visits are abandoned if a site takes longer than 3 seconds to load

- Slow websites will be labeled by Google Chrome

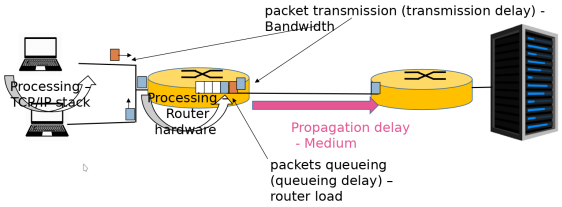
1.5.2 Response times for websites

- **Ideal:** "blink of an eyeïs 300-400 ms
- **Excellent:** 500ms to 1.5 seconds at most
- **Barely acceptable:** 3 seconds

Response time = Network latency + processing

- 2.9 seconds is faster than 50% of the web
- 1.7 seconds is faster than 75% of the web
- 0.8 seconds is faster than 94% of the web

1.5.3 4 components of network latency

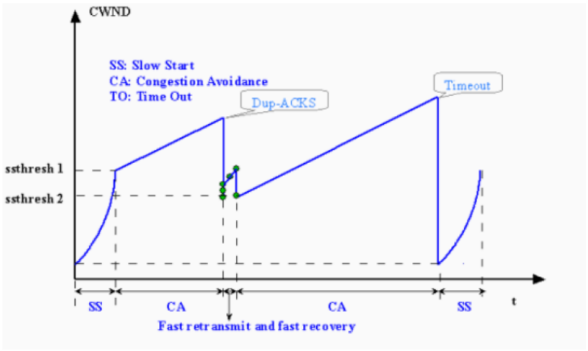


Figuur 7: Network latency diagram

- Processing delay
  - Processing network software stack (TCP/IP layers)
  - Routing decisions
- Transmission delay
  - Bits on physical link (Bandwidth plays a big role, ex: 1Gbit/s)
- Propagation delay
  - Speed of EM signals in fiber: 200.000 km/s (67% of lightspeed)
  - Changes with distance and medium (Copper: 64% of lightspeed)
- Queing delay
  - Time spent in router & NIC buffers

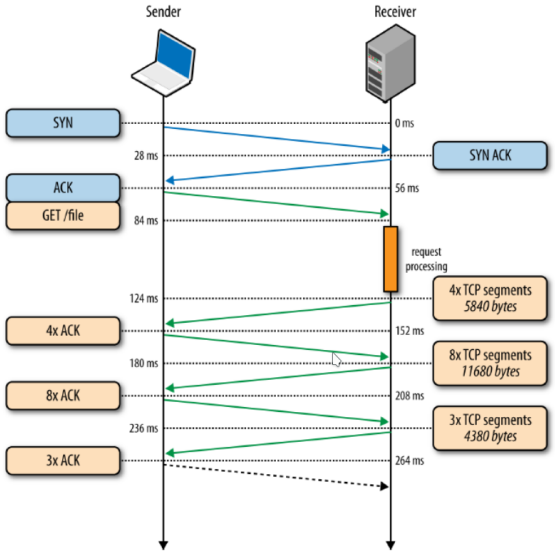
1.5.4 TCP Congestion Window - slow start

- Network congestion = a network node or link is carrying more data than it can handle
- The internet is built around dropped packages



Figuur 8: TCP Congestion window

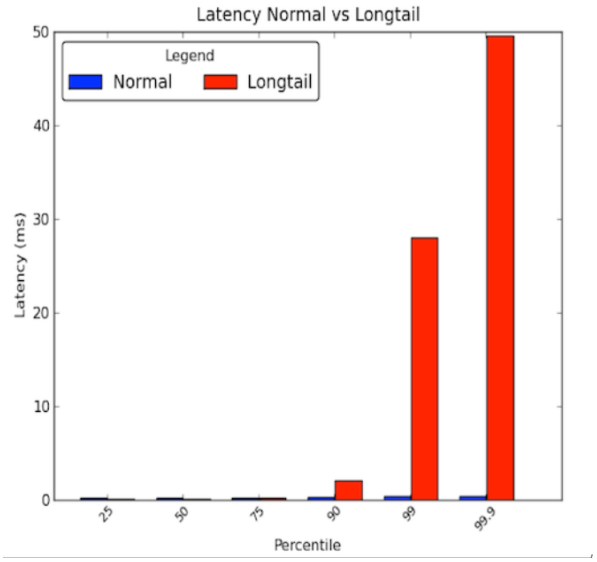
- 4-8-16-32 TCP segments (Win 2008, Win7)
- 10-20-40 (Linux 2.6+, Windows Server 2016 / Windows 10)



Figuur 9: Because of many handshakes, there is a lot of latency

- Solution: KeepAlive of a HTTP Persistent Connection
  - Only one 3-way handshake for many requests
  - Lower network & CPU load
  - Lower response times
  - **Downside**: more connections open ⇒ more memory, more connection failures, app crashing, . . .
- Measure parallel requests of a website using `https://www.webpagetest.org/`
- Get a waterfall view of a webpage

1.5.5 Long tail latency



Figuur 10: Long tail latency vs Normal latency

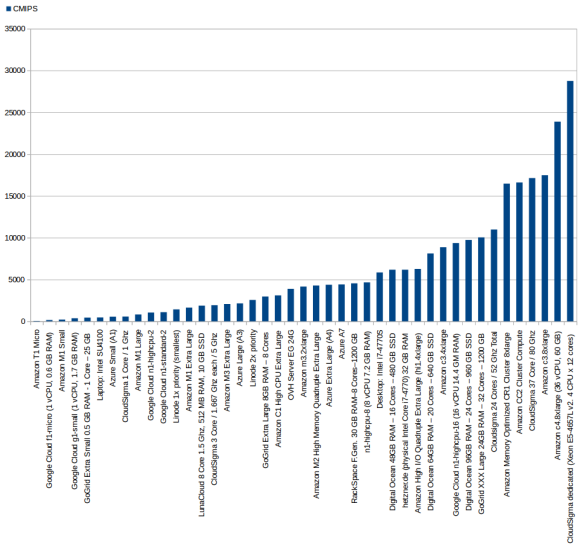
- Average = useless
- Long tail latency = 99th percentile
  - To be experienced by a lot more than 1% of users!
- Best customers encounter highest percentiles
- URL consists of many requests

1.6 Conclusion

- Our goal is RAMS (or RASS)
- Many data models & stores: transactional, timeseries, text search
- Website 99th percentile + DNS + TCP $\Rightarrow$ < 2s response time
  - Efficient caching
  - Think about your architecture (infrastructure + software) before coding

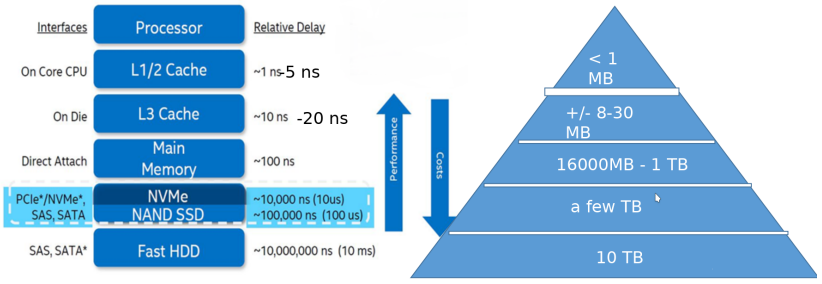
2 Professional storage

2.1 Cloud MIPS



Figuur 11: MIPS = Million Instructions Per Second

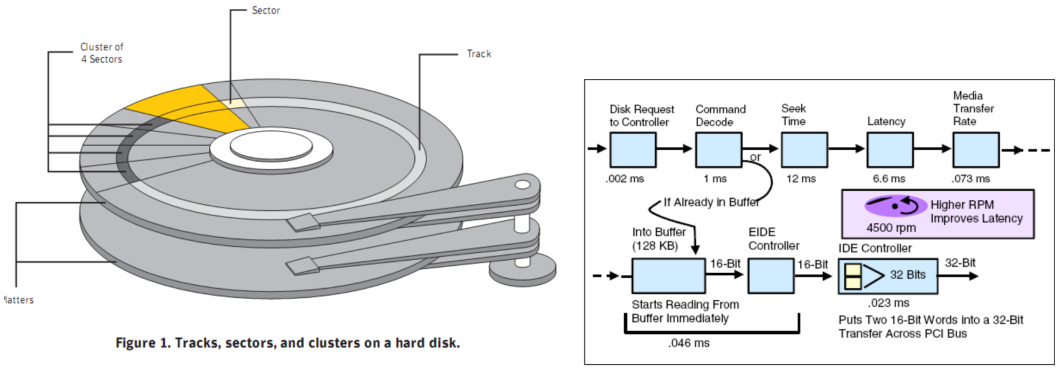
2.2 Latency vs storage space pyramid



Figuur 12: The higher the performance, the higher the cost per byte of storage

2.3 Storage media

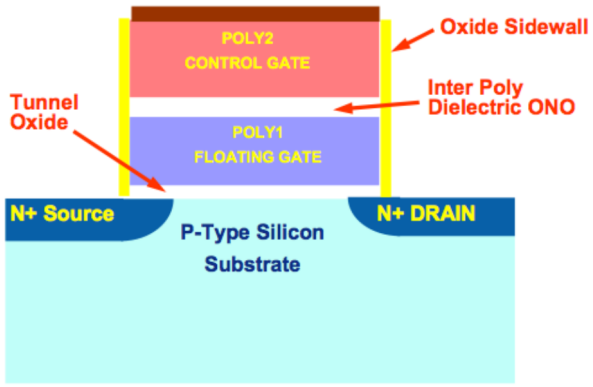
2.3.1 Magnetic disks



Figuur 13: Massive capacity but mechanical latency

- Seek time and latency are the key bottlenecks
- Need large quantity of disks for good server performance

2.3.2 Flash (NAND) / SSDs



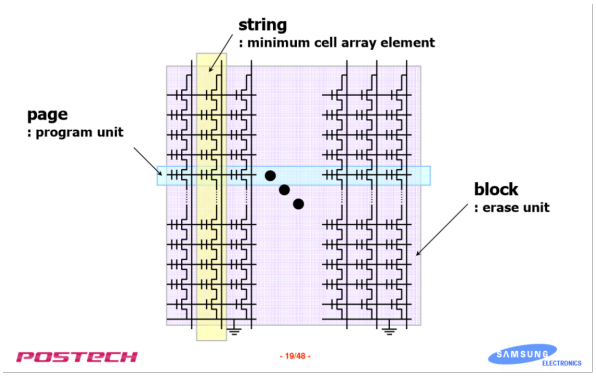
Figuur 14: Flash storage

- SSD = Solid State Drive
- NAND = MOSFET + floating gate
- Voltage between control gate and N+ : electrons in floating gate
- This works very quickly

Architecture

- Page = 4 KB, pages are in block
- Block = 128 pages (4KB * 128 = 512 KB)
- You can read or write page per page

- Erasing has to erase the entire block



Figuur 15: Diagram of a flash Block

2.3.3 Big difference between read and writing

	MLC NAND flash
Random Read (page)	50-100 µs
Erase (block)	1000-2000 µs per block
Programming (page)	40-250 µs

Figuur 16

- Limited number of writes
- Slow block write
- Limited "normal"write (programming)

2.3.4 IOPS vs Bandwidth

- Transactions & virtualized workloads: lots of random access
- Timeseries fileserving: mostly sequential
- HDD: random performance can be extremely low to medium
- IOPS = Input/Output Operations Per Second

Storage device	Seagate Enterprise HDD	Intel SSD NVMe
	ST8000NE0001	DC3700
Capacity	8 TB	800 GB
Spindle speed (rpm)	7200	N/A
Max. BW (MB/s)	**230**	**600**
Latency (ms)	4,16	N/A
Seek time	8	N/A
Total Random read time ms	12	0,08
Random Performance	1000 Random 4 KB blocks	1000 Random 4 KB blocks
Total Random read time (ms)	12000	80
Transfer time (ms)	17,4	6,7
Sustained Transfer rate (MB/s)	**0,33**	**46,15**
IOPS	83	11538
Sequential Performance	1x 4 MB block	1x 4 MB block
Total Random read time (ms)	12	0,08
Transfer time (ms)	17	7
Sustained Transfer rate (MB/s)	**136**	**593**

Figuur 17: An enterprise HDD vs an NVME SSD

2.3.5 Storage options

	Media Type	Interface	Read Latency (µs)	Write latency (µs)	Random IOPS	BW (MB/s)
HDD	Magnetic	SATA	10.000	10.000	100	1-200
Low-end SSD	NAND Flash	SATA	100-300+	40-2000+	5k-20k	100-550
High-end SSD	NAND Flash	NVMe	100-200+	20-1000+	50-200k	100-1800
3D-Xpoint	Electric resistance	NVMe	10-40	10-60	500+k	200-2000

Figuur 18: Storage options

2.3.6 Performance Conditions

Type	Queue depth	Random?	Write vs Read	Perf consistency
HDD	As low as possible (1-2)	Sequential ! Random as low as 50 IOPS	Write slightly slower	Terrible (1 -200 MB/s)
Low-end SSD	8-16	Random	Write can be a lot slower	IOPS writes can vary 2-4x
High-end SSD	16+	Both	Write can be a lot slower	IOPS writes can vary 10-30 percent
3D-Xpoint	2+	Both	Does not matter	Very good

Figuur 19: Performance Conditions

2.4 RAID

2.4.1 Definition

Redundant Array of Inexpensive Disks is a storage technology that combines multiple physical drives into one logical unit.

Purpose:

- Data redundancy
- Performance improvement
- Both

2.4.2 Hardware <> chip

2.4.3 Raid levels

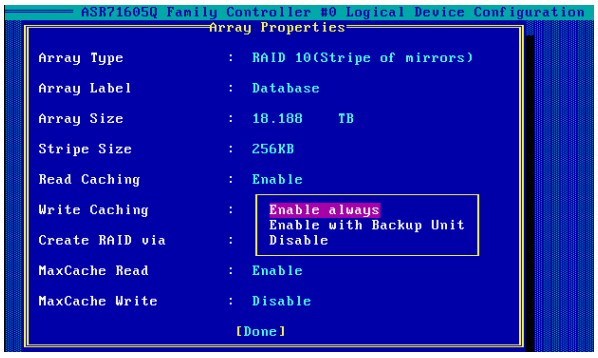
- RAID 0
- RAID 1
- RAID 5
- Combinations are possible (RAID 10, 01, 51, 15)

Level	Benaming	Schijven	Capaciteits verlies	Availability	Lezen sequentieel	Schrijven sequentieel	Lezen random	Schrijven random
RAID 0	Striping	Min. 2	geen	Slechter!	Sneller	Sneller	gelijk	Gelijk
RAID 1	Mirror	Min. 2	50%	Beter	iets Sneller	Gelijk	Sneller	Iets trager
RAID 10	Stripe + Mirror	Min. 4	50%	Beter	Sneller	Sneller	iets Sneller	Gelijk
RAID 01	Mirror + Stripe	Min. 4	50%	Beter	iets Sneller	iets Sneller	Gelijk	Gelijk
RAID 5	Stripe+ Parity	Min. 3	33%	Beter, slechter tijdens rebuild	Sneller	iets Sneller	iets Sneller	Gelijk

Figuur 20: RAID level choices

2.4.4 Caching & BBU

- RAM caching: to allow more users to access your data at a time
- RAID = lower latency by caching
- Not always durable: backup solutions needed like Battery Backup Unit (BBU)
- RAID = more bandwidth, +- same latency
  - Latency does not increase as fast when load increases (vs single disk)
  - More bandwidth & capacity available



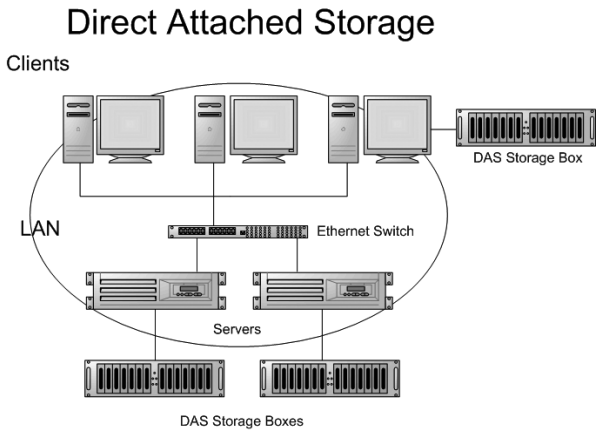
Figuur 21: RAID configuration

2.5 Professional Storage Topology

2.5.1 Components

- Enclosure
- Controller
- Disk Array
- HotSpare (=backup disk if a disk fails)
- LUN (logical unit number) / Volumes (= logical storage areas)

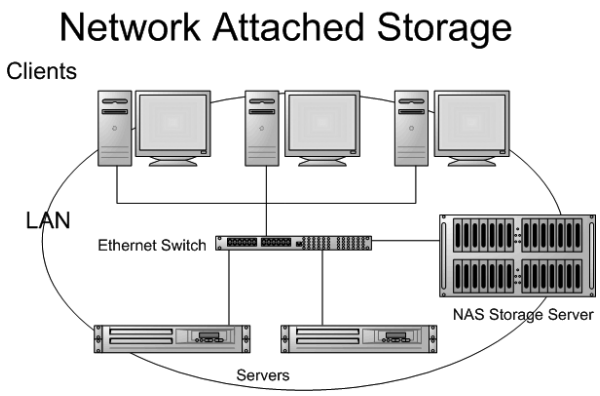
2.5.2 DAS - Block storage



Figuur 22

- Up to 122 disks per SAS controller
- Similar to disks inside the server
- No centralized back-up

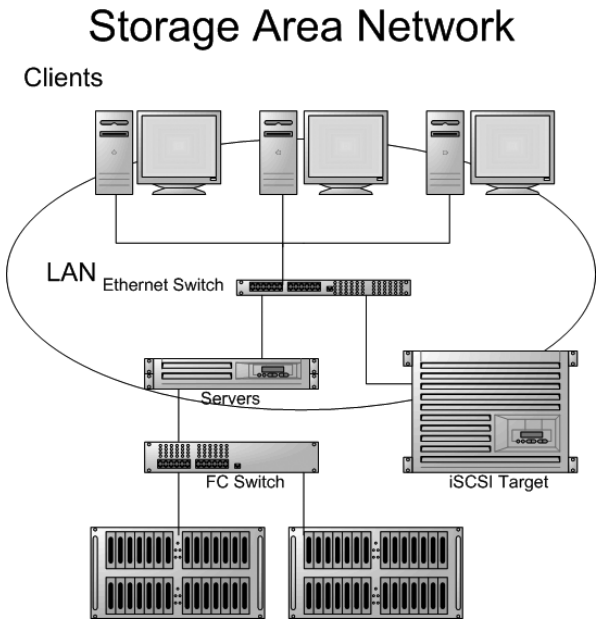
2.5.3 NAS - File storage



Figuur 23

- Common Internet File System (CIFS) for Windows
- $\rightarrow$ SMB protocol
- Network File System (NFS) for UNIX $\Rightarrow$ mounting via network
- SMB also available in Linux

2.5.4 SAN - Block storage on a network



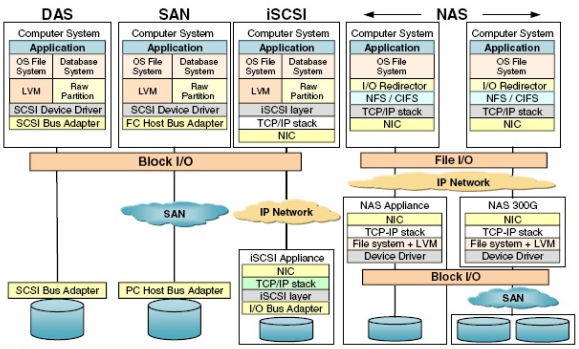
Figuur 24

- Seperate Block storage network

- Centralized backup & management
- Good scaling, no load on LAN
- But:
  - No standards - proprietary
  - Expensive

2.5.5 iSCSI terminology

- iSCSI Target = the iSCSI 'server'
  - IP + port = Portal
  - Portal: LUNs / Volumes
  - Volume = IQN
- iSCSI Initiator = the iSCSI 'client'
  - Connects targets
  - Find LUNs/Volumes



Block I/O compared to file I/O

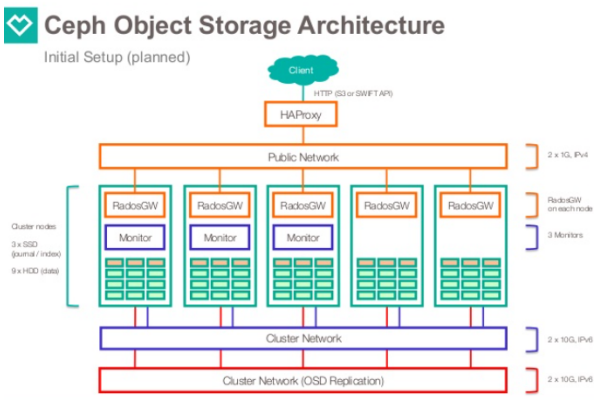
Storage characteristic	iSCSI SAN	Fibre Channel SAN	NAS
Protocol	Serial SCSI	Fibre Channel Protocol	NFS, CIFS
Network	Ethernet, TCP/IP	Fibre Channel	Ethernet, TCP/IP
Source / target	Server / Device	Server / Device	Client / Server or Server / Server
Transfer	Blocks	Blocks	Files
Storage device connection	Direct on network	Direct on network	I/O bus
Embedded file system	No	No	Yes

Figuur 25

2.5.6 Object storage

- NAS hardware
  - Distributed over multiple datacenters
- Object Data
  - Metadata
- Globally Unique Identifier

  - URL
  - RESTful API
- Examples:
  - AWS S3
  - Ceph - Lustre
  - Google Cloud storage



Figuur 26

2.5.7 Link with Databases & other data storage

- Transactional database: needs block storage
  - Performance
  - Durability
  - Consistency
- Block storage best for ‘raw data’ (no meta data involved)
- NAS = ‘file based’ services like sharepoint
- static objects on Object Cloud storage
  - good match for OOP & ‘unstructured data’
  - highly available
  - ‘Eventually’ consistent

3 Relational databases

Data intensive application: needs RAMS!

- **Reliable**
- Available
- Maintainable

- Scalable

3.1 Components of a relational database

- **Tables** = Relations are saved in the format of tables
- **Relationships** = a logical connection between different tables
  - Join, key, foreign key
  - Relation schema
- **Tuple** = A single row (record) of a table, which contains a single unordered record for that relation
  - A dataset representing an object, an item ('person')
  - Columns represent the attributes
  - Tuples are unique
  - Tuples are similar to Python dictionaries or JavaScript objects

SNAME	AGE	MAJOR	ID	SEX	ADDRESS	CITY	STATE
Anderson B.	19	CS	55555501	M	101 Rocket Way	Atlantis	CA
Barnes D.	17	MATH	55555502	M	1402 Elf Lane	Ruston	LA
Bronson P.	26	MATH	55555503	M	1 Web Master	Ruston	LA
Brooks D.	18	CS	55555504	F	900 Baird Street	Dallas	TX
Garrett D.	20	PSY	55555505	M	BGB Consulting	Dallas	TX
Howard M.	21	CS	55555506	M	5 Scarborough	Dallas	TX
Huey B.	20	CS	55555507	F	1 Historic Place	Jackson	MS
Kleinpeter J.	24	CS	55555508	M	69 Watson Lane	Ruston	LA
Kyzar D.	18	CS	55555509	M	49 Animae Way	Hammond	LA
Moore D.	19	MATH	55555510	M	No. 7 Seagram	Ruston	LA
Moore L.	20	MATH	55555511	F	2 Pot Place	New York	NY
Morton M.	30	ACCT	55555512	M	2010 Skid Row	Compton	CA
Pittard S.	22	ACCT	55555513	M	111 Easy Street	Ruston	LA
Plock C.	22	MGT	55555514	M	13 NSF Road	Ruston	LA
Slack J.	28	PSY	55555515	M	1 Pirate's Cove	Ruston	LA
Talton J.	19	PSY	55555516	M	666 Microsoft	Redmond	WA
Teague L.	18	PSY	55555517	F	Fern Gully Farm	Terry	LA
Tucker T.	45	MGT	55555518	F	Prop Wash Way	Eldorado	AR
Walker J.	23	CS	55555519	M	42 Ocean Drive	Venice	CA
Walker R.	21	CS	55555520	M	9 Iron Drive	Monroe	LA

Figuur 27: 1 relation 'student': 20 tuples, 8 attributes

3.2 Reliability problems

- Applications crash
- Client (website) - network - database
  - $\Rightarrow$ network is very unreliable
- Multi-threaded code: race conditions $\Rightarrow$ who gets access to 1 piece of data
- Disks can fail

3.3 Example

1 database: bank

- Checking account = table 1
- Savings account = table 2

3.3.1 The problem

```
SELECT saldo FROM checking WHERE customer_id = 10233276;
UPDATE balance SET balance = balance - 200.00 WHERE customer_id = 10233276;

# CRASH: -200 but not on savings account!

UPDATE Savings SET balance = balance + 200.00 WHERE customer_id = 10233276;

# Crash: +200, and application might try again: +400
```

3.3.2 The solution: Transactions

= multiple operations are executed on multiple objects as one unit

```
START TRANSACTION;
SELECT balance FROM checking WHERE customer_id = 10233276;
UPDATE checking SET balance = balance - 200.00 WHERE customer_id = 10233276;
UPDATE savings SET balance = balance + 200.00 WHERE customer_id = 10233276;
COMMIT;
```

VERY IMPORTANT! Every transaction is ACID

- **Atomic**
  - Each transaction is treated as a single 'unit', which either succeeds completely, or fails completely.
  - If all succeed ⇒ Commit transaction
  - If at least one fails ⇒ Rollback transaction
- **Constistent**
  - Data cannot get 'magically' deleted or added
  -
  - Example: when sending money to another bank account, the money cannot exist on both accounts after a transaction
- **Isolated**
  - Transactions cannot interfere with each other
- **Durable**
  - Data is written in a reliable way
  - Storage medium must be reliable

Commit / Rollback does not protect agains threads that overwrite each other! It only protects agains crashes from one thread.

3.4 Single object entry

Situation:

- Input = 1 record - row - object
  - What if the network fails while sending the input

- Single Object Atomicity & isolation:
  - Create log entry (WAL = Write Ahead Log)
  - Write lock when writing
  - Create log entry if successful
  - Restart if fail
- (Almost) all database - storage engines support this
- This is not a transaction!

3.5 Isolation levels

= Choose between strong isolation or strong performance

- Modern processing 8 - 100+ threads
- Choose an isolation level:
  - Read Uncommitted (weakest isolation, most performance)
  - Read Committed
  - Repeatable Read (=snapshot isolation)
  - Serial Execution (strongest isolation, least performance)

	Default	Max	Source
SQL Server	Read Committed	Serializable	https://docs.microsoft.com/en-us/sql/t-sql/statements/set-transaction-isolation-level-transact-sql?redirectedfrom=MSDN&view=sql-server-ver15
MySQL InnoDB	Repeatable read	Serializable	https://dev.mysql.com/doc/refman/5.7/en/innodb-transaction-isolation-levels.html
MySQL MyISAM	No Transactions!	No Transactions!	
Oracle	Read Committed	Snapshot Isolation ("Serializable" (*))	https://docs.oracle.com/cd/B14117_01/server.101/b10743/consist.htm#i17856
MongoDB/Cassandra	No Transactions!	No Transactions!	

Figuur 28: (default) isolation levels in current databases. (*) Wrong, not ANSI compliant

3.5.1 Read Uncommited

TODO

3.5.2 Read Committed

= No dirty reads & no dirty writes

TODO

Solutions

1. Read locks (bad performance)
2. Remember the old value until 'commit' (better performance)