



NYU

Center for
Data Science

Week 01.2:

Storage and computation

DS-GA 1004: Big Data

Instructor: Brian McFee

What are our resources?

- **Storage**

- Where and how is data kept?
- How much data can we keep?

- **Computation**

- How quickly can we process data?

- **Communication**

- How quickly can we move data between locations?

The cost of storage over time...



\$3398 = \$10,442
10MB
THE HARD DISK YOU'VE BEEN WAITING FOR

XCOMP introduces a complete micro-size disk subsystem with more:

- **MORE STORAGE**
- **MORE SPEED**
- **MORE VALUE**
- **MORE SUPPORT**

\$100 users — The XCOMP subsystem is now available with 10 megabytes of storage, 5 megabytes also available at \$2,898.00. Compare the price and features of any other 5 1/4-inch — or even 8-inch system, and you'll agree that XCOMP's value is unbeatable.

OUTPERFORMS OTHER HARD DISKS
Floppy disk and larger, more expensive hard disks are no match for this powerful little system. More data is available on every seek, 64K on 10MB and 32K on 5MB. Faster seek time too — an average of 70ms. It provides solid performance anywhere with only 20 watts of power. Data is protected in the sealed enclosure, and the leveling zone for heads provides another margin of safety. The optional power board plugs directly into the S100 bus and provides power for the drive.

FAST CONTROLLER
The XCOMP controller is the key to the system's high efficiency operation. Speed-up features include interleave without table lookup, block-lookup with controller buffer, and read lookahead. OEMs worldwide have already proven the outstanding performance of the XCOMP controller.

MORE SOFTWARE
Included with the system is software for testing, formatting, I/O drivers for CP/M[®], plus an automatic CP/M driver attach program. Support software and drivers for MP/M[®] and Oasis[®] are also available. The sophisticated formatting program assigns alternate sectors for any weak sectors detected during formatting, assuring the lowest possible error rate — at least ten times better than floppies.

WARRANTY
The system has a full one-year warranty on parts and workmanship.

ALSO AVAILABLE FROM XCOMP

- General Purpose controllers (8 bit interface), with easy interface to microprocessor-based systems.
- GP controller adapter that plugs directly into most 280 computers.
- STR GP controller for the 5MB and 10MB drive above, with S100 type interface.
- Squi GP controller for SA1000 interface.
- DASH GP controller for storage module drives.
- S15, S35, and DMS, same as above, for the S100 bus.

Quantity discounts available. Distributor, Dealer, and OEM inquiries invited.

See your local Dealer, or call:

XCOMP, Inc.
7560 Trade Street
San Diego, CA 92121
Tel: (714) 271-8730
Telex: 182786

XCOMP

Circle 425 on inquiry card.

The cost of storage over time...



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\$3398 = \$10,442 in 2022

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Circle 426 on inquiry card.



HGST
a Western Digital brand

HGST Ultrastar He10 HDD
10000GB Serial ATA III internal hard drive

\$8,591.⁰⁰

Free Shipping

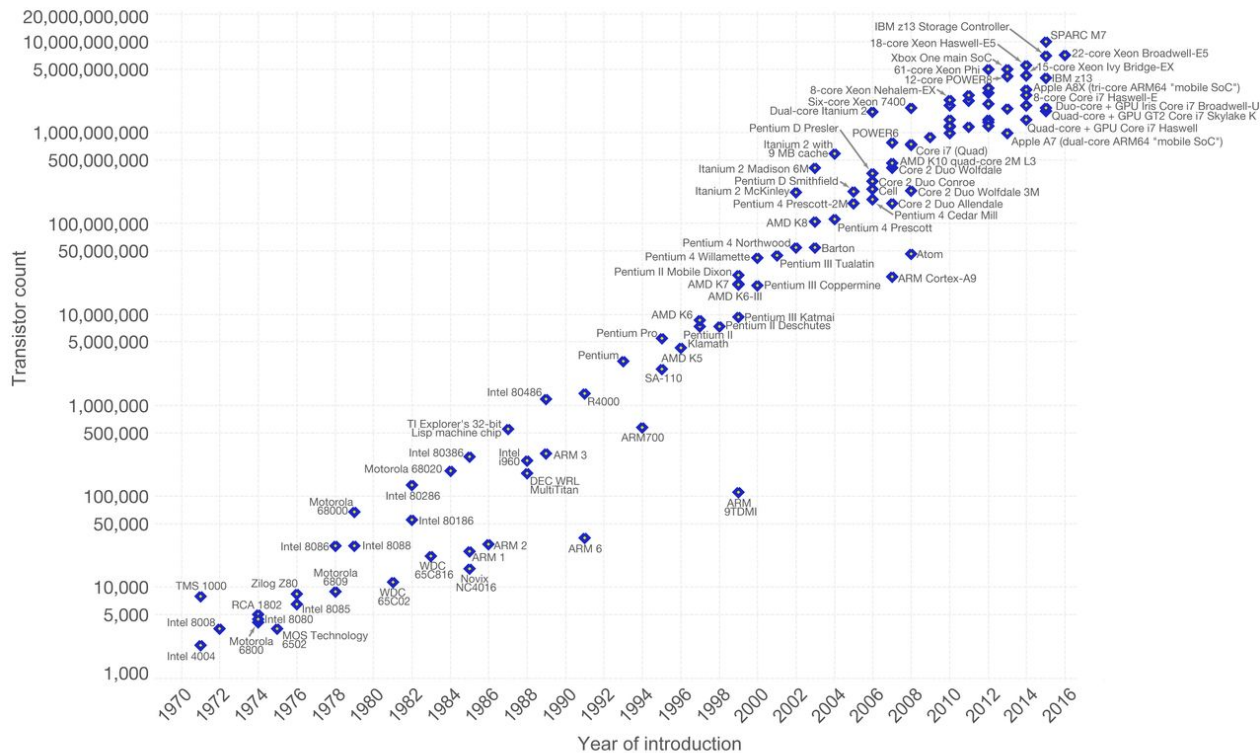
x20

Volume and velocity

- (2019) Facebook generates 4 Petabytes (4e15 bytes) of new data per day
<https://research.fb.com/facebook-s-top-open-data-problems/>
- (2019) YouTube collects 300 hours of HD video every minute
<http://www.businessofapps.com/data/youtube-statistics/>
- (2017) Twitter stores >500PB of data
https://blog.twitter.com/engineering/en_us/topics/infrastructure/2017/the-infrastructure-behind-twitter-scale.html
- (2017) CERN data center: > 200PB
<https://home.cern/news/news/computing/cern-data-centre-passes-200-petabyte-milestone>

Moore's Law – The number of transistors on integrated circuit chips (1971-2016) Our World in Data

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are strongly linked to Moore's law.



Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)

The data visualization is available at [OurWorldinData.org](https://ourworldindata.org). There you find more visualizations and research on this topic.

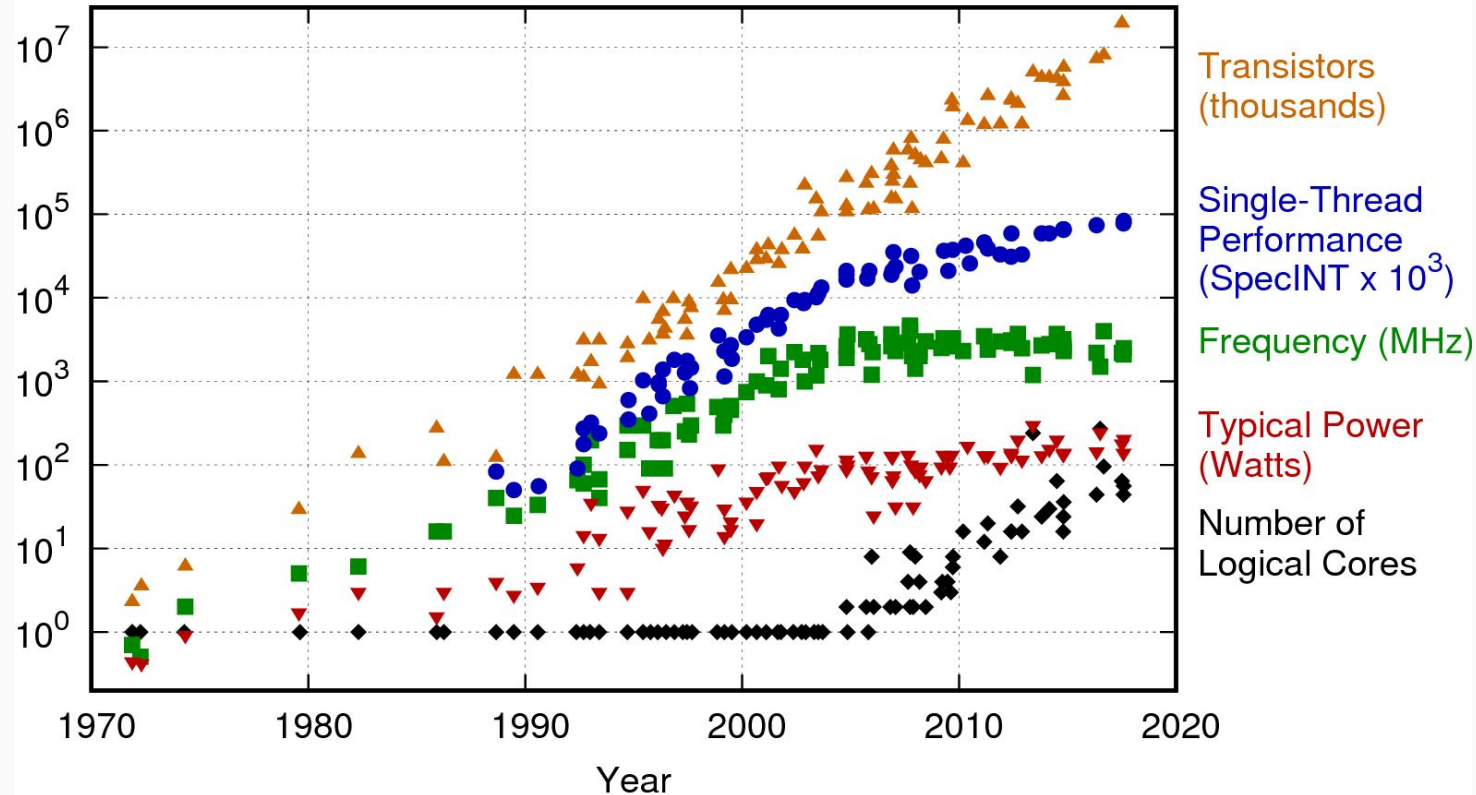
Licensed under CC-BY-SA by the author Max Roser.

Note: transistor count \neq speed!

Moore in 2015:

"I see Moore's law dying here in the next decade or so."

42 Years of Microprocessor Trend Data



Gains now come from **parallelism** (multi-core), not **clock speed**.

Original data up to the year 2010 collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
New plot and data collected for 2010-2017 by K. Rupp

What does this tell us?

- Storage capacity (per \$) continues to increase
- Data velocity is increasing
- CPU speed is not keeping up

In pioneer days, they used oxen for heavy pulling, and when one ox couldn't budge a log, they didn't try to grow a bigger ox.

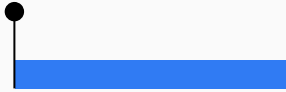
*We shouldn't be trying for bigger computers, but for more **systems of computers**.*



Grace Hopper (1906-1992)

File systems

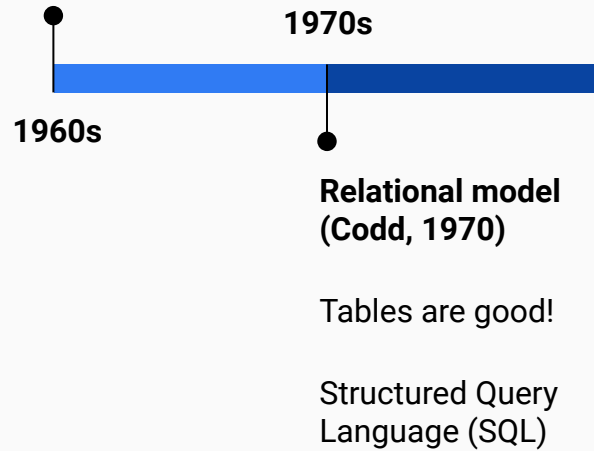
Custom software for
each application / query



1960s

File systems

Custom software for
each application / query



File systems

Custom software for
each application / query

RDBMS takes off

Databases for
commodity computers

SQL standardizes



Relational model
(Codd, 1970)

Tables are good!

Structured Query
Language (SQL)

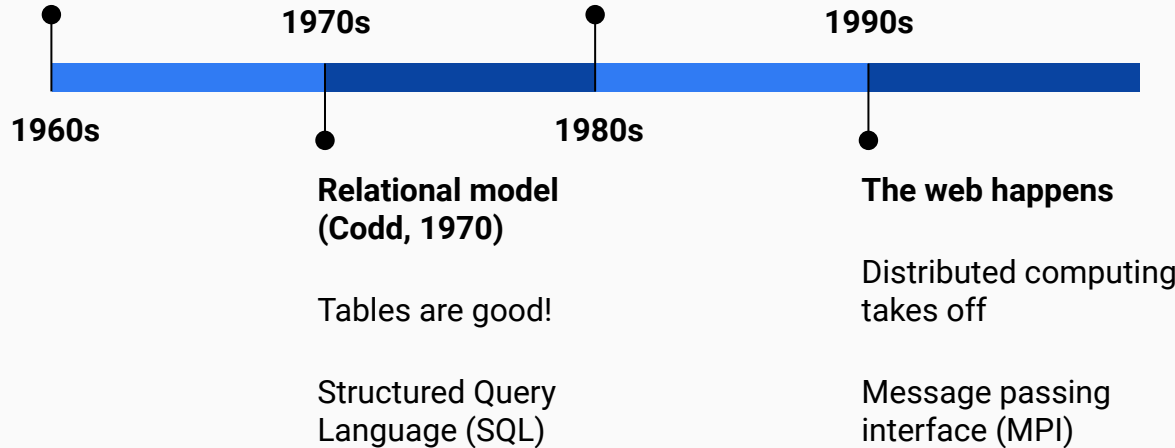
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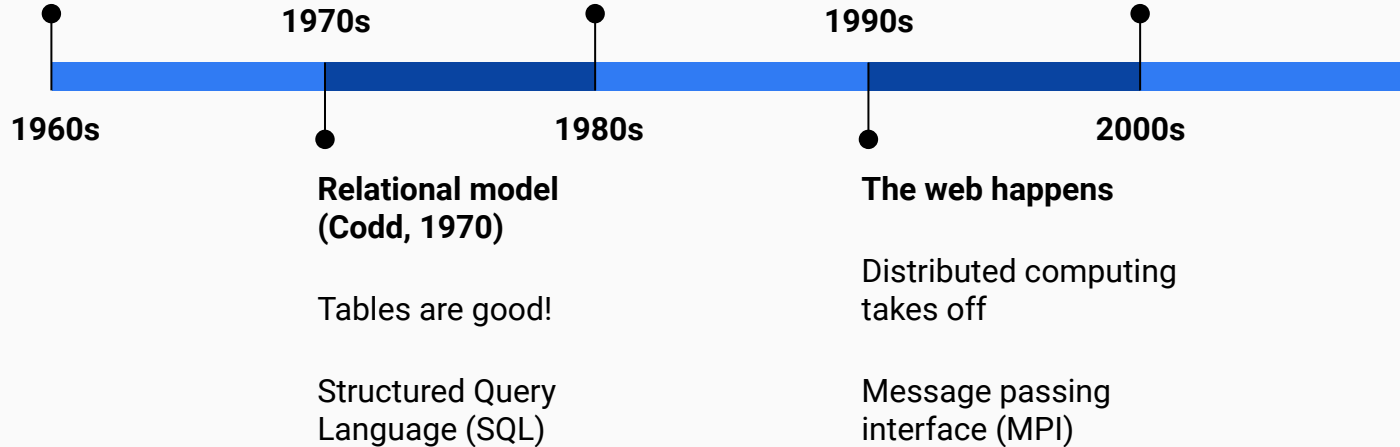
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SQL standardizes

MapReduce, NoSQL

Simpler abstractions for
distributed computation
and storage



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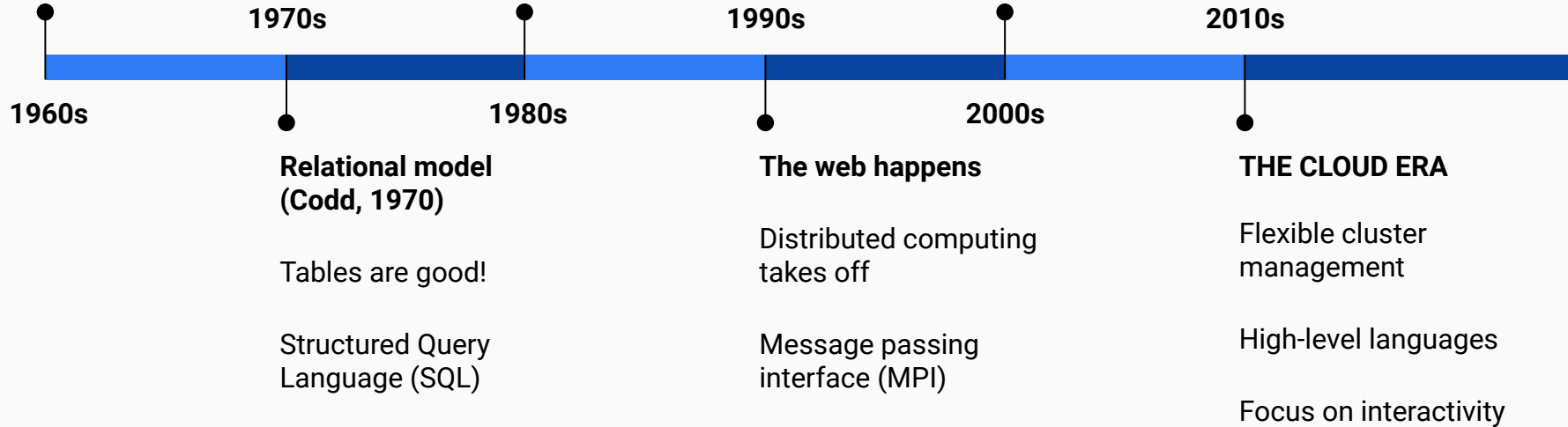
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Simpler abstractions for
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and storage



Starting at the beginning

File systems!

- To understand modern tools, it helps to understand the previous generation.
- What problems did people face in designing:
 - Relational databases?
 - Map-reduce?
 - Spark?
 - Dask?

File systems

- Use directories to organize your data
- Structured data can be stored as files

⇒ data persists across application runs

```
bmcfee@mariana.cims.nyu.edu /scratch/bmcfee/data/MSD
→ find data | head -30 | grep h5
data/A/A/A/TRAAAZF12903CCCF6B.h5
data/A/A/A/TRAAAK128F9318786.h5
data/A/A/A/TRAAAYX128F4263BC0.h5
data/A/A/A/TRAAAV128F421A322.h5
data/A/A/A/TRAAAW128F429D538.h5
data/A/A/A/TRAAAY128F42A73F0.h5
data/A/A/A/TRAAABD128F429CF47.h5
data/A/A/A/TRAAACN128F9355673.h5
data/A/A/A/TRAAACV128F423E09E.h5
data/A/A/A/TRAAADJ128F4287B47.h5
data/A/A/A/TRAAADT12903CCC339.h5
data/A/A/A/TRAAADZ128F9348C2E.h5
data/A/A/A/TRAAAE128F935A30D.h5
data/A/A/A/TRAAAE128E0783FAB.h5
data/A/A/A/TRAAAEF128F4273421.h5
data/A/A/A/TRAAAE128F93347B9.h5
data/A/A/A/TRAAAEW128F42930C0.h5
data/A/A/A/TRAAAFD128F92F423A.h5
data/A/A/A/TRAAAFI12903CE4F0E.h5
data/A/A/A/TRAAAFP128F931B4E3.h5
data/A/A/A/TRAAAFW128F42A4CFD.h5
data/A/A/A/TRAAAGF12903CEC202.h5
data/A/A/A/TRAAAGR128F425B14B.h5
data/A/A/A/TRAAAGW12903CC1049.h5
data/A/A/A/TRAAHD128F42635A5.h5
data/A/A/A/TRAAHE12903C9669C.h5
```

File systems

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data/A/A/A/TRAAAE128F935A30D.h5
data/A/A/A/TRAAAE128E0783FAB.h5
data/A/A/A/TRAAAEF128F4273421.h5
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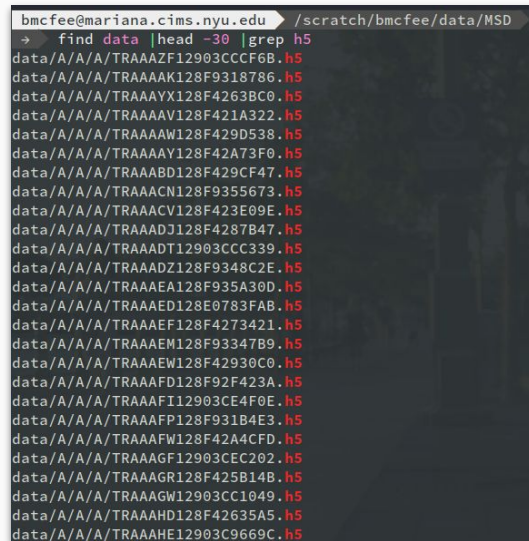
- Use directories to organize your data
 - Structured data can be stored as files
- ⇒ data persists across application runs
- Some great properties:
 - **Easy** to implement
 - **Portable** across systems
 - Network file systems (NFS) enable **limited distributed processing**

File systems can be awesome!

- If the data doesn't have obvious structure to index
 - Or if your data is naturally organized by the file system (**name** and **time**)
 - E.g., system logs
- **Or** if indexing isn't worth the cost
 - E.g., one-off jobs
- **Or** if you want maximum portability across platforms

Reasons not to rely (only) on file systems

- Does not expose or exploit the structure of data
 - What if I want to search by file contents?
Better options than brute force?
- Each query / analysis required writing a new program
 - Little re-usability between similar analyses
 - Or the same analysis with slightly different data structures
- Directory hierarchies may be too restrictive
- Practical limitations of filesystems (inode count, etc)



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data/A/A/A/TRAAHD128F42635A5.h5
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```

When are file systems not awesome?

- When your data is structured along multiple axes
- When data have complex interactions
- When your analyses are complex
- When the benefits of indexing outweigh the costs
 - E.g., finding items in sub-linear time
- **Relational databases to the rescue!**

Databases did not replace file systems

- File archives are still the most common way to share large datasets
 - But we usually include some metadata/indexing structure as well
- As we'll see soon, **Hadoop** relies on a distributed file system
 - DB abstractions can be built on top
 - But this comes with restrictions on file contents
- Key differences now:
 - Standardized (restricted) file formats ("CSV", Parquet, HDF5, NPY, etc.)

Next week

Relational databases

- Structure can be a very good thing!
- Relational model and SQL
- Databases as a service