Massive Data Algorithmics

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Danske Bank

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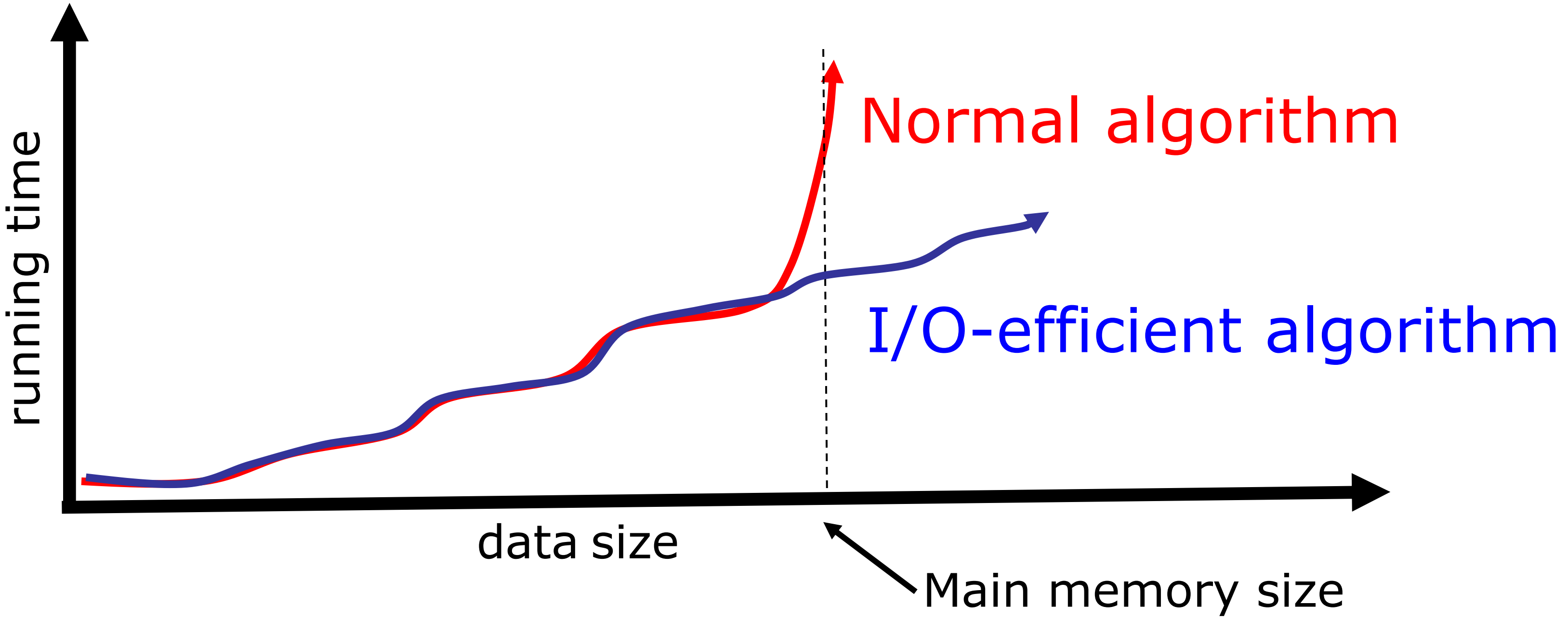
The core problem...

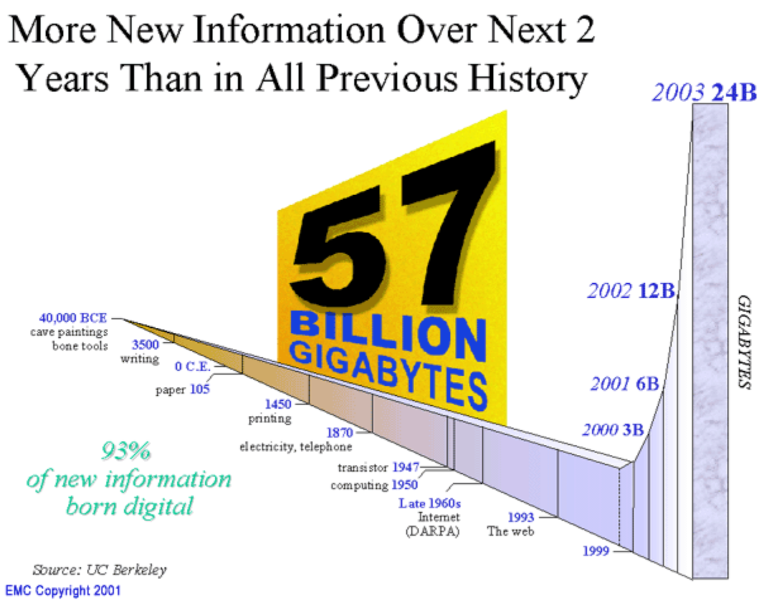


Outline of Talk

- Examples of massive data
- Hierarchical memory
- Basic I/O efficient techniques
- MADALGO center presentation
- A MADALGO project

Massive Data Examples

- Massive data being acquired/used everywhere
- Storage management software is billion-$ industry



- Phone: AT&T 20TB phone call database, wireless tracking
- Consumer: WalMart 70TB database, buying patterns
- WEB: Google index 8 billion web pages
- Bank: Danske Bank 250TB DB2
- Geography: NASA satellites generate Terrabytes each day

Massive Data Examples

- Society will become increasingly "data driven"
  - Sensors in building, cars, phones, goods, humans
  - More networked devices that both acquire and process data

  → Access/process data anywhere any time

- Nature 2/06 issue highlight trends in sciences: "2020 – Future of computing"
  - Exponential growth of scientific data
  - Due to e.g. large experiments, sensor networks, etc
  - Paradigm shift: *Science will be about mining data*

  → Computer science paramount in all sciences

- Increased data availability: "nano-technology-like" opportunity

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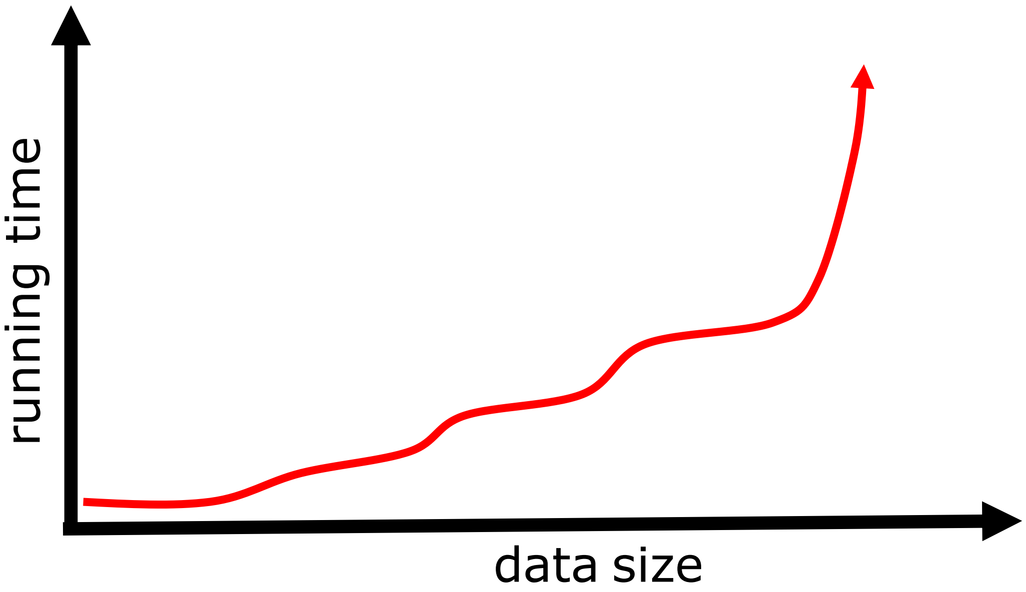
Where does the slowdown come from ?



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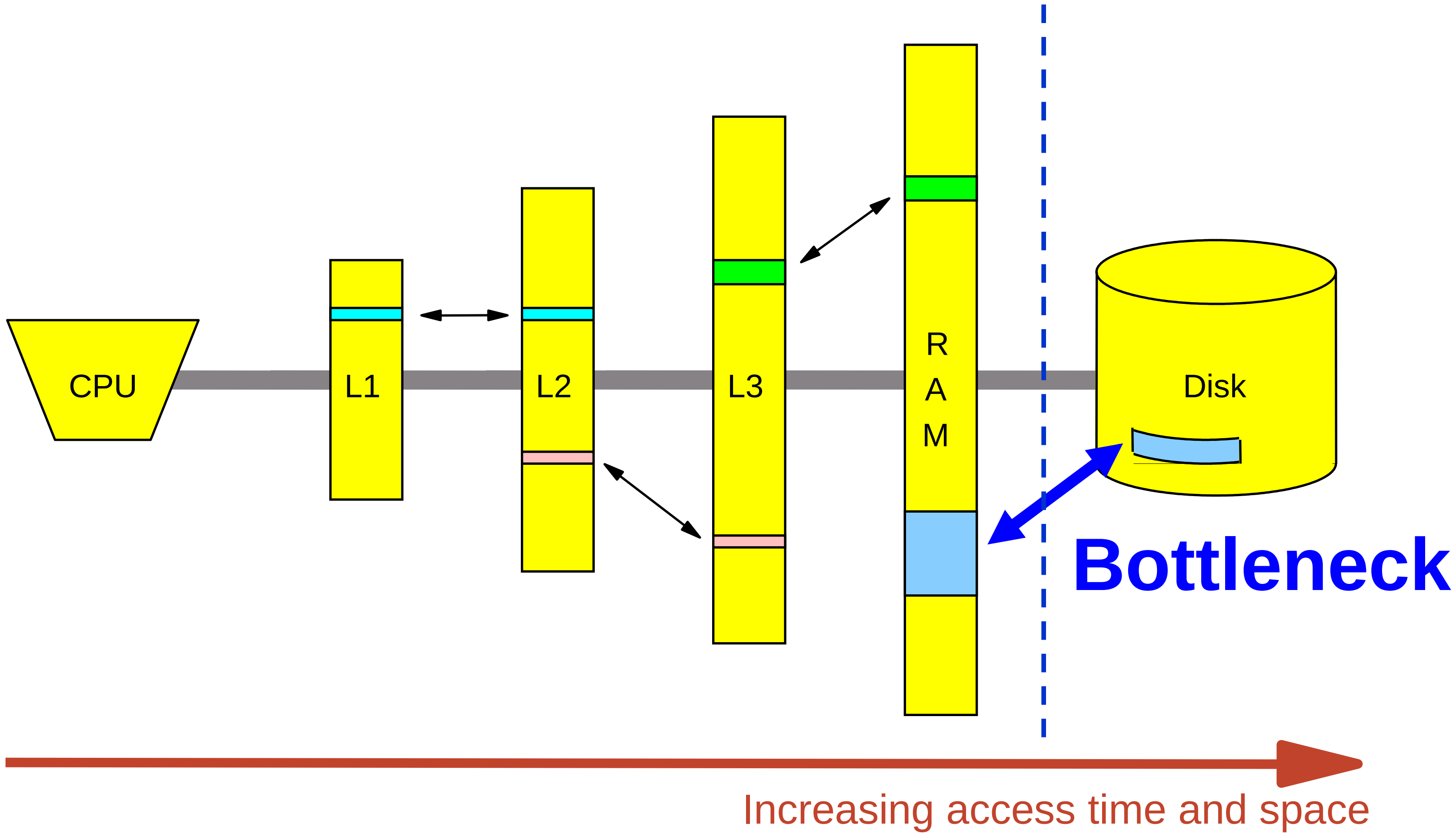
Hierarchical Memory Basics



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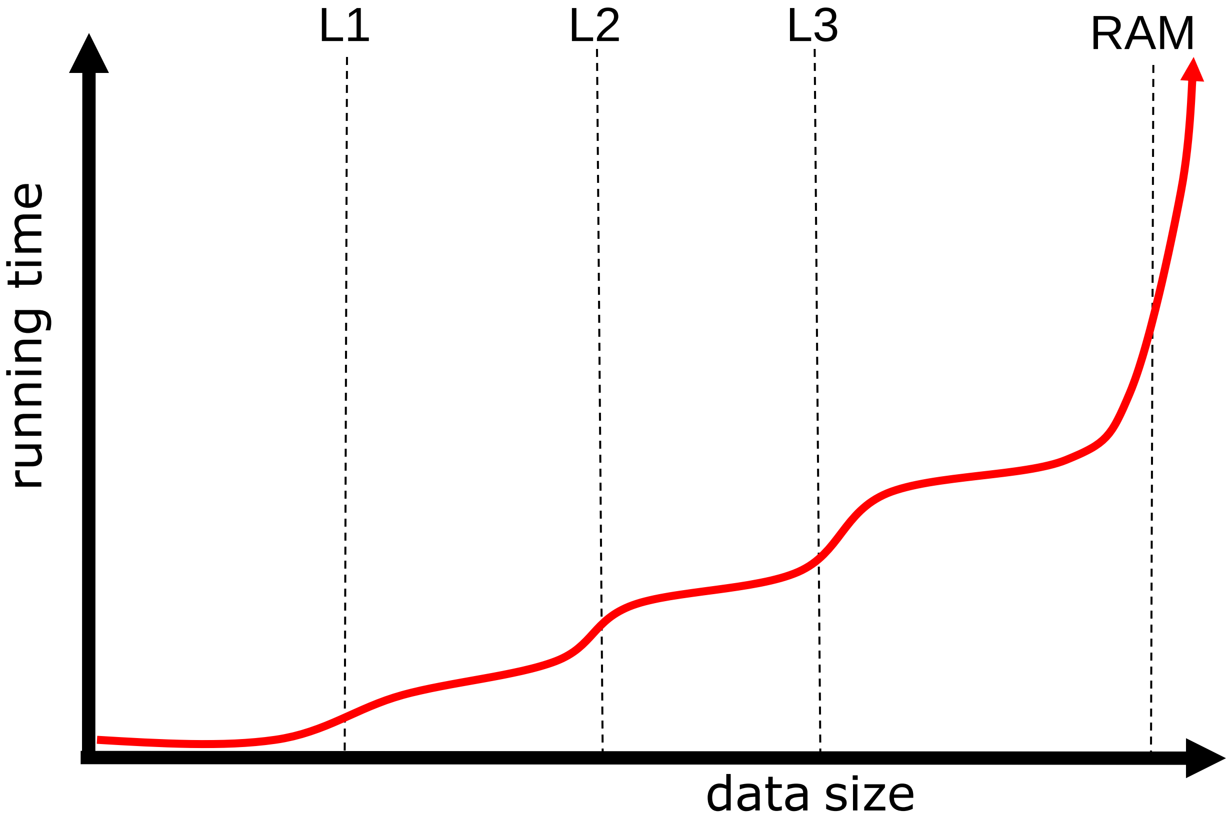
Memory Hierarchy vs Running Time



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Memory Access Times

	Latency	Relative to CPU
Register	0.5 ns	1
L1 cache	0.5 ns	1-2
L2 cache	3 ns	2-7
DRAM	150 ns	80-200
TLB	500+ ns	200-2000
Disk	10 ms	10^7

Increasing

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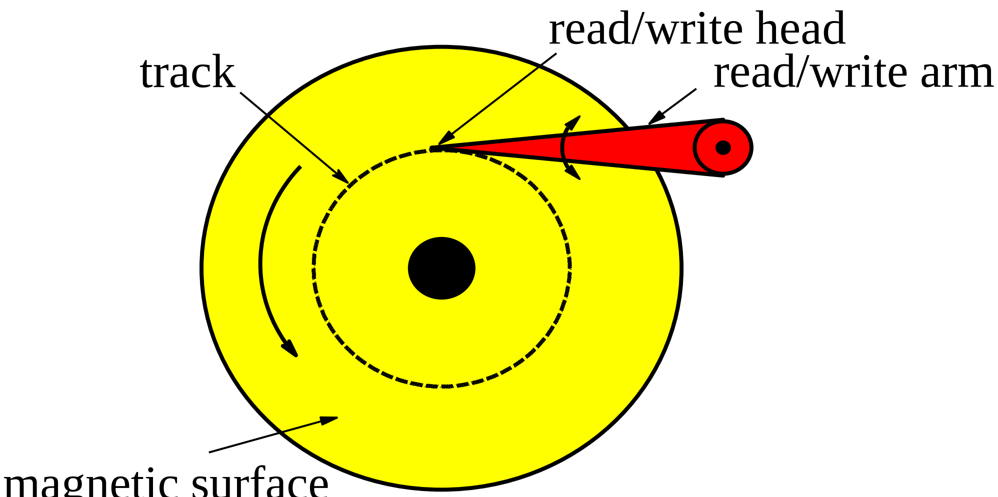
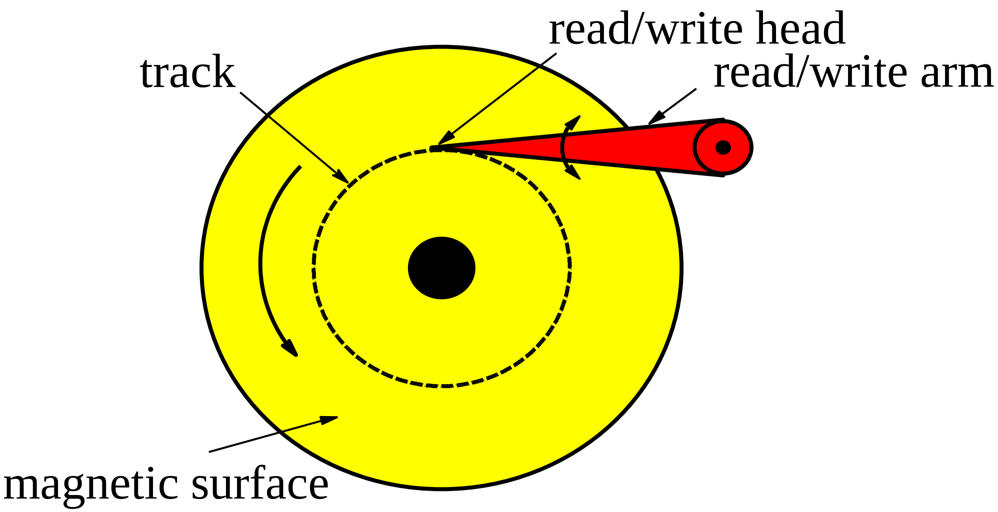
Disk Mechanics



"The difference in speed between modern CPU and disk technologies is analogous to the difference in speed in sharpening a pencil using a sharpener on one's desk or by taking an airplane to the other side of the world and using a sharpener on someone else's desk." (D. Comer)

Disk Mechanics



- I/O is often bottleneck when handling massive datasets
- Disk access is 10^7 times slower than main memory access!
- Disk systems try to amortize large access time transferring large contiguous blocks of data
- Need to store and access data to take advantage of blocks !

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The Algorithmic Challenge

- Modern hardware is not uniform — *many* different parameters
  - Number of memory levels
  - Cache sizes
  - Cache line/disk block sizes
  - Cache associativity
  - Cache replacement strategy
  - CPU/BUS/memory speed...
- Programs should ideally run for many different parameters
  - by knowing many of the parameters at runtime, or
  - by knowing few essential parameters, or
  - ignoring the memory hierarchies ← **Practice**
- Programs are executed on unpredictable configurations
  - Generic portable and scalable software libraries
  - Code downloaded from the Internet, e.g. Java applets
  - Dynamic environments, e.g. multiple processes

Basic Algorithmic I/O Efficient Techniques

- Scanning
- Sorting
- Recursion
- B-trees

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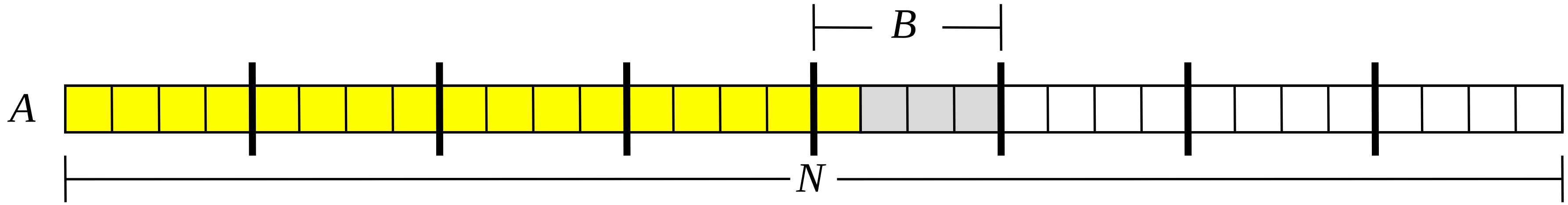
I/O Efficient Scanning

```
sum = 0
for i = 1 to N do sum = sum + A[i]
```



$O(N/B)$ I/Os

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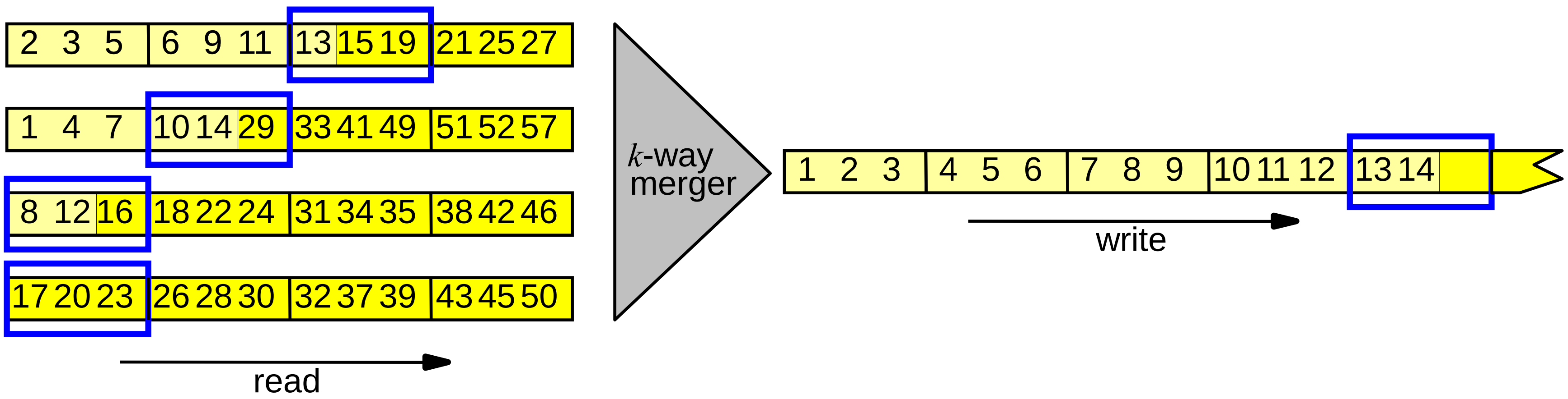
External-Memory Merging



Merging k sequences with N elements requires $O(N/B)$ IOs (provided $k \le M/B - 1$)

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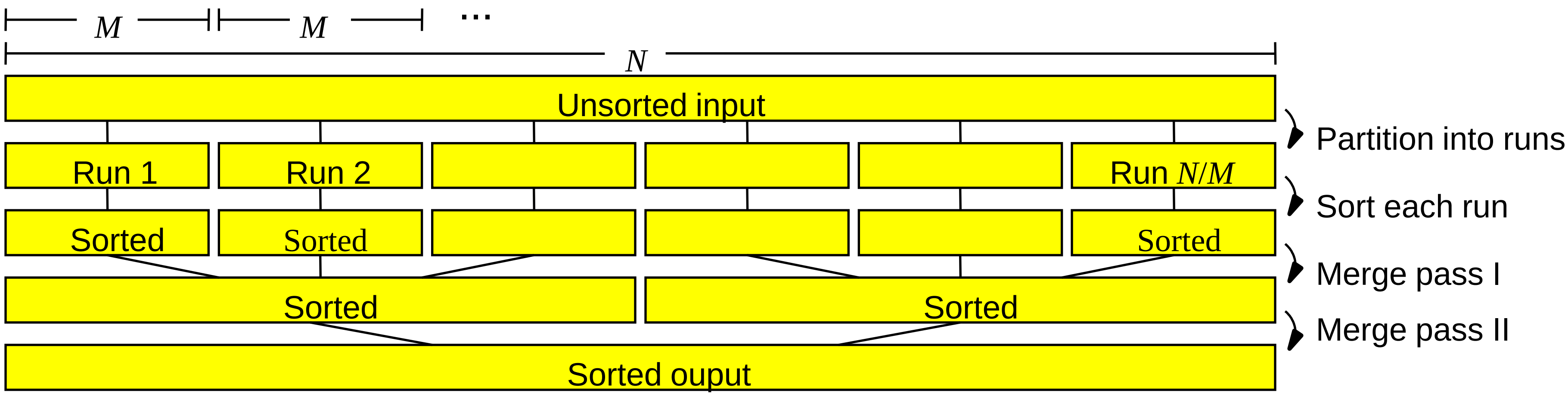
External-Memory Sorting



- MergeSort uses $O(N/B \cdot \log_{M/B}(N/B))$ I/Os
- Practice number I/Os: 4-6 x scanning input

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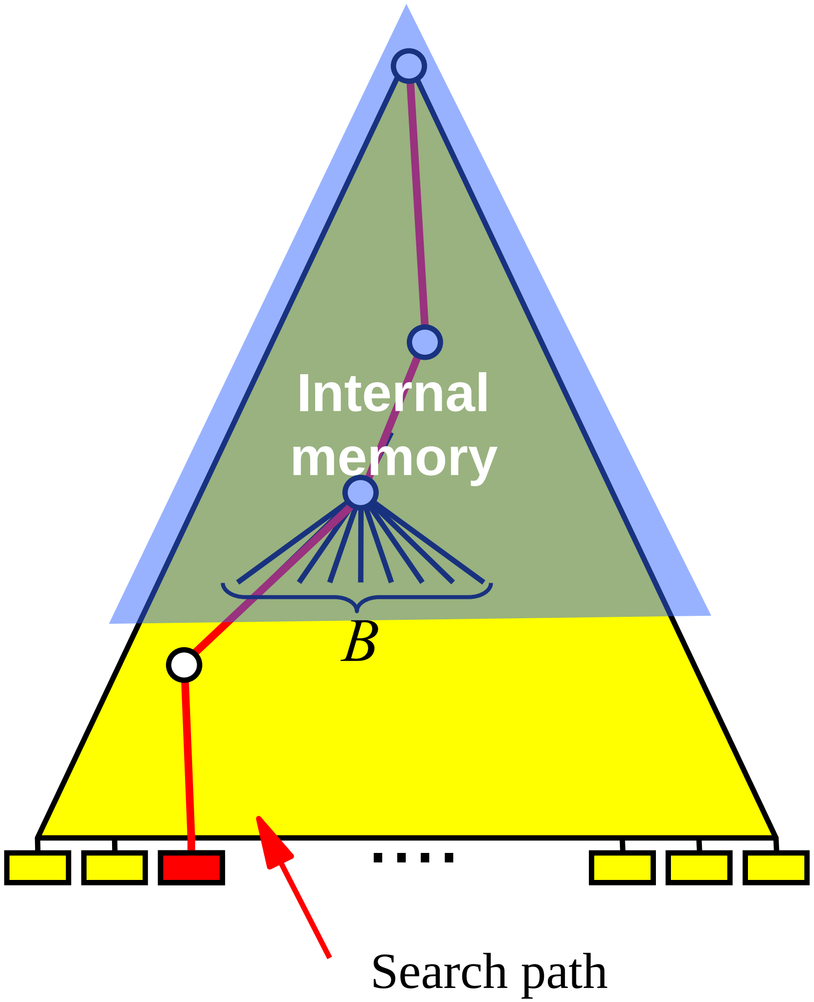
B-trees - The Basic Searching Structure



- **Searches**
  Practice: 4-5 I/Os
- **Repeated searching**
  Practice: 1-2 I/Os

!!! Bottleneck !!!
Use sorting instead of B-tree (if possible)

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About MADALGO (AU)

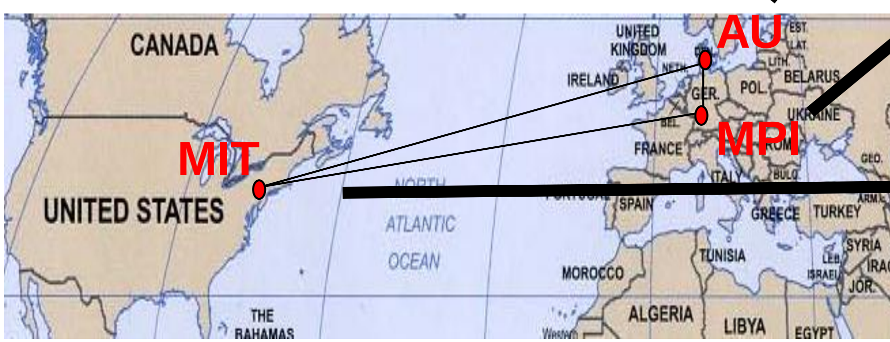
- Center of DANMARKS GRUNDFORSKNINGSFOND DANISH NATIONAL RESEARCH FOUNDATION
- Lars Arge, Professor
- Gerth S. Brodal, Assoc. Prof.
- 3 PostDocs, 9 PhD students, 5 MSc students
- Total 5 year budget ~60 million kr (8M Euro)

Center Leader
Prof. Lars Arge

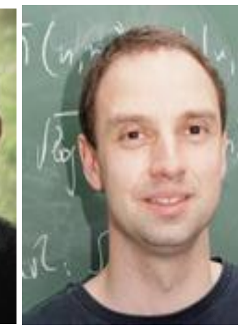
- High level objectives
  - Advance algorithmic knowledge in massive data processing area
  - Train researchers in world-leading international environment
  - Be catalyst for multidisciplinary collaboration

Center Team

- International core team of algorithms researchers
- Including top ranked US and European groups




Arge Brodal

Mehlhorn Meyer

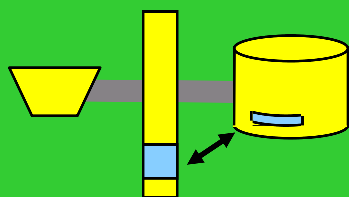

Demaine Indyk

Center Collaboration

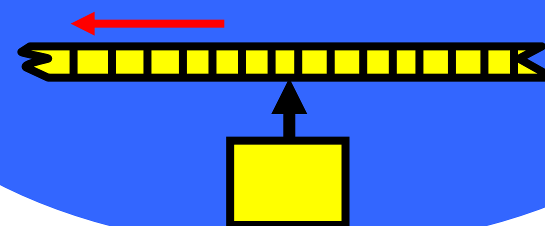
- COWI, DHI, DJF, DMU, Duke, NSCU
- Support from Danish Strategic Research Council and US Army Research Office
- Software platform for Galileo GPS
  - Various Danish academic/industry partners
  - Support from Danish High-Tech Foundation
- European massive data algorithmics network
  - 8 main European groups in area

MADALGO Focus Areas

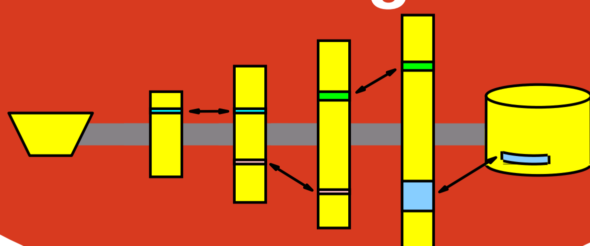
I/O Efficient Algorithms



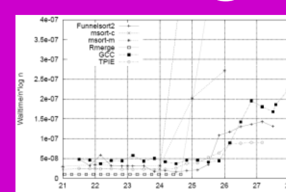
Streaming Algorithms



Cache Oblivious Algorithms



Algorithm Engineering



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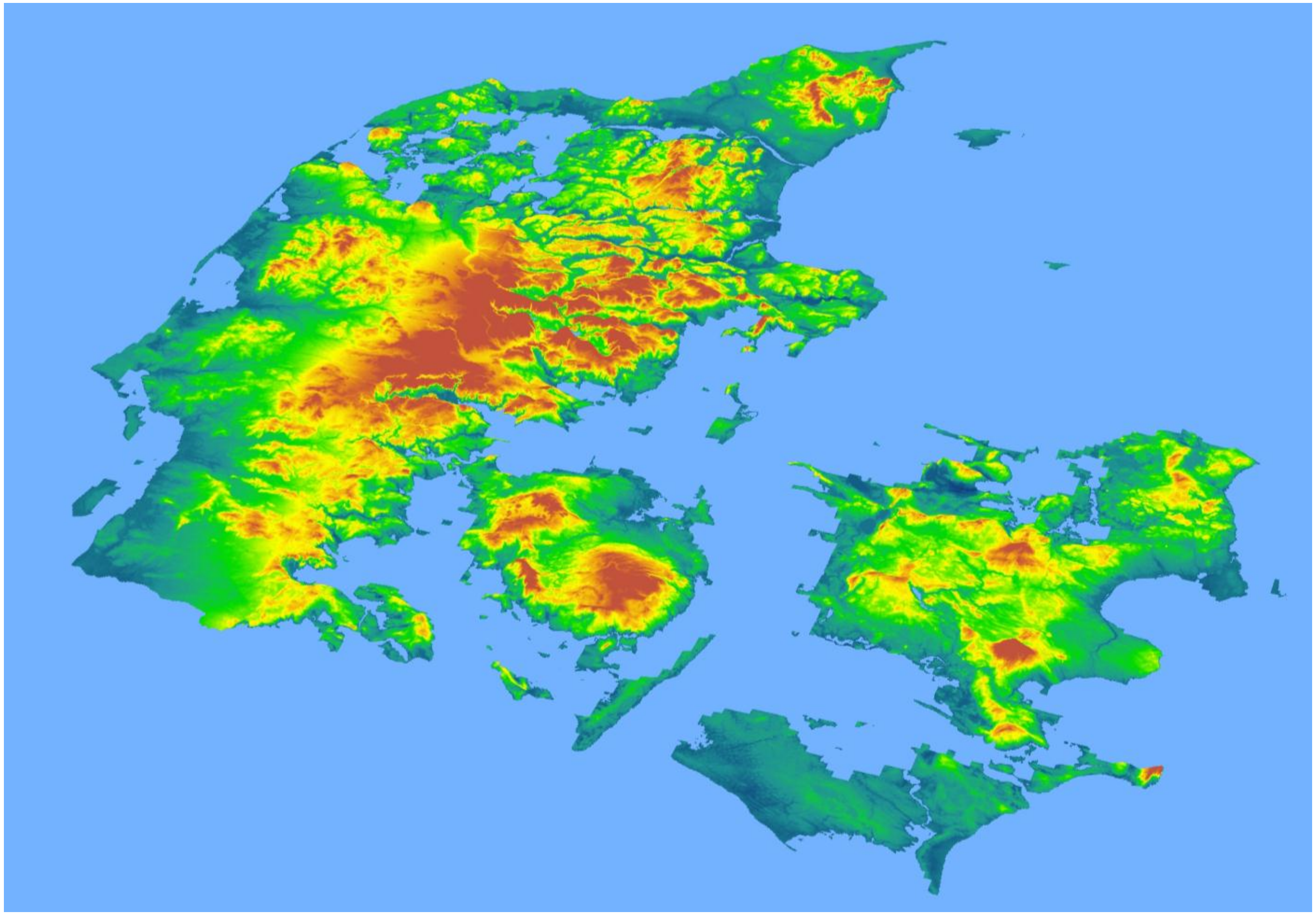
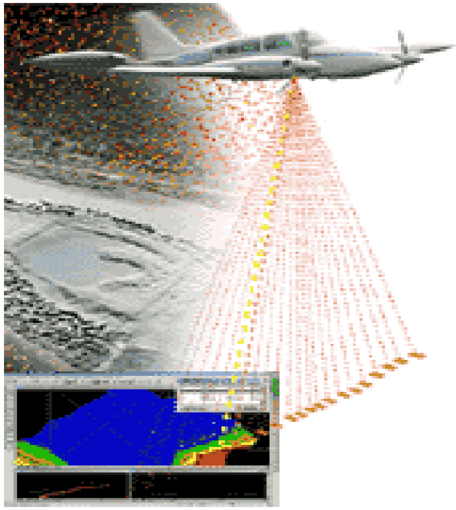
A MADALGO Project

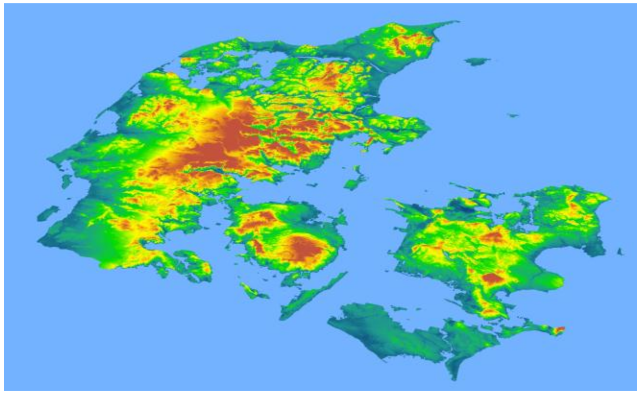
Massive Terrain Data



Terrain Data

- New technologies:
  Much easier/cheaper to collect detailed data
- Previous 'manual' or radar based methods
  - Often 30 meter between data points
  - Sometimes 10 meter data available
- New laser scanning methods (LIDAR)
  - Less than 1 meter between data points
  - Centimeter accuracy (previous meter)





Denmark

- ~2 million points at 30 meter (<<1GB)
- ~18 billion points at 1 meter (>>1TB)
- COWI (and other) now scanning DK
- NC scanned after Hurricane Floyd in 1999

Hurricane Floyd

Sep. 15, 1999

7 am

3pm

Denmark Flooding

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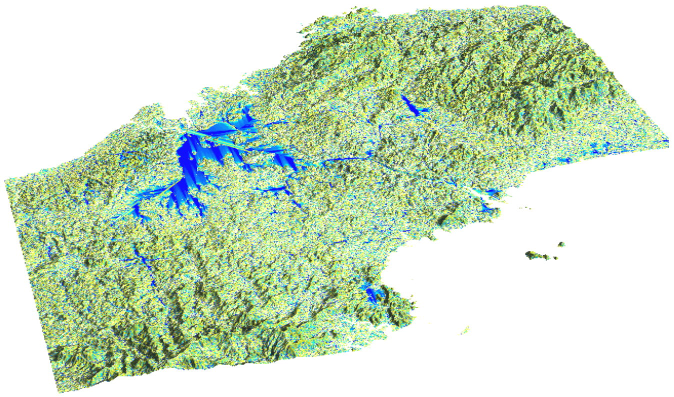
Example: Terrain Flow

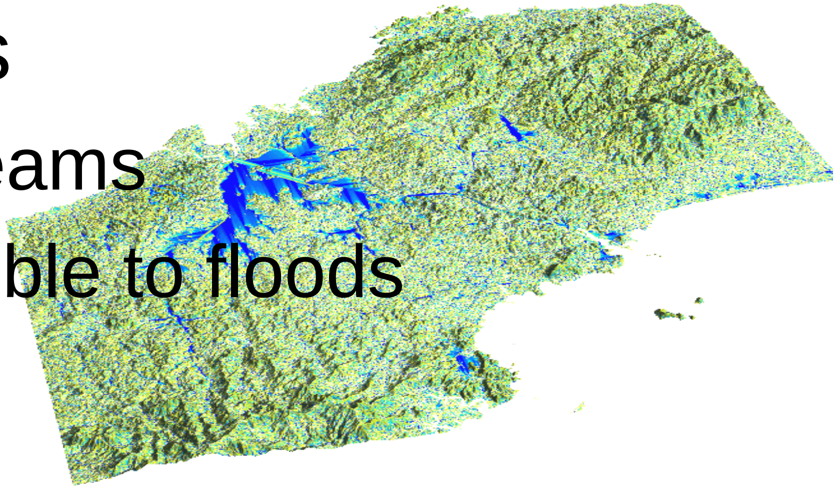


- Conceptually flow is modeled using two basic attributes
  - Flow direction: The direction water flows at a point
  - Flow accumulation: Amount of water flowing through a point

- Flow accumulation used to compute other hydrological attributes: drainage network, topographic convergence index…

Example: Flow on Terrains

- Modeling of water flow on terrains has many important applications
  - Predict location of streams
  - Predict areas susceptible to floods
  - Compute watersheds
  - Predict erosion
  - Predict vegetation distribution
  - ……



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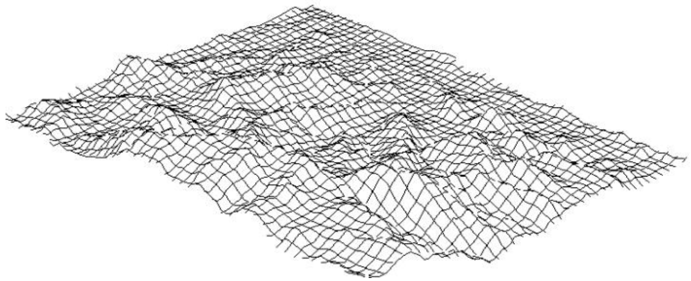
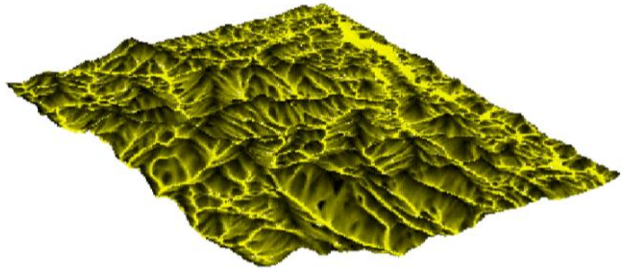
Terrain Flow Accumulation





- Collaboration with environmental researchers at Duke University
  - Appalachian mountains dataset:
    - 800x800km at 100m resolution $\Rightarrow$ a few Gigabytes
    - On ½GB machine: 14 days!!
- ArcGIS:
  - Performance somewhat unpredictable
  - Days on few gigabytes of data
  - Many gigabytes of data…..
- Appalachian dataset would be Terabytes sized at 1m resolution

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Terrain Flow Accumulation: TerraFlow

- We developed theoretically I/O-optimal algorithms
- TPIE implementation was very efficient
  - Appalachian Mountains flow accumulation in 3 hours!

- Developed into comprehensive software package for flow computation on massive terrains: TerraFlow
  - Efficient: 2-1000 times faster than existing software
  - Scalable: >1 billion elements!
  - Flexible: Flexible flow modeling (direction) methods

- Extension to ArcGIS

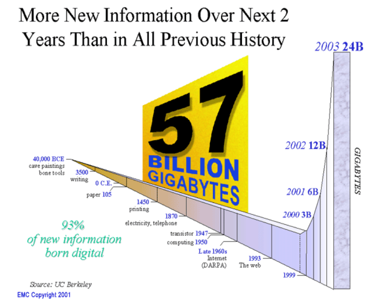
Examples of Ongoing Terrain Work

- Terrain modeling, e.g
  - "Raw" LIDAR to point conversion (LIDAR point classification) (incl feature, e.g. bridge, detection/removal)
  - Further improved flow and erosion modeling (e.g. carving)
  - Contour line extraction (incl. smoothing and simplification)
  - Terrain (and other) data fusion (incl format conversion)
- Terrain analysis, e.g
  - Choke point, navigation, visibility, change detection,…

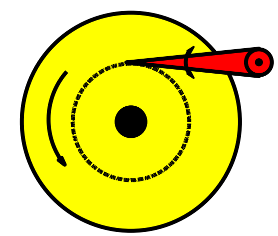
- Major grand goal:
  - Construction of hierarchical (simplified) DEM where derived features (water flow, drainage, choke points) are preserved/consistent

Summary

- Massive datasets appear everywhere



- Leads to scalability problems
  - Due to hierarchical memory and slow I/O



- I/O-efficient algorithms greatly improves scalability