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STXXL: Standard Template Library for XXL Data Sets

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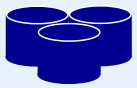
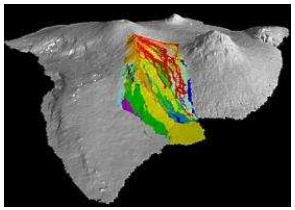


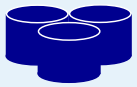
Large Data Sets are Growing

- Geographic Information Systems: detailed maps occupy many GBytes



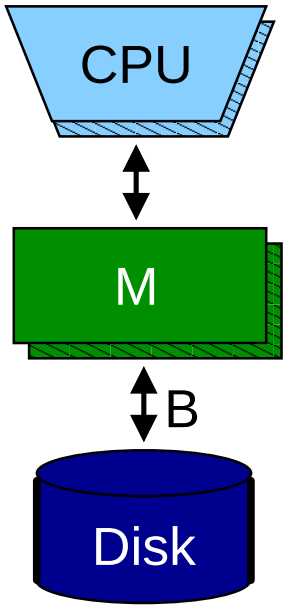
- Texts: Google searches over 8 billion web pages
- Data warehouses: hundreds of terabytes

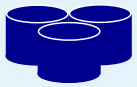
- Scientific computing: global climate simulations, aerodynamics, . . .



I/O Model

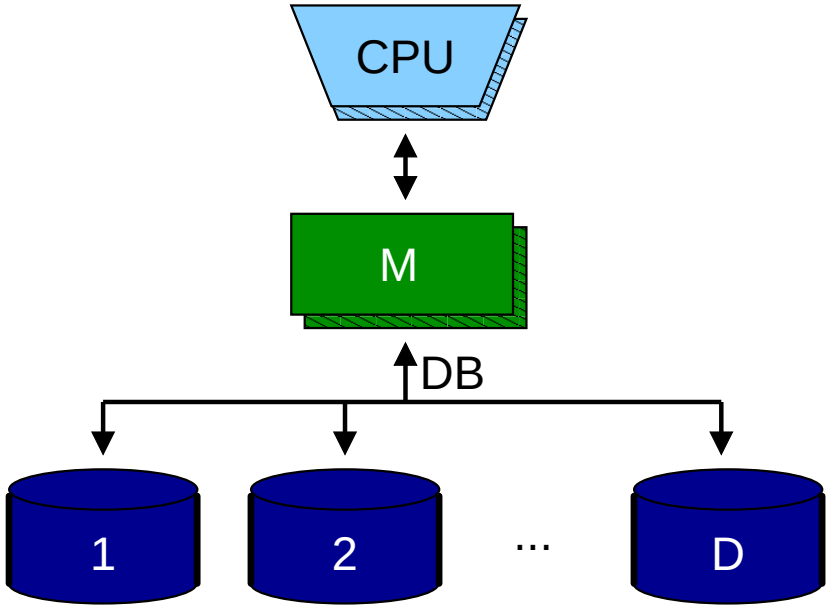
- Disk access involves a mechanical movement $\Rightarrow$ slow
  - Random disk access: 1–20 ms
  - Random main memory access: 1–50 ns
  - Sequential reading/writing next elements is “for free”
- Aggarwal–Vitter I/O model
  - N — size of input
  - M — size of main memory
  - B — size of transfer block
  - Cost measure – number of I/Os

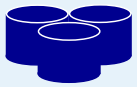




Parallel Disks

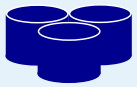
- Add disks to improve bandwidth:
  Parallel Disk Model (PDM) by Vitter–Shriver
  - D independent disks
  - In an I/O step try transfer D blocks between main memory and disks





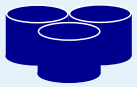
What is STXXL?

- STL – C++ Standard Template Library, implements basic containers (maps, sets, priority queues, etc.) and algorithms (quicksort, mergesort, selection, etc.)
- STXXL: Standard Template Library for XXL Data Sets
  `http://stxxl.sourceforge.net`
  containers and algorithms that can process huge volumes of data that only fit on disks (I/O-efficient)
  - Compatible with STL
  - Performance–oriented



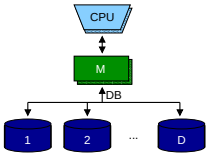
Related Work

- TPIE (1994–) Duke University, USA
  - Sorting, merging, matrix operations, geometric search data structures
- LEDA-SM (1998–2003) Max-Planck-Institut für Informatik, Germany
  - Sorting, priority queues, search trees, suffix arrays
- FG (2002–) Dartmouth College, USA
  - Parallel design framework for clusters
  - Pipelining helps to mitigate disk and communication latency

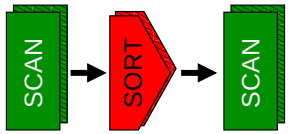


STXXL Features

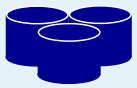
- Parallel disk support



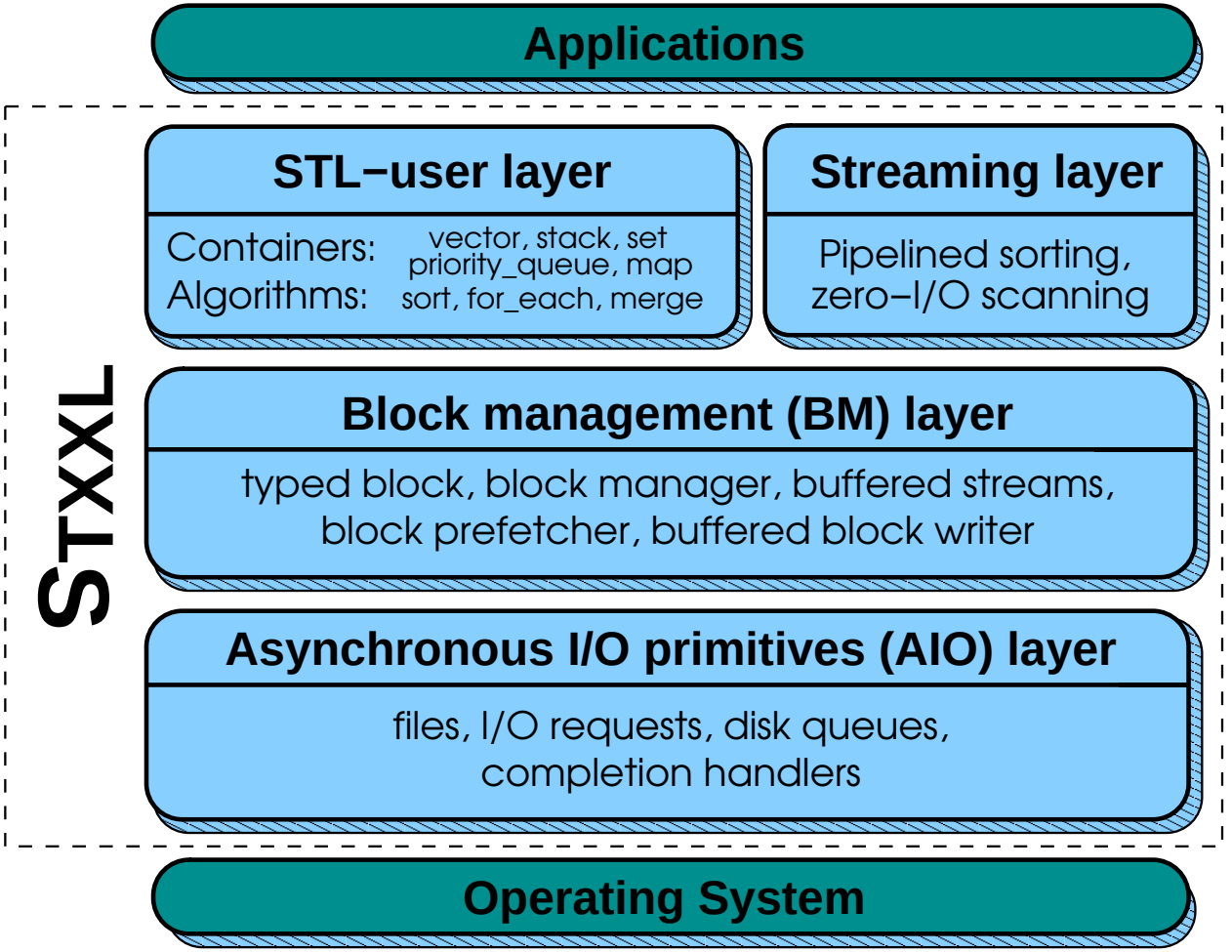
- Handles very large problems (up to terabytes)
- Pipelining saves many I/Os
  - Feed output of EM alg. to input of another EM alg. directly

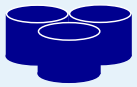


- Explicitely overlaps I/O and computation
- Avoids superfluous copying
  - in OS I/O subsystem and the library itself
- Compatible with STL – C++ Standard Template Library
  - Short development times
  - Reuse of STL code (e.g. selection alg.)



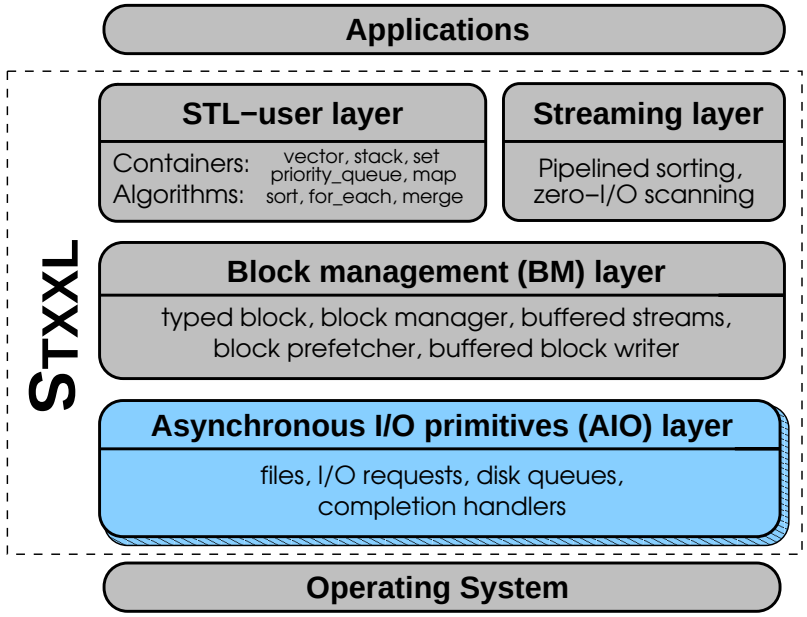
STXXL Design

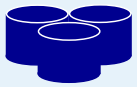




STXXL Design: AIO Layer

- Hides details of async. I/O (portability)
- Implementations for POSIX/UNIX system
- Asynchrony provided by POSIX threads or Boost Threads

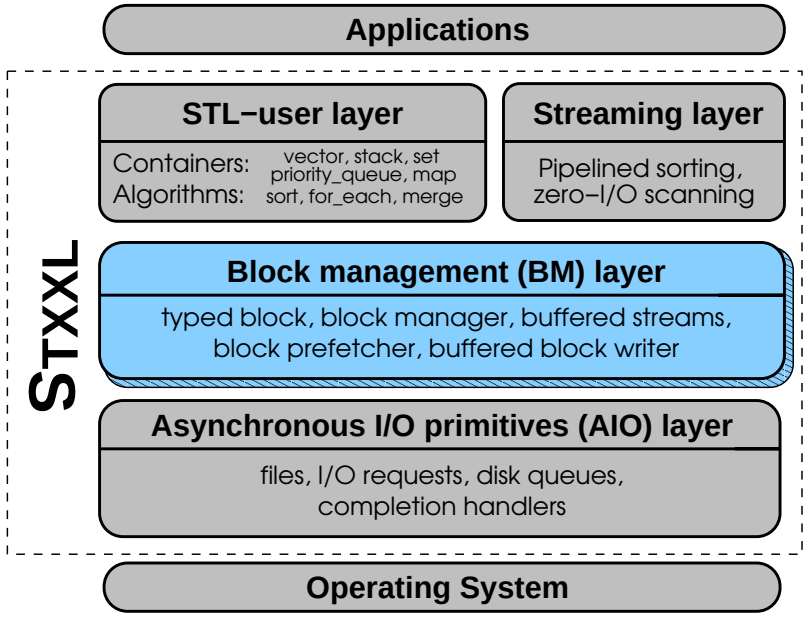


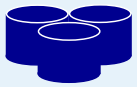


STXXL Design: BM Layer

- Block abstraction
- Parallel disk model
- (randomized) striping and cycling
- parallel disk buffered writing and optimal prefetching

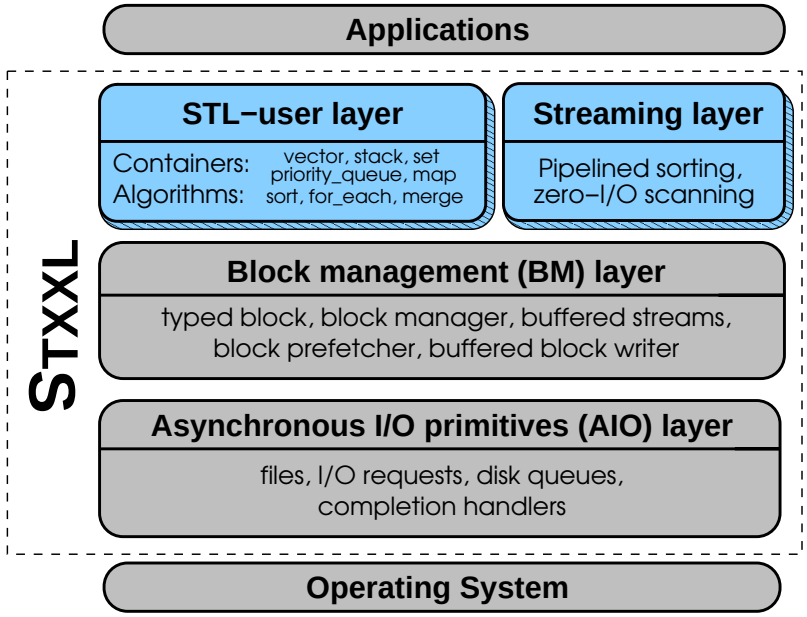
[HutchinsonSandersVitter01]

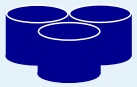




STXXL User Layers

- STL-user layer: compatible with STL
- Streaming layer: programming with pipelining

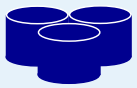




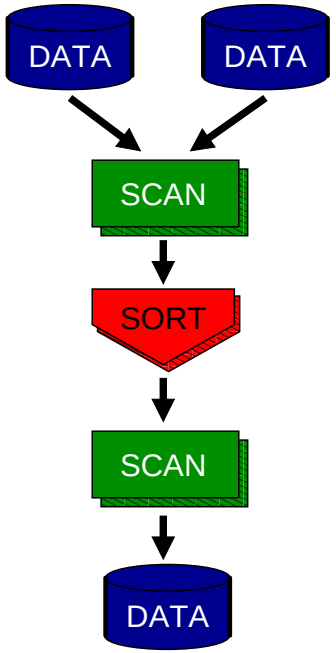
STL-User Layer

- EM containers: `vector`, `priority_queue`, `stack`, `map`, `queue`
  - Can be directly used with algorithms from STL
- EM algorithms: `sort` [DemSan03], `ksort`, `for_each`, ...

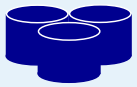
```
1 stxxl::vector<edge> Edges(10000000000ULL);
2 std::generate(Edges.begin(),Edges.end(),random_edge());
3 stxxl::sort(Edges.begin(),Edges.end(),edge_cmp(),
4                          512*1024*1024);
5 stxxl::vector<edge>::iterator NewEnd =
6                          std::unique(Edges.begin(),Edges.end());
7 Edges.resize(NewEnd - Edges.begin());
```



Streaming Layer and Pipelining



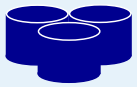
- EM algorithm $\Rightarrow$ data flow through a DAG
- Feed output data stream directly to the consumer algorithm
- Saves many (factor 2–3) I/Os in many EM algorithms
- A new iterator-like interface for EM algorithms
- Basic pipelined implementations (file, sorting nodes, etc.) provided by STXXL



STXXL Performance: a Benchmark

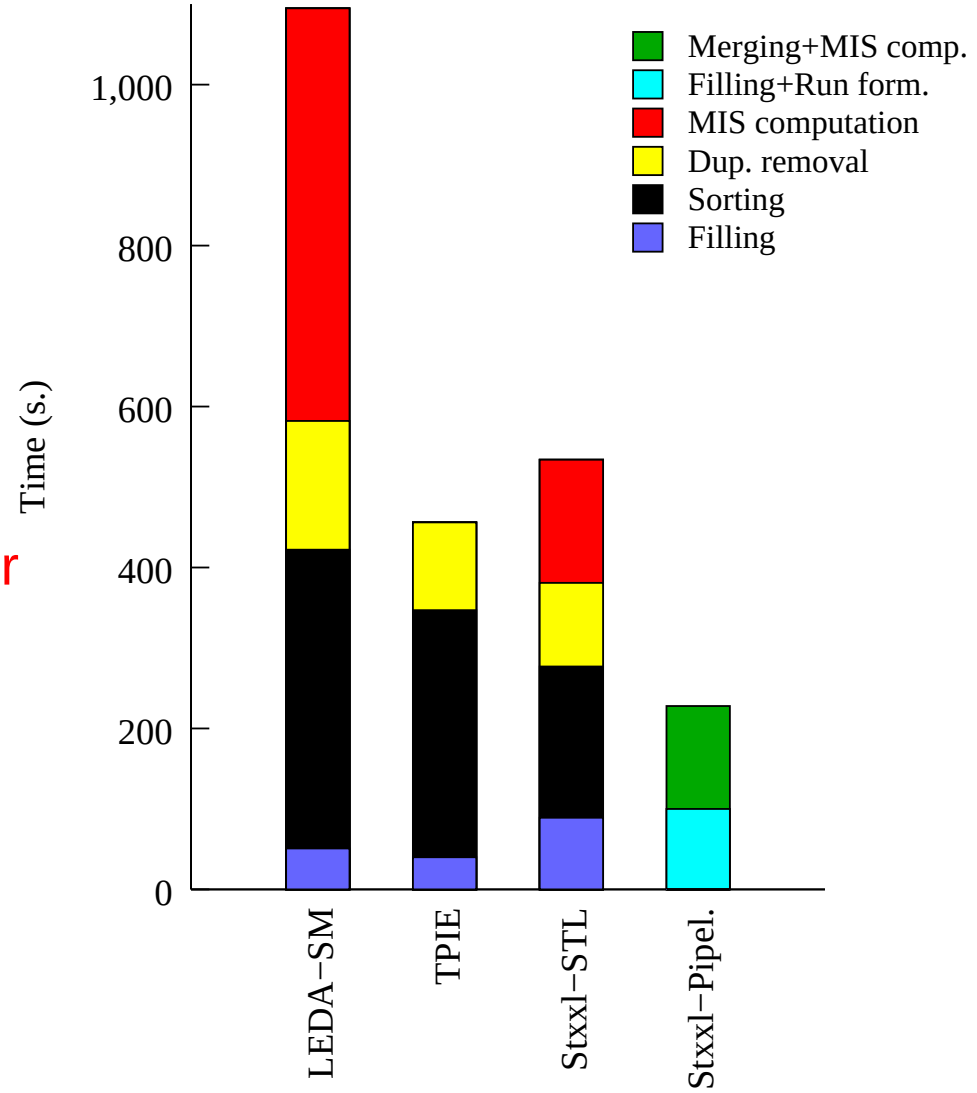
- Maximal Independent Set (+input generation)
- I/O optimal [ZehPhd]: time forward processing, scanning, sorting, priority queue

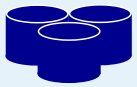
```
1  pq_type depend(PQ_PPOOL_MEM,PQ_WPOOL_MEM);
2  stxxl::vector<node_type> MIS; // output
3  for(;!edges.empty();++edges) {
4          while(!depend.empty() && edges->src > depend.top())
5                  depend.pop(); // delete old events
6          if(depend.empty() || edges->src != depend.top() ) {
7                  if(MIS.empty() || MIS.back() != edges->src )
8                          MIS.push_back(edges->src);
9                  depend.push(edges->dst);
10         }
11 }
```



MIS: Running Times

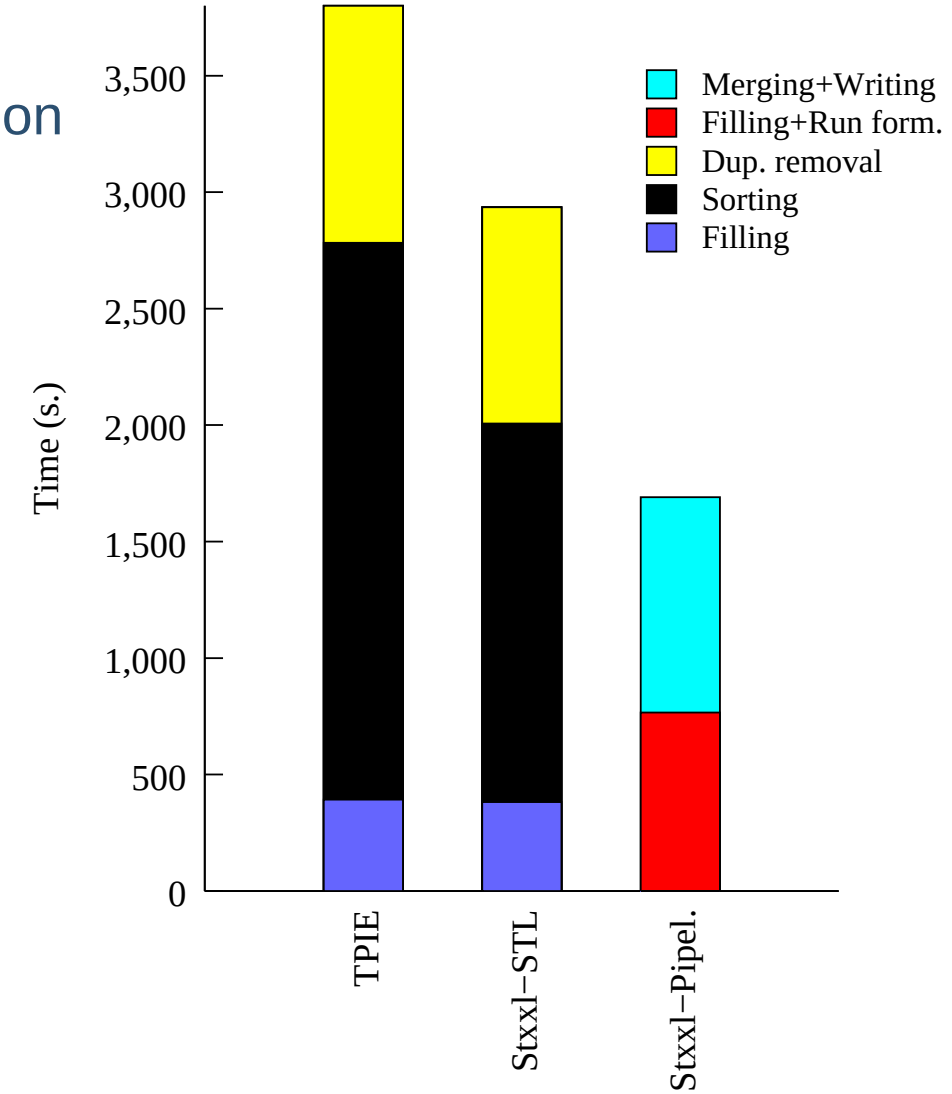
- Debian Linux, g++ -O3
- 2×Xeon 2GHz
- single disk
- N = 2000 MBytes
- M = 512 MBytes
- TPIE: only graph gen.
- STXXL PQ is 3 times faster

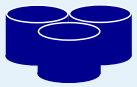




MIS: Larger Inputs

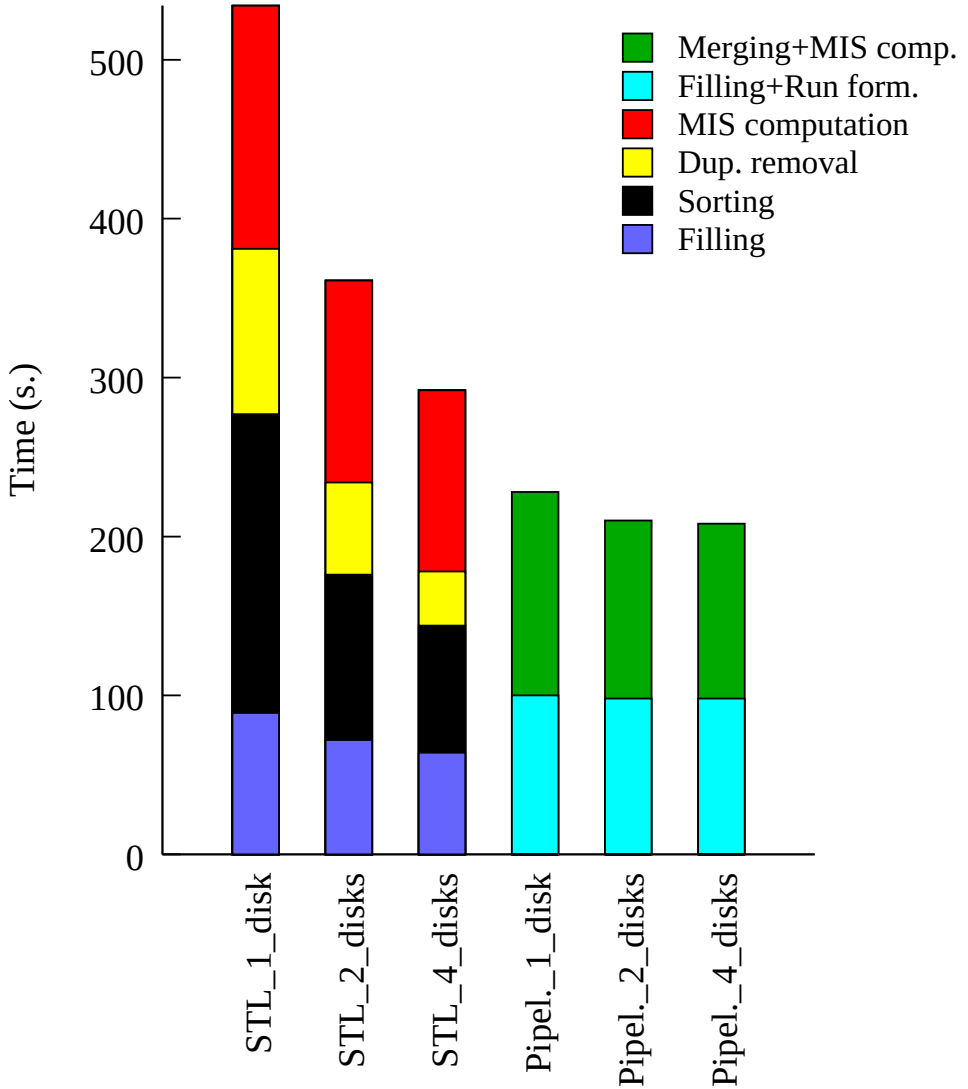
- Only graph generation
- single disk
- N = 16 GBytes
- M = 512 MBytes
- Scales well

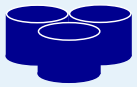




MIS: More Disks

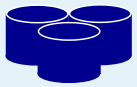
- 2,4 disks
- N = 2000 MBytes
- M = 512 MBytes
- Pipel. – CPU bound
- I/O-wait counters





MIS: The Largest Graph

- The largest graph:
- $4.3 \cdot 10^9$ nodes, $13.4 \cdot 10^9$ edges = 100 GBytes
- Working space takes 4 hard disks
- Computation on an Opteron system took 3h 7min



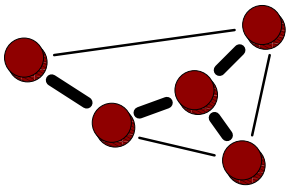
STXXL Projects

Fast suffix array construction:

- index $4 \cdot 10^9$ characters in 11h on a PC [in ALENEX05]

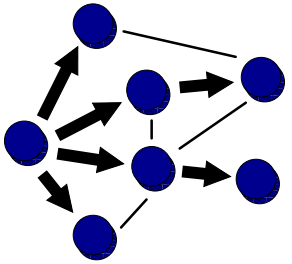
Minimum spanning tree:

- 96 GByte input graph in 8h 40min on a PC [in TSC04]



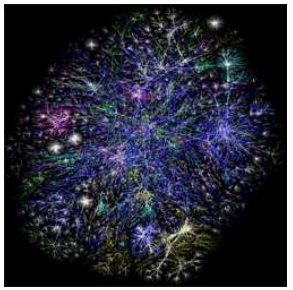
BFS: $32 \cdot 10^6$ nodes, $128 \cdot 10^6$ edges

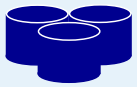
- grid graphs in less than a day
- random sparse graphs within an hour [in SODA06]



Network analysis:

- count triangles in WWW link graph $135 \cdot 10^6$ nodes, $1.2 \cdot 10^9$ edges in 4h 46min





Future Work

- Windows port: done
- More flexible error handling using C++ exceptions
- Inclusion in Boost libraries
- More algorithms and data structures: hash tables, strings, string sorting, . . .
- Support of arbitrary variable-size objects