ROOT

An Object-Oriented Data Analysis Framework

Efficient Access to Remote Data in High Energy Physics

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Roadmap

- Current Status
- Problem
- Taking Advantage of ROOT
- Solution
- Limitations
- Future Work
- Conclusions

Motivation

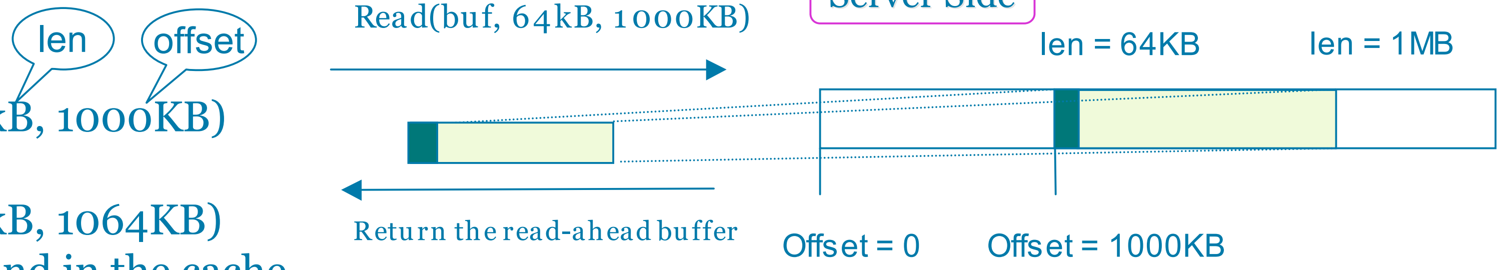
- ROOT was designed to process files locally or in local area networks.
- Reading trees across wide area networks involved a big number of transactions. Therefore, processing in high latency networks was inefficient.
- If we want to process the whole file (or a big part of it), it’s better to transfer it locally first.
- If we want to process only a small part of the file, transferring it would be wasteful and we would prefer to access it remotely.

Traditional Solution

- The way this problem has been treated is always the same (old versions of ROOT, RFIO, dCache, etc):
  - Transfer data by blocks of a given size. For instance, if a block of len 64KB in the position 1000KB of the file is requested, it doesn't just transfer the 64KB but a big chunk of 1MB starting at 1000KB.

Client Side

1. Read(buf, 64kB, 1000KB)
2. Read(buf, 64kB, 1064KB)
   - It is found in the cache
   - Read it locally



- This works well when two conditions are met:
  - We read sequentially
  - We read the whole file.

Inside a ROOT Tree

- In data analysis those two conditions don't always apply.
- We can read only a small (and sparse) part of the file and we can read it non-sequentially.
- In conclusion, a traditional cache will transfer data that won't be used (increasing the overhead).

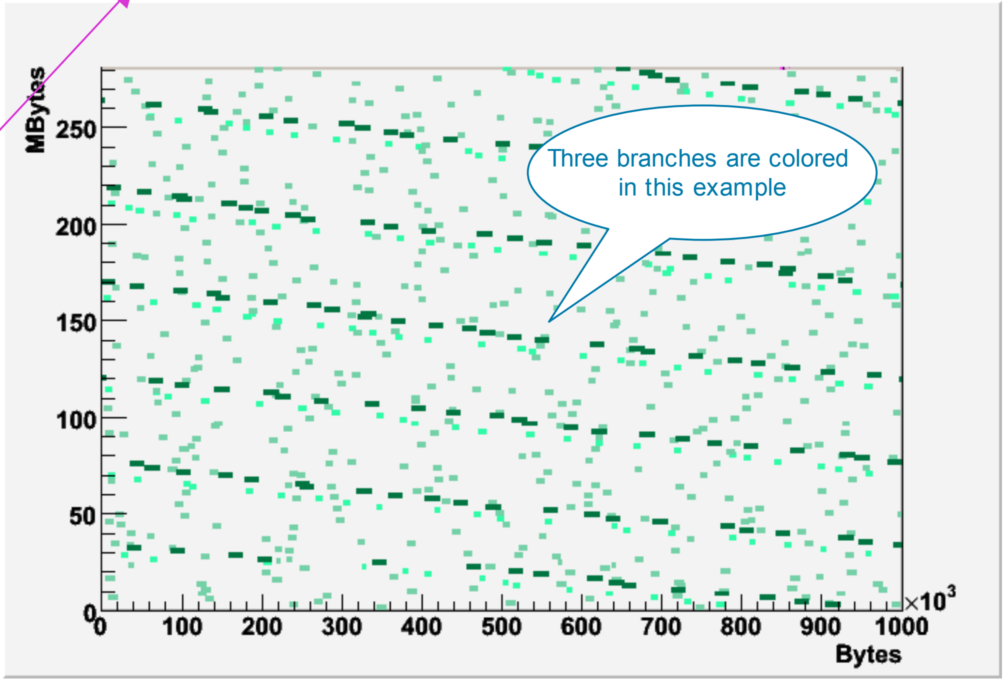
With the command: `Tree.Draw("rawtr", "E33>5")`

We have to read 2 branches (yellow and purple in the picture) scattered through the file in 4800 buffers of 1.5KB on average.

Why are buffers in ROOT so small?

• They are 8KB big in this example (32KB by default) but it becomes 1.5KB after compression.

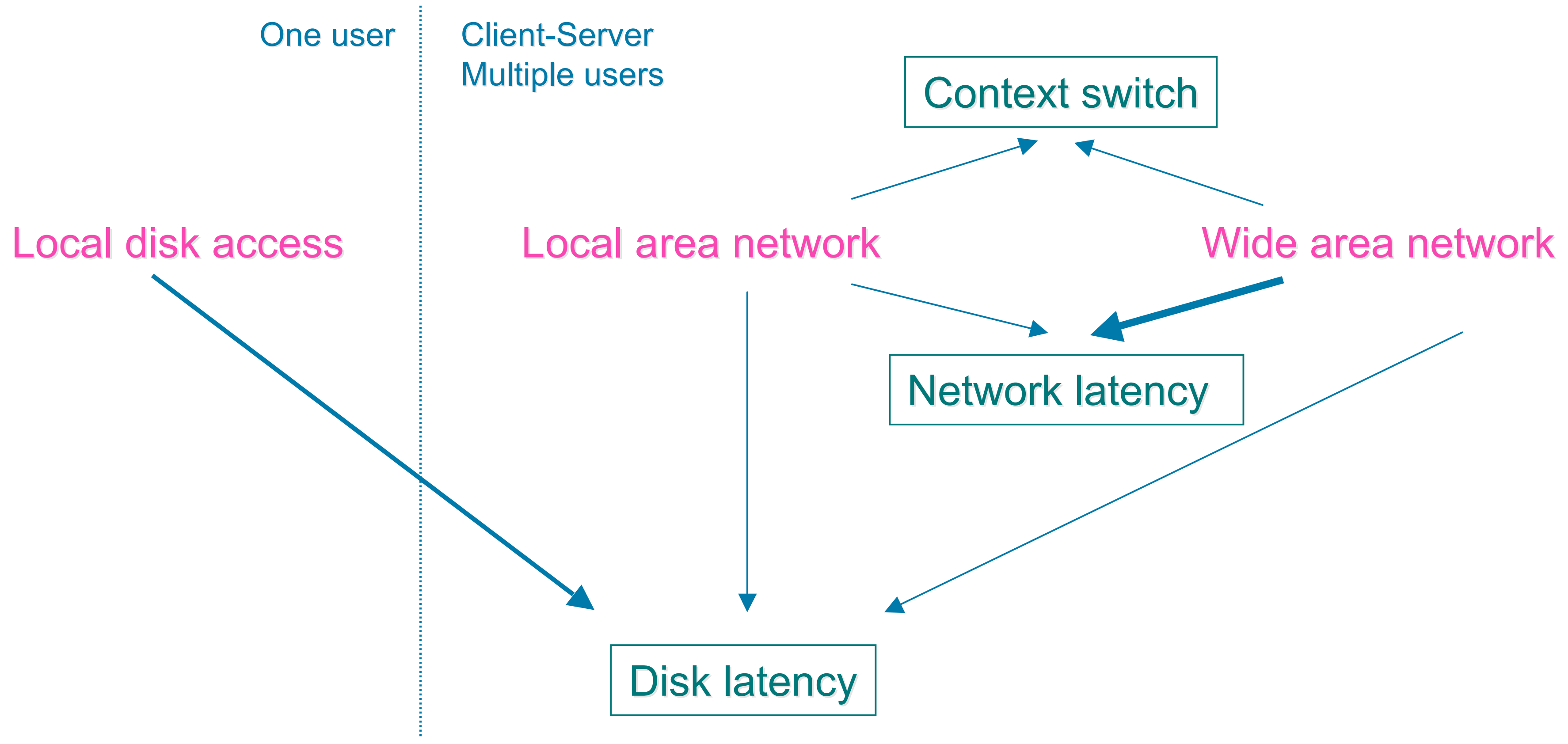
• We need to keep one buffer per branch in memory. Trees can have hundreds or thousands of branches nowadays.



• The file in this picture is 267MB big.
• It has 1 tree with 152 branches.

Facing Various Latency Problems ❶

- We have three different cases to consider:



Facing Various Latency Problems ❷

How can we overcome the problems in these three cases ?:

- Disk latency: Is an issue in all the cases but it's the only one when doing local readings.
  - Can be reduced by reading sequentially and in big blocks (less transactions).

- Context switching: Is a problem for loaded servers. Since they have to serve multiple users, they are forced to switch between processes (switching is usually fast but doing it often can produce a noticeable overhead).
  - Can be very harmful if it's combined with disk latency.
  - It helps to reduce the number of transaction and/or the time between them.

- Network latency: It increases proportionally to the distance between the client and the server. It's a big issue when reading scattered data through long distances.
  - Reducing the number of transactions will improve the performance.

Data Access Parameters ❶

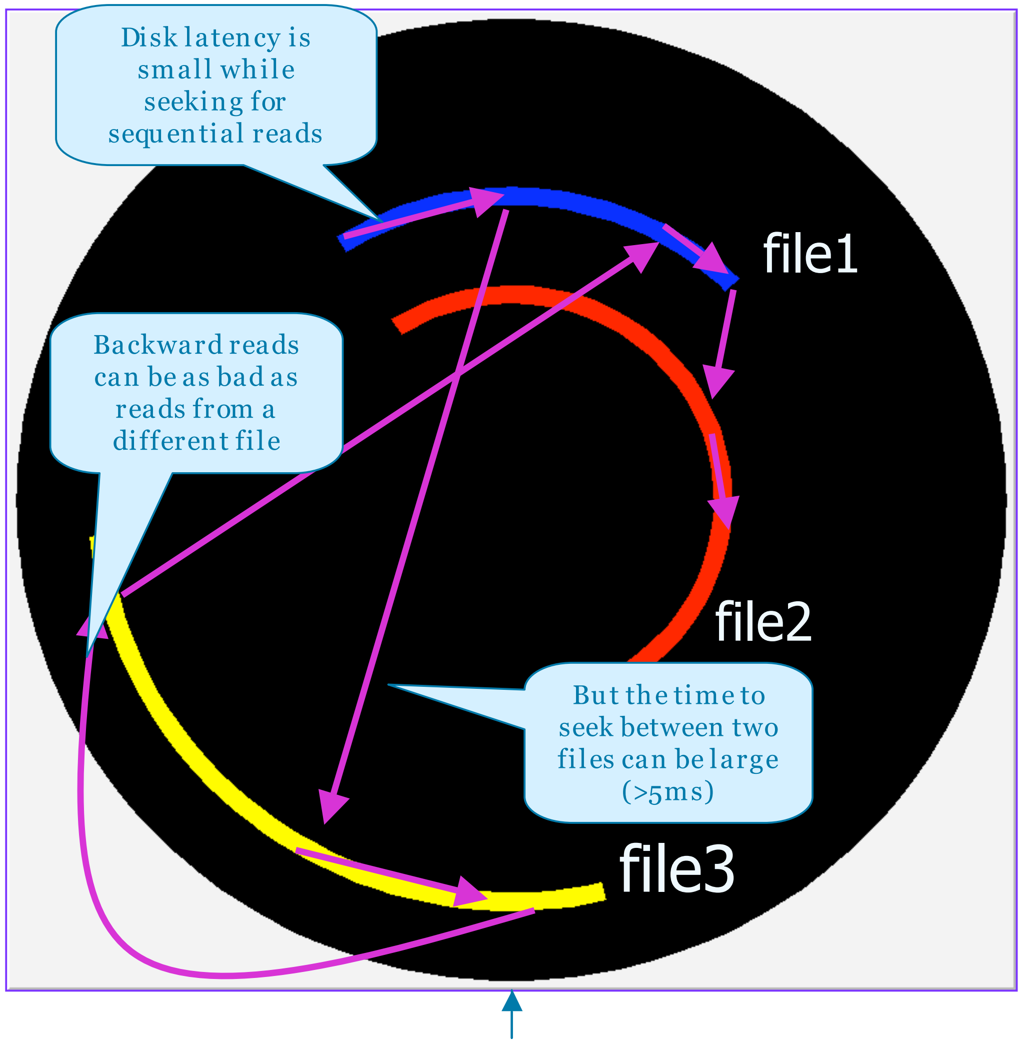
Disk Latency:

• Reading small blocks from disk in the server might be inefficient.

• Seeking randomly on disk is bad. It's better to read sequentially if you can.

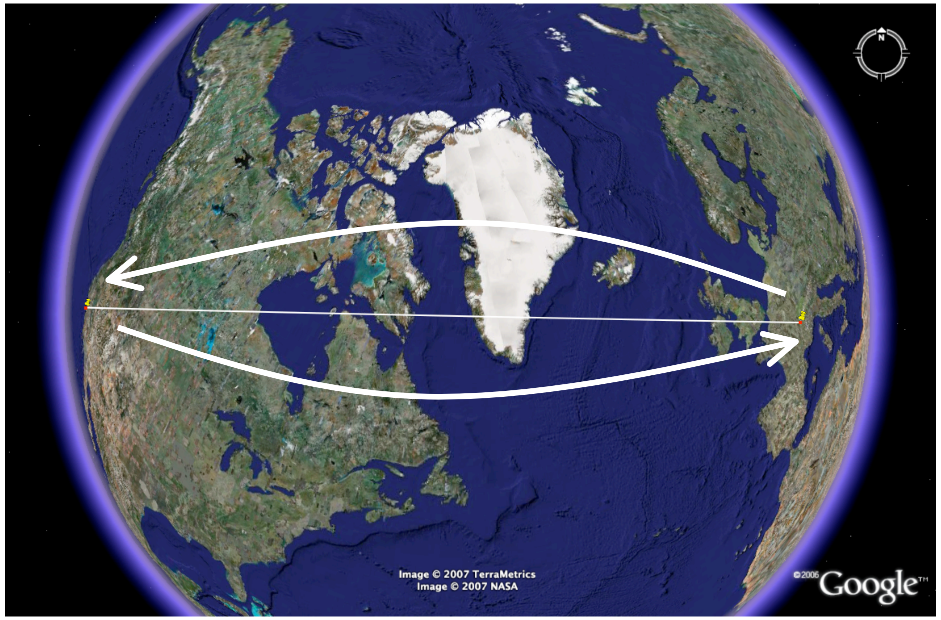
• Multiple concurrent users reading from the same disk generate a lot of seeks (each one greater than 5ms).

• These considerations are less important in a batch environment, but absolutely vital for interactive applications.


Disk latency is small while seeking for sequential reads
file1
Backward reads can be as bad as reads from a different file
file2
But the time to seek between two files can be large (>5ms)
file3

Data Access Parameters ❷

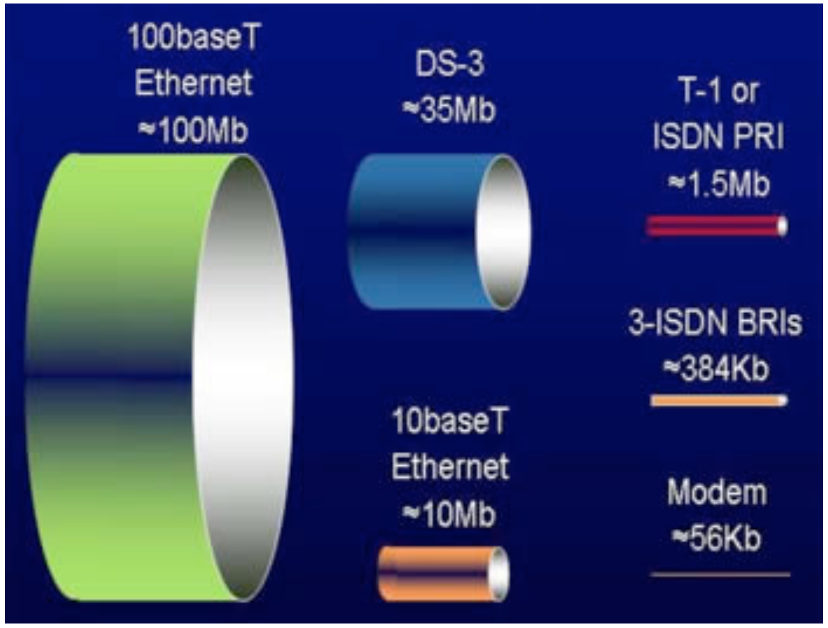
- **Network Latency** : The time it takes a packet to get from point A to point B. Usually referred as RTT (round trip time), which is the time it takes a packet to go from A to B and back.



Latency between CERN and SLAC: 160ms (RTT)

Data Access Parameters ❸

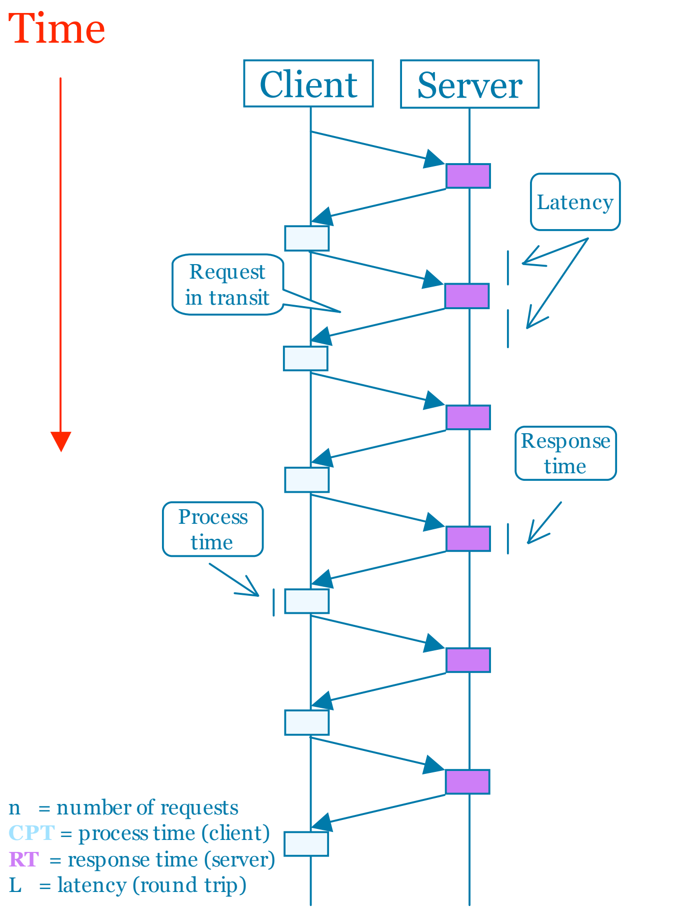
- **Bandwidth**: It’s the channel capacity, measured in bits/seconds (it can be seen as the diameter of the pipe). For the rest of the talk, we assume this is not an issue.



Problem

- While processing a large (remote) file the data has, so far, been transferred in small chunks.
  - It doesn't matter how many chunks you can carry if you will only read them one by one.
- In ROOT, each of those small chunks is usually spread out in a big file.
- The time spent exchanging messages to get the data could be a considerable part of the total time.
- This becomes a problem when we have high latency connections (independently of bandwidth).

Network Latency



n = number of requests
CPT = process time (client)
RT = response time (server)
L = latency (round trip)

Total time = n (CPT + RT + L)

The equation depends on both variables

- The file is on a CERN machine connected to the CERN LAN at 100MB/s.
- **A** is on the same machine as the file (local read)
- **B** is on a CERN LAN connected at 100 Mbits/s and latency of 0.3 ms (P IV 3 Ghz).
- **C** is on a CERN Wireless network at 10 Mbits/s and latency of 2ms (Mac duo 2Ghz).
- **D** is in Orsay; LAN 100 Mbits/s, WAN of 1 Gbits/s and a latency of 11 ms (3 Ghz).
- **E** is in Amsterdam; LAN 100 Mbits/s, WAN of 10 Gbits/s and a latency of 22ms.
- **F** is connected via ADSL of 8Mbits/s and a latency of 70 ms (Mac duo 2Ghz).
- **G** is connected via a 10Gbits/s to a CERN machine via Caltech latency 240 ms.
- The times reported in the table are realtime seconds

client	latency(ms)	cache=0	cache=64KB	cache=10MB
A	0.0	3.4	3.4	3.4
B	0.3	8.0	[illegible]	[illegible]
C	2.0	11.6	5.6	4.9
D	11.0	124.7	[illegible]	[illegible]
E	22.0	230.9	11[illegible]	8.4
F	72.0	743.7	48.3	28.0
G	240.0	>1800.0 seconds	1[illegible]5.4	9.9

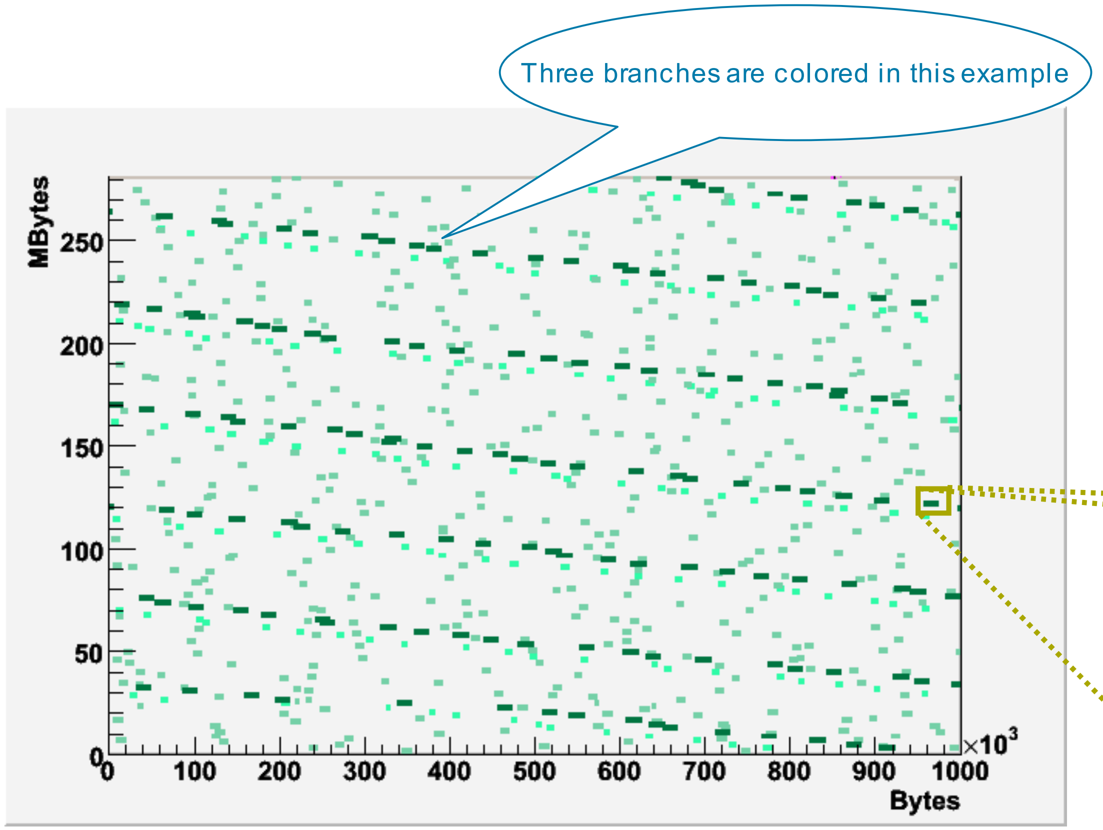
Tree.Draw("rawtr", "E33>5");

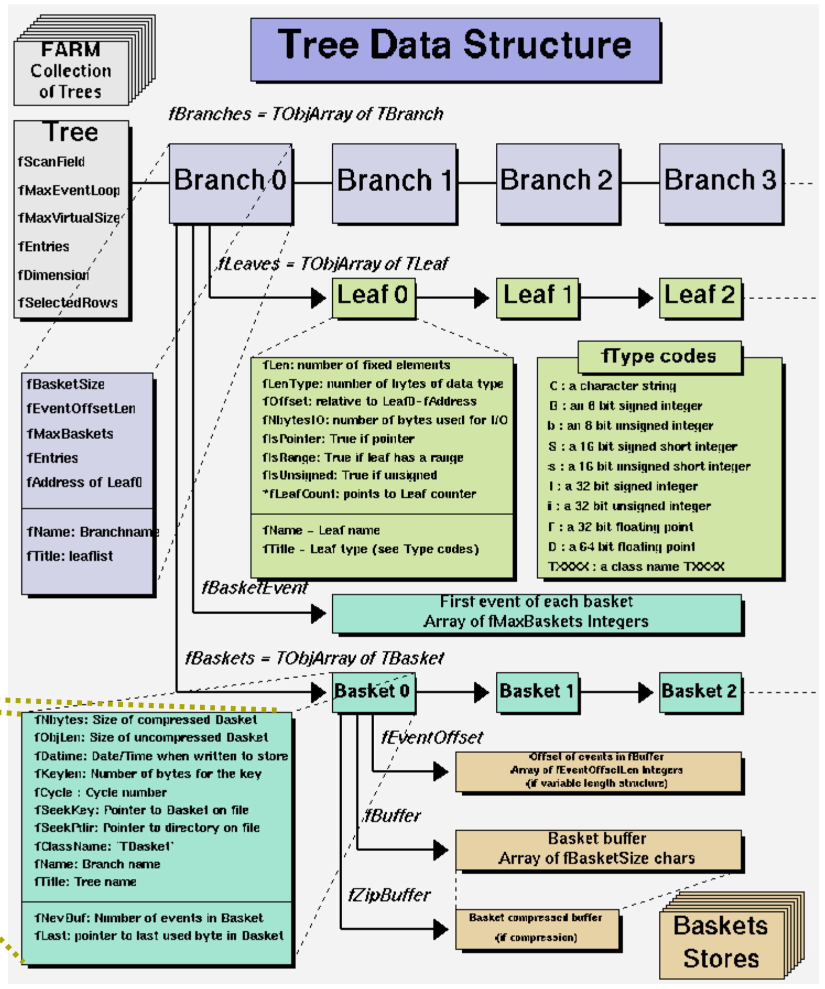
Time taken to execute this query

Wide Area Network: this will be our main concern.

Taking Advantage of ROOT Trees

ROOT Trees are designed in such a way, that it's possible to know what set of buffers go together.



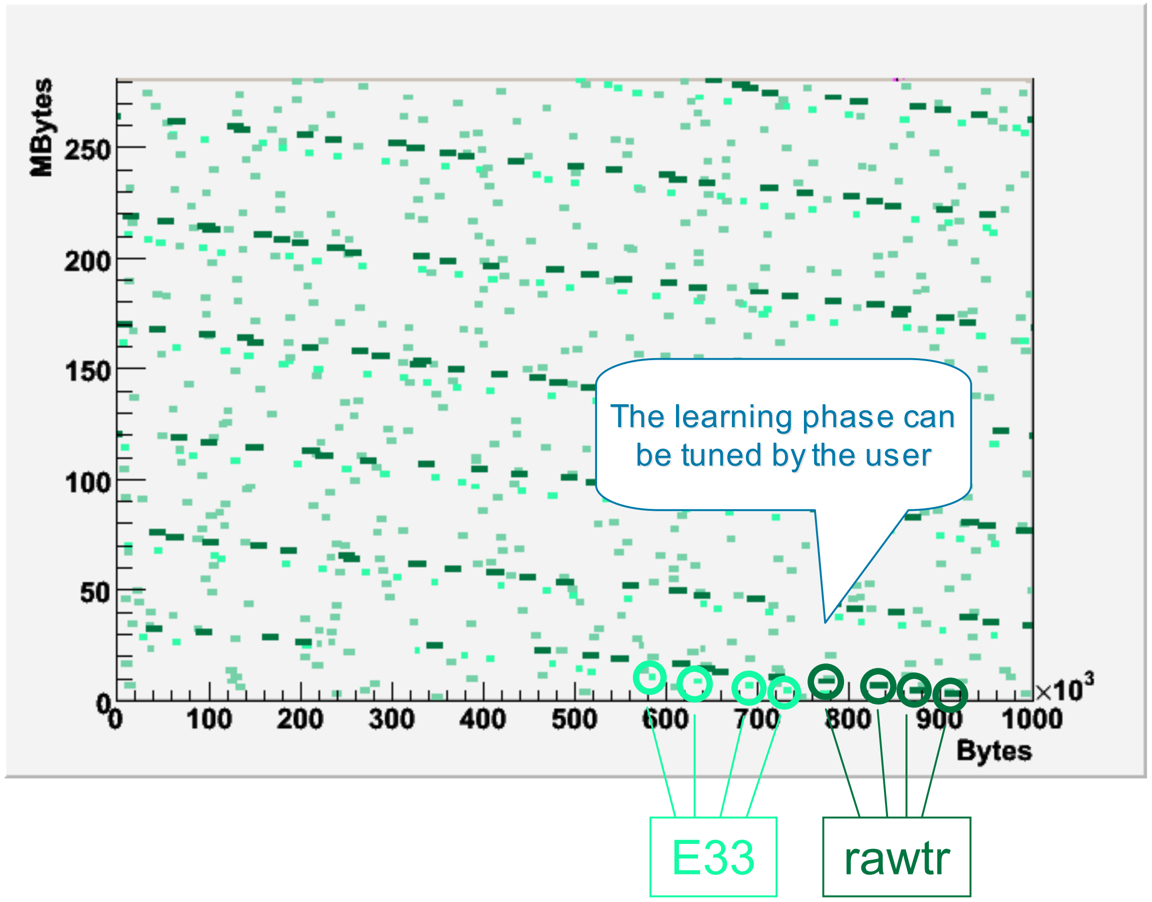

Tree Data Structure
FARM Collection of Trees
Tree
fScanField
fMaxEventLoop
fMaxVirtualSize
fEntries
fDimension
fSelectedRows
fBranches = TObjArray of TBranch
Branch 0
Branch 1
Branch 2
Branch 3
fLeaves = TObjArray of TLeaf
Leaf 0
Leaf 1
Leaf 2
fBasketSize
fEventOffsetLen
fMaxBaskets
fEntries
fAddress of Leaf0
fName: Branchname
fTitle: leaflist
fLen: number of fixed elements
fLenType: number of bytes of data type
fOffset: relative to Leaf0-fAddress
fNbytesIO: number of bytes used for I/O
fIsPointer: True if pointer
fIsRange: True if leaf has a range
fIsUnsigned: True if unsigned
*fLeafCount: points to Leaf counter
fName – Leaf name
fTitle – Leaf type (see Type codes)
fType codes
C : a character string
B : an 8 bit signed integer
b : an 8 bit unsigned integer
S : a 16 bit signed short integer
s : a 16 bit unsigned short integer
I : a 32 bit signed integer
i : a 32 bit unsigned integer
F : a 32 bit floating point
D : a 64 bit floating point
TXXXX : a class name TXXXX
fBasketEvent
First event of each basket Array of fMaxBaskets Integers
fBaskets = TObjArray of TBasket
Basket 0
Basket 1
Basket 2
fNbytes: Size of compressed Basket
fObjLen: Size of uncompressed Basket
fDatime: Date/Time when written to store
fKeylen: Number of bytes for the key
fCycle : Cycle number
fSeekKey: Pointer to Basket on file
fSeekPdir: Pointer to directory on file
fClassName: 'TBasket'
fName: Branch name
fTitle: Tree name
fNevBuf: Number of events in Basket
fLast: pointer to last used byte in Basket
fEventOffset
Offset of events in fBuffer Array of fEventOffsetLen Integers (if variable length structure)
fBuffer
Basket buffer Array of fBasketSize chars
fZipBuffer
Basket compressed buffer (if compression)
Baskets Stores

TTreeCache Algorithm ❶

- The ***key point*** is to predict data transfers.

```
Tree.Draw("rawtr", "E33>5");
```

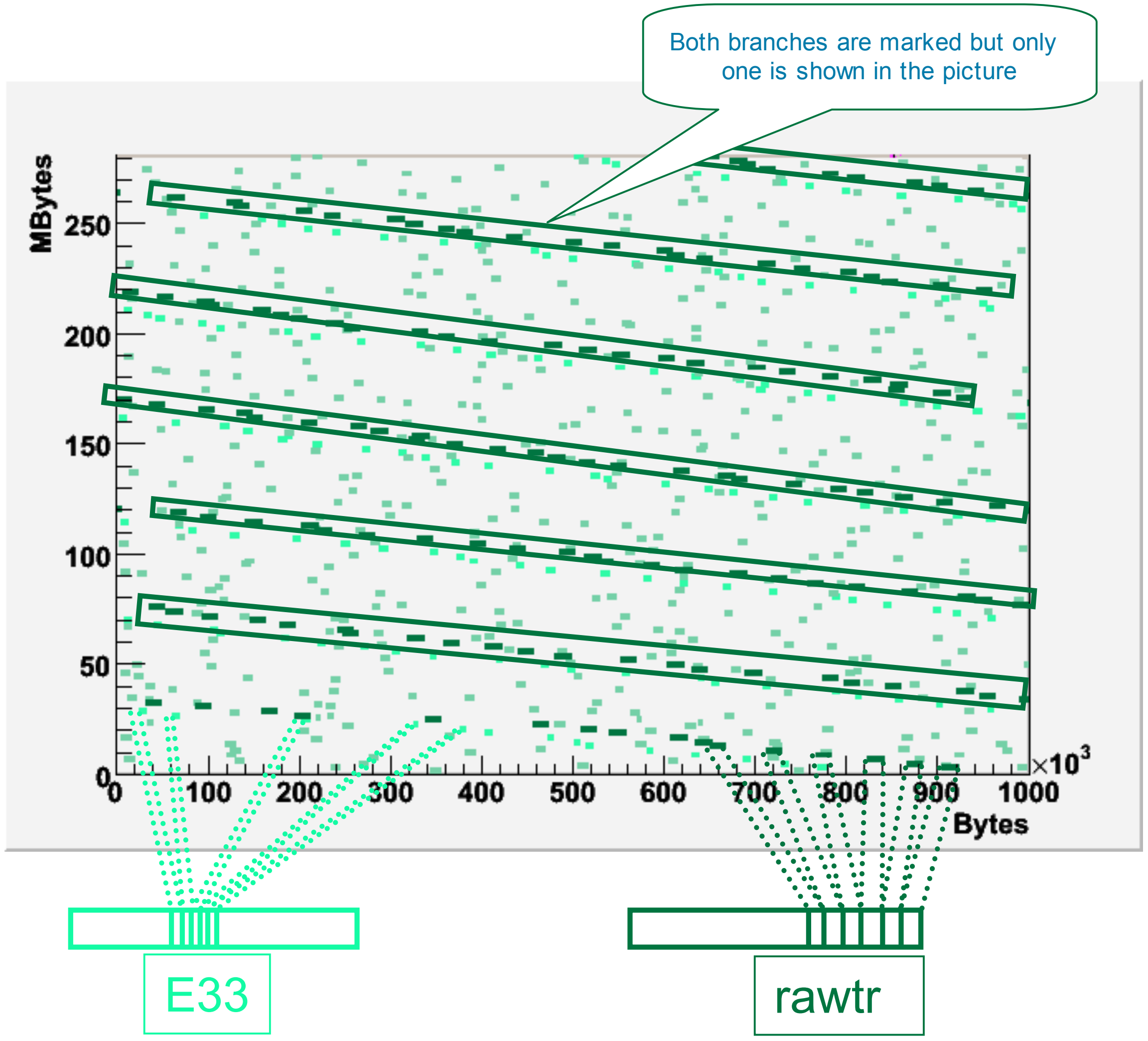
- The system (TTreeCache) enters a learning phase.
  - Every time a buffer is read, its branch is marked.
- After a few entries the learning phase stops.
- Now we have a list of the branches that will be used during the analysis.



TTreeCache Algorithm ❷

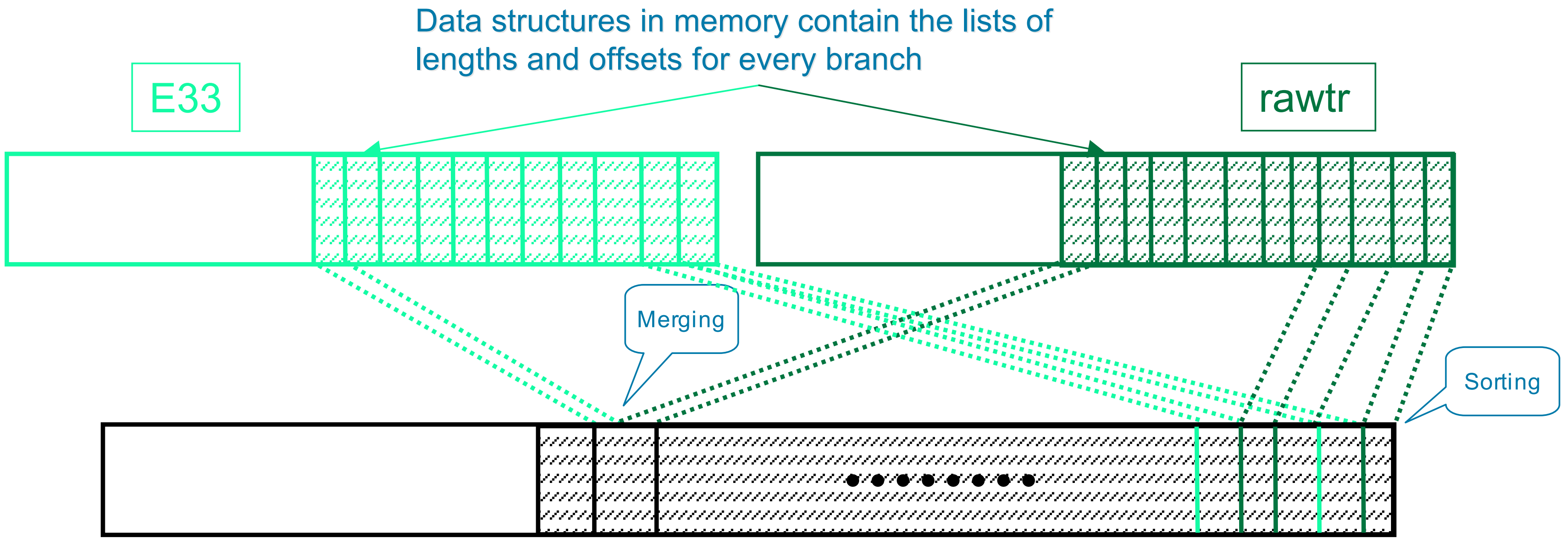
- With the list of branches, we calculate how many buffers fit our local cache.
- We create a list with the buffers to be transferred (for each branch).

*Both branches add up to 4800 buffers of 1.5KB on average.



TTreeCache Algorithm ❸

- Lists of branch buffers are **sorted** and **merged** to create a final list of request

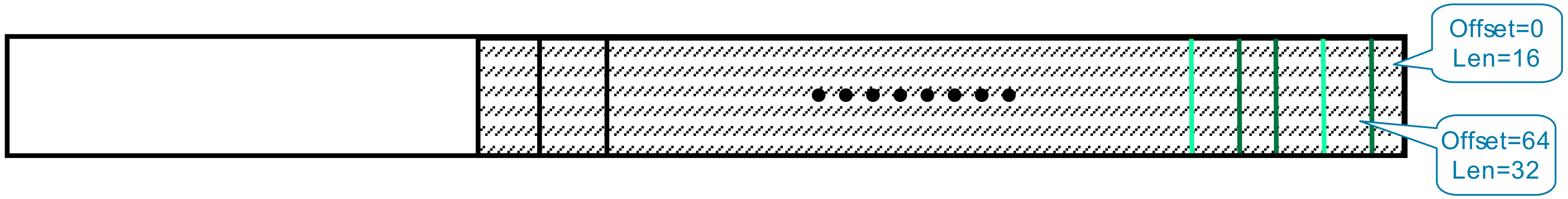

Data structures in memory contain the lists of lengths and offsets for every branch
E33
rawtr
Merging
Sorting

Sorting is not very important for network latency but can be a big factor for disk access.

Servers Require Protocol Extensions

Now we have a list of all the buffers needed for this transfer (only as a set of lengths and offsets):

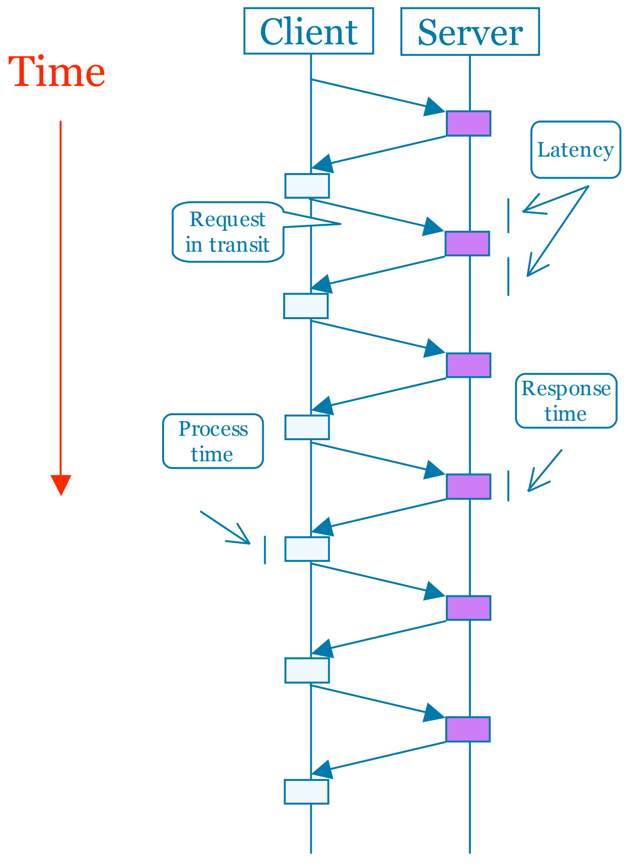
- As mentioned before, here we have 2 branches composed of 4800 buffers.
- With a buffer of 1.5KB on average we would need to transfer 7MB.
- If we have a cache of 10MB then we would need only one transfer.



- But this won't be of much use if we can't pass the full list to the server in just one transaction.
- For that, a new operation is needed (the protocol has to be extended) and since it resembles the standard "readv()" in unix systems we usually call it like that: ***vectored read***. Although a more appropriate could be ***scattered read***.

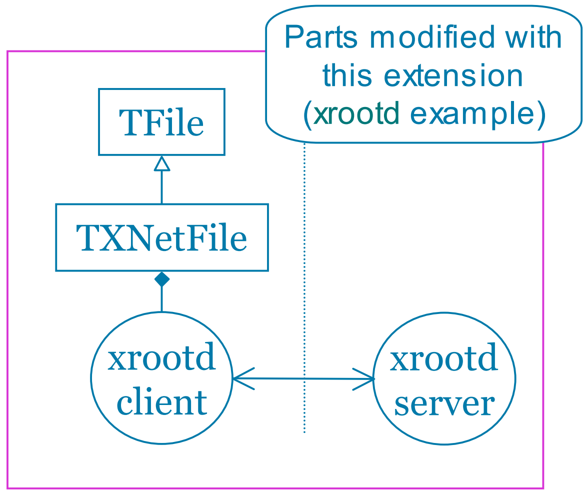
- This requires changes in the server side in addition to those in ROOT (client side) and the client must always check weather those changes are implemented, if not, it just uses the old method.
- We have introduced the changes in rootd, xrootd and http. The dCache team introduced it in a beta release for their server and the dCache ROOT client.

Solution

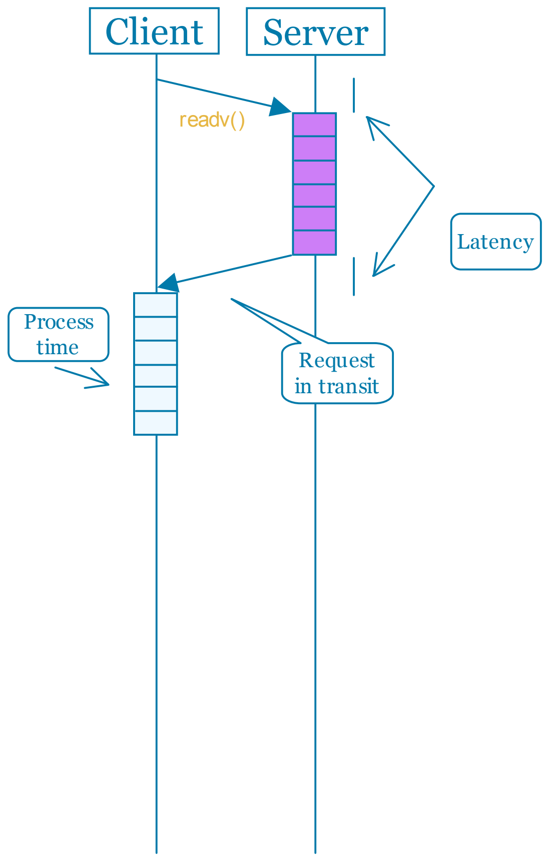


Total time = n (CPT + RT + L)

The equation depends on both variables



Perform big requests instead of many small reads



n = number of requests
CPT = process time (client)
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L = latency (round trip)

Total time = n (CPT + RT) + L

The equation does not depend on the latency anymore !!!

Real Measurements

- The file is on a CERN machine connected to the CERN LAN at 100MB/s.
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- **E** is in Amsterdam; LAN 100 Mbits/s, WAN of 10 Gbits/s and a latency of 22ms (AMD64).
- **F** is connected via ADSL of 8Mbits/s and a latency of 70 ms (Mac duo 2Ghz).
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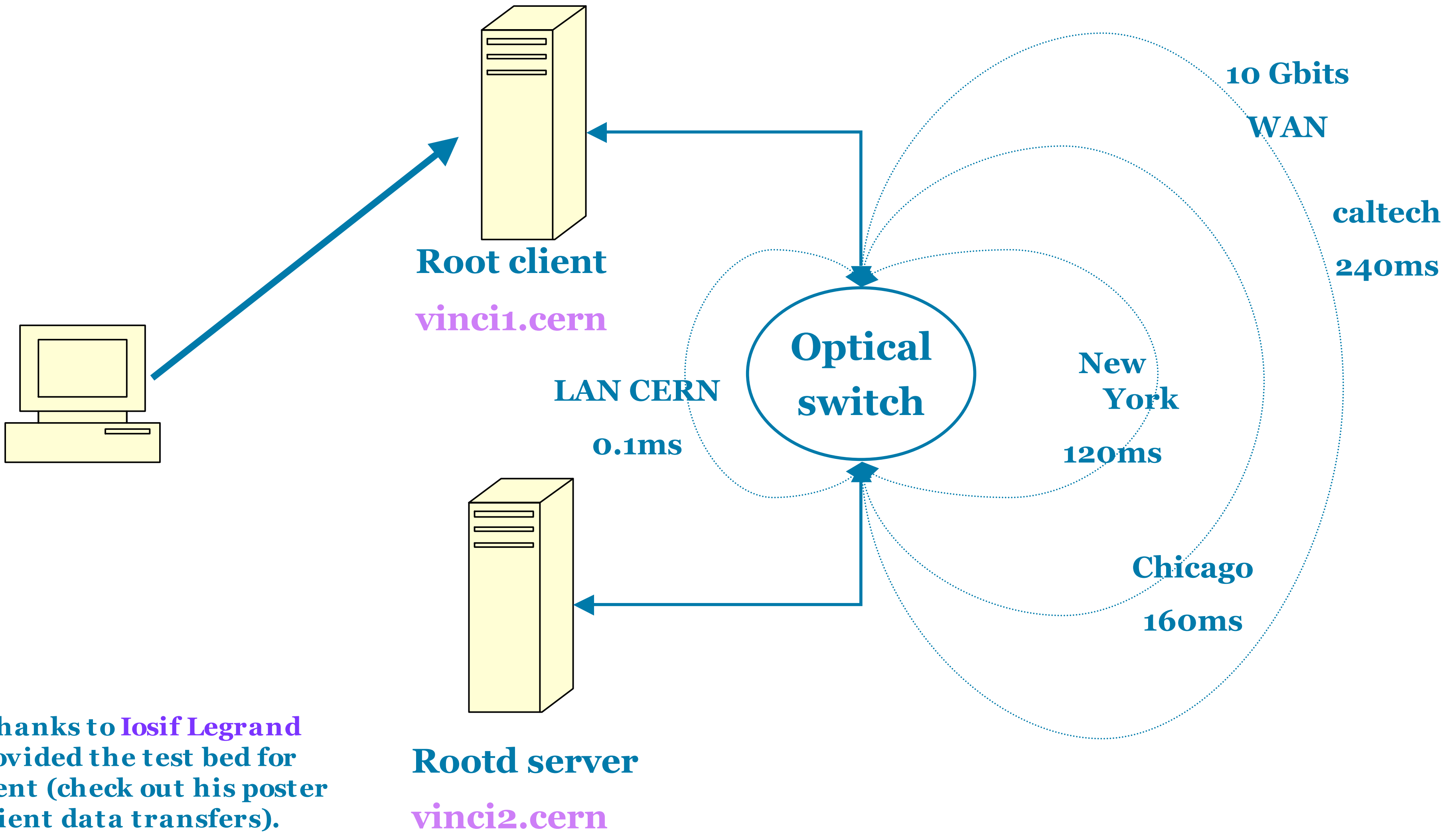
One query to
a 280 MB Tree
I/O = 6.6 MB

Interesting Case: Client G



Many thanks to Iosif Legrand who provided the test bed for this client (check out his poster on efficient data transfers).

Client G: Considerations

- The test used the 10 GBits/s line CERN->Caltech->CERN with TCP/IP Jumbo frames (9KB) and a TCP/IP window size of 10 Mbytes.
- The TTreeCache size was set to 10 Mbytes. So in principle only one buffer/message was required to transport the 6.6 Mbytes used by the query.
- But even with these parameters (10Gb/s, jumbo frames, etc), we need 10 roundtrips to open the congestion window completely. With such a big latency, this means 2.4 seconds spent in the "slow start" (next slide).
- To open the file, 7 messages are exchanged. This adds 1.6 seconds at the very beginning of the connection.
- In addition, the TTreeCache learning phase had to exchange 4 messages to process the first few events, ie almost 1 second.
- As a result more time was spent in the first 10 events than in the remaining 283000 events !!
- Further work to do to optimize the learning phase. In this example, we could process the query in 5 seconds instead of 9.9.

Client G: Considerations

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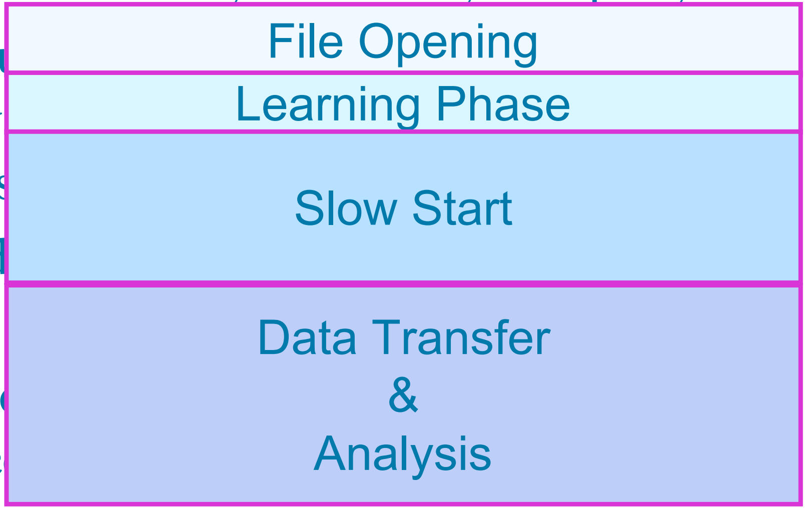


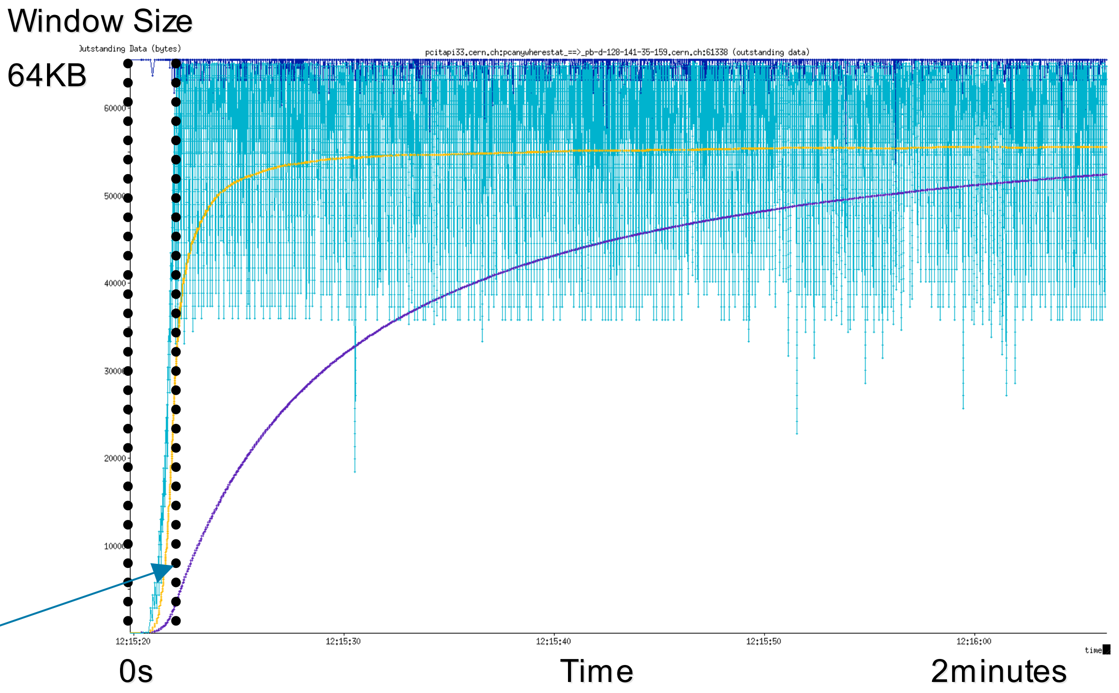
Limitation ❶: Slow Start

- **TCP Algorithms**:
- Slow Start — *cwnd < threshold:* cwnd = 2 * cwnd (exponential growth at the beginning)
  cwnd > threshold: -> Congestion Avoidance
- Congestion Avoidance — *cwnd > threshold:* cwnd = cwnd + 1 / cwnd (linear growth after that)
  After timeout: -> Slow Start (threshold=cwnd/2 , cwnd=1)

Max window size: 64KB
RTT : 100ms
Big transfer (200MB)

Slow start
(more than 1 s)

** 300KB/s at the end of the slow start.*



TCP Works well with:

- Small delays
- Big transfers

With big latency, bigger windows and larger transferences are needed.

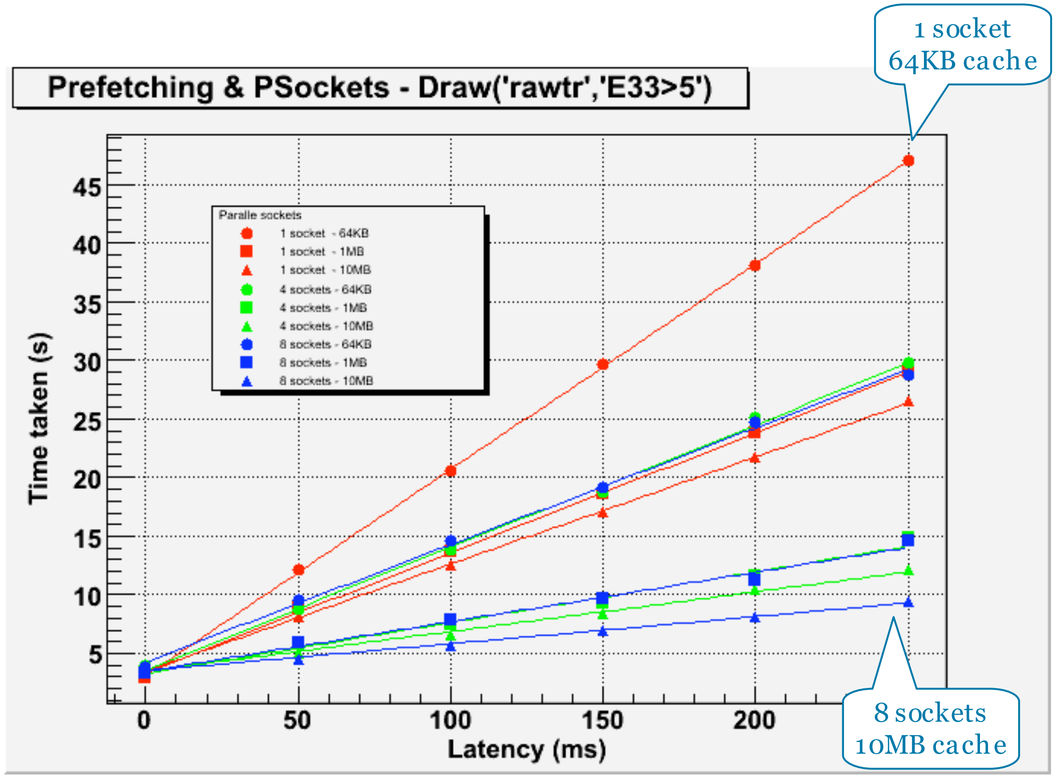
* Check out Fabrizio's talk for more details

Limitation ❷ : Transfer size

- To transfer all the data in a single request is not realistic. The best we can do is to transfer blocks big enough to improve the performance.
- Let's say our small blocks are usually 2.5KB big, if we have a buffer of 256KB we will be able to perform 100 requests in a single transfer.
- But even then we will be limited by the maximum size of the congestion window in TCP (in our examples it was 64KB, which is the default in many systems).

Maximizing it out: Parallel Sockets

- It is a good option for fat pipes (long delay/bandwidth).
- The results are similar to those obtained by increasing the TCP congestion window.
- Performance increases with the size of the cache but a big cache may not be worthwhile for small queries.
- Available in different transfer servers like rootd and xrootd.



rootd server

Current and Future Work

- With this new cache, we were able to try another improvement: **Parallel Unzipping**. We can now use a second core to unzip the data in the cache and boost the overall performance.
- We are in close collaboration with Fabrizio Furano (xrootd) to test the new asynchronous readings.
  - A modified TTreeCache is used and the readv() is replaced by a bunch of async requests.
  - The results are encouraging* and we would like to improve it further with an async readv() request. This would reduce the overhead of normal async reads and allow us to parallelize the work.
- Still some work to do to fine tune the learning phase and file opening (reduce the opening to 2 requests).
- Understand how new technologies like BIC-TCP can improve the slow start.

* Check out Fabrizio's talk for more details

Conclusions

- Data analysis can be performed efficiently from remote locations (even with limited bandwidth like an ADSL connection).
- The extensions have been introduced in:
  - rootd, http, xrootd(thanks to Fabrizio* and Andy), dCache (from version 1.7.0-39) and Daniel Engh from Vanderbilt showed interest for IBP (Internet Backbone Protocol).
- In addition to network latency, disk latency is also improved in certain conditions. Specially if this kind of read is done atomically to avoid context switches between processes.
- TCP (and all the its variants seen so far) are optimized for "data transfer", making "data access" extremely inefficient. More work is needed in collaboration with networking groups to find an efficient way for data access.
- We have to catch up with bandwidth upgrades and change the block sizes according to that (more bandwidth, bigger block transfers and bigger TCP windows).

* Check out Fabrizio's talk for more details