Neue Datenbank-Technologien

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+ more than 5 years experience in text compression
+ more than 7 years experience in tree compression
+ more than 10 years experience in XML processing

+ worked with more than 30 companies

New Challenges for Data Management

Big Data

Streaming data

Mobile data

Versions

Main memory database management

New data formats (text, documents, multimedia, graphs, ...)

Big Data / Streaming Data Examples

Data from sensors, RFID readers, cameras, microphones, ...

Financial transactions

Scientific data, satelite data, wheather data

Telecommunication data

Webserver-Logs

Smart metering data

Big Data Challenges

Storage & transport (compression, (lossy) aggregation, ...)

Search (Keyword search, index creation, ...)

Quality (correctness, data cleaning, modification, ...)

Presentation (transformation, aggregation, visualisation)

Focus of today‘s talk

Data formats: text & tree structured data

Data compression, i.e., text compression & tree compression

Search (Keyword search, query processing,...)

Modification

Data Transformation

Research perspective

Why text compression? Why block-sorting?

Energy & data transfer costs:

→ data compression

Search in Big Data:
search engines need fast location of keyword in documents

→ tries, suffix arrays, Burrows Wheeler Transformation (BWT) (e.g. in bzip2)

Text compression

Large texts shall be compressed –
many different ideas:

→ learning and reusing patterns	→ e.g., LZ family
+ using grammars	→ e.g. sequitur
→ using enthropy coding	→ e.g. Huffman encoding
→ encoding character repititions	→ e.g. Run Length Encoding (RLE)

Some techniques, e.g. RLE, are only good, if there are many repititions:
→ start with preparation step finding a permutation that has more repititions
e.g. BWT

→ idea: Burrows Wheeler Transformation (BWT) is based on locality
e.g. (in English text) '…_ugh…' it is very likely that _ is 'o'
when sorting all letter of a text (e.g. 'o') according to their suffix (e.g. ,'ugh…') , the 'o' of many sequences '…ough…' are sorted together
➔ Run Length Encoding gives better results

BWT – how to construct it from the Input ?

Input = $ a b c $ c b a $ b a c

compute all rotations:

$ a b c $ c b a $ b a c
a b c $ c b a $ b a c $
b c $ c b a $ b a c $ a
c $ c b a $ b a c $ a b
$ c b a $ b a c $ a b c
c b a $ b a c $ a b c $
b a $ b a c $ a b c $ c
a $ b a c $ a b c $ c b
$ b a c $ a b c $ c b a
b a c $ a b c $ c b a $
a c $ a b c $ c b a $ b
c $ a b c $ c b a $ b a

F (first)

L (last) =BWT

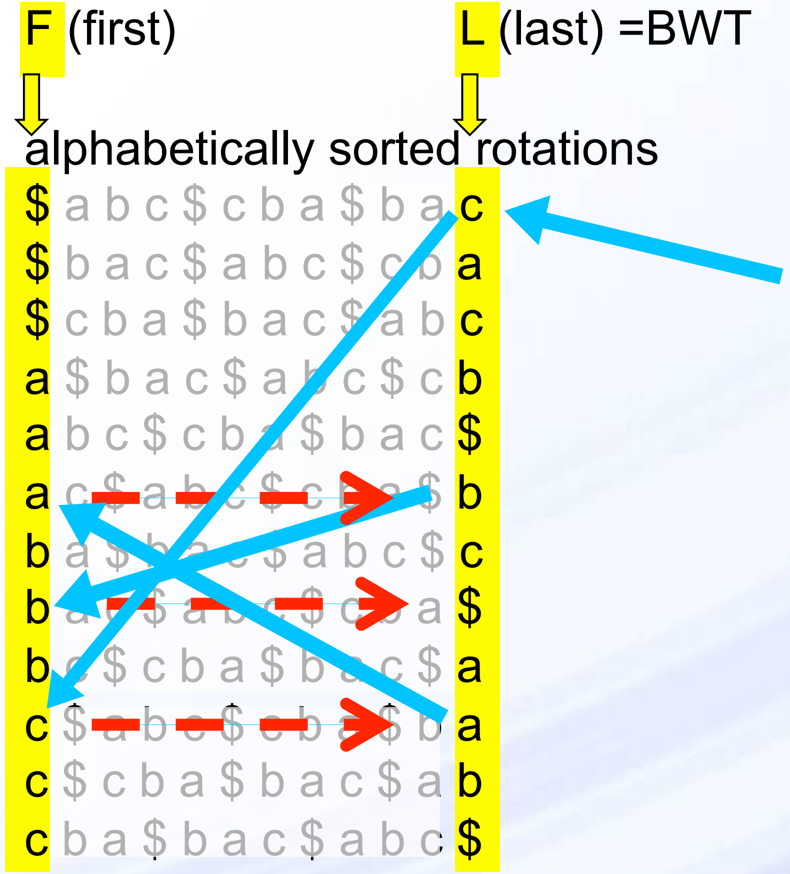
sort rotations alphabetically :

$ a b c $ c b a $ b a c
$ b a c $ a b c $ c b a
$ c b a $ b a c $ a b c
a $ b a c $ a b c $ c b
a b c $ c b a $ b a c $
a c $ a b c $ c b a $ b
b a $ b a c $ a b c $ c
b a c $ a b c $ c b a $
b c $ c b a $ b a c $ a
c $ a b c $ c b a $ b a
c $ c b a $ b a c $ a b
c b a $ b a c $ a b c $

E (end of Input)

store only this

BWT-Decompression using Rank on L & Select on F



F (first) **L** (last) =BWT

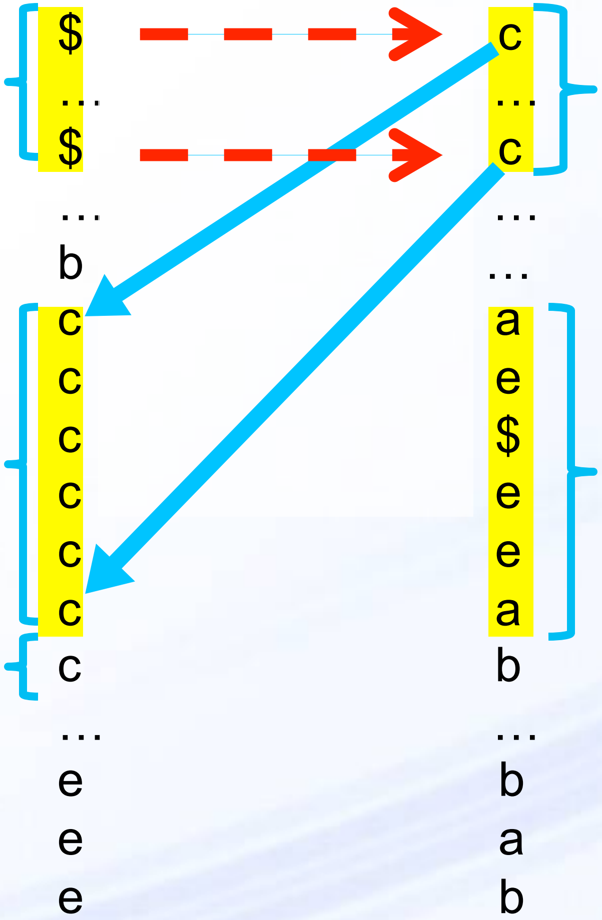
alphabetically sorted rotations

```
$ a b c $ c b a $ b a c
$ b a c $ a b c $ c b a
$ c b a $ b a c $ a b c
a $ b a c $ a b c $ c b
a b c $ c b a $ b a c $
a c $ a b c $ c b a $ b
b a $ b a c $ a b c $ c
b a c $ a b c $ c b a $
b c $ c b a $ b a c $ a
c $ a b c $ c b a $ b a
c $ c b a $ b a c $ a b
c b a $ b a c $ a b c $
```

start decompression at E(end)

The arrows ↙ illustrate the L→F function

BWT – backwards interval search for „bec$“



$ = word delimiters

6 c characters before a word delimiter ($) = last characters of the words in Input

$	c
…	…
$	c
…	…
b	…
c	a
c	e
c	$
c	e
c	e
c	a
c	b
…	…
e	b
e	a
e	b

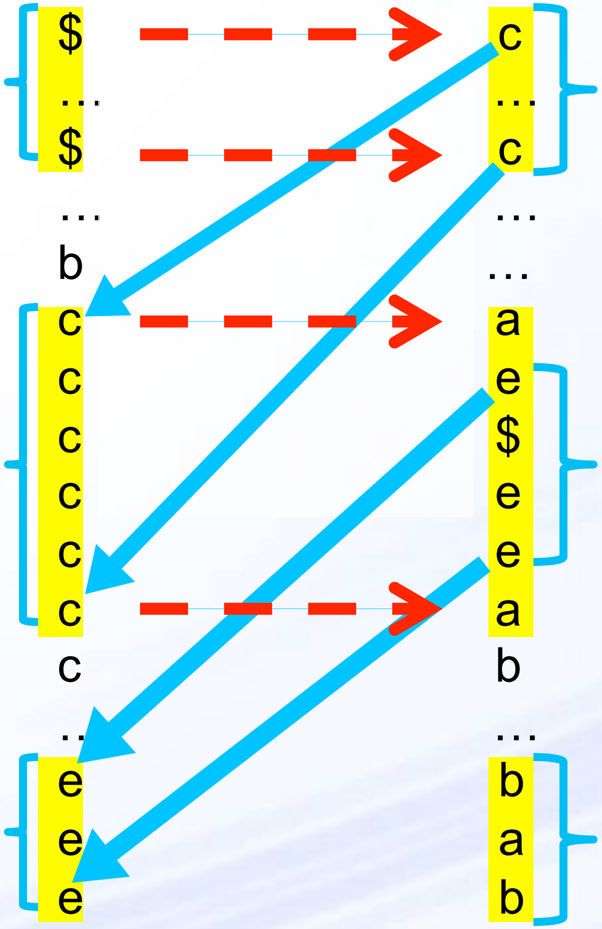
6 c characters before a word delimiter ($) occur next to each other

2nd last characters of words ending with “c$“

7th c character not followed by $

The arrows ↙ illustrate the L→F function

BWT – backwards interval search for „bec$“



$ = word delimiters

6 c characters before a word delimiter ($) = last characters of the words in Input

6 c characters before a word delimiter ($) occur next to each other

e-interval of 2nd last characters of words ending with “c$“

3 e characters before “c$“

b-interval of 3rd last characters of words ending with “ec$“

BWT pros and cons

BWT

+ good compression (when used with MTF&Huffman in bzip2)

+ excellent for keyword search (when used like suffix arrays)

- creation (sorting) takes too long (limit approx. 50 TB)

- modification impossible

→ improvement: IRT

IRT - a Queryable and Updateable Text Compression

IRT – small modification of BWT

\+ texts compressed with IRT + RLE + Wavelet Tree are
queryable and
updateable (fast insert and delete on compressed texts)
without decompression

➔ compressed trees (e.g. XML documents, JSON trees)
including text and attribute values are
queryable and
updateable (fast insert and delete of compressed subtrees)
without decompression

Difference IRT ←→ BWT: deletion and BWT do not commute

Even if the position of the first/last letter of the word to be deleted is known (e.g. by an index), deletion of a word and transformation by BWT do not commute

Let S be a text and W an arbitrary word of S, then

$$\begin{tikzcd}
\mathbf{S} \arrow[rr, "\text{transformation}"] \arrow[dd, "\text{deletion of W from S}"'] & & \mathbf{BWT(S)} \arrow[d, "\text{deletion of W from BWT(S)}"] \\
& & \mathbf{BWT(S) - BWT(W)} \\
\mathbf{S\text{-}W} \arrow[rr, "\text{transformation}"] & & \mathbf{BWT(S - W)}
\end{tikzcd}$$

in general different

BWT(S) – BWT(W) ≠ BWT(S-W)

i.e. in contrast to IRT, a word cannot be deleted from BWT(S) without retransformation of BWT(S) to S.

Difference IRT ←→ BWT: but deletion and IRT commute

However, deletion of a word and transformation by IRT commute

Let S be a text and W an arbitrary word of S, then

$$\begin{tikzcd}[column sep=huge, row sep=huge] \mathbf{S} \arrow[r, "\text{transformation}"] \arrow[d, "\substack{\text{deletion of W}\\ \text{from S}}"'] & \mathbf{IRT(S)} \arrow[d, "\substack{\text{deletion of W}\\ \text{from IRT(S)}}"] \\ \mathbf{S\text{-}W} \arrow[r, "\text{transformation}"] & \mathbf{IRT(S - W)} \end{tikzcd}$$

whatever we do first (transform string or delete W), we always get the same result

IRT(S) – IRT(W) = IRT(S-W)

i.e. in contrast to BWT(S), a word in IRT(S) can be deleted from IRT(S) without retransformation of IRT(S) to S.

Difference IRT ←→ BWT: insertion and BWT do not commute

Even if the position of the first/last letter of the word to be inserted is known (e.g. by an index), insertion of a word and transformation by BWT do not commute

Let S be a text and W an arbitrary word of S, then

$$\begin{tikzcd}
\mathbf{S} \arrow[r, "\text{transformation}"] \arrow[dd, "\text{insertion of W as Nth word of S into S}"'] & \mathbf{BWT(S)} \arrow[d, "\text{insertion of W as Nth word of S into BWT(S)}"] \\
 & \mathbf{BWT(S) + BWT(W)} \\
\mathbf{S+W} \arrow[r, "\text{transformation}"] & \mathbf{BWT(S + W)}
\end{tikzcd}$$

in general different

BWT(S) + BWT(W) $\neq$ BWT(S+W)

i.e. in contrast to IRT, a word cannot be inserted into BWT(S) without retransformation of BWT(S) to S.

Difference IRT ←→ BWT : but insertion and IRT commute

Insertion of a word and transformation by BWT commute

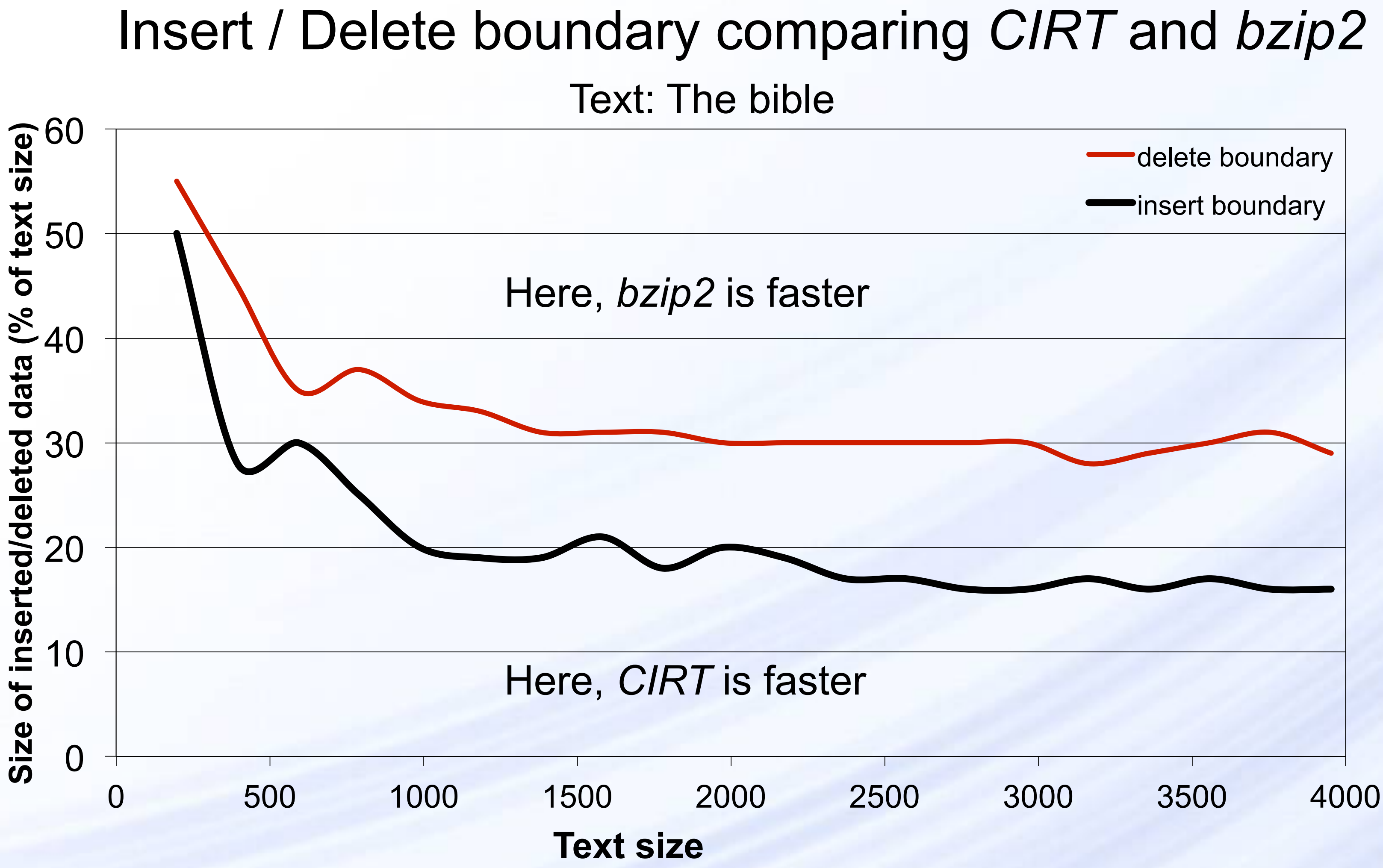
Let S be a text and W an arbitrary word of S, then

$$\begin{tikzcd}
\mathbf{S} \arrow[r, "\text{transformation}"] \arrow[d, "\text{insertion of W as Nth word of S into S}"'] & \mathbf{IRT(S)} \arrow[d, "\text{insertion of W as Nth word of S into IRT(S)}"] \\
\mathbf{S+W} \arrow[r, "\text{transformation}"] & \mathbf{IRT(S + W)}
\end{tikzcd}$$

whatever we do first
(transform string or insert W),
we always get the same result

IRT(S) + IRT(W) = IRT(S+W)
i.e. in contrast to BWT, a word can be inserted into
IRT(S) without retransformation of IRT(S) to S.

String Compression Results (2) : update time CIRT vs. bzip2

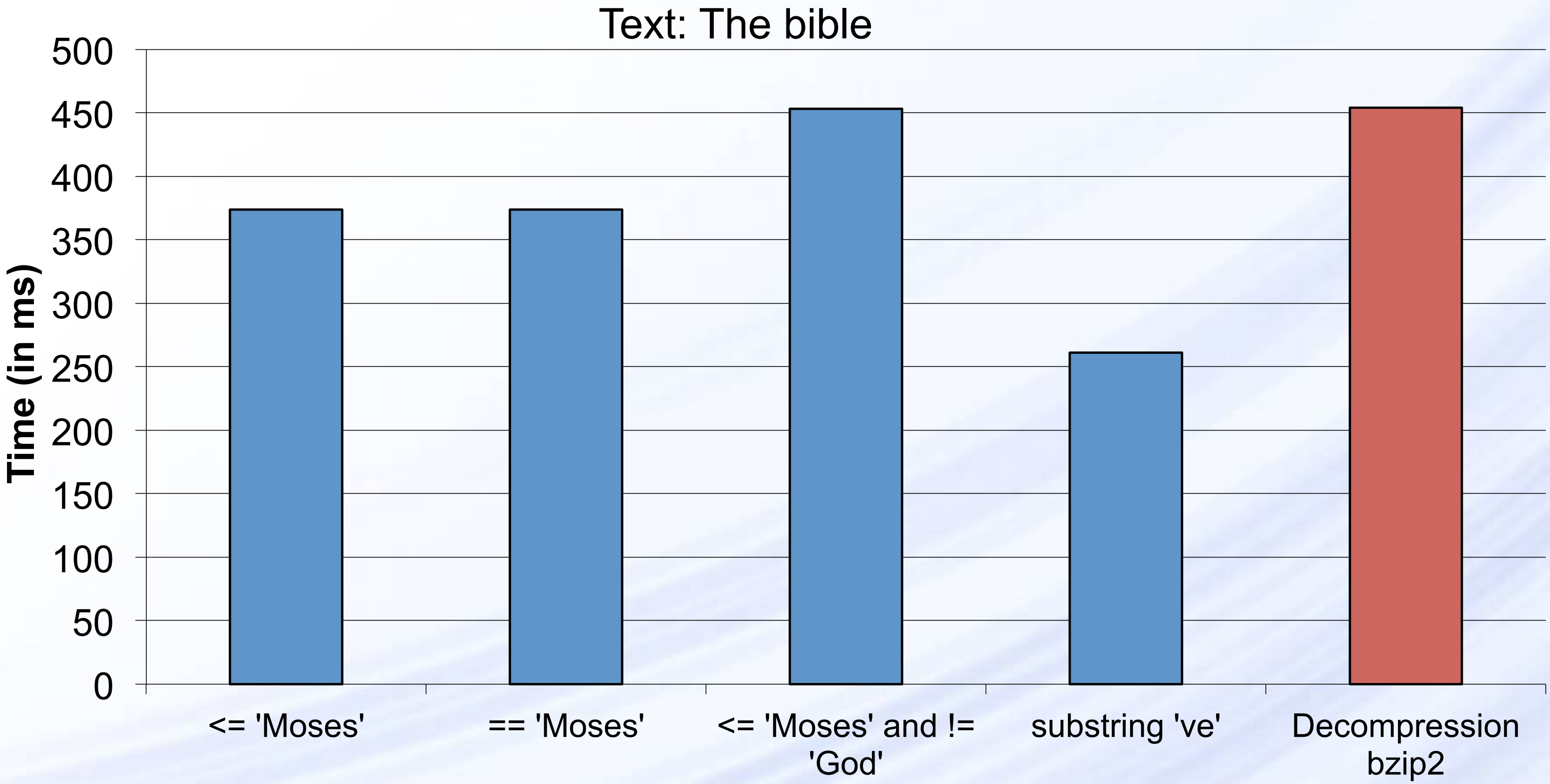


Here, *bzip2* is faster

Here, *CIRT* is faster

String Compression Results (1) : Query time on CIRT

Query time on compressed IRT often faster than decompressing bzip2-compressed text



Summary IRT, a Queryable and Updateable Text Compression

Technique: IRT – a transformation similar to BWT, but

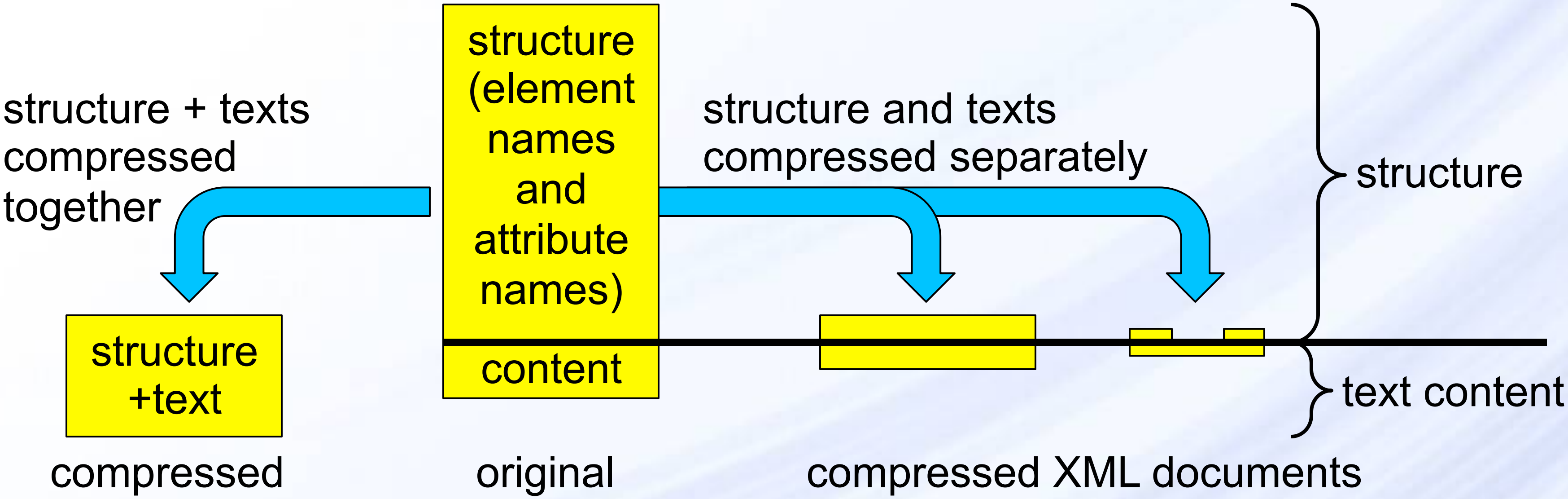
\+ texts compressed with IRT + RLE + Wavelet Tree are queryable and updateable (fast insert and delete on compressed texts) without decompression

\+ inserts of up to 18% are faster in CIRT than in bzip2
\+ deletions up to 30% are faster in CIRT than in bzip2

→ good for compressing text documents
→ good for compressing text columns of relational databases

Why separate text and structure compression?

- Query processing easier
- Compression factors for texts are weaker (factors 4-10) than for structure compression (factor 12-170)



structure + texts compressed together

structure (element names and attribute names)

content

structure and texts compressed separately

structure

text content

structure +text

compressed

original

compressed XML documents

- Usually more structure than text , e.g. 4:1

  → use optimal structure compression

Why tree compression for XML (or JSON or YAML) ?

Goal:
Reduce verbose structure of XML (overhead of e.g. factor 3-5) by XML compression (typically a factor 12-170)

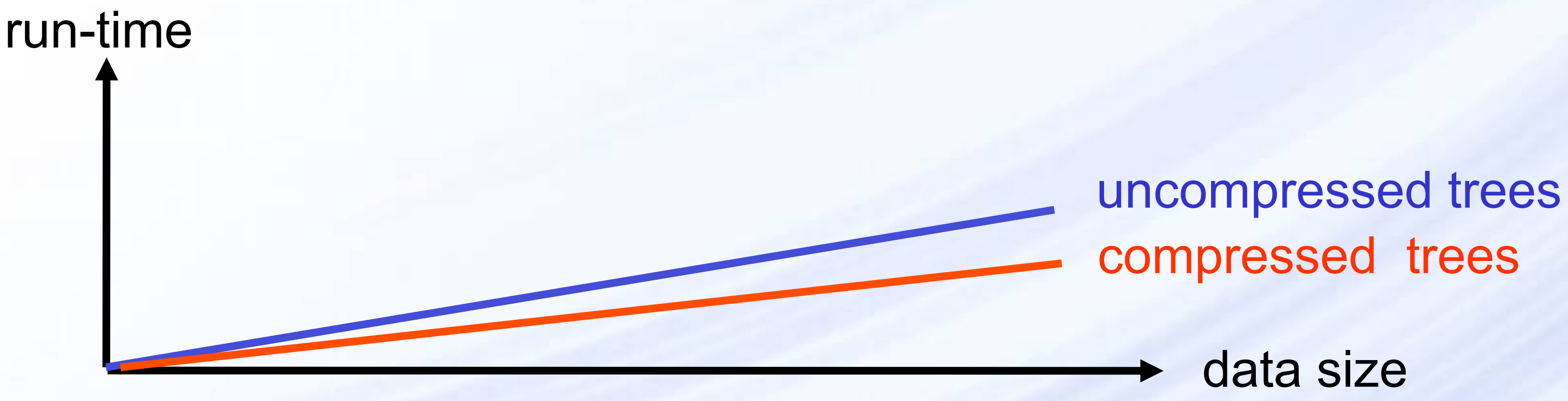
Nice to have properties and requirements to compressed XML:

- queryable → at least as fast as on uncompressed XML
- updateable
- cacheable
- streamable
- transformable by XQuery/XSLT
- directly producable from SQL/XML

} without decompression

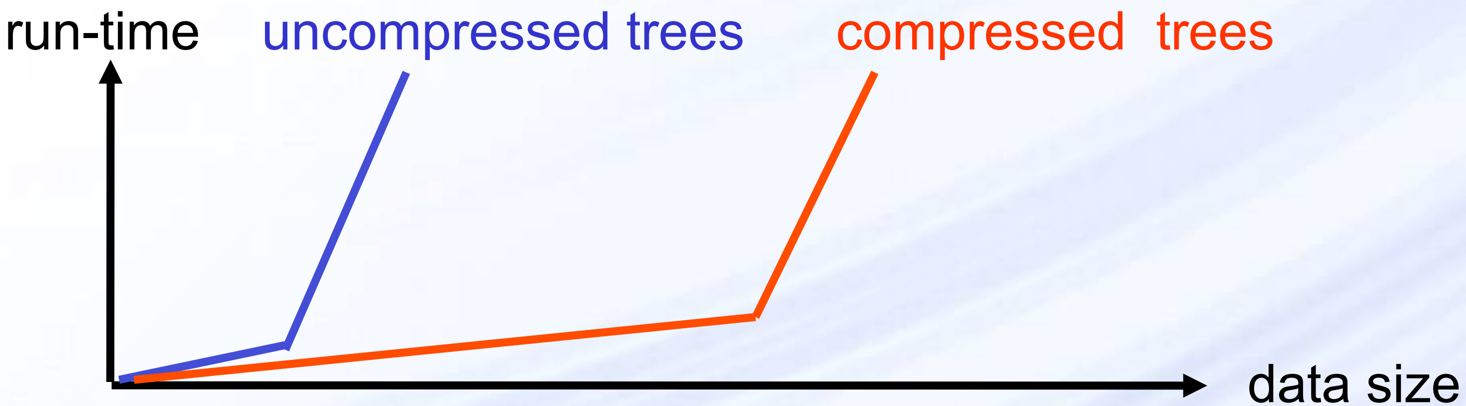
Why tree compression?

Different from text search,
Queries on compressed trees are faster than on uncompressed trees



Why tree compression?

Different from text compression,
Queries on compressed trees are faster than on uncompressed trees



Summary – Technologies for XML structure compression

compression

XML aware

Encoding based

- FI
- Succinct
- …

Schema based

- DTD-Sub
- XSDS
- …

Structure based

- DAG
- RePair
- …

…

- …

Text compression

- gzip
- bzip2
- …
- IRT

Succinct Encoding - Summary

**Technique: encoding based (roughly similar to FI, but …) ,
uses bit-stream, text compression, inverted element lists**

Compression strength:

- comparable to gzip, bzip2
- much stronger than FI, …

Query Evaluation Performance:

- faster than queries in JAXP
- similar to queries on SAX (in our framework)

Further features:

- streaming possible
- updates without decompression possible
- caching possible
- XQuery (XSLT) transformation without decompression

XSDS - Compression Strength

+ significant compression improvement if XML Schema exists

e.g. MS-Word	(60% of the size of Microsofts compressed format)
e.g. SEPA	(11% of original size)
e.g. OpenStreetMap	(10% of original size)
e.g. SOAP , OTA , …	

and wherever we have an XML standard for XML data

XSDS - Summary

Technique: remove tags given by (DTD or XML-) Schema

Compression strength:

- better than gzip, bzip2, FI, …

Query evaluation on XSDS compressed XML:

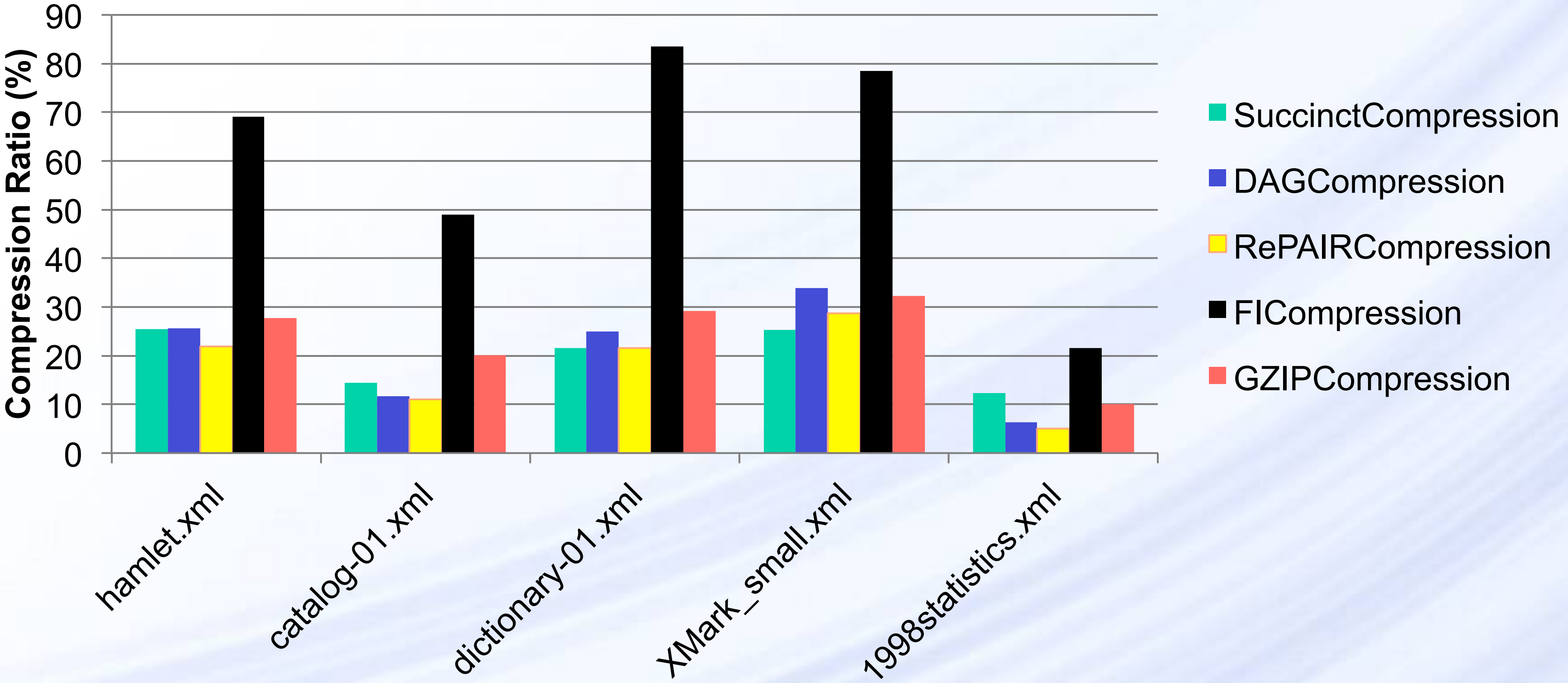
- 20 to 40 times faster than complete XML decompression
- 10 to 20 times faster than on uncompressed XML using our XML framework
- 3 to 7 times faster than JAXP

Further features: streamable, updateable, …

RePair – Compression Strength

Compression strength:

- better than Succint, DAG, gzip, bzip2, …



RePair Compression - Summary

Technique: sharing similar sub-trees (more general than DAG):

Compression strength:

- better than gzip, bzip2, FI, succinct encoding…

Query evaluation:

- usually faster than queries on uncompressed XML and faster than on succinct encoding

Nice to have properties:

- streaming possible
- (fast parallel) updates possible
- caching (one of two strategies) possible
- queryable archives of multiple versions (data deduplication)

A selection of further results

Storage and search on multiple versions

Processing and filtering huge data streams

Combining caching and compression

Querying transformed data through XQuery/XSLT views

Improvement and Generalization of SQL/XML query processing

Lessons learned about what to avoid

Overview of implemented modules

Grammar-based storage of multiple versions

V1: message from a customer

V1 → M F C

V(X) → M F X C

V1 → V(“ “)

V2: message from a **very important** customer

V2 → M F I C

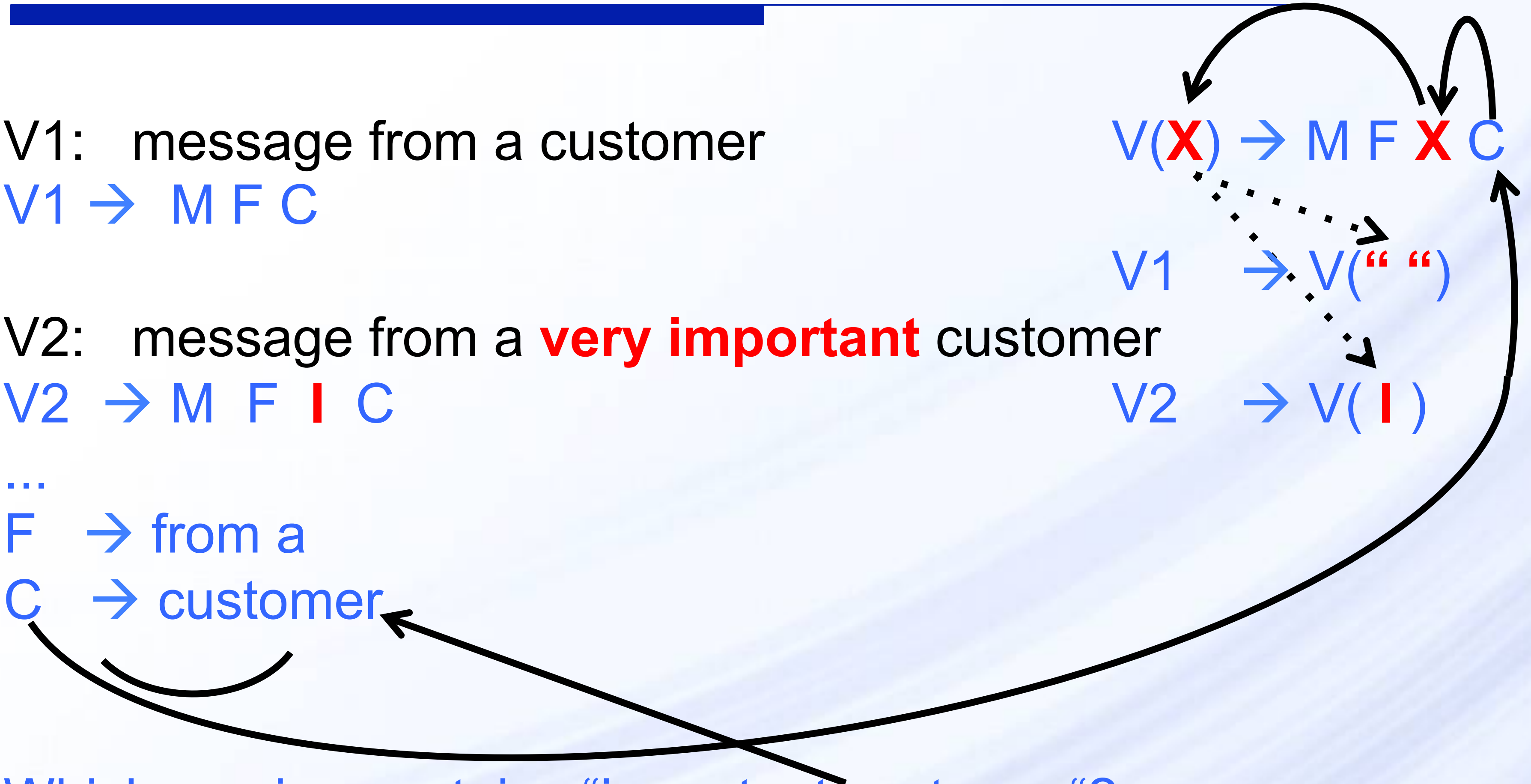
V2 → V(I)

...

F → from a

Grammar describes text patterns / data structures,
i.e. grammar rules for common text phrases / data structures
→ common text / common structures are encoded only once
→ saves memory, energy, ...
→ faster search on multiple versions posssible
works for text and for structured data

Search on multiple versions



V1: message from a customer

V1 → M F C

V2: message from a **very important** customer

V2 → M F **I** C

...

F → from a

C → customer

V(**X**) → M F **X** C

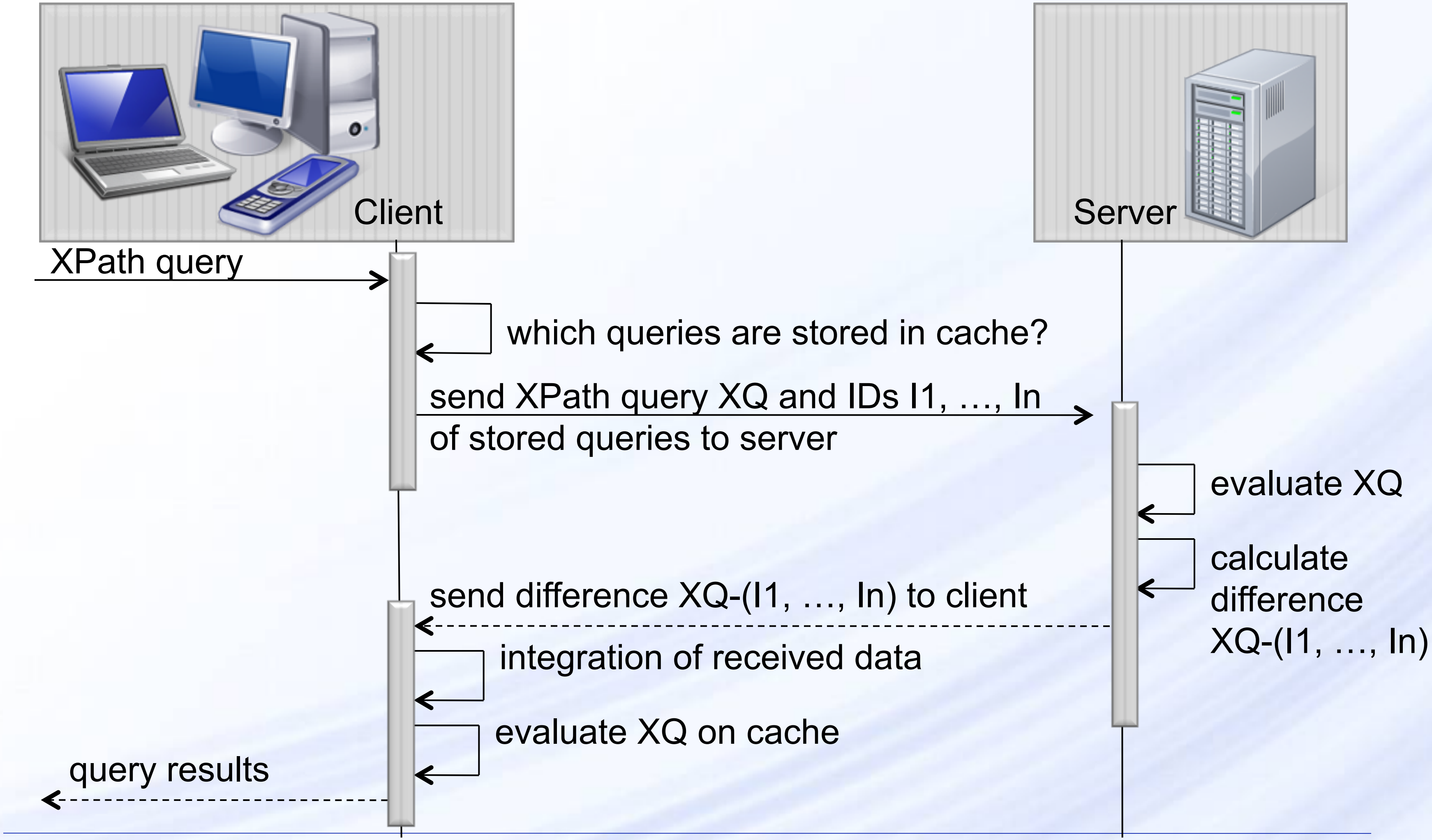
V1 → V(“ “)

V2 → V(**I**)

Which version contains “important customer“?

Search through all versions possible at the same time

Combining XML Compression and Caching – Strategy 1



Client

Server

XPath query

which queries are stored in cache?

send XPath query XQ and IDs I1, …, In of stored queries to server

evaluate XQ

calculate difference XQ-(I1, …, In)

send difference XQ-(I1, …, In) to client

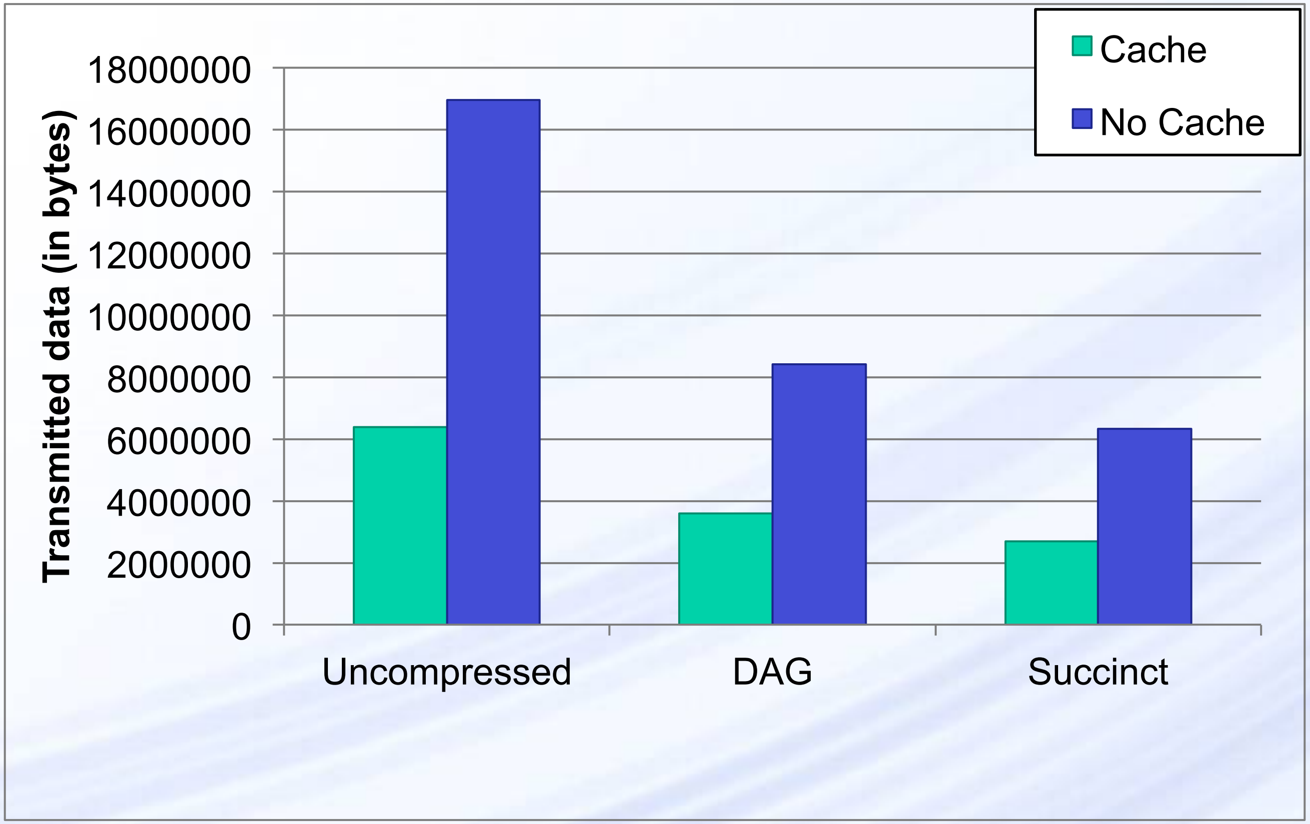
integration of received data

evaluate XQ on cache

query results

Evaluation – Transferred Data Volume

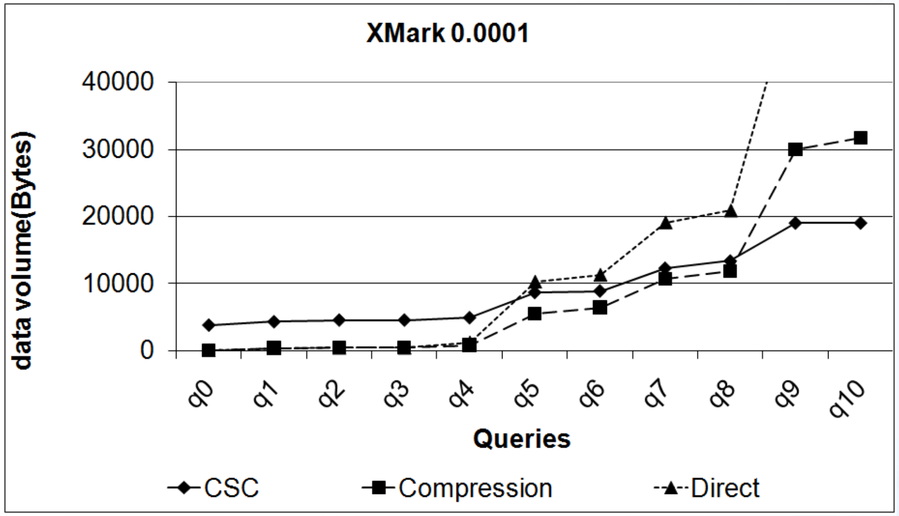
- XMark documents
- 22 queries based on XPath-A of XPathMark

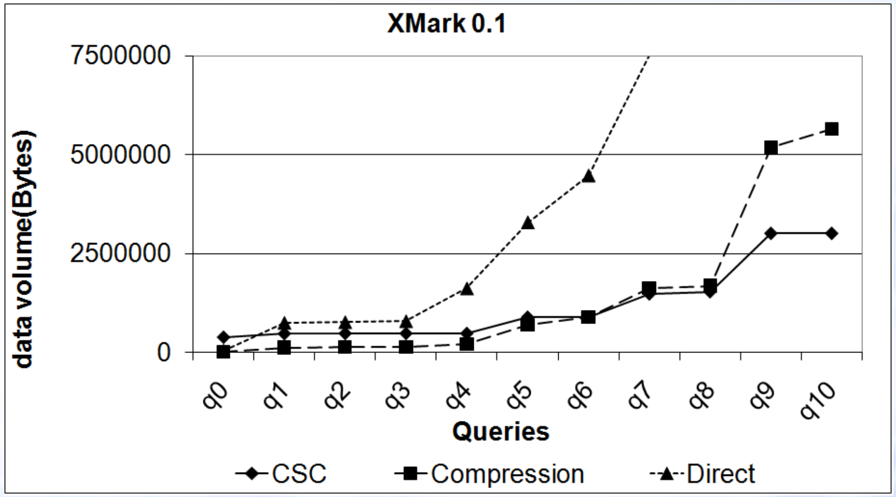


Caching Compressed XML – Strategy 1 - Summary

- Combination of compression and caching
  - avoids unnecessary decompression
  - less data transfer than with caching alone
  - less data transfer than with compression alone
- Generic approach
  - supports different compression techniques (e.g. DAG, Succinct)
  - supports different ID/Numbering schemes (e.g. OrdPath)

Caching – Strategy 2 – Performance evaluation





Dataset
XMark [Schmidt at al. 2002]
(sizes 34kB to 11MB)

XMark	XML	tree	compr. tree
.0001	34kB	8kB	3.4kB
.001	116kB	37kB	8kB
.01	1.1MB	374kB	48kB
.1	11MB	3.6MB	364kB

Transferred data volume

send/receive for 10 consecutive queries

Caching Compressed XML – Strategy 2 - Summary

Less transferred data than (compressed) query shipping through

→ only sending the **difference** in data values that are needed by Client for evaluating the given query.

→ the **difference** is determined by Server through running/simulating the given query

Data values are sent compressed,
and in the order as needed by evaluator.

➔ performance gain depends on the choice of (a) **query evaluator** and (b) **compressor**

Transformation of Compressed XML - Summary

Goal: fast transformation of compressed data

Techniques: compute paths to required data,
copy compressed data if possible

+ faster than decompression+transformation+compression

+ sometimes faster than transforming uncompressed XML

Compression techniques supported: Succinct, DAG, RePair

Generating XML from SQL/XML Views

SQL-Query

```
select
xmlelement( name "Kunde",
              xmlelement(name "Kundennr", K.Knr) ,
              xmlelement(name "Name", K.Name) ,
              xmlelement(name "Ort",
K.Wohnort)   )   from Kunde K   where …
```

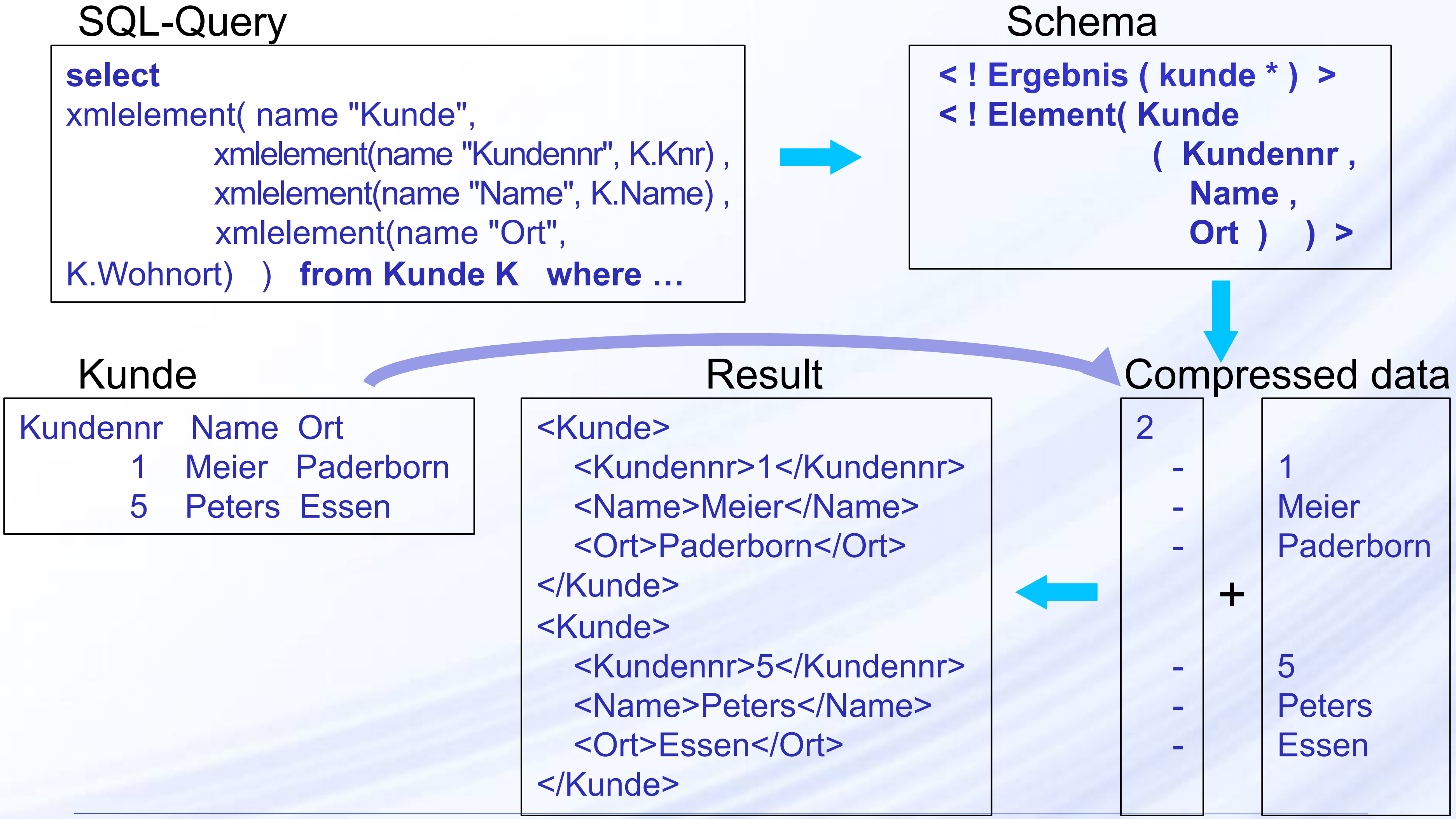
Kunde

Kundennr	Name	Ort
1	Meier	Paderborn
5	Peters	Essen

Result

```
<Kunde>
   <Kundennr>1</Kundennr>
   <Name>Meier</Name>
   <Ort>Paderborn</Ort>
</Kunde>
<Kunde>
   <Kundennr>5</Kundennr>
   <Name>Peters</Name>
   <Ort>Essen</Ort>
</Kunde>
```

Generating compressed XML from SQL/XML Views



SQL-Query

```
select
xmlelement( name "Kunde",
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             xmlelement(name "Ort",
K.Wohnort)   )   from Kunde K   where …
```

Schema

```
< ! Ergebnis ( kunde * )  >
< ! Element( Kunde
                    (  Kundennr ,
                       Name ,
                       Ort  )     )  >
```

Kunde

Kundennr	Name	Ort
1	Meier	Paderborn
5	Peters	Essen

Result

```
<Kunde>
    <Kundennr>1</Kundennr>
    <Name>Meier</Name>
    <Ort>Paderborn</Ort>
</Kunde>
<Kunde>
    <Kundennr>5</Kundennr>
    <Name>Peters</Name>
    <Ort>Essen</Ort>
</Kunde>
```

Compressed data

2		
-		1
-		Meier
-		Paderborn
	+	
-		5
-		Peters
-		Essen

Many more improvements … but complex algorithms

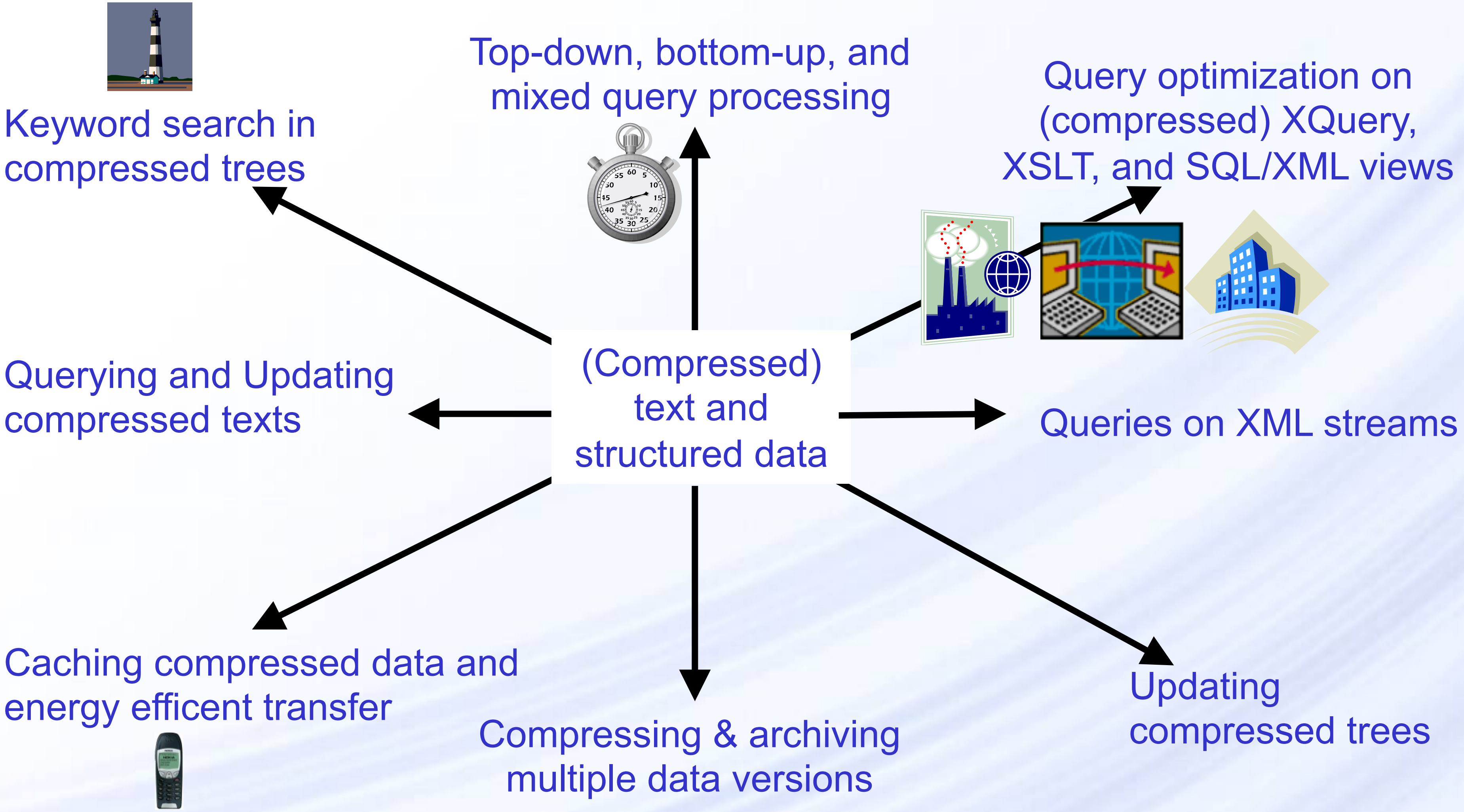
Technology transfer includes: Help to avoid complex approaches!

Examples:

We have implemented combined compression strategies (succinct+DAG compression, …, RePair+DTD-Subtraction, etc.)
→ small improvement in compression
in comparison to DAG/RePair alone,
but algorithms get more complex (too complex for industry)

We have used funtional dependecies to compress text data
→ little improvement in comparison to bzip2,
but algorithms get more complex (too complex for industry)

Topics Around (Compressed) Structured Data



(Compressed) text and structured data

Keyword search in compressed trees

Top-down, bottom-up, and mixed query processing

Query optimization on (compressed) XQuery, XSLT, and SQL/XML views

Querying and Updating compressed texts

Queries on XML streams

Caching compressed data and energy efficent transfer

Compressing & archiving multiple data versions

Updating compressed trees