GPU-Acceleration of In-Memory Data Analytics

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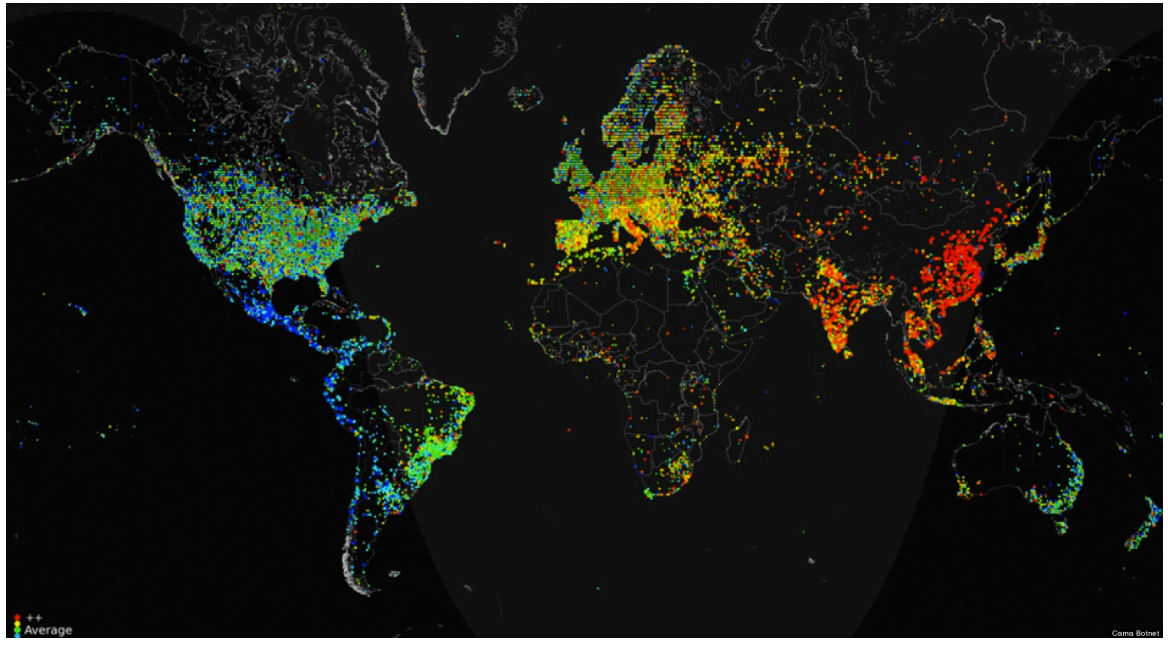
AWS Redshift

GPUs for Telcos

- Fast query-time
  - Quickly identify network problems
  - Respond fast to customers

No time to index data

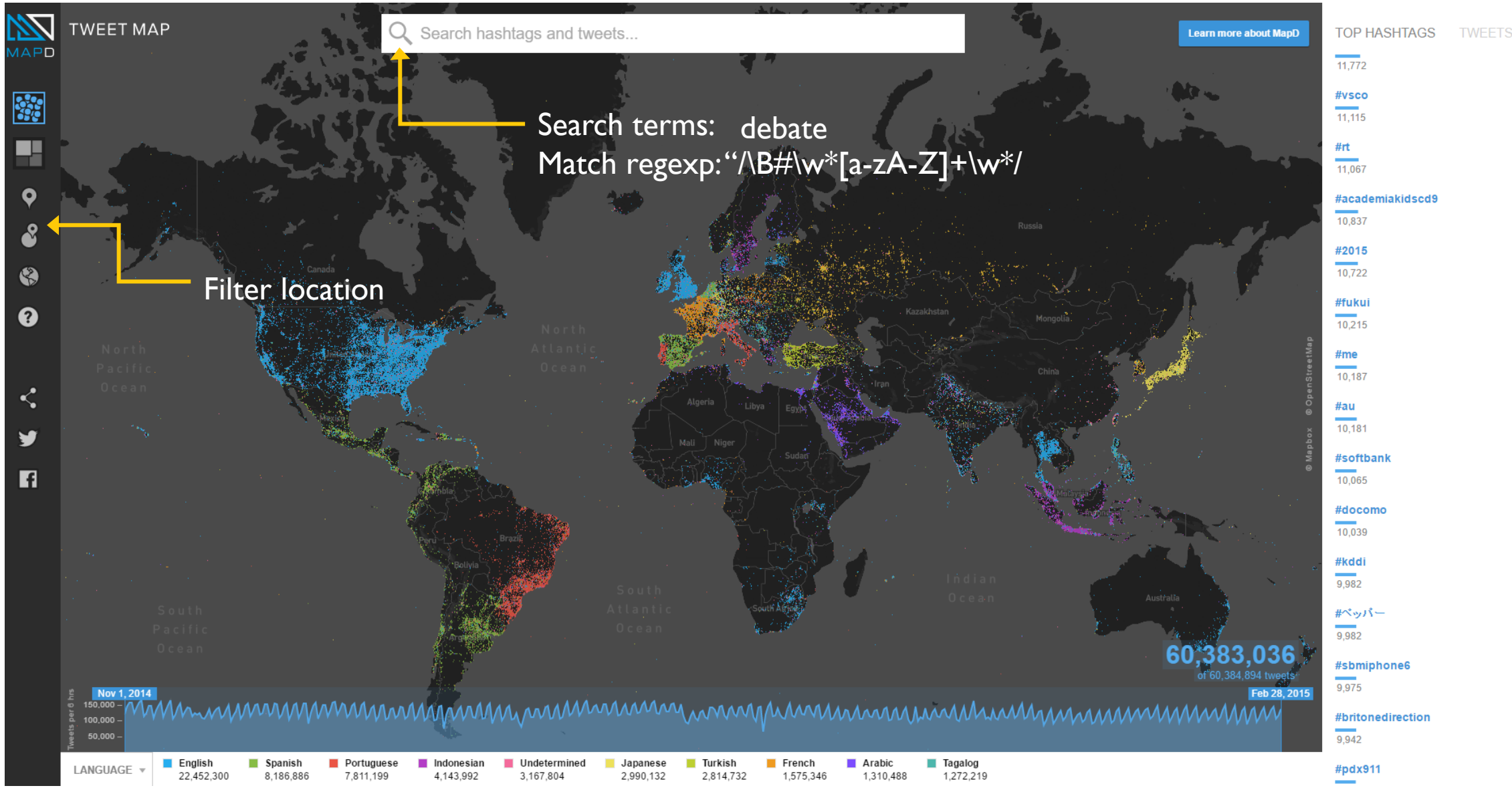
- Geospatial visualization
  - Take advantage of GPU visualization capabilities



SMS Hub traffic

*Picture taken from:
http://www.vizualytics.com/Solutions/Telecom/Telecom.html

GPUs for Social Media Analytics



Challenges for GPU Databases

- Special threading model → Increased programming complexity
  - Which algorithms more efficient for GPUs?
  - How much multiple code paths increase cost of code maintenance?
- Special memory architecture
  - How to adapt data layout?
- Limited memory capacity
  - Data transfer cost between CPUs and GPUs
    a) Through PCI/E link to the GPU
    b) From storage system to the GPU
- Fair comparison against software-based solutions

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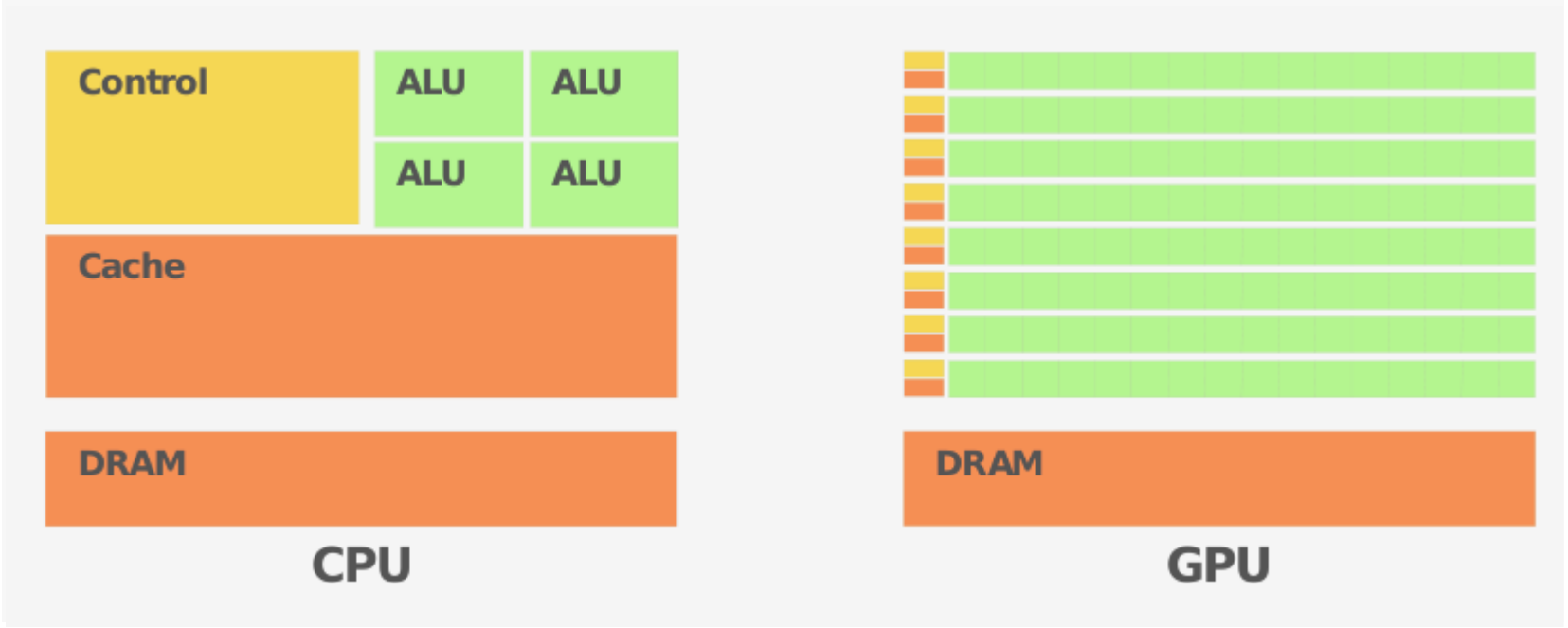
Outline

- **CPU vs GPU introduction**
- Accelerated wildcard string search
  - **Insight:** Change the layout of the strings in the GPU main memory
  - **3X** speed-up & **2X** energy savings against parallel state-of-the-art CPU libraries
- Gompresso: Massively parallel decompression
  - **Insight:** Trade-off compression ratio for increased parallelism
  - **2X** speed-ups & **1.2X** energy savings against multi-core state-of-the-art CPU libraries
- GPUs on the cloud

CPU-GPU Analogies

Goal: Low latency

Goal: High throughput
(overlapping different instructions)



CPU thread ⟷ GPU warp

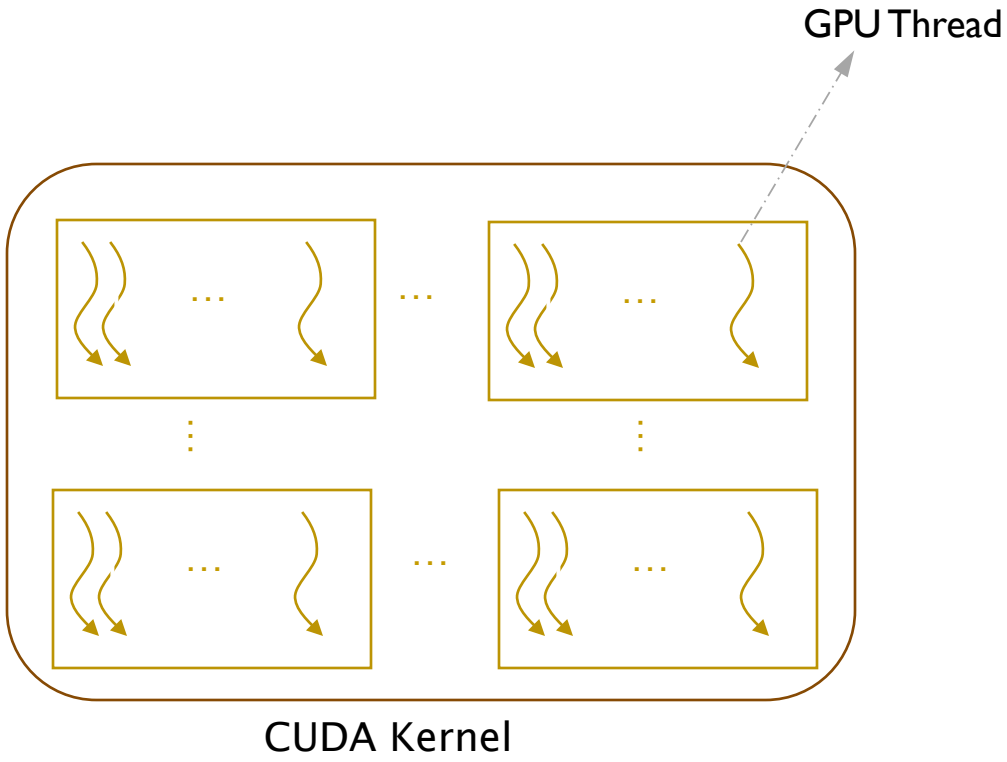
RAM ⟷ Global memory

Tens of threads ⟷ Thousands of threads

Hundreds of GBs capacity ⟷ Few tens of GB

GPU Architecture

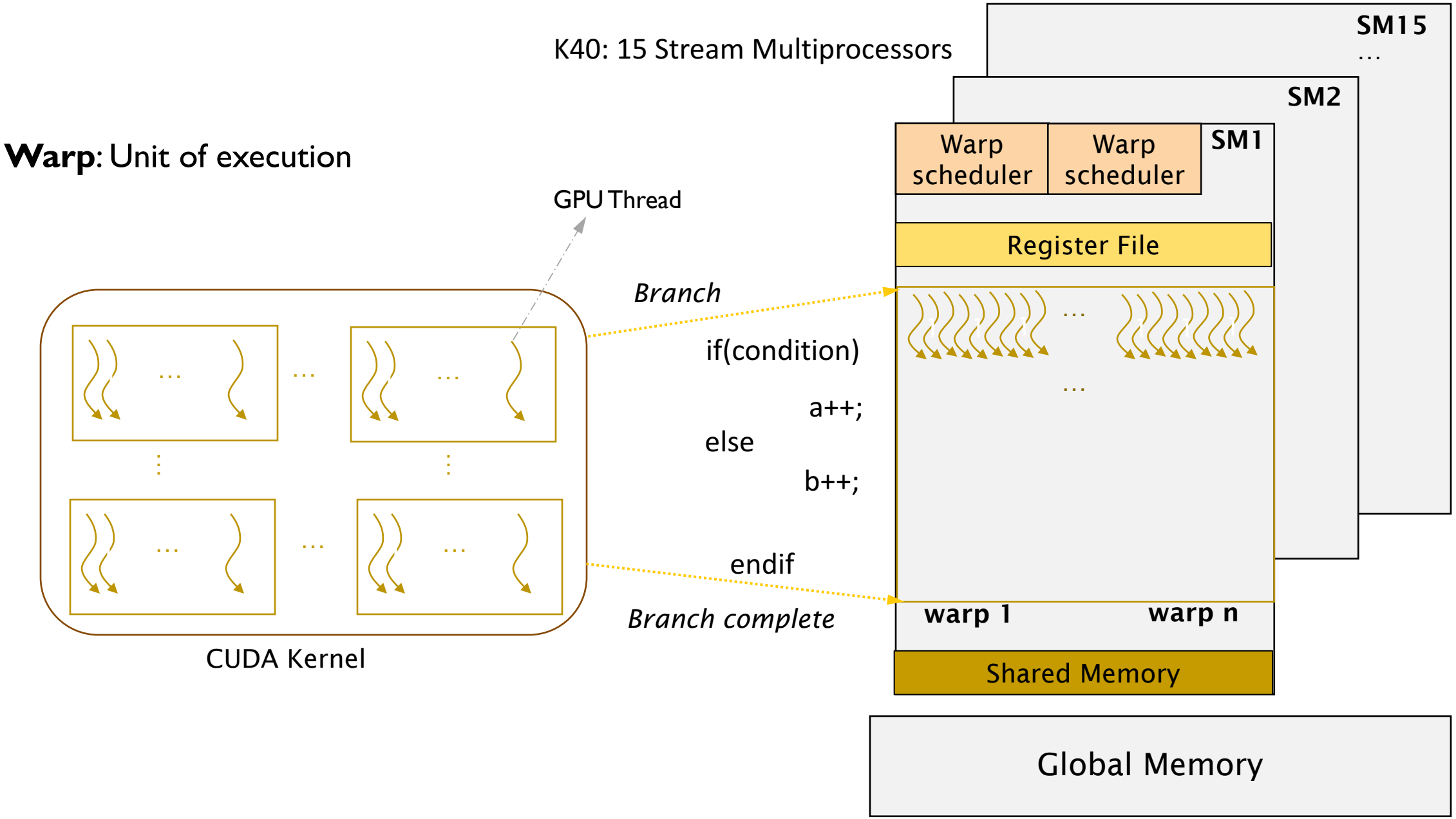
K40: 15 Stream Multiprocessors



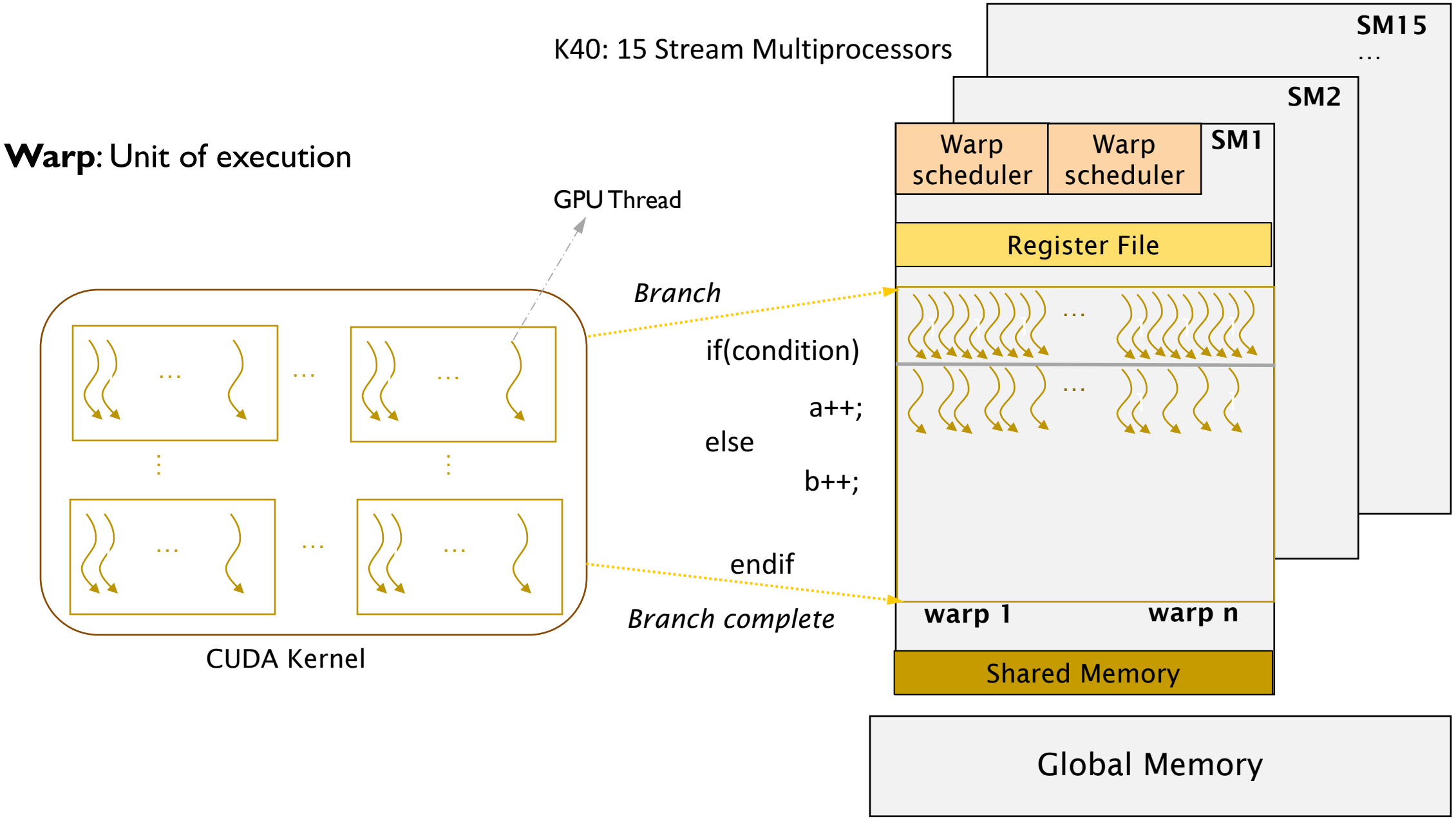

```
if(condition)
        a++;
else
        b++;

  endif
```

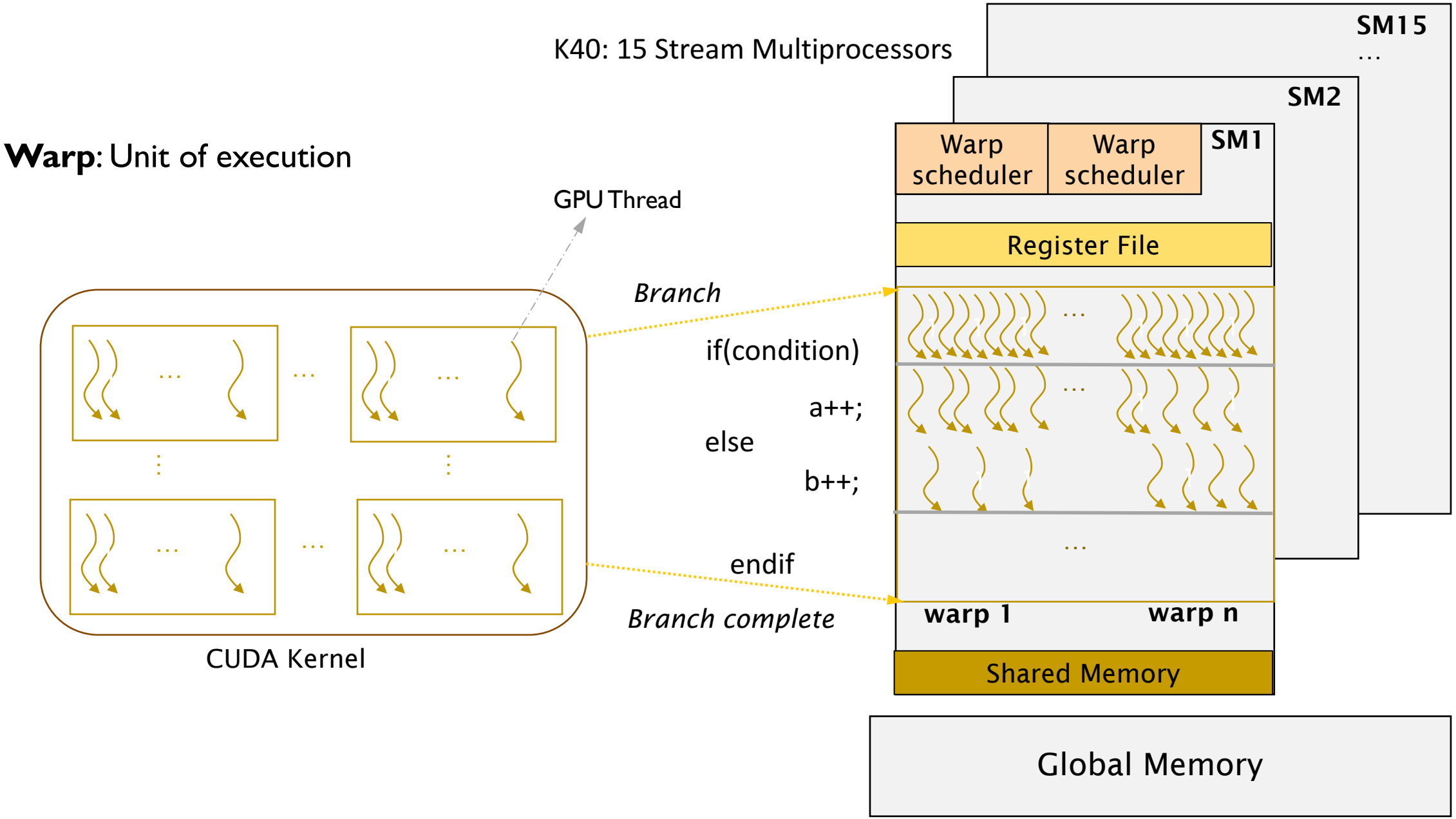
GPU Architecture



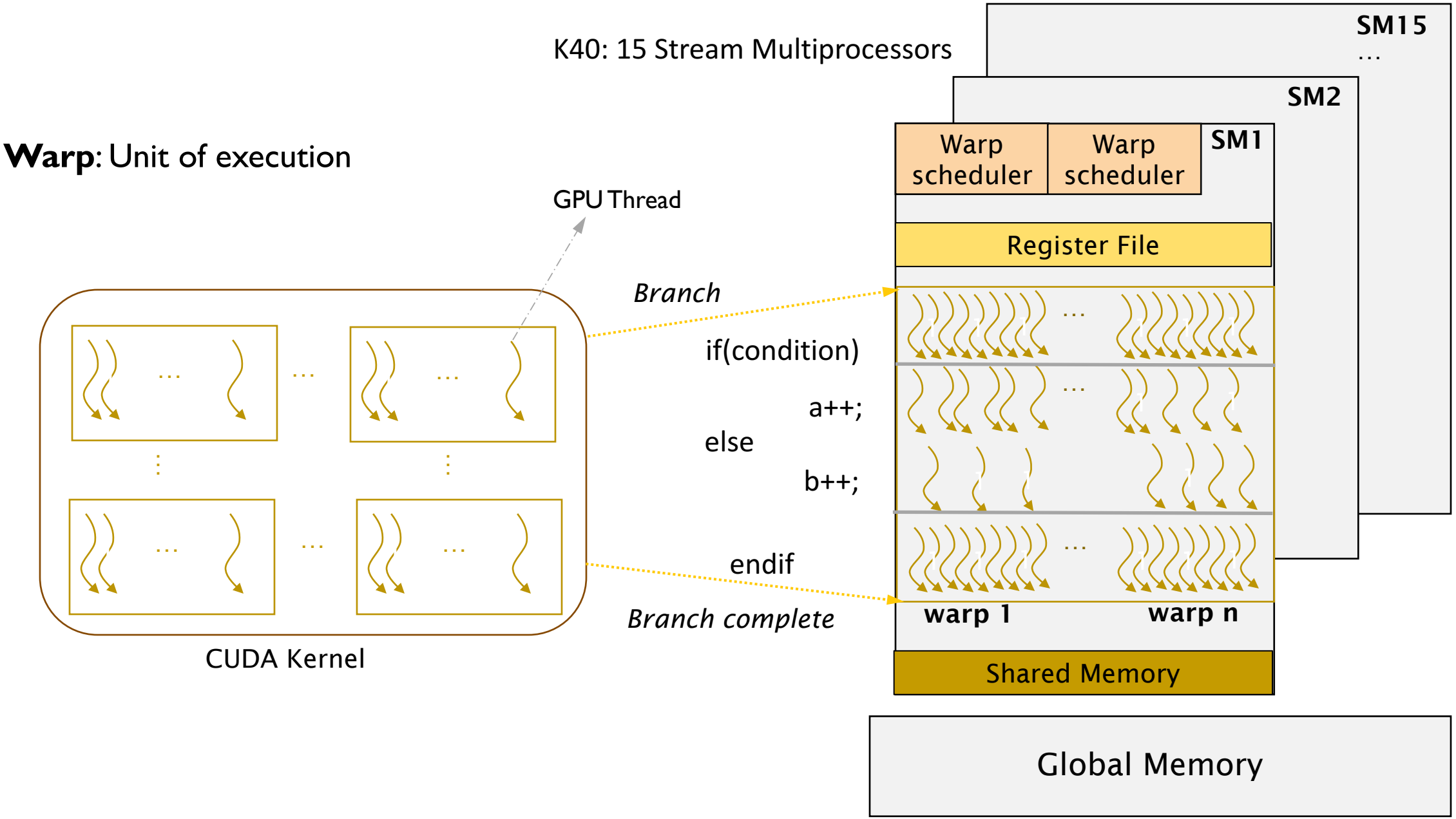
GPU Architecture



GPU Architecture



GPU Architecture



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Text Query Applications

ACGTACCTGATCGTAGGATCCCAAGTACATCATTTC

Input

ACC

Search Pattern

GENOMIC DATA

Id	Address
3	"9 Front St, Washington DC, 20001"
8	"3338 A Lockport Pl #6, Margate City, NJ, 8402"
9	"18 3rd Ave, New York, NY, 10016"
15	"88 Sw 28th Ter, Harrison, NJ, 7029"
16	"87895 Concord Rd, La Mesa, CA, 91142"

Wild card searches

"*3rdAve*New York*"

Search Pattern

DATABASE COLUMNS

Q2,9,13,14,16,20 of TPC-H contain expensive LIKE predicates

Wildcard Search Challenges

- Approaches simplifying search cannot be applied
  - String indexes, e.g. suffix trees
    - For query '%customer%complaints' multiple queries need be issued
      - '%customer%' AND '%complaints%'
      - Confirm results
  - Dictionary compression
    - Wildcard searches not simplified using dictionaries
    - String data need to be decompressed

Background: How to Search Text Fast?

Knuth-Morris-Pratt Algorithm

Input: ACACA**T**ACCTACTTTACGTACGT **Step 6** i=5 j=5

Pattern: ACACA**C**G Character mismatch

Shift pattern table -1 0 0 1 2 3 4

Advance to the next character:

a) If the input matches to the pattern

b) While there is a mismatch shift to the left of the pattern

Stop when the beginning of the pattern has been reached

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Input: ACACA**T**ACCTACTTTACGTACGT

Pattern: ACACA**C**G

Step 6 i=5 j=5

Character mismatch

ACACA**T**ACCTACTTTACGTACGT

ACA**C**ACG

Step 7 i=5 j=1

Shift pattern

Shift pattern table -1 0 0 1 2 3 4

Advance to the next character:

a) If the input matches to the pattern

b) While there is a mismatch shift to the left of the pattern

Stop when the beginning of the pattern has been reached

GPU Limiting factor: Cache Pressure

Threads matching different strings

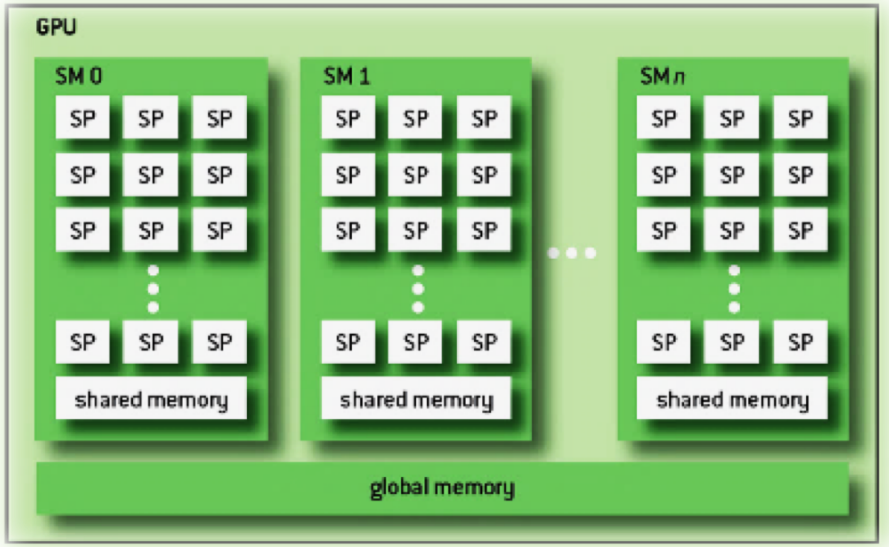
Warp size: 32
Stream Multiprocessors: 15
#Warps in each SM: 64

x

Cache footprint: 30720 cache lines

>>

L2 Capacity: 12288 cache lines



Tesla K40 architecture

Smaller cache size per thread than CPUs: Need improved locality!

Adapt Memory Layout: Pivoting Strings

Baseline (contiguous) layout

String 1 **String 2** **String 3**

CTAACCGAGTAAAGAACGTAAACTCATTCGACTAAACCGAGTAAAGA…

Pivoted layout

CTAAACGTCTAA…CCGAAAACACCG…GTAATCATAGTA…AAGATCGAAAGA…

- Split strings in equally sized pieces
- Interleave pieces in memory → Improve locality

Initially: Each warp loads a **cache line** (128 bytes)

CTAAACGTCTAA…CCGAAAACACCG…GTAATCATAGTA…AAGATCGAAAGA…

T0 T1 T2

Partial solution: Threads might progress in different rate

Adapt Memory Layout: Pivoting Strings

Baseline (contiguous) layout

String 1 **String 2** **String 3**

CTAACCGAGTAAAGAACGTAAACTCATTCGACTAAACCGAGTAAAGA…

Pivoted layout

CTAAACGTCTAA…CCGAAAACACCG…GTAATCATAGTA…AAGATCGAAAGA…

- Split strings in equally sized pieces
- Interleave pieces in memory → Improve locality

In presence of partial matches some threads might fall "behind"

Partial solution: Threads might progress in different rate

Transform Control Flow of KMP

Shift pattern table -1 0 0 1 2 3 4

Knuth-Morris-Pratt Algorithm

Input: ACACA**T**ACCTACTTTACGTACGT

Pattern: ACACA**C**G

Step 6 i=5 j=5

Character mismatch

While Loop

ACACA**T**ACCTACTTTACGTACGT
ACA**C**ACG

i=5 j=3

Mismatch→ Shift pattern

ACACA**T**ACCTACTTTACGTACGT
A**C**ACACG

i=5 j=1

Mismatch→ Shift pattern

…

ACACA**T**ACCTACTTTACGTACGT
ACACA**C**G

Step 7 i=6 j=0

Shift pattern

KMP Hybrid: Advance input in pivoted piece size

GPU vs. CPU Comparison

```
select s_suppkey
from supplier
where s_comment like '%Customer%Complaints%'
```

- Performance Metrics
  - Price ($)
  - Performance (GB/s)
  - Performance per $
  - Estimated energy consumption
- Evaluate three systems
  - CPU only system
  - GPU only system
  - CPU+GPU combined system

GPU vs. CPU Comparison

	GPU	CPU (Boost BM)	CPU (CMPISTRI)	CPU+GPU
Price ($)	3100	952	952	4052
Performance (GB/s)	98.7	40.75	43.1	138.7
Energy consumed (J)	1.27	2.49	2.35	1.78
Performance/$	31.89	42.8	45.28	34.25

Circle best column value per row

CPU: Dual-socket E5-2620 – Band. 102.4 GB/s
GPU: Tesla K40 – Band. 288 GB/s

Design system by choosing the desired trade-offs

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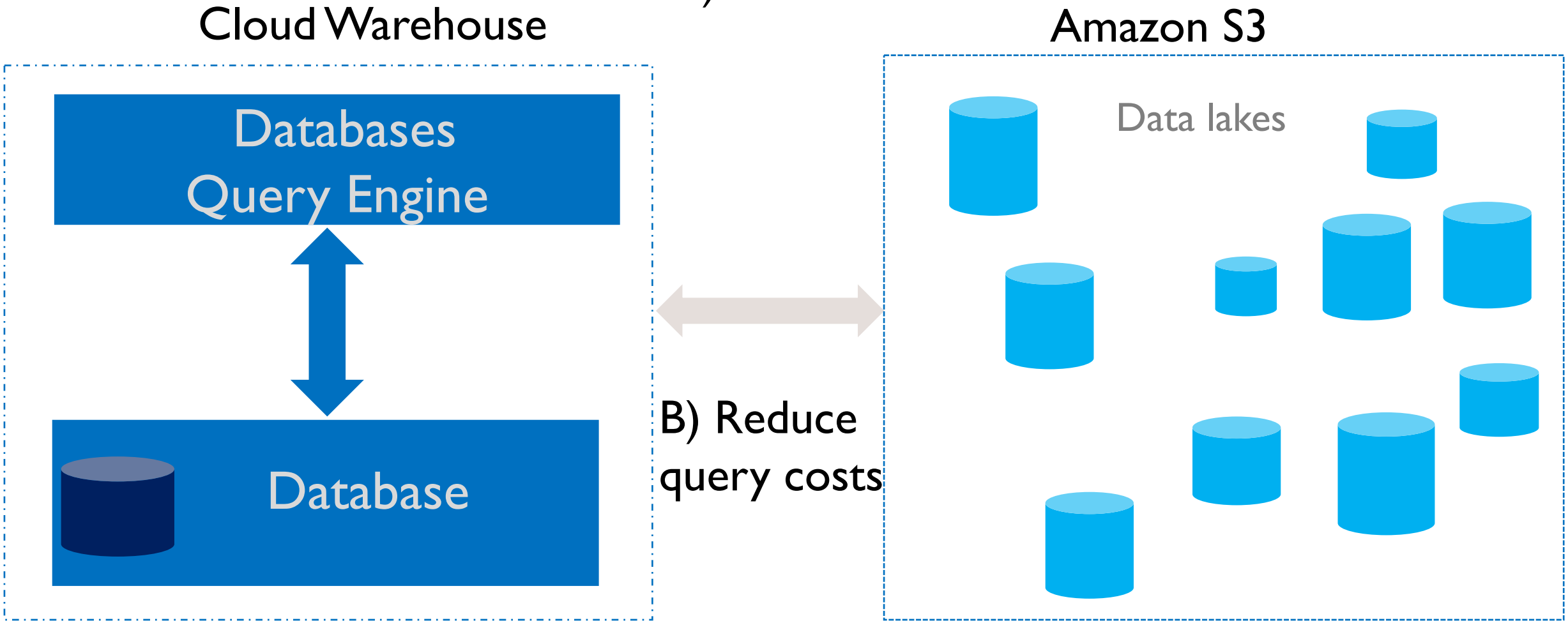
Example: Why Use Compression?

A) Reduce basic S3 costs



Decompression speed more important than compression speed

Background: LZ77 Compression

Input characters

0 1 2 3 …
ATTACTAGAATGT TACTAATCTGAT
CGGGCCGGGCCTG

Output

*ATTACTAGAATGT***(2,5)…**

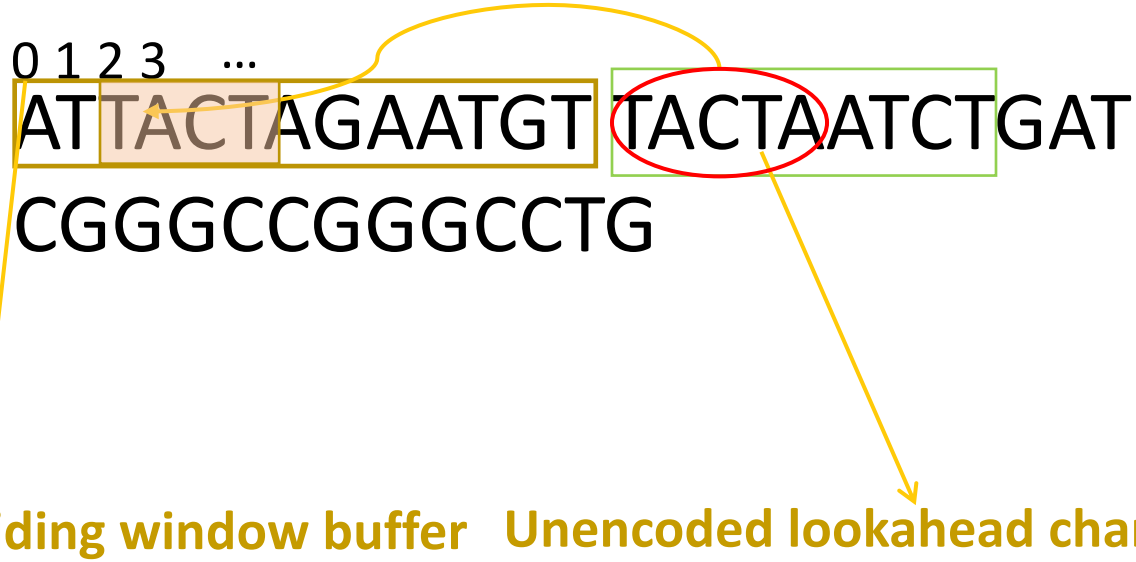
Literals
Unmatched characters

Backreferences
(Position, Length)

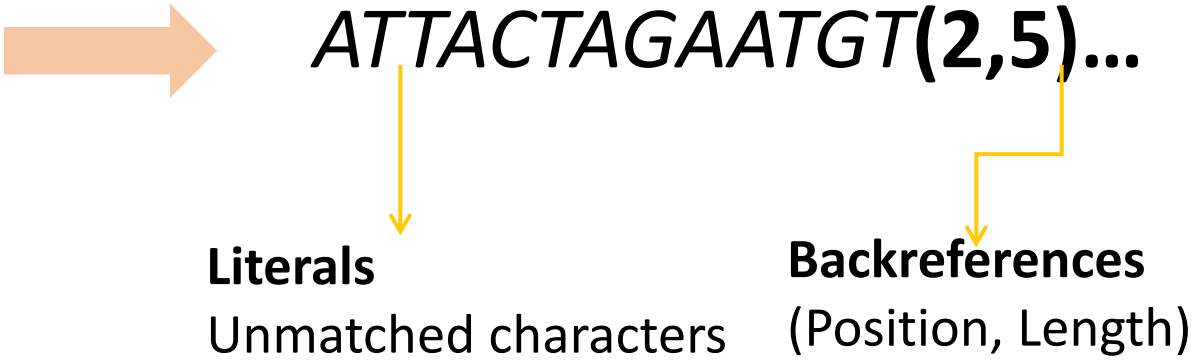
Background: LZ77 Compression

Input characters

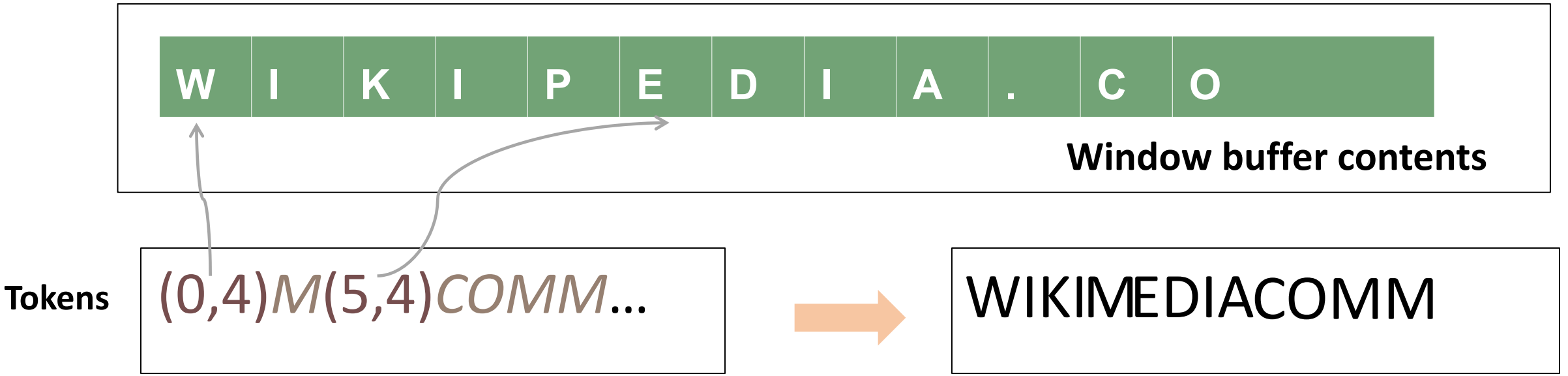
Find longest match



Output

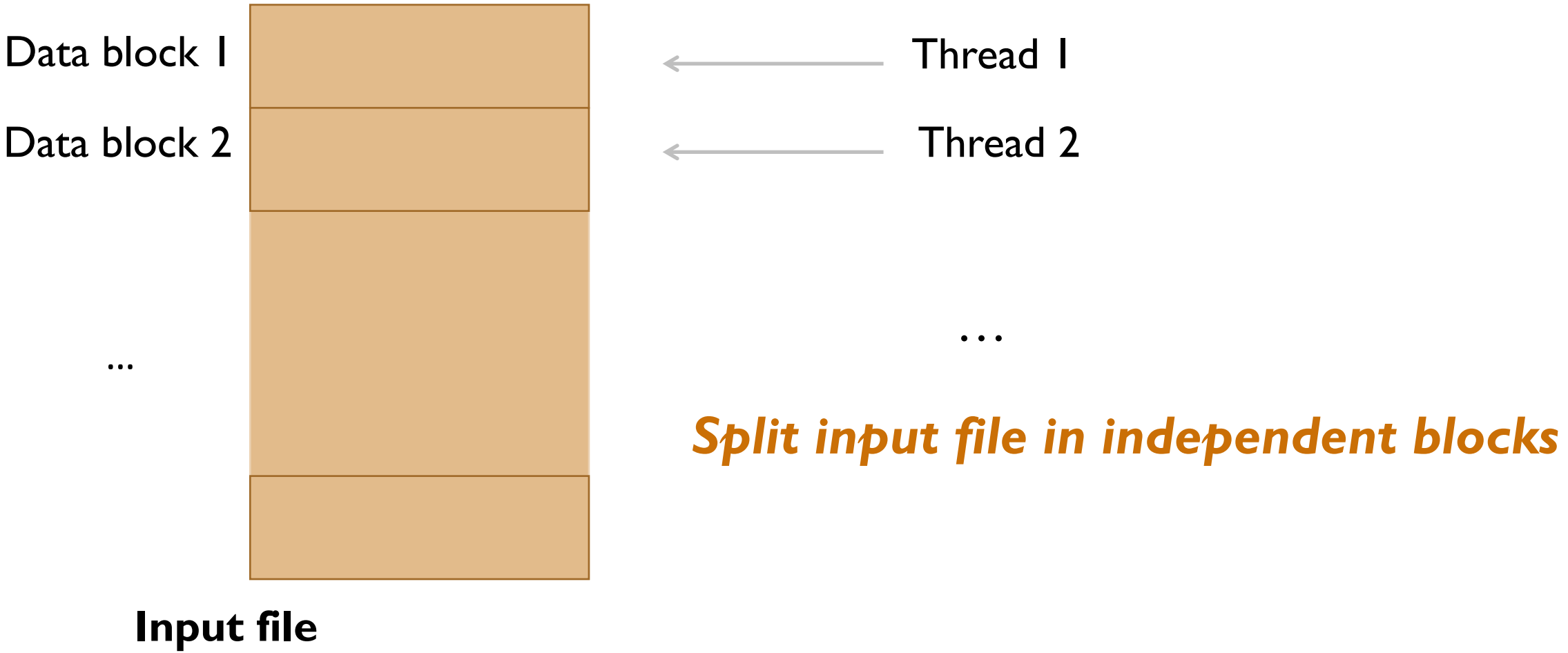


Background: LZ77 Decompression



How to Parallelize Decompression?

>1000 threads available!

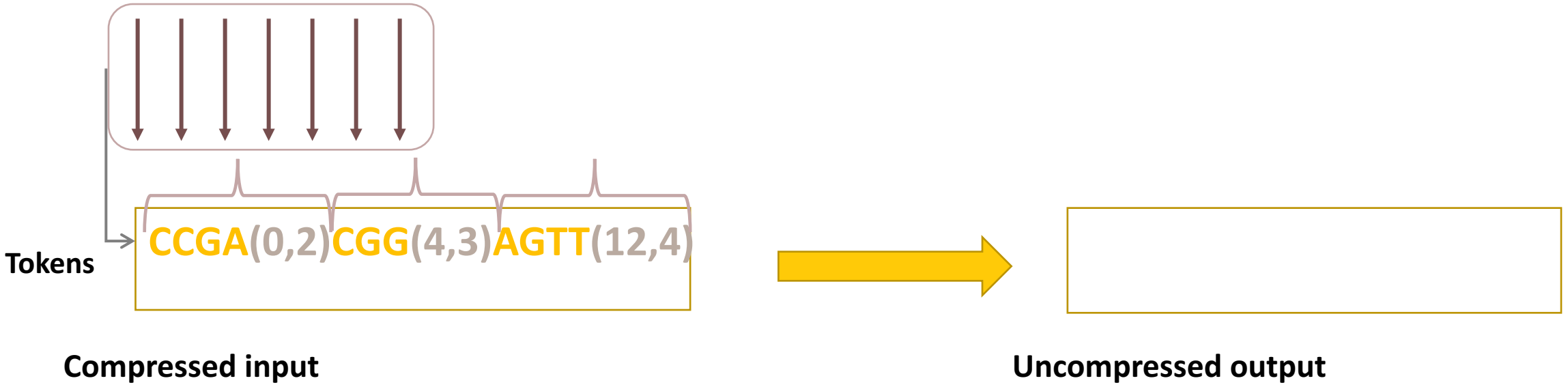


Split input file in independent blocks

Naïve approach performance 200 MB/s << 250 GB/s (K20x)

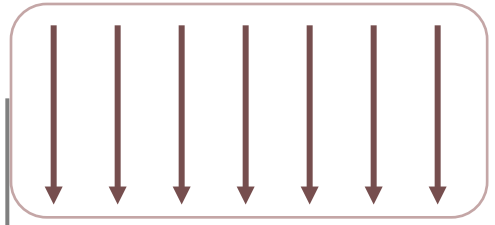
GPU LZ77 Decompression

Improve utilization: Group strings of literals with the following back-reference



GPU LZ77 Decompression

1) Read tokens (parallel)



Tokens

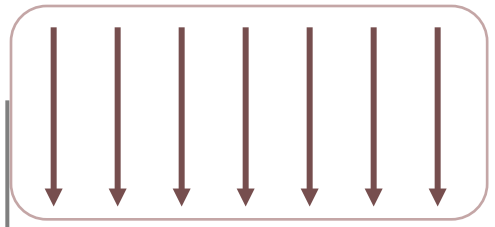
CCGA(0,2)CGG(4,3)AGTT(12,4)

Compressed input

Uncompressed output

GPU LZ77 Decompression

2) Write literals (parallel prefix sum)



Tokens

CCGA(0,2)CGG(4,3)AGTT(12,4)

CCGA CGG AGTT

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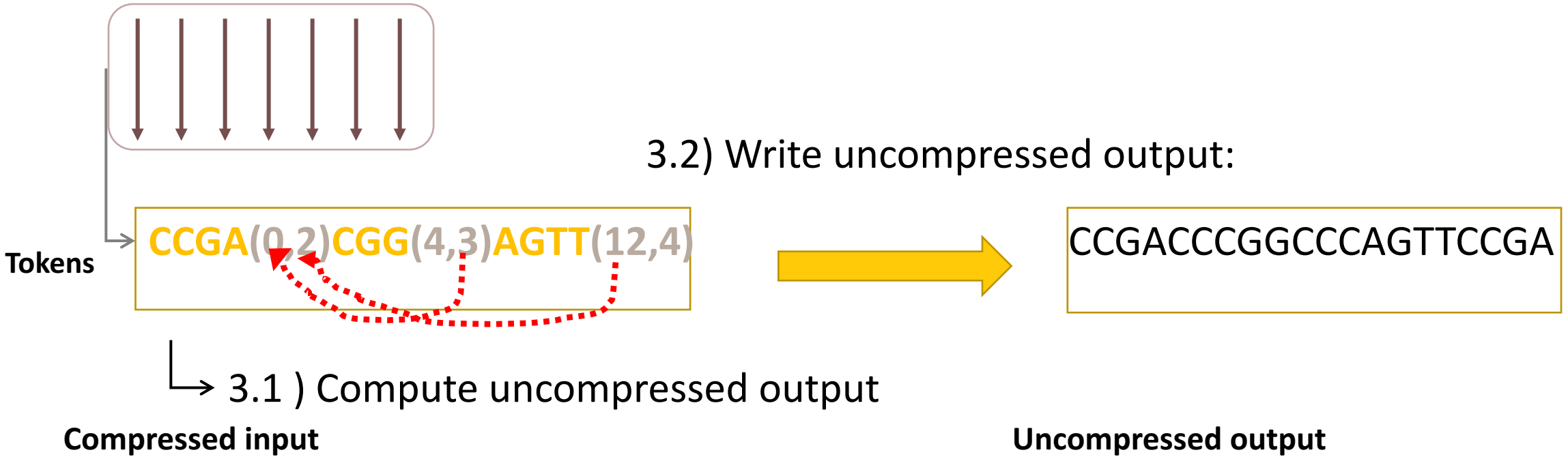
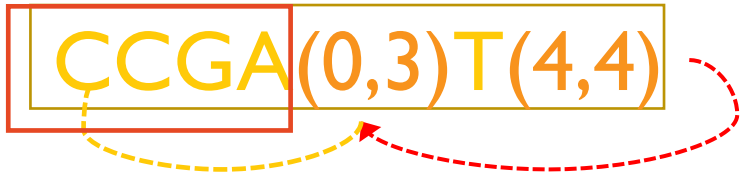


Problem: Back-references processed in parallel might be dependent! →
Use voting function __*ballot* to detect dependencies

How to Handle Thread Dependencies?

MRR

Tokens 

Second loop: Dependencies satisfied

1) Write literals (parallel)
2) While(!all backreferences written)
   a) Check dependencies satisfied (parallel)
   b) Copy back-references w/o pending dependencies

Bandwidth: 7 GB/s

DE

Tokens 

A) Compression

Only search for matches w/o dependencies

B) Decompression

Copy back-references (fully parallel)

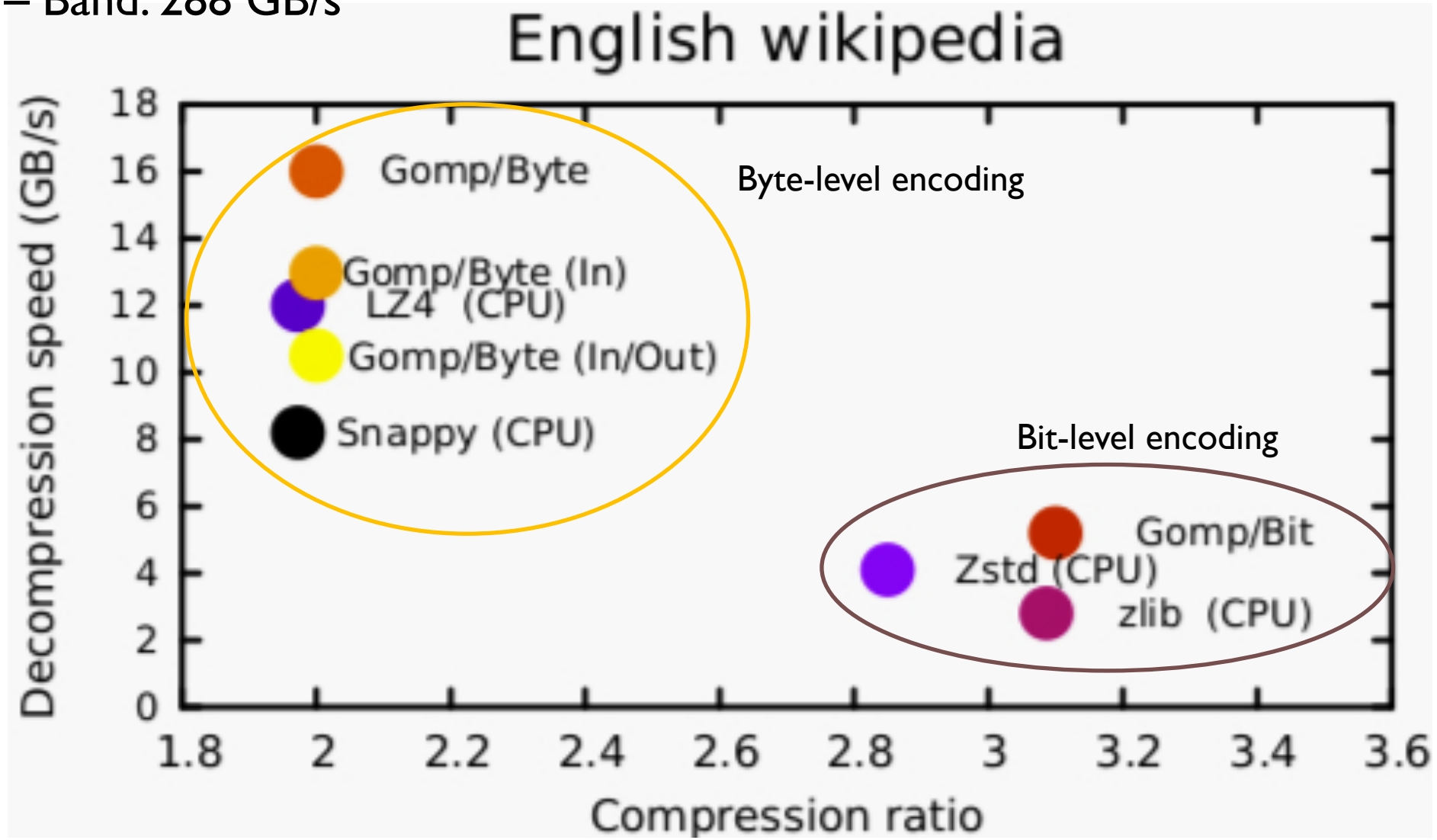
Bandwidth: 16 GB/s

Uncompressed input …CCGACGTTCCGT…

Decompression Skyline

CPU: Dual-socket E5-2620 – Band. 102.4 GB/s

GPU: Tesla K40 – Band. 288 GB/s



GPUs on the Cloud

- Cloud offerings
  - AWS
  - Google Cloud
  - Microsoft Azure
  - IBM Softlayer
  - Nimbix
- Opportunity
  - Evaluate the usefulness of GPUs/FPGAs without the high investment
- Special considerations
  - Charging model
  - Scaling capabilities
  - Software licensing

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  - **Insight:** Trade-off compression ratio for increased parallelism
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- GPUs on the cloud: Open questions