State management in distributed stream processing systems

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Agenda

- Distributed stream processing
  - What is state? How is it typically managed?

- Fault tolerance
  - Types of checkpointing
  - Focus on continuous incremental checkpointing
    - CEC
    - LinkedIn Samza
    - Recent experience with Samza

- Exactly-once semantics

References

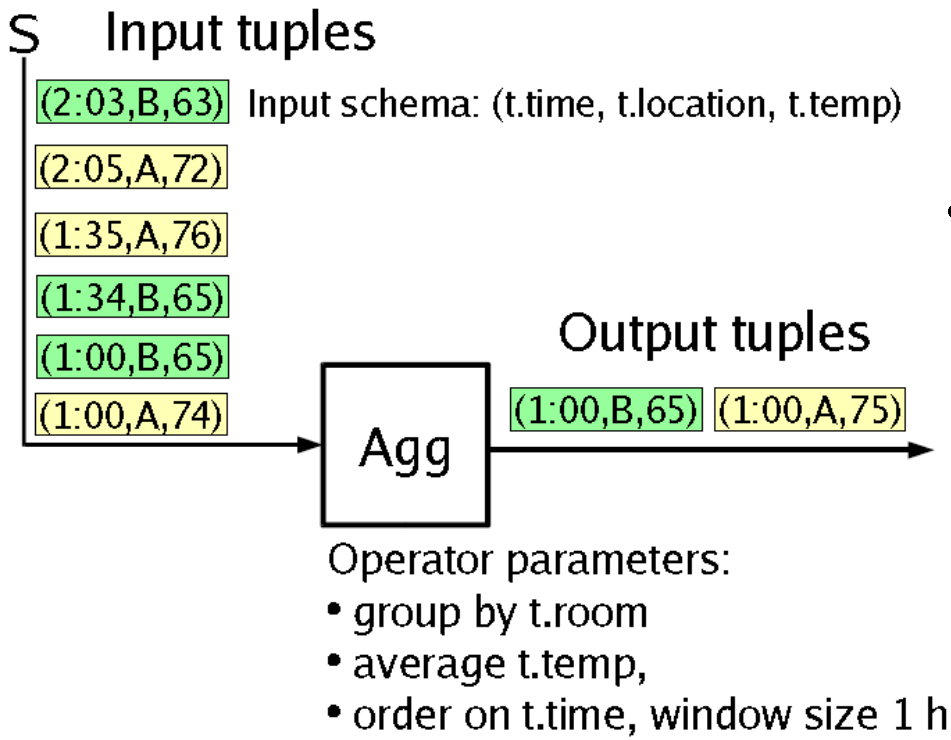
- Z. Sebepou, K. Magoutis. "Continuous Eventual Checkpointing for Data Stream Processing Operators", IEEE DSN 2011, Hong Kong, China, July 6-9, 2011

- S. Noghabi, K. Paramasivam, Y. Pan, N. Ramesh, J. Bringhurst, I. Gupta, R. H. Campbell. "Samza: stateful scalable stream processing at LinkedIn", Proc. VLDB Endow. 10, 12, Aug. 2017

- P. Carbone, S. Ewen, G. Fóra, S. Haridi, S. Richter, K. Tzoumas. "State management in Apache Flink: consistent stateful distributed stream processing", Proc. VLDB Endow. 10, 12, Aug. 2017

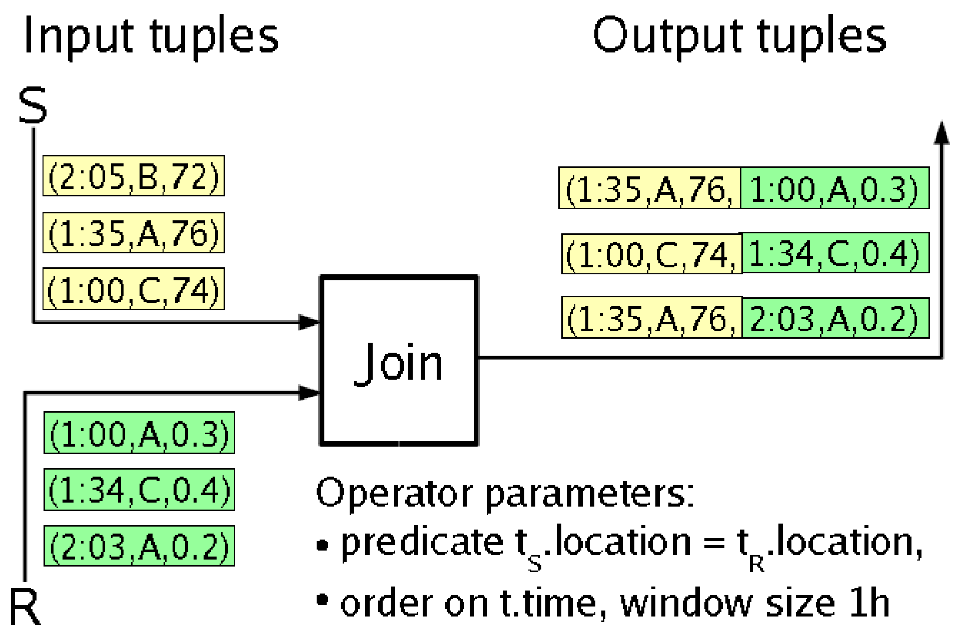
- A. Chronarakis, A. Papaioannou, K. Magoutis, "On the impact of log compaction on incrementally checkpointing stateful stream-processing operators", Proc. DRSS'19, to be held in conjunction with SRDS'19, Lyon, France, October 1, 2019

General principles: Aggregate operator



- Operator state (per window) may be
  - One value (accumulating state)
  - All tuples that enter the window

General principles: Join operator



Fault-tolerance in stream processing systems

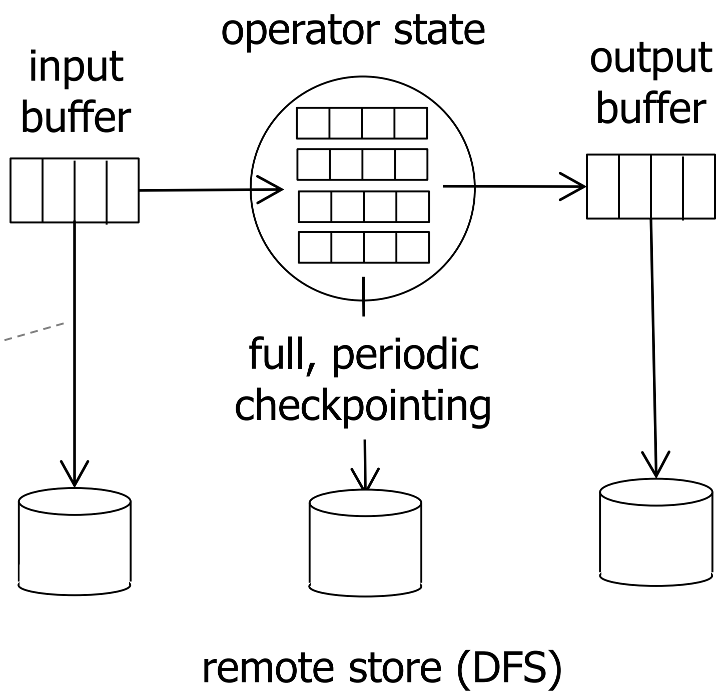
- State replication
  - Maintain full replicas of operator state across nodes
  - High availability, memory requirements

- Checkpoint roll-backward
  - Checkpoint to remote disk
  - On recovery, load most recent checkpoint

- Types of checkpointing
  - Full, periodic
  - Delta (incremental), periodic
  - Continuous incremental (log of updates)

Full, periodic checkpoints

Trim after operator checkpoints



Store durably only

- for replay at a later time
- spill-over

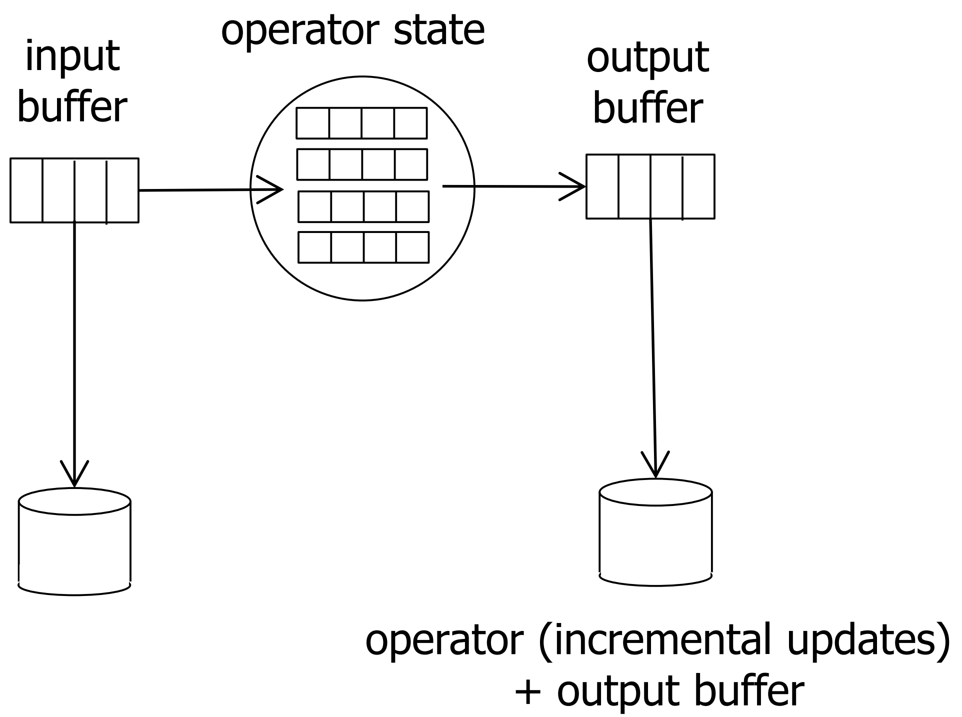
Operator freezes during checkpoint

- Large response-time spikes

Efficient implementations use copy-on-write (COW)

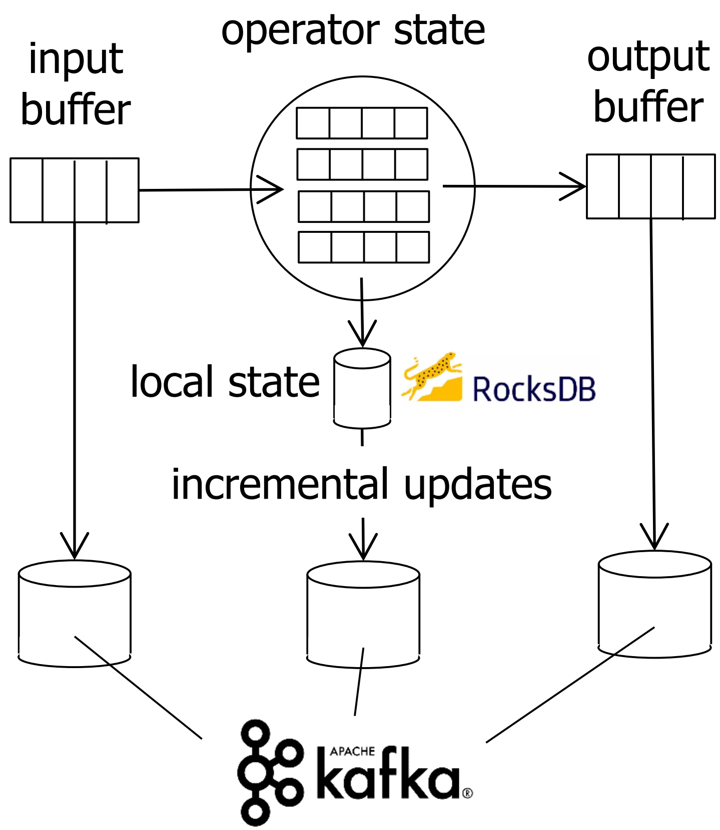
- Complex to implement
- Overhead to compute what needs to be checkpointed
- Overhead handling exceptions during protection fault

Incremental checkpointing (CEC, DSN'11)

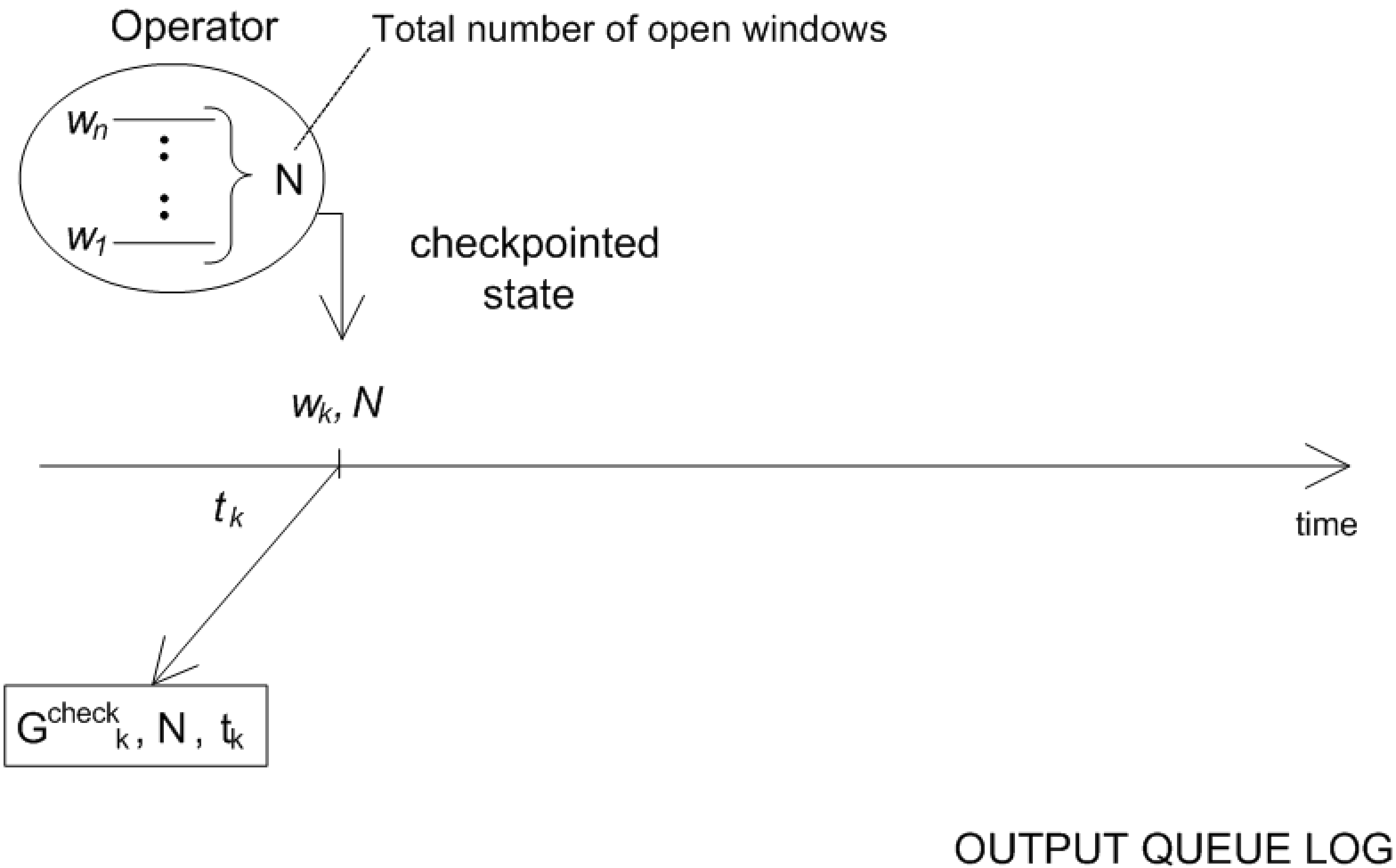


Z. Sebepou, K. Magoutis, Continuous eventual checkpointing for data stream processing operators, in *Proc. of IEEE DSN'11*

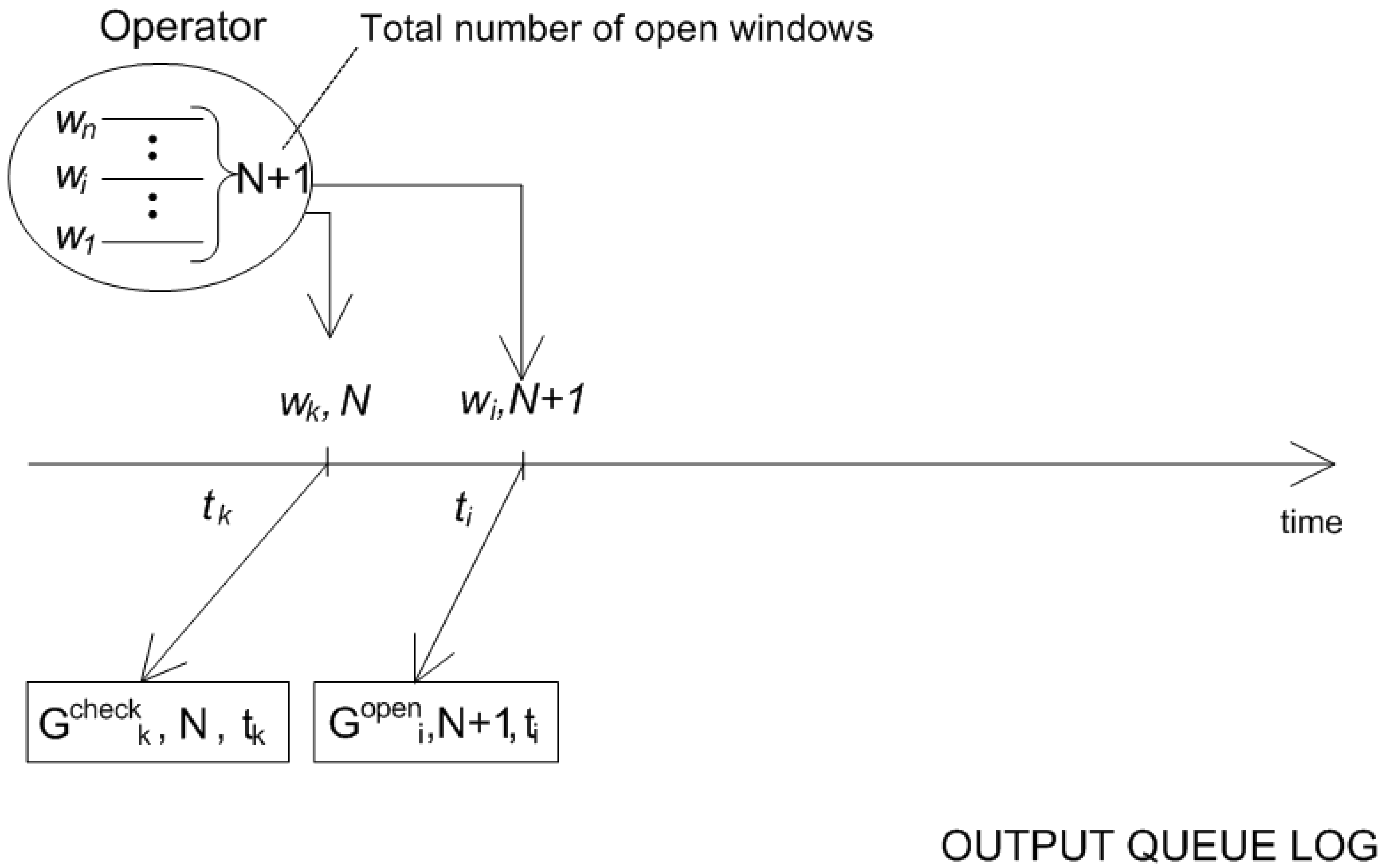
Incremental + local state



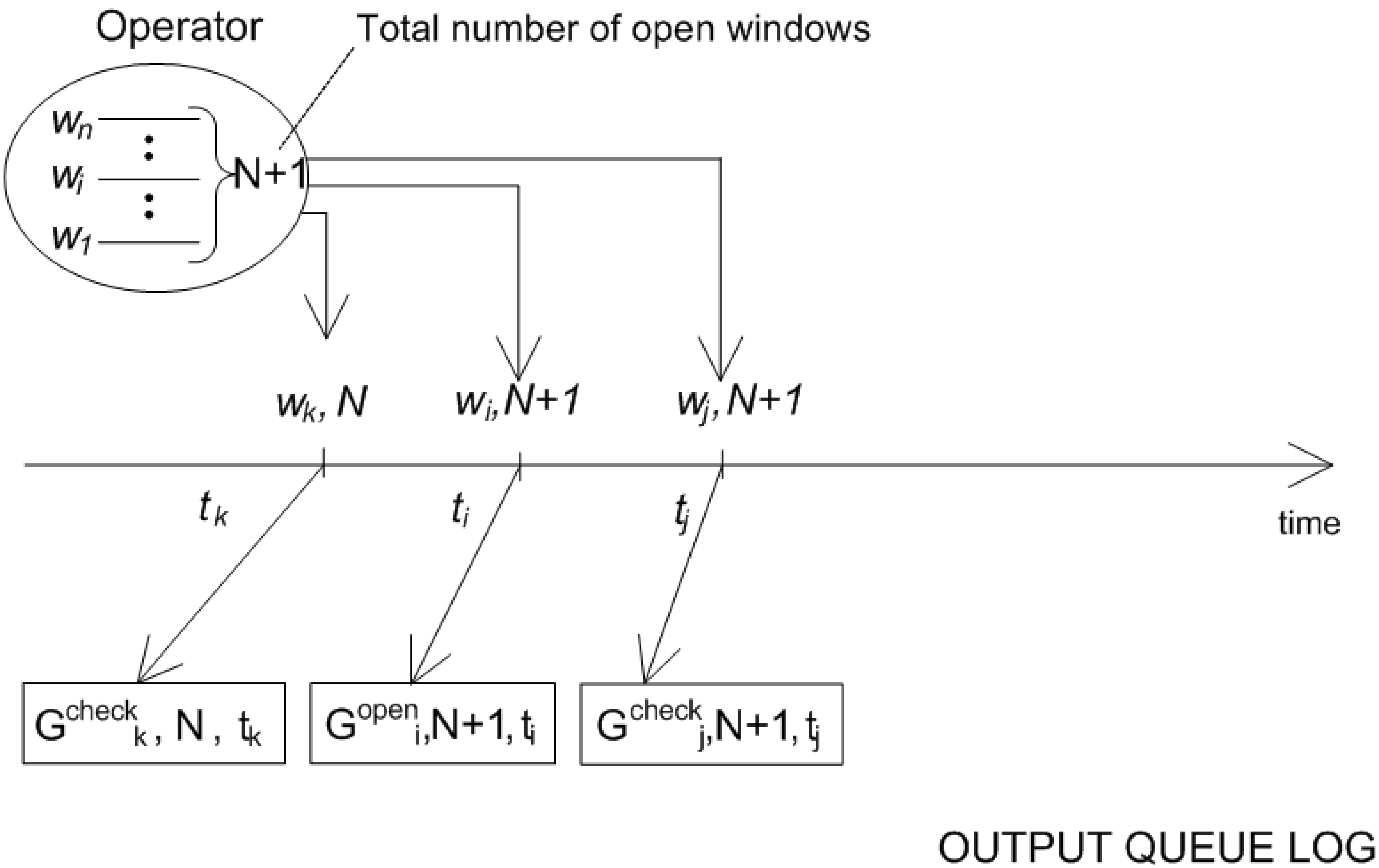
Continuous eventual checkpointing (CEC)



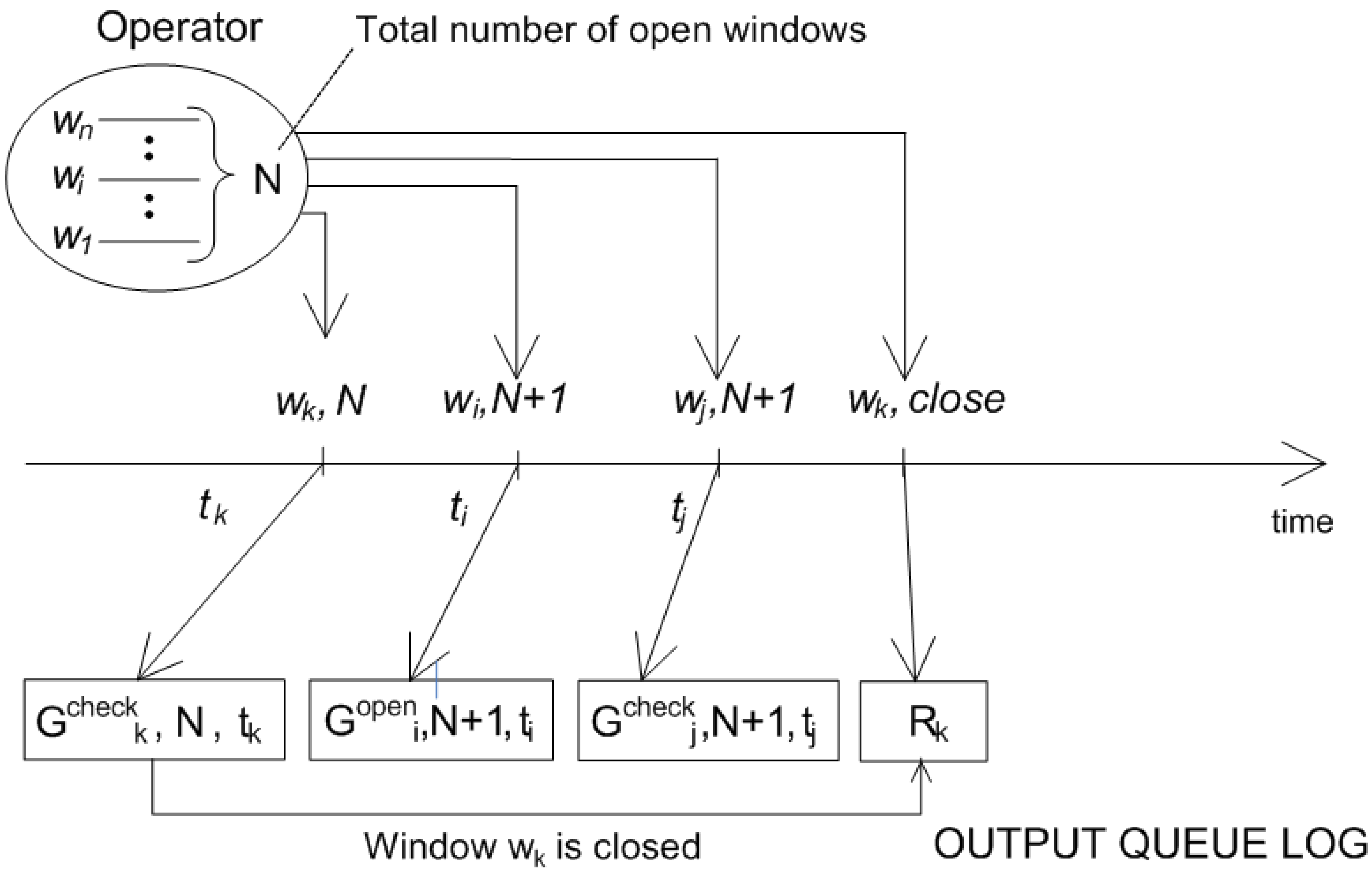
Opening of a new window



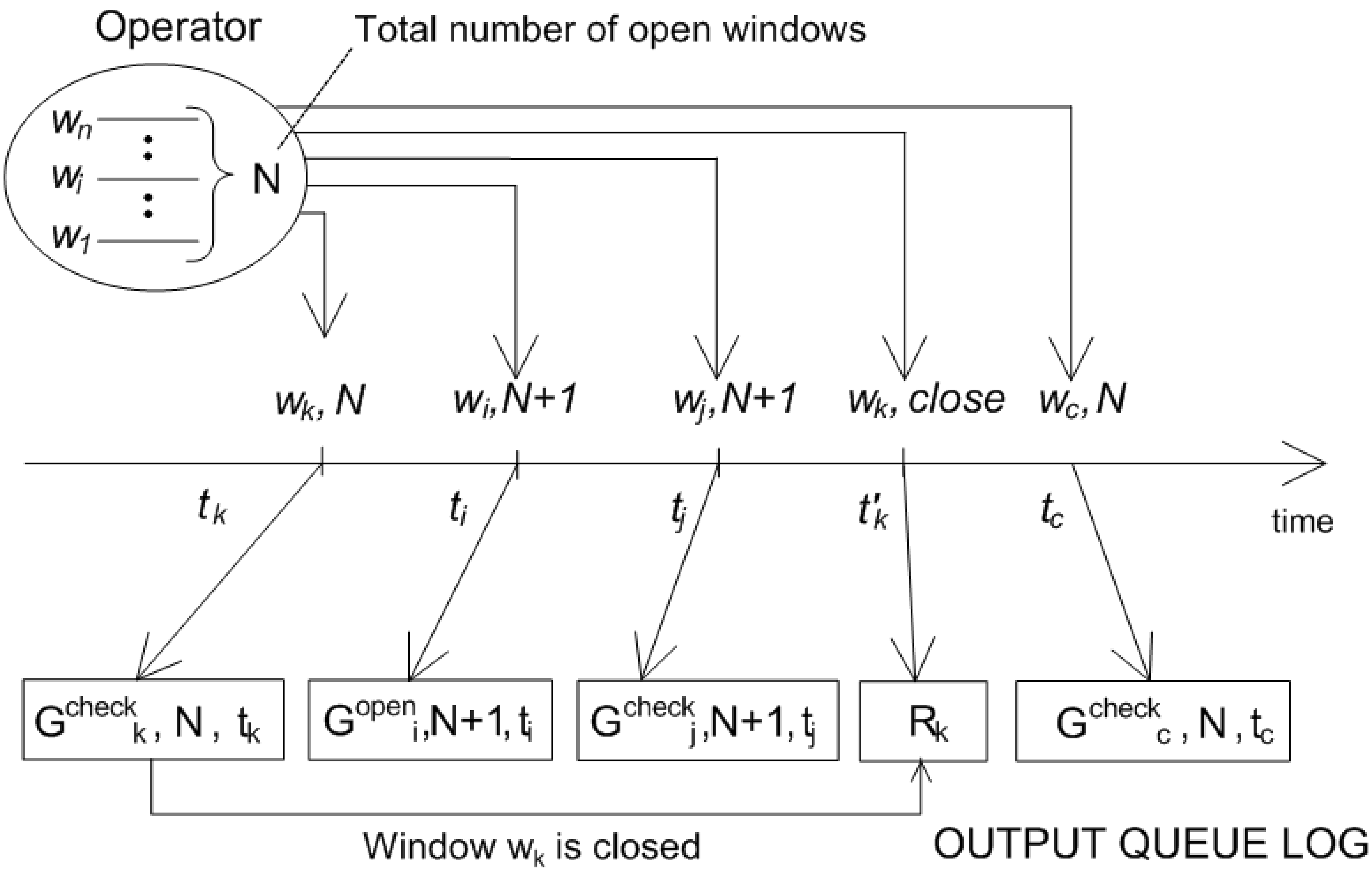
Another checkpoint of an open window



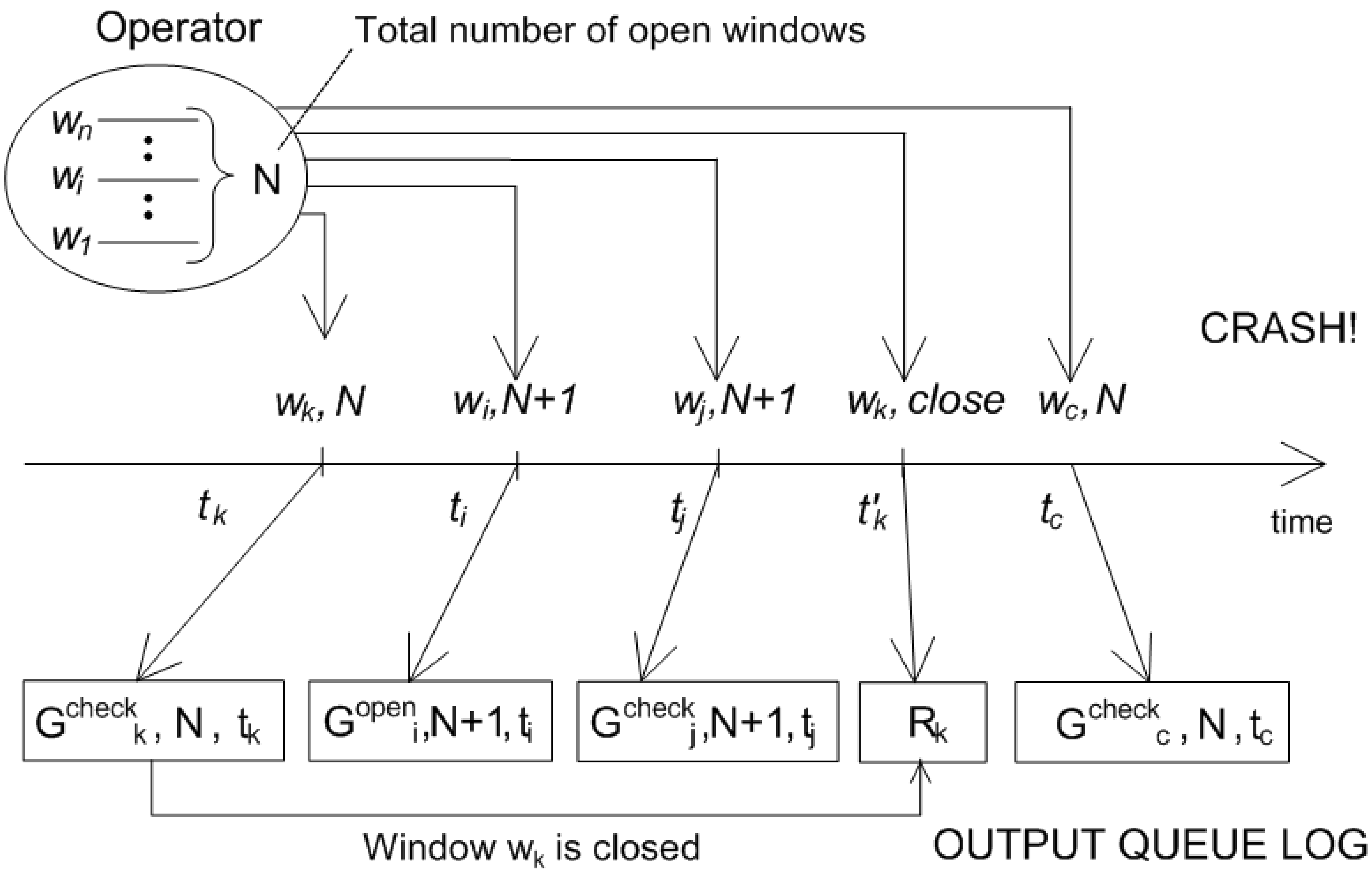
Closing of a window



Another checkpoint of an open window

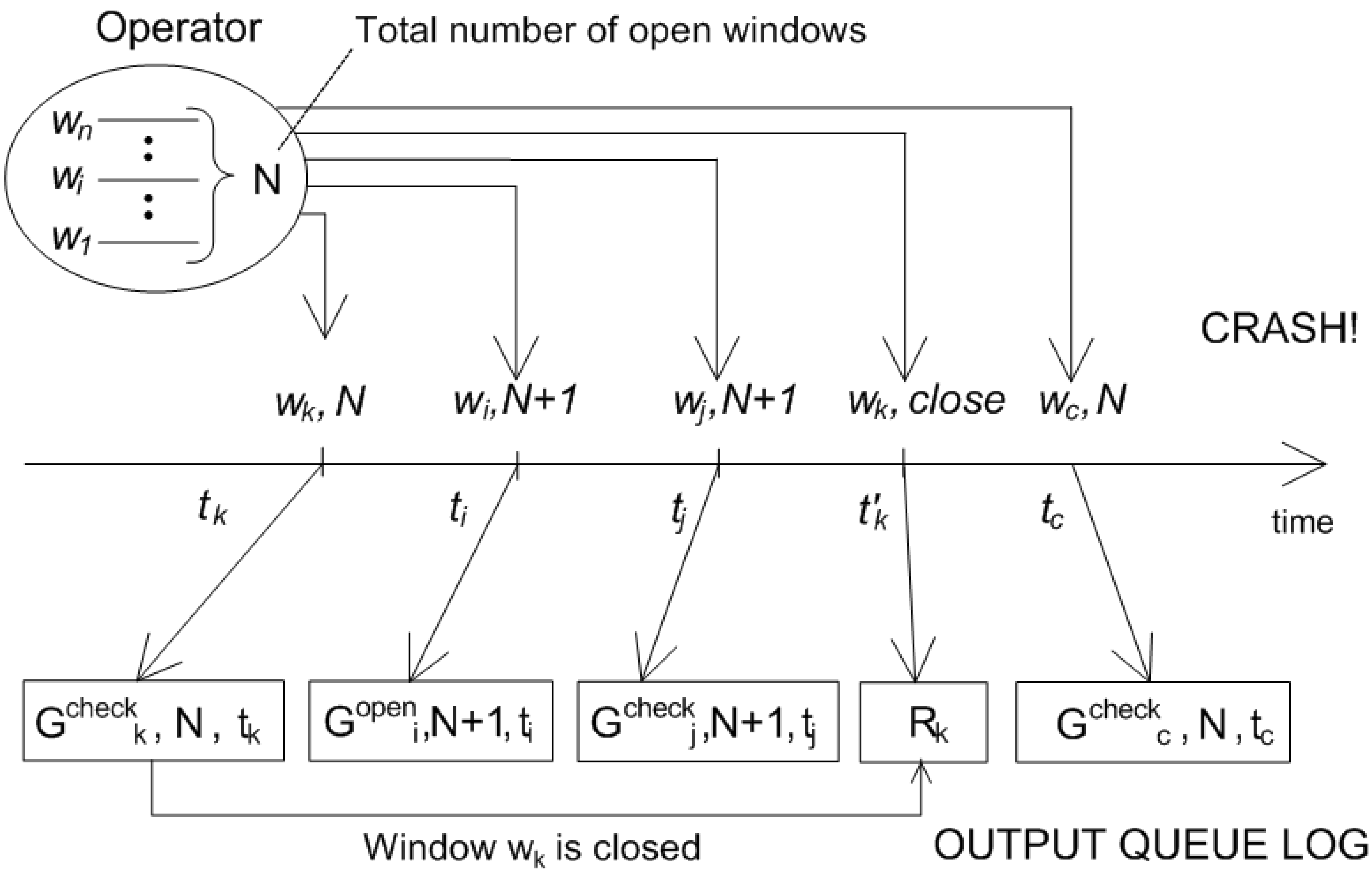


Crash



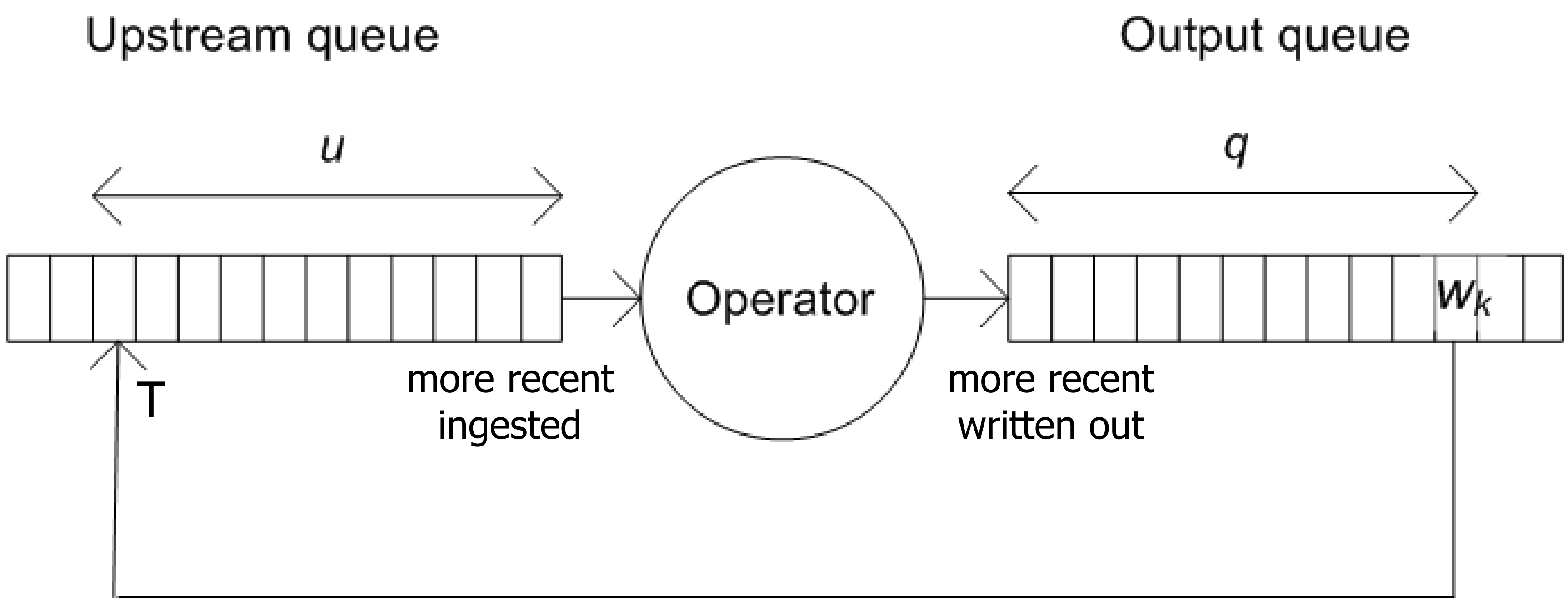
Operator
Total number of open windows
w_n
w_i
w_1
N
CRASH!
w_k, N
w_i, N+1
w_j, N+1
w_k, close
w_c, N
t_k
t_i
t_j
t'_k
t_c
time
G^{check}_k, N, t_k
G^{open}_i, N+1, t_i
G^{check}_j, N+1, t_j
R_k
G^{check}_c, N, t_c
Window w_k is closed
OUTPUT QUEUE LOG

Recovery



Operator
Total number of open windows
w_n
w_i
w_1
N
CRASH!
w_k, N
w_i,N+1
w_j,N+1
w_k, close
w_c, N
t_k
t_i
t_j
t'_k
t_c
time
G^{check}_k, N, t_k
G^{open}_i,N+1, t_i
G^{check}_j,N+1, t_j
R_k
G^{check}_c, N, t_c
Window w_k is closed
OUTPUT QUEUE LOG

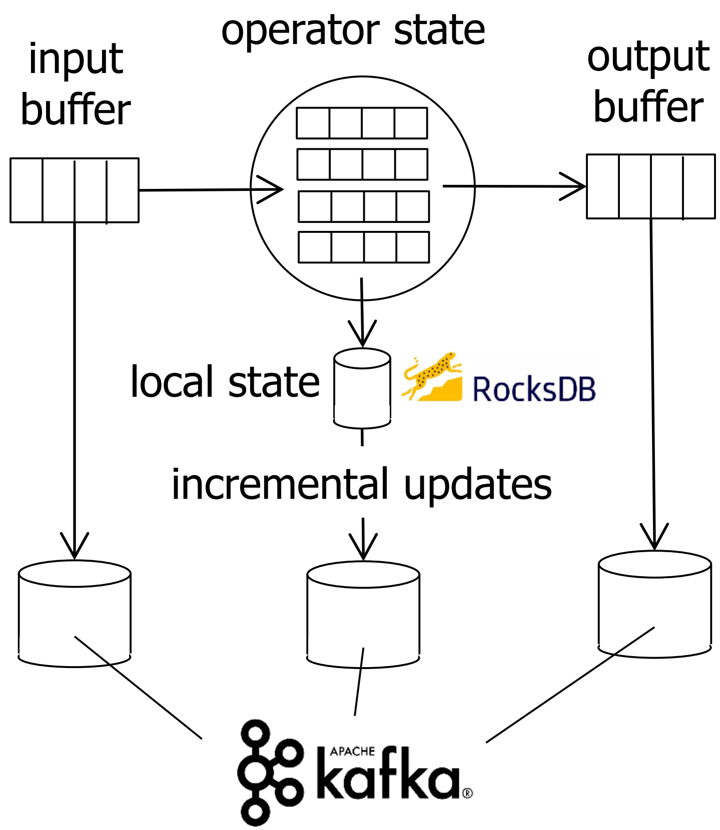
Overall view



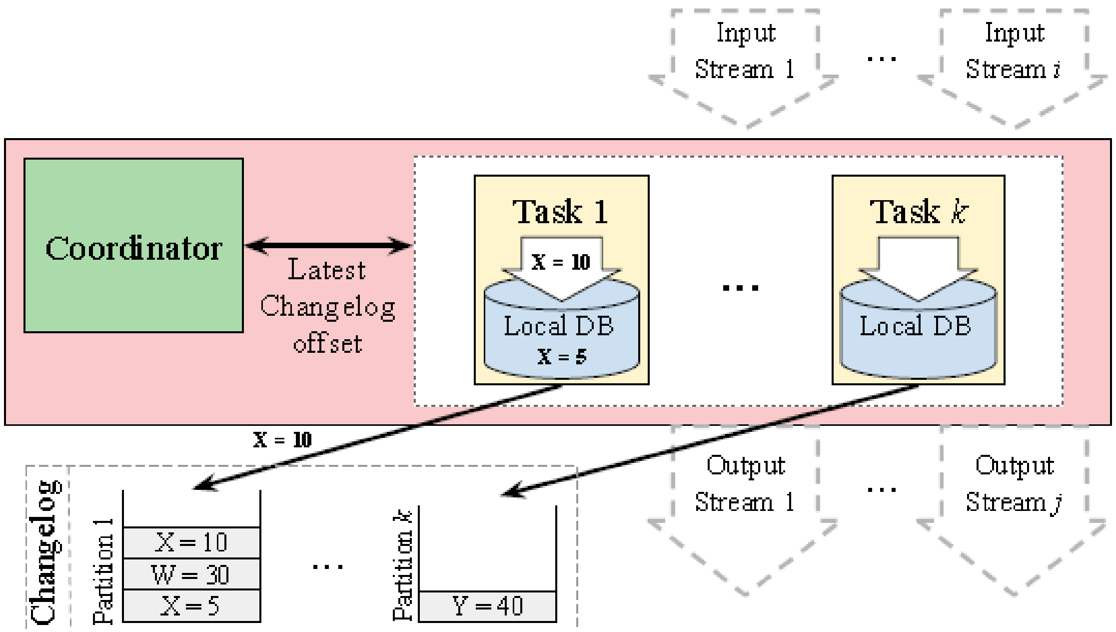
- Window w_k has oldest checkpoint in output queue log
- Producing a checkpoint for it will reduce *q*
- It will also reduce the number of tuples to replay *u*

Incremental checkpointing: LinkedIn Samza

Incremental + local state



Use of changelog



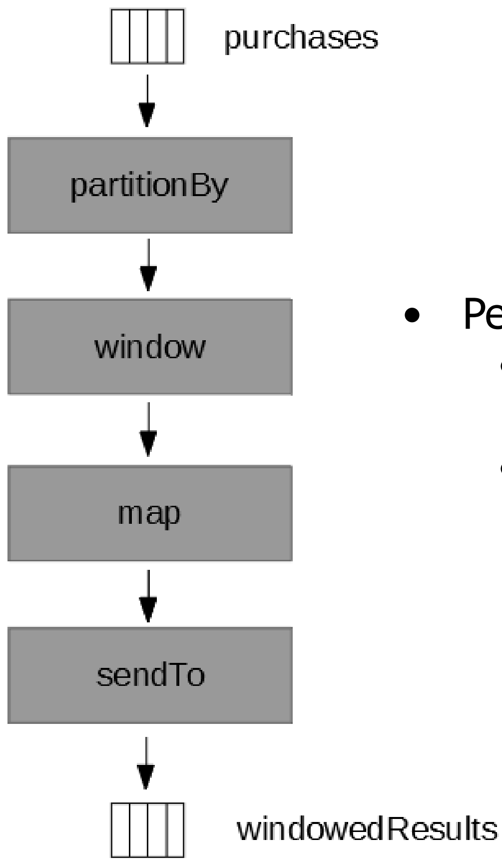
Sync changelog, then update "successfully processed" input offset (=>*at least once*)

S. Noghabi et al. "Samza: stateful scalable stream processing at LinkedIn", Proc. VLDB Endow. 10, 12, Aug. 2017

Recent experience with incremental checkpointing in Samza

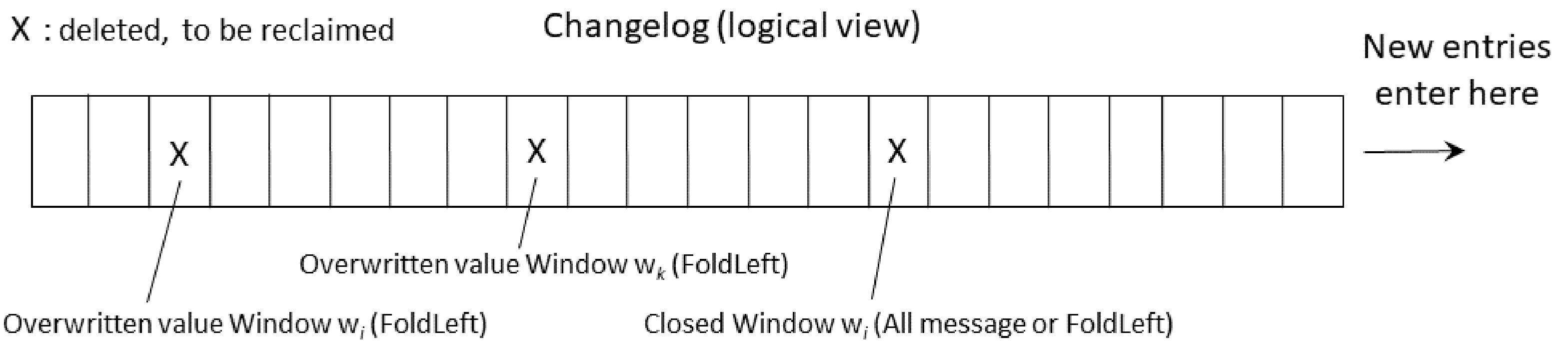
Window-based streaming application

purchases.
partitionBy(...).
window(...).
map(...).
sendTo(windowedResults);



- Per-window operator state may contain
  - One value (accumulating state)
    - FoldLeftFunction (FLF)
  - All tuples that enter the window
    - Retain all (RetainALL)

Changelog and compaction



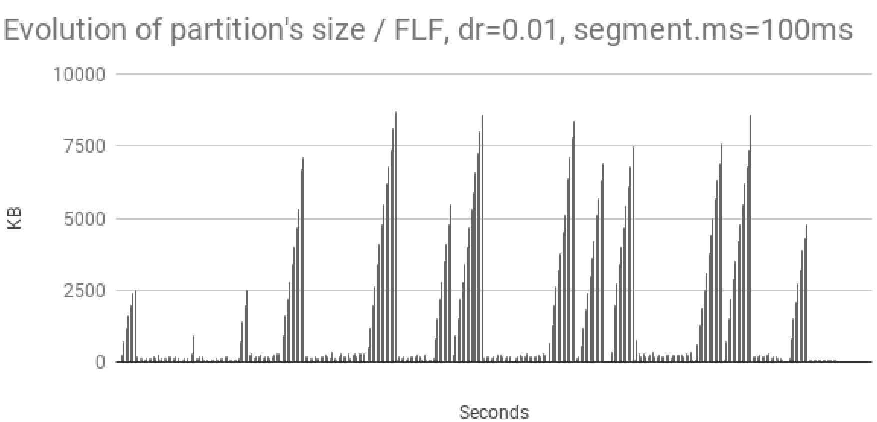
Research questions

- How does recovery time depend on changelog size?
- What policies can be used to limit changelog size ?

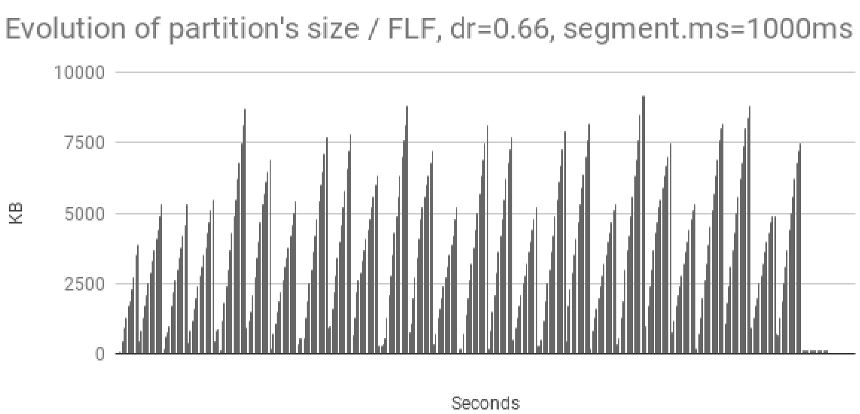
Changelog-size vs. overhead

- Compaction parameters (policies) affect
  - Size of changelog, CPU usage of broker
- Trade-off between restore time and overhead

Aggressive compaction



Relaxed compaction



- Experiments with segment.ms= {100ms,1000ms} & dirty ratio= {0.01, 0.33, 0.66}

Overall

- Appropriate tuning of compaction configuration parameters needed to achieve recovery time goals
- What about (exactly-once / at-least-once) semantics?

Exactly-once semantics

- Flink’s pipelined (asynchronous barrier) checkpointing
- Reminiscent of Chandy-Lamport global snapshots
  - Inject markers at input streams
  - Take local operator snapshots after having accounted for all input prior to snapshot time

References

- Z. Sebepou, K. Magoutis. “Continuous Eventual Checkpointing for Data Stream Processing Operators”, IEEE DSN 2011, Hong Kong, China, July 6-9, 2011

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Questions?

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