Mitigating Asymmetric Read and Write Costs in Cuckoo Hashing for Storage Systems

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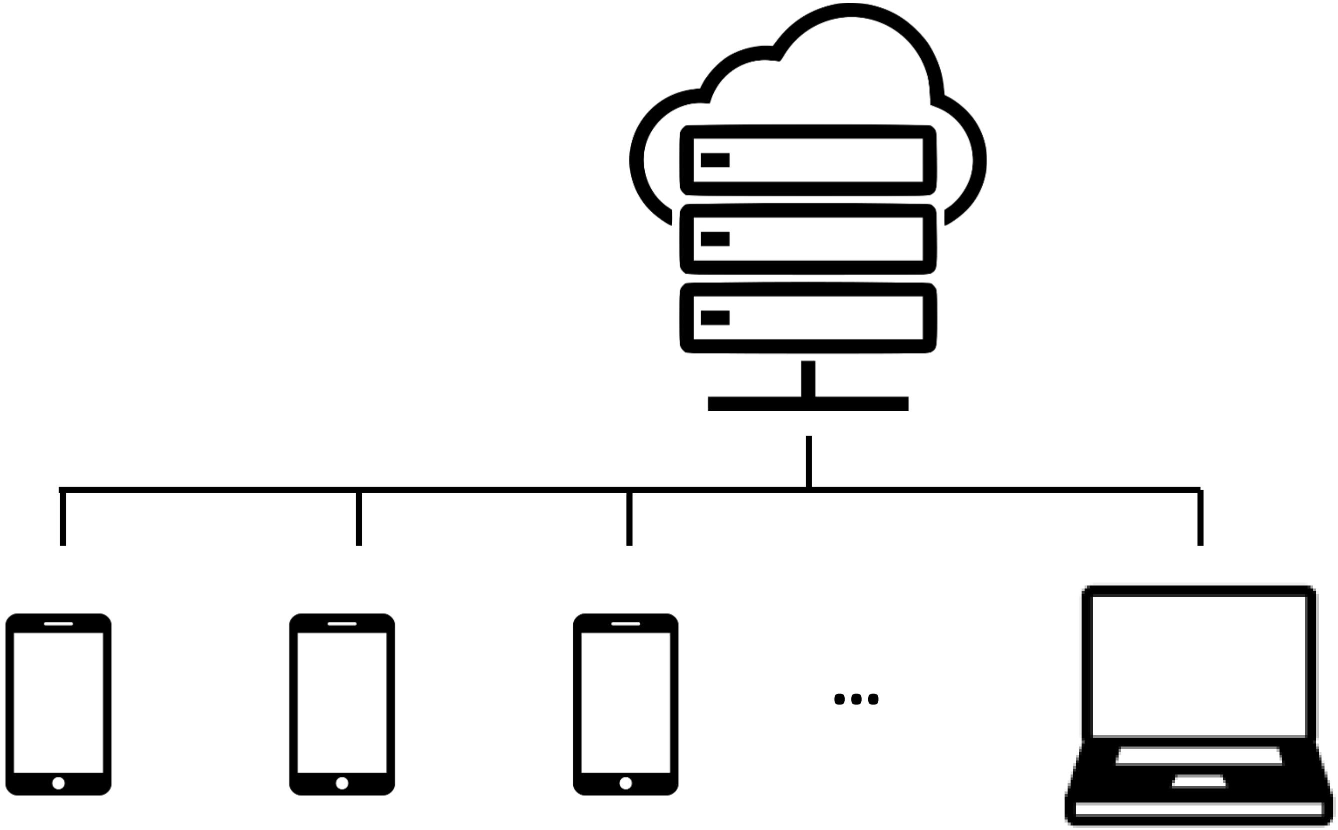
Query Services in Cloud Storage Systems

- **Large amounts of data**
  - **300 new profiles and more than 208 thousand photos per minute [September 2018@Facebook]**



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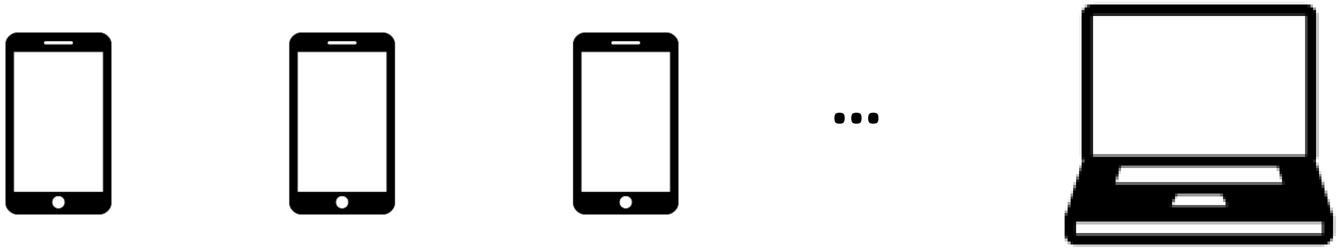
Demanding the support of low-latency and high-throughput queries



Hash structures

✓ **Constant-scale read performance**

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χ **High latency for handling hash collisions**

Cuckoo Hashing

- **Multi-choice hashing**
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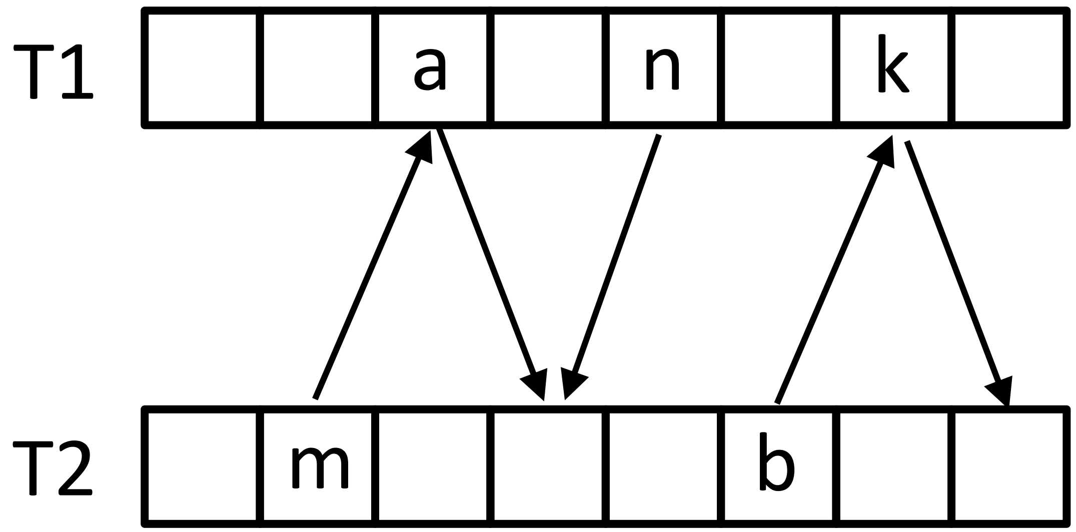

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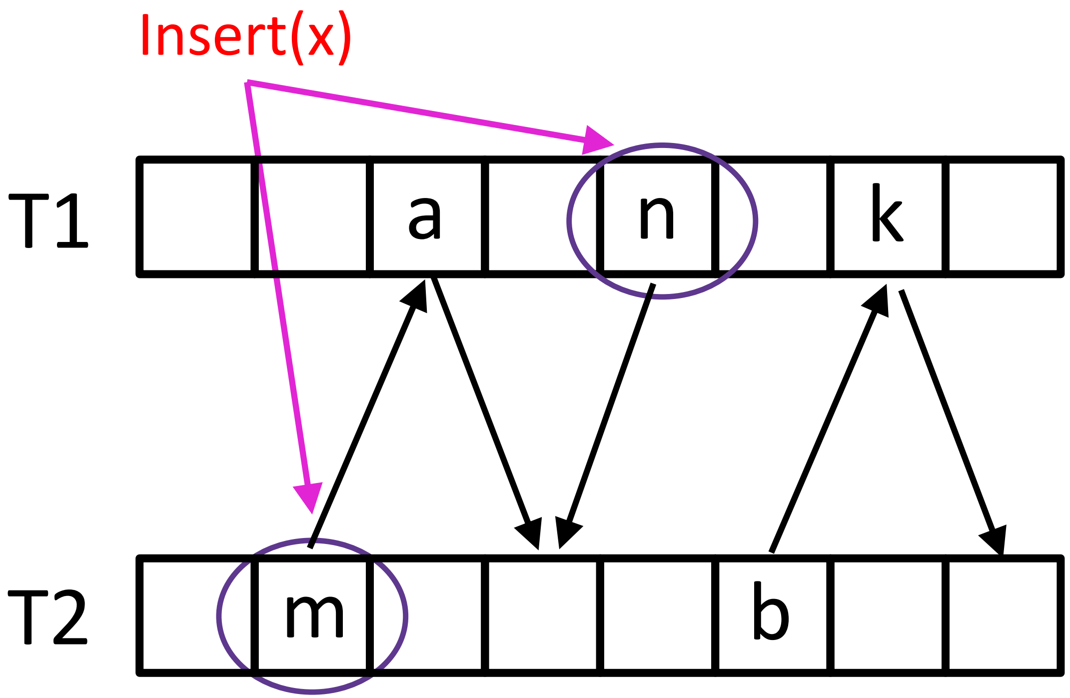

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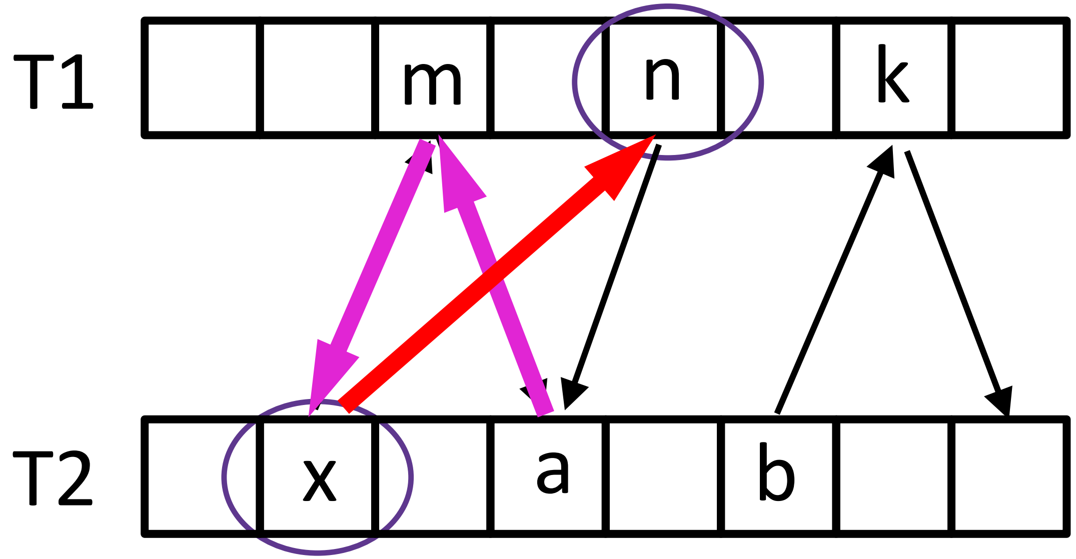

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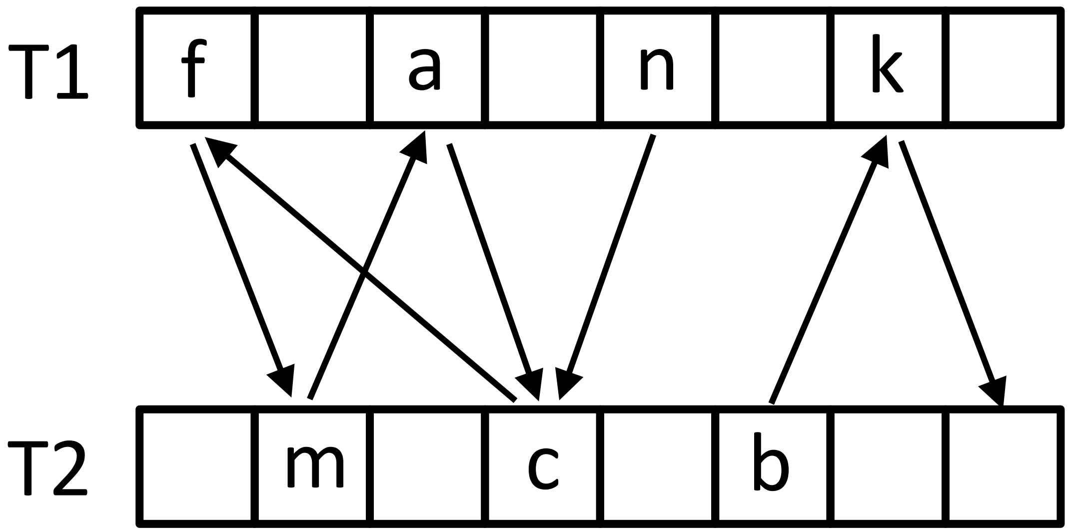

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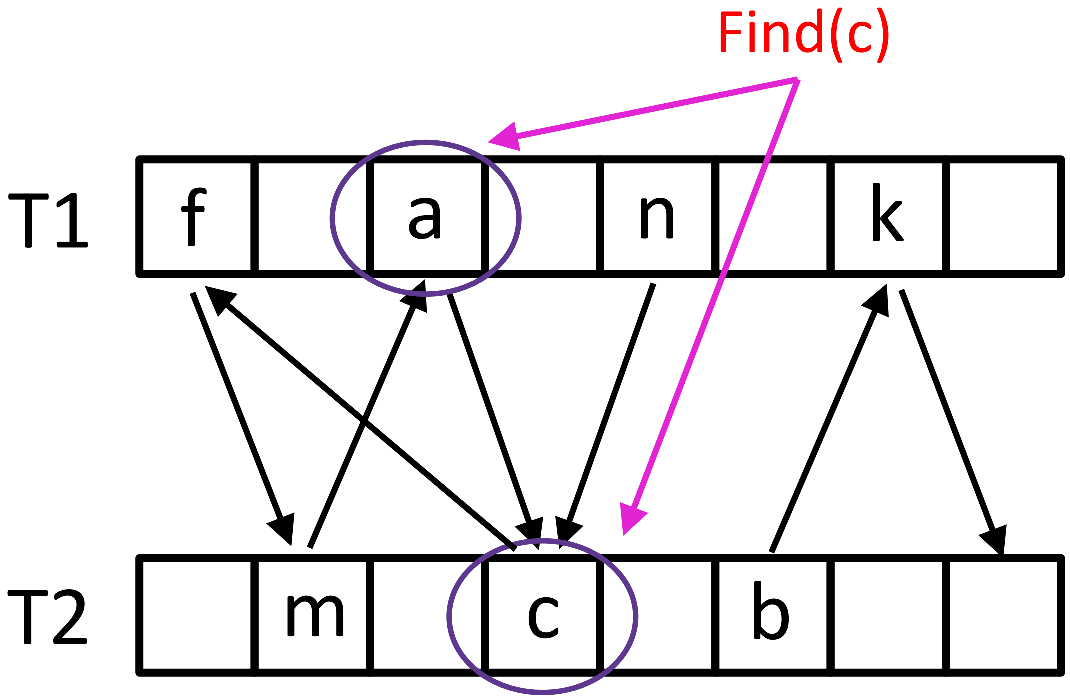

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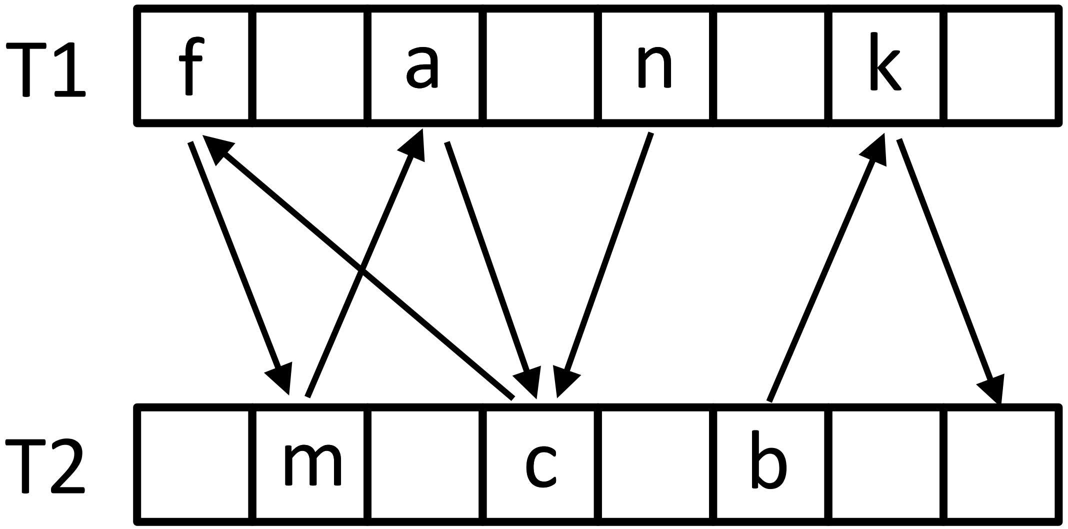

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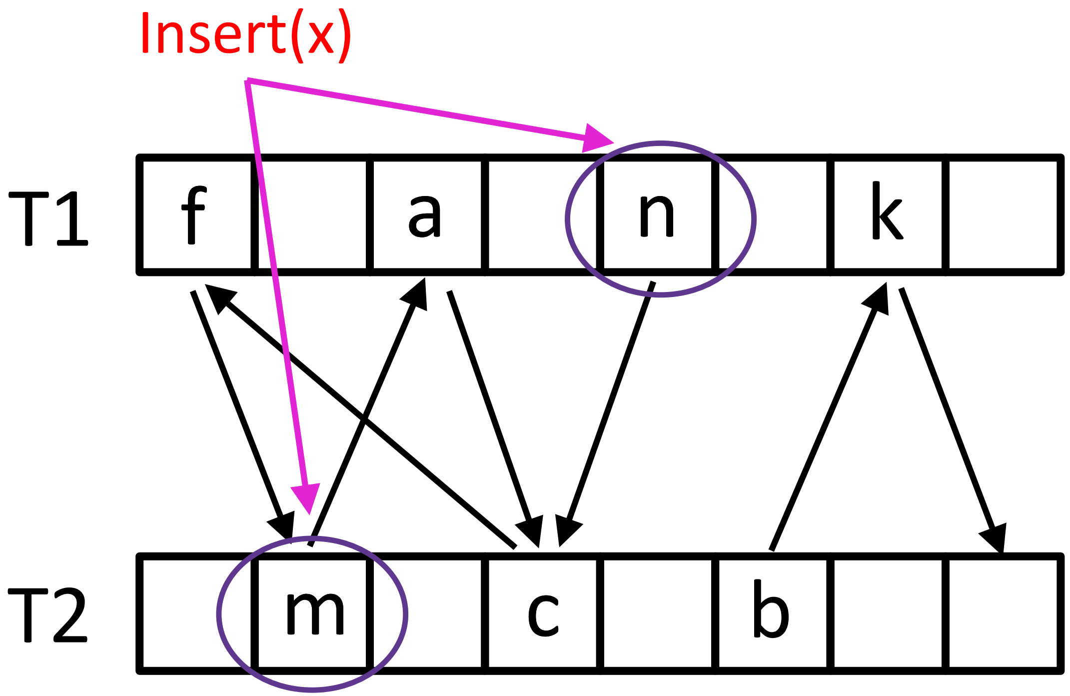

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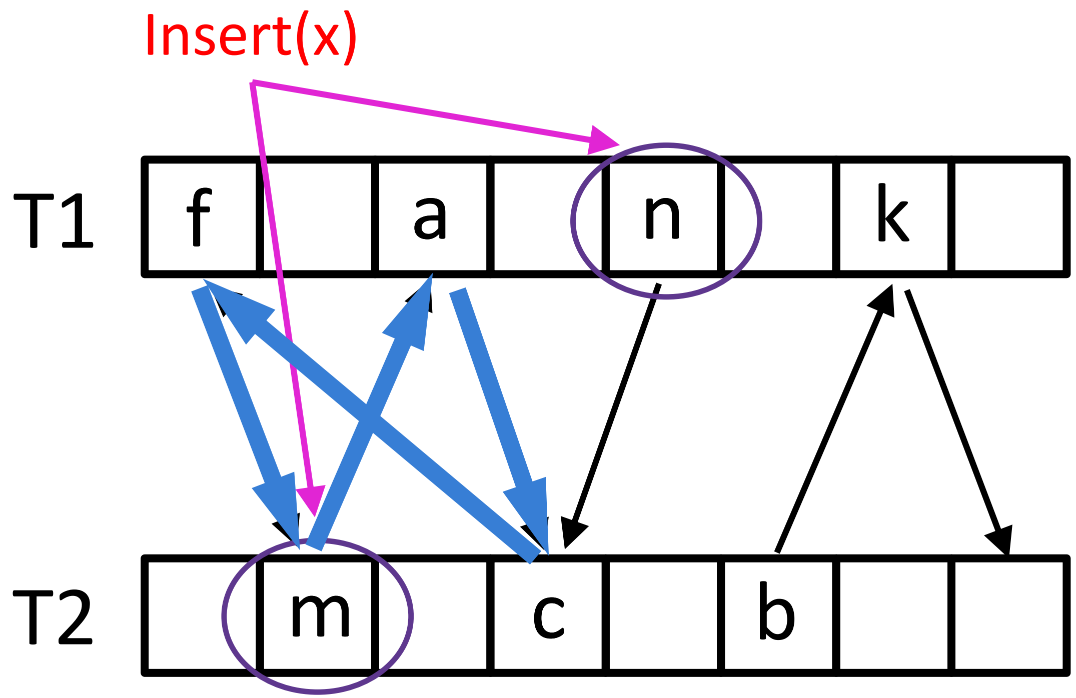

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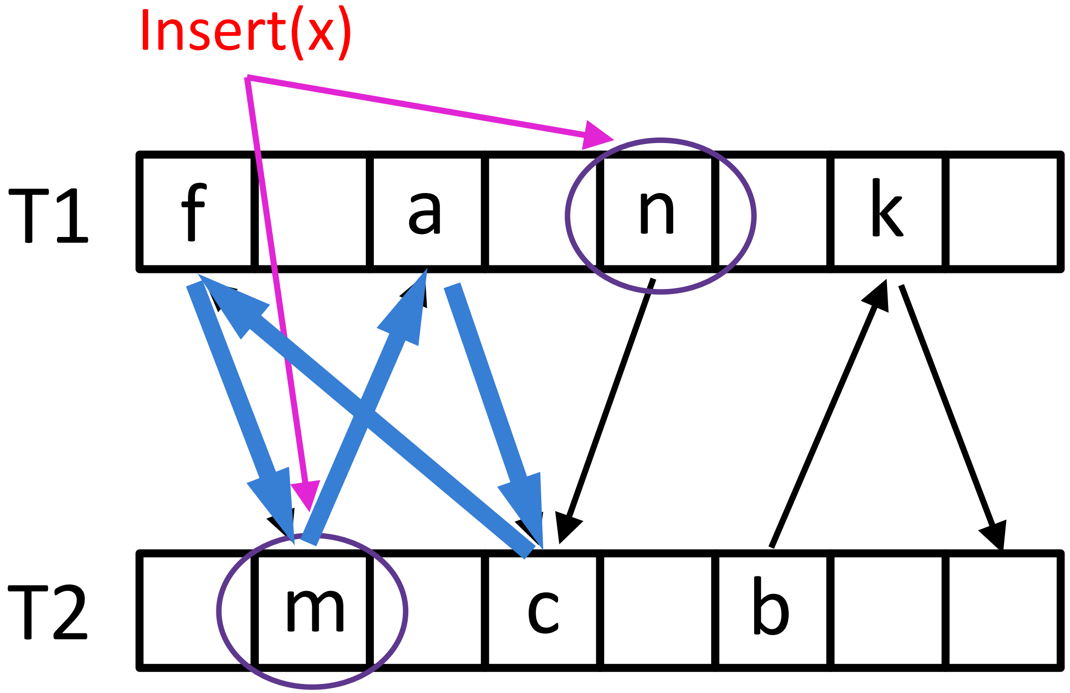

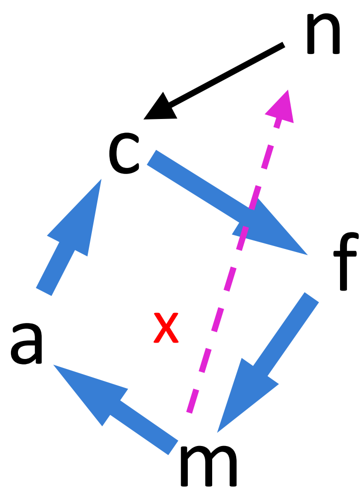

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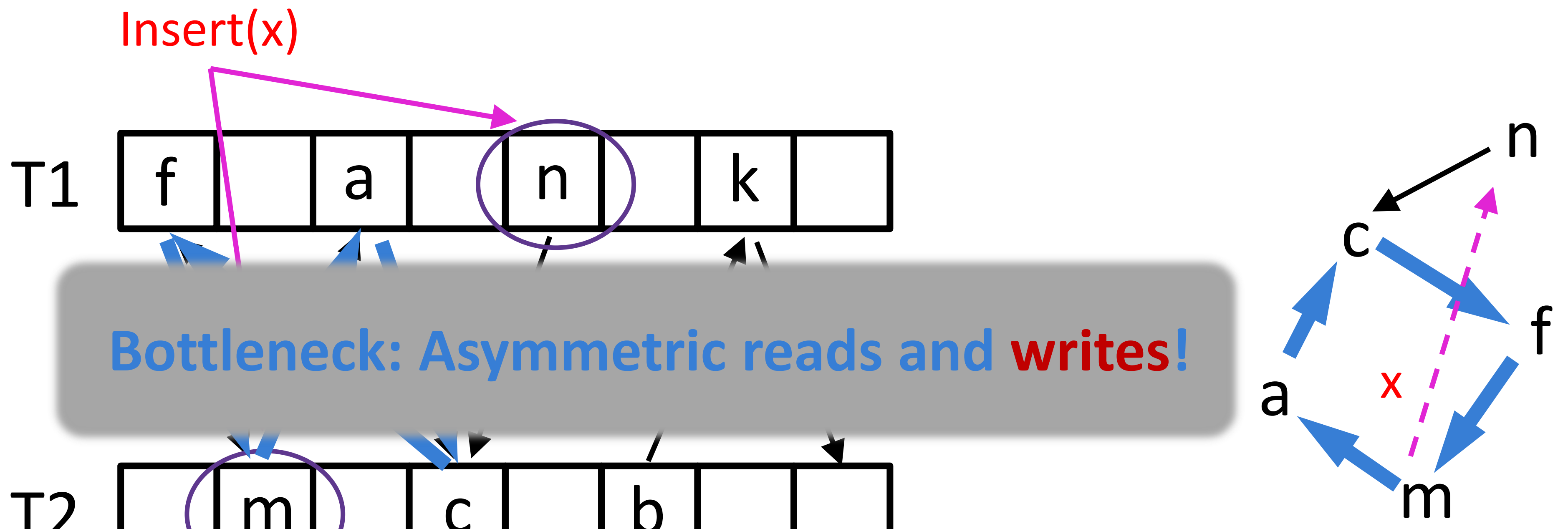

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Concurrency in Multi-core Systems

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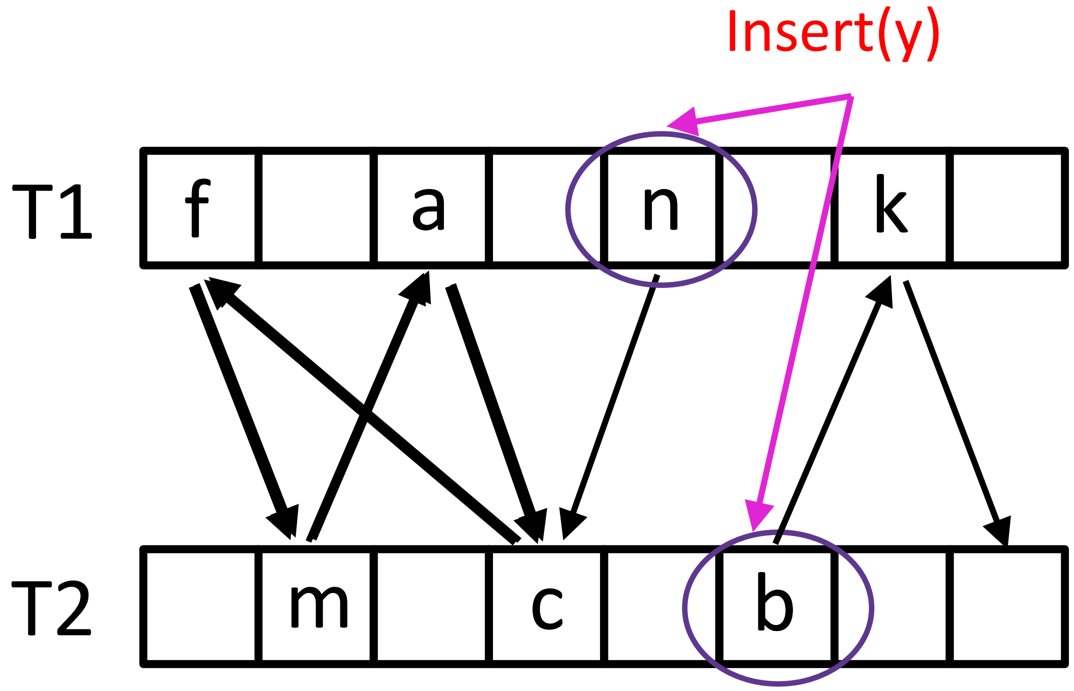
- **Design goal:**
  - **A high-throughput and concurrency-friendly cuckoo hash table**

Our Approach: CoCuckoo

- **Pseudoforests to predetermine endless loops**
- **Efficient concurrency strategy**
  - **A graph-grained locking mechanism**
  - **Concurrency optimization to reduce the length of critical path**
- **Higher throughput than state-of-the-art scheme, i.e., libcuckoo**

Pseudoforest

- **Vertex: a bucket**
- **Edge: an inserted item from the storage vertex to its backup vertex**
- **Identify endless loops: #Vertices = #Edges (called maximal)**



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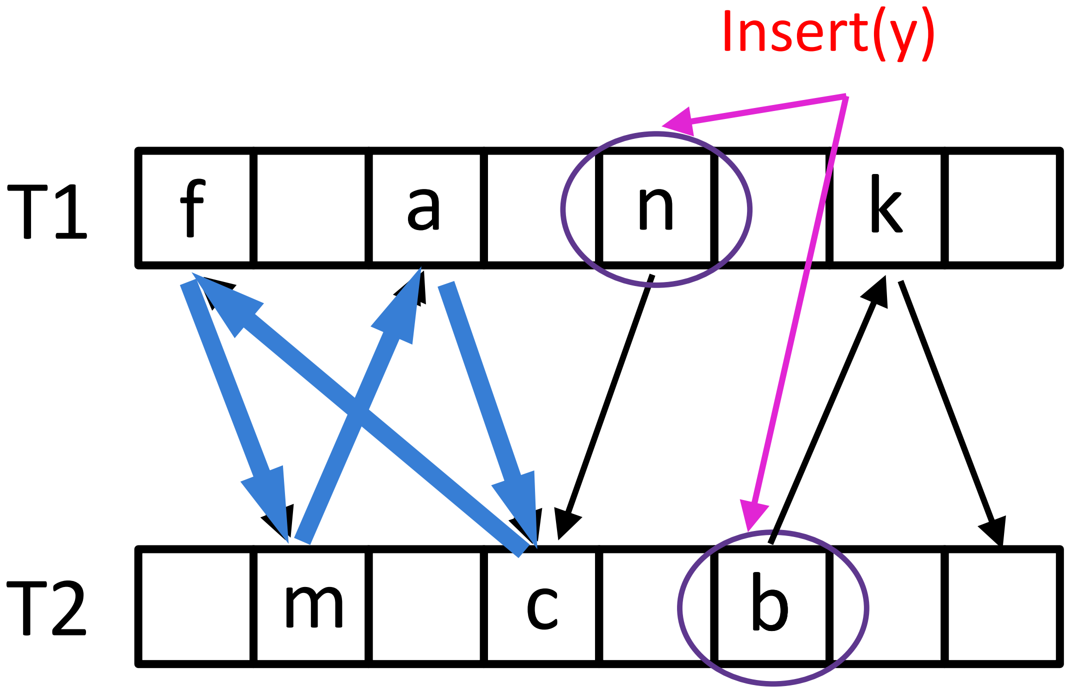

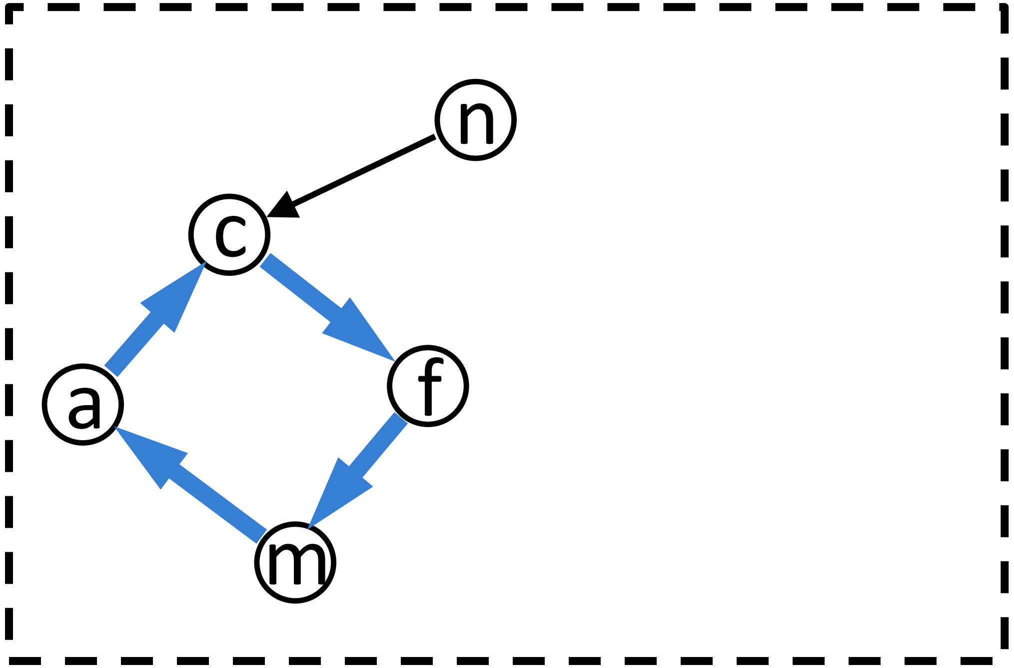

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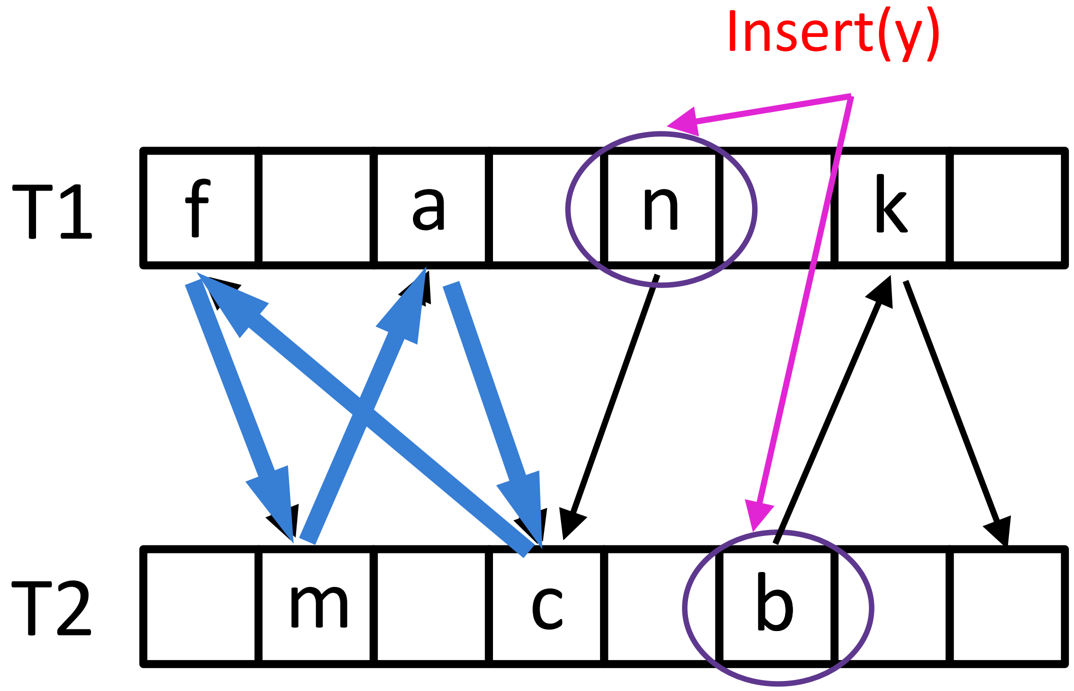

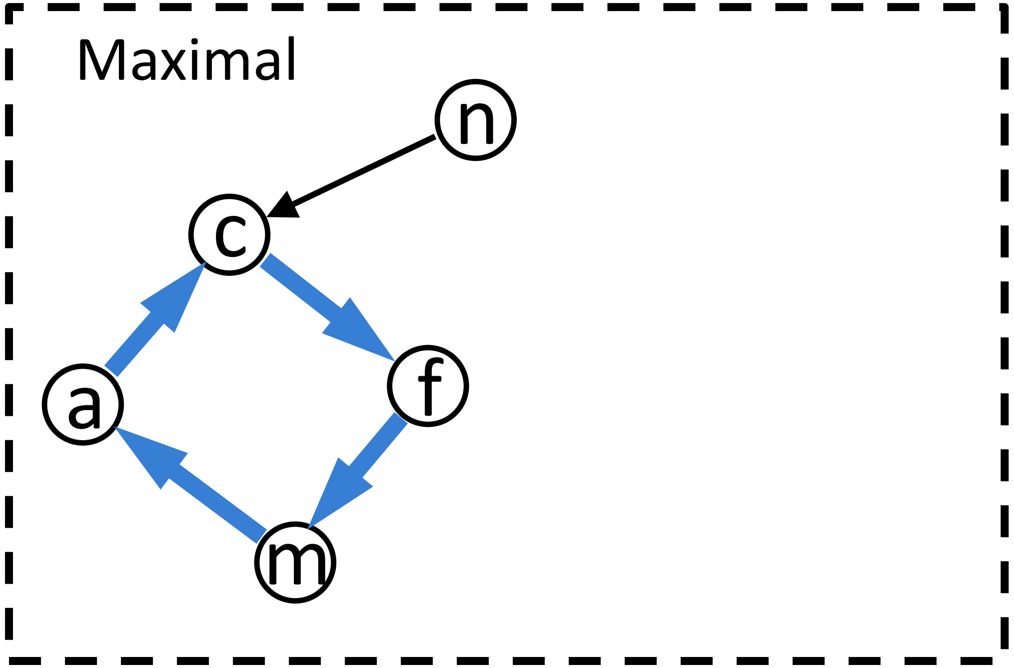

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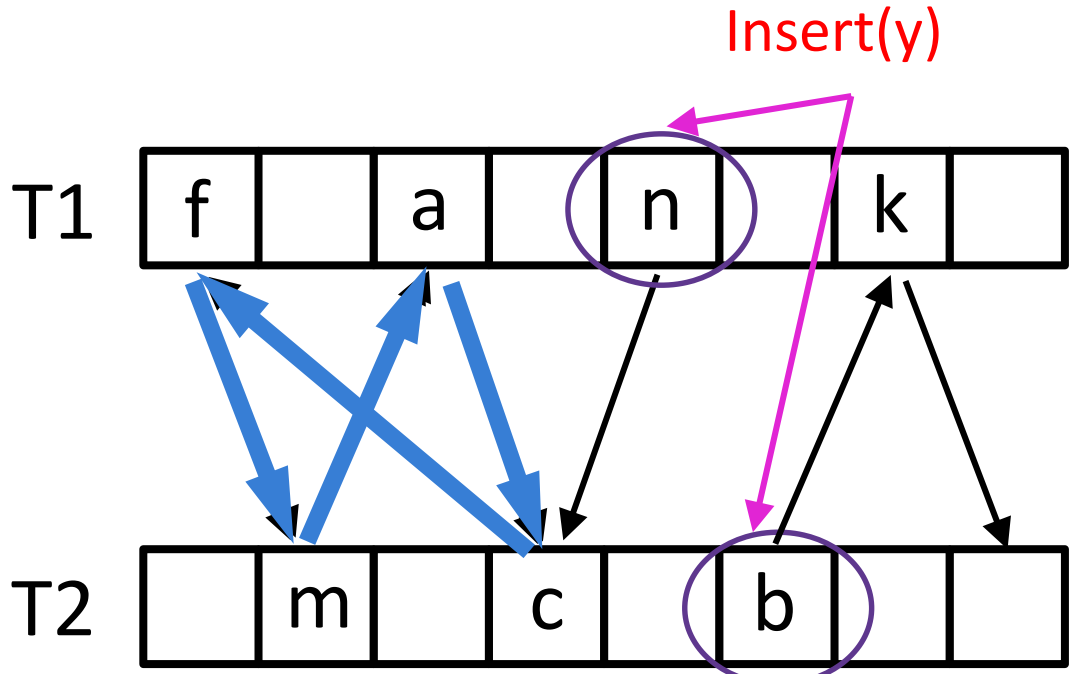

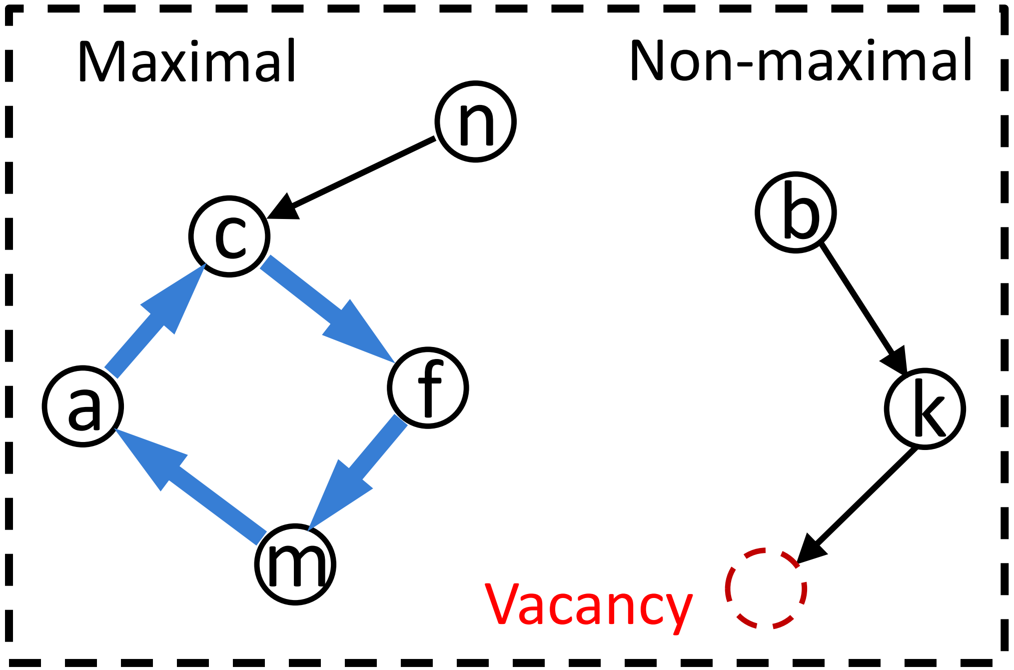

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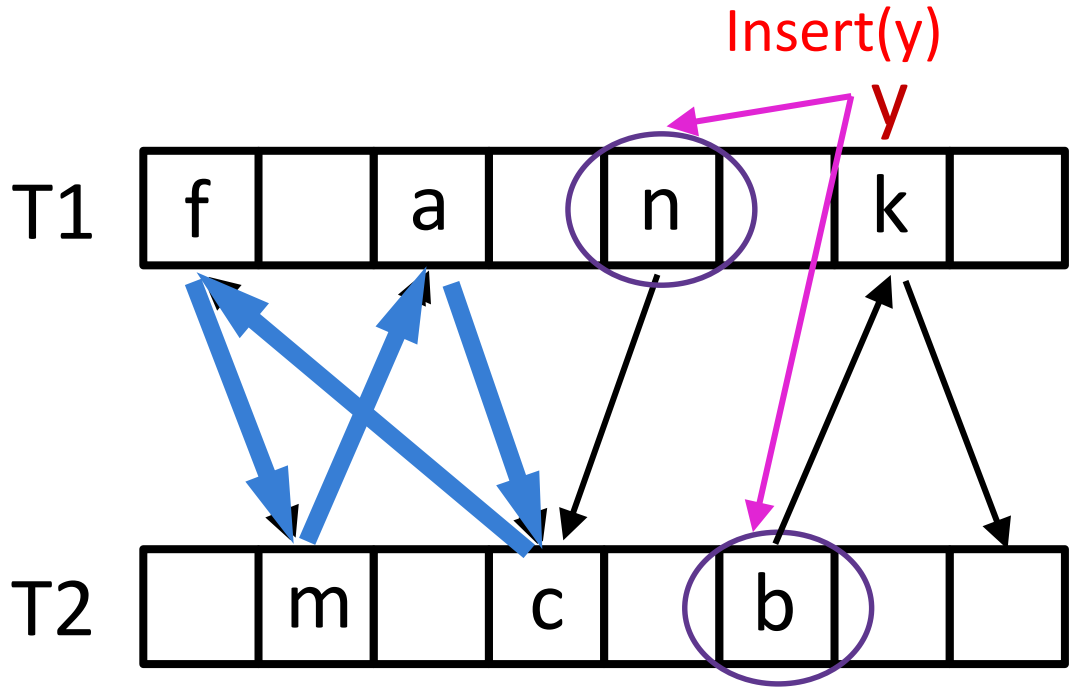

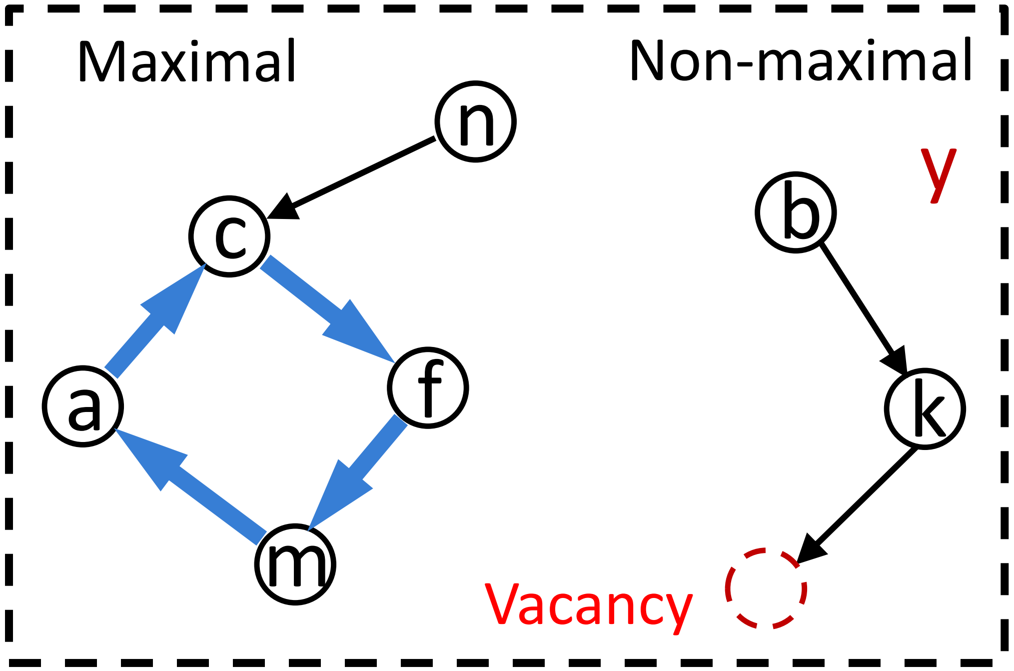

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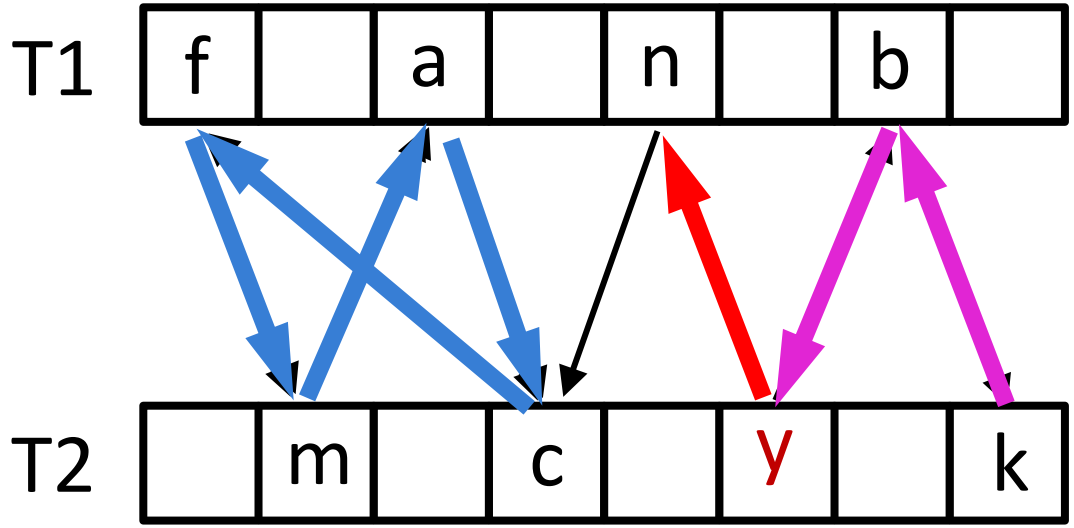
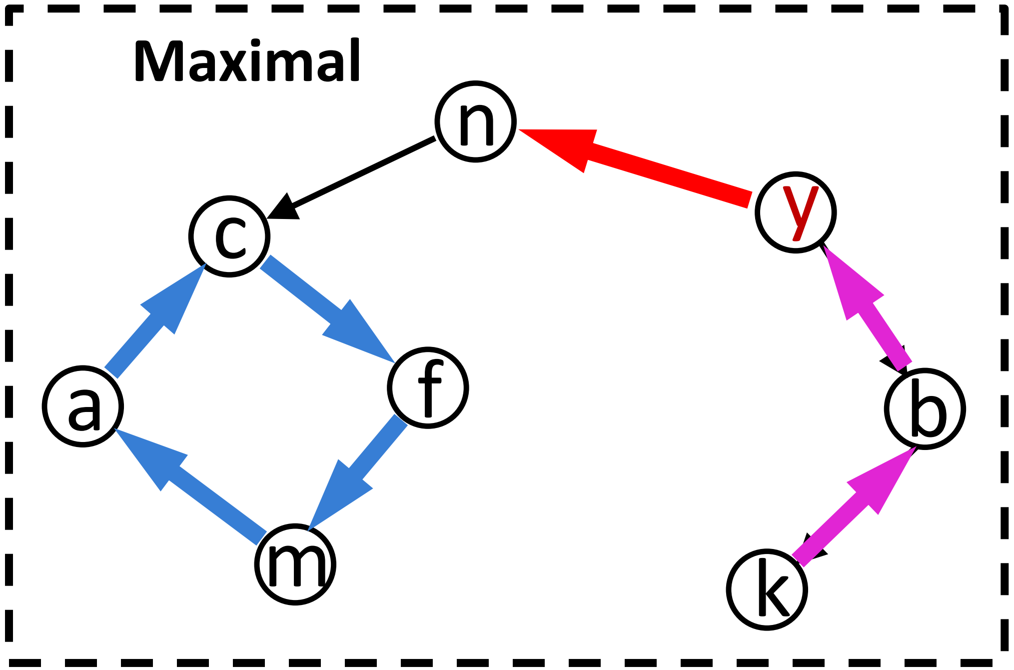
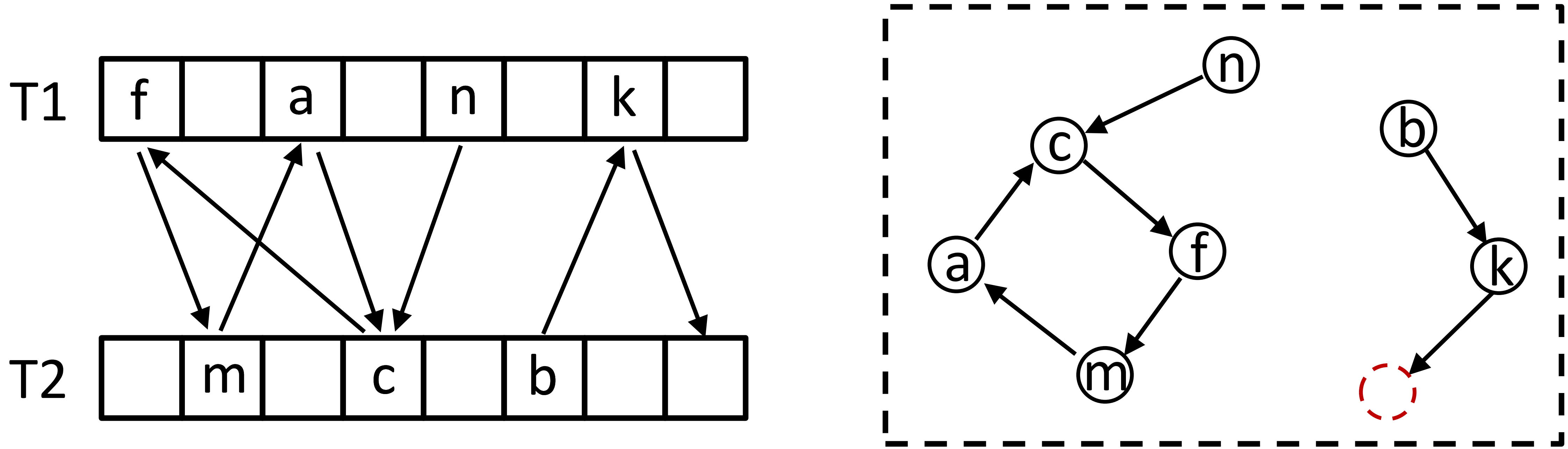




Graph-grained Locking

- **EMPTY subgraph**: buckets not represented in pseudoforest



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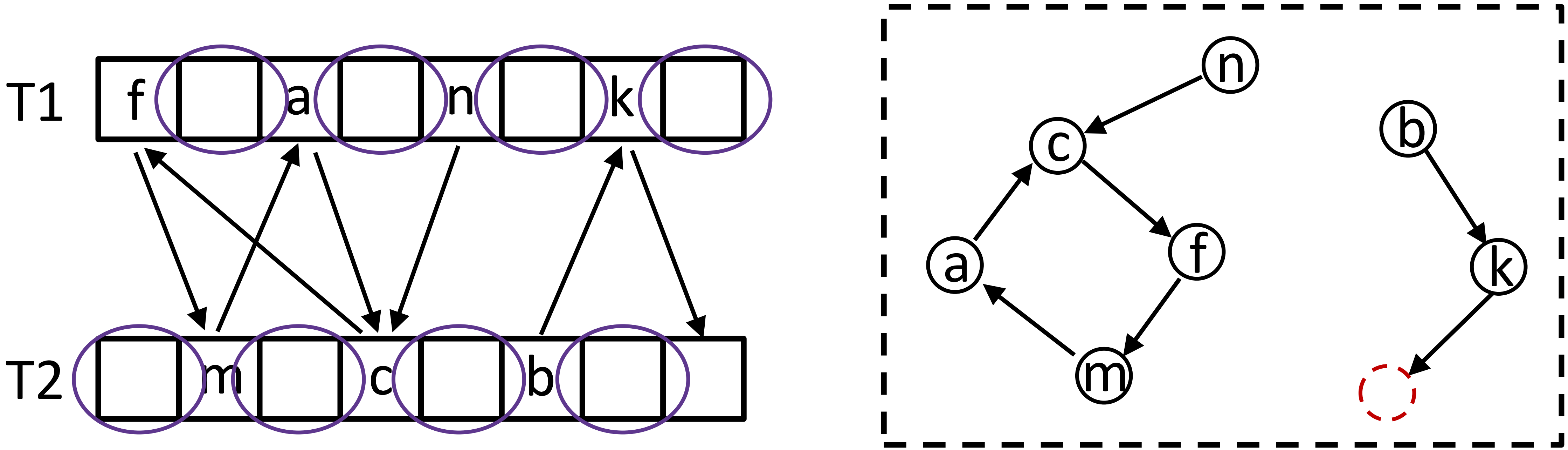

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- **Classify insertions into 3 cases, which include 6 subcases**

○ EMPTY
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● Maximal

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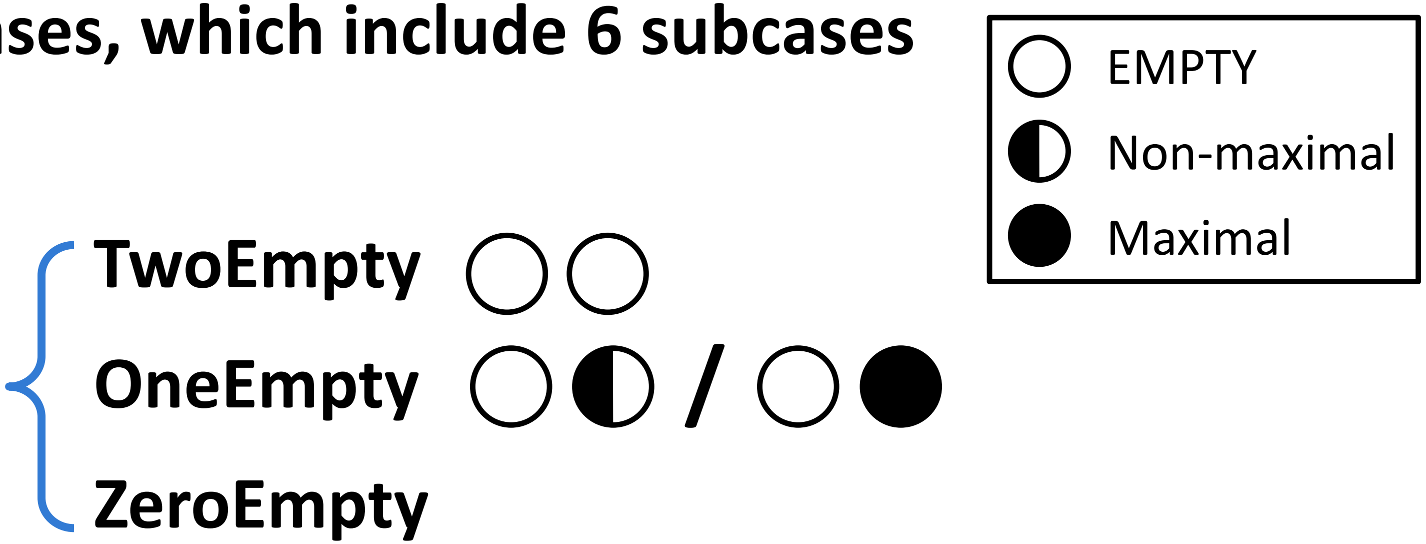

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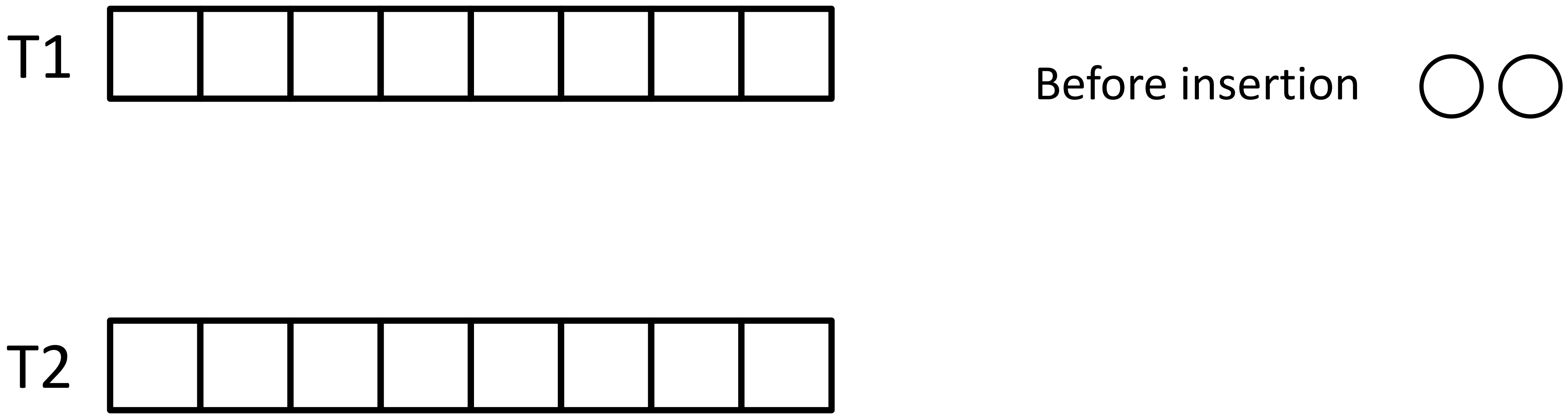
According to the number of corresponding EMPTY subgraphs

- **TwoEmpty** ○ ○
- **OneEmpty** ○ ◐ / ○ ●
- **ZeroEmpty**
  - **Diff_non_non** ◐ ◐
  - **Same_non** ◐
  - **Diff_non_max** ◐ ●
  - **Max** ● ● / ●

According to the states and the number of subgraphs

TwoEmpty

- **Two EMPTY subgraphs**

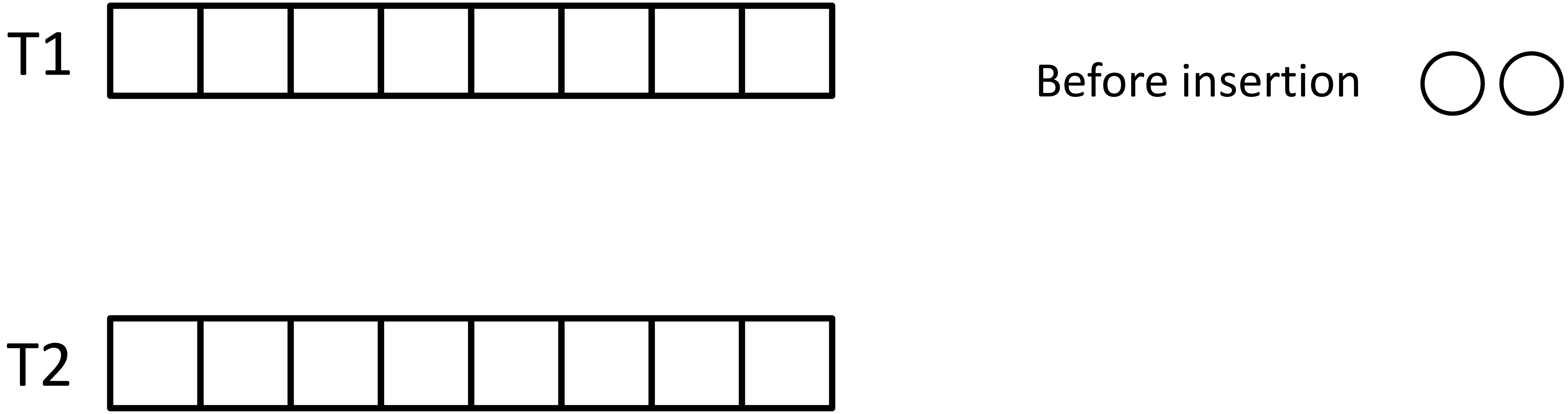


TwoEmpty

- **Two EMPTY subgraphs**
- **Insertion algorithm:**
  - **Atomically assign allocated subgraph number to two buckets**
  - **Insert item**
  - **Mark the subgraph as non-maximal**

critical path

With graph-grained lock(s)
Out of the critical path



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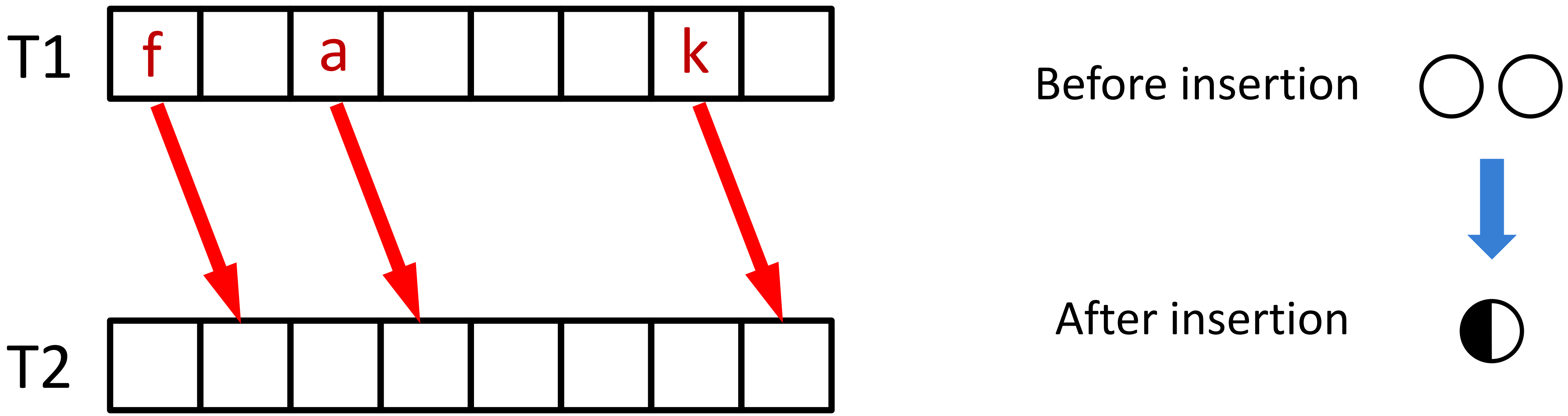

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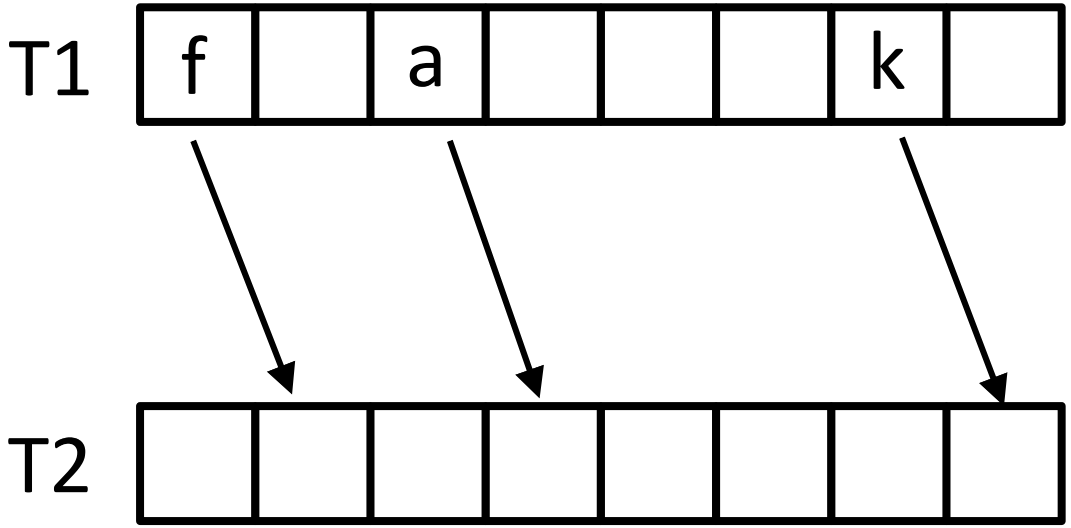
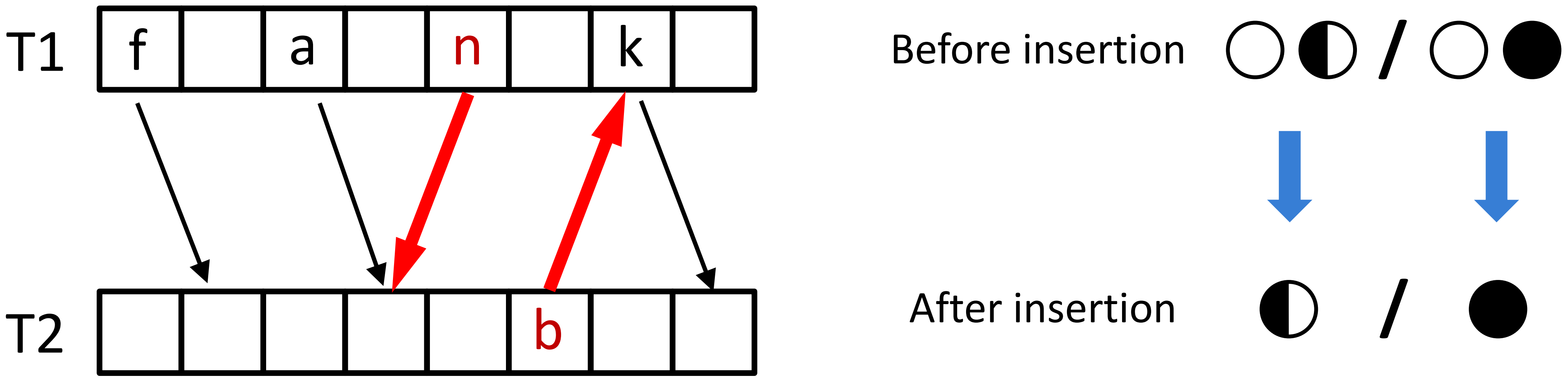
➢ **One EMPTY subgraph (the other is non-maximal/maximal)**



Before insertion ○◐ / ○●

OneEmpty ○◐ / ○●

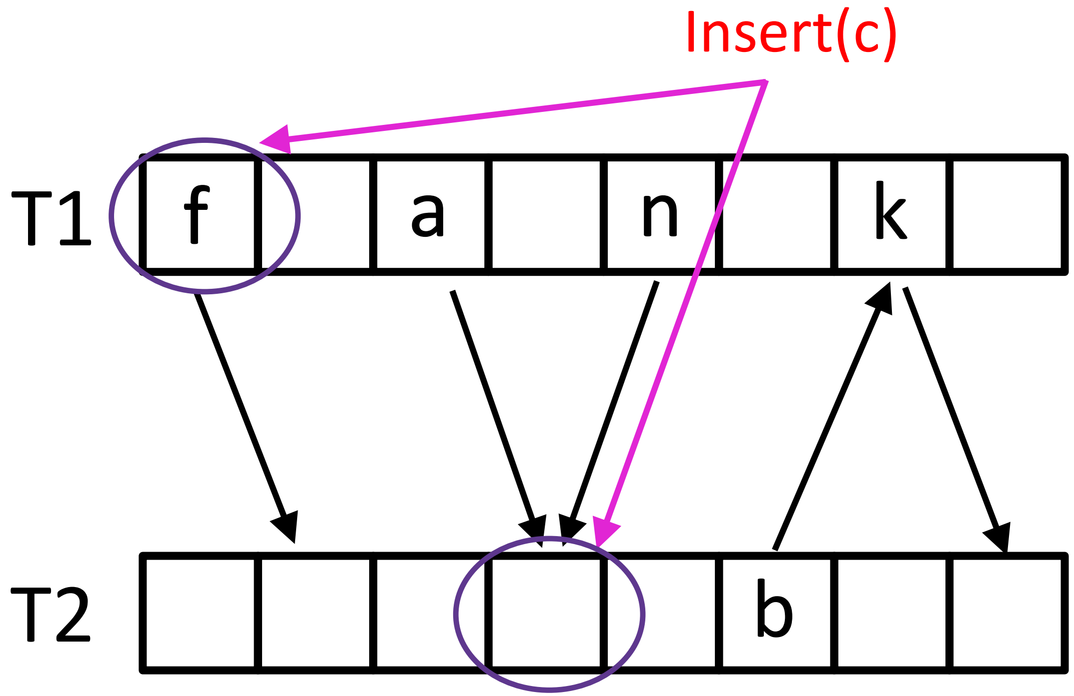
- **One EMPTY subgraph (the other is non-maximal/maximal)**
- **Insertion algorithm:**
  - ✓ **Two atomic operations without locks**
    - **Assign the existing subgraph number to the new vertex**
    - **Insert the item into the new vertex**



ZeroEmpty (Diff_non_non) ◐◐

- **Two different non-maximal subgraphs**
- **Insertion algorithm:**
  - **Kick-out (with item insertion)**
  - **Merge two subgraphs**

Before insertion ◐◐



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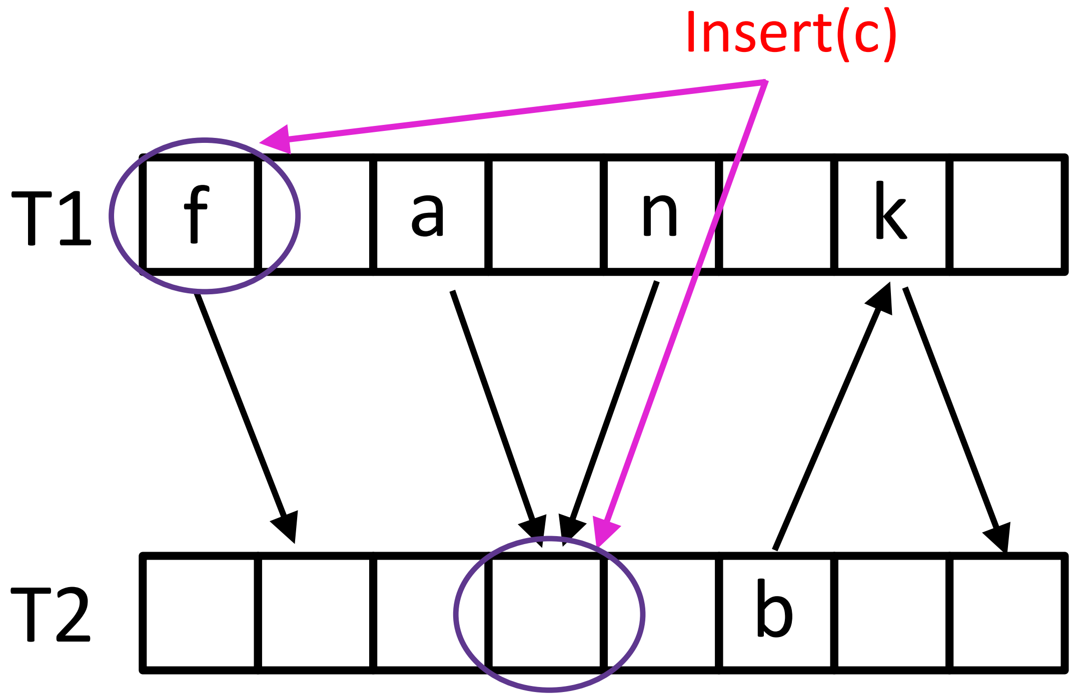

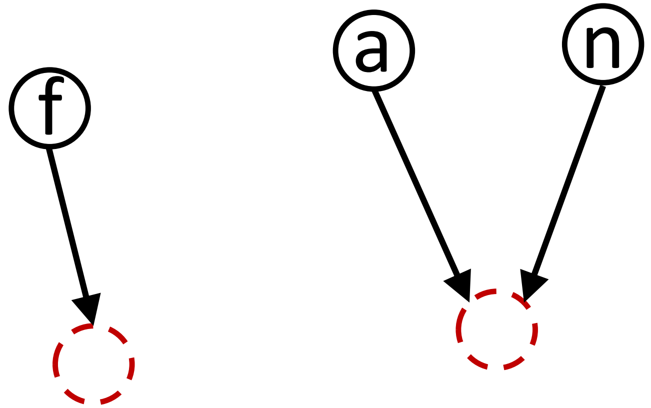

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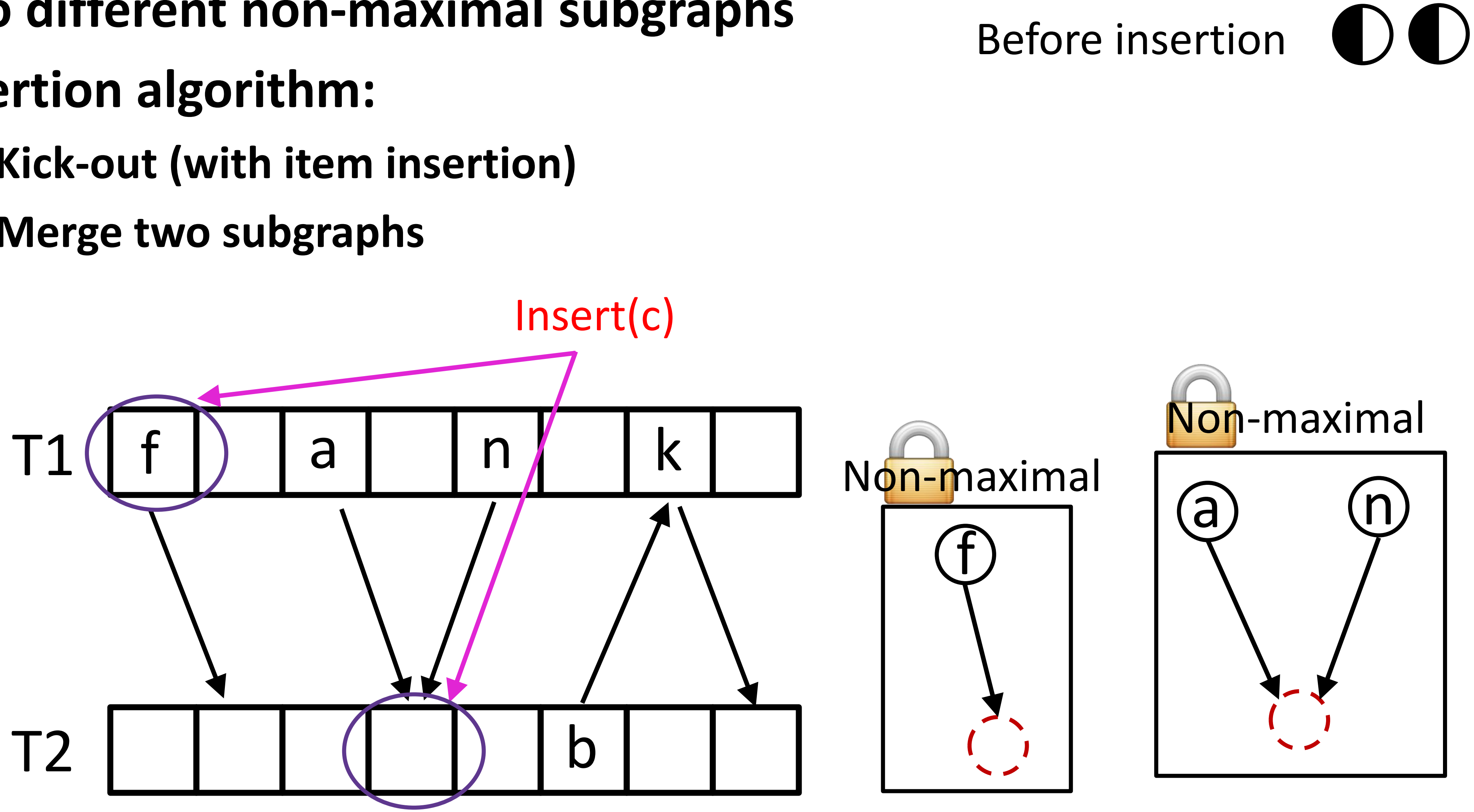

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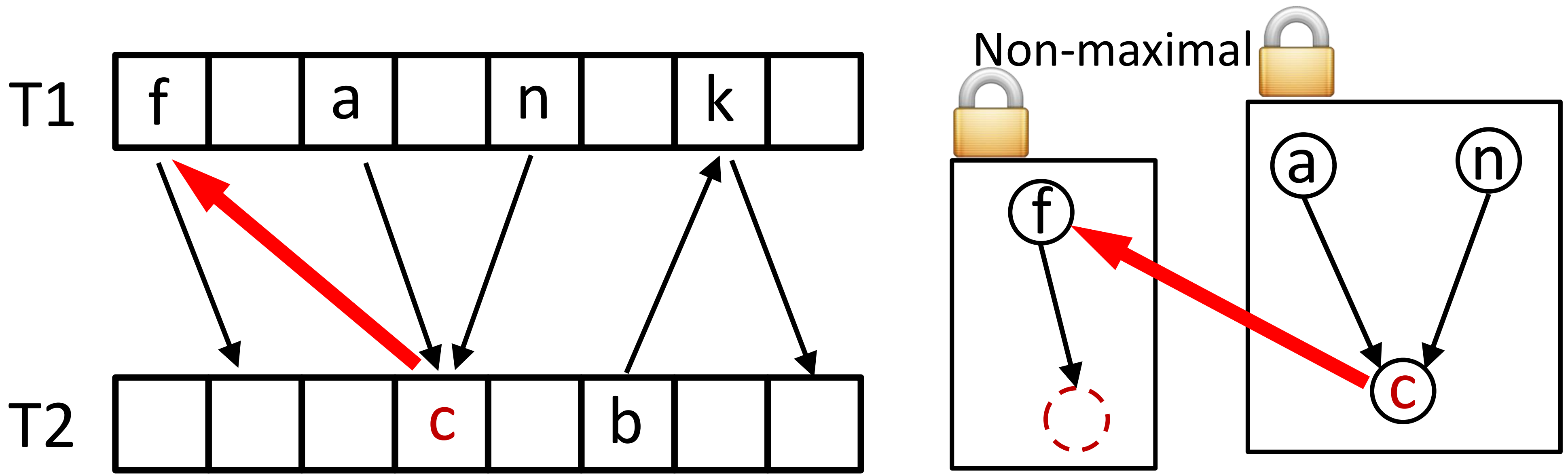

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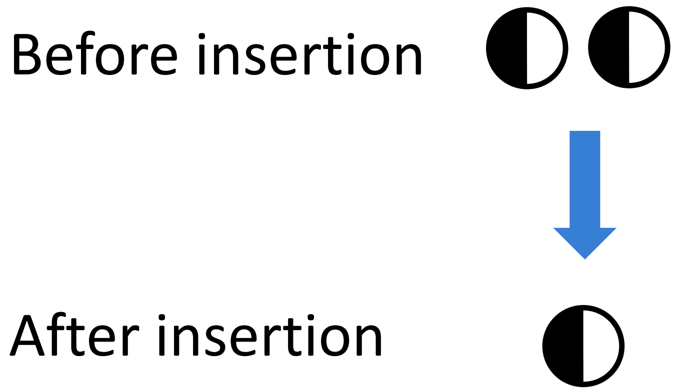
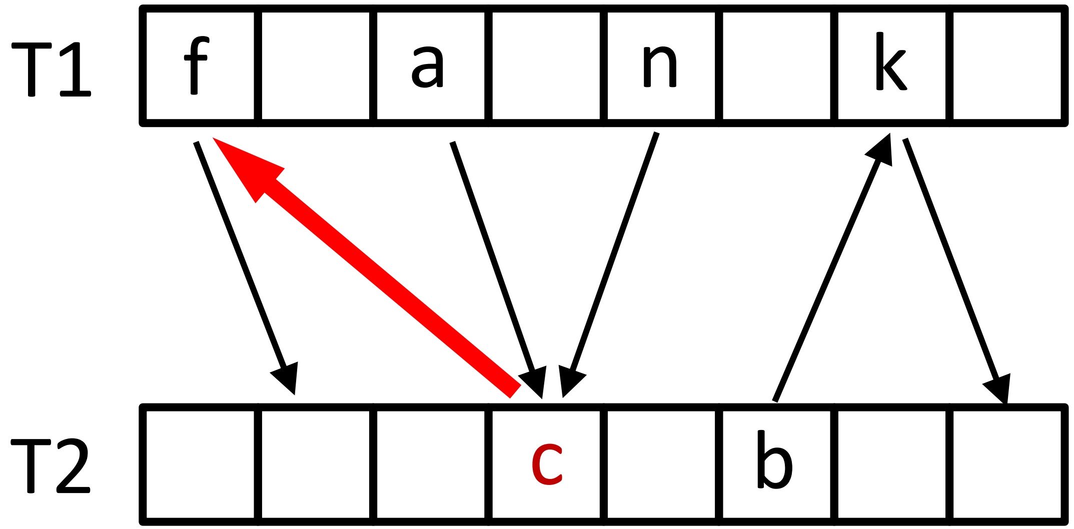
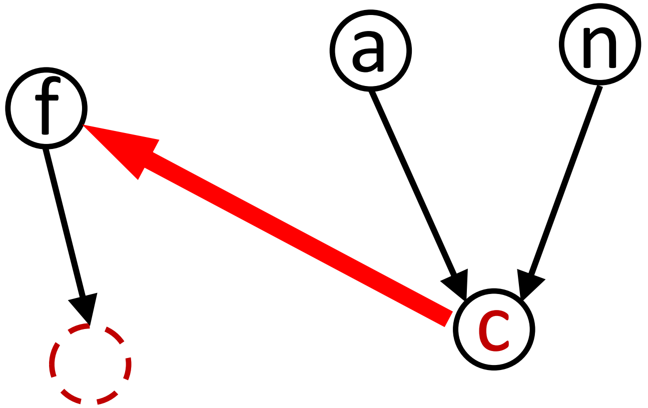




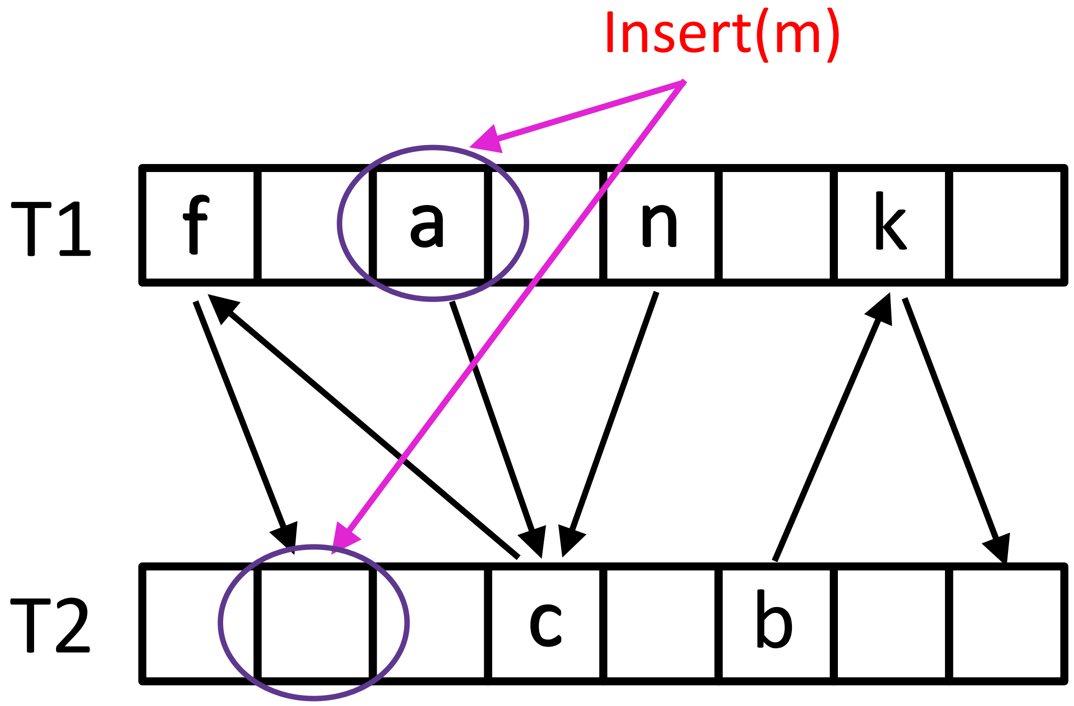
Non-maximal



ZeroEmpty (Same_non) ◐

- The same non-maximal subgraph
- Insertion algorithm:
  - 🔒 Mark as maximal
  - ✓ Kick-out (with item insertion)

Before insertion ◐



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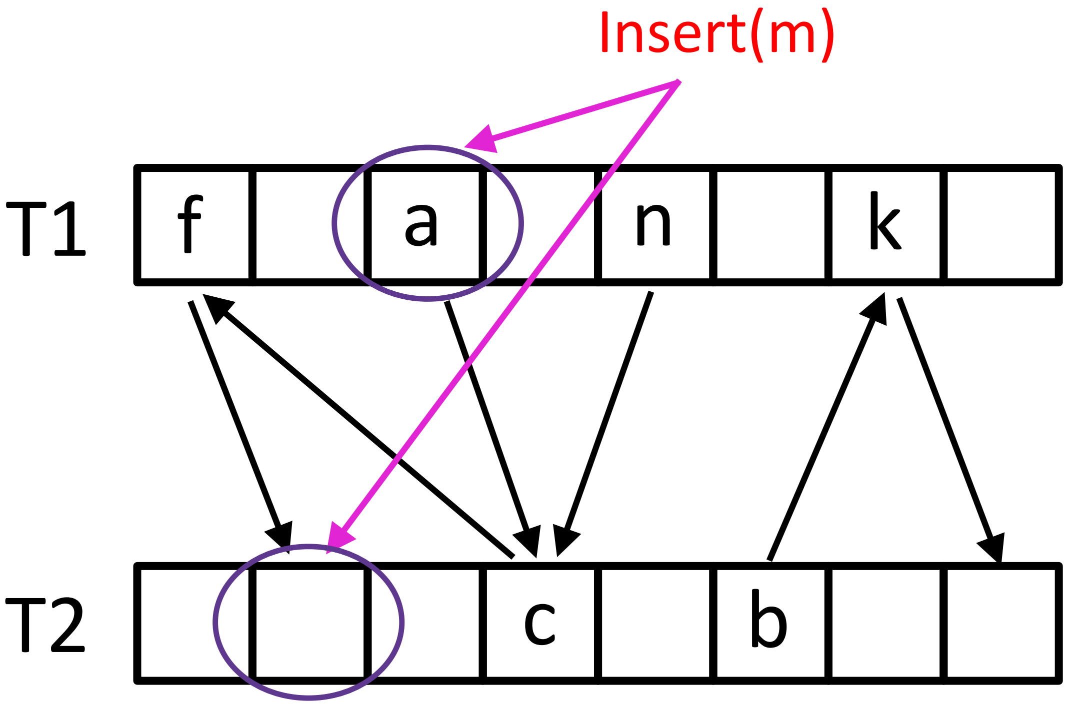

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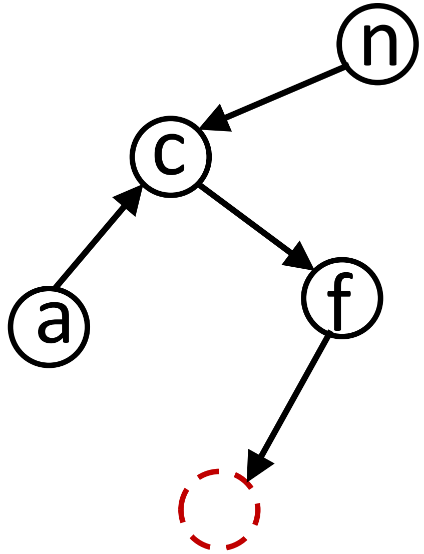

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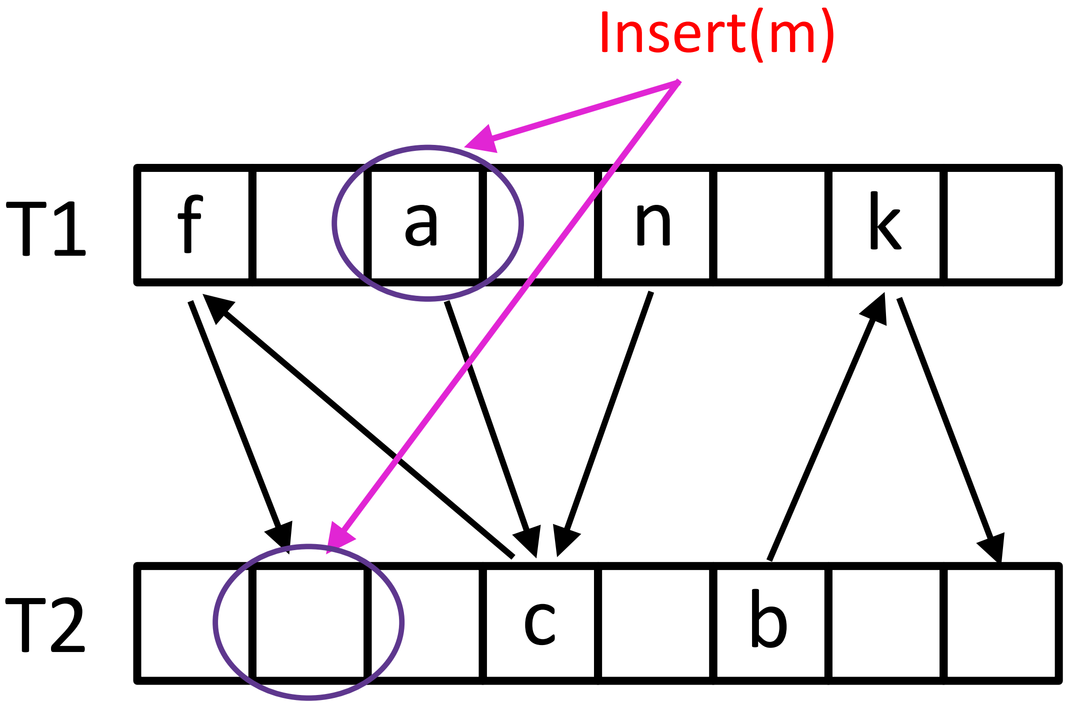

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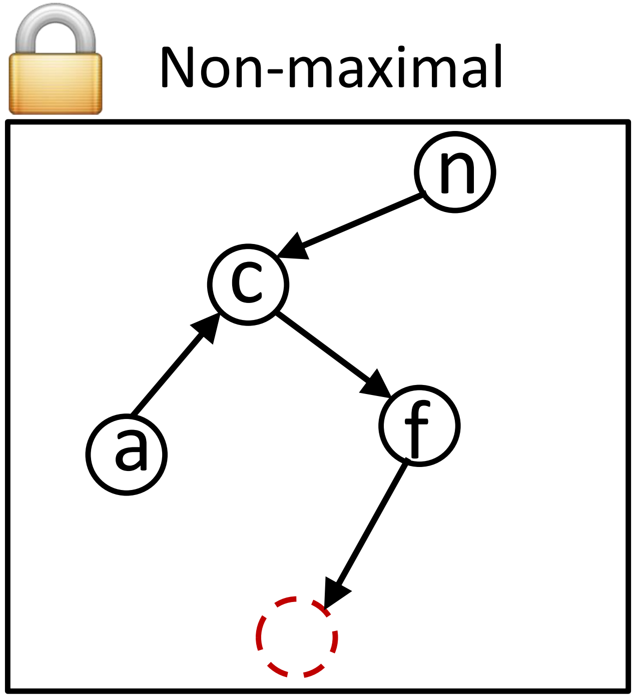

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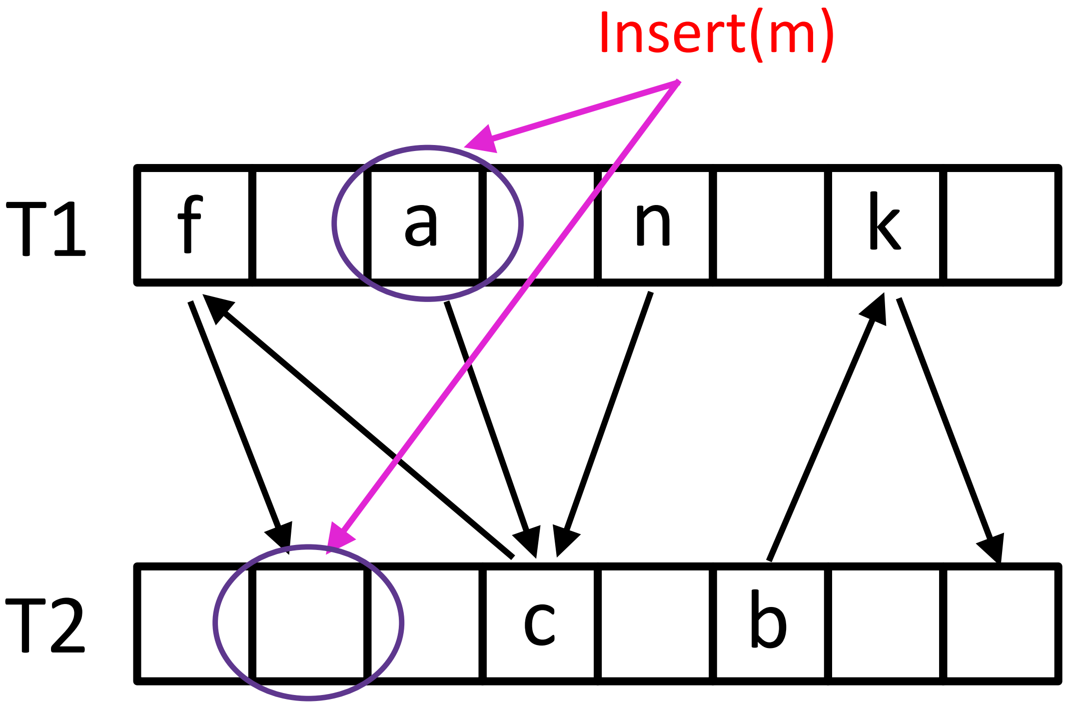

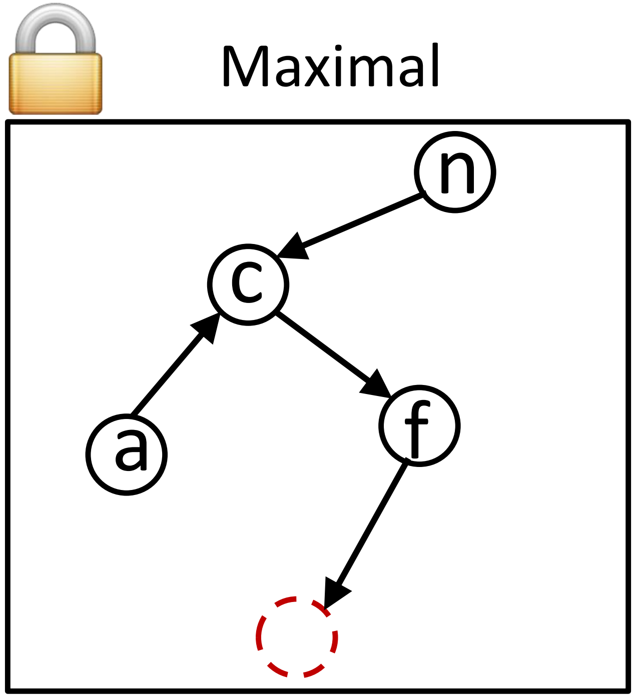

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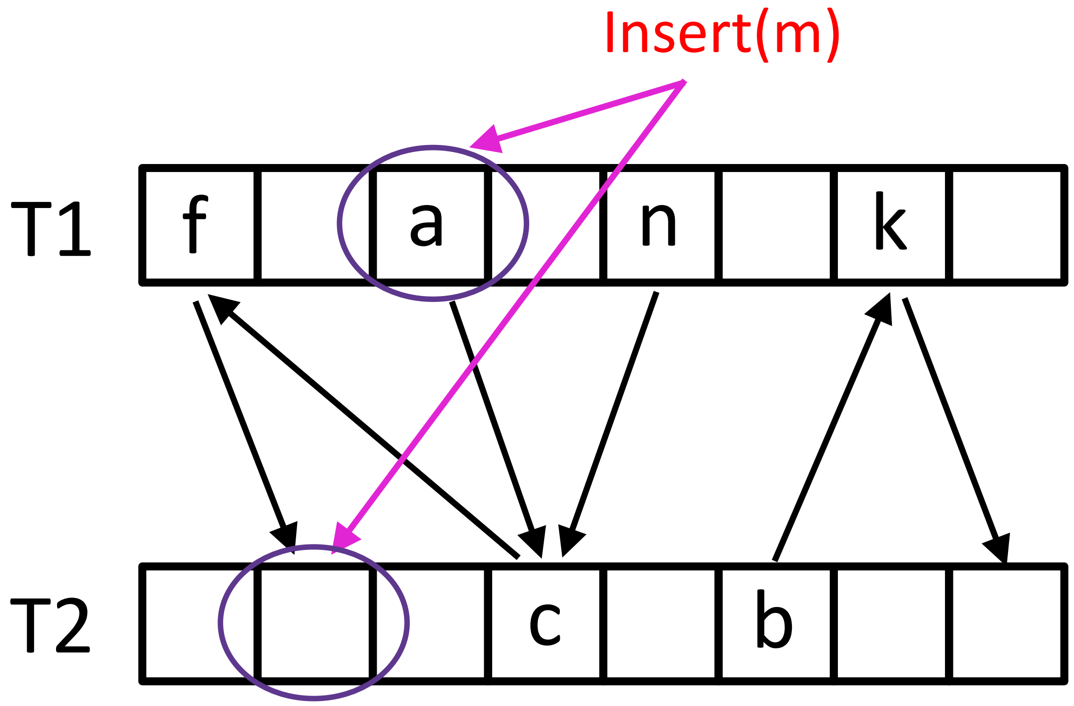

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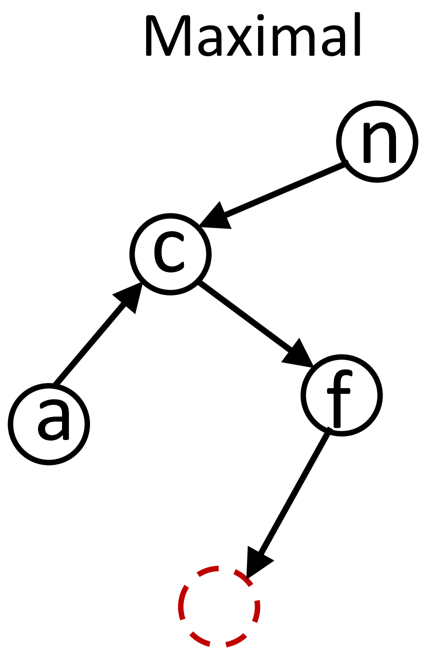

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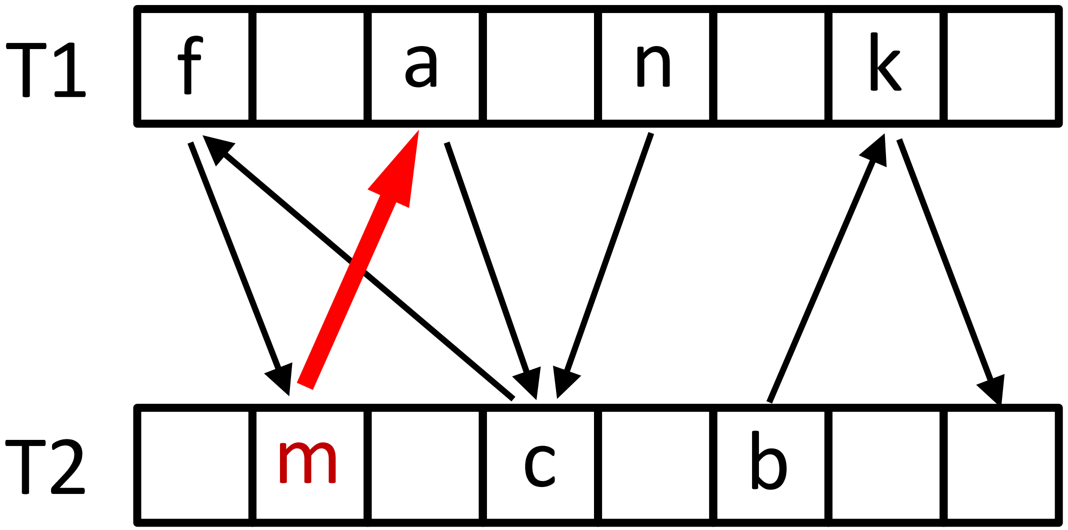
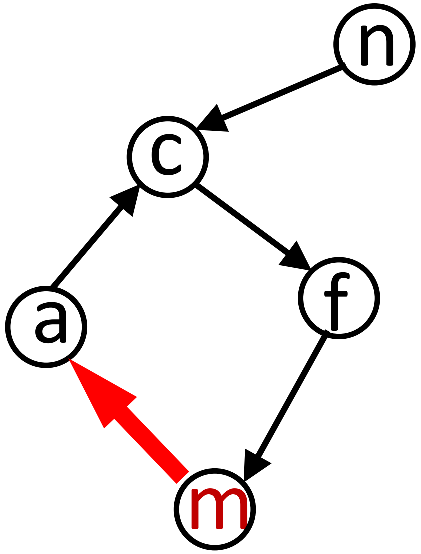
Before insertion ◐

After insertion ●

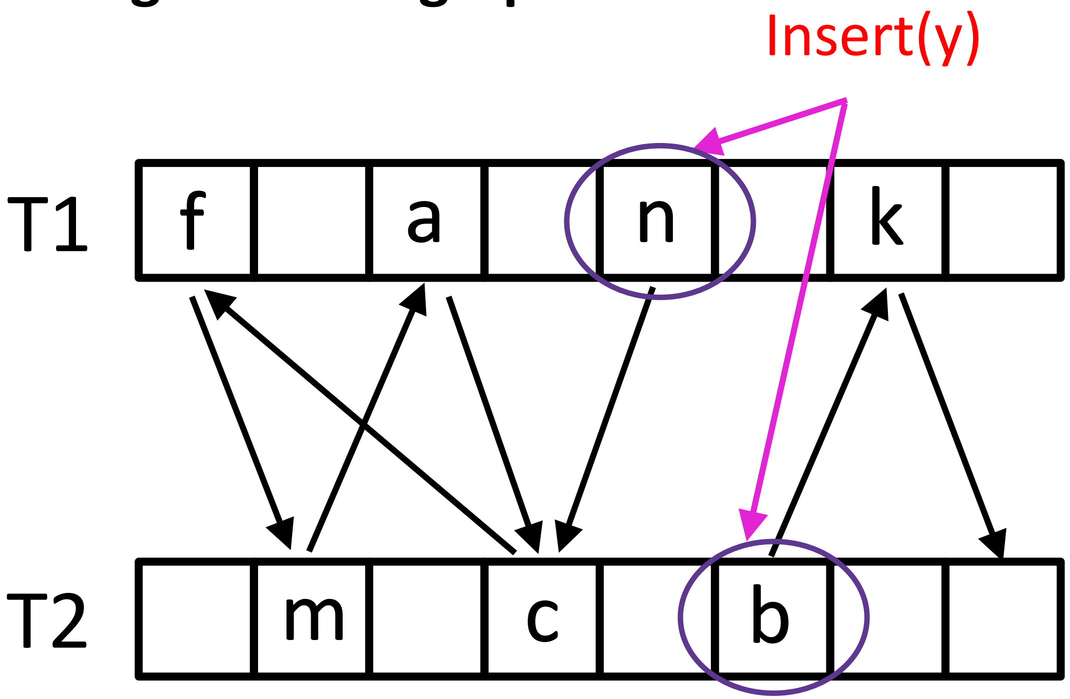


Maximal



ZeroEmpty (Diff_non_max) ◐ ●

- ➢ **One non-maximal subgraph and one maximal subgraph** ◐ ●
- ➢ **Insertion algorithm (similar to same_non):**
  - 🔒 **Mark as maximal**
  - ✓ **Kick-out (with item insertion)**
  - ✓ **Merge two subgraphs**



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- One non-maximal subgraph and one maximal subgraph ◐ ●
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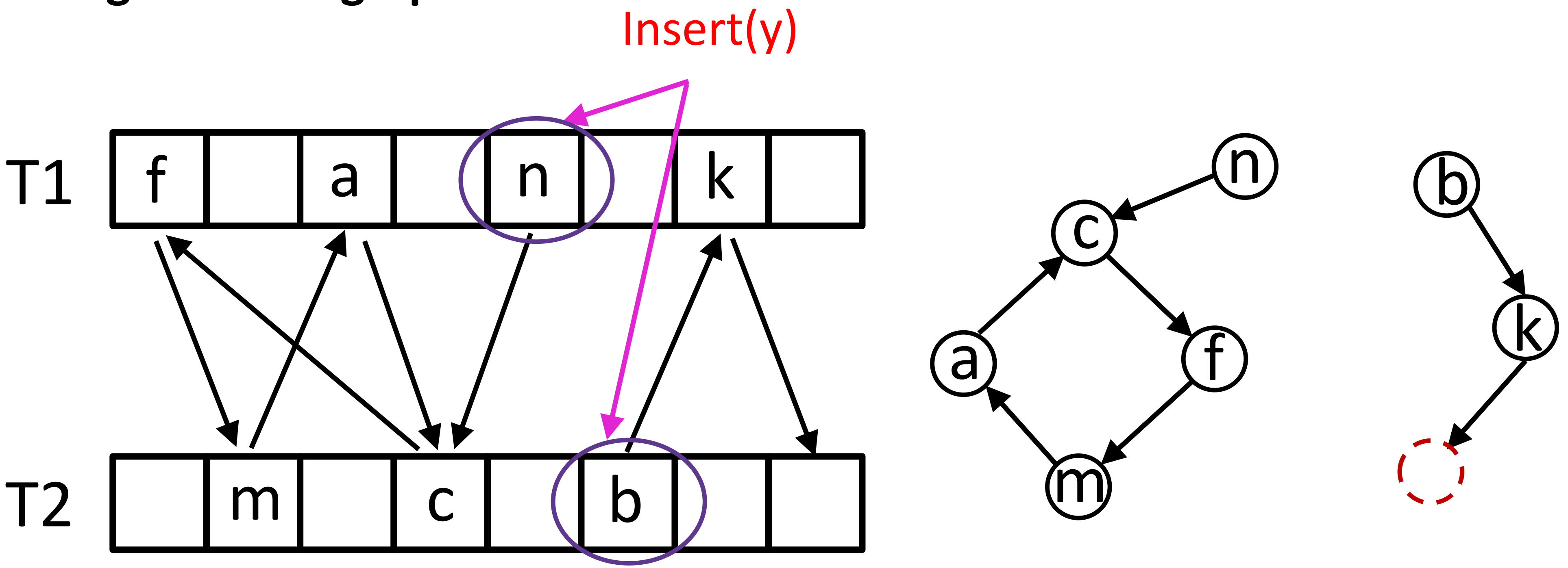

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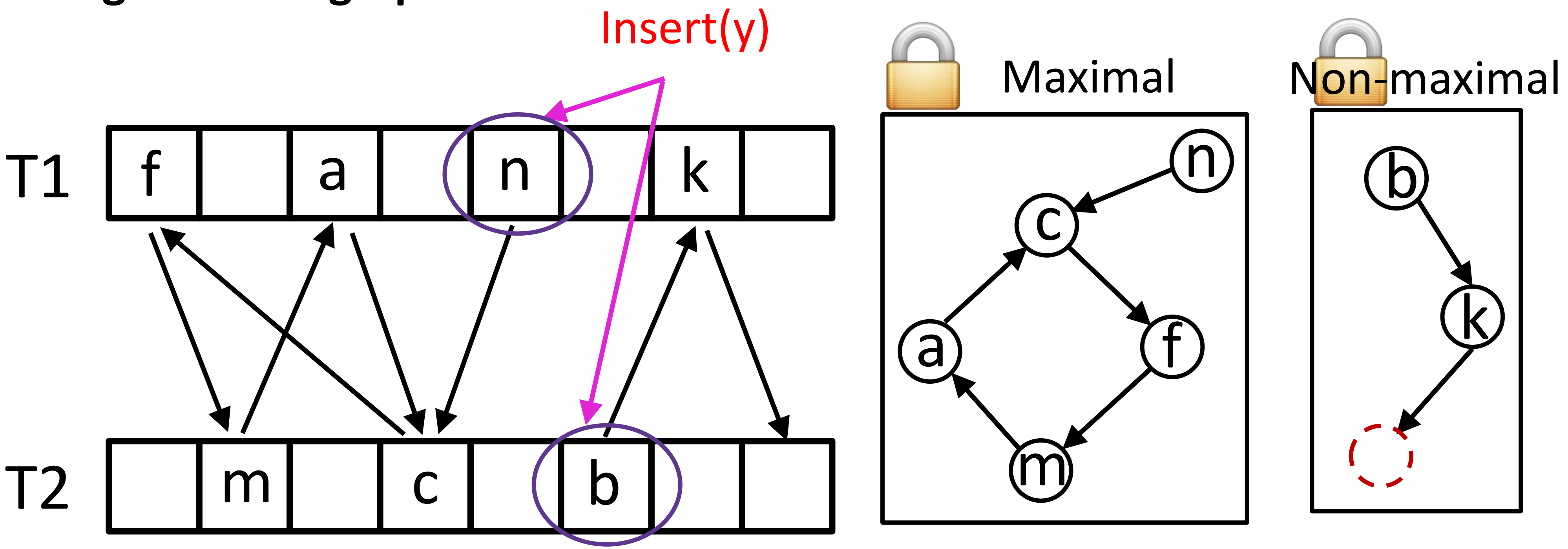

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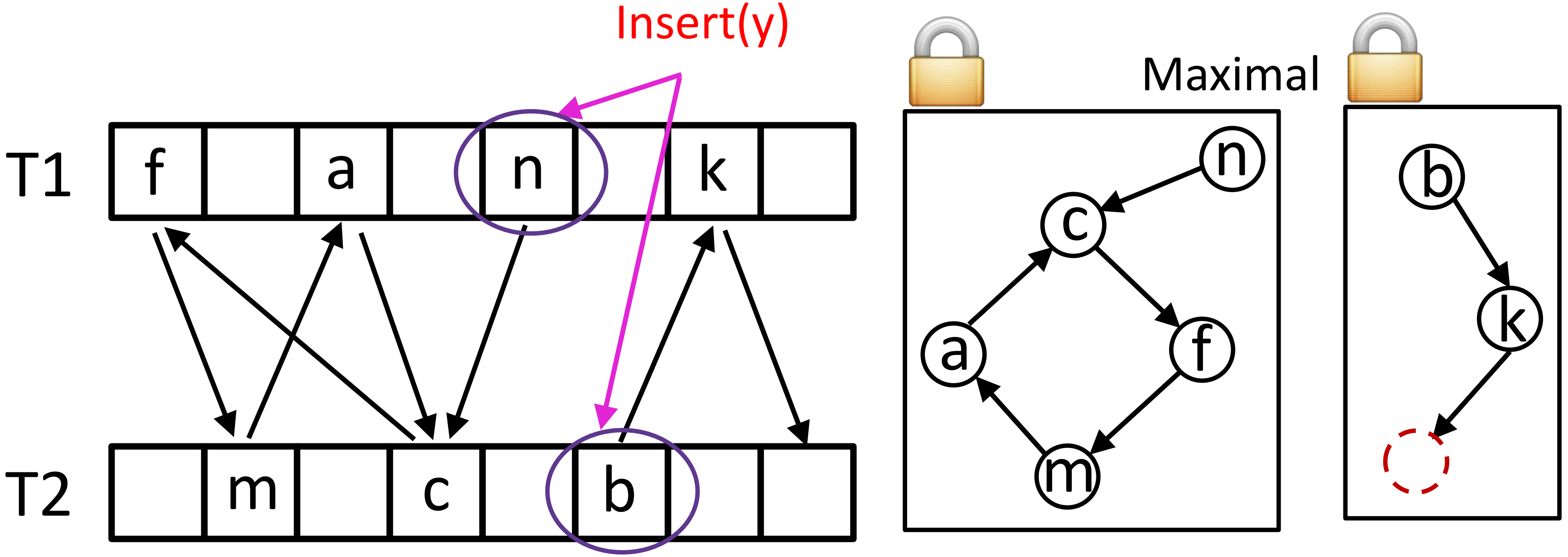

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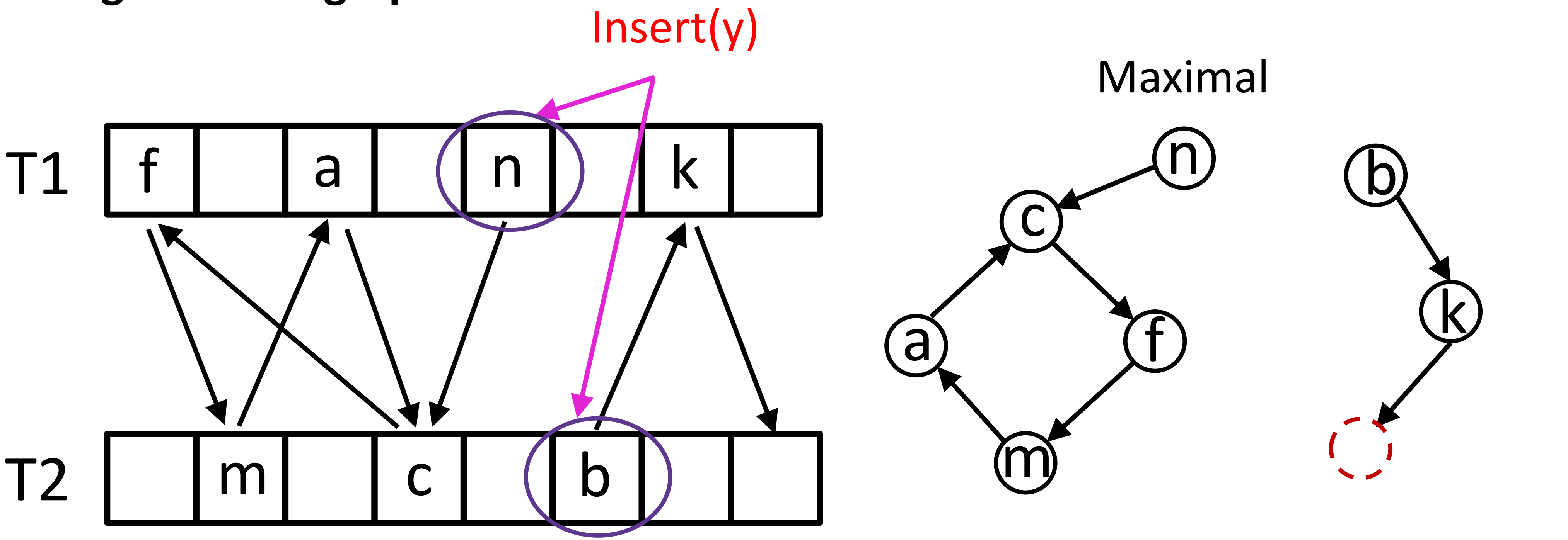

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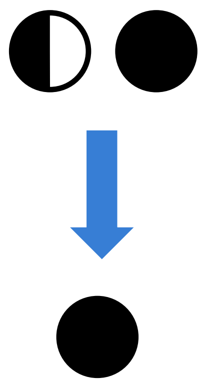

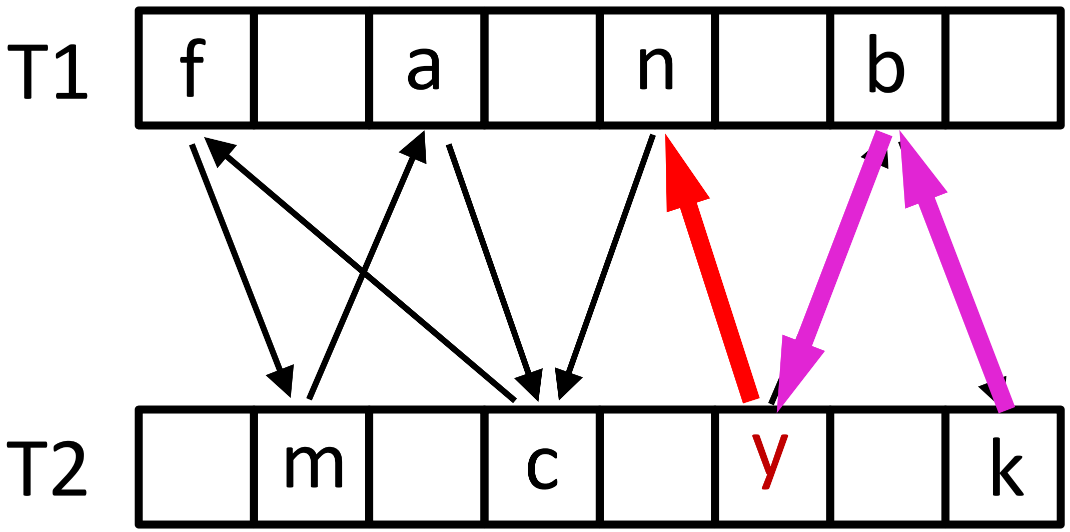

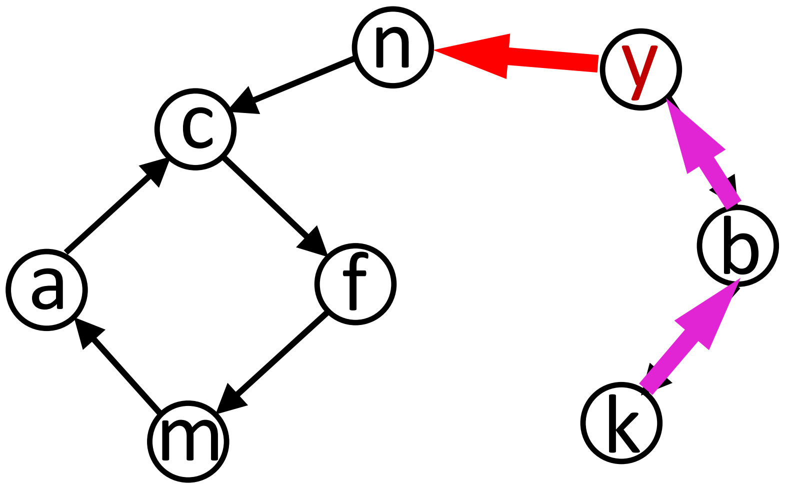

ZeroEmpty (Max) ●● / ●

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- **Always walking into a loop and predetermined to be a failure**
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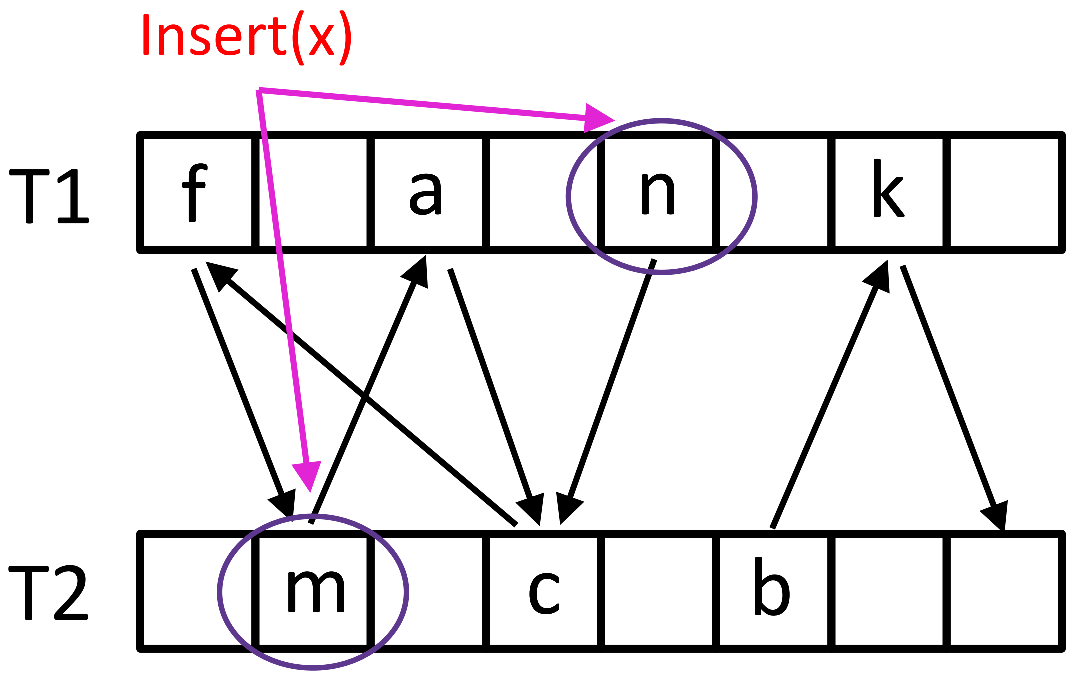

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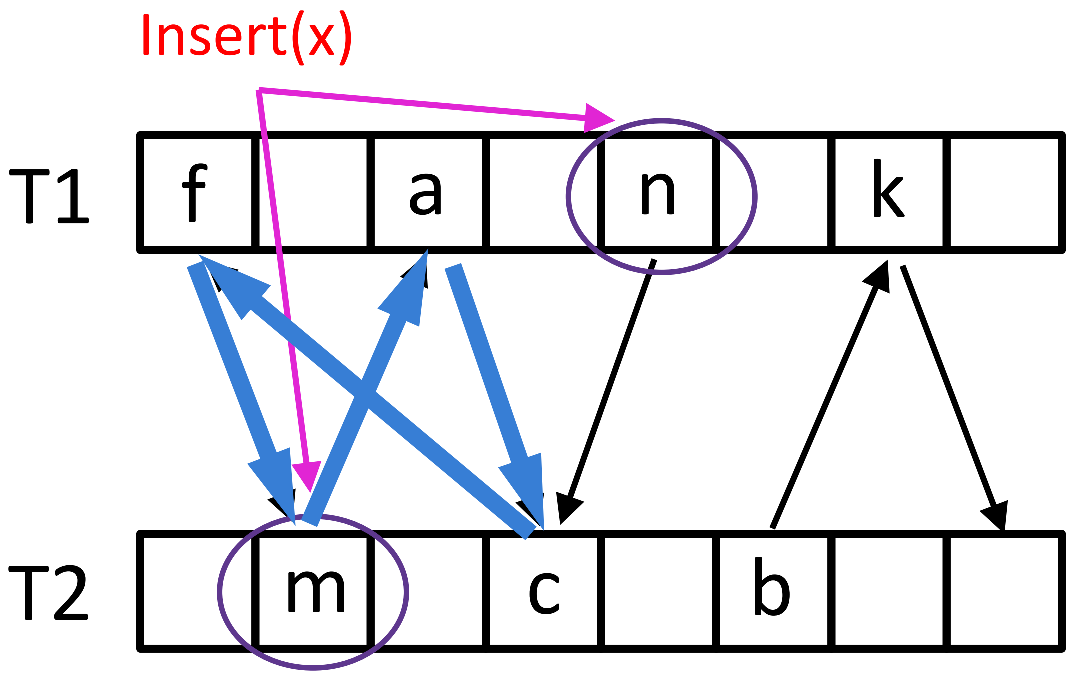

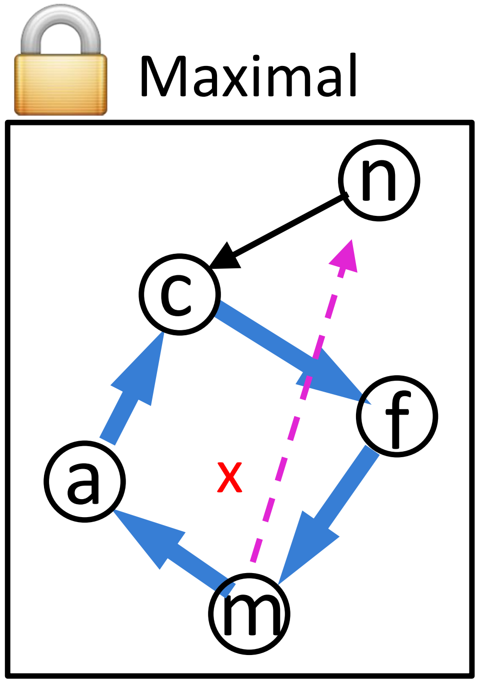

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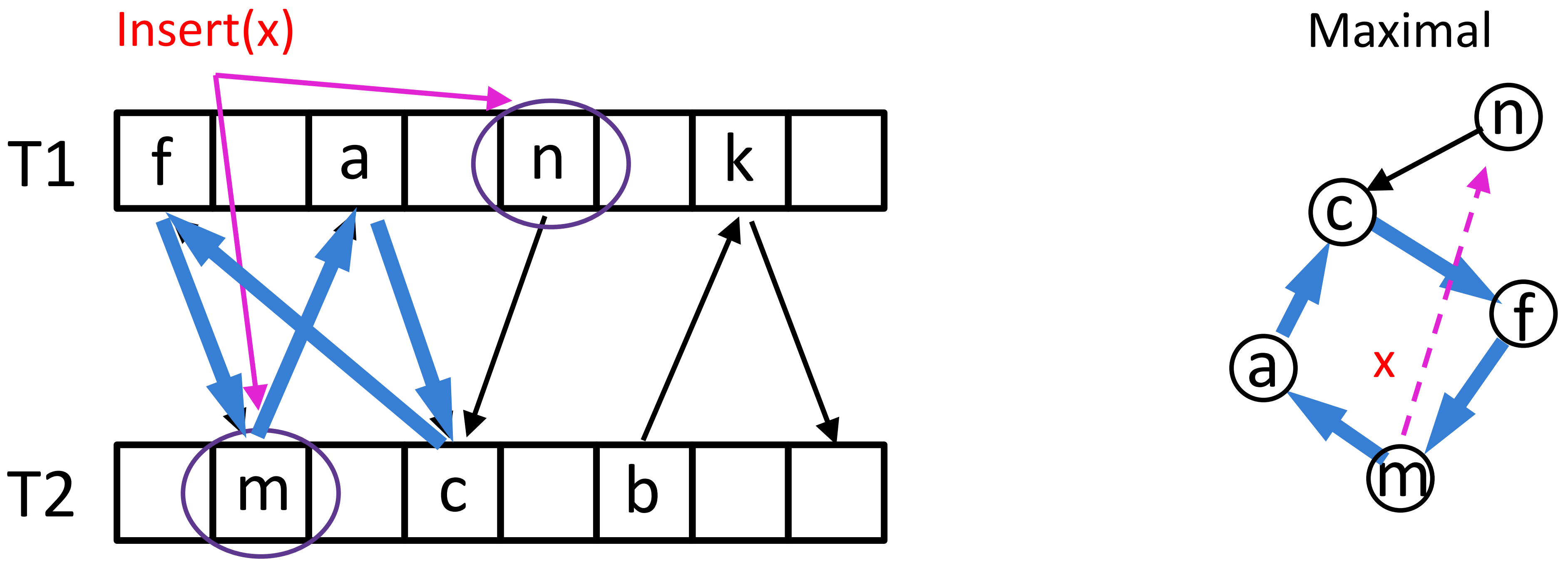
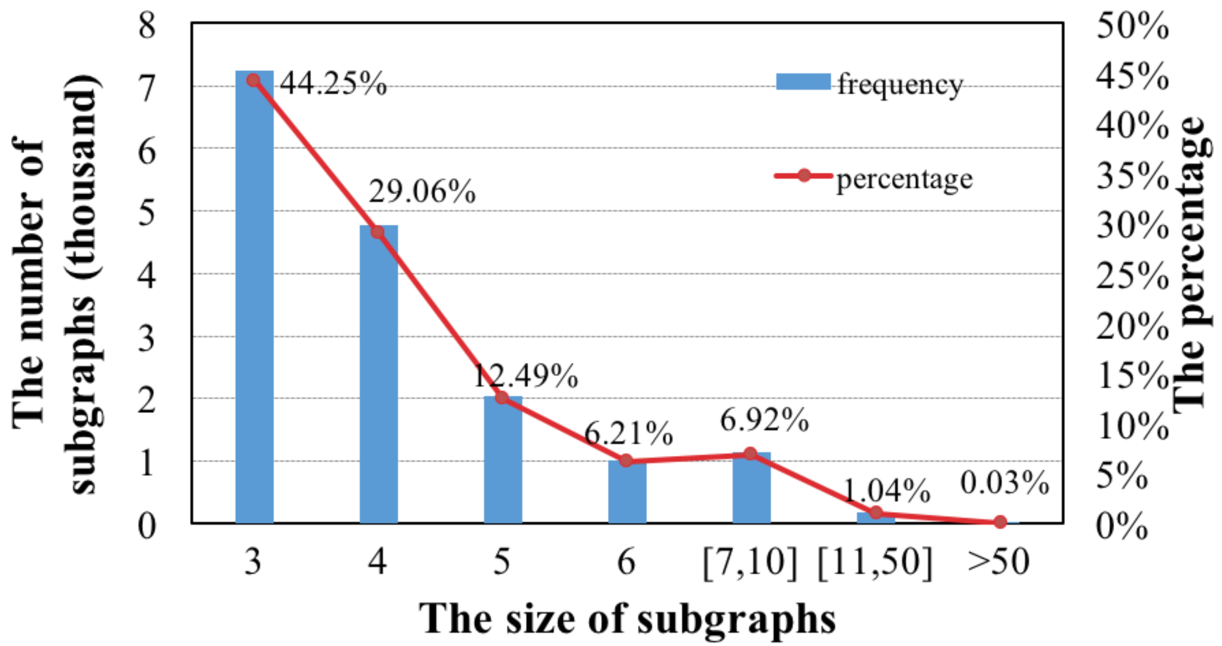


Lock Granularity

- **Most subgraphs are small ➡ the granularity of graph-grained locks is acceptable**
  - **Only constraining a very small number of buckets**
  - **3 vertices (44.25% subgraphs)**
  - **No more than 10 vertices (99% subgraphs)**



Subgraph Management

- **Subgraph number allocation**
  - **Subgraph number: identifying a unique subgraph**
  - **Unique without the need of continuity**

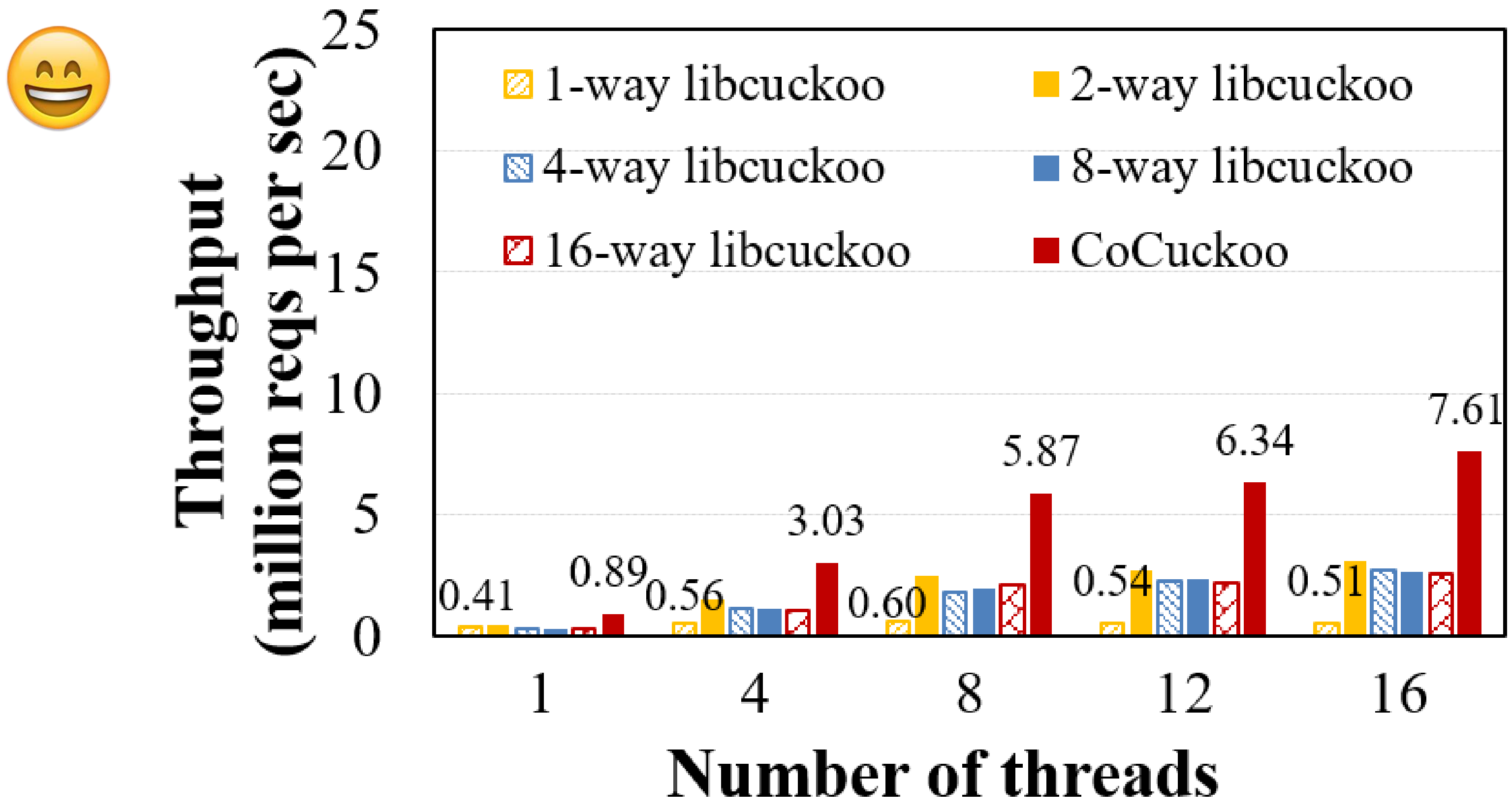
- **Subgraph number generator: a simple modular function**
  - **Modulus: the total number of threads *p***
  - **Remainder: the number of each thread *r***
  - ***n = kp+r , e.g.,* 8-thread CoCuckoo, Thread 2, n=2,10,18,…**

Performance Evaluation

- **Comparison:**
  - **libcuckoo@EuroSys'14**
  - **Slot numbers: 1, 2, 4, 8, 16**
- **Workloads:**
  - **YCSB: https://github.com/brianfrankcooper/YCSB @SOCC'11**
  - **2 million key-value pairs per workload**
- **Threads: 1, 4, 8, 12, 16**
- **Metrics:**
  - **Throughput**
  - **Predetermination for insertion**
  - **Extra space overhead**

Workload	Insert	Lookup
Insert-only (INS)	100%	0%
Insert-heavy (IH)	75%	25%
Insert-lookup balance (ILB)	50%	50%
Lookup-heavy (LH)	25%	75%
Lookup-only (LO)	0%	100%

Average Insertion Throughput



- ➢ **CoCuckoo significantly increases average throughputs.**
- ➢ **75%-150% improvements compared to 2-way libcuckoo.**

Predetermination for Insertion

Workloads	TwoEmpty	OneEmpty	Same_non	Max	Diff_non_non	Diff_non_max
Insert-only	25.673%	37.9628%	0.0003%	13.9802%	13.1447%	9.239%
Insert-heavy	32.9343%	40.4907%	0.0004%	3.5921%	16.7513%	6.2312%
Insert-lookup balance	44.675%	39.6011%	0.0002%	0%	15.7235%	0.0002%
Lookup-heavy	64.4448%	30.1658%	0%	0%	5.3894%	0%

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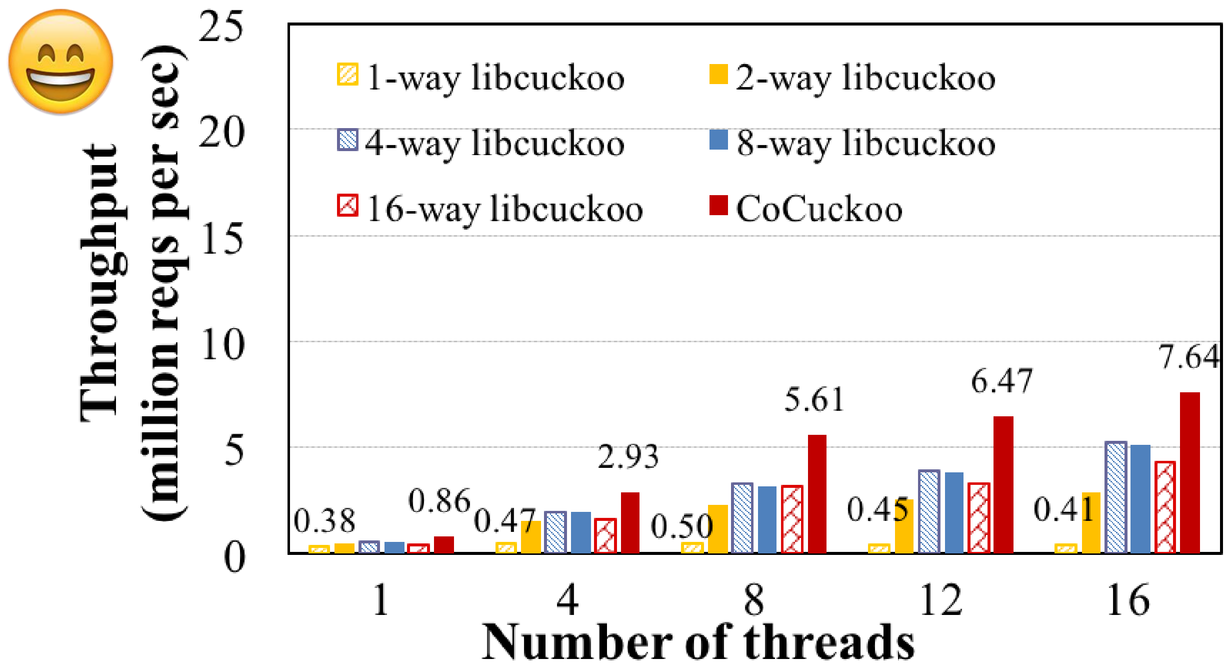
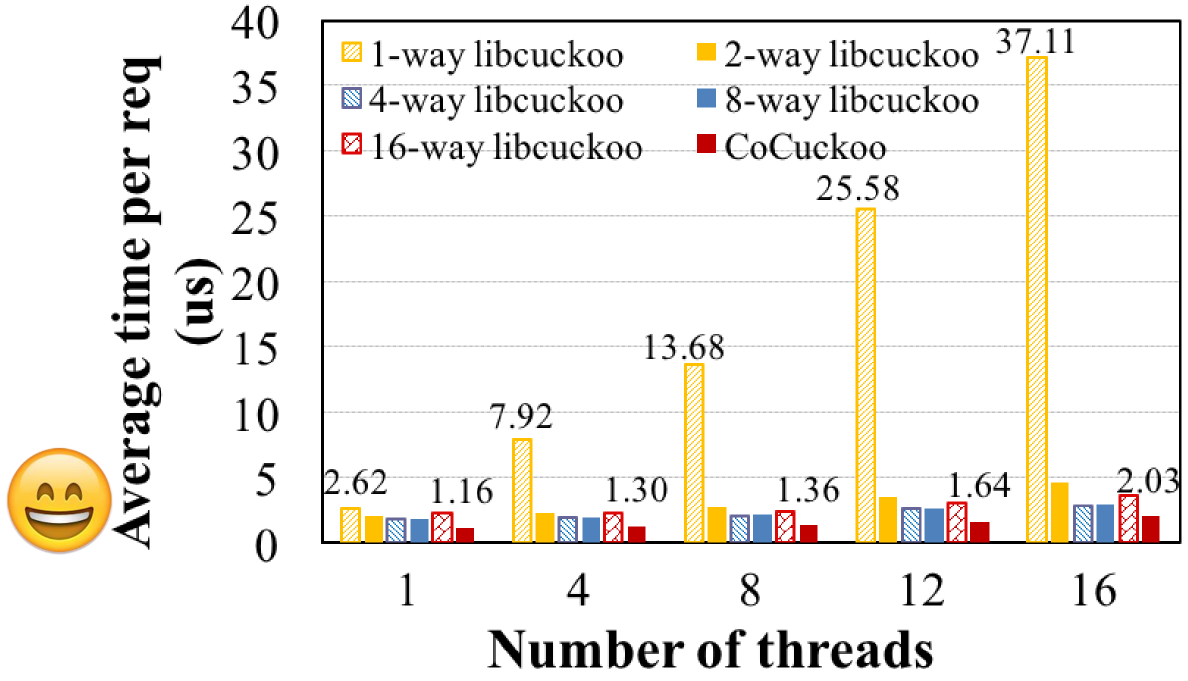
- **TwoEmpty and OneEmpty account for a large proportion**
  - **Short-term or no locks for the shared buckets**

- **Max:**
  - **Predetermine insertion failures and release locks without any kick-out operations**

Extra Space Overhead





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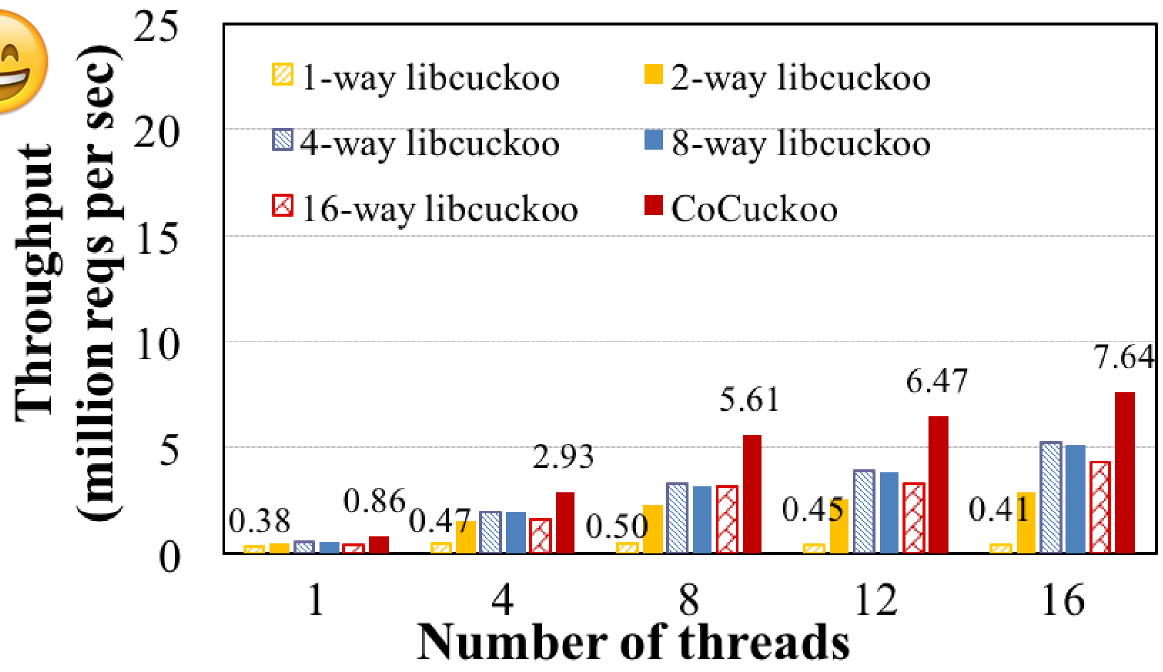

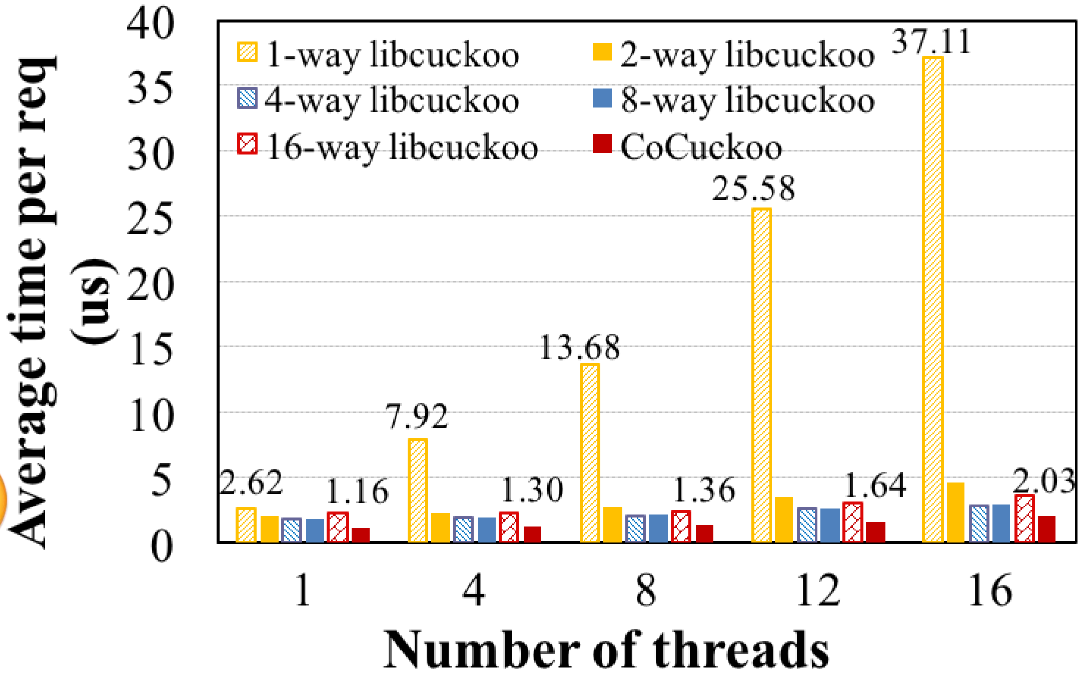

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  - **CoCuckoo increases the throughput over 2-way libcuckoo by 73% - 159%.**
  - **CoCuckoo significantly decreases the average execution time per request.**

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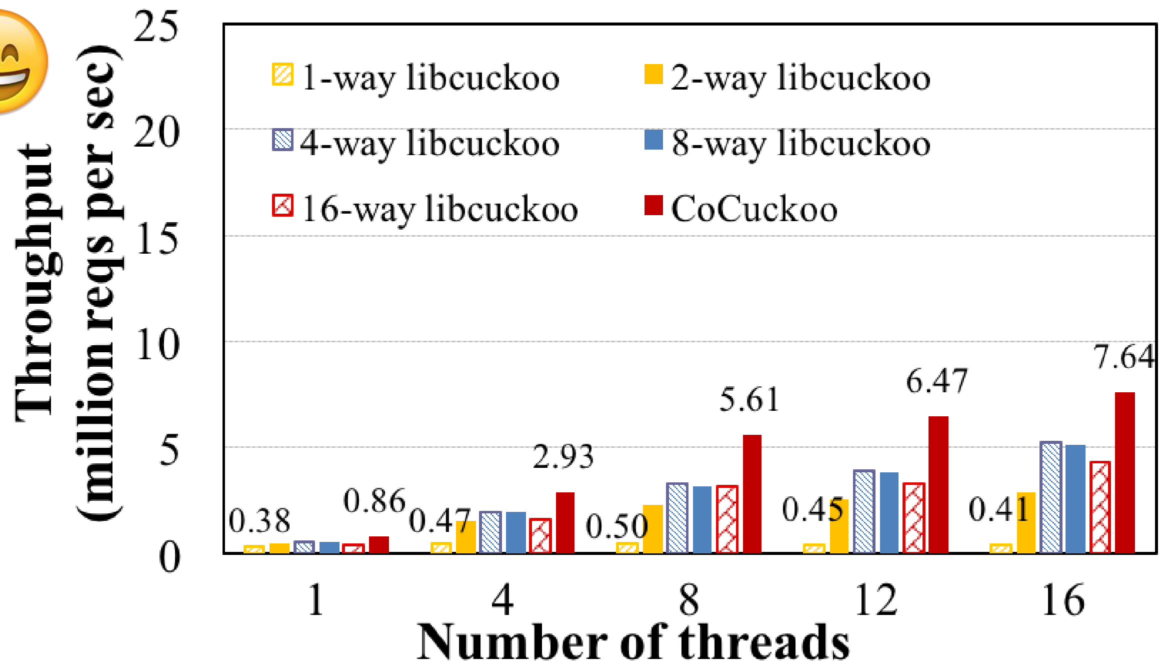

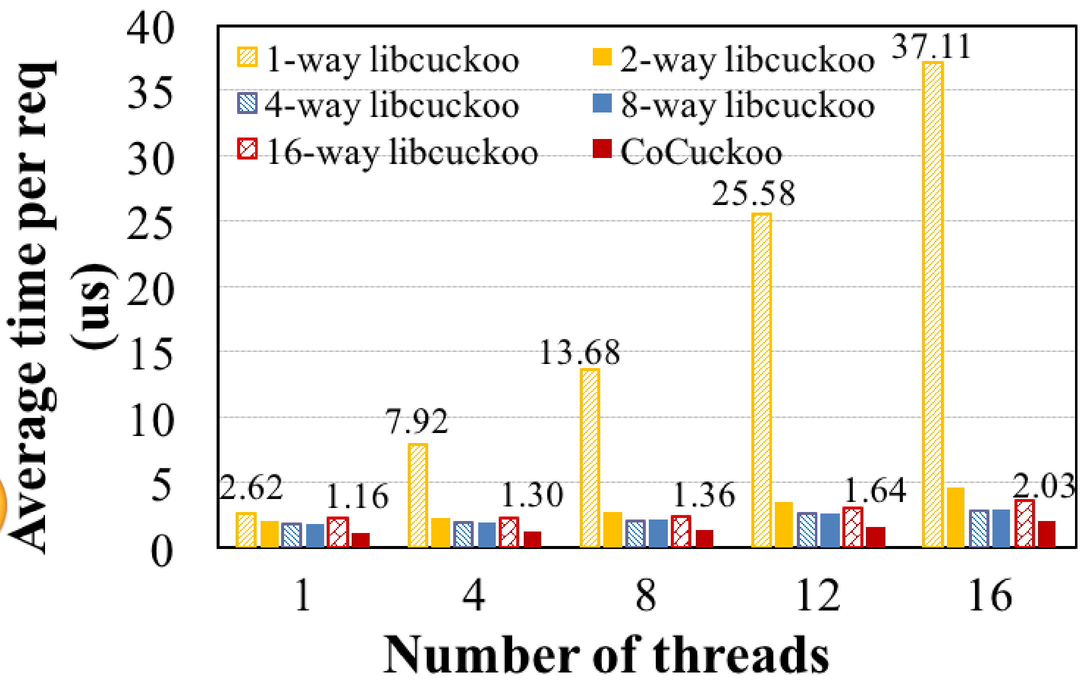

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  - **CoCuckoo increases the throughput over 2-way libcuckoo by 73% - 159%.**
  - **CoCuckoo significantly decreases the average execution time per request.**
- **The extra space overhead is small**

Conclusion

- **CoCuckoo mitigates the asymmetric read and write costs in cuckoo hashing via**
  - **A pseudoforest to predetermine and avoid occurrence of endless loops**
  - **Graph-grained locking mechanism and concurrency optimization**

- **CoCuckoo achieves 75%-150% write throughput improvements compared with 2-way libcuckoo.**

Q&A

Homepage:: https://csunyy.github.io/