Dynamic FIB Aggregation without Update Churn

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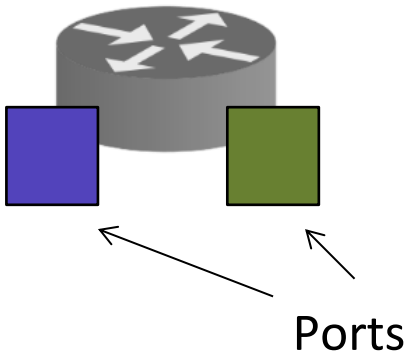
Marcin Bienkowski
Nadi Sarrar
Stefan Schmid
Steve Uhlig

Poor Routers!

Key Functionality: Forwarding



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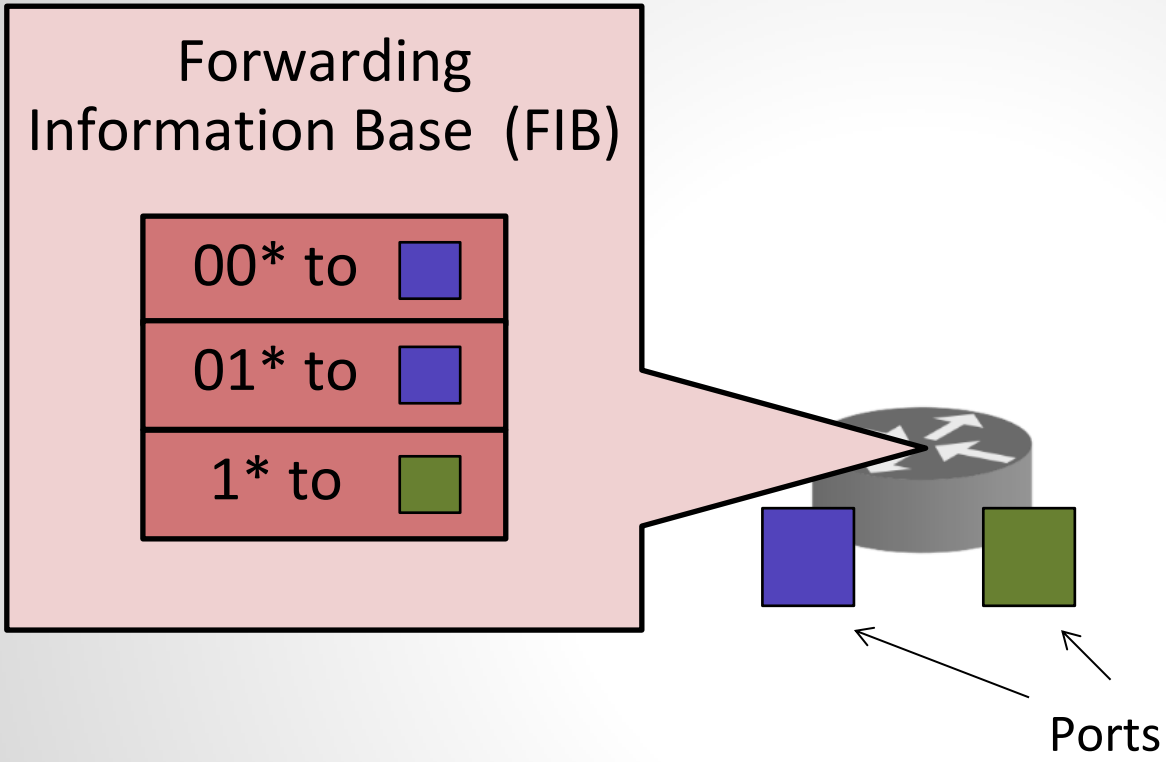

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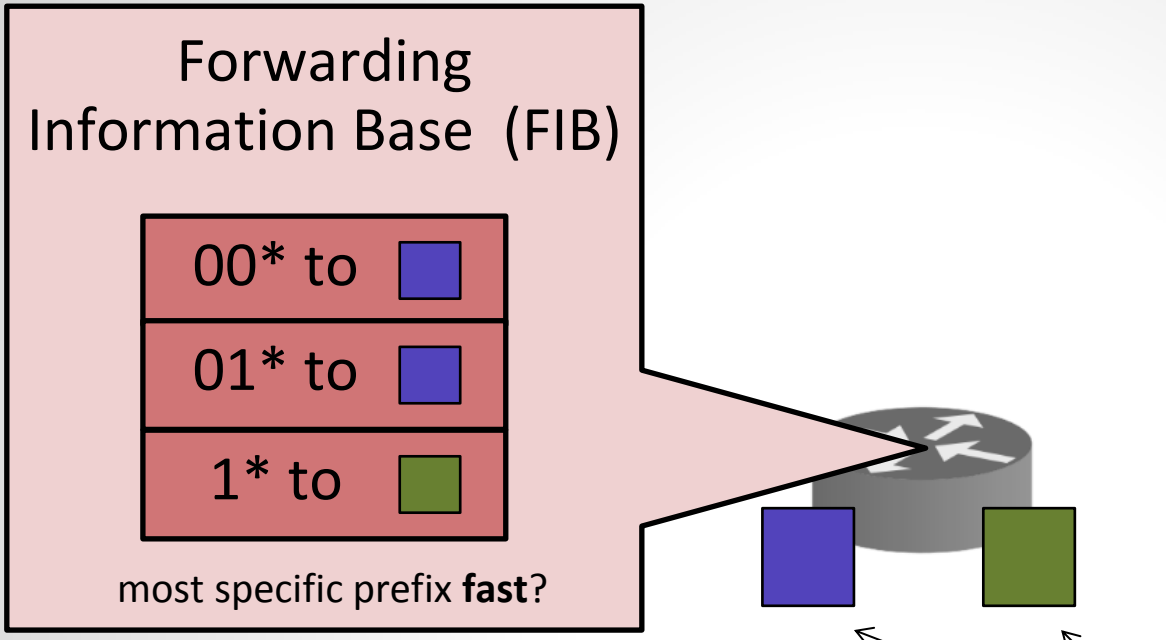


Ports

TCAM memory expensive
and power-hungry…

Poor Routers!

Key Functionality: Forwarding

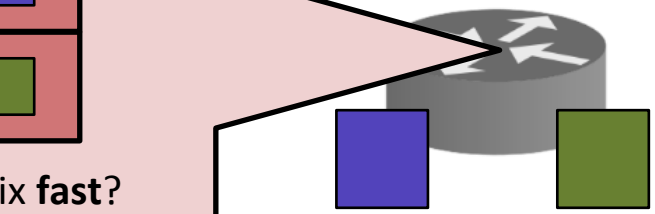
Forwarding Information Base (FIB)

00* to

01* to

1* to

most specific prefix **fast**?



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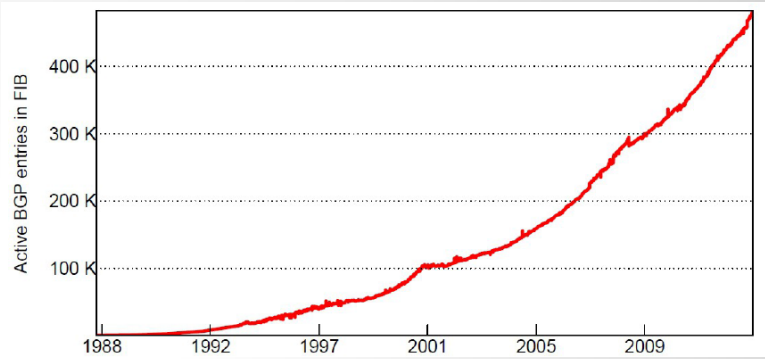

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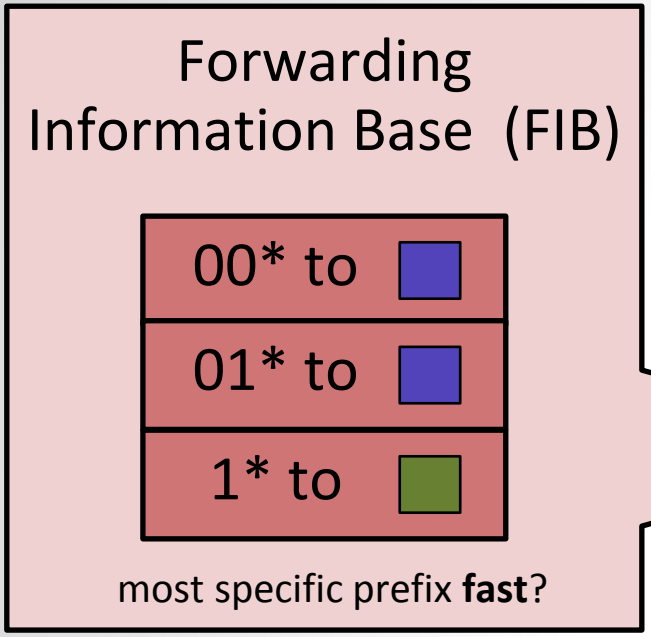

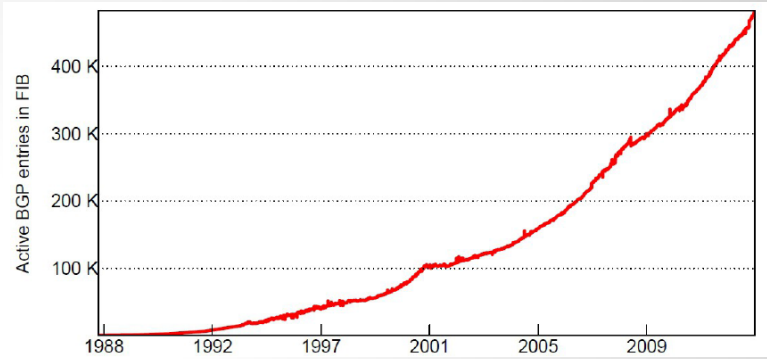

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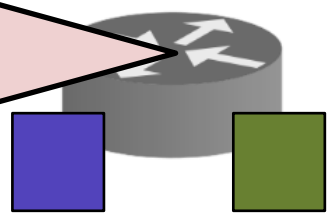
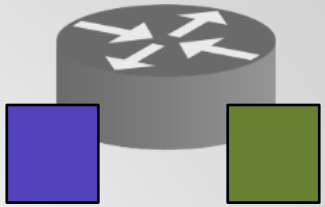


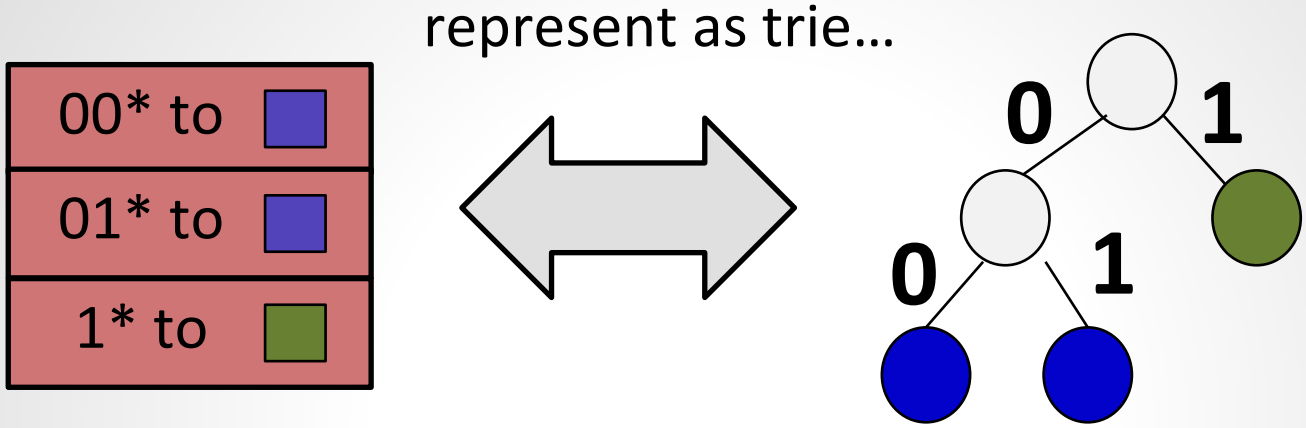
TCAM memory expensive and power-hungry…

Ports

Idea to prolong the router lifetime: Compress the FIB!

Idea: Compress the FIB





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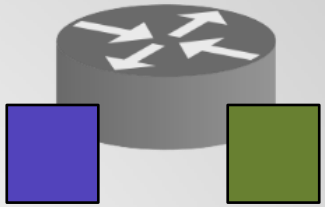
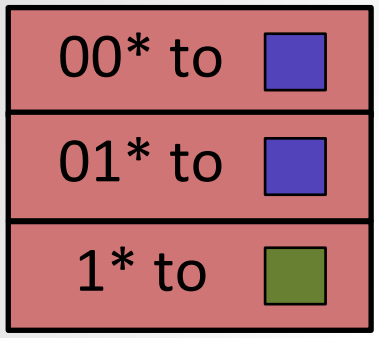
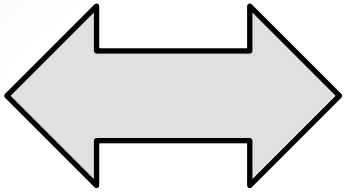
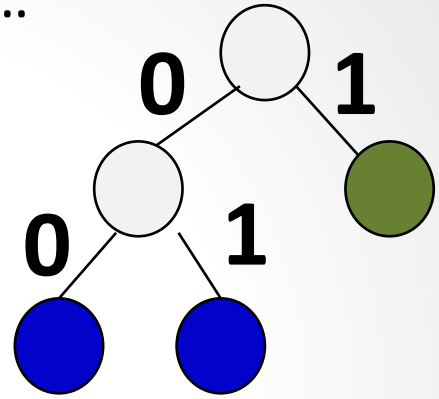
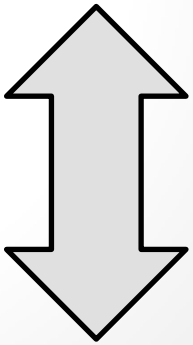




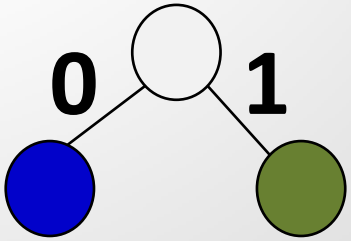
represent as trie…







… and compress it!



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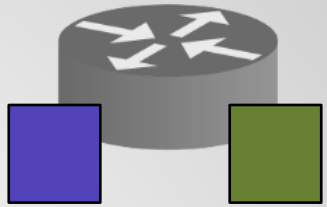

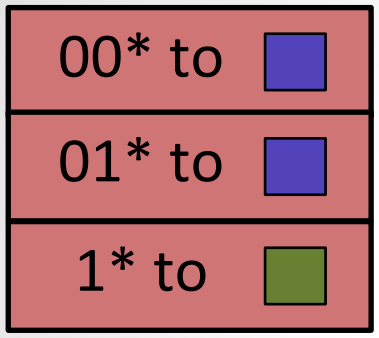

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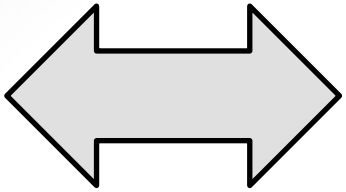
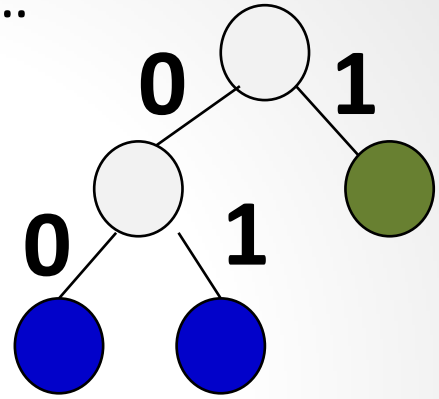
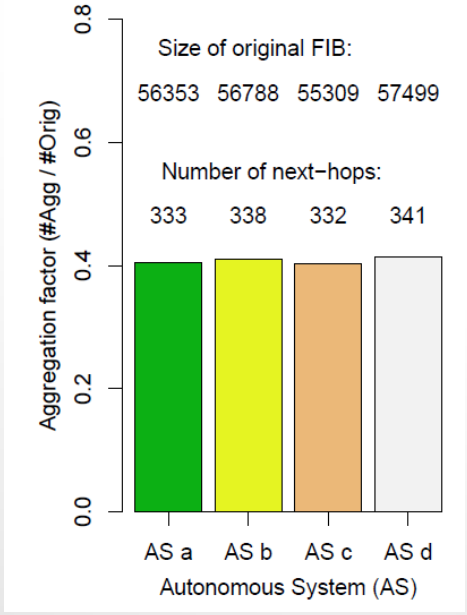
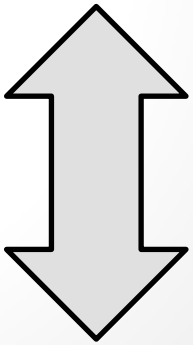




Good Potential:

Down to 40% (RouteView), depending on # ports.





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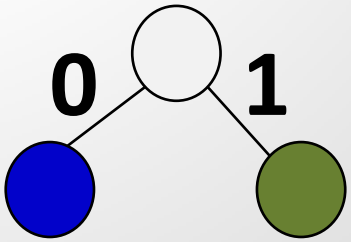

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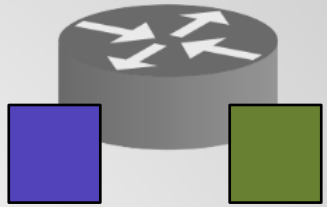

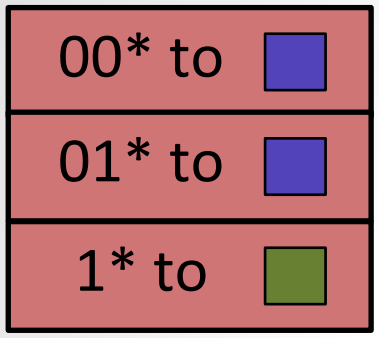

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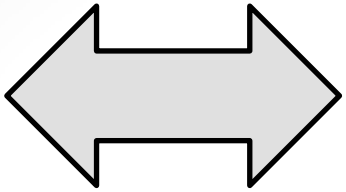
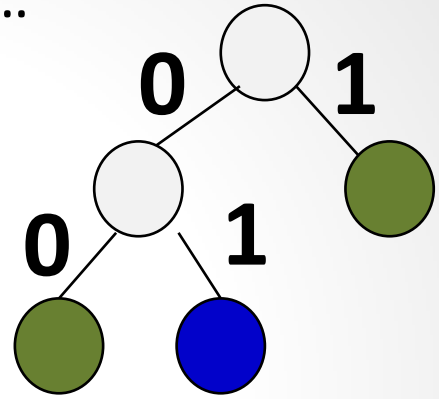
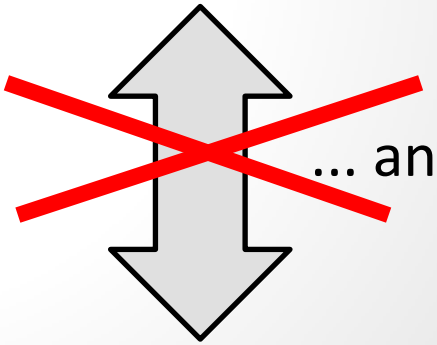




BGP event!

But: May introduce churn!

Deaggregate upon route change.



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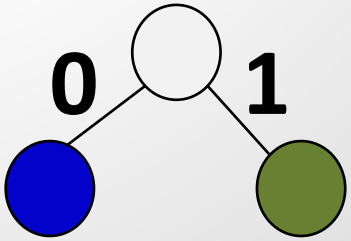

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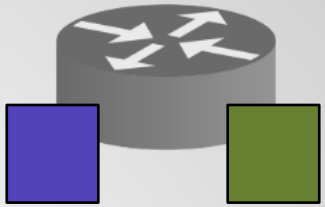

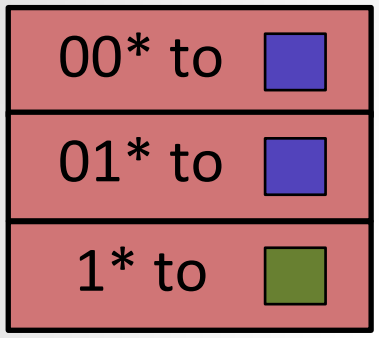

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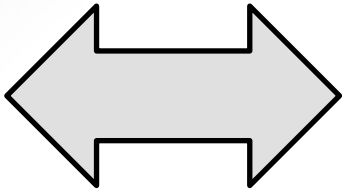

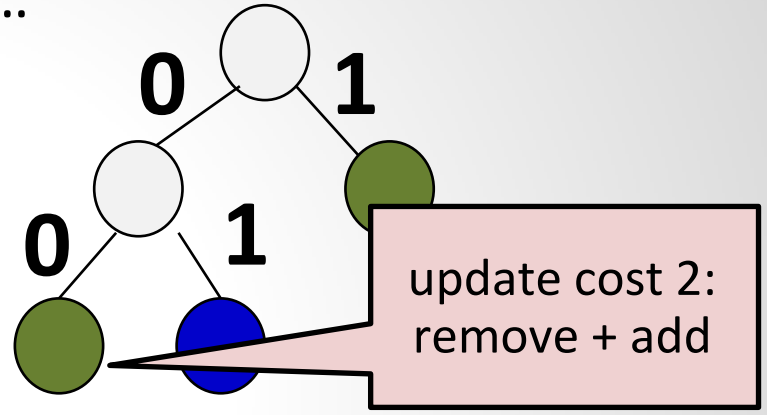

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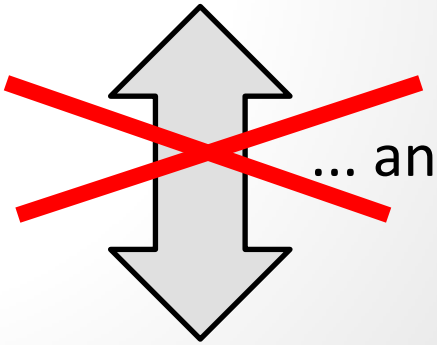

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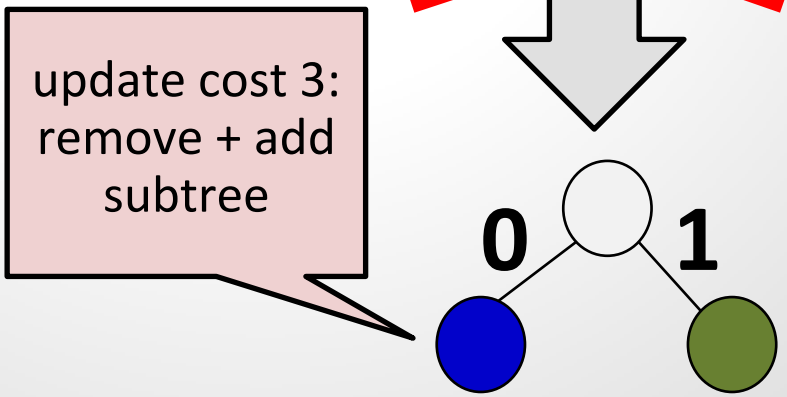

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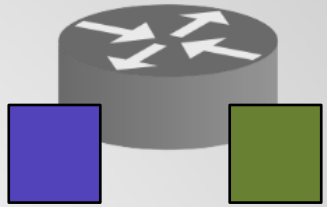

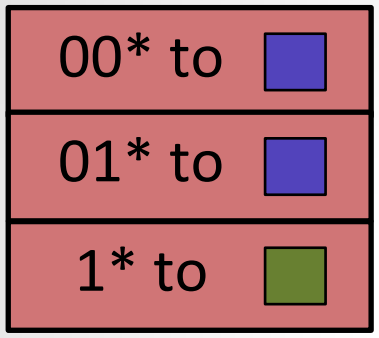

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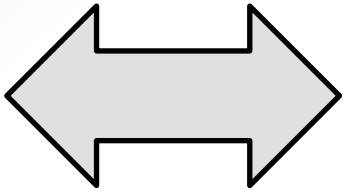
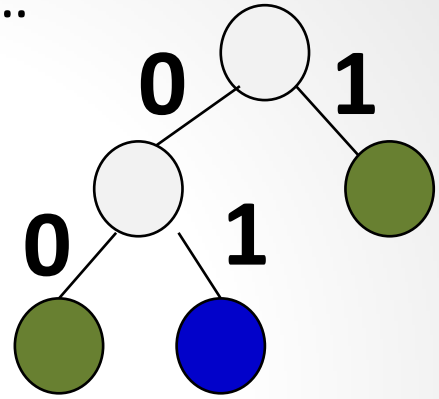


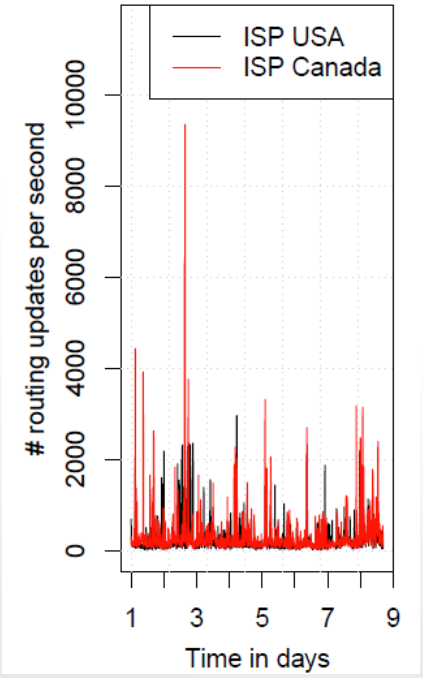


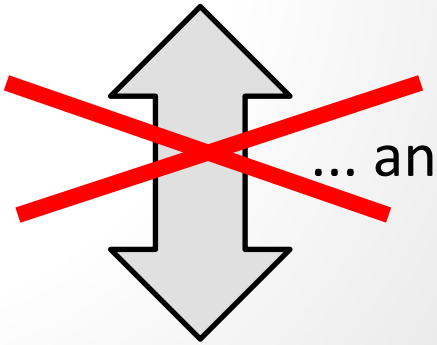
BGP event!

But: May introduce churn!

Deaggregate upon route change.

Already without churn: 1000s/sec updates in BGP!





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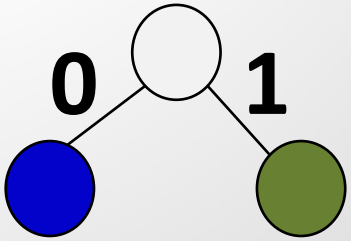
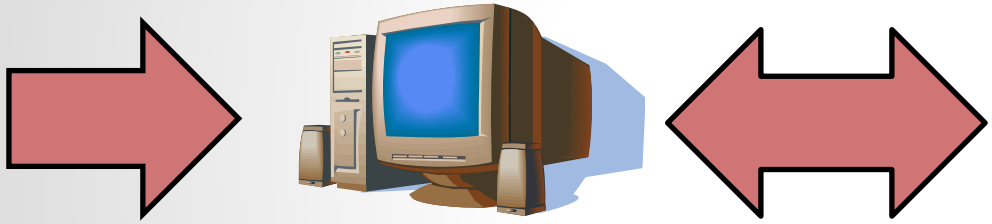


An Optimization Problem

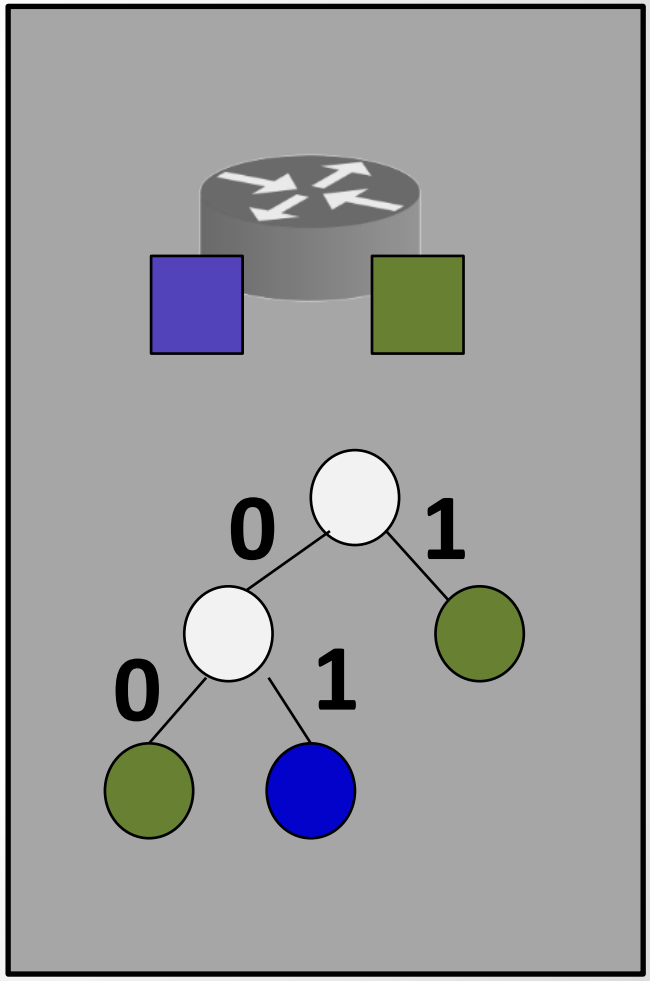
Route Processor or SDN Controller

FIB or SDN Switch

BGP Events



update!



An online problem:

1. Forwarding must always be correct (equivalent)
2. Minimize update cost and memory size

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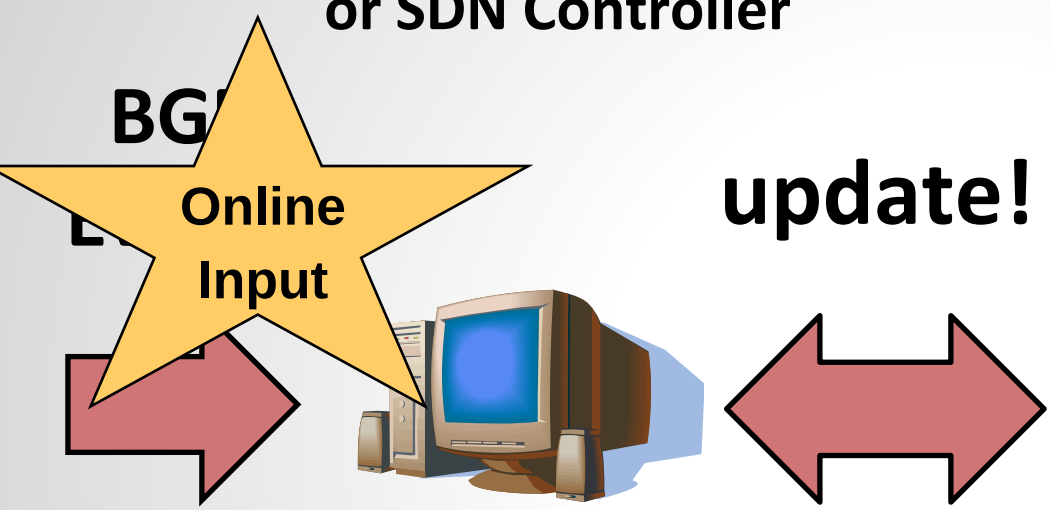
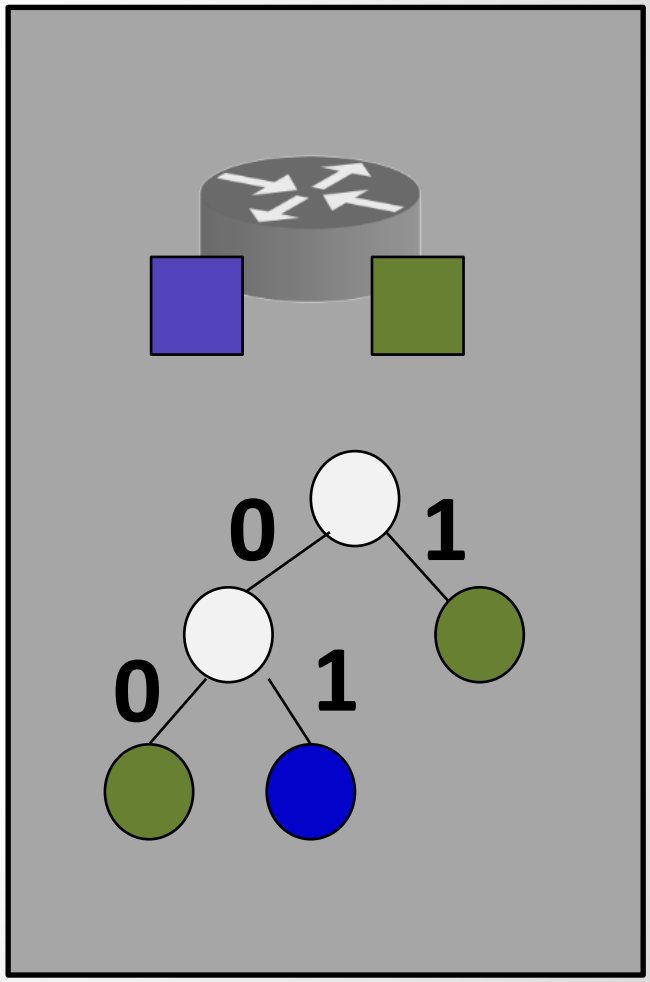
FIB or SDN Switch





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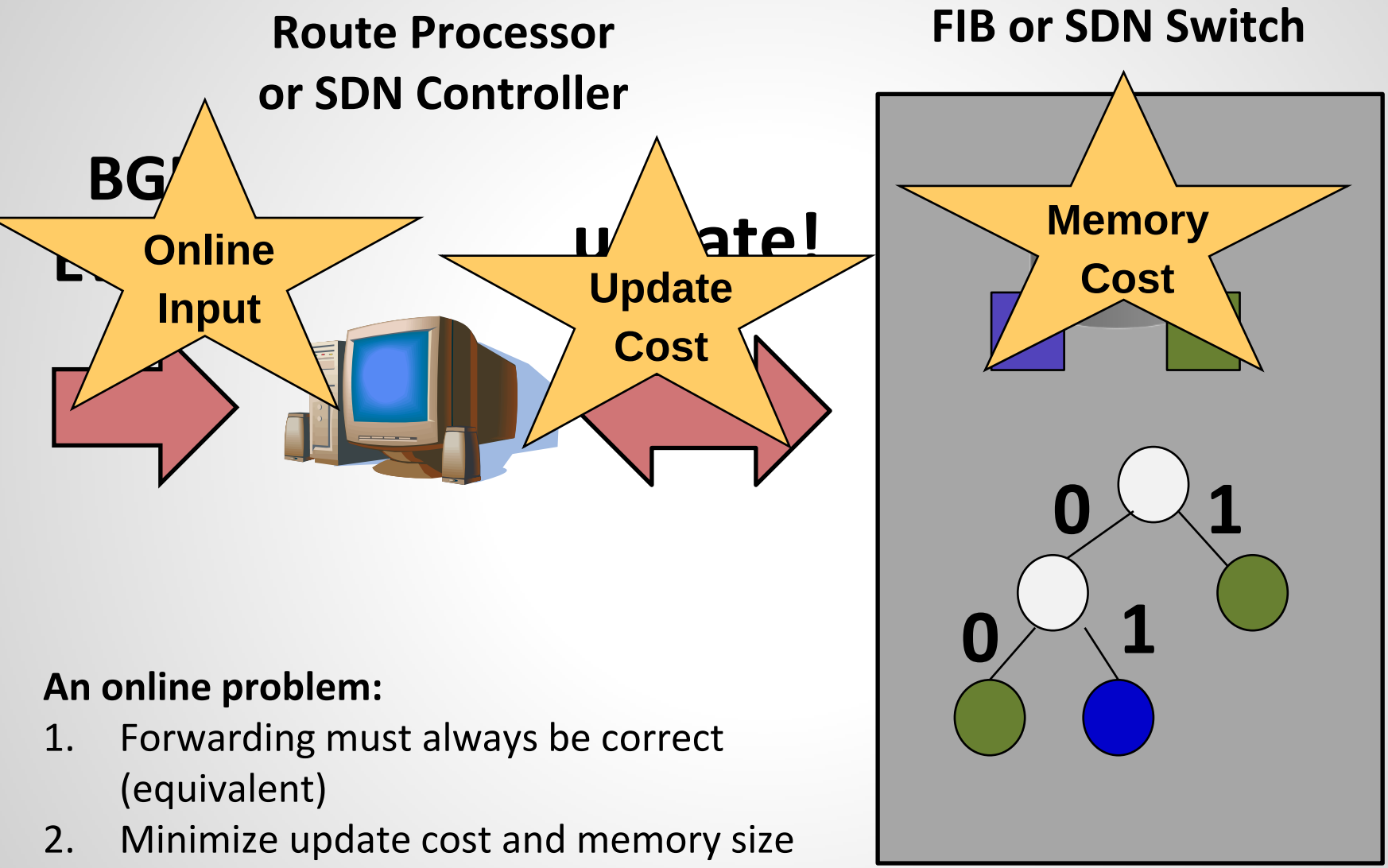

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An

Joint Optimization:

Cost = α (# updates) + $\int_t$ FIB size

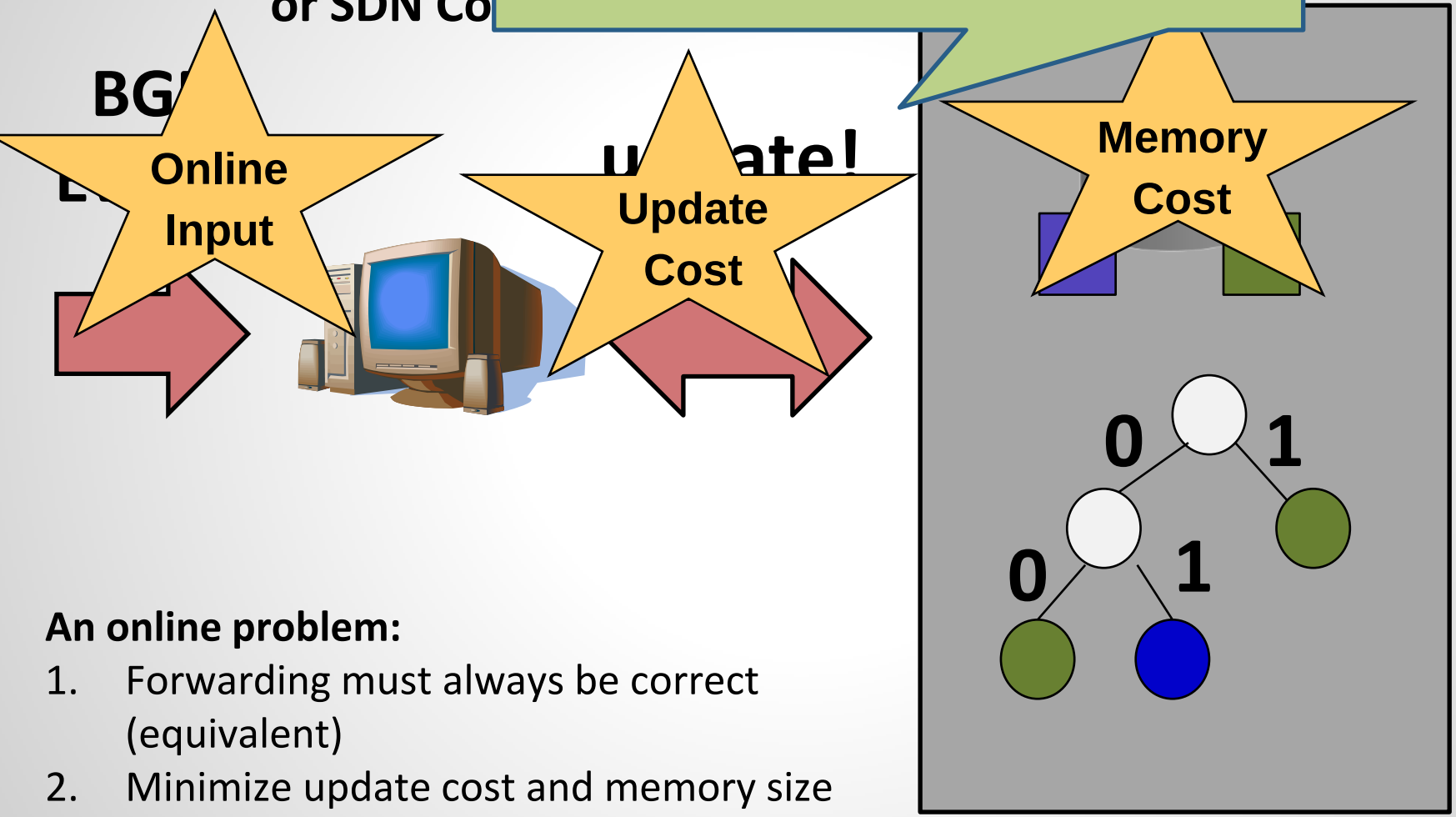
Route Pro

or SDN Co

tch

BG

ate!



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BG

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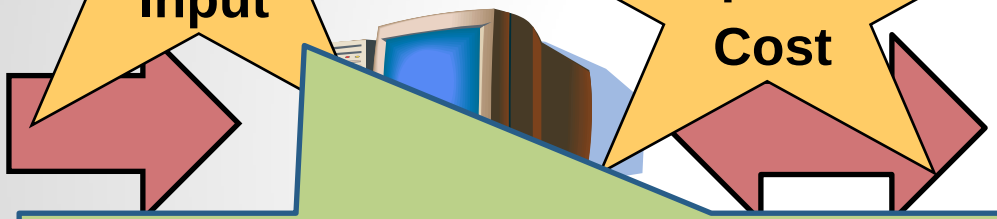
Joint Optimization:

Cost = α (# updates) + $\int_t$ FIB size

Online Input

Update Cost

Memory Cost



Realm of Online Algorithms and Competitive Analysis!

Competitive Ratio = max Cost(ON)/Cost(OFF)

A

1

2. Minimize update cost and memory size

What Was Known So Far?

Static Compression

E.g., ORTC (INFOCOM'99): dynamic programming algorithm to compute optimally compressed FIB

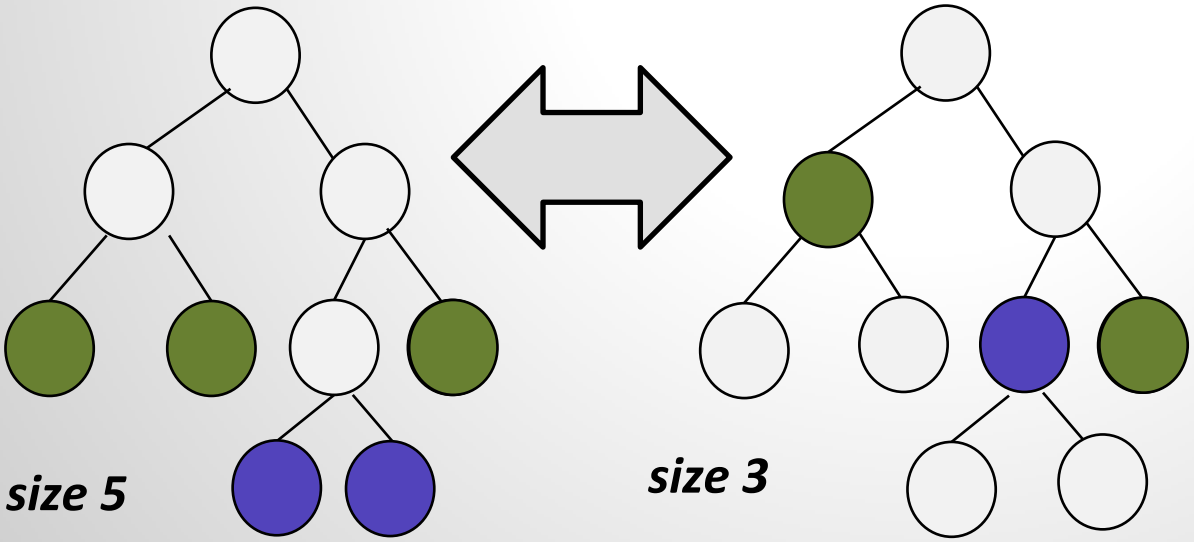
Dynamic Compression

No free lunch! (But can also *reduce* churn!)

Lots of work over the last 15 years (since Lulea) to find better tradeoffs between memory and updates. Often implicitly though. Heuristics: SMALTA (CoNEXT'11), FIFA (INFOCOM'13)

Online algorithm BLOCK for «independent prefixes»

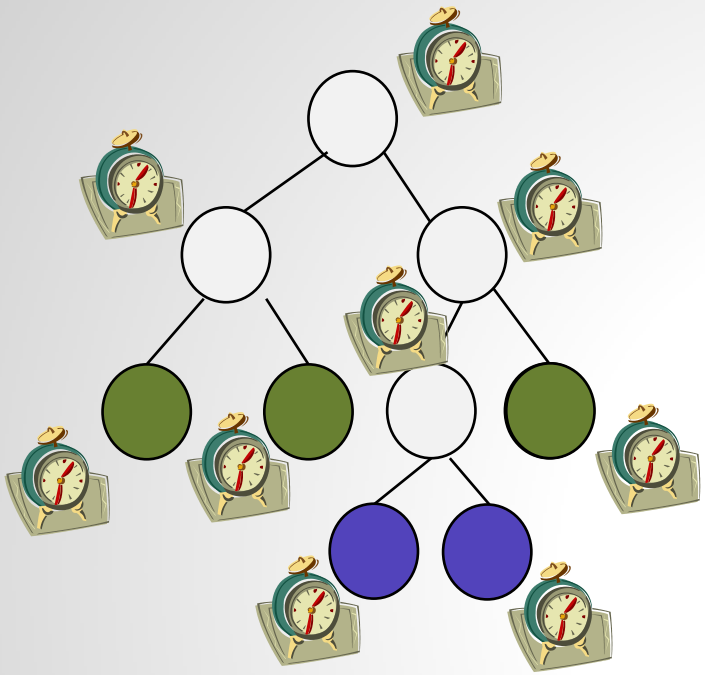
a.k.a. without exceptions (SIROCCO 2013)



BLOCK is 3.603-competitive.

Any online algorithm is at least 1.636-competitive. (Even if ON can use exceptions and OFF not.)

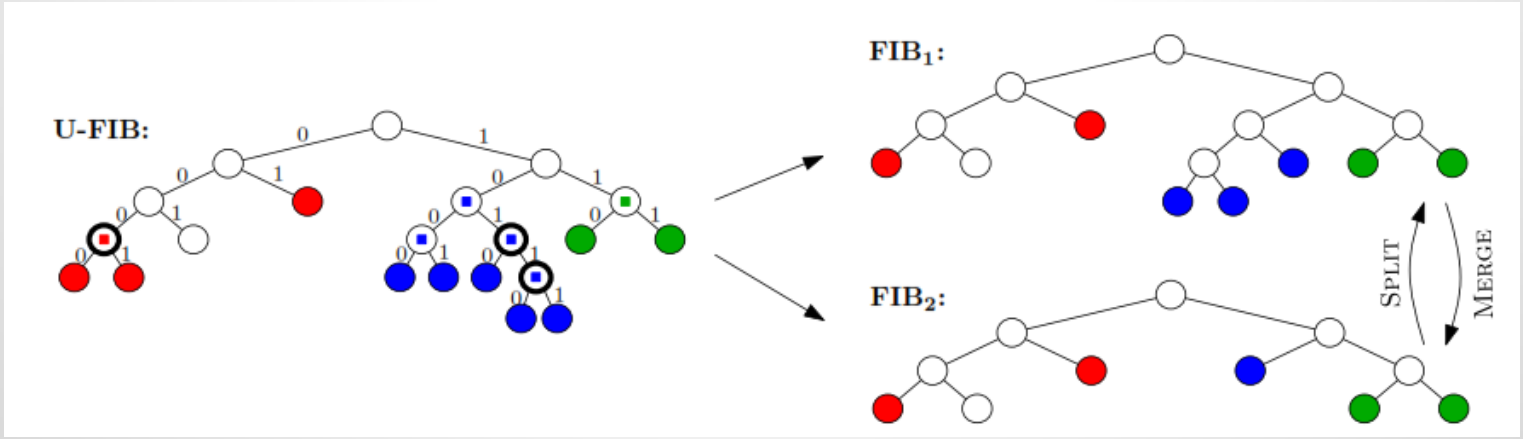
Idea of BLOCK



BLOCK(A,B) operates on trie:

1. balances memory and update costs
2. exploits possibility to merge multiple tree nodes simultaneously at lower price (thresholds A and B)

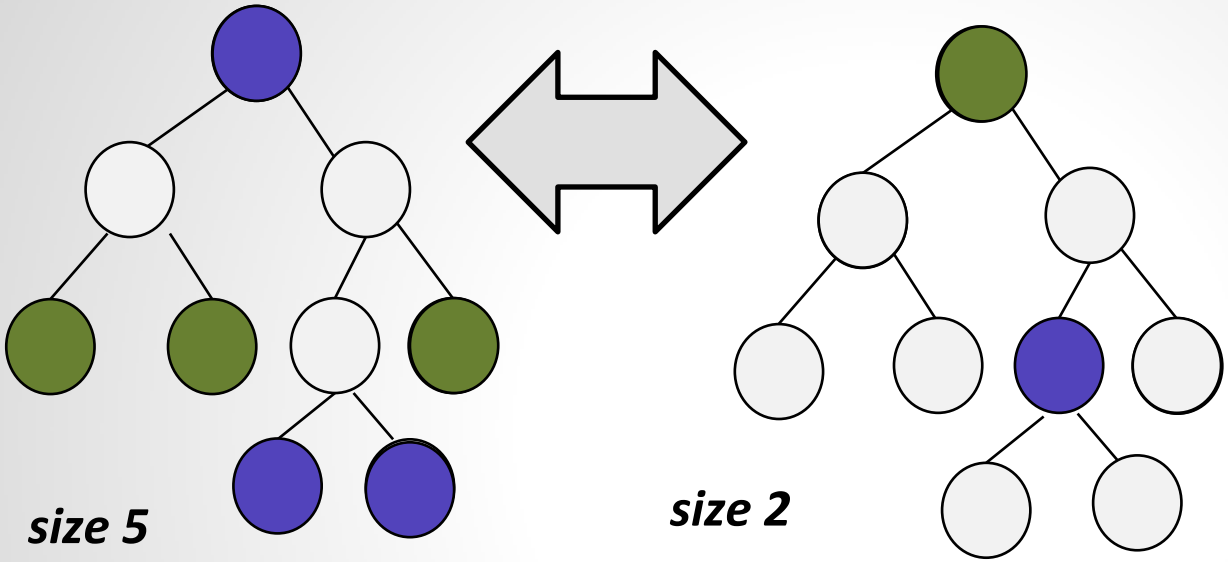
- Timers/counters for each trie node
- Wait before aggregating to save update costs
- Thresholds A and B for amortization (A ≥ B) of update costs
- Definition: internal node v is c-mergeable if subtree T(v) only constains color c leaves
- Trie node v monitors: how long was subtree T(v) c-mergeable without interruption? Counter C(v).
- If C(v) ≥ A **α**, then aggregate entire tree T(u) where u is furthest ancestor of v with **C(u) ≥ B α.**
- Split lazily: only when forced.



Nodes with square inside: mergeable.

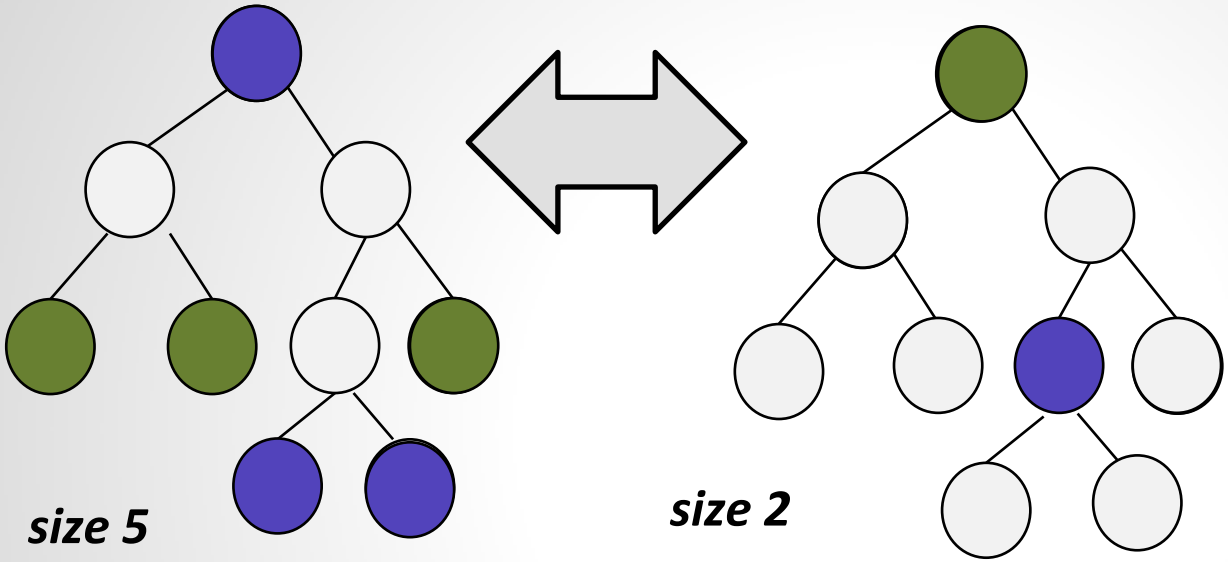
Our Contribution:

Competitive Compression for Dependent Prefixes



Our Contribution:

Competitive Compression for Dependent Prefixes



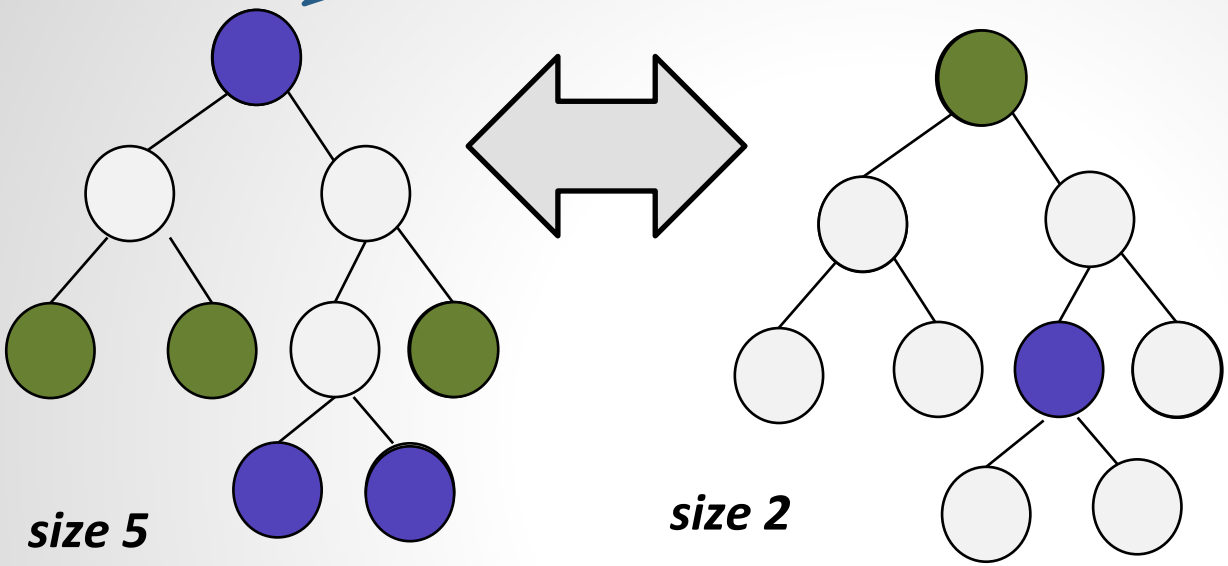
UFIB: Uncompressed trie with exceptions

FIB: Compressed equivalent trie

Always stored in controller!

Contribution:

Comp sion for Dependent Prefixes



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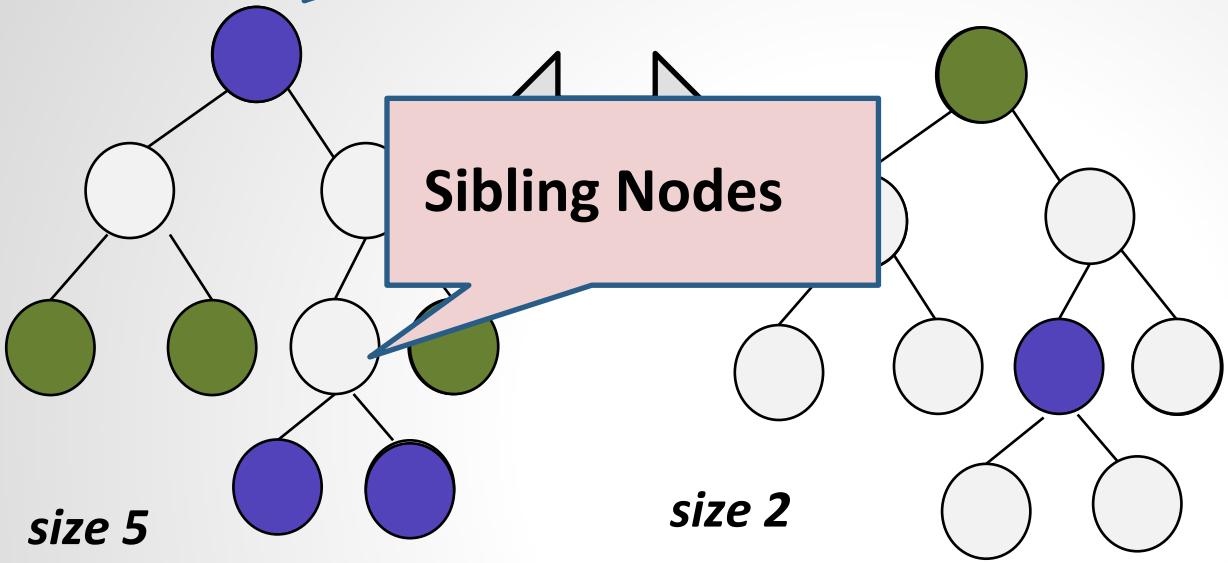

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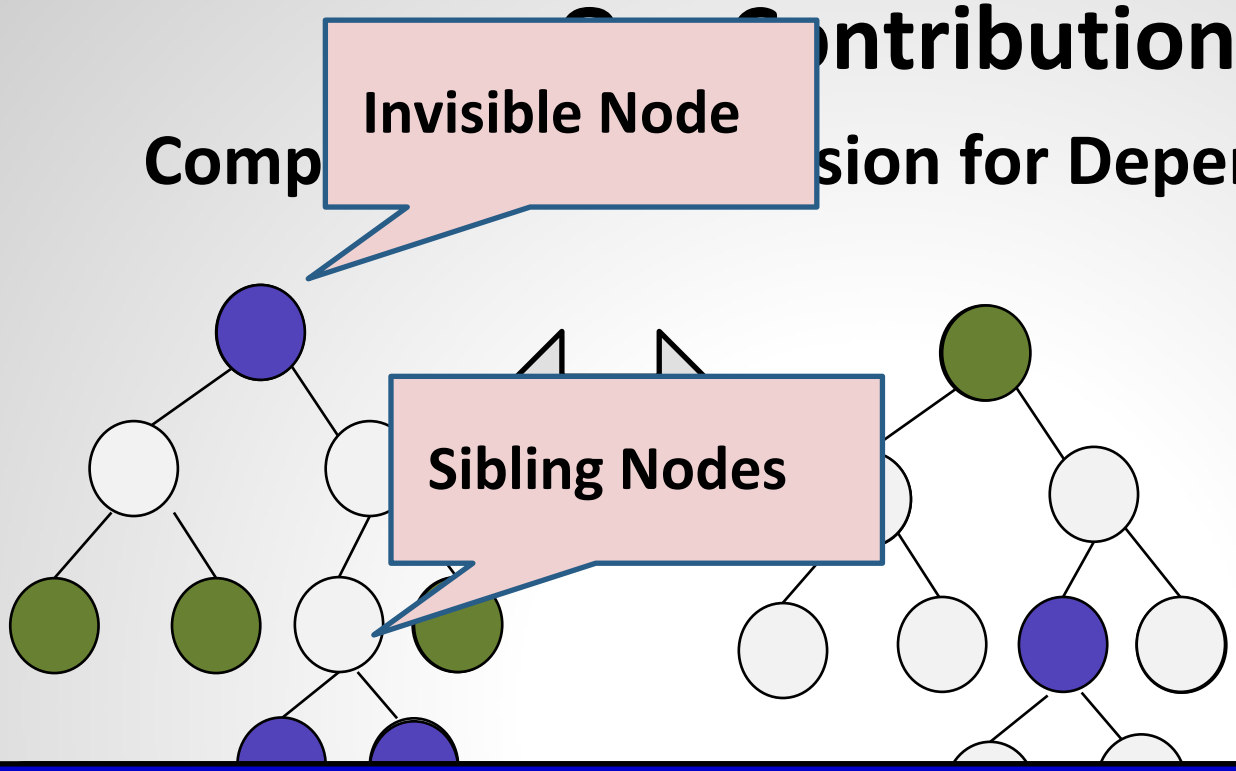

Theorem 1: HIMS

HIMS («Hide Invisible Merge Siblings») is O(w)-competitive, where w is prefix length. HIMS is deterministic.

Our Contribution:

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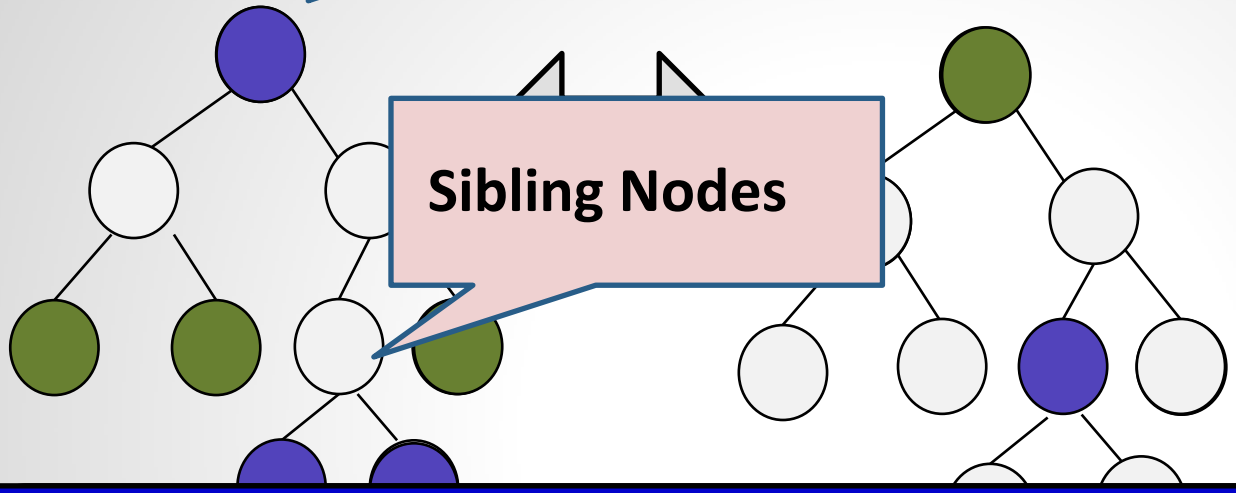


Theorem 1: HIMS

HIMS («Hide Invisible Merge Siblings») is O(w)-competitive, where w is prefix length. HIMS is deterministic.

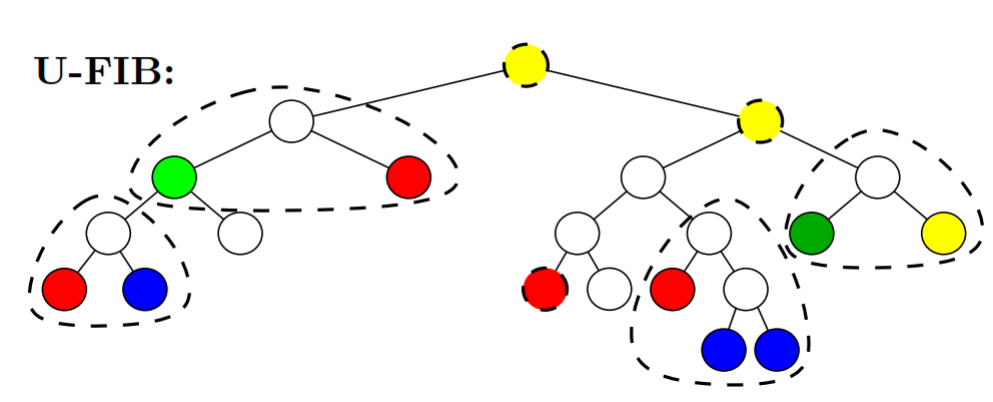
Theorem 2: Lower Bound

This is optimal for a large class of online and offline algorithms.

Ideas of HIMS.

Concept of Sticks: (on UFIB!)

Maximal subtrees of UFIB with colored leaves and blank internal nodes.

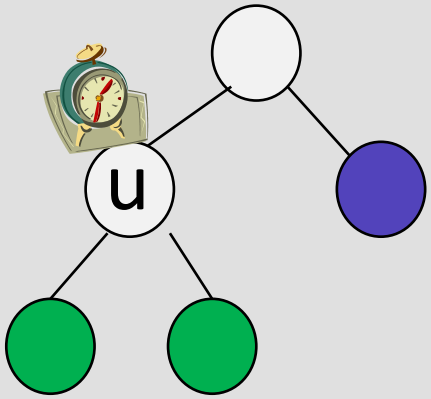


Idea: if all leaves in stick have same color, they would become mergeable.

Ideas of HIMS.

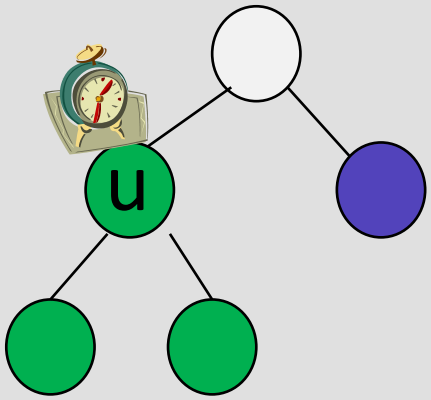
Two counters at nodes:

Merge Sibling Counter C(u)



C(u) = time since stick descendants are unicolor

Hide Invisible Counter H(u)



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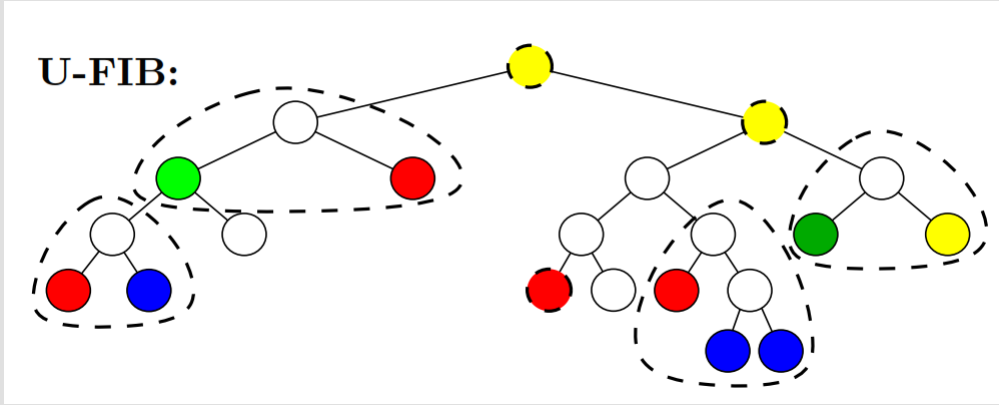

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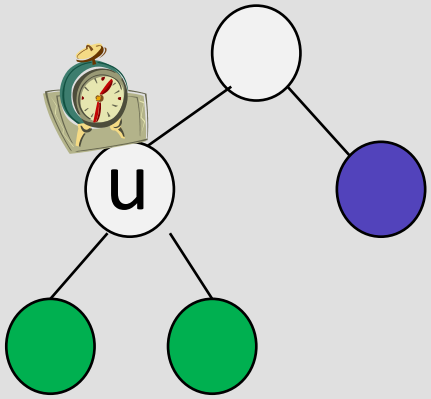

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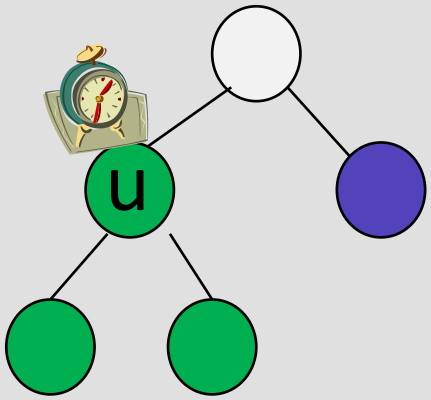

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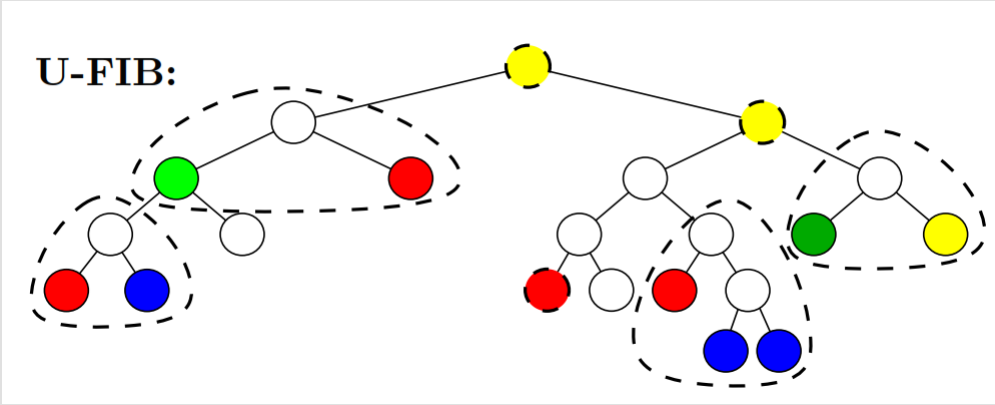

Idea: if all leaves in stick have same color, they would become mergeable.

Monotonic properties: E.g., color change of stick leaf resets all counters to root. So $C(u) \geq C(p(u))$ and $H(u) \geq H(p(u))$, and also $C(u) \geq H(u)$, as I need ancestor. Where p() is parent in trie.

Ideas of HIMS.

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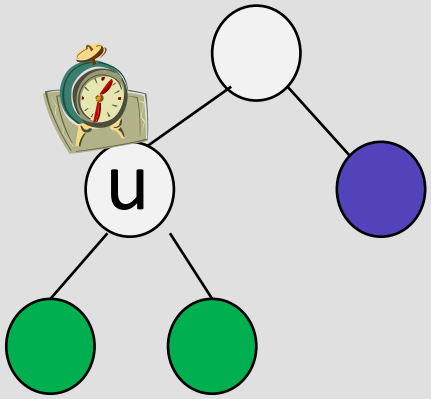

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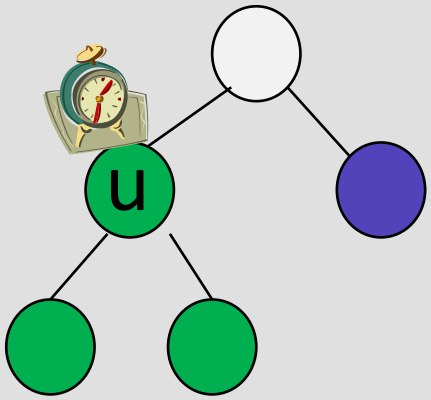

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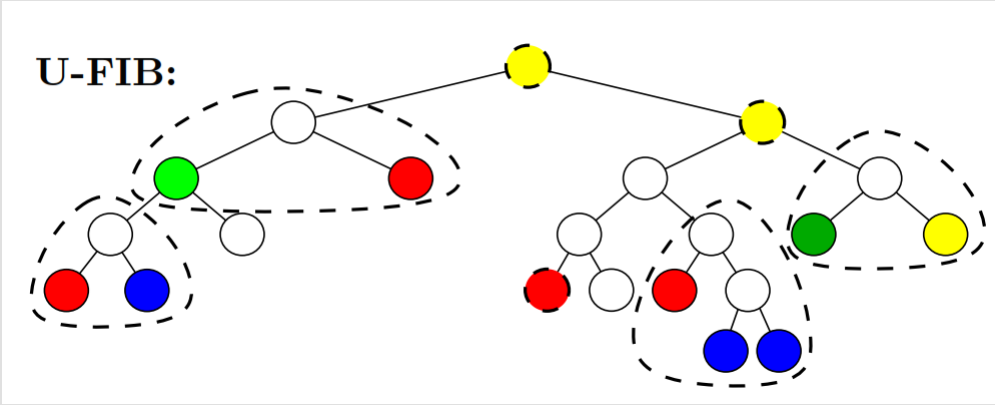

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HIMS Algo: Keep rule in FIB if and only if all three conditions hold:

(1) $H(u) < \alpha$ (remove if hidden for long)

(2) $C(u) \geq \alpha$ or u is a stick leaf (always true for UFIB rule)

(3) $C(p(u)) < \alpha$ or u is a stick root (remove if amortized parent)

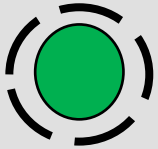
Ideas of HIMS.

Concept of Sticks: (on UFIB!)

Maximal subtrees of UFIB with colored leaves and

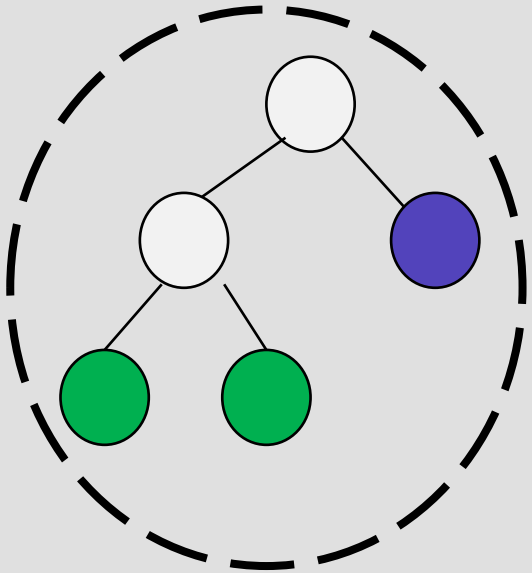
Example.

Ex 1.



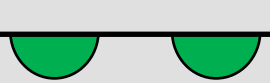
Trivial stick: node is both root and leaf (Conditions 2+3 fulfilled). So HIMS simply waits until invisible node can be hidden.

Ex 2.



Stick without colored ancestors: H(u)=0 all the time (Condition 1 fulfilled). So everything depends on sibling counters inside stick. E.g., if no change for time α and unicolor leaves, only root stays (all three conditions fulfilled).

Ex 3. Inner nodes of the stick are never longer than α in the FIB. (Otherwise second condition violated.)



H(u) = how long do nodes have same color as the least colored ancestor in UFIB?

(1) H(u) < **α** (remove if hidden for long)

(2) C(u) **≥ α** or u is a stick leaf (always true for UFIB rule)

(3) C(p(u)) < **α** or u is a stick root (remove if amortized parent)

Upper Bound: Proof Idea

Theorem:

HIMS is O(w) -competitive.

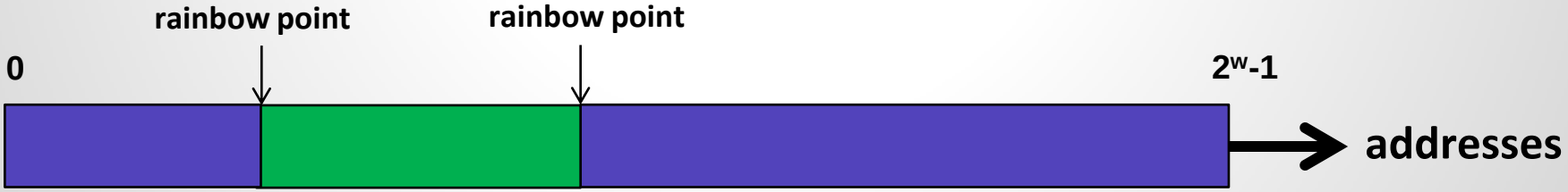
Proof idea:

- In the absence of further BGP updates

  (1) HIMS does not introduce any changes after time **α**

  (2) After time **α**, the memory cost is at most an factor O(w) off

- In general: for any snapshot at time t, either HIMS already started aggregating or changes are quite new
- Lower bound for OFF: Concept of rainbow points and line coloring useful.



- A rainbow point is a “witness” for a FIB rule.
- Many different rainbow points over time give lower bound.

Lower Bound: Proof Idea

Theorem:

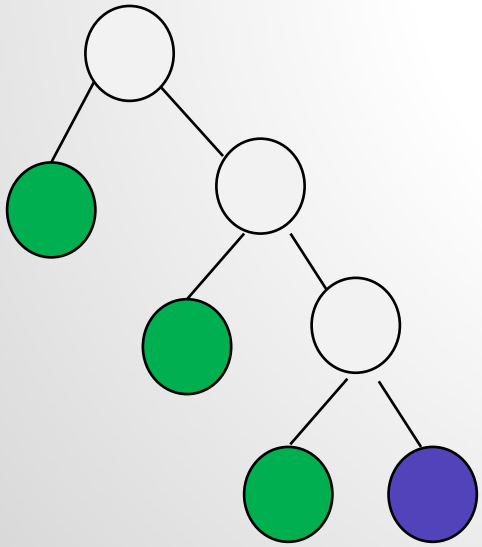
Any (online or offline) Stick-based algo is Ω(w) -competitive.

Proof idea:

Stick-based: (1) never keep a node outside a stick

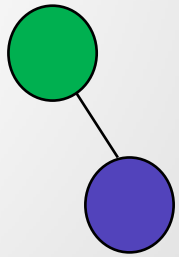
(2) inside a stick, for any pair u,v in ancestor-descendant relation, only keep one

Consider single stick: prefixes representing lengths 2^{w-1}, 2^{w-2}, ..., 2^1, 2^0, 2^0



Cannot aggregate stick!

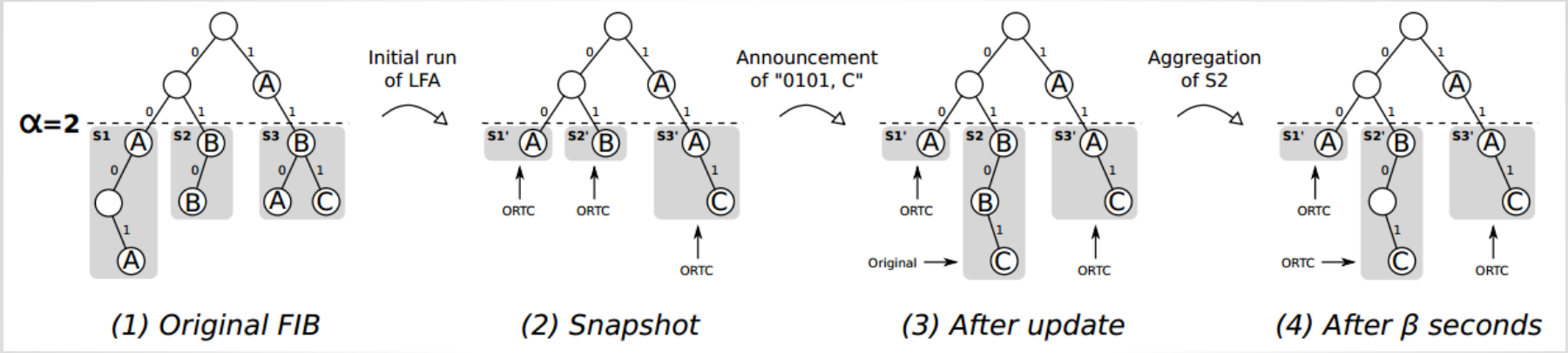
But OPT could do that:



QED

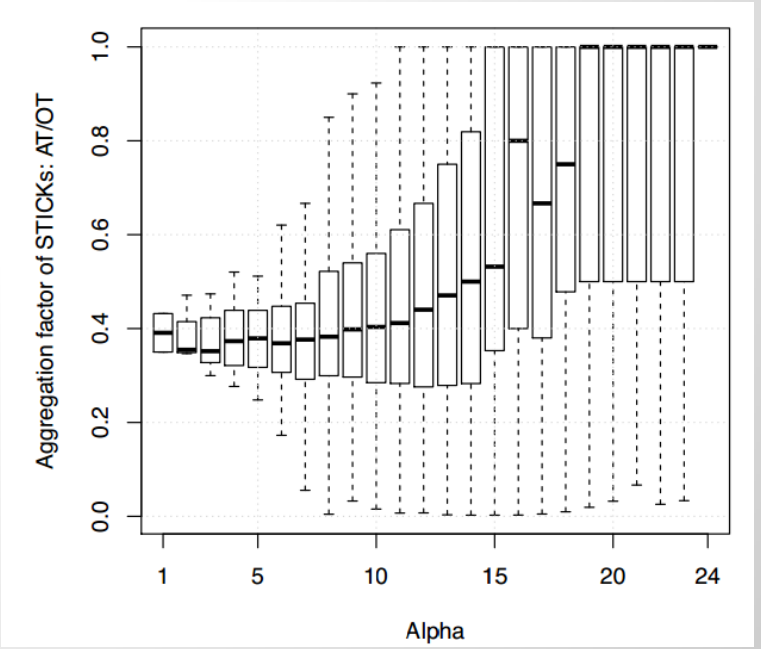
Simulations: The Simplified Version LFA

- LFA: Locality-aware FIB aggregation



- Combines stick aggregation with offline optimal ORTC
  - Parameter α: depth where aggregation starts
  - Parameter β: time until aggregation

For small alpha, Aggregated Table (AT) significantly smaller than Original Table (OT)



Conclusion

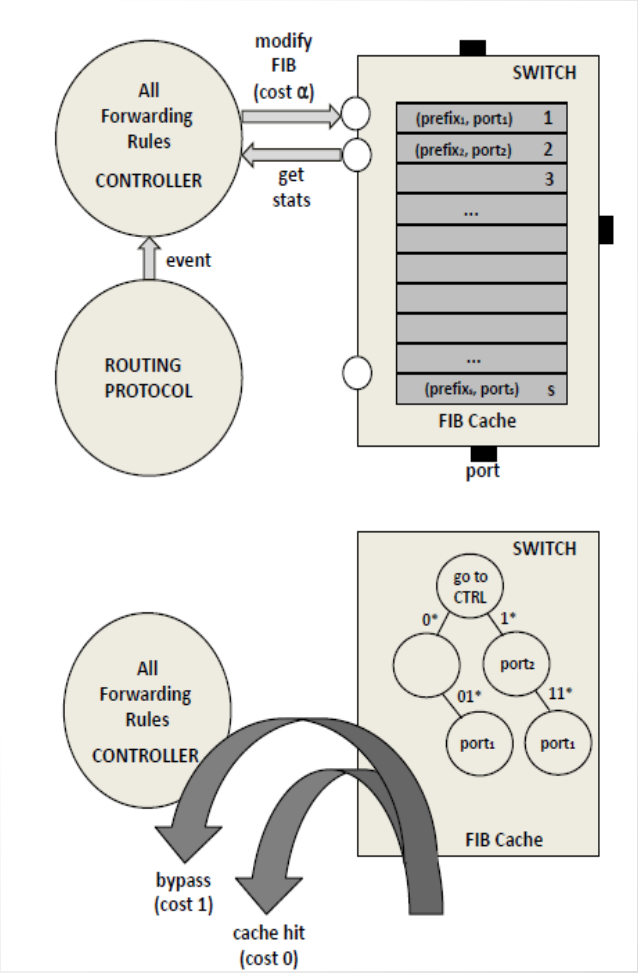
- Without exceptions in input and output: BLOCK is constant competitive
- With exceptions in input and output: HIMS is O(w)-competitive
- Note on offline variant: fixed parameter tractable, runtime of dynamic program in $f(\alpha)\, n^{O(1)}$

Thank you! Questions?

Why Aggregation in Worst Case?

With fixed switch size and sum over time?

- Start to make errors late!
- Or offload rest...



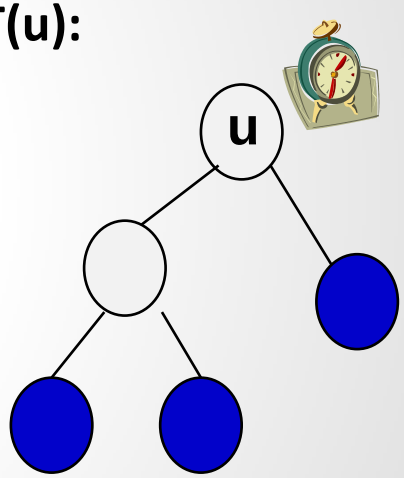
Analysis

Theorem: BLOCK(A,B) is 3.603-competitive.

Proof idea (a bit technical):

- Time events when ALG merges k nodes of T(u) at u
- **Upper bound ON cost:**
  - k+1 counters between B **α** and A **α**
  - Merging cost at most (k+3) **α**: remove k+2 leaves, insert one root
  - Splitting cost at most (k+1) 3**α**: in worst case, remove-insert-remove individually
- **Lower bound OFF cost:**
  - Time period from t- **α** to t
  - If OPT does not merge anything in T(u) or higher: high memory costs
  - If OPT merges ancestor of u: counter there must be smaller than B **α**, memory and update costs
  - If OPT merges subtree of T(u): update cost and memory cost for in- and out-subtree
- Optimal choice: A = $\sqrt{13} - 1$, B = $(2\sqrt{13})/3 - 2/3$
- Add event costs (inserts/deletes) later!

T(u):



QED

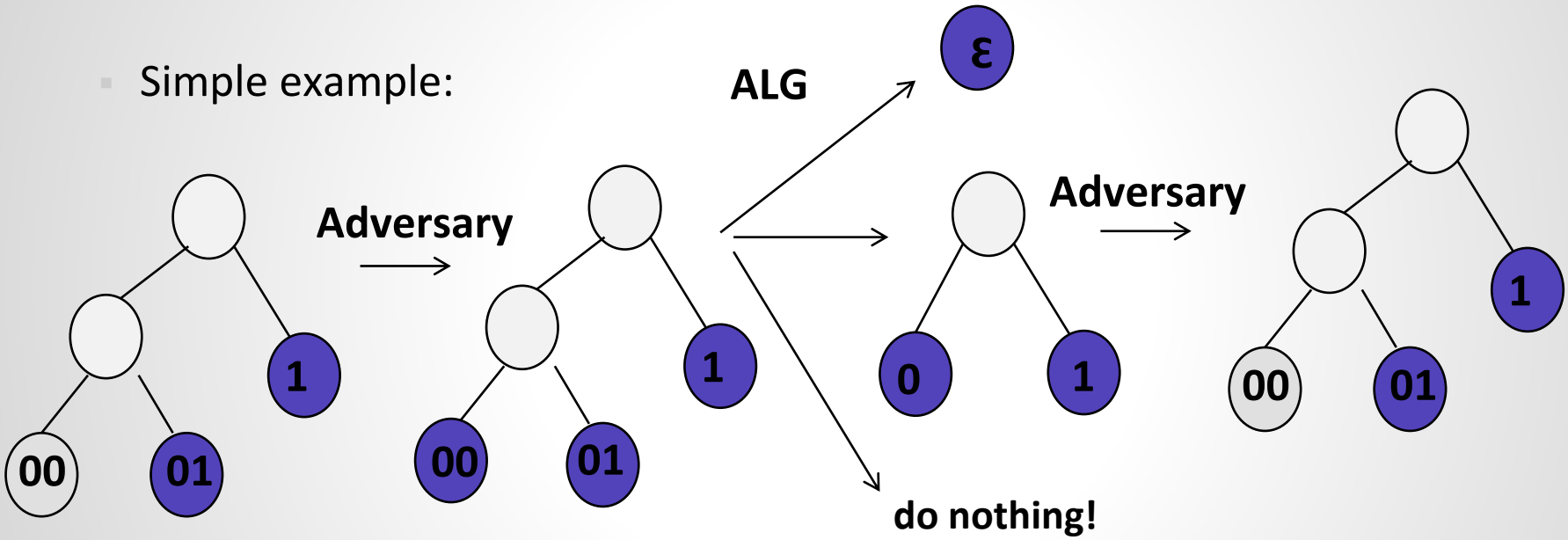
Lower Bound

Theorem:

Any online algorithm is at least 1.636-competitive.

Proof idea:

- Simple example:



(1) If ALG does never changes to single entry, competitive ratio is at least 2 (size 2 vs 1).

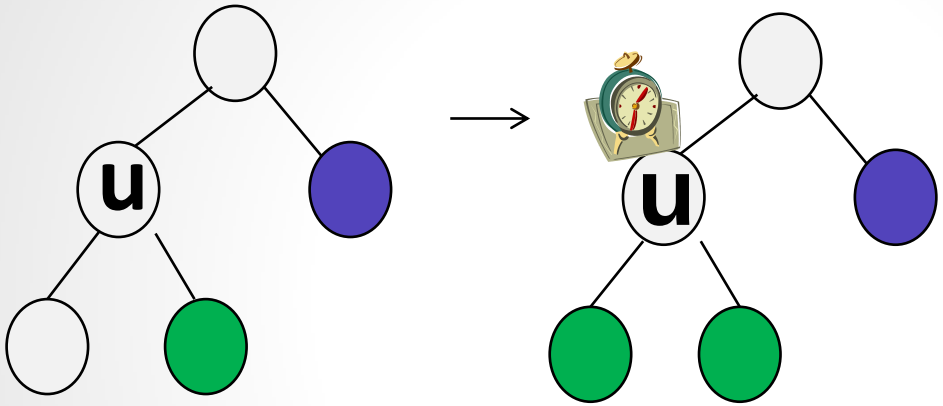
(2) If ALG changes before time **α**, adversary immediately forces split back! Yields costly inserts...

(3) If ALG changes after time **α**, the adversary resets color as soon as ALG for the first time has a single node. Waiting costs too high.

Note on Adding Insertions and Deletions

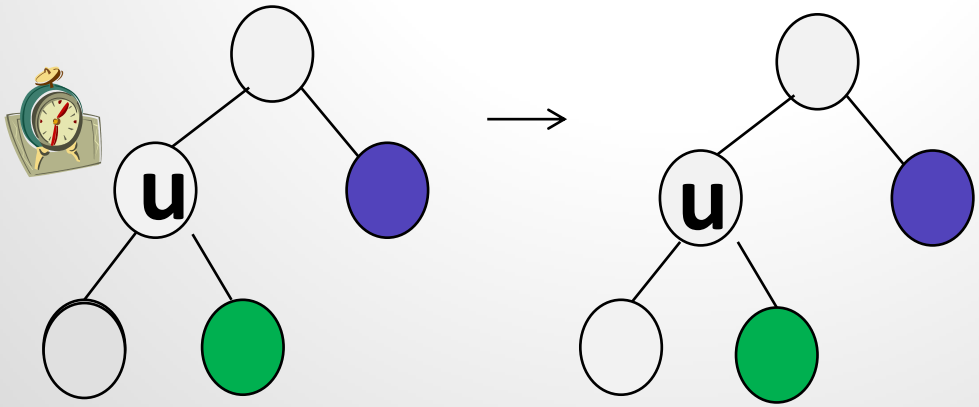
- Algorithm can be extended to insertions/deletions

Insert:



u becomes mergeable!

Delete:



u no longer mergeable!

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