Dynamic Forwarding Table Aggregation without Update Churn: The Case of Dependent Prefixes

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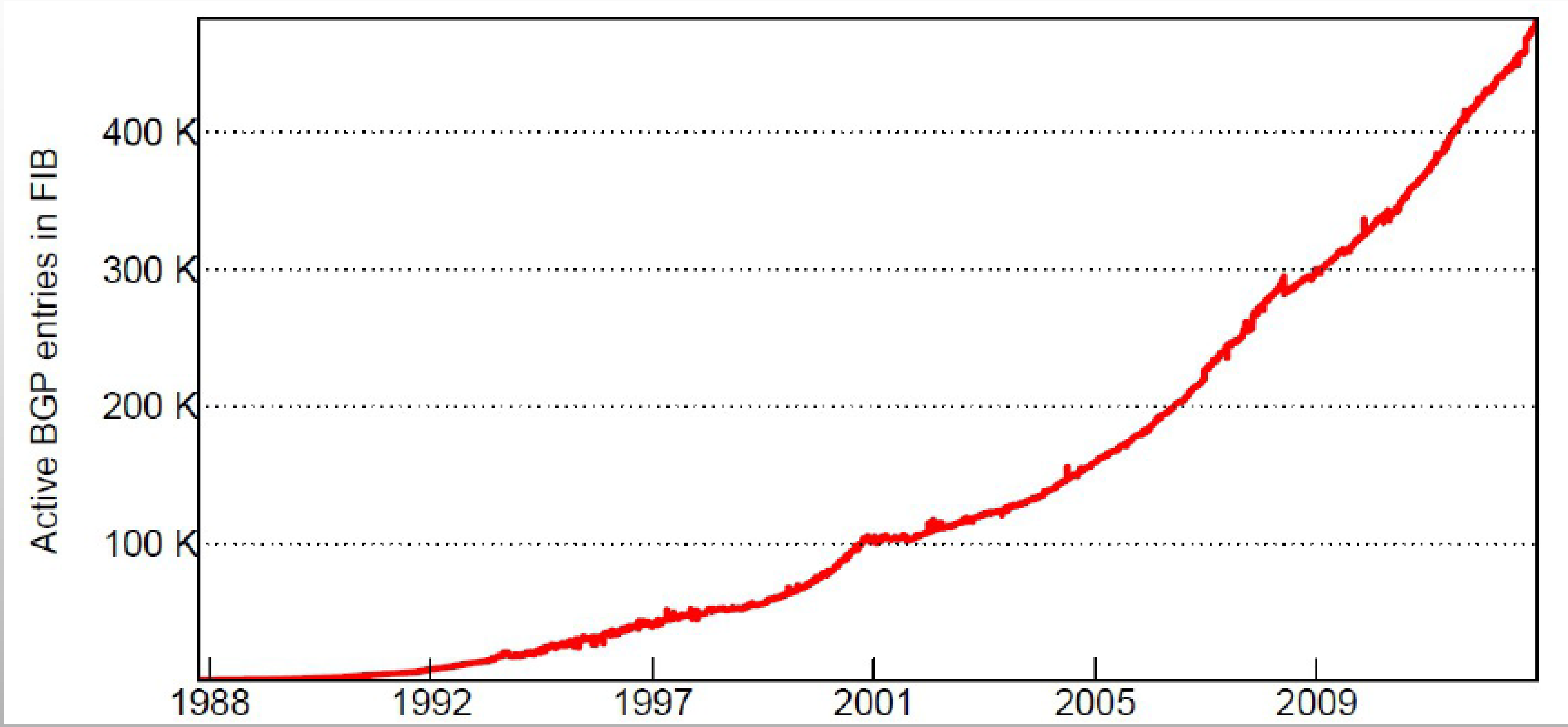
Wow! Growth of Forwarding Tables



Why? Scale, virtualization, …

Problem: - TCAM expensive and power-hungry!

- IPv6 may not help!

Local FIB Compression: 1-Page Overview

Model

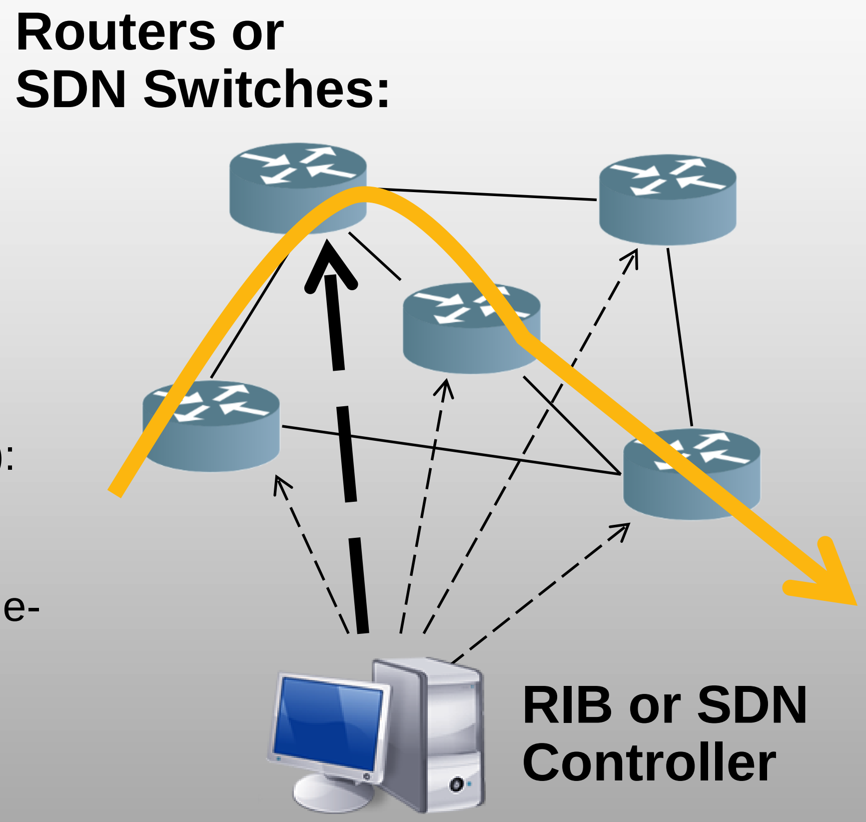
- FIB: Forwarding Information Base
- FIB consists of
  - set of <prefix, next-hop>
  - IP only: most specific IP prefix
- Control: (1) RIB or (2) SDN Controller (s. picture)

Basic Idea

- Dynamically aggregate FIB
  - "Adjacent" prefixes with same next-hop (= color): one rule only!
- But be aware that BGP updates (next-hop change, insert, delete) may change forwarding set, need to de-aggregate again

Benefits

- Only single router affected
- Aggregation = simple software update



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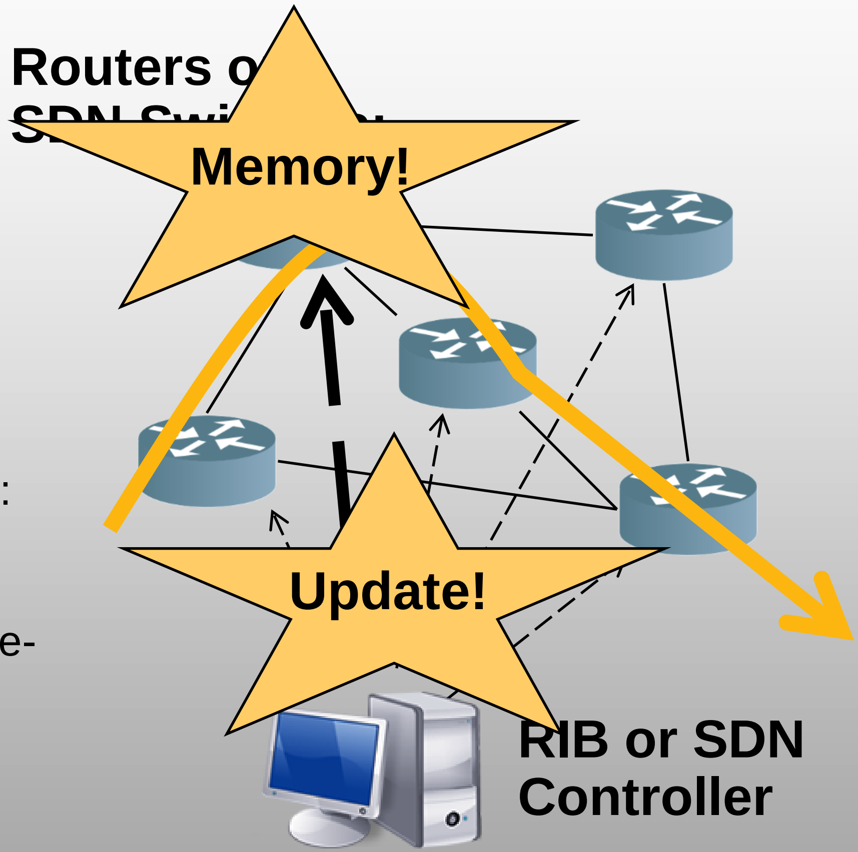
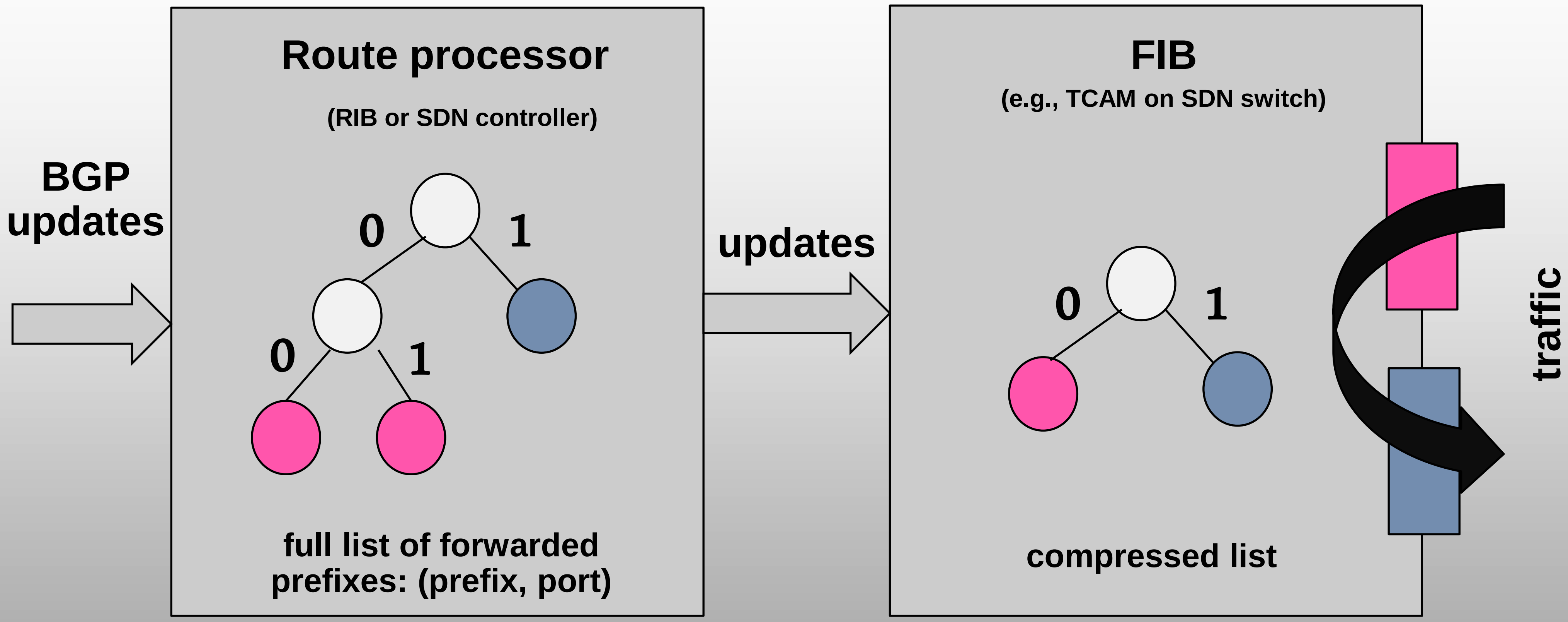


Setting: A Memory-Efficient Switch/Router



Goal: keep FIB small but consistent!

Without sending too many additional updates.

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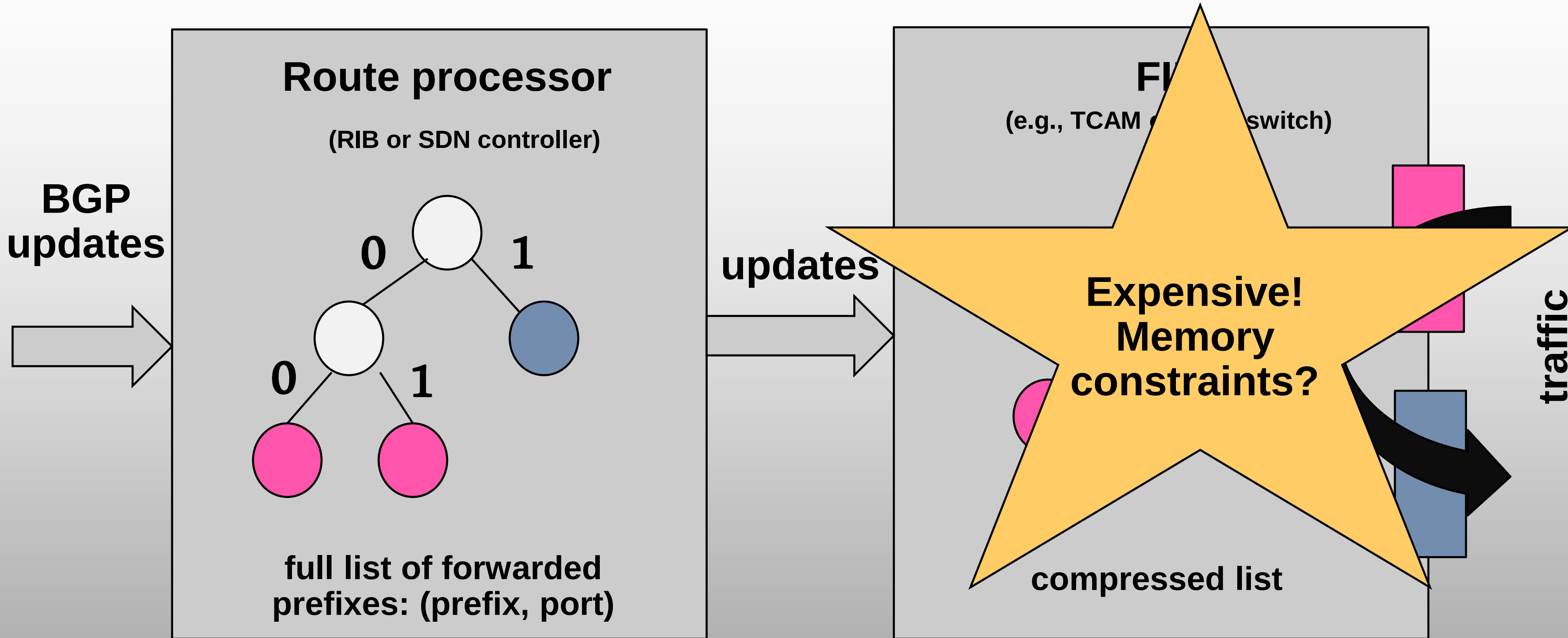

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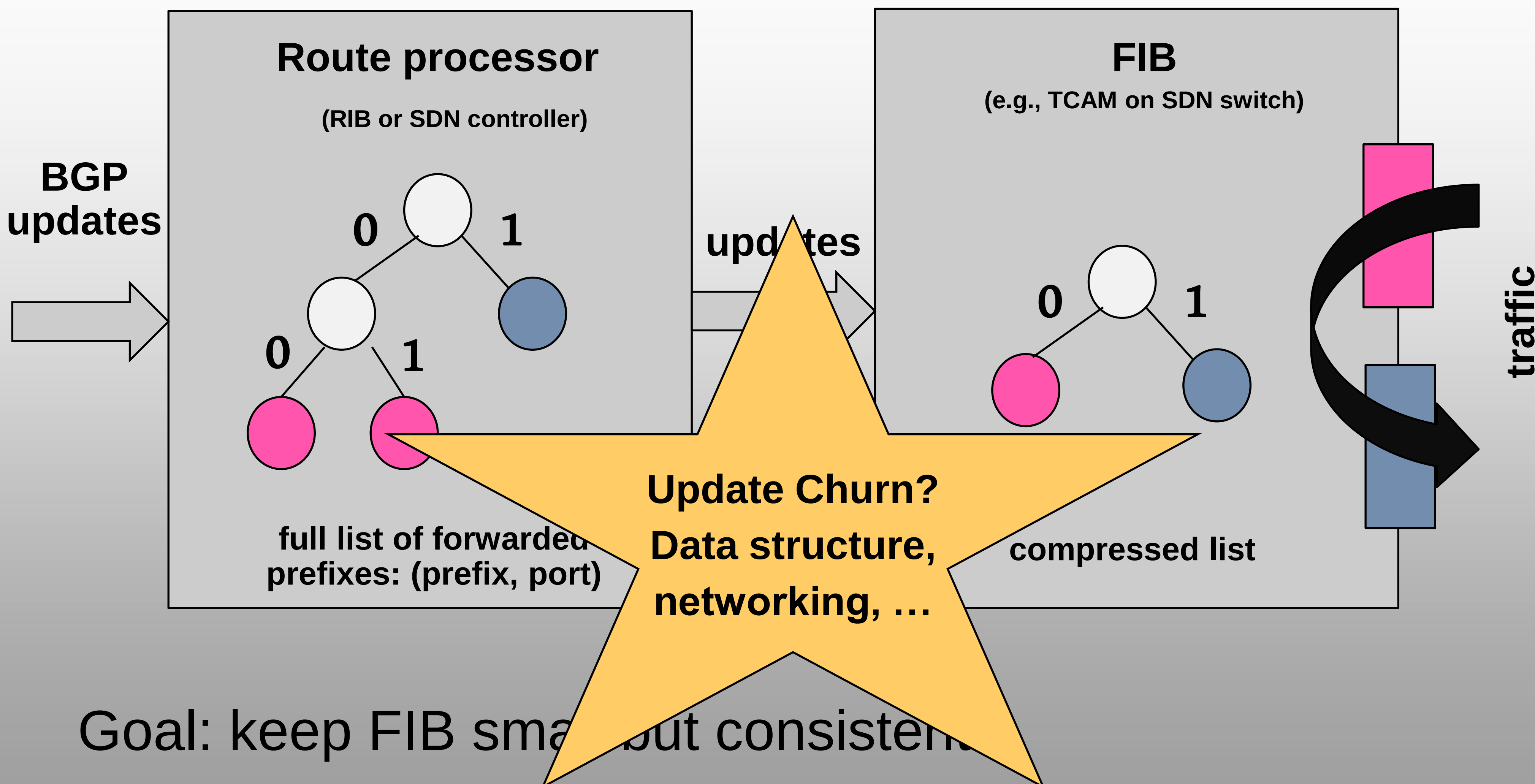

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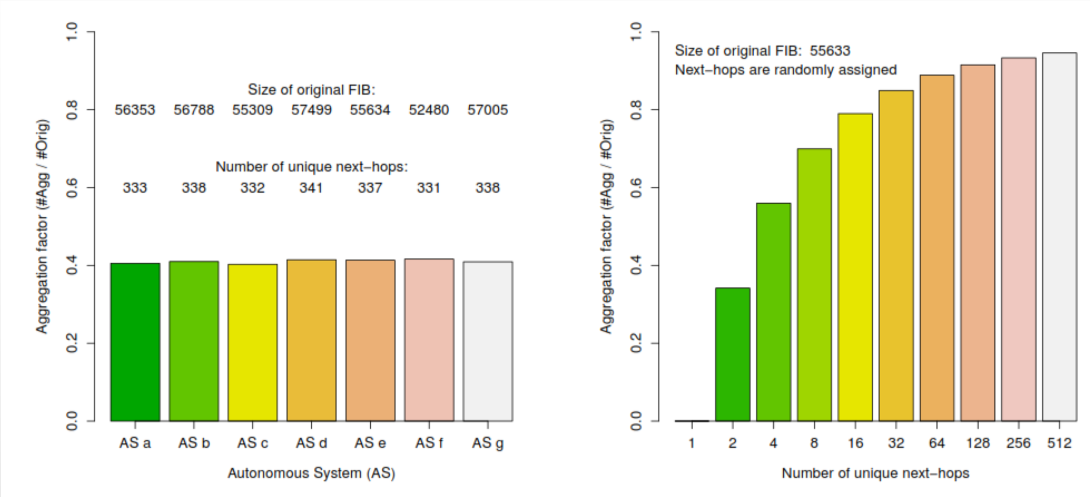
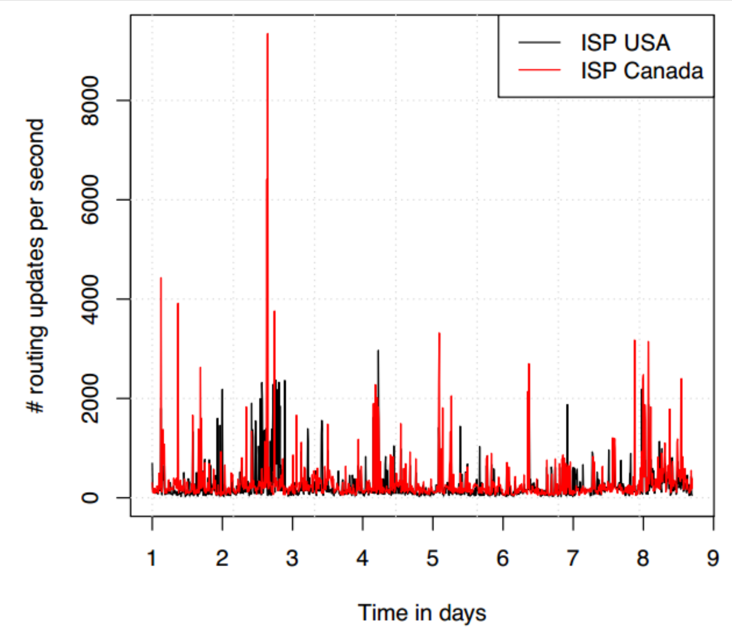
Motivation: FIB Compression and Update Churn



Benefits of FIB aggregation

- Routeviews snapshots indicate 40% memory gains
- More than under uniform distribution
- But depends on number of next hops



Churn

- Thousands of routing updates per second
- Goal: do not increase more (or improve!)

Model: Online Perspective

Competitive analysis framework:

Online Algorithm

Online algorithms make decisions at time t without any knowledge of inputs at times t'>t.

Competitive Analysis

An *r-competitive online algorithm* ALG gives a worst-case performance guarantee: the performance is at most a factor r worse than an optimal offline algorithm OPT!

Competitive Ratio

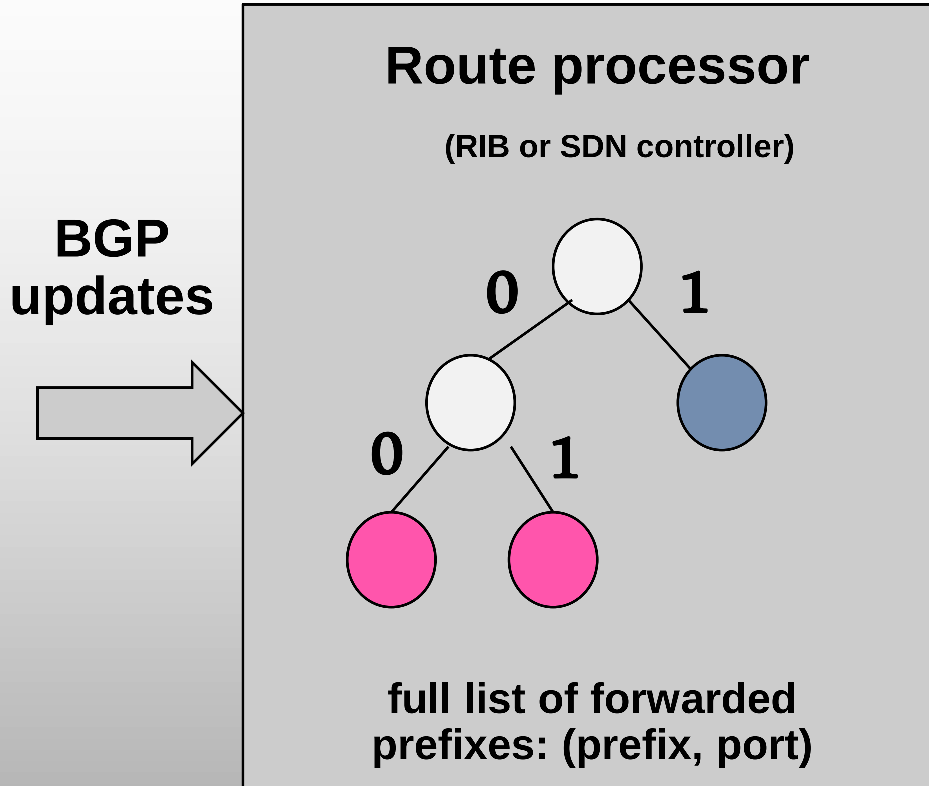
Competitive ratio r,

$$r = \text{Cost(ALG)} / \text{cost(OPT)}$$

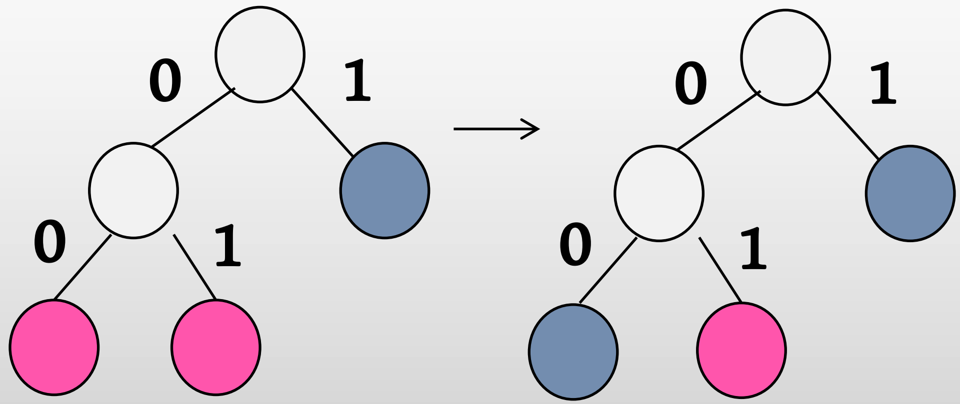
The price of not knowing the future!

No need for complex predictions but still good!

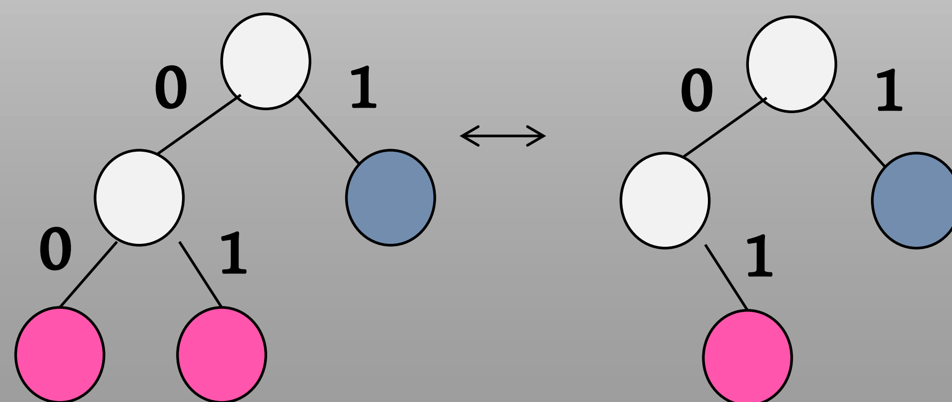
Model: Online Input Sequence



Update: Color change

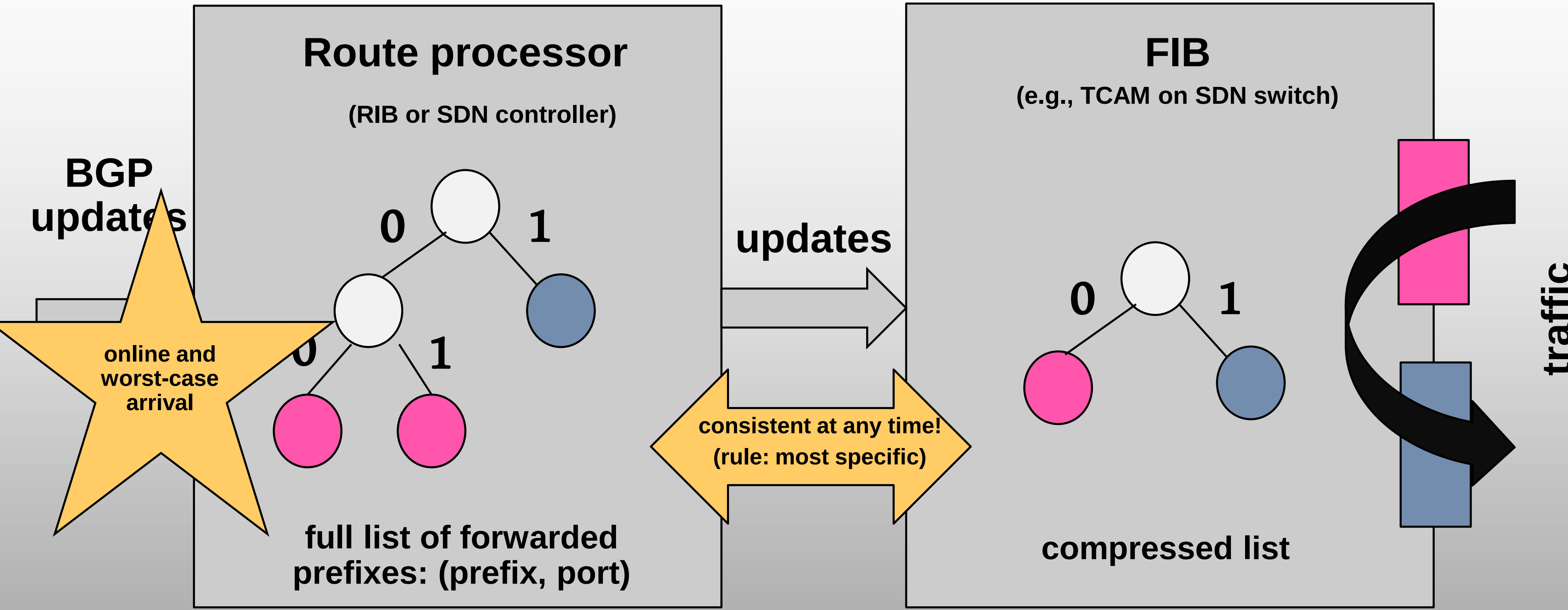


Update: Insert/Delete



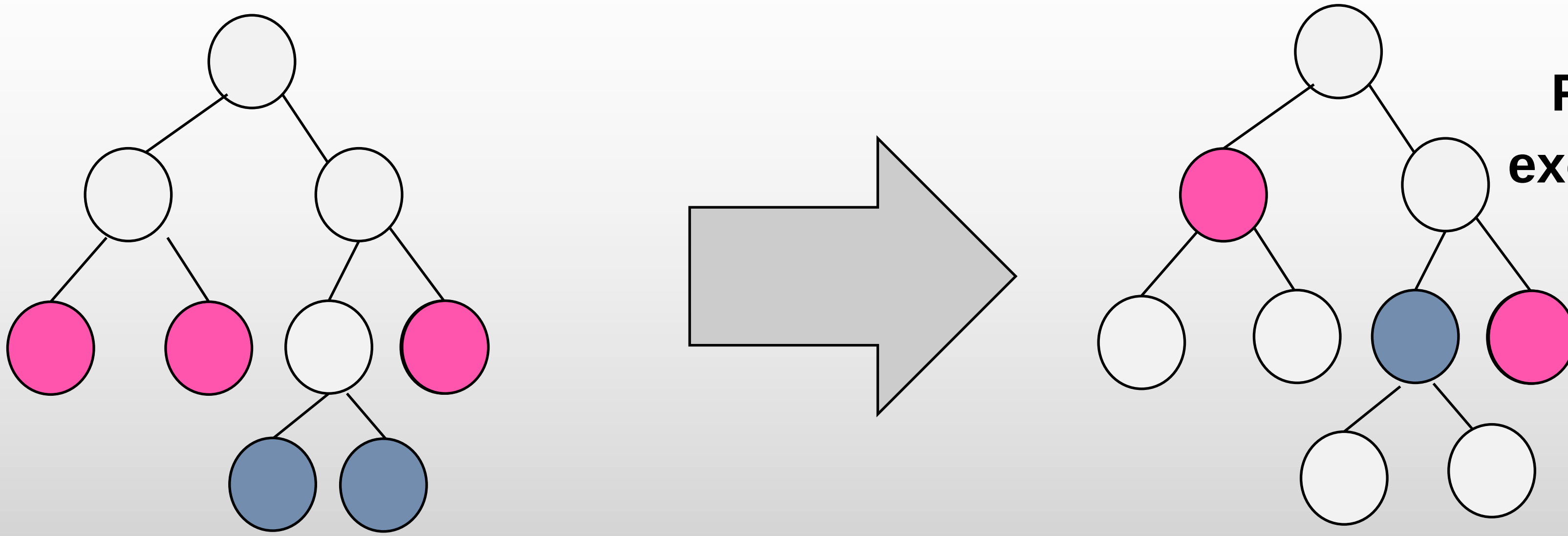
Model: Costs

Ports = Next-Hops = Colors



$$\text{Cost} = \alpha\,(\#\ \text{updates to FIB}) + \int_t \text{memory}$$

Model 1: Aggregation without Exceptions (SIROCCO 2013)



FIB w/o exceptions

size 3

Uncompressed FIB (UFIB): independent prefixes

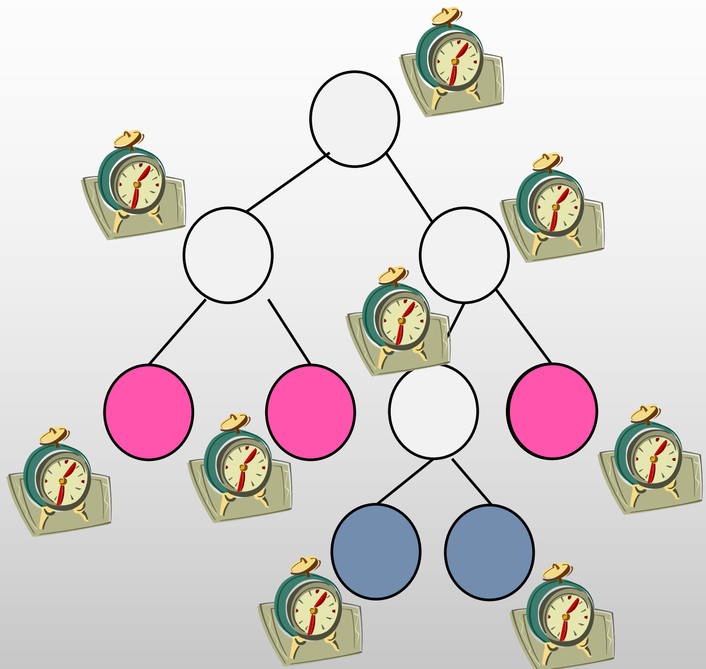
size 5

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

Theorem:
Any online algorithm is at least 1.636-competitive.
(Even ALG can use exceptions and OPT not.)

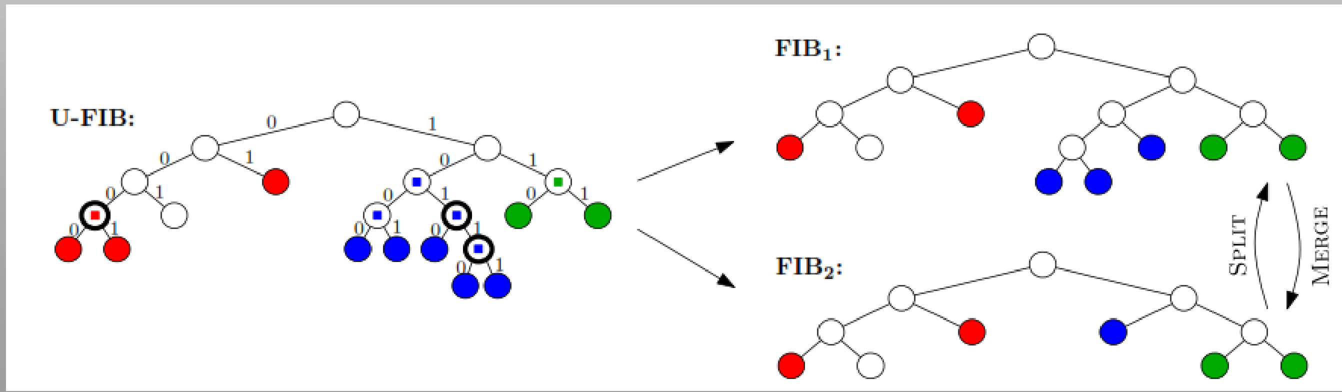
# less specifics	0	1	2	3	4	5	6
% of prefixes	50.1%	38.2%	9.5%	1.7%	0.4%	0.1%	0.01%

Model 1: Aggregation without Exceptions (SIROCCO 2013)



BLOCK(A,B) operates on trie:

- Two parameters A and B for amortization (A ≥ B)
- 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. (Maybe v is u.)
- Split lazily: only when forced.



Nodes with square inside: mergeable. Nodes with bold border: suppressed for FIB1.

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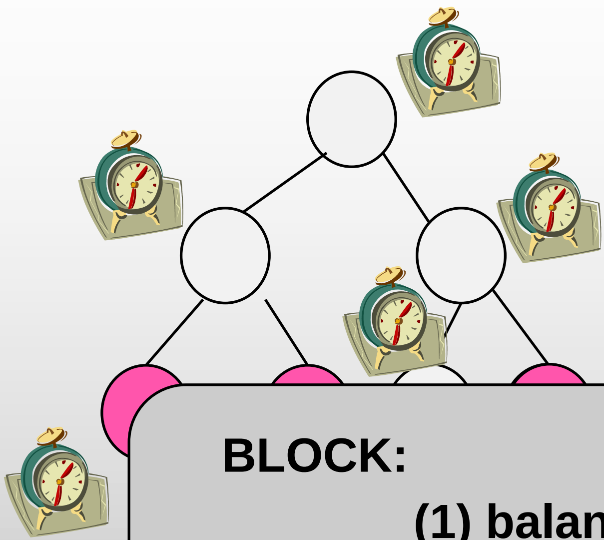

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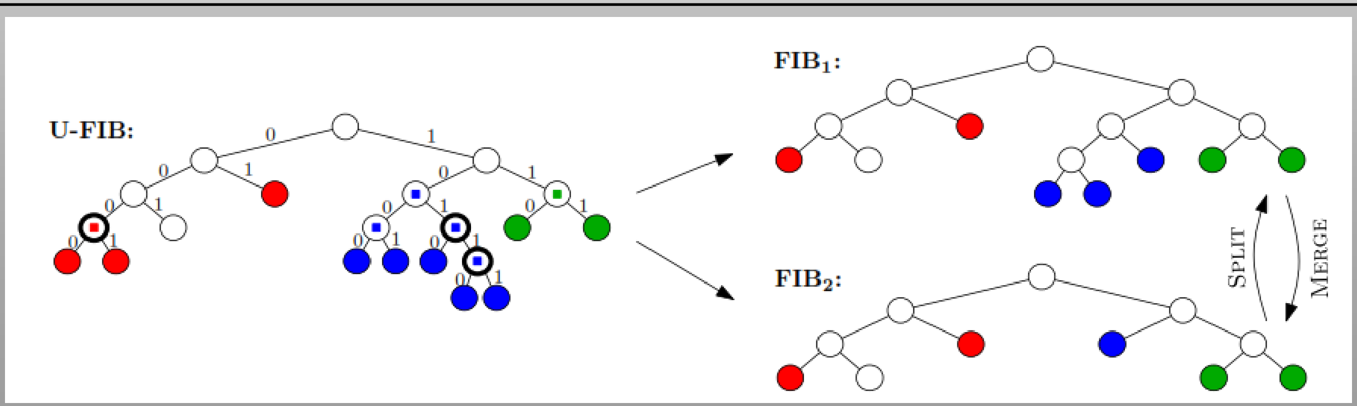
BLOCK:

(1) balances memory and update costs

(2) exploits possibility to merge multiple tree nodes simultaneously at lower price (threshold A and B)



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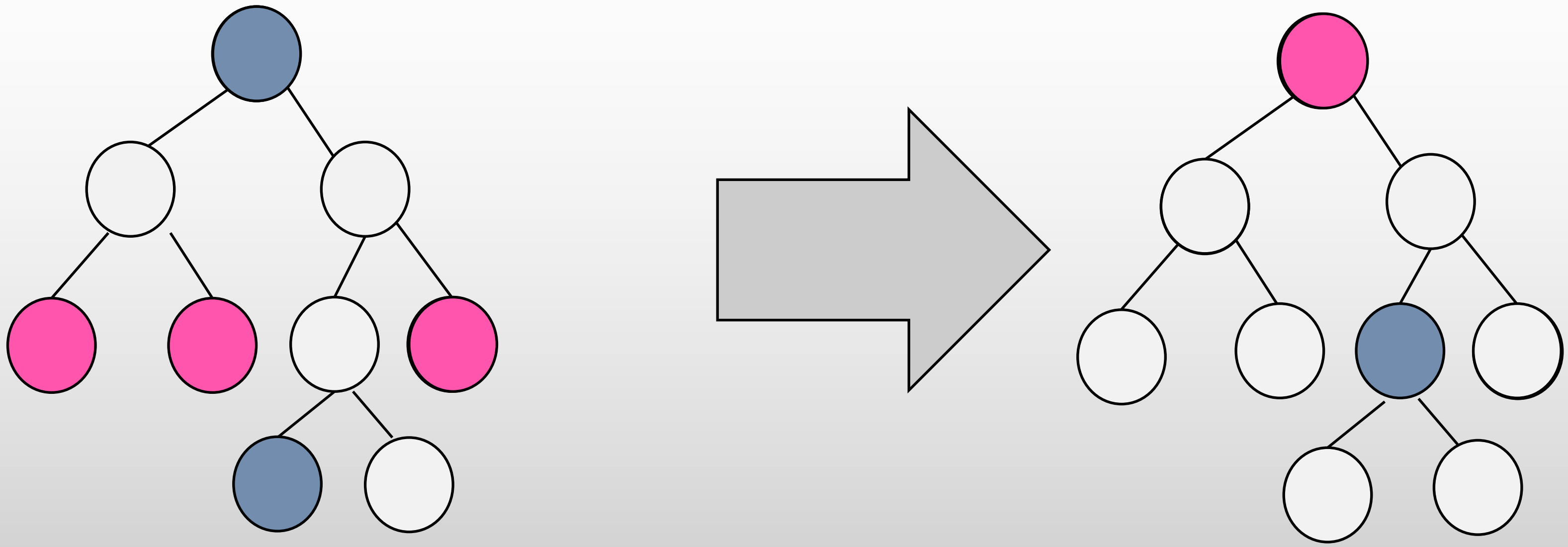
Model 2: Aggregation with Exceptions (DISC 2013)



FIB w/ exceptions

size 2

Uncompressed FIB (UFIB): dependent prefixes

size 5

Theorem:

HIMS is O(w)-competitive, w = address length.

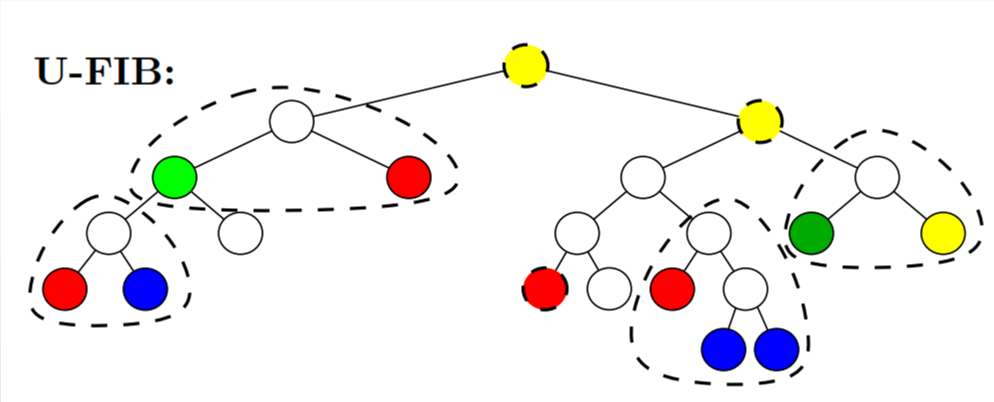
Theorem:

Asymptotically optimal for general class of online algorithms.

Exceptions: Concepts and Definitions

Sticks

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

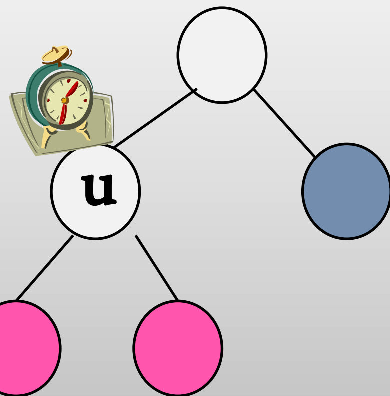


Idea: if all leaves in Stick have same color, they would become mergeable.

The HIMS Algorithm

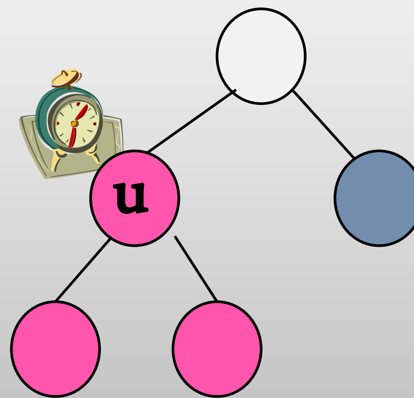
- Hide Invisibles Merge Siblings (HIMS)
- Two counters in Sticks:

Merge Sibling Counter:



C(u) = time since Stick descendants are unicolor

Hide Invisible Counter:



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

Note: C(u) ≥ H(u), C(u) ≥ C(p(u)), H(u) ≥ H(p(u)), where p() is parent.

The HIMS Algorithm

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

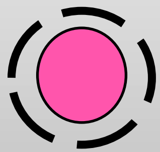
(1) $H(u) < \alpha$ (do not hide yet)

(2) $C(u) \geq \alpha$ or u is a stick leaf (do not aggregate yet if ancestor low)

(3) $C(p(u)) < \alpha$ or u is a stick root

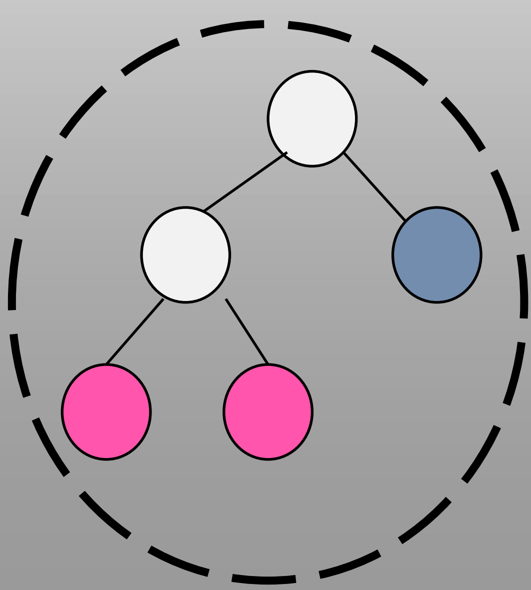
Examples:

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 counters inside stick. If counters large, only root stays.

Analysis

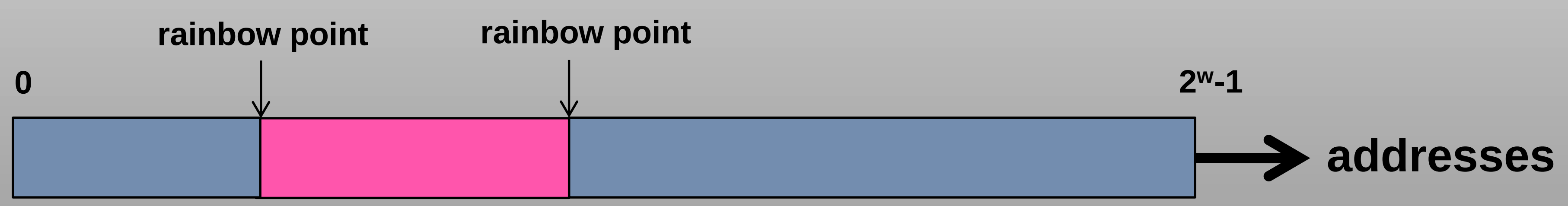
Theorem:

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
- 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

Theorem:

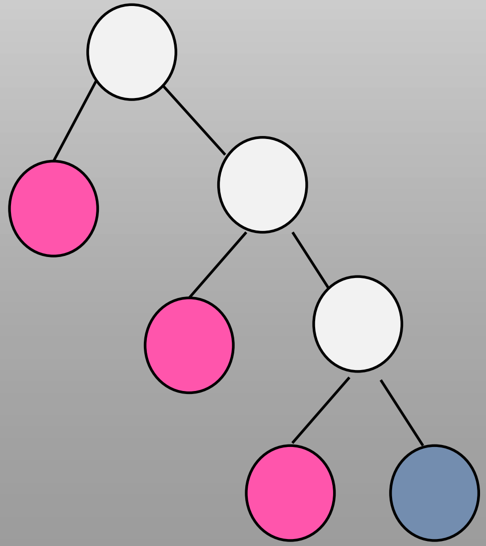
Any (online or offline) Stick-based algo is $\Omega(w)$ -competitive.

Proof idea:

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

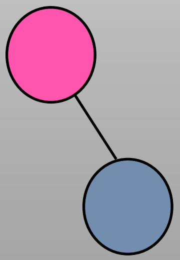
(2) inside a stick, for any pair u,v in ancestor-descendant relation, only keep one

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



Cannot aggregate stick!

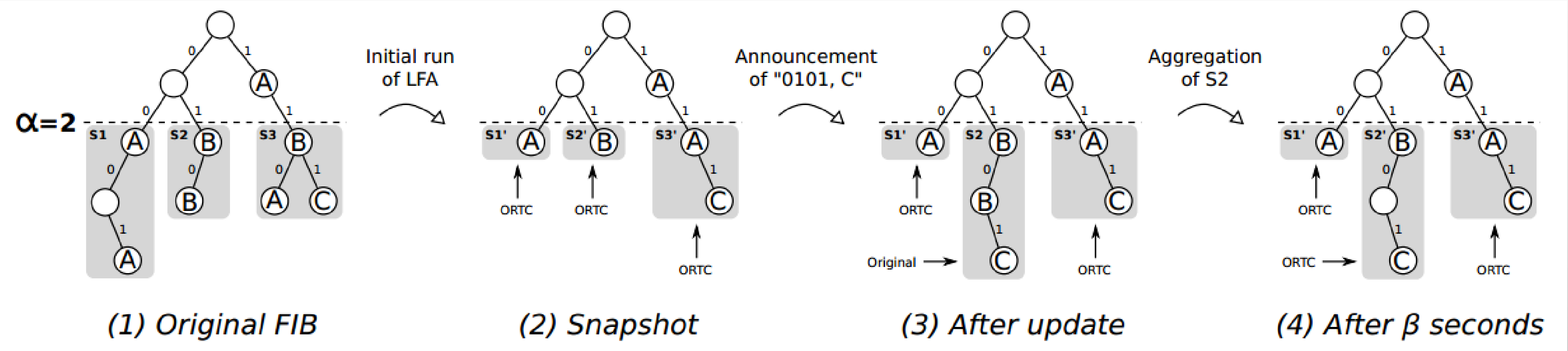
But OPT could do that:



QED

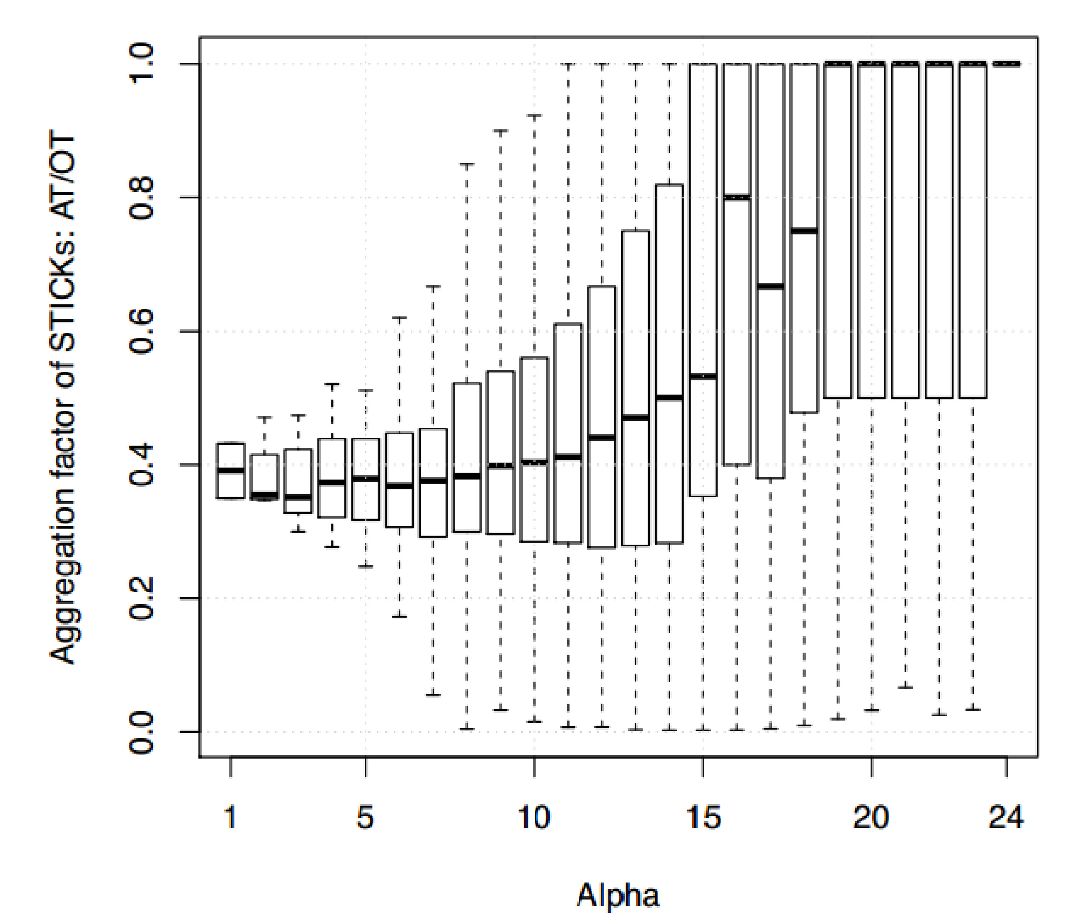
LFA: A Simplified Implementation

- LFA: Locality-aware FIB aggregation



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

LFA Simulation Results



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?