TCP ex Machina: Computer-Generated Congestion Control

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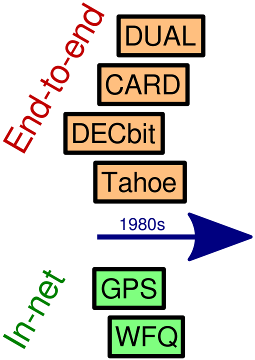
Congestion control!

- Prevents congestion collapse
- Allocates network resources among users
- Can be purely end-to-end or not

The march of congestion control mechanisms



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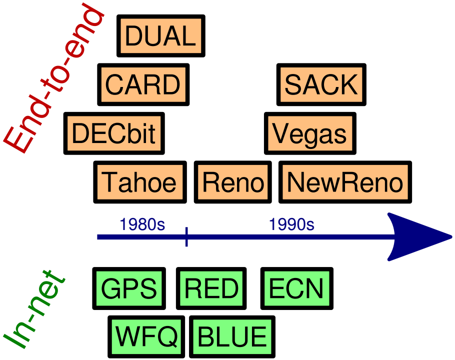

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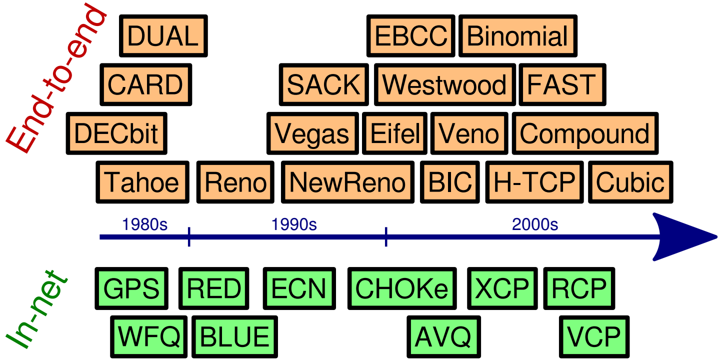

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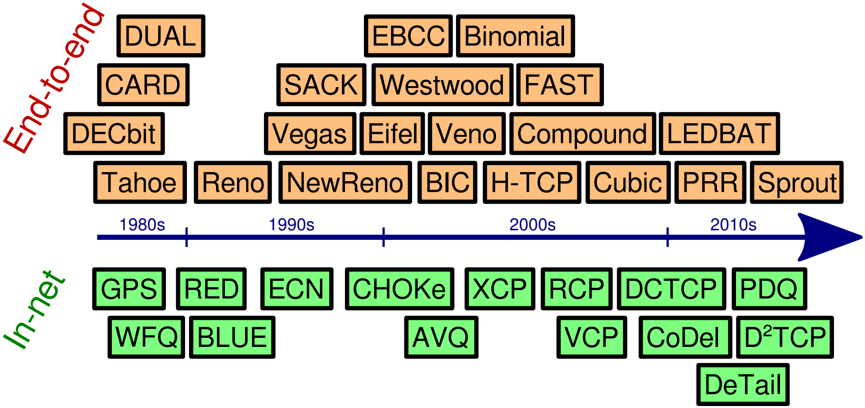

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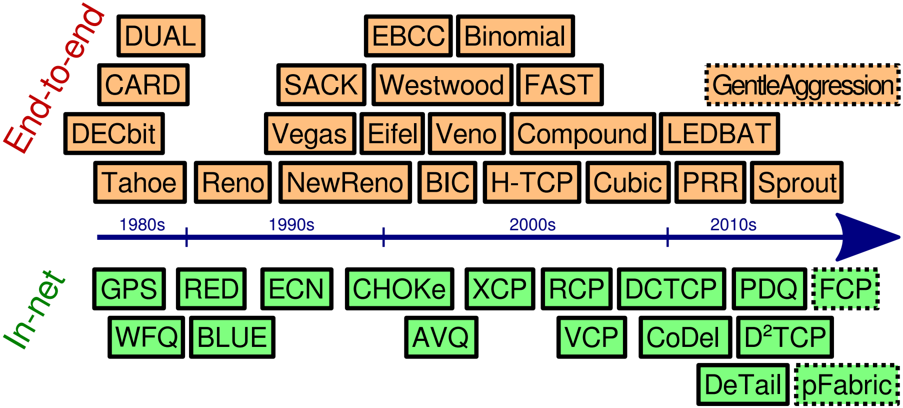

Our work

If congestion control is the answer,
what's the question?

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Are there better answers?

Rational choice of scheme is challenging

Cubic vs. **Compound**

- Different goals?
- Different assumptions about network?
- One scheme just plain better?

Networks constrained by a fuzzy idea of TCP's assumptions

- Mask stochastic loss
- Bufferbloat
- Mask out-of-order delivery
- No parallel/multipath routing

Advice for Internet Subnetwork Designers (RFC 3819) is 21,000 words!

Apps hack around TCP

- Open lots of flows
- Goose slow start
- Add pacing
- Give up and do it yourself

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Chrome (QUIC)
BitTorrent (μTP)
Mosh (SSP)
Aspera (fasp)

Better: free the network to evolve

Transport layer should adapt to **whatever**:

- network does
- application wants

What we built

Remy: a program that generates congestion-control schemes offline

Input:

- Prior assumptions (what network may do)
- Goal (what app wants)

Output: CC algorithm for a TCP sender (RemyCC)

Time: a few hours

Cost: \$5–\$10 on Amazon EC^2

The basic question of congestion control

At this moment, do I:

- send a packet
- not send a packet?

Objectives of congestion control

Maximize

- $\sum_i \log\left[\text{throughput}_i\right]$ (proportionally fair throughput)

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- $\min_i \text{throughput}_i$ (max-min throughput)

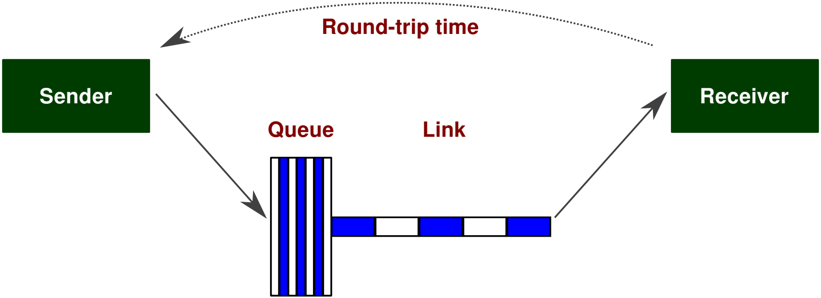
Minimize

- average flow completion time
- page load time
- tail completion time

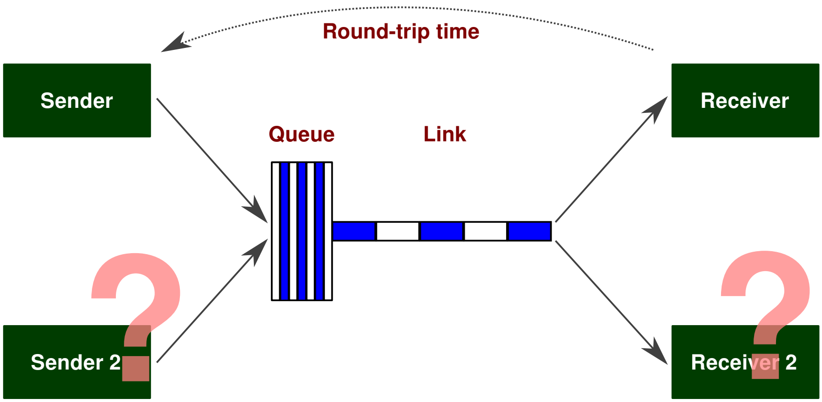
Prior assumptions

- Model of network uncertainty
  - Link speed distribution
  - Delay distribution
- Traffic model
  - Web browsing, MapReduce, videoconferencing

Dumbbell network



Dumbbell network



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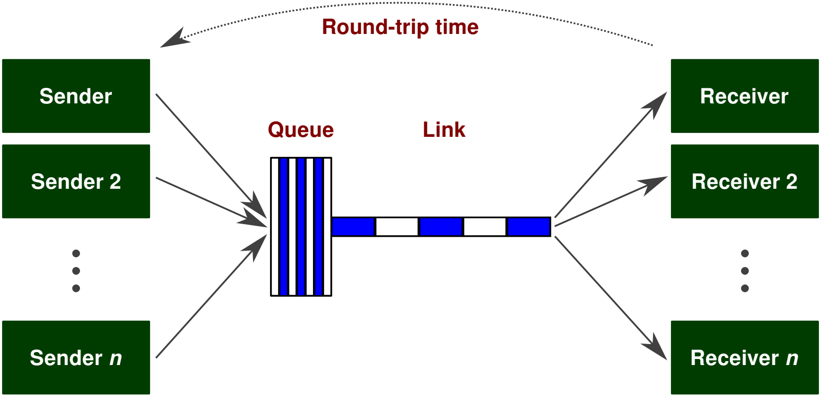


Superrational congestion control

At this moment,* do I:

- send a packet
- not send a packet?

* Assuming every node is running the same algorithm.

Remy: search for superrationality

- Remy searches for the best congestion-control algorithm
- Optimizes expected objective over prior assumptions
- Makes tractable by limiting available state

A RemyCC tracks three congestion signals

r_ewma: moving average of interval between acks

s_ewma: . . . between sender timestamps echoed in acks

rtt_ratio: ratio of last RTT to smallest RTT so far

Why these three congestion signals?

- Benefit can be measured empirically
  - In our experiments, little help from adding more
  - Other networks might find differently
- More signals increase search time

A RemyCC maps each state to an action

$$\textsc{Rule}(\mathit{r\_ewma}, \mathit{s\_ewma}, \mathit{rtt\_ratio}) \rightarrow \langle m, b, \tau \rangle$$

- m Multiple to congestion window
- b Increment to congestion window
- τ Minimum interval between two outgoing packets

Runtime for a RemyCC

On ack:

- $\langle m, b, \tau \rangle \leftarrow \textsc{Rule}(r\_ewma, s\_ewma, rtt\_ratio)$
- $\texttt{cwnd} \leftarrow m \cdot \texttt{cwnd} + b$

Send packet if:

- $\texttt{cwnd} > \texttt{FlightSize}$, and
- last packet sent $> \tau$ ago

Remy's job

Find piecewise-continuous $\textsc{Rule}()$ that optimizes expected value of objective function.

Remy example: 2D state space

On ack:

- $\langle m, b, \tau \rangle \leftarrow \textsc{Rule}(r\_ewma, s\_ewma,$ **rtt_ratio** $)$

Remy example: 2D state space

On ack:

- $\langle m, b, \tau \rangle \leftarrow \textsc{Rule}(r\_ewma, s\_ewma,$ [redacted]$)$

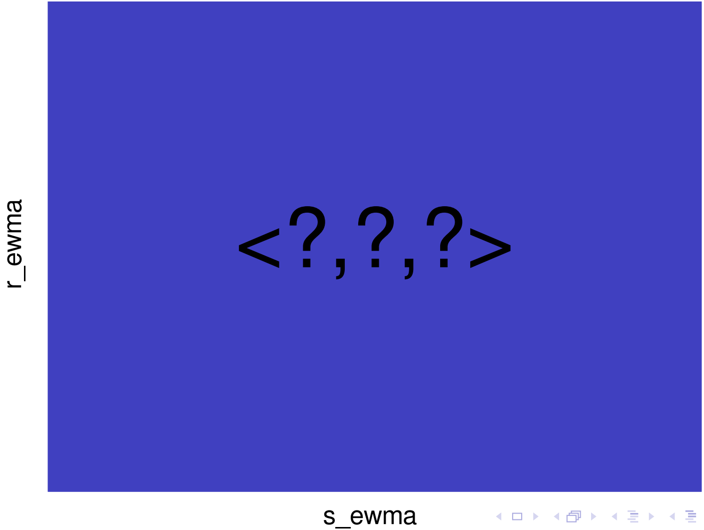
Remy example: Prior assumptions

Quantity	Distribution	Units
Link speed	Uniform(10, 20)	Mbps
RTT	Uniform(100, 200)	ms
n	Uniform(1, 16)	
"On" process "Off" process	$\exp[\mu = 5]$ same	seconds

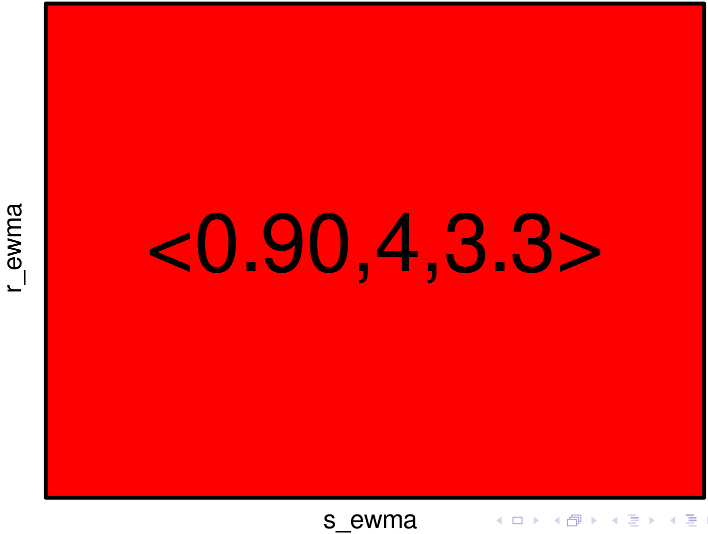
Remy example: Objective

$$\sum_i \log \left[\frac{\text{throughput}_i}{\text{delay}_i} \right]$$

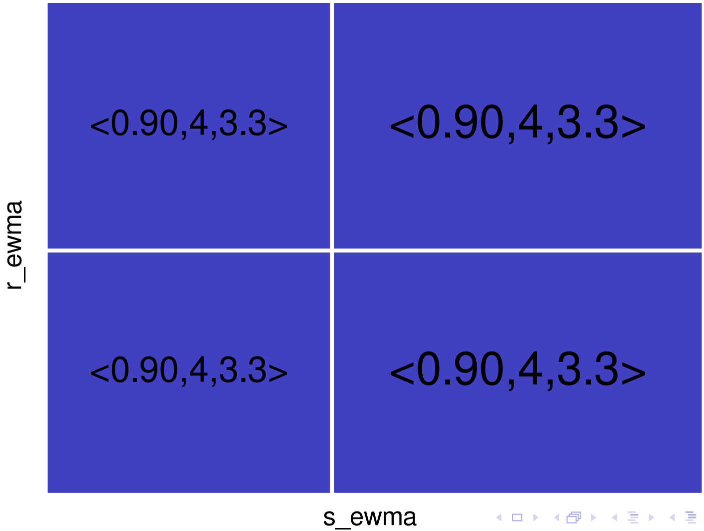
One action for all states. Find the best value.



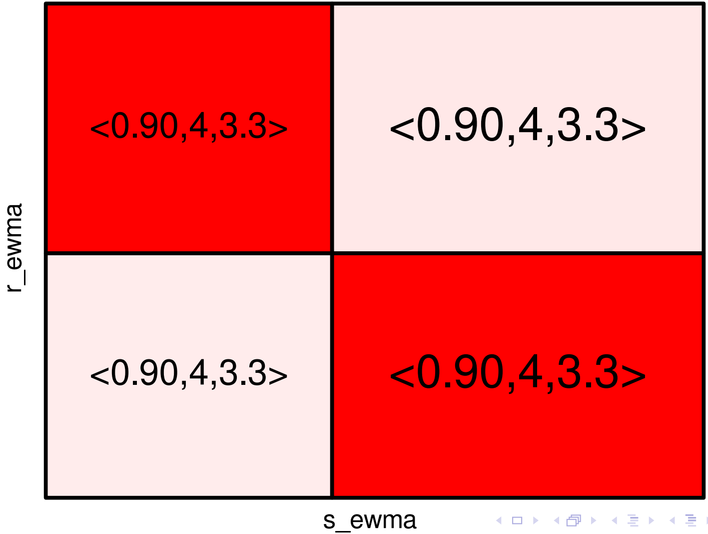
The best (single) action. Now split it on median.



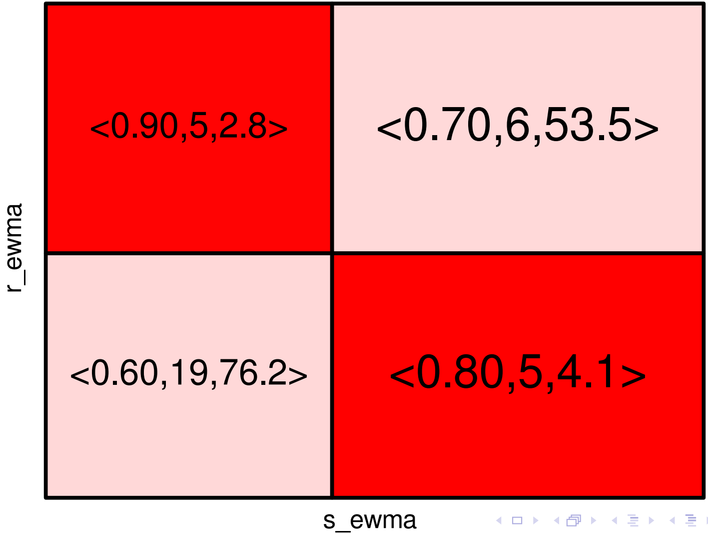
Simulate



Optimize each of the new actions



Now split the most-used rule



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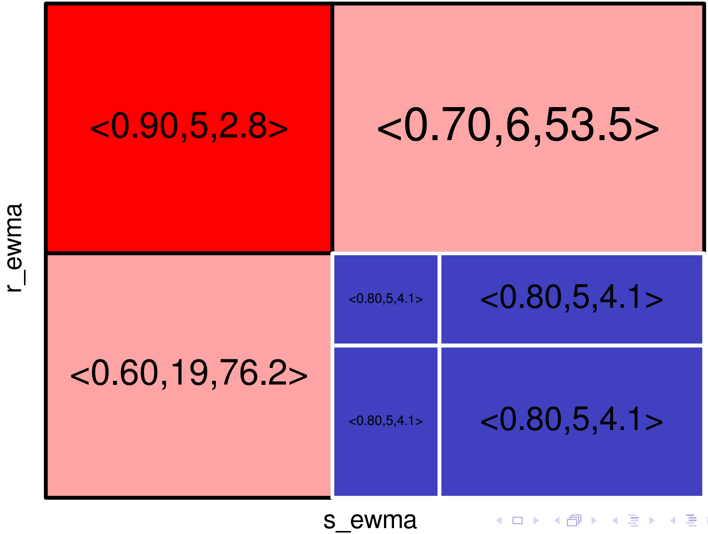
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r_ewma
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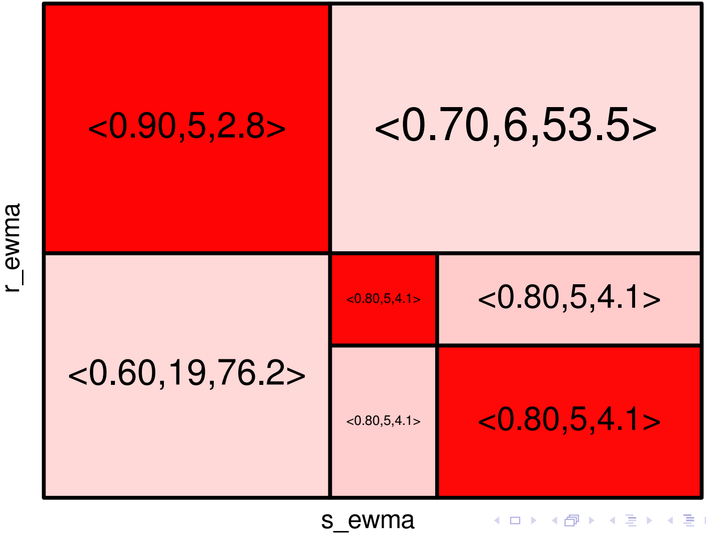
Optimize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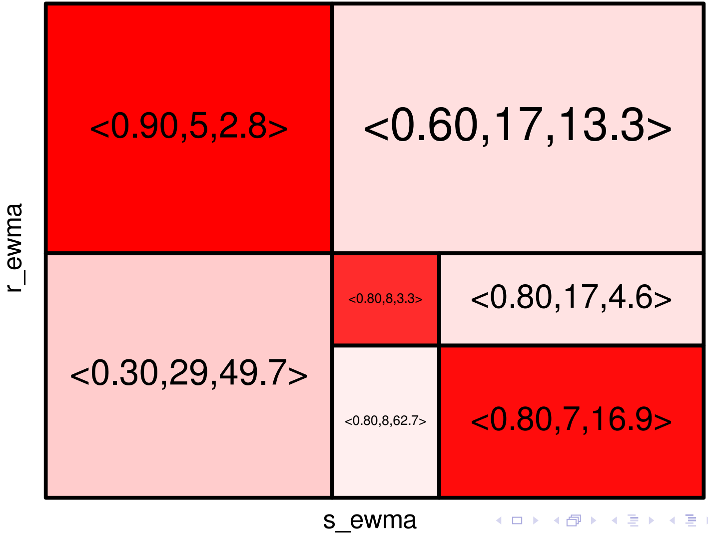

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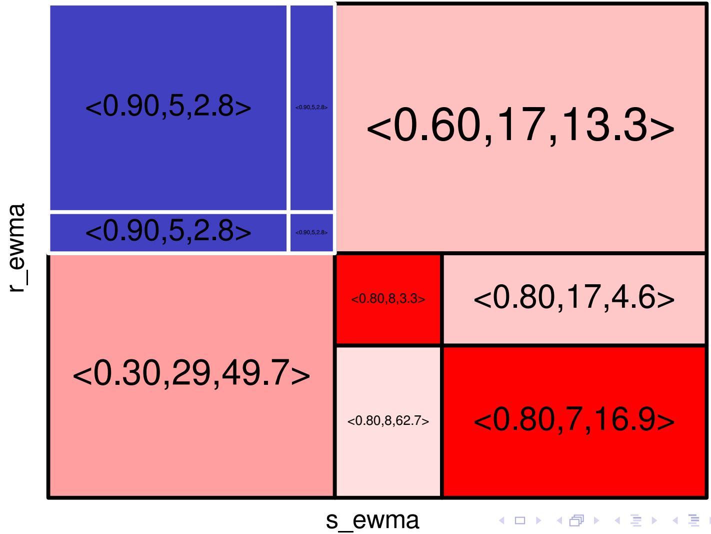
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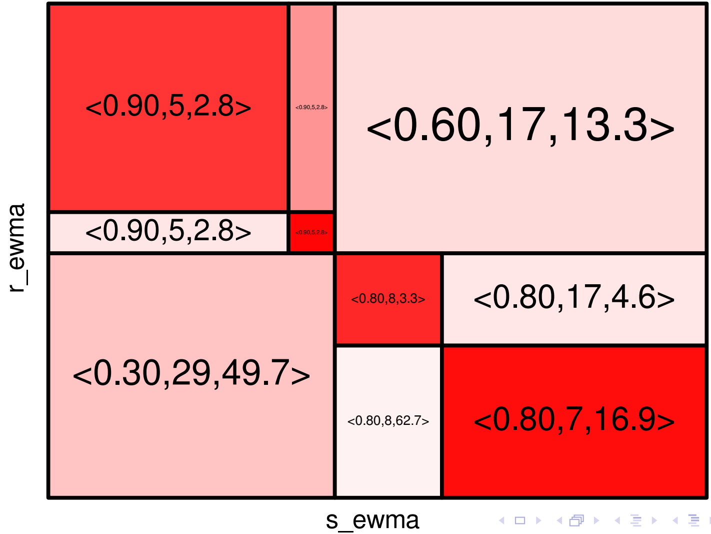
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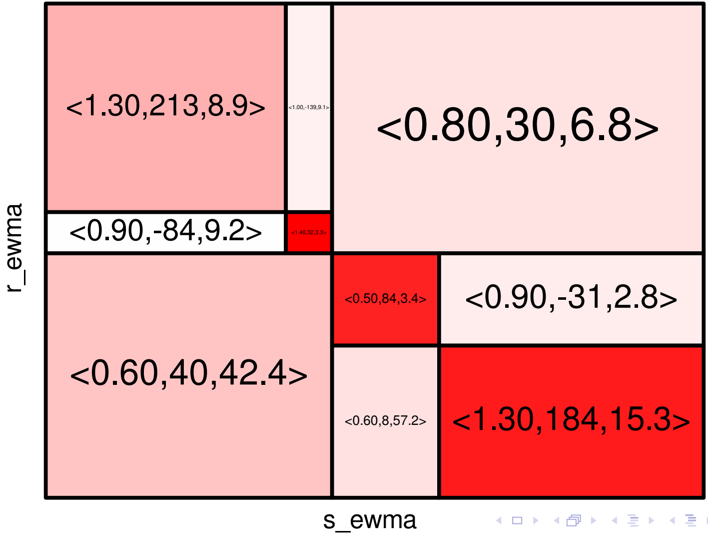
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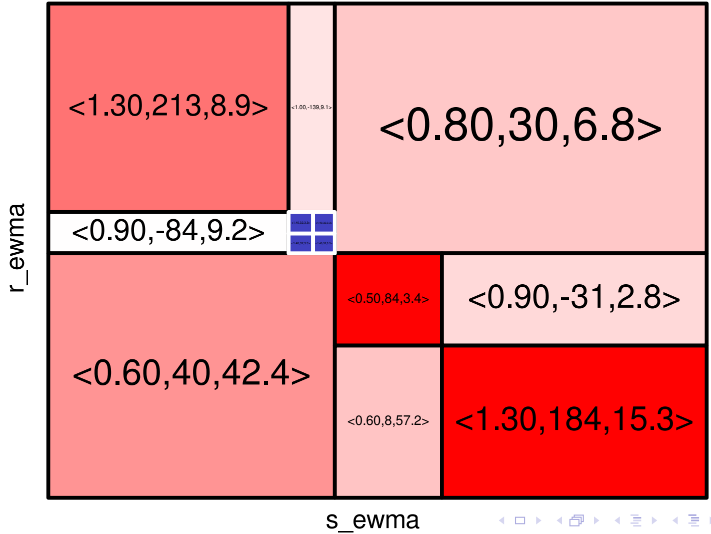
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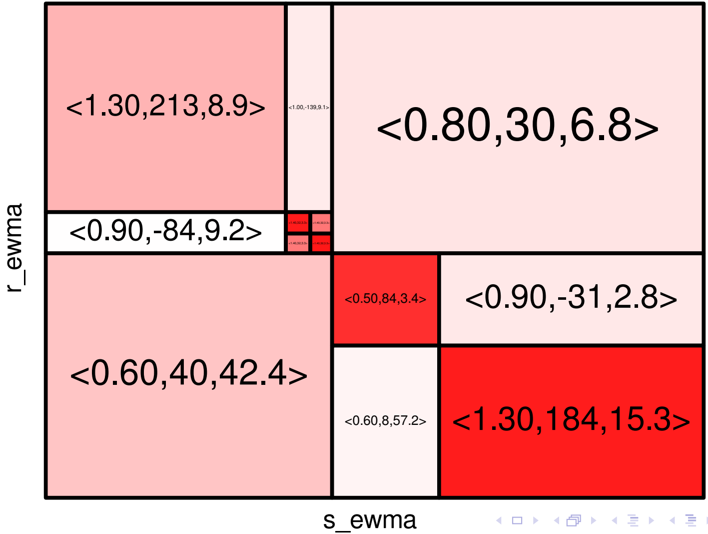
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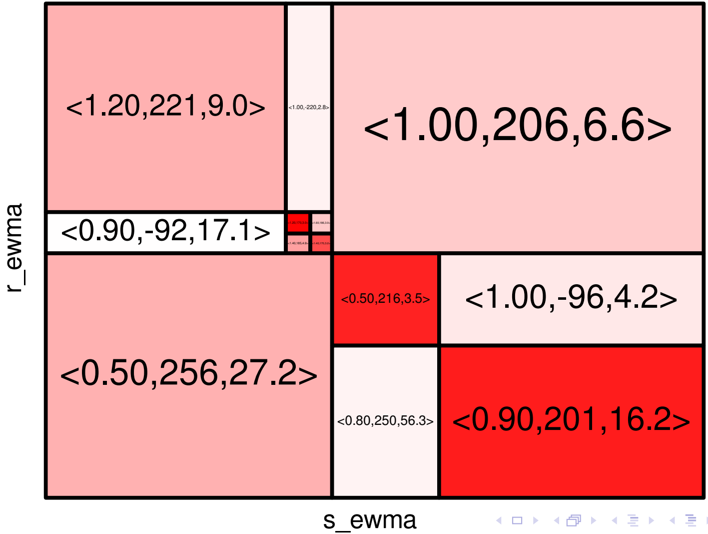

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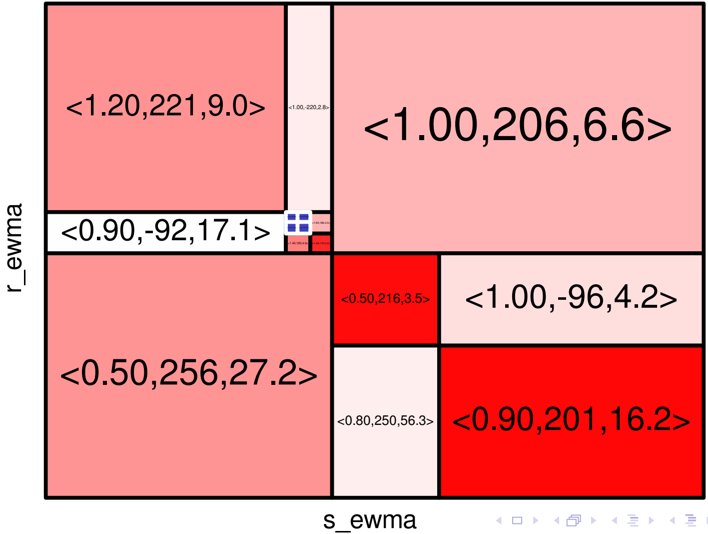
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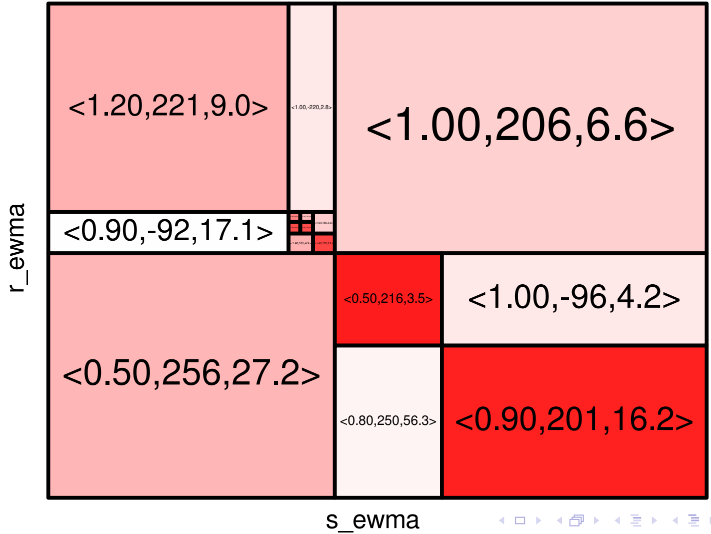
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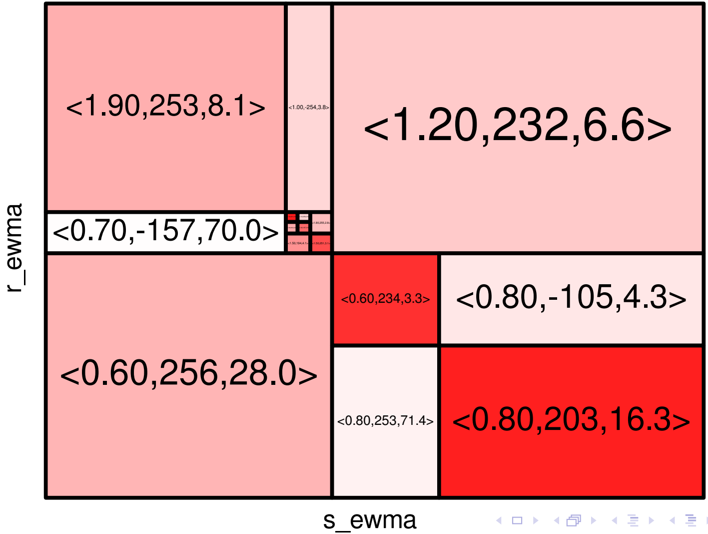

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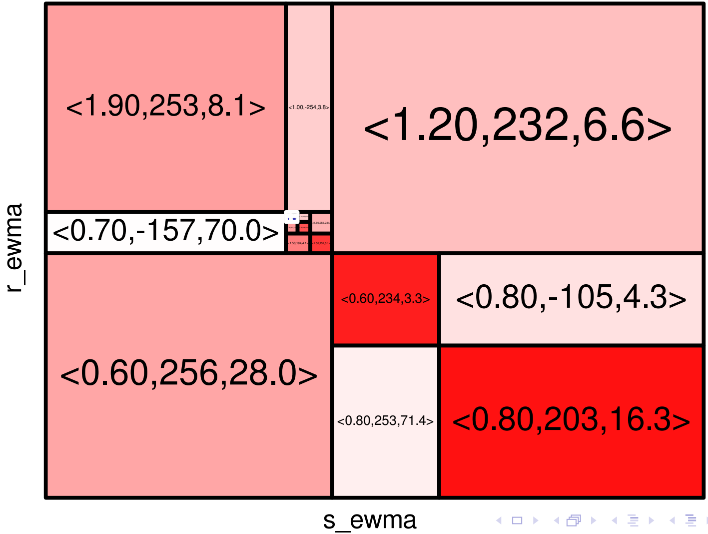
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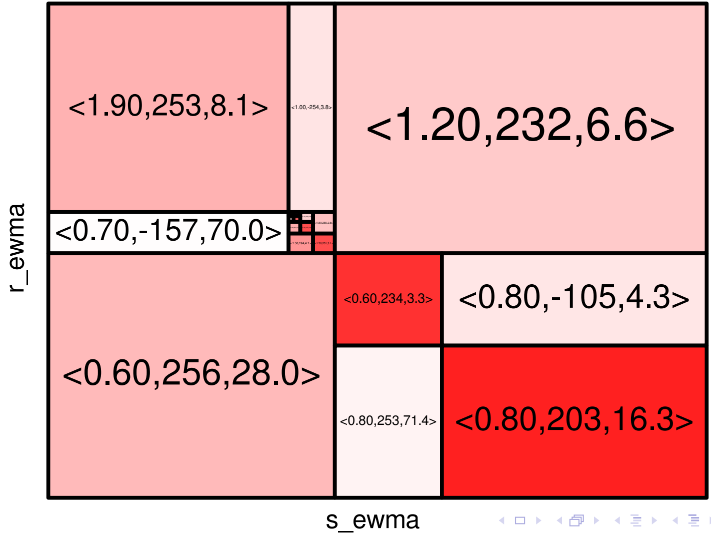
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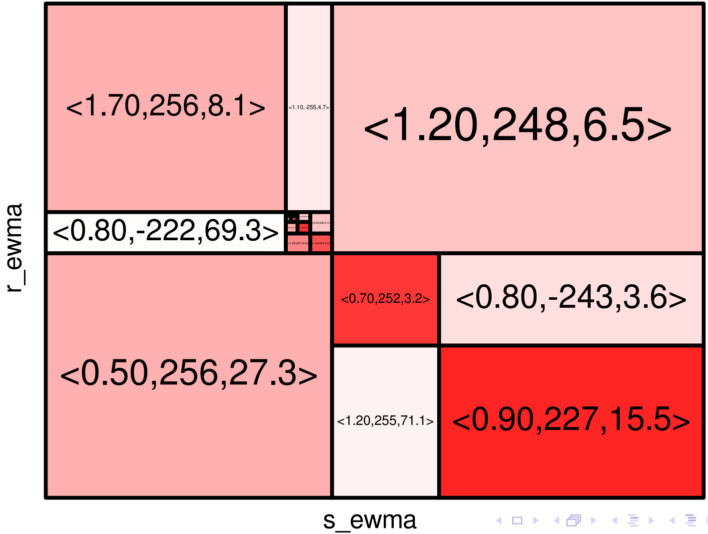

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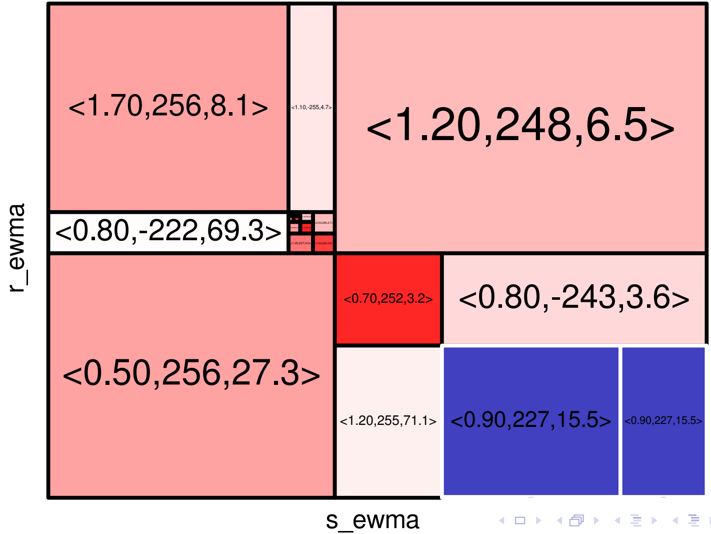

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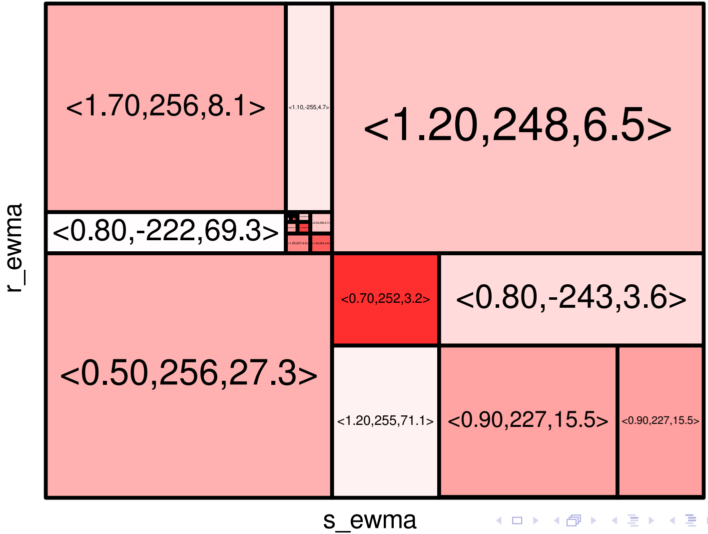
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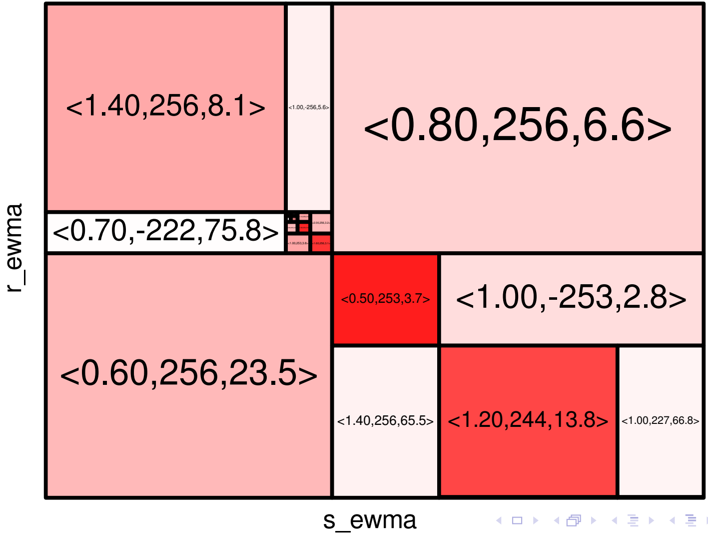
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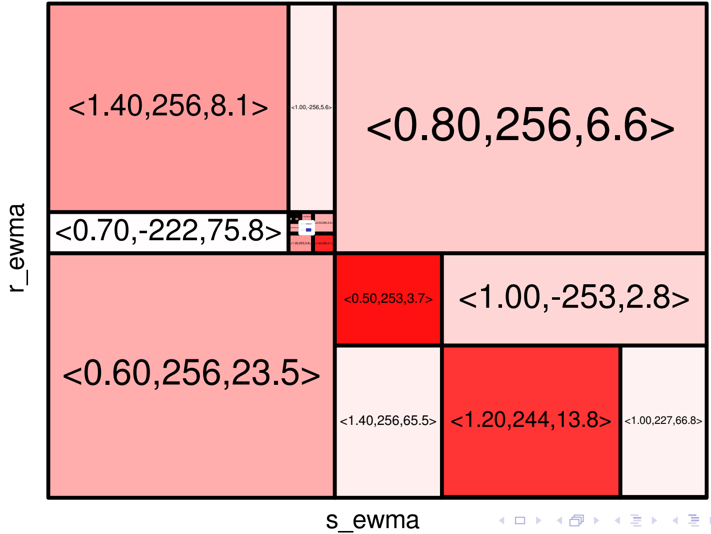
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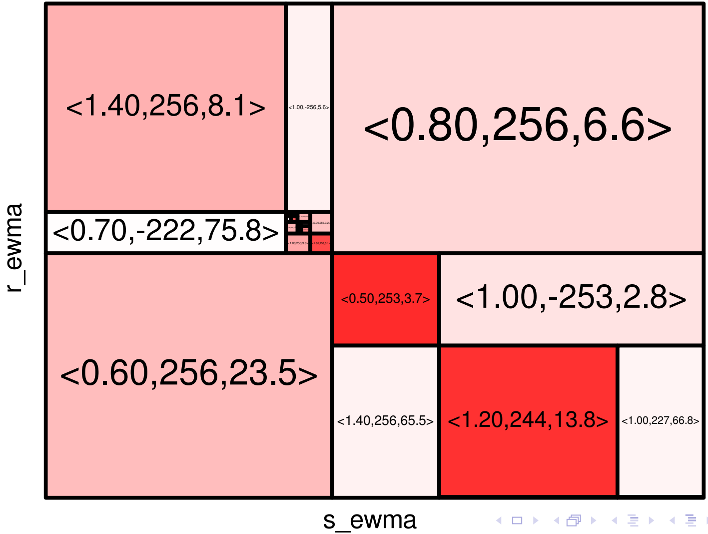

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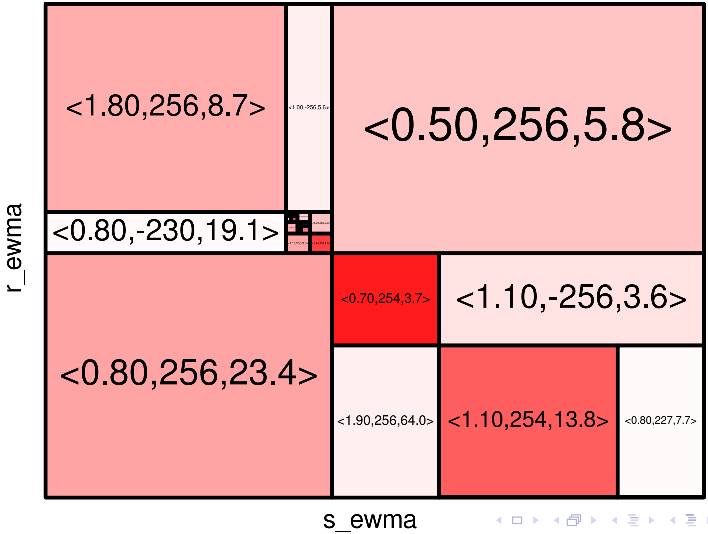

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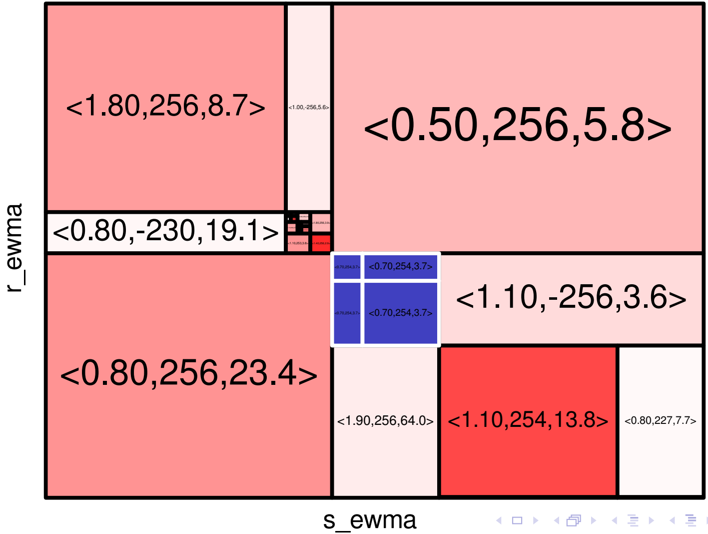
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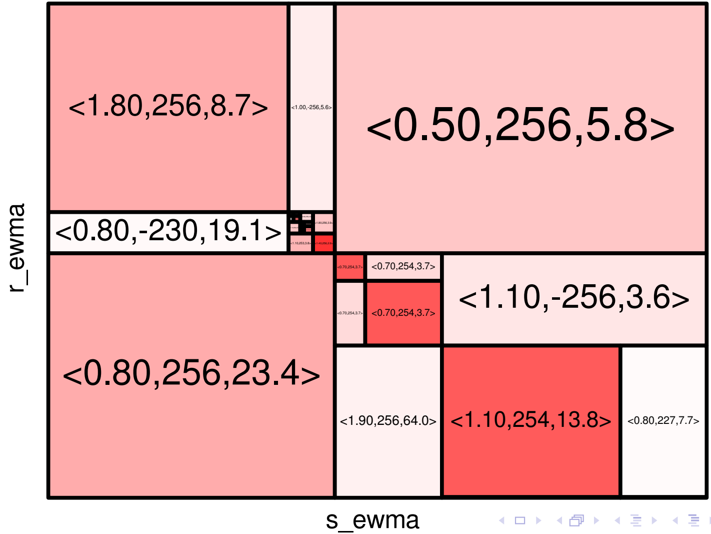
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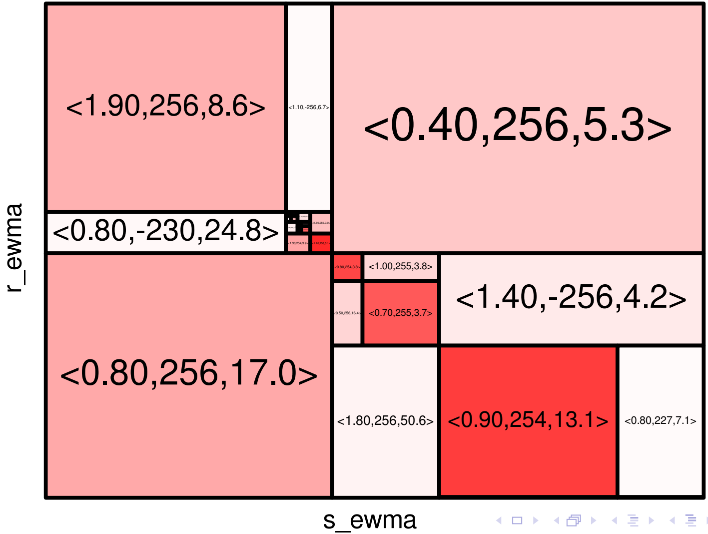
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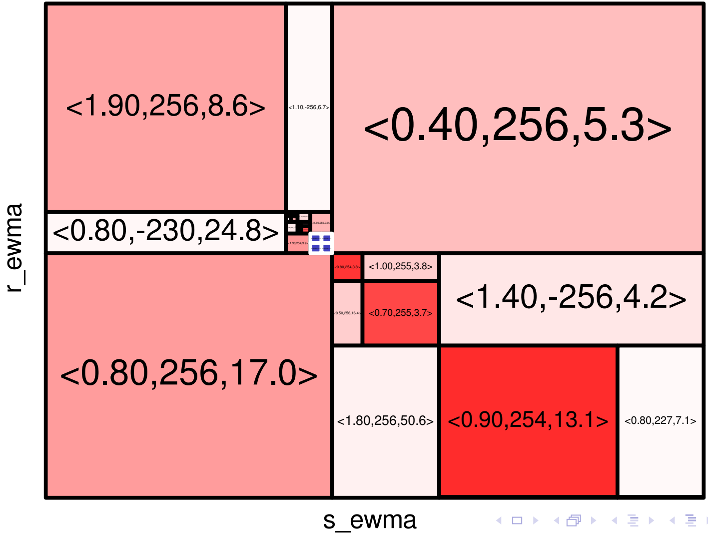
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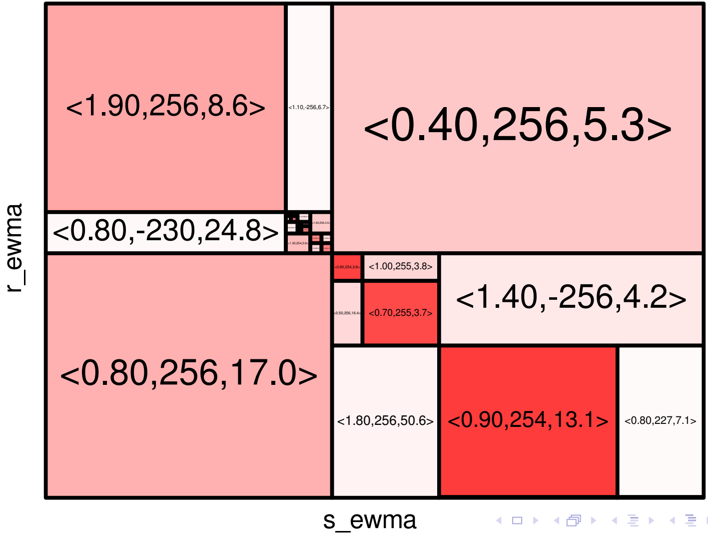

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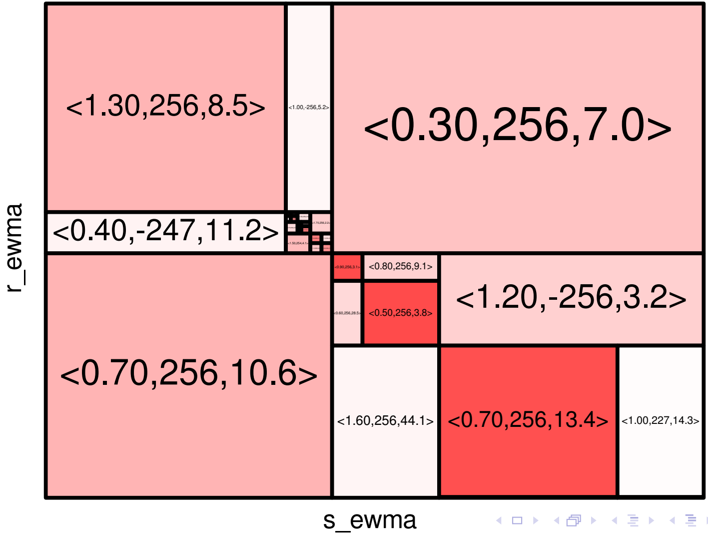

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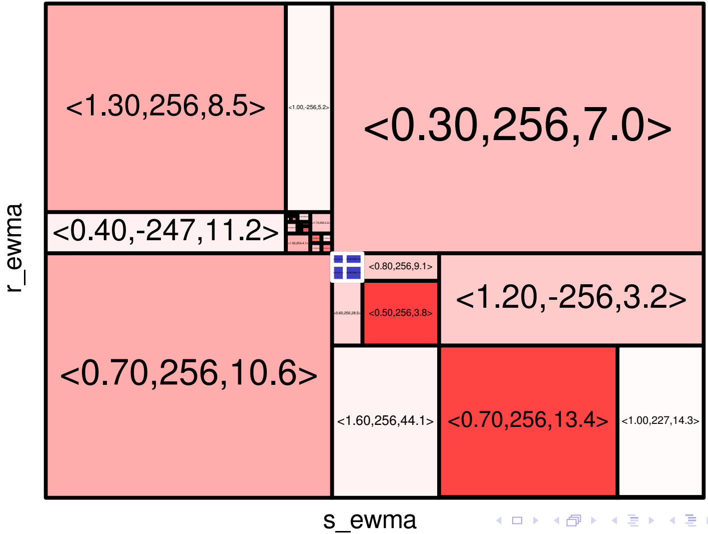
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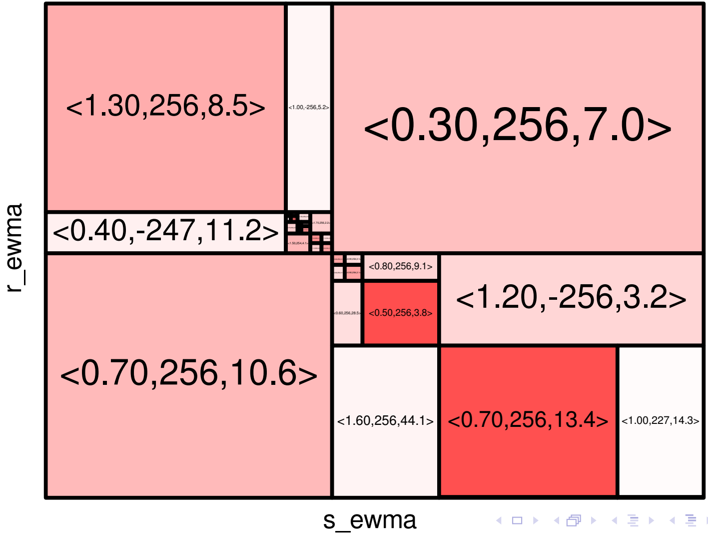

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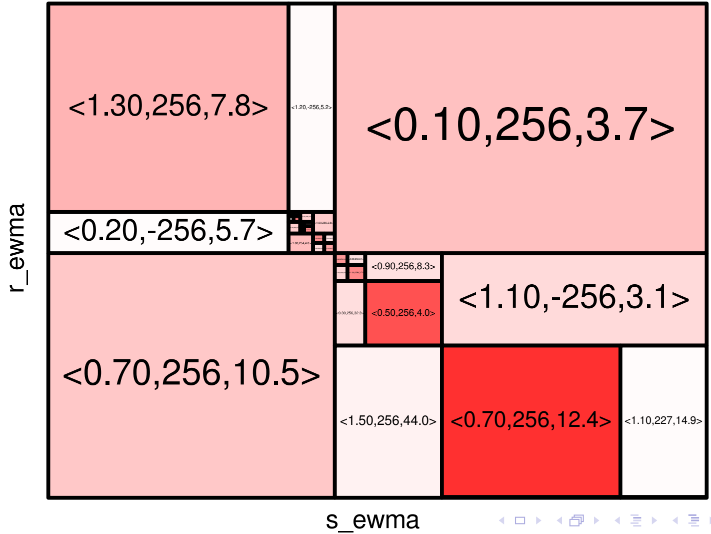
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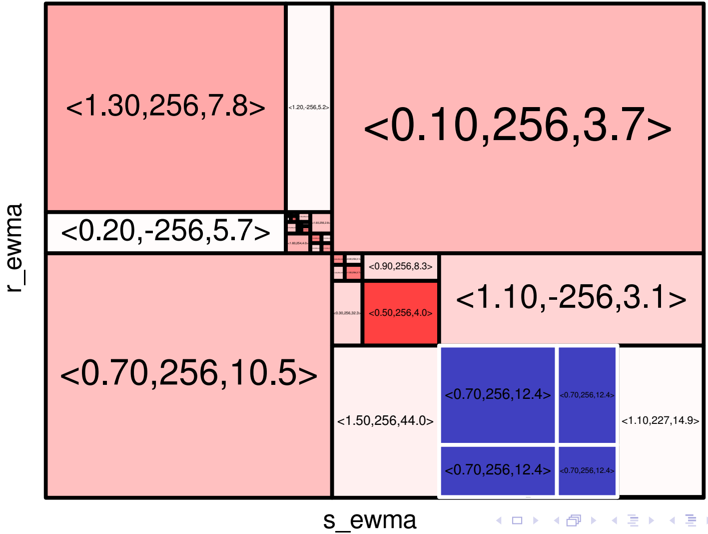
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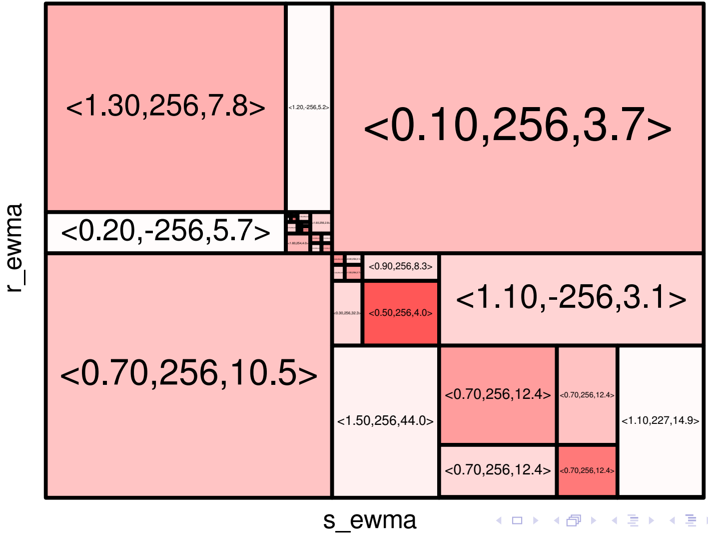
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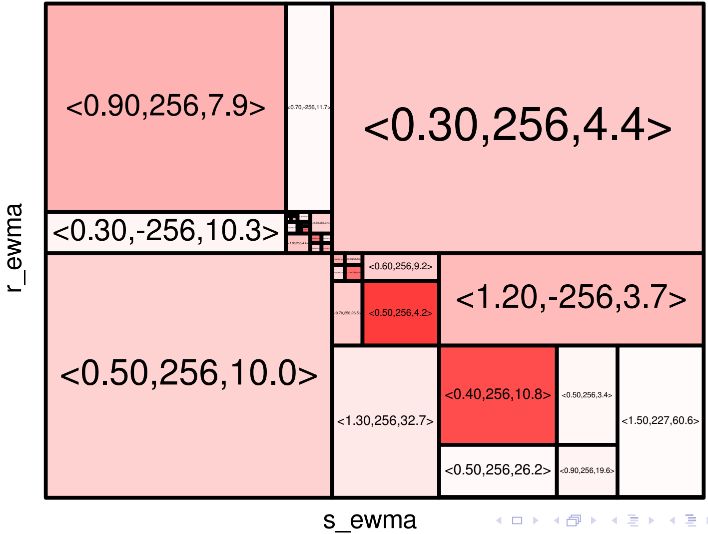
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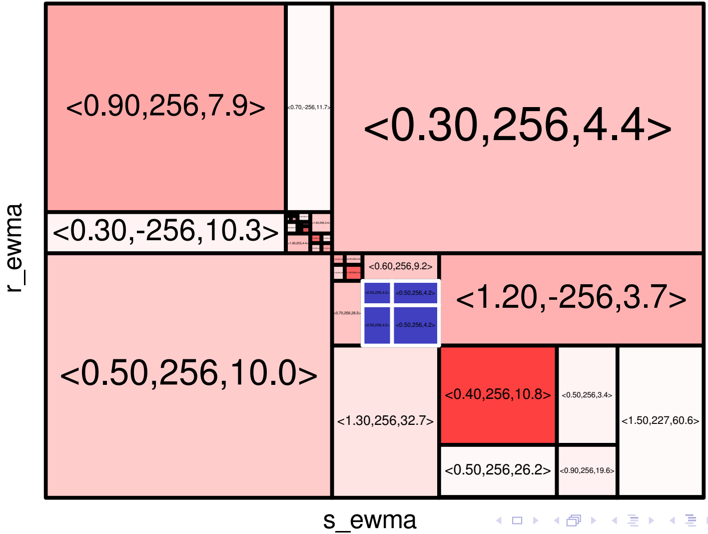
Simulate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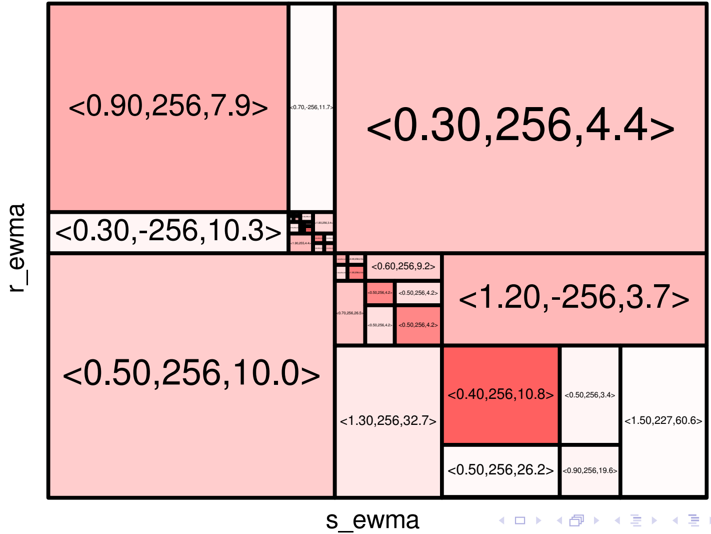
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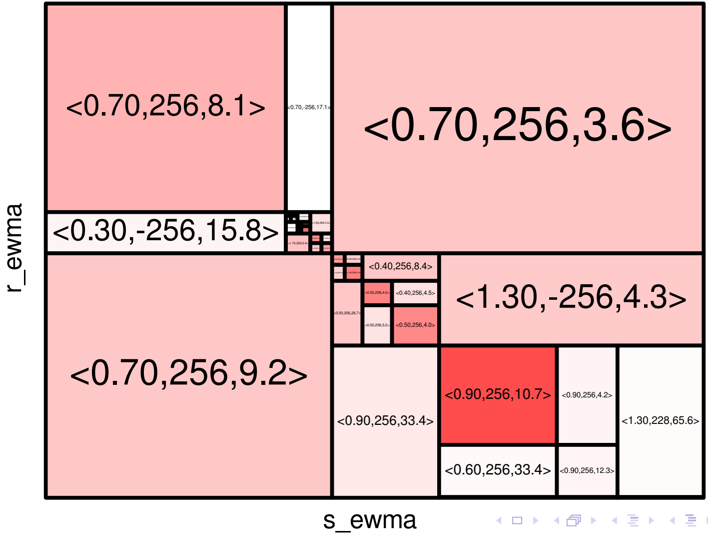
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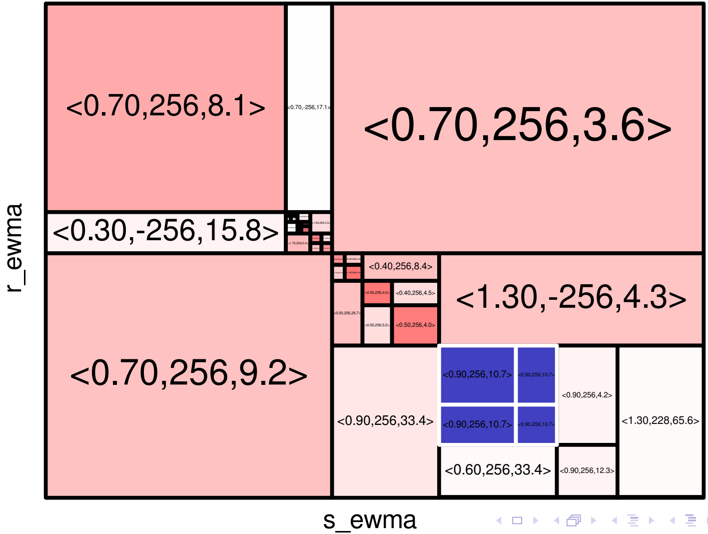
Simulate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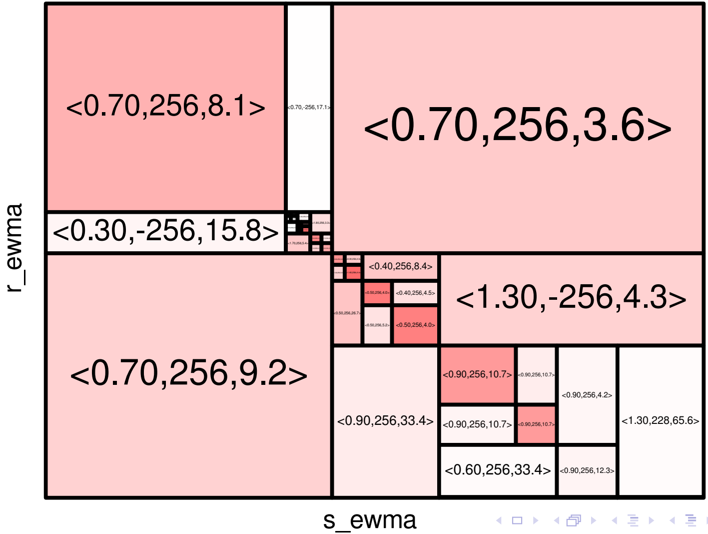
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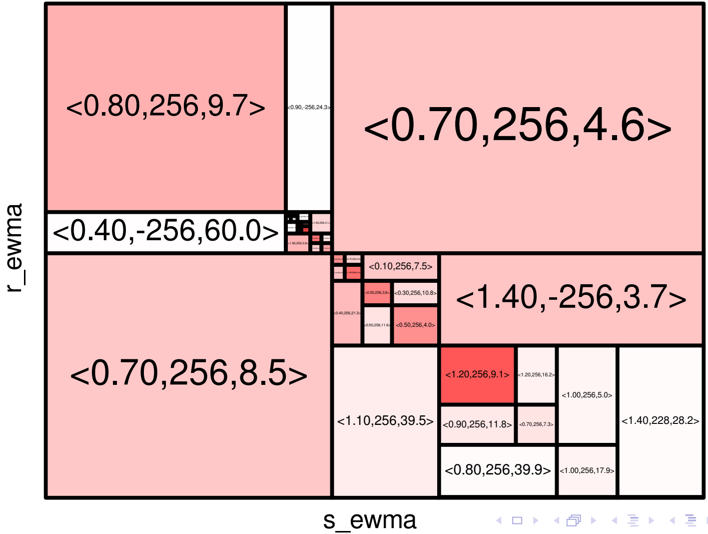
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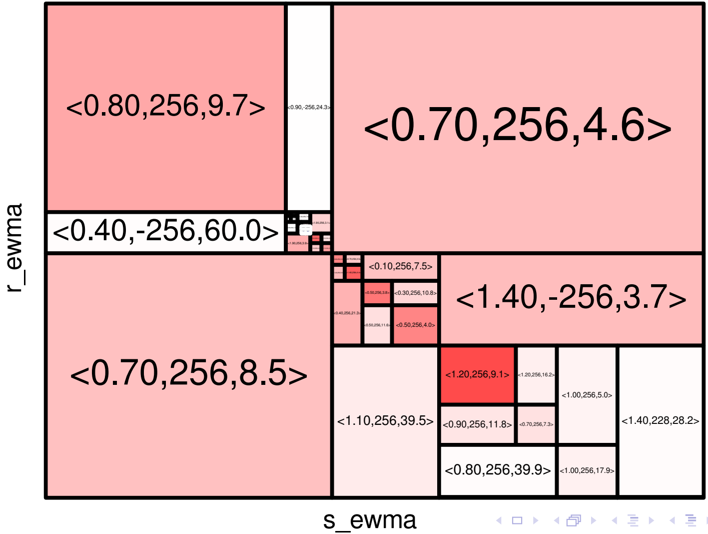
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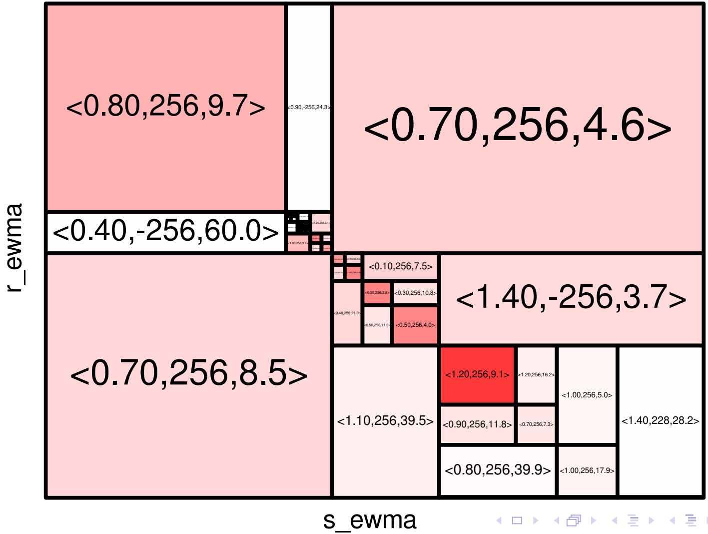
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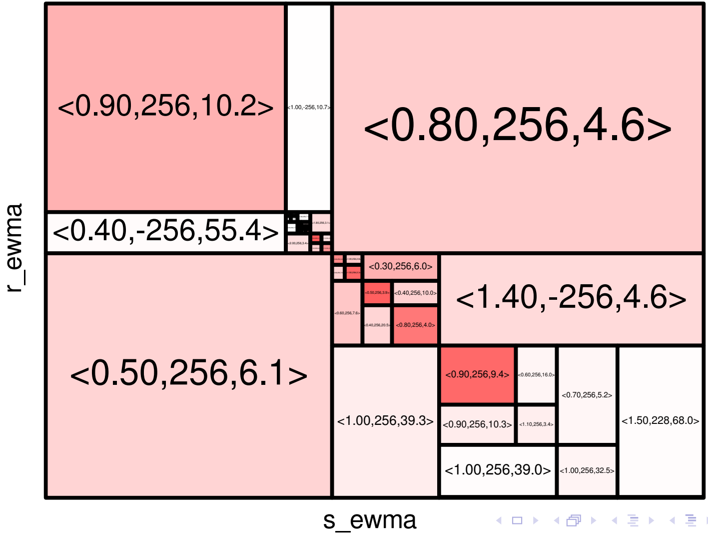

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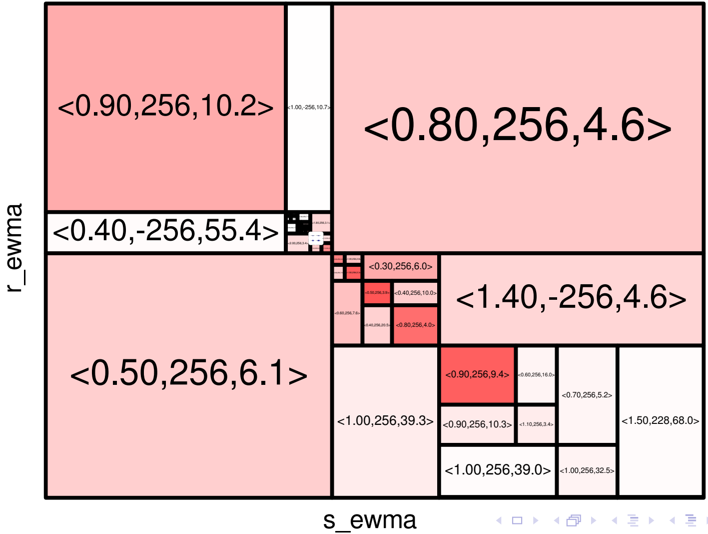
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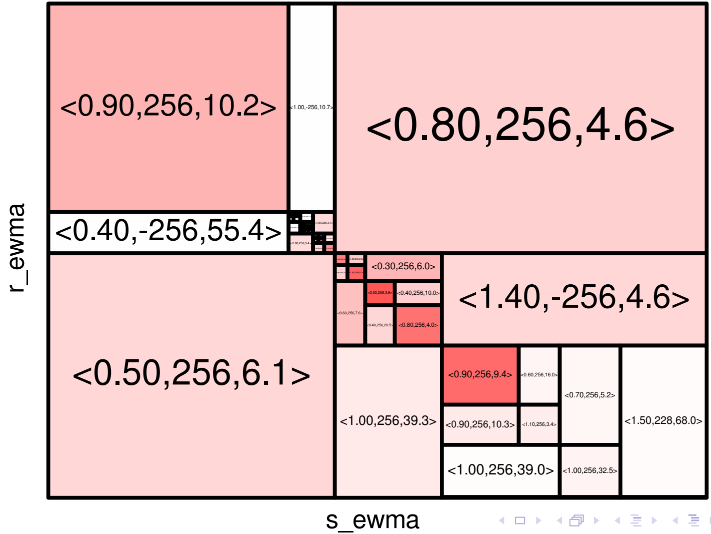

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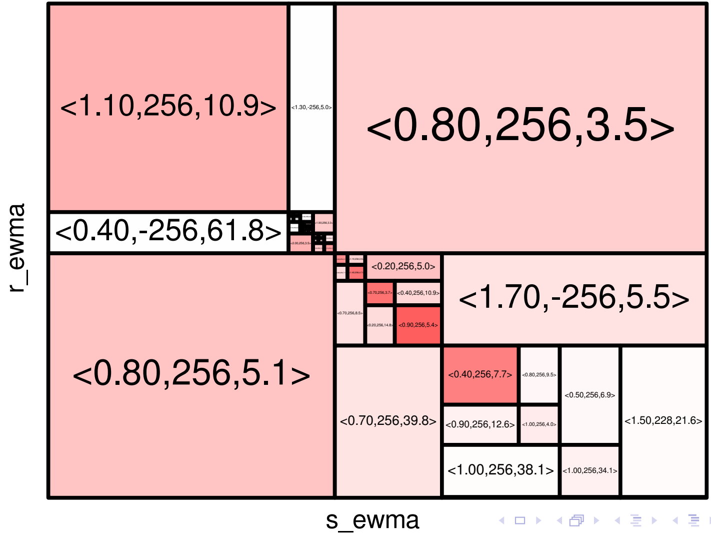
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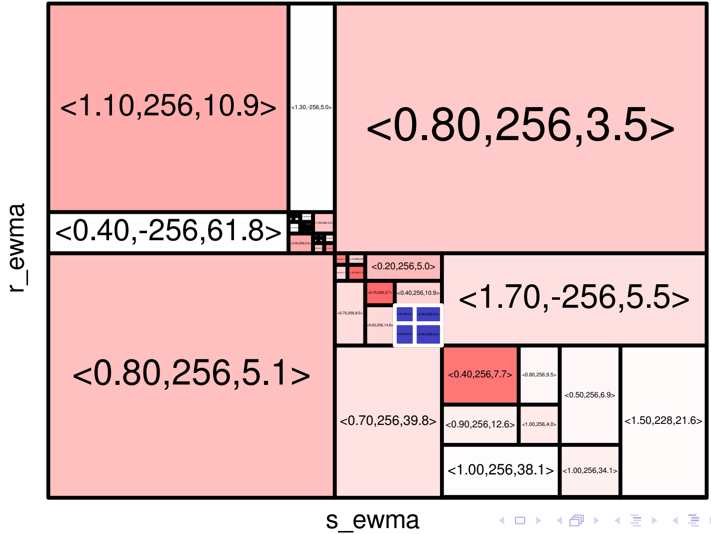
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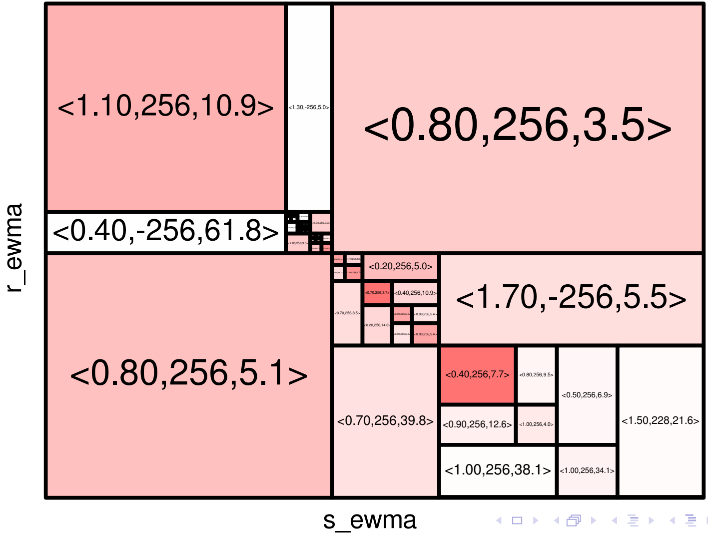

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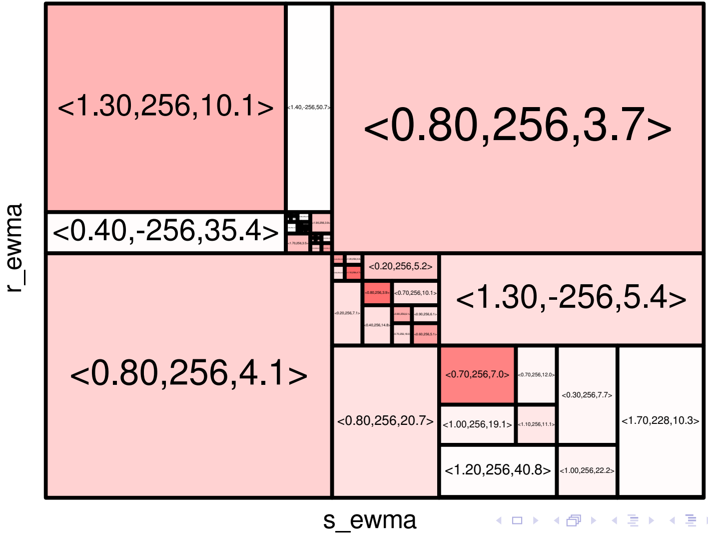
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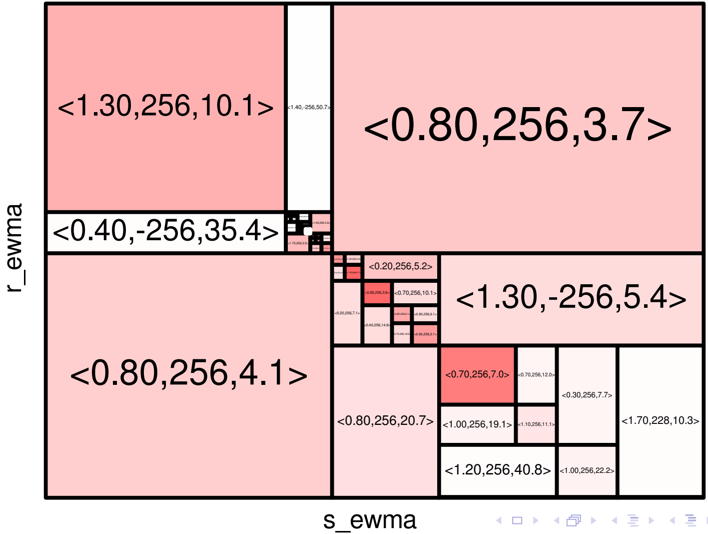
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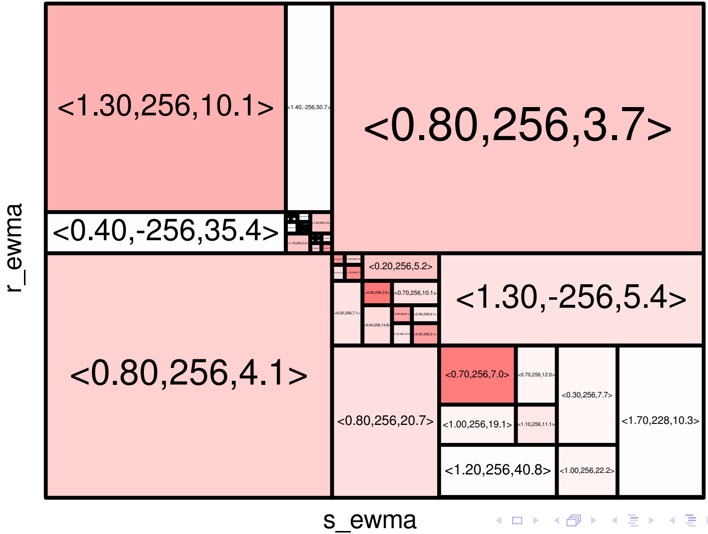
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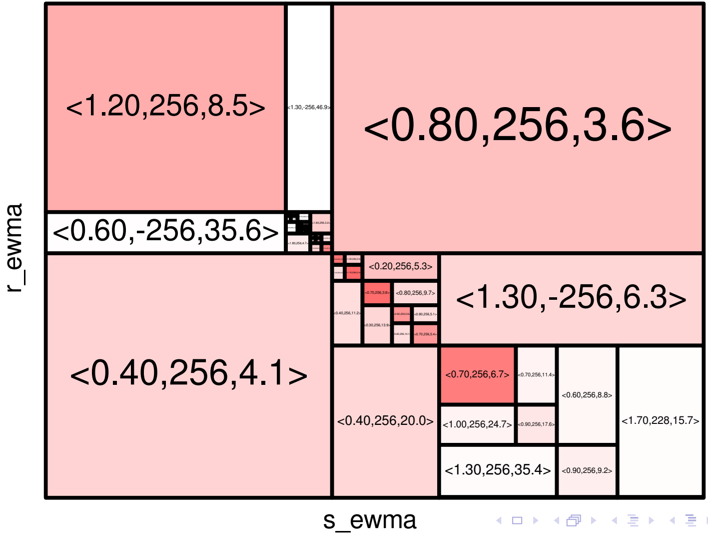

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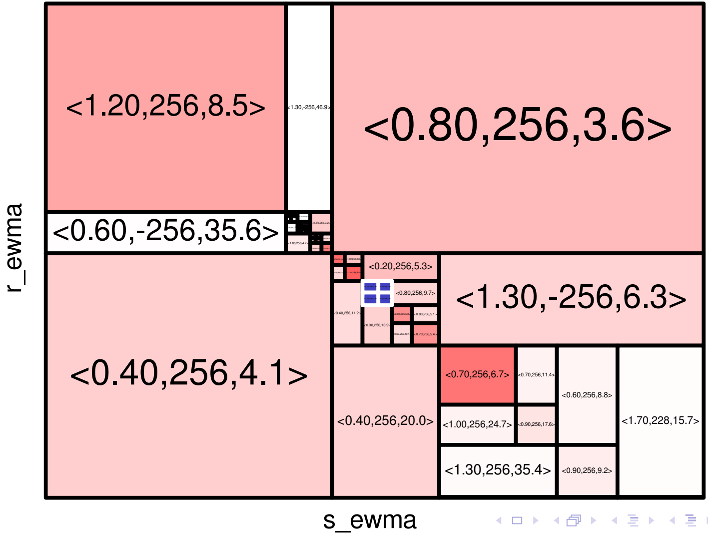
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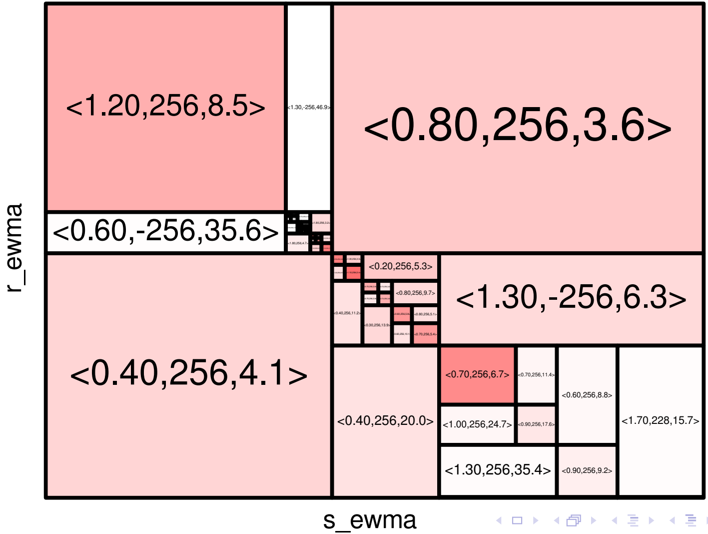
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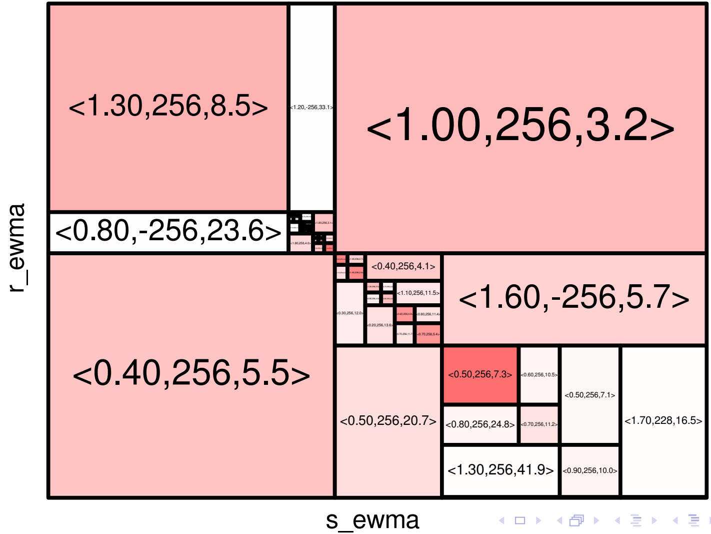

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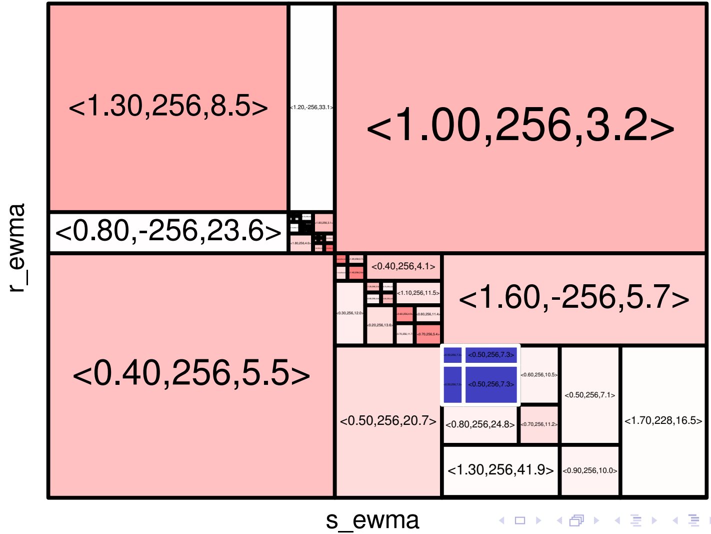
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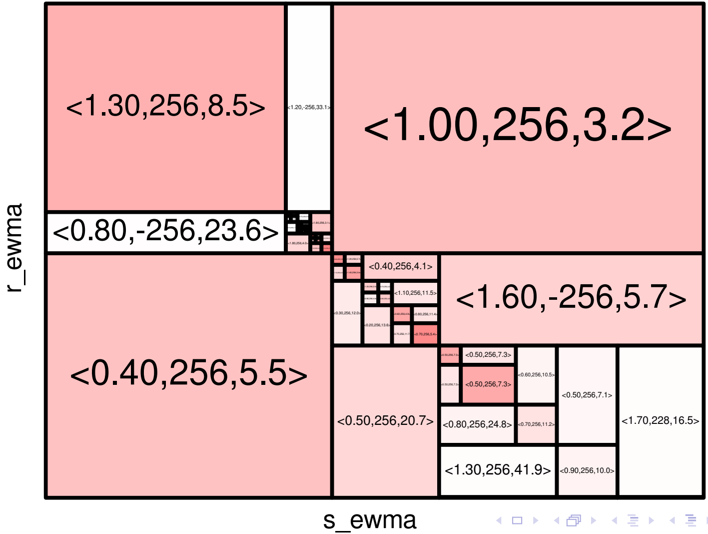
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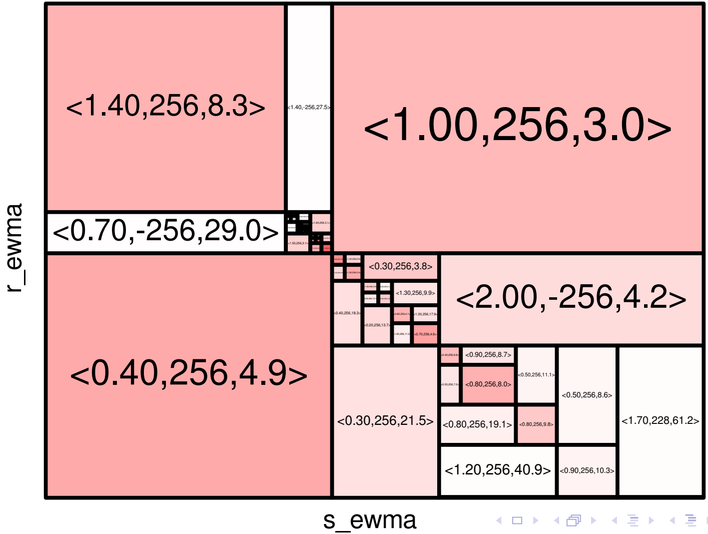
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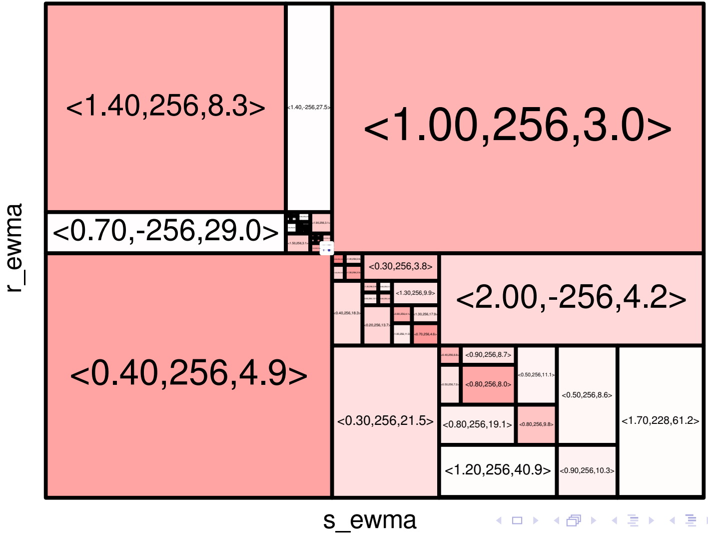
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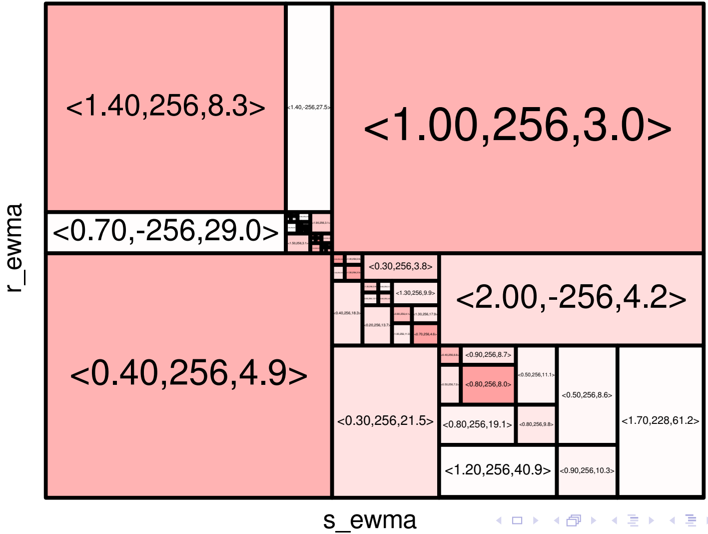

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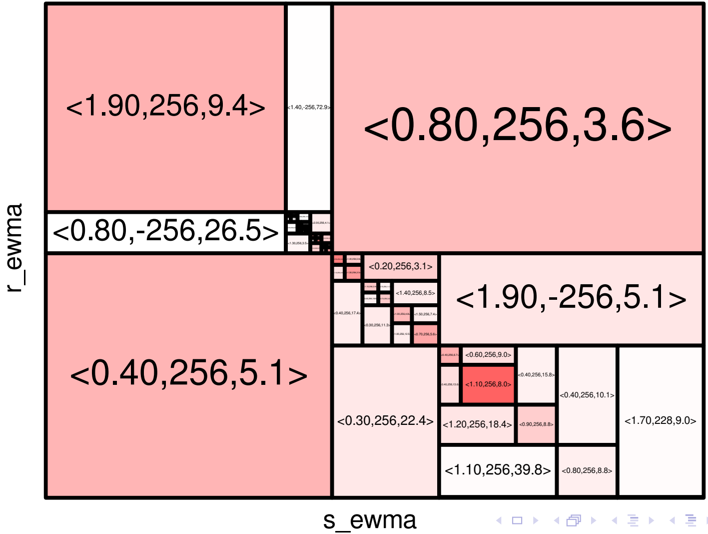
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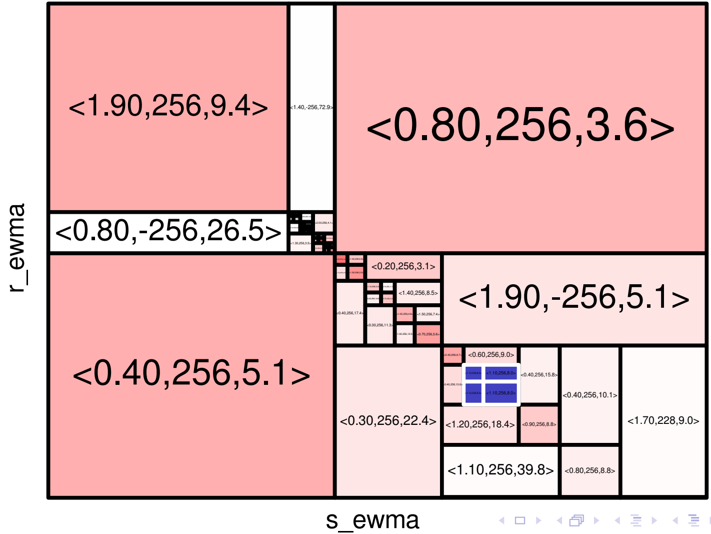
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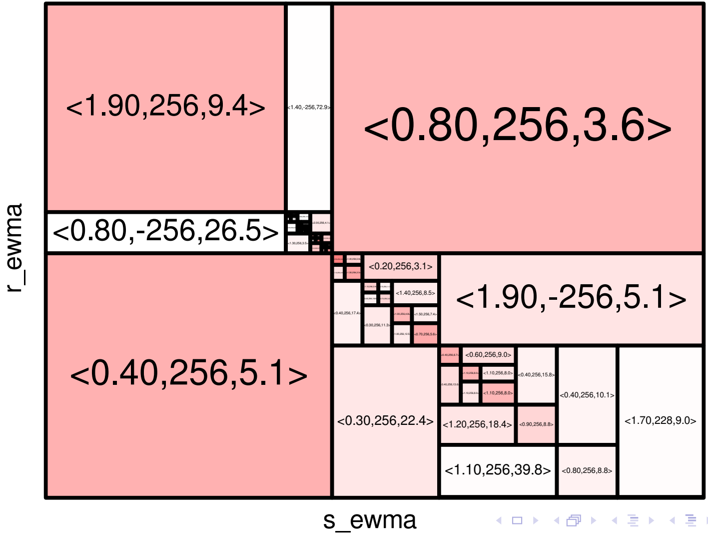
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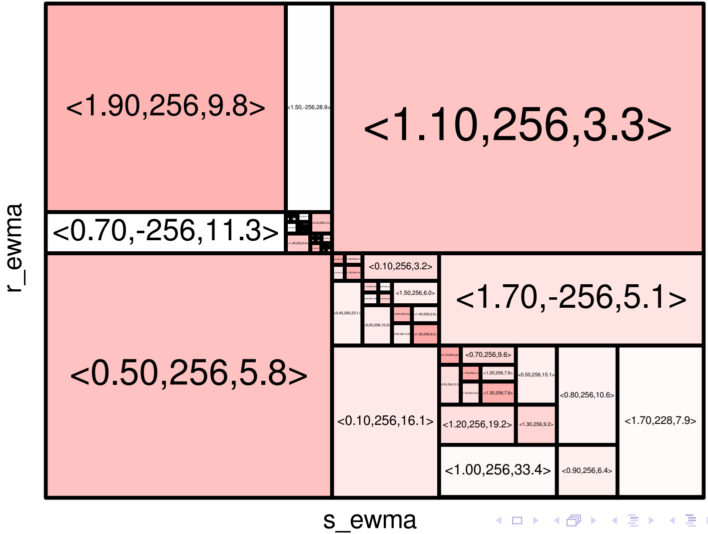
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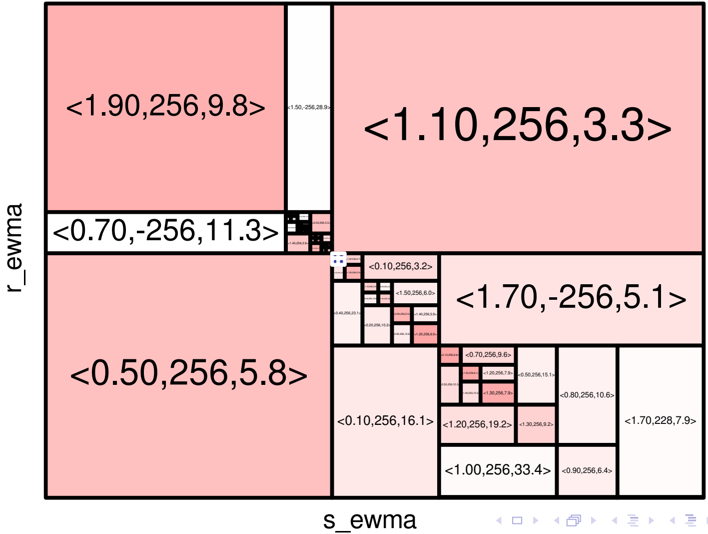

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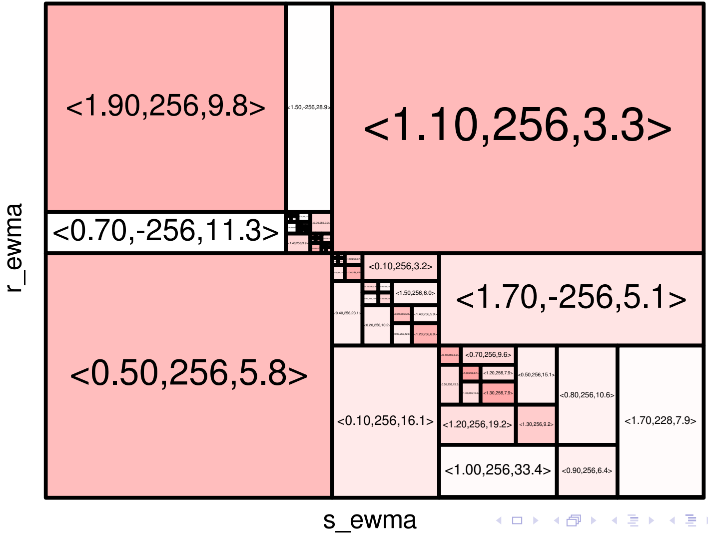
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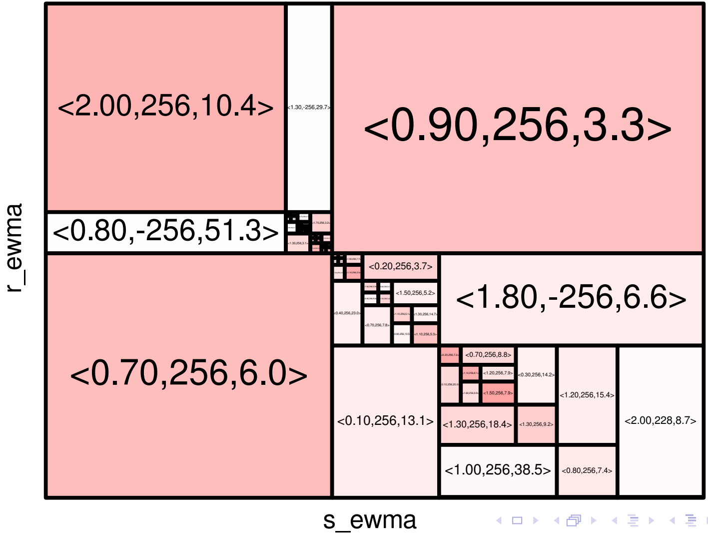
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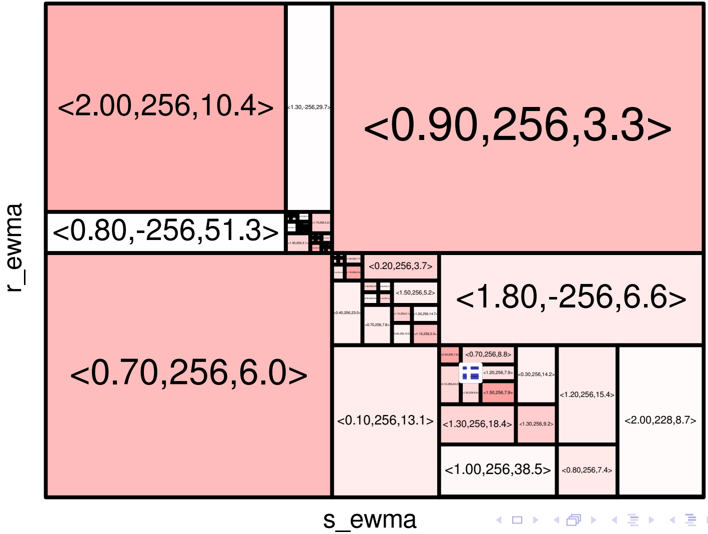
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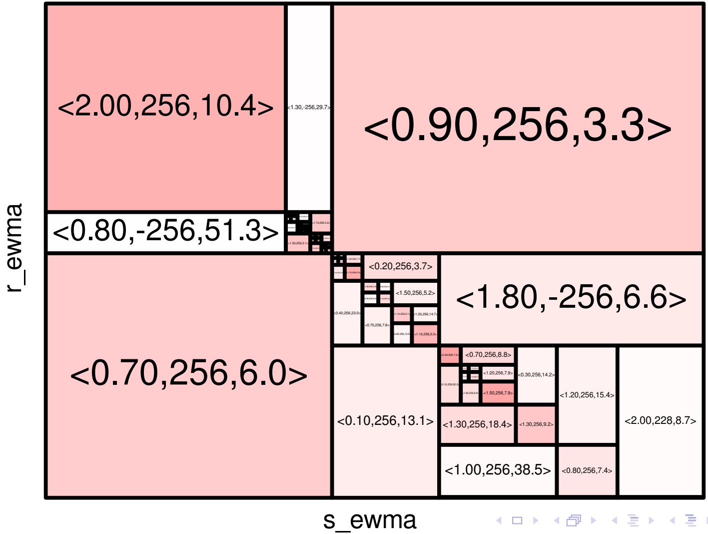

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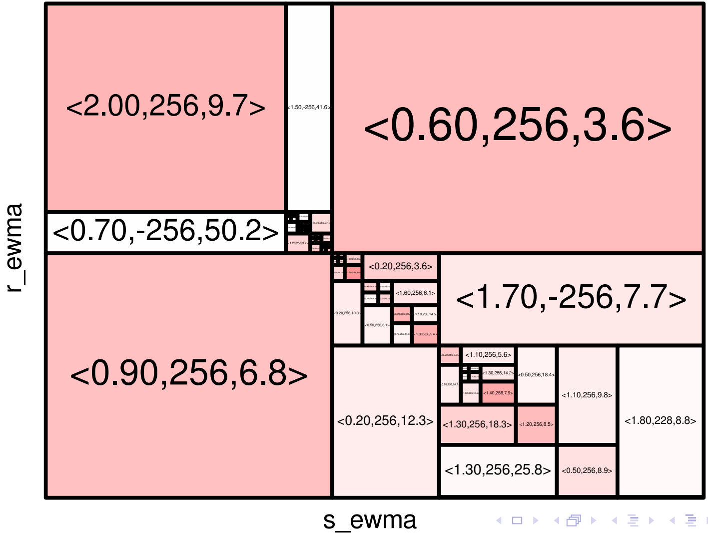
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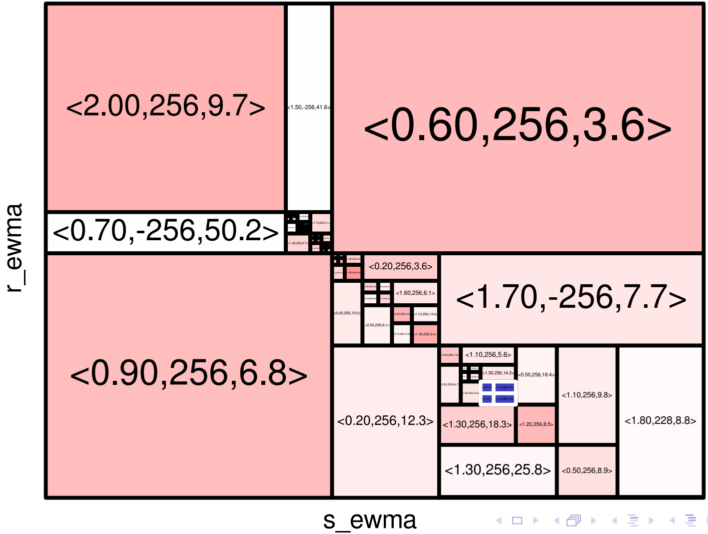
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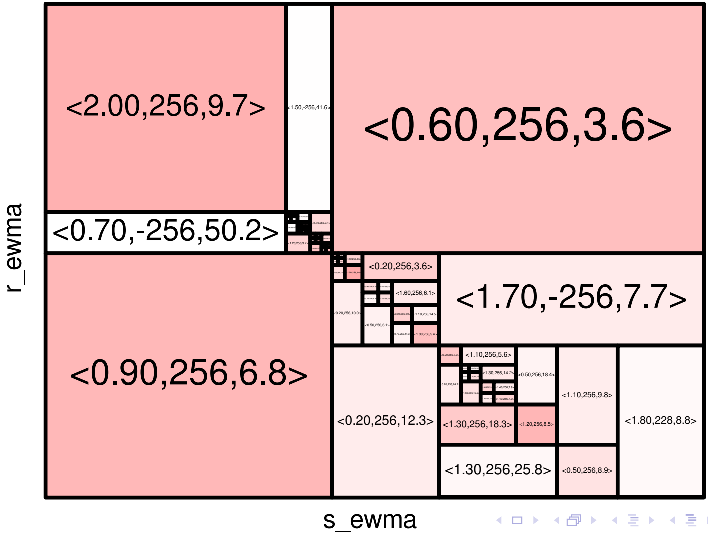
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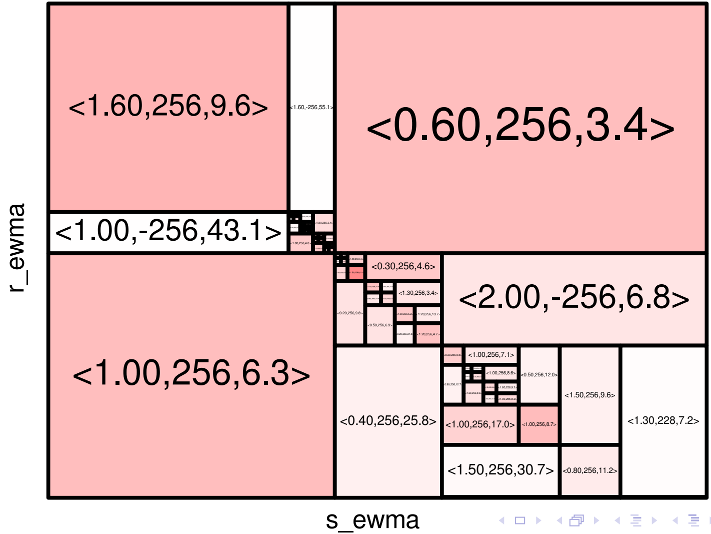

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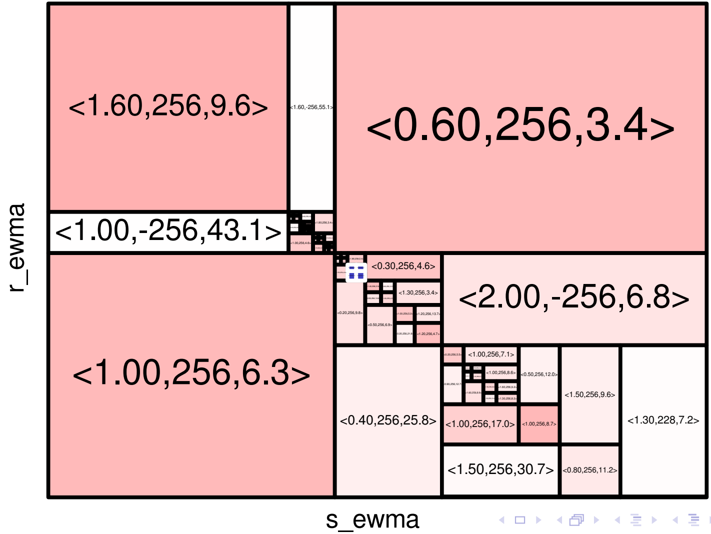
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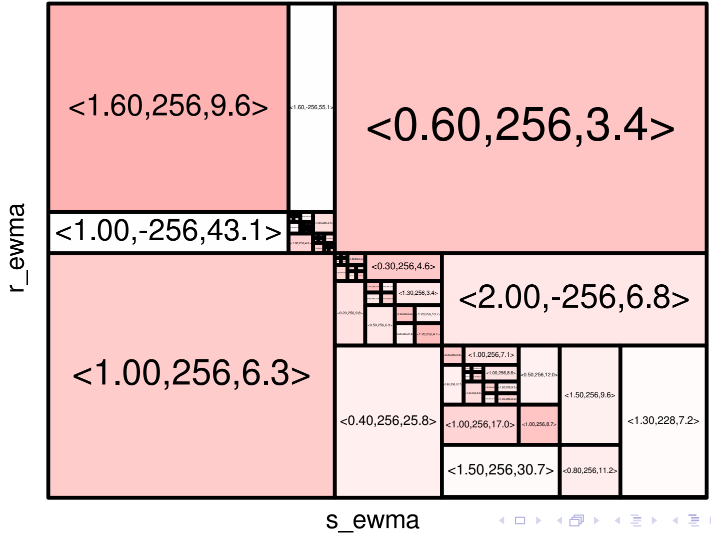
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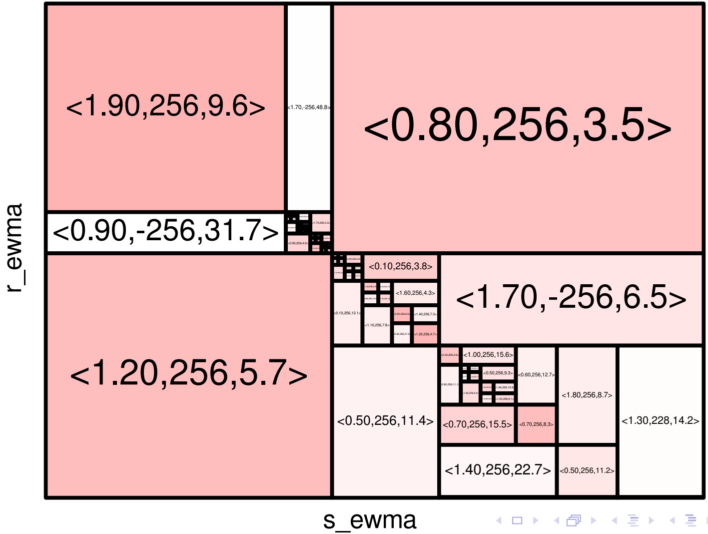
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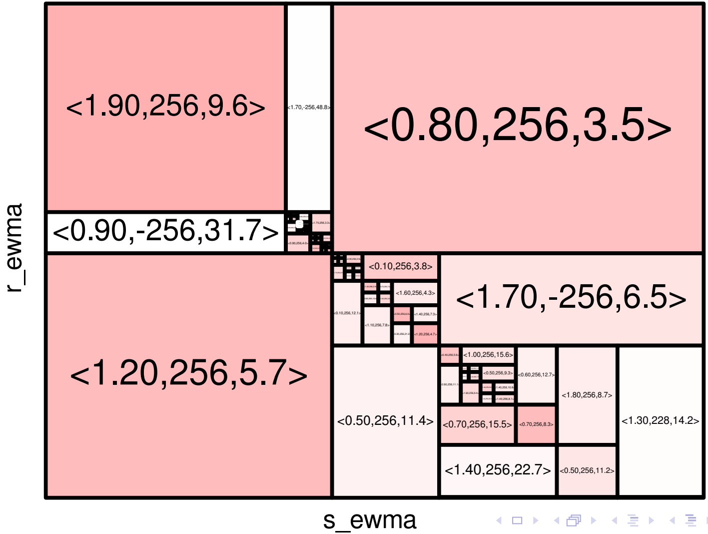
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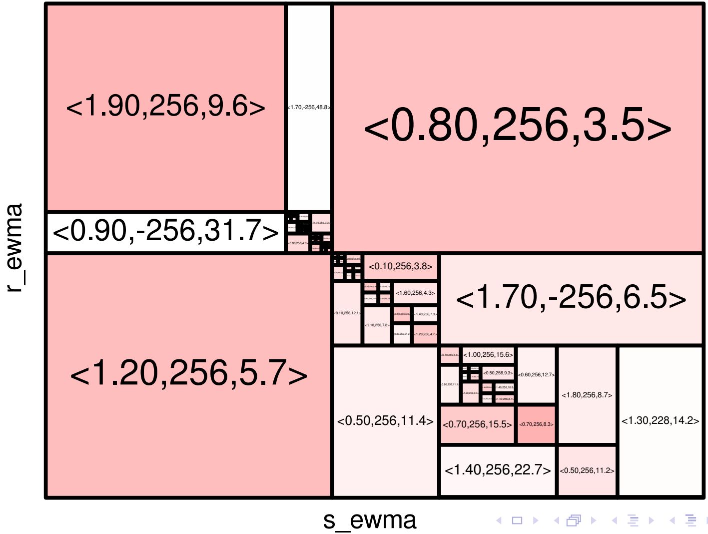

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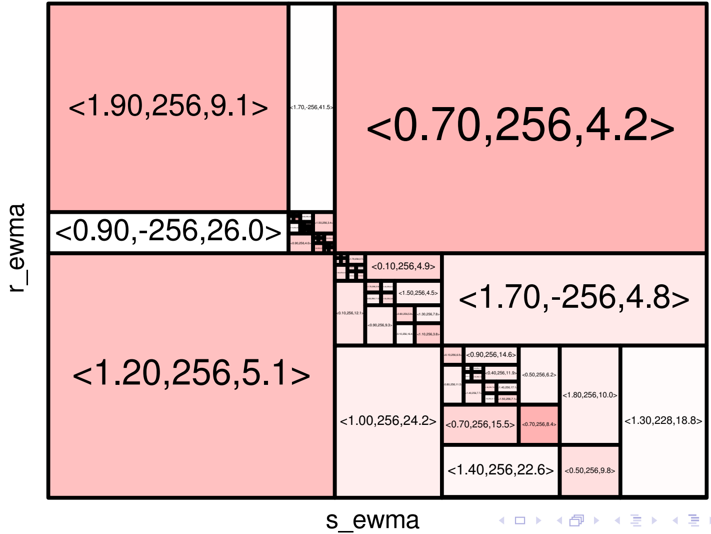
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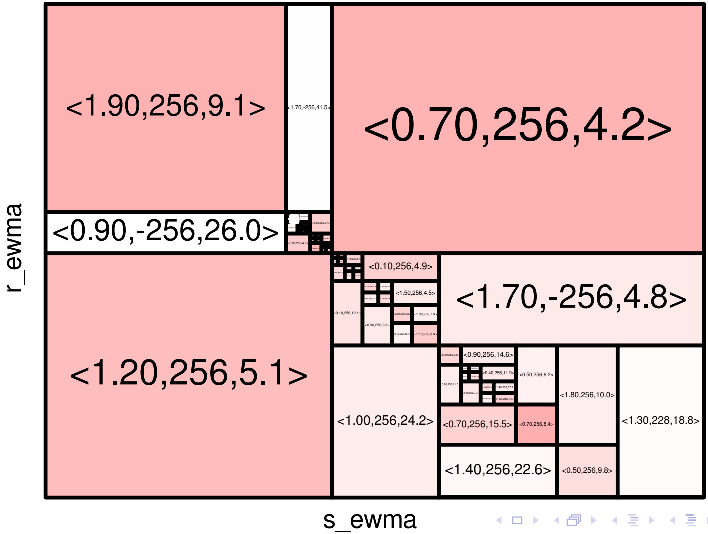
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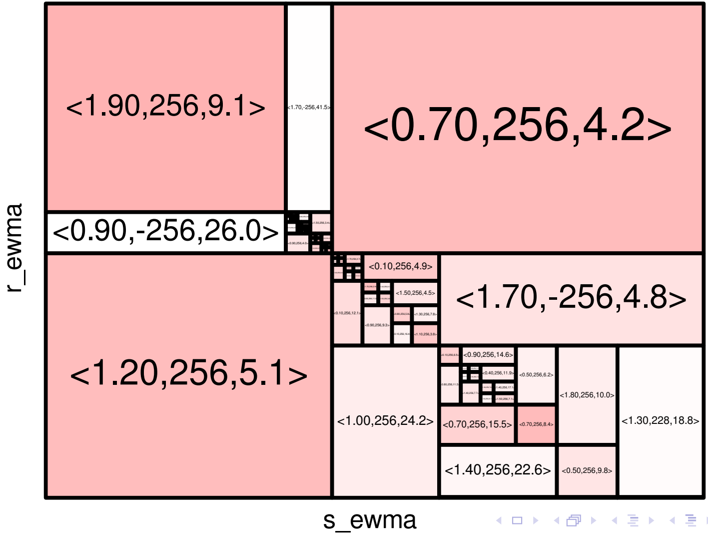
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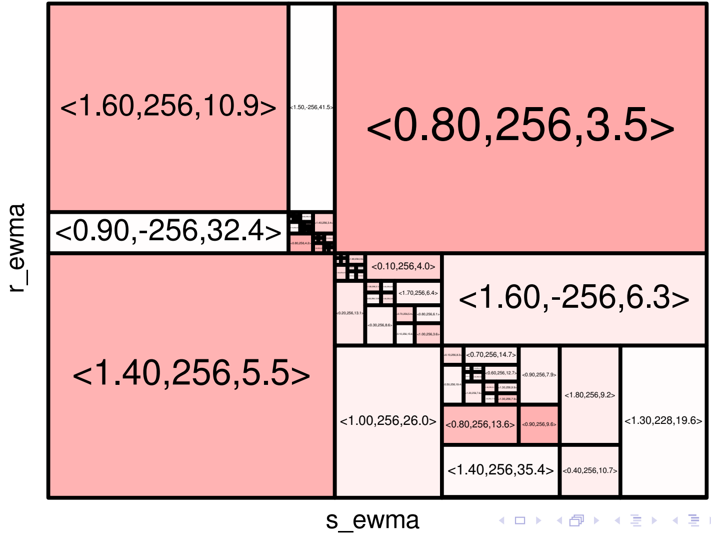
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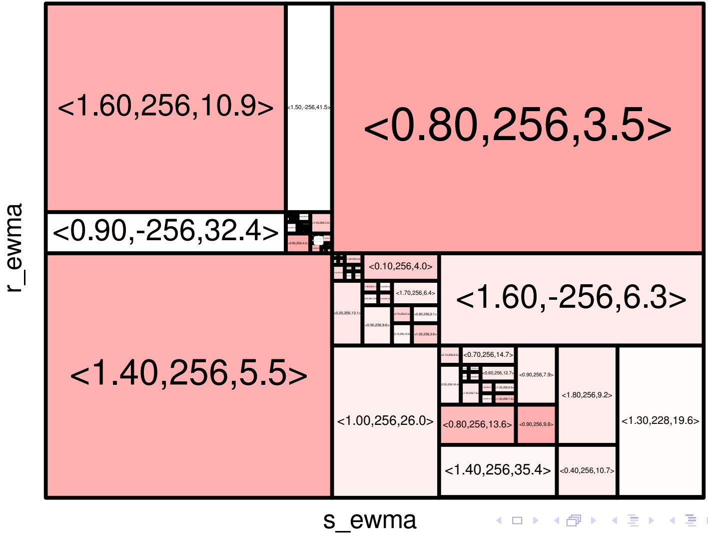

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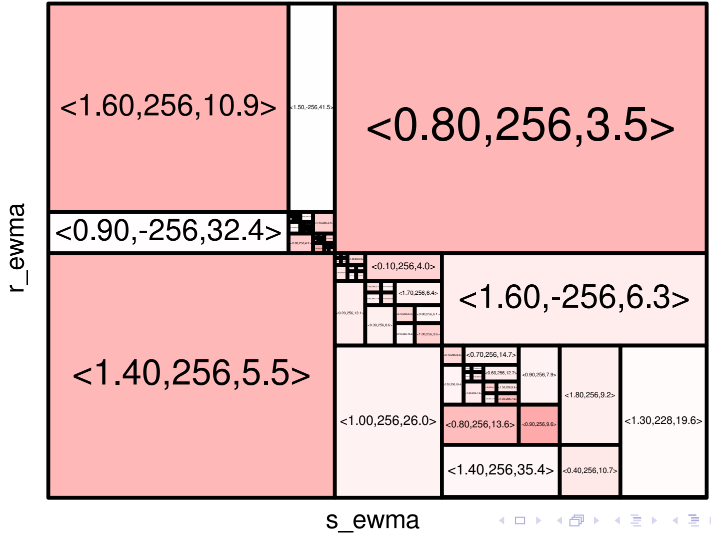

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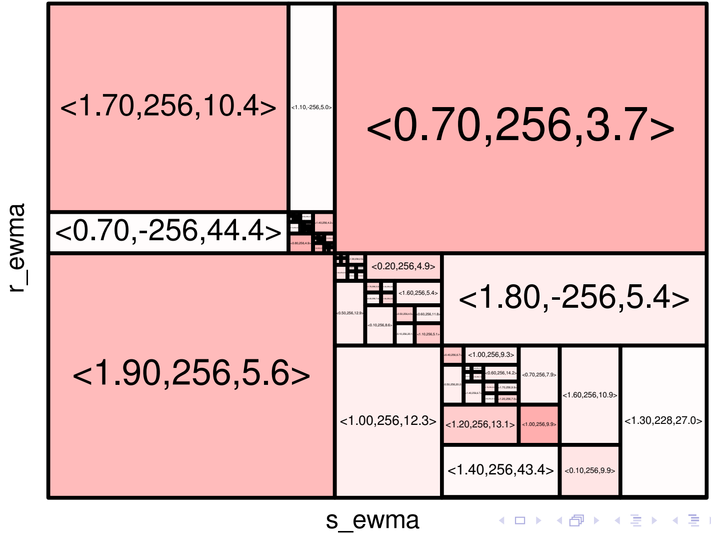
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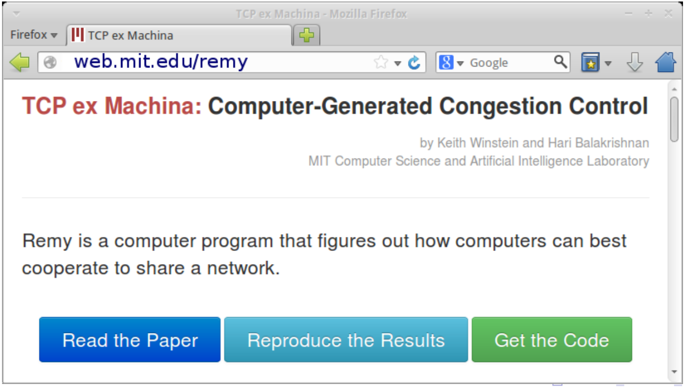
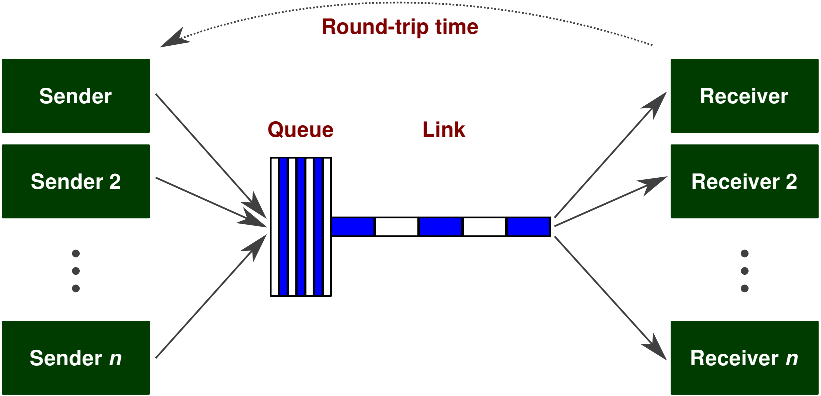
Evaluation in ns-2

- End-to-end comparators: NewReno, Cubic, Compound, Vegas
- In-net comparators: Cubic-over-sfqCoDel, XCP
- Simulation setup published for replication



Scenario 1: fixed-rate network, homogenous senders



Scenario 1: details

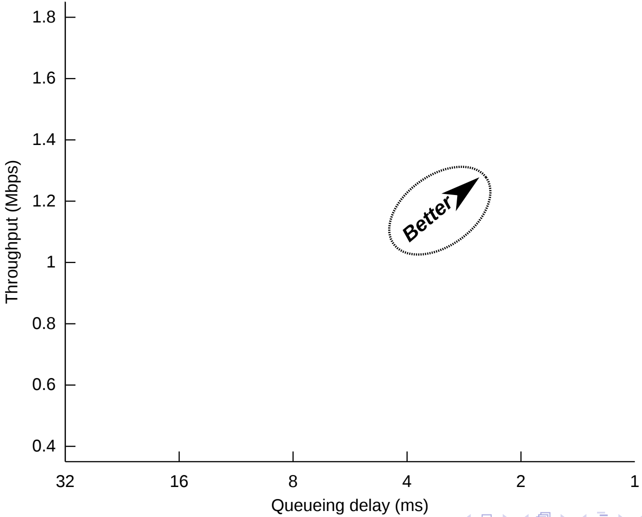
Quantity	Simulation parameter	Remy assumptions
Link speed	15 Mbps	Uniform(10, 20) Mbps
RTT	150 ms	Uniform(100, 200) ms
n	8	Uniform(1, 16)
"On" process	$\exp[\mu = 100]$ **kB**	$\exp[\mu = 5]$ **s**
"Off" process	$\exp\left[\mu = \frac{1}{2}\right]$ s	$\exp[\mu = \mathbf{5}]$ s

Remy objective:

$$\sum_i \log\left[\frac{\text{throughput}_i}{(\text{delay}_i)^{\delta}}\right]$$

$$\delta \in \left\{\frac{1}{10}, 1, 10\right\}$$

Scenario 1: throughput-delay plot



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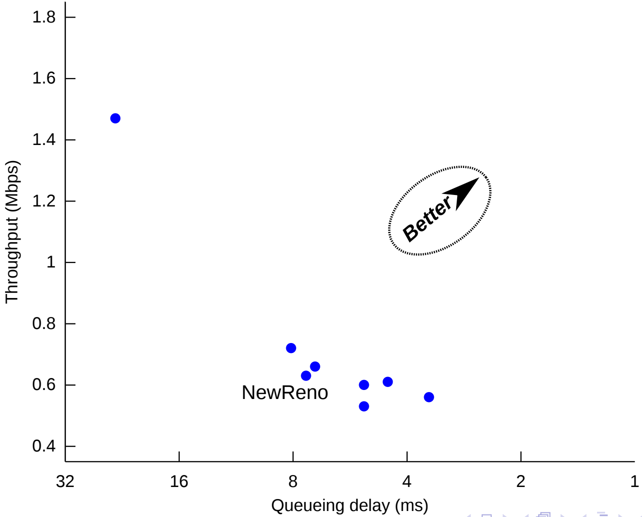

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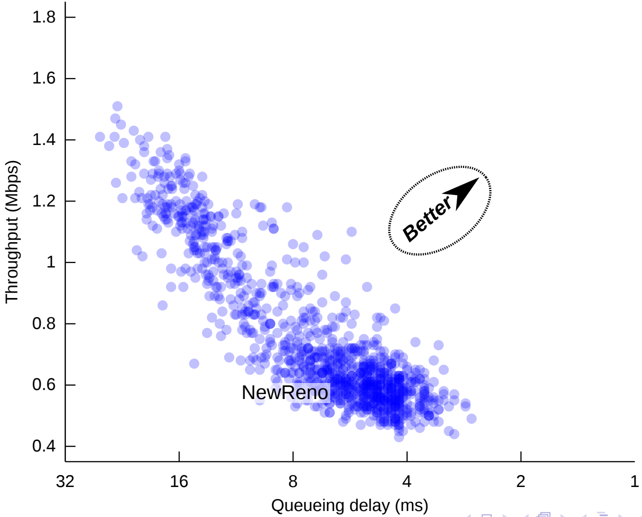

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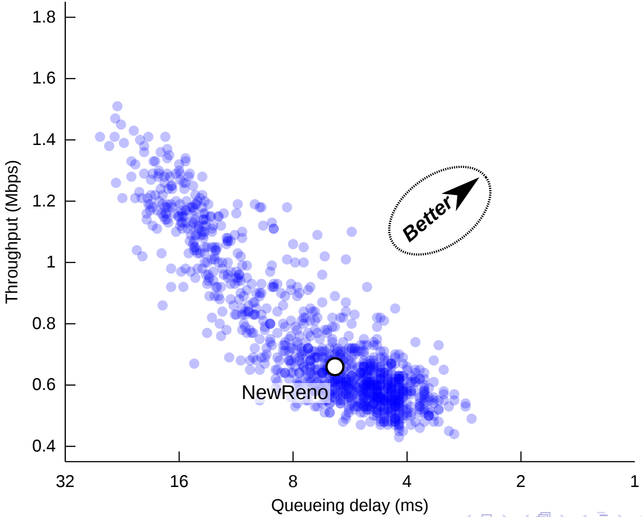

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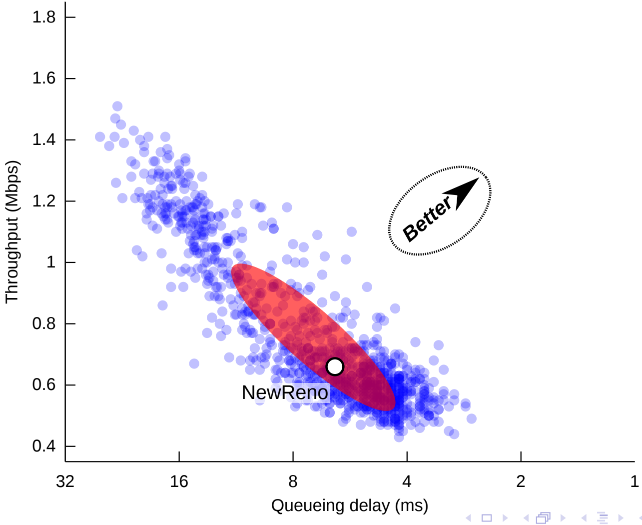

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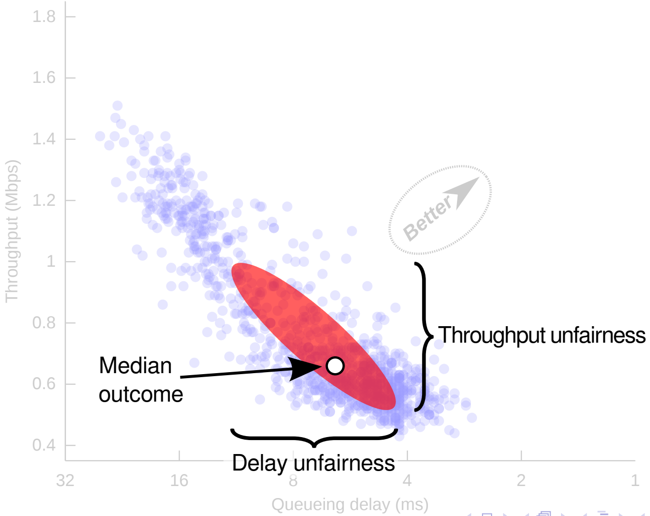

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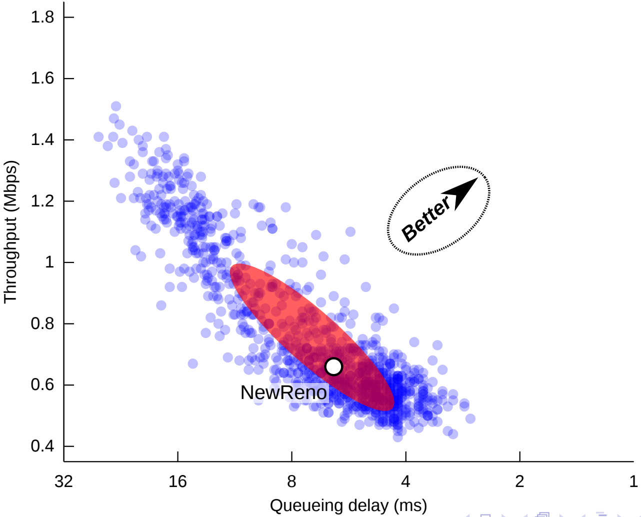

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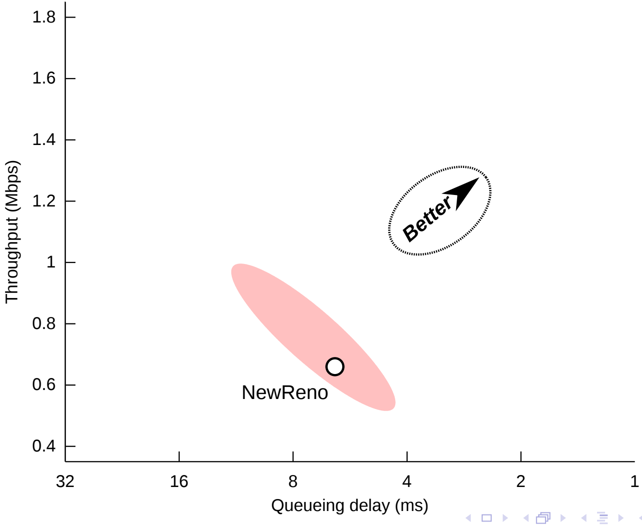

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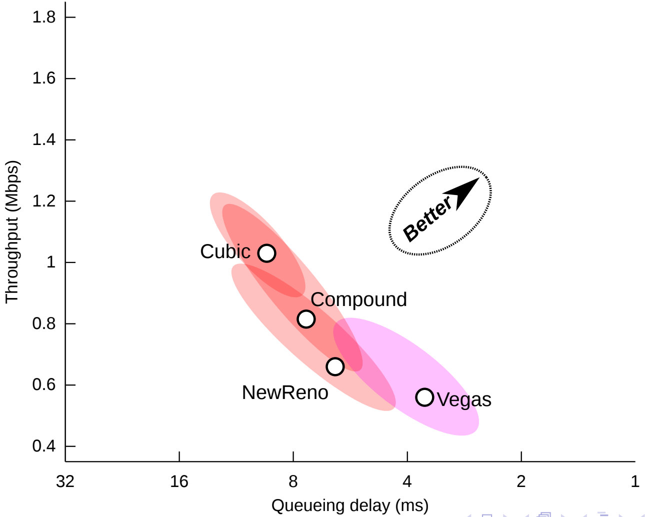

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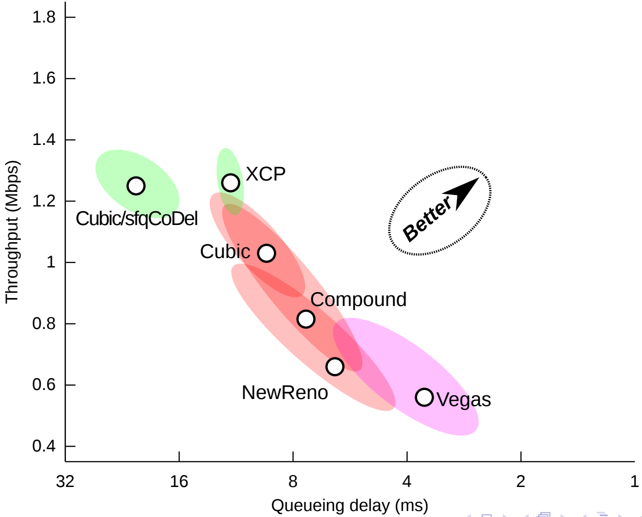

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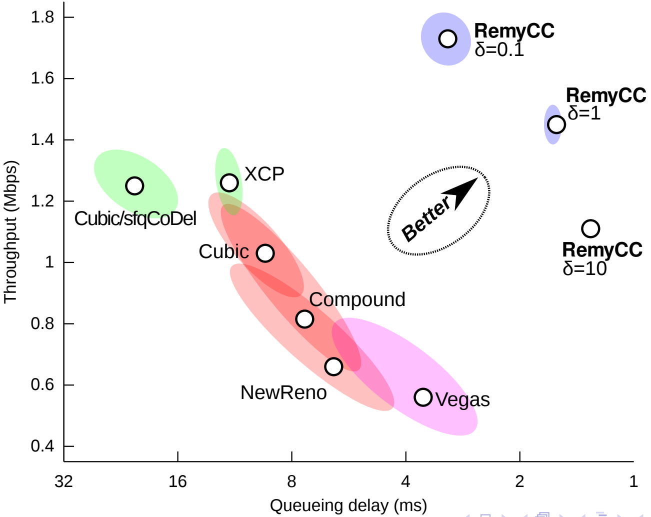

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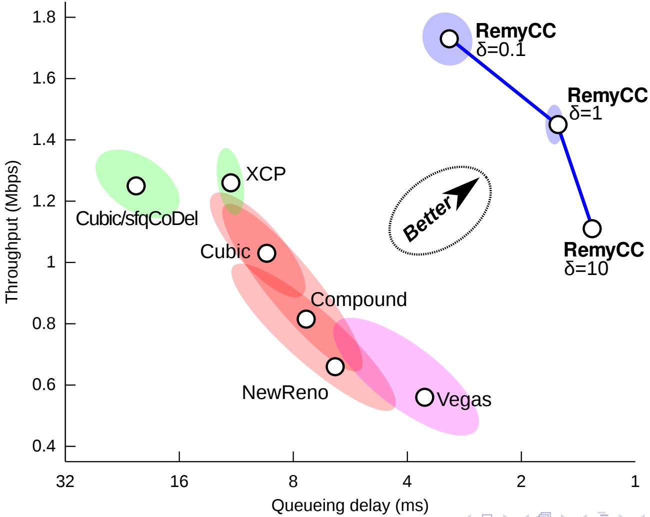

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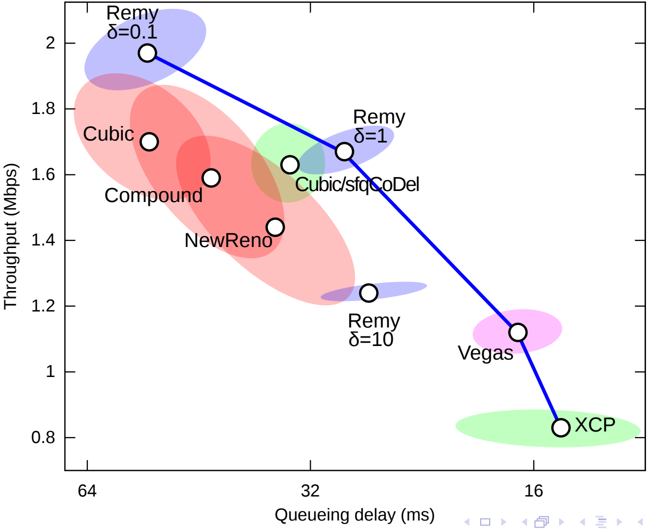
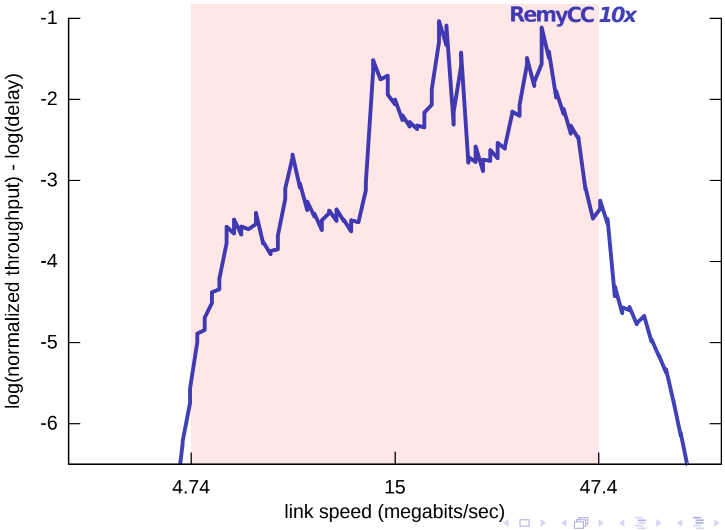
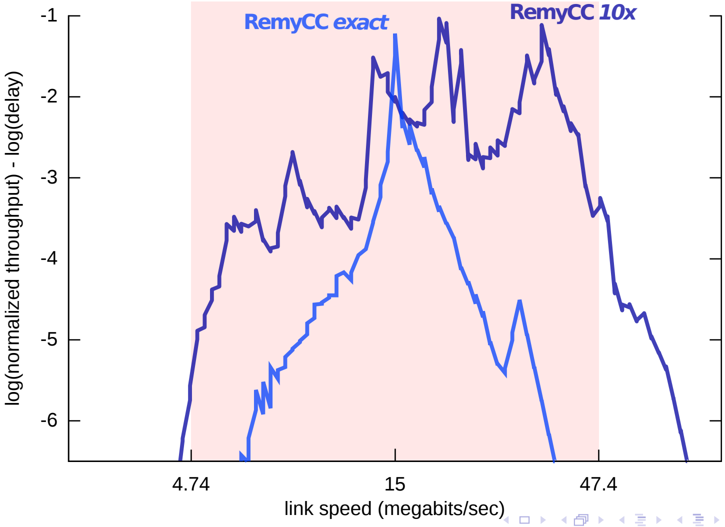


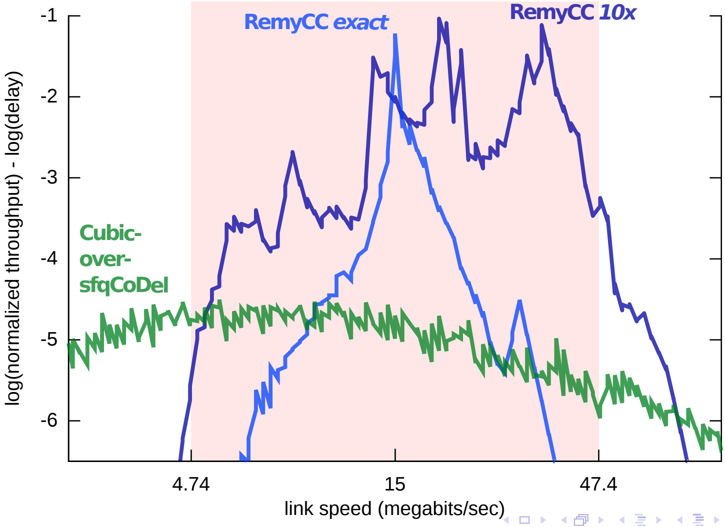
The effect of prior knowledge



The effect of prior knowledge



The effect of prior knowledge



Limitations and unknowns

- Tested only in simulation so far
- How to characterize robustness to the unforeseen?
- Can we make a RemyCC for a 10,000x range of throughputs?
- Agreeing on assumptions and goal may not be easy
- End-to-end = hard to handle an overaggressive competitor
- Not proposing Internet-scale deployment any time soon

Conclusions

- Traditionally: simple rules, complex behavior
- With Remy: complex rules, consistent behavior

- Computer-designed > human-designed
- End-to-end > in-network

- The network evolves. Transport should let it!

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