Consistency without concurrency control in large, dynamic systems

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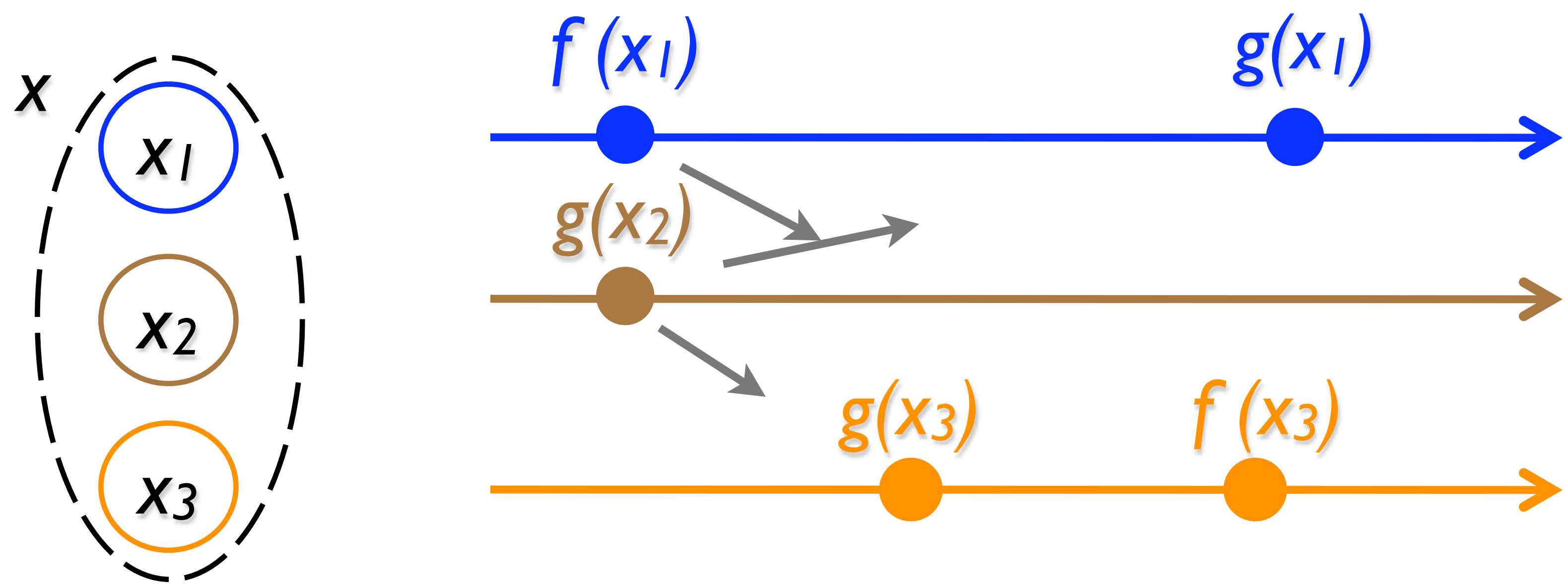
Two things
- no concurrency control
- large dynamic

Consistency without concurrency control



Object x, operation $f(x)$

- *propose* $f(x_1)$
- eventually *replay* $f(x_2)$, $f(x_3)$, ...

If $f \parallel g$ commute: converges safely without concurrency control

Commutative Replicated Data Type (CRDT): *Designed for commutative operations*

Not same order at 1 and 2?
OK if

- concurrent f and g commute

Assuming causal delivery

A sequence CRDT

Treedoc = sequence of elements:

- *insert-at-pos*, *delete*
- Commutative when concurrent
- Minimise overhead
- Scalable

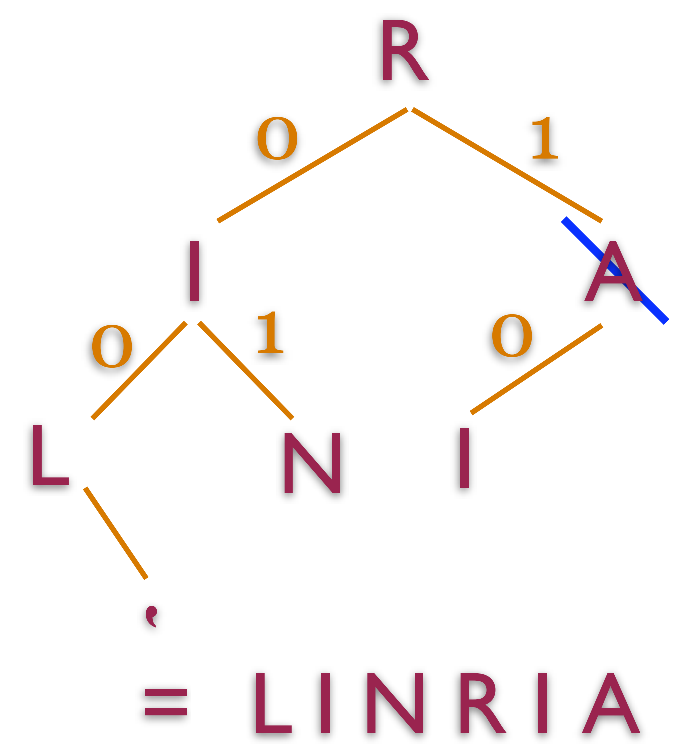
A commutative replicated data type for cooperative editing, ICDCS 2009

Focus today:

- Garbage collection
- vs. scale

I will just skim the surface of the Treedoc design
Refer to ICDCS paper for the details

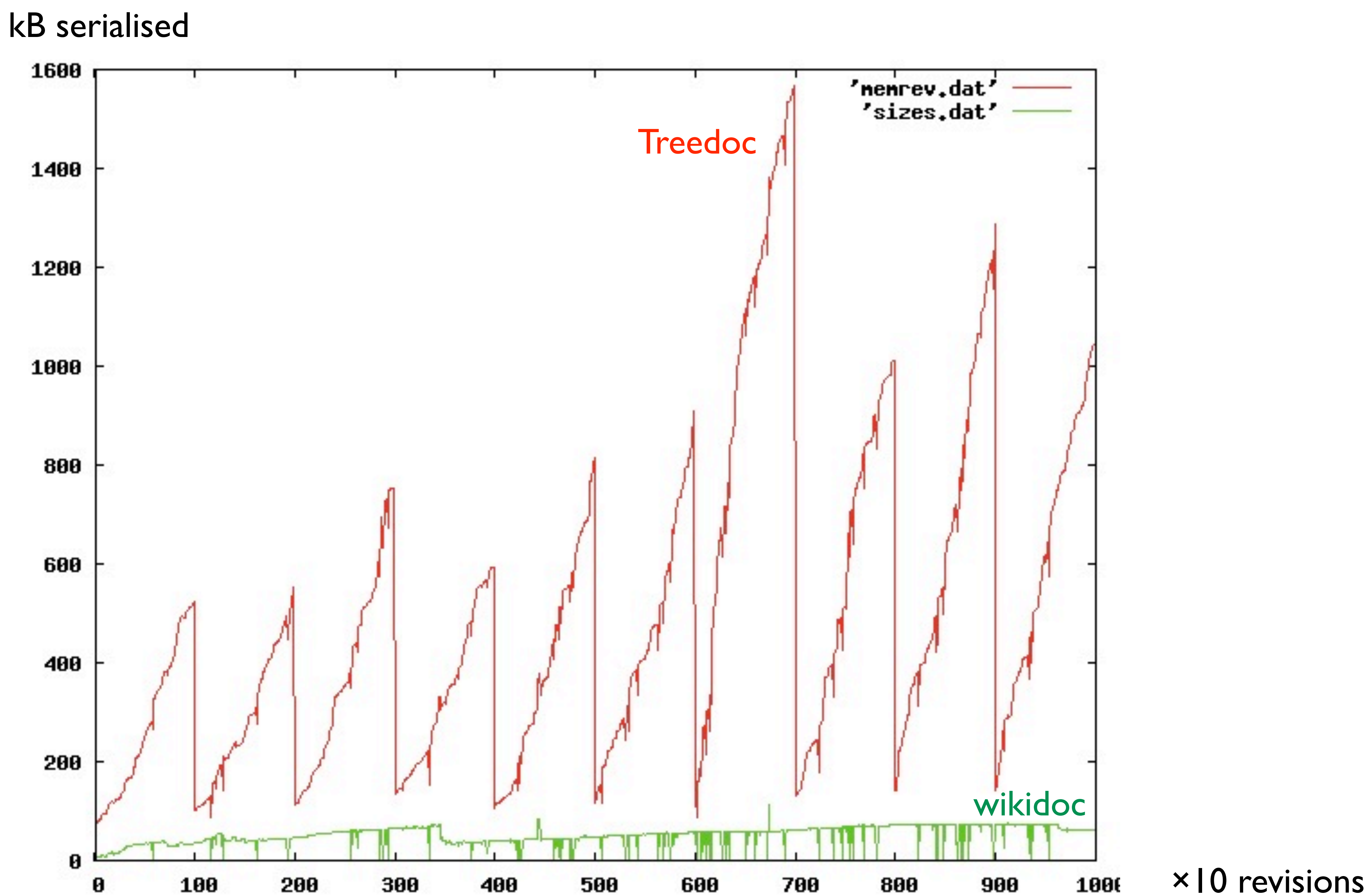
Commutative updates



Naming tree: minimal, self-adjusting: logarithmic
TID: path = [0|1]*
Contents: infix order
insert adds leaf ⇒ non-destructive, TIDs don't change
Delete: *tombstone*, TIDs don't change

Thanks to non-destructive updates, immutable TIDs: concurrent updates commute
Efficient: Data structures and TID lengths logarithmic *if balanced*
Ignoring lots of details, e.g. concurrent inserts at same position (see paper)

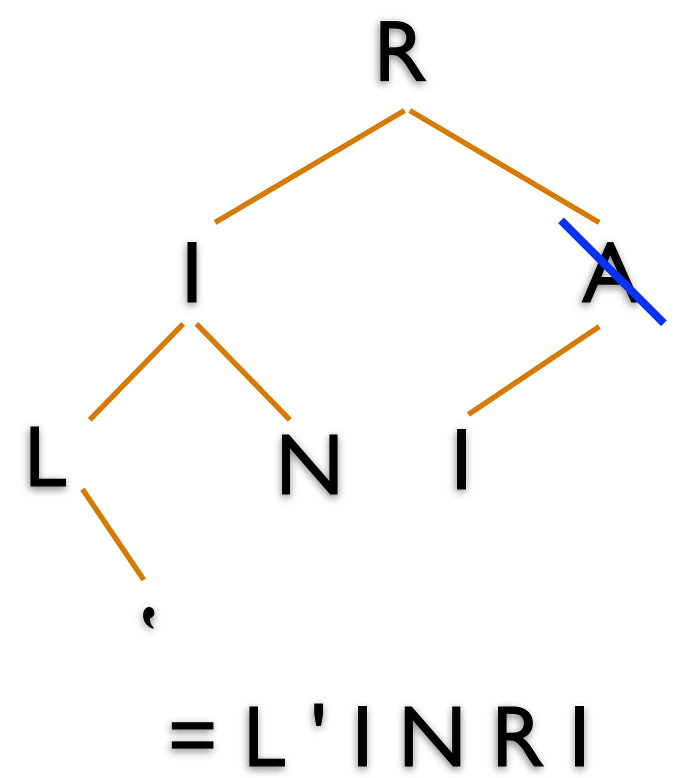
Wikipedia GWB page: space overhead

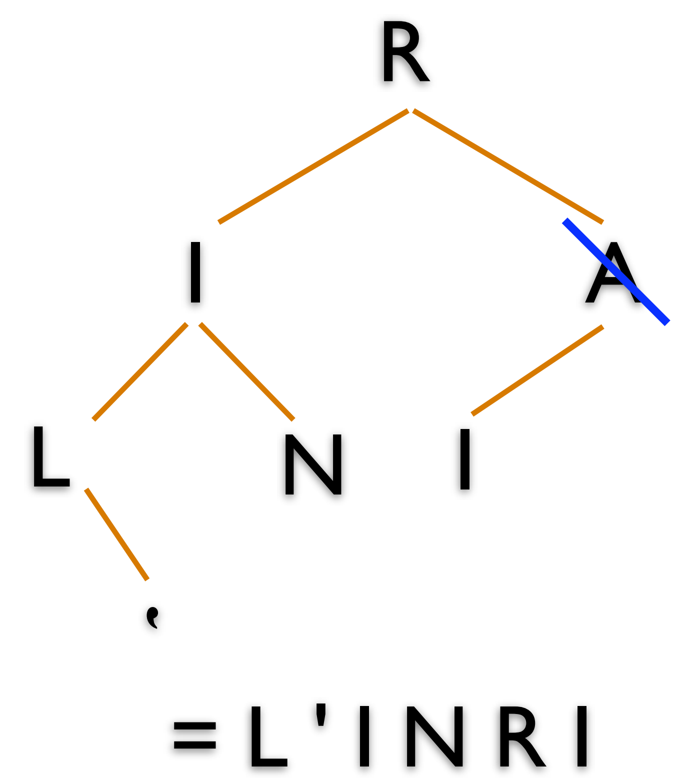


GWB: most edited page
Edits translated into treedoc insert/deletes

- Tree unbalanced, long TIDs, lots of tombstones: not logarithmic

Rebalance

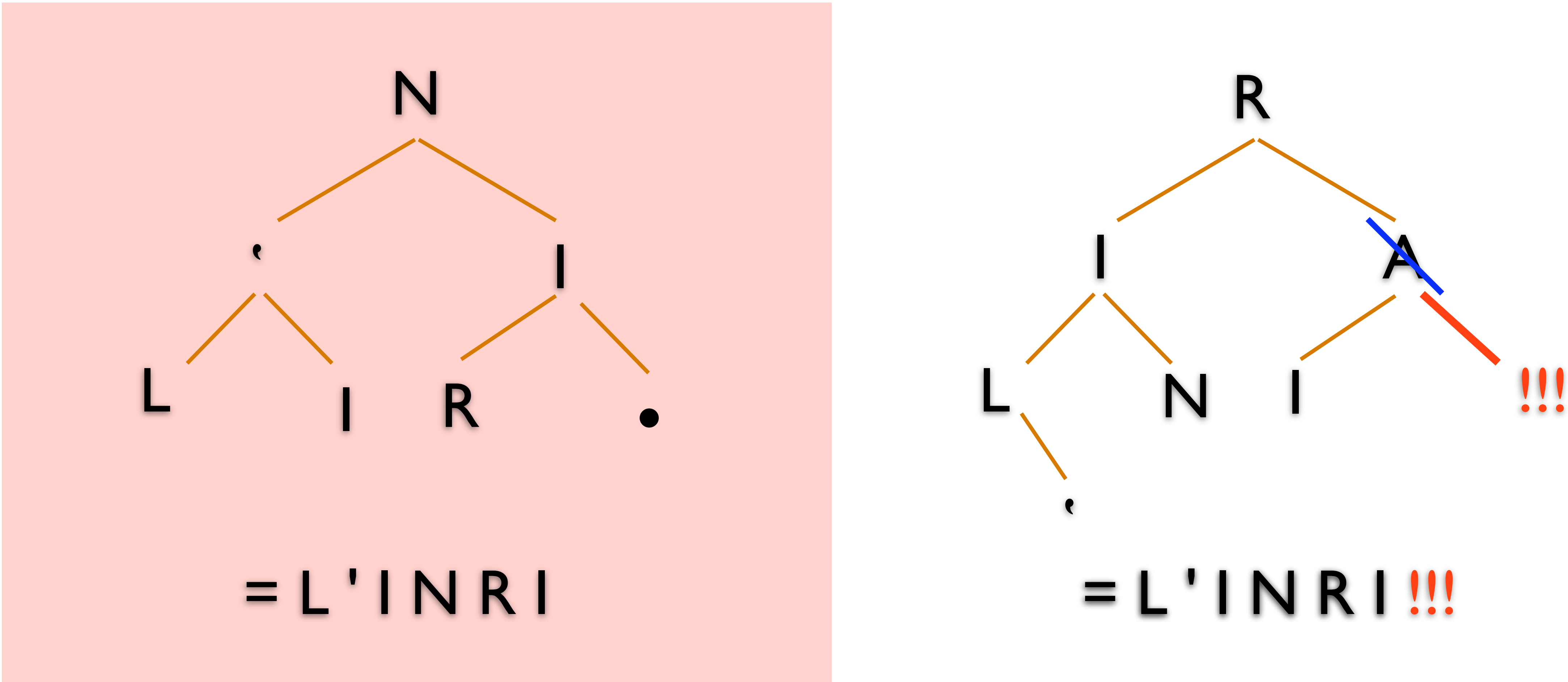




In this example rebalancing is not spectacular.
Imagine a deep unbalanced tree with lots of tombstones: large effect.
Why rebalance:

- Unbalanced tree costs time, space
- Long TIDs
- Tombstone overhead

Rebalance



Invalidates TIDs:

- Frame of reference = *epoch*
- Requires agreement
- Pervasive!
  - e.g. Vector Clocks

TID changed: R was ε, now 10
Pervasive problem:

- asynchronous updates ==> old data structures
- see cleaning up Vector Clocks

(Background colour indicates epoch)

Rebalance in large, dynamic systems

Rebalance requires consensus

Consensus requires small, stable membership

- Large communities?!
- Dynamic scenarios?!

Solution: two tiers

- *Core:* rebalancing (and updates)
- *Nebula:* updates (and rebalancing)
- Migration protocol

Core: controls rebalancing

Core

Group membership

Small, stable

Rebalance:

- Unanimous agreement (2-phase commit)
- All core sites in same epoch

Nebula

Arbitrary membership

Large, dynamic

Communicate with sites in same epoch only

Catch-up to rebalance, join core epoch

Migrate core to nebula: just leave group

Core

Group membership

Small, stable

Rebalance:

- Unanimous agreement (2-phase commit)
- All core sites in same epoch

Nebula

Arbitrary membership

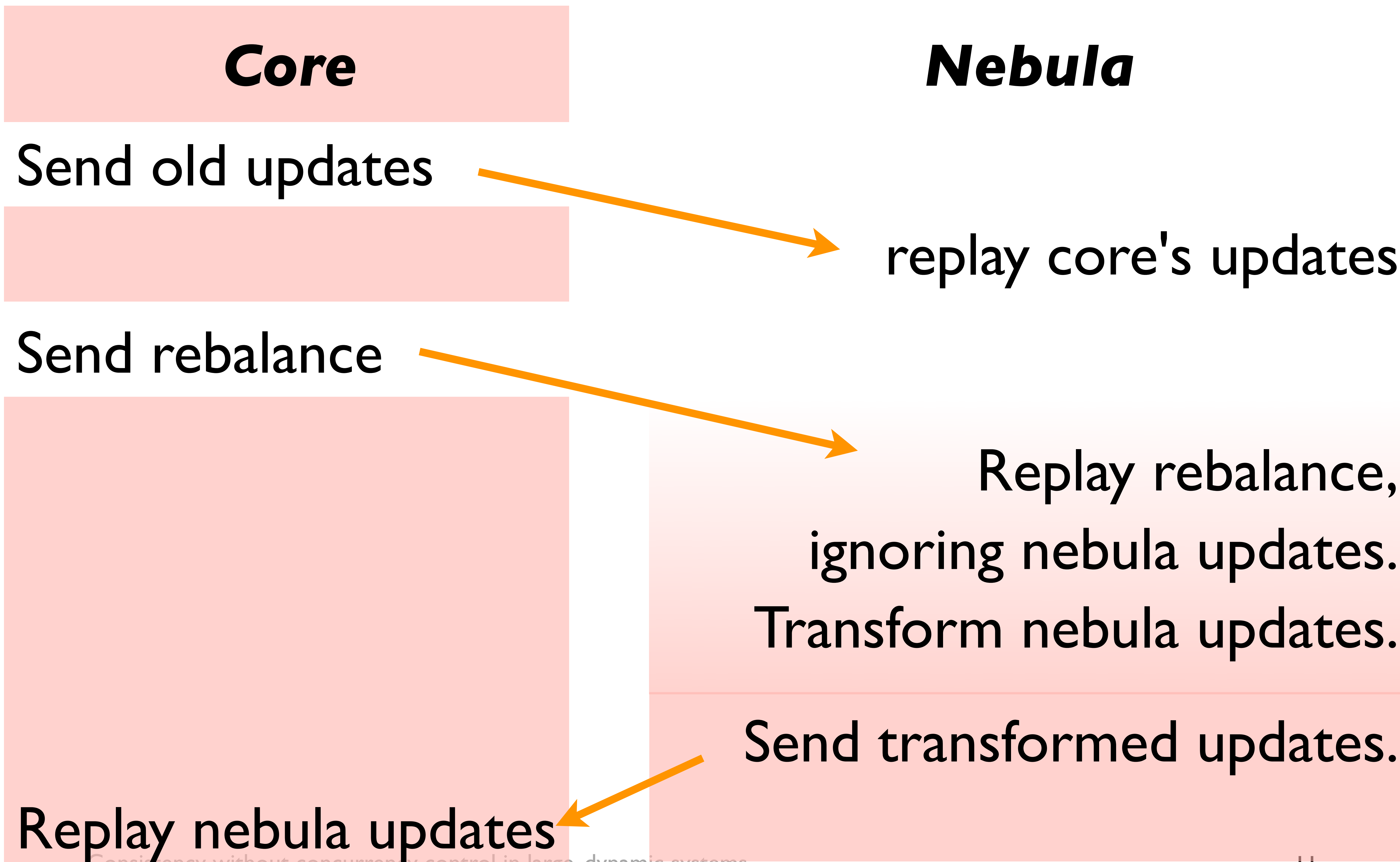
Large, dynamic

Communicate with sites in same epoch only

Catch-up to rebalance, join core epoch

Migrate from nebula to core: migrate to core epoch + join group

Catch-up protocol summary



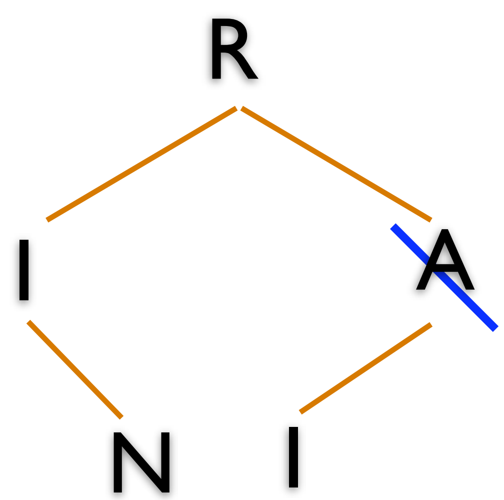
Here is the basic insight to the migration protocol
• Replay core's updates: N now in same state as C before rebalance
• Replay rebalance: *ignoring concurrent N updates*, has same effect as in C ==> same TIDs, same epoch
• Transform buffer: now ready to be replayed in C (in different order, but that's OK since they commute)
• N now in C state, can join the core or remain in nebula

Furthermore updates are idempotent (multiple catch-ups cause no harm)

Catch-up protocol

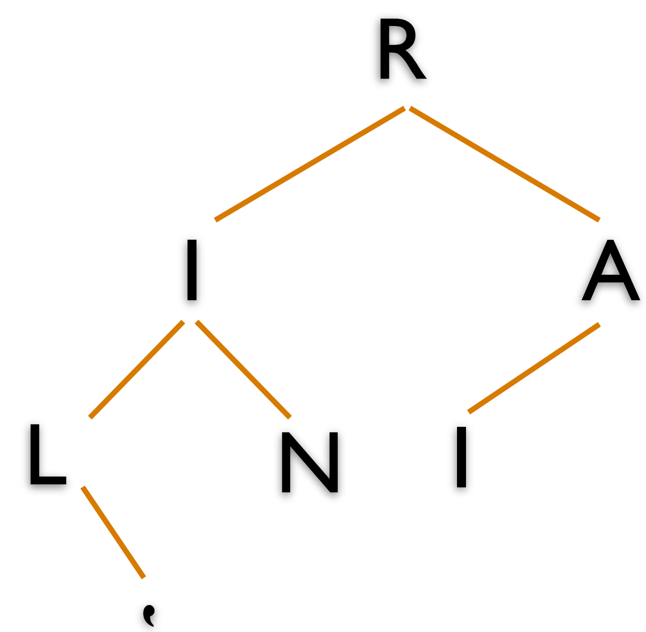
Core Site

del(1)



Nebula Site

ins(L,00)
ins(',001)



del(1)

ins(L,00)
ins(',001)

del in old epoch
old epoch
rebalance starts new epoch

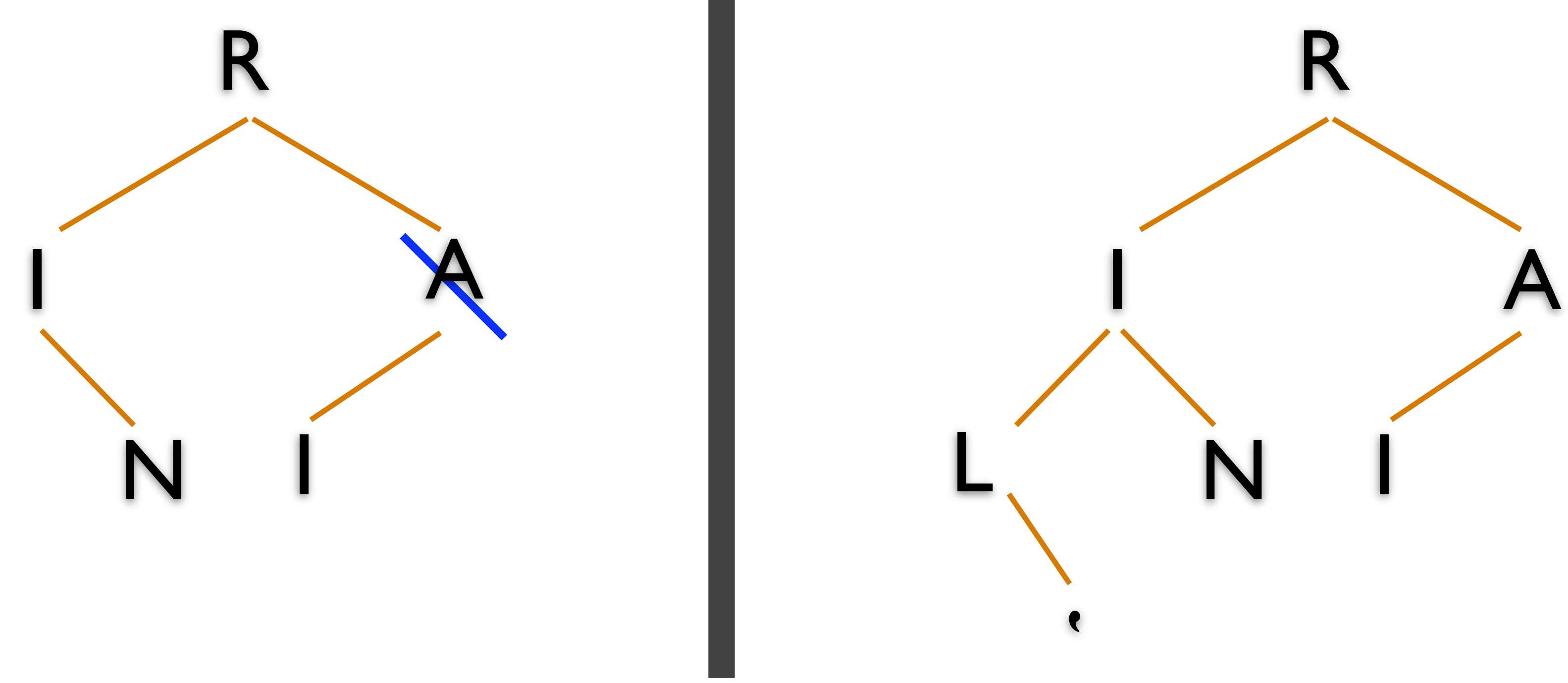
ins + ins in

Catch-up protocol

Core Site | Nebula Site

rebalance

ins(L,00)
ins(',001)



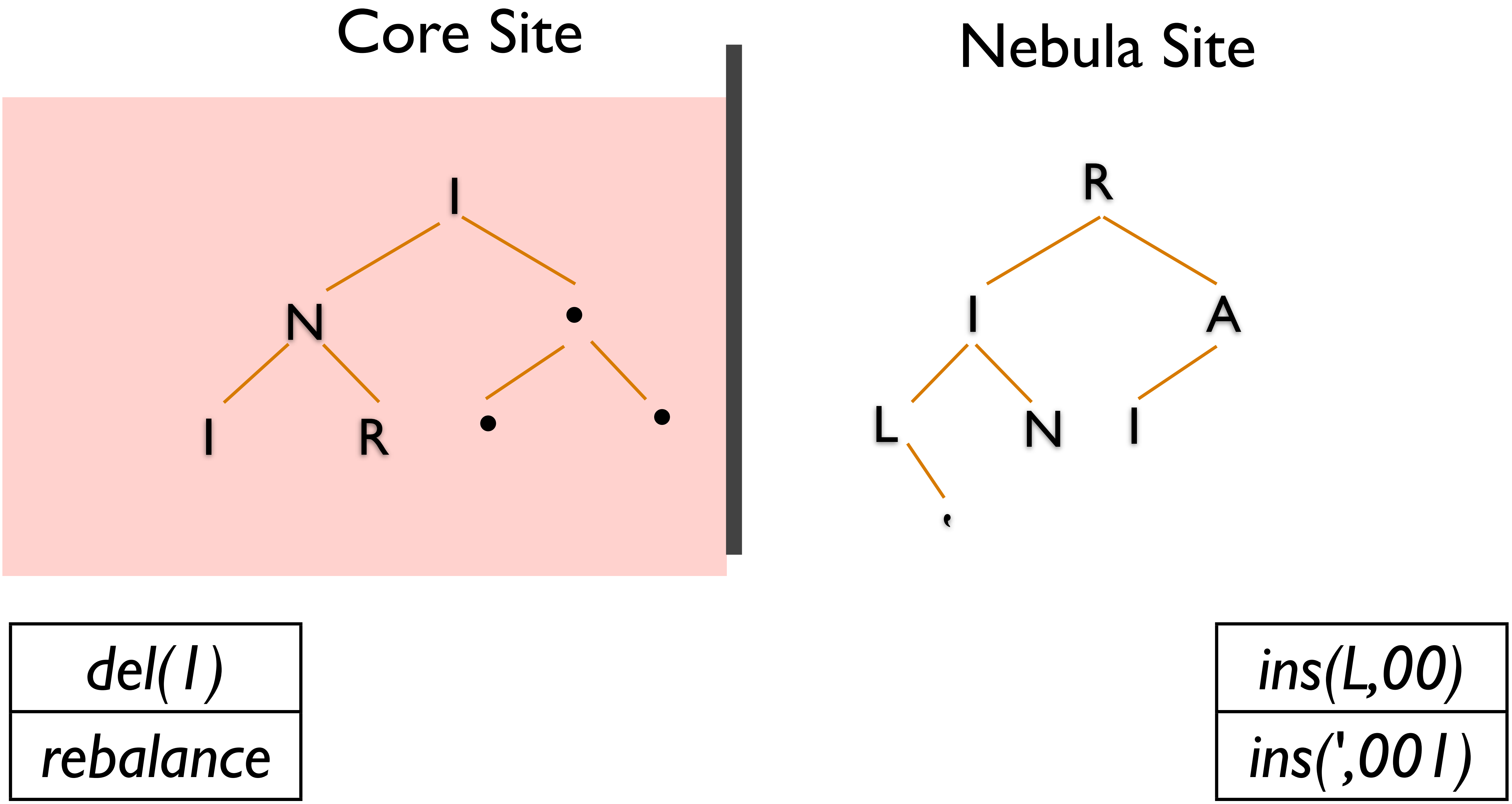
del(1)
rebalance

ins(L,00)
ins(',001)

del in old epoch
old epoch
rebalance starts new epoch

ins + ins in

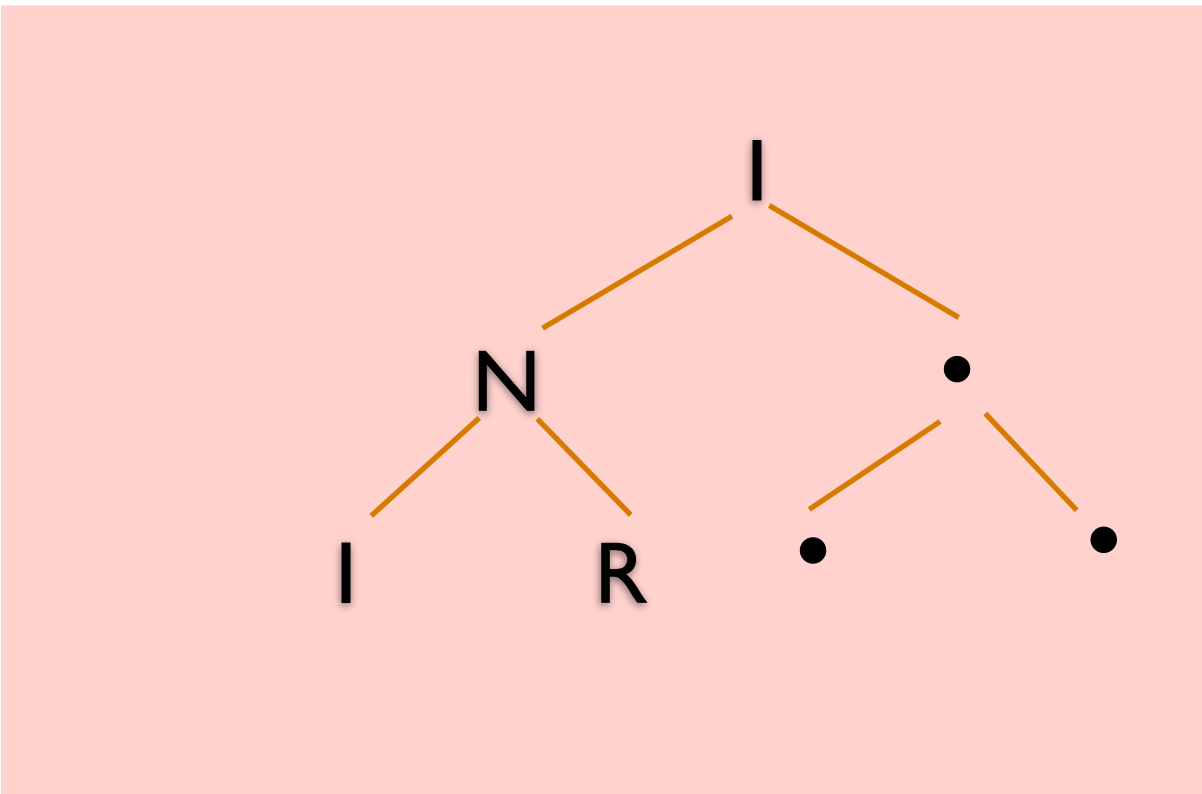
Catch-up protocol



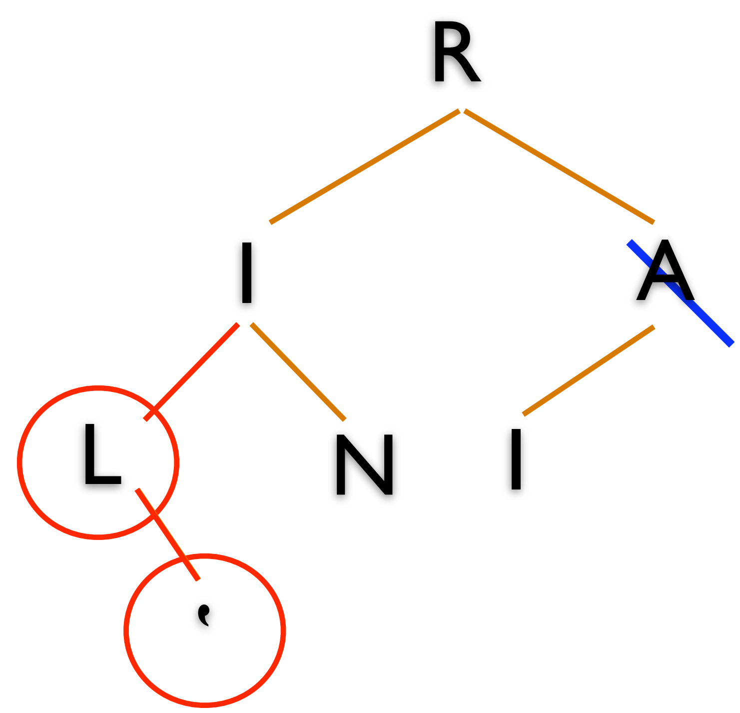
white = old epoch
pink = new epoch

Catch-up protocol

Core Site



Nebula Site



del(1)
rebalance

del(1) →

rebalance →

ins(L,00)
ins(',001)

del uttered in old epoch ==> can send to S
now up to date with Core
send rebalance

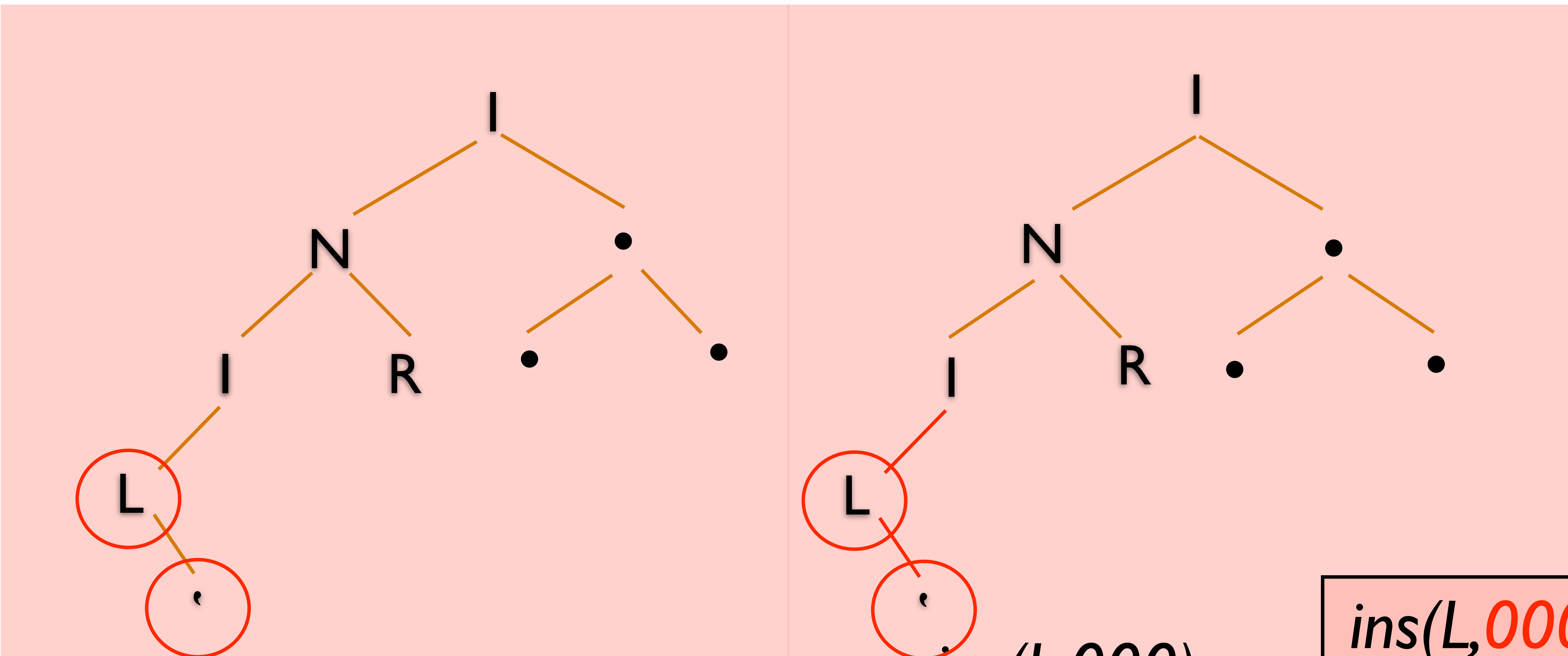
S replays del;

S replays rebalance;
intervening ins move;
S now in new epoch

Catch-up protocol

Core Site

Nebula Site



ins(L,000)
ins(',0001)

ins(L,000)
ins(',0001)

ins arguments transformed to new epoch

Core replays ins

Summary

CRDT:

- Convergence ensured
- Design for commutativity

GC cannot be ignored

- Requires commitment
- Pervasive issue

Large-scale commitment:

- Core / Nebula
- To synchronise: catch-up + migration

CRDT = non−locking synchronisation in weak memory model

Future work

More CRDTs

Understanding CRDTs: what invariants can be CRDTized

Approximations of CRDTs

Data types for consistent cloud computing without concurrency control