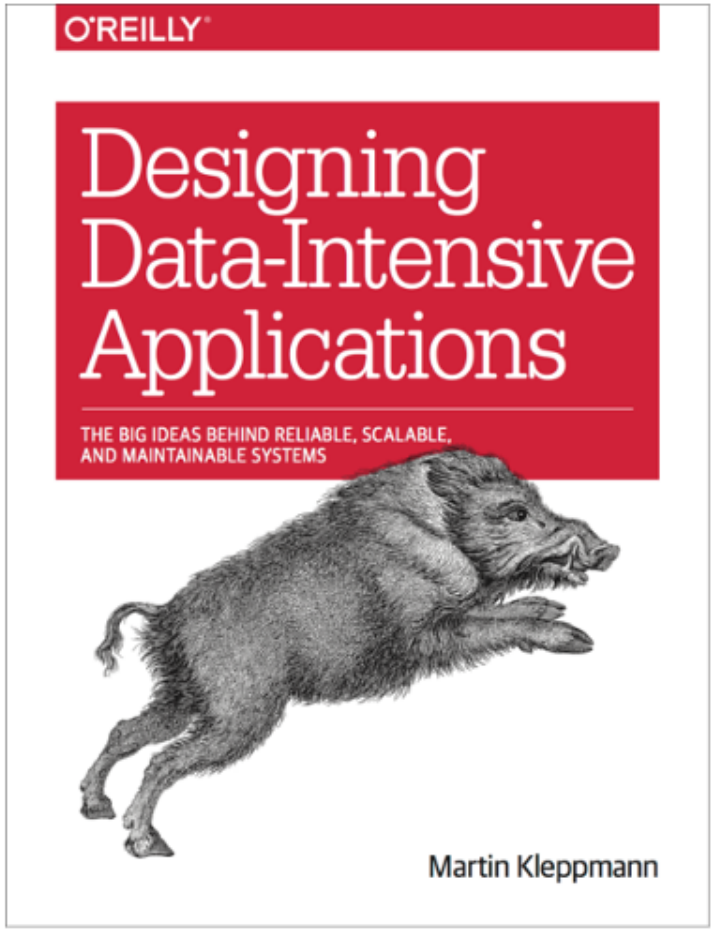
CONVERGENCE versus CONSENSUS

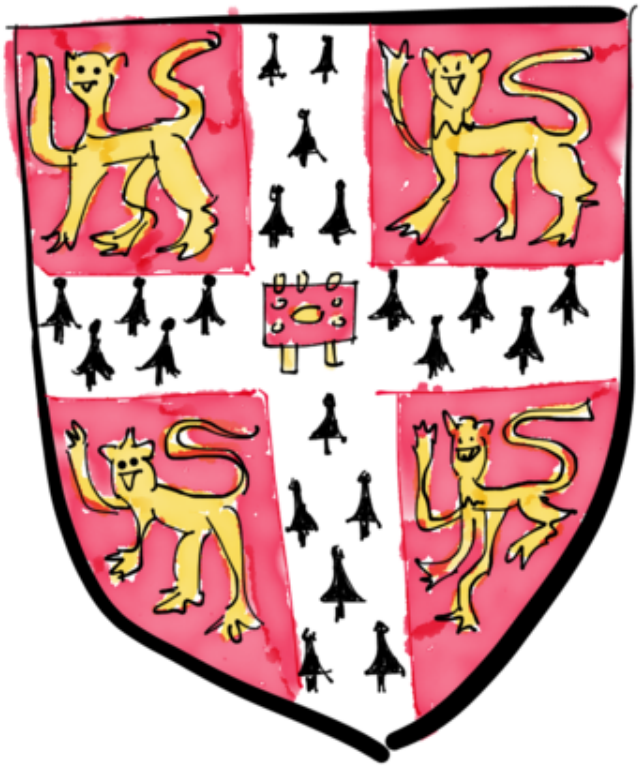
CRDTs and the quest for DISTRIBUTED CONSISTENCY

Martin Kleppmann • University of Cambridge • @martinkl

dataintensive.net



@martinkl



UNIVERSITY OF CAMBRIDGE

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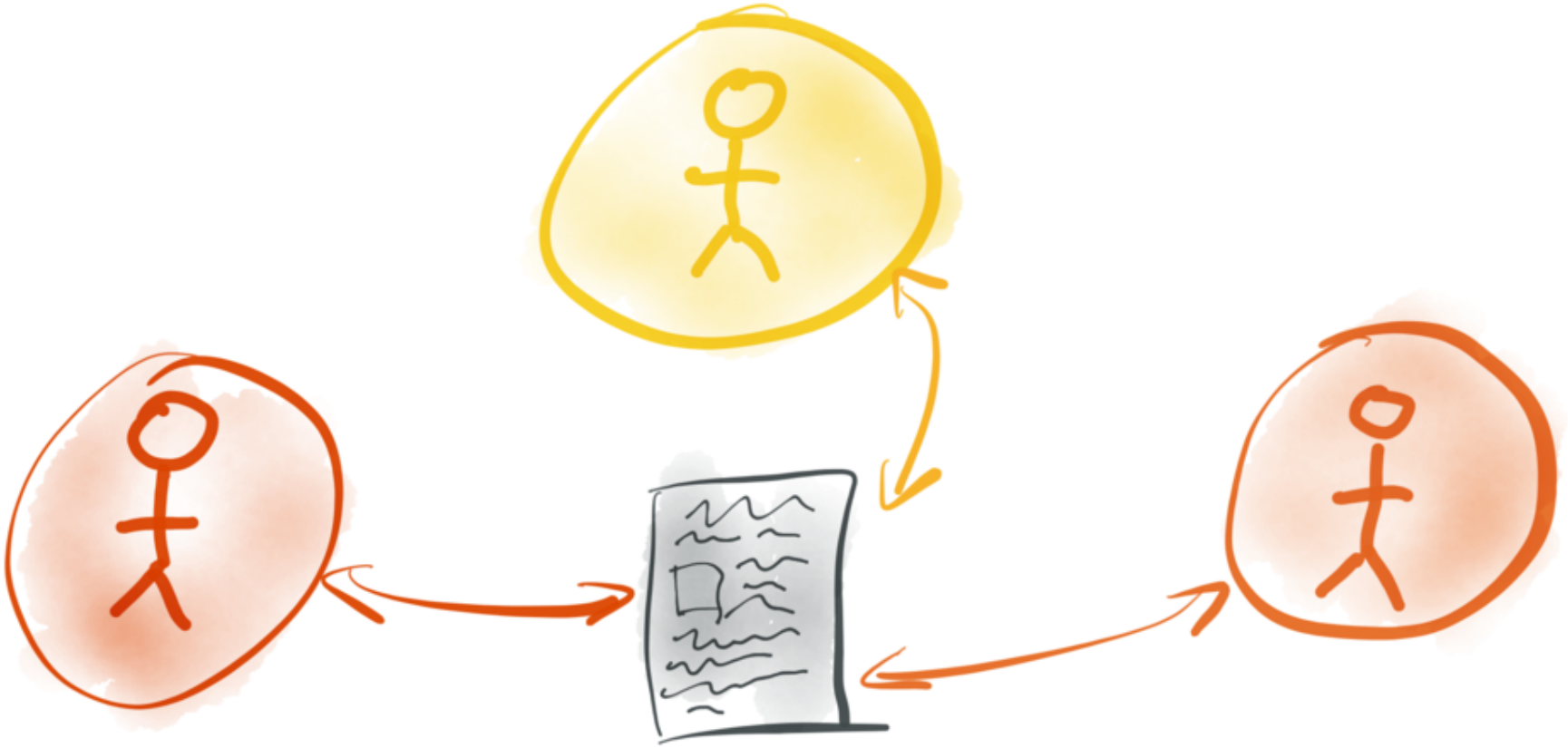
ON STRIKE TODAY

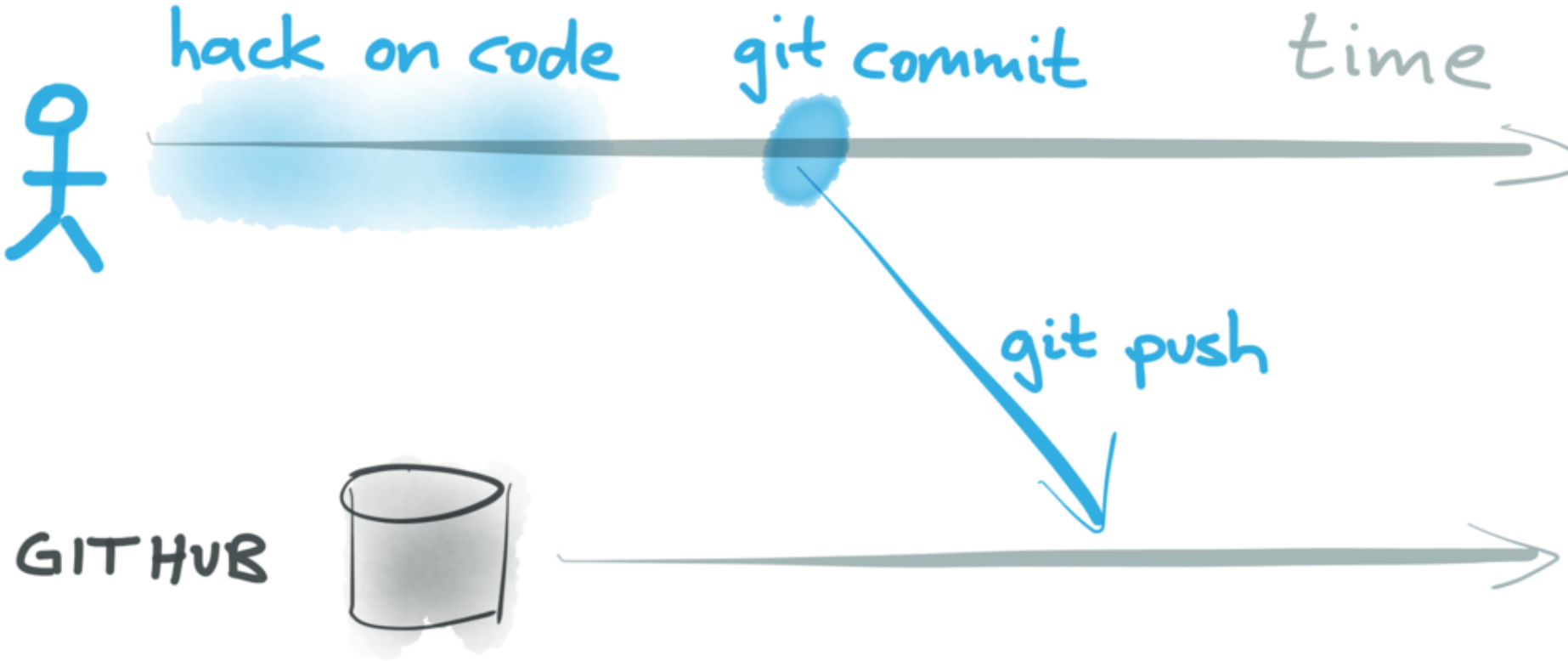
https://www.ucu.org.uk/why-we-are-taking-action-over-USS

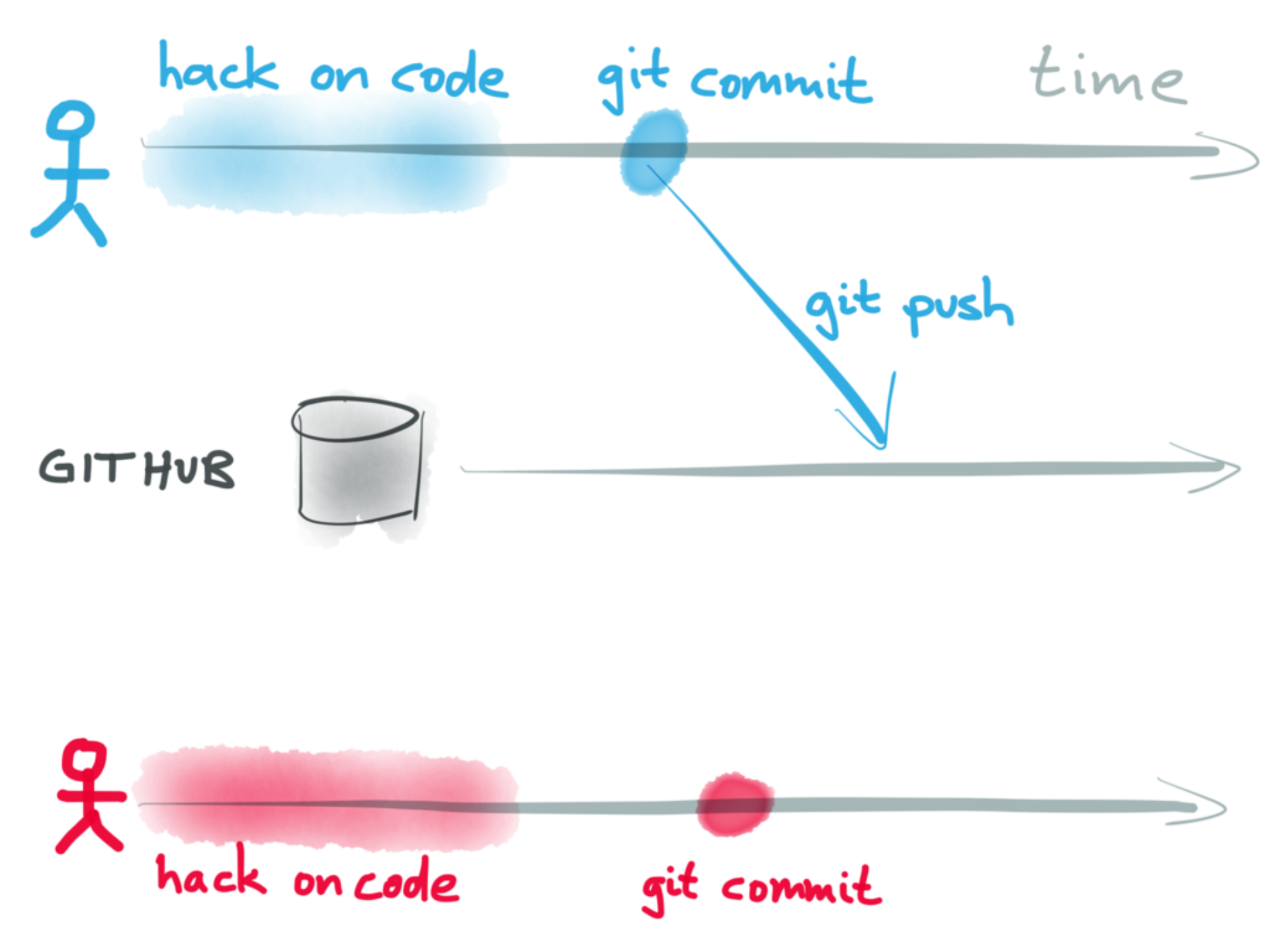
COLLABORATIVE APPLICATIONS

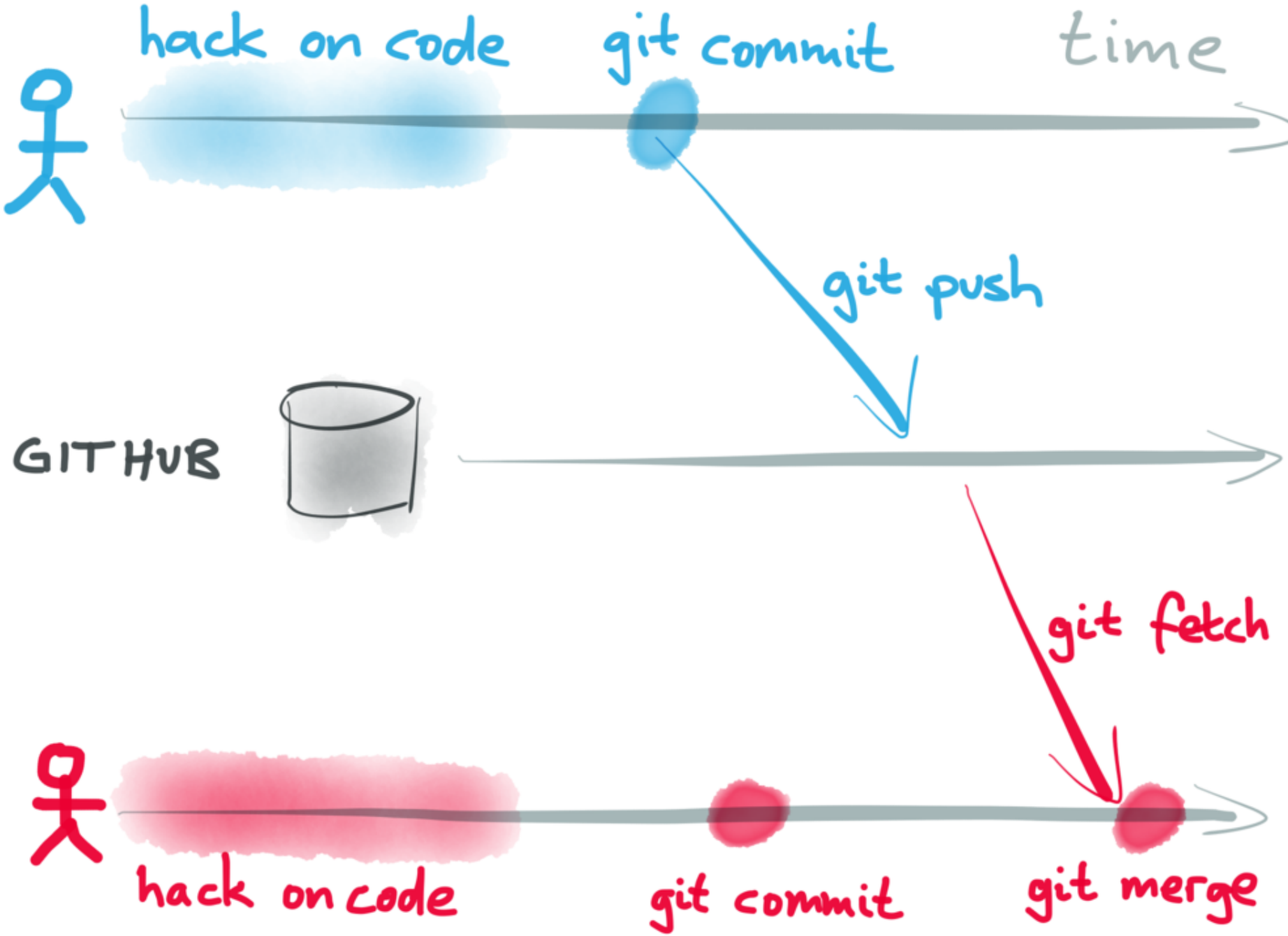



hack on code
time

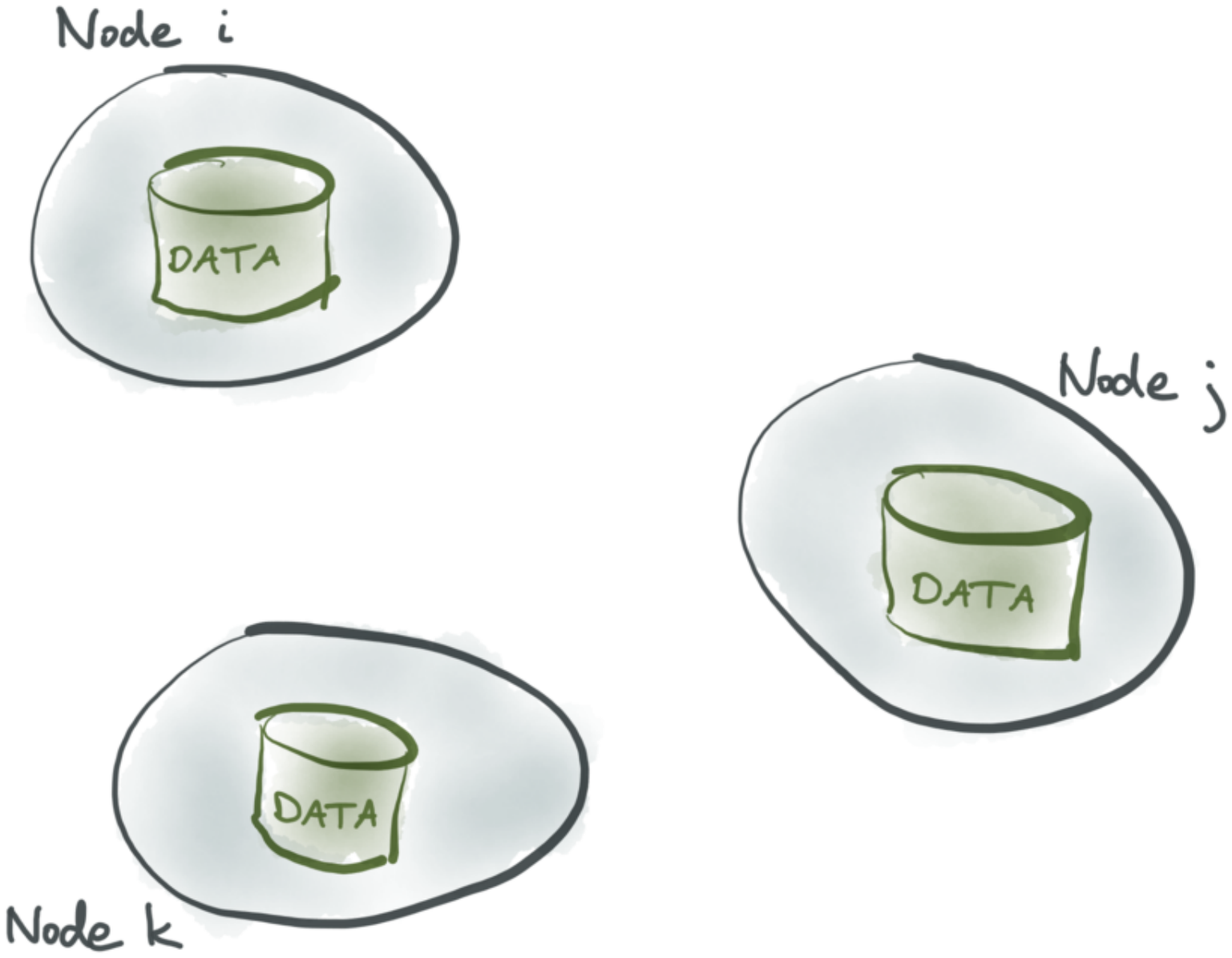

hack on code
git commit
time


hack on code
git commit
time
git push
GITHUB

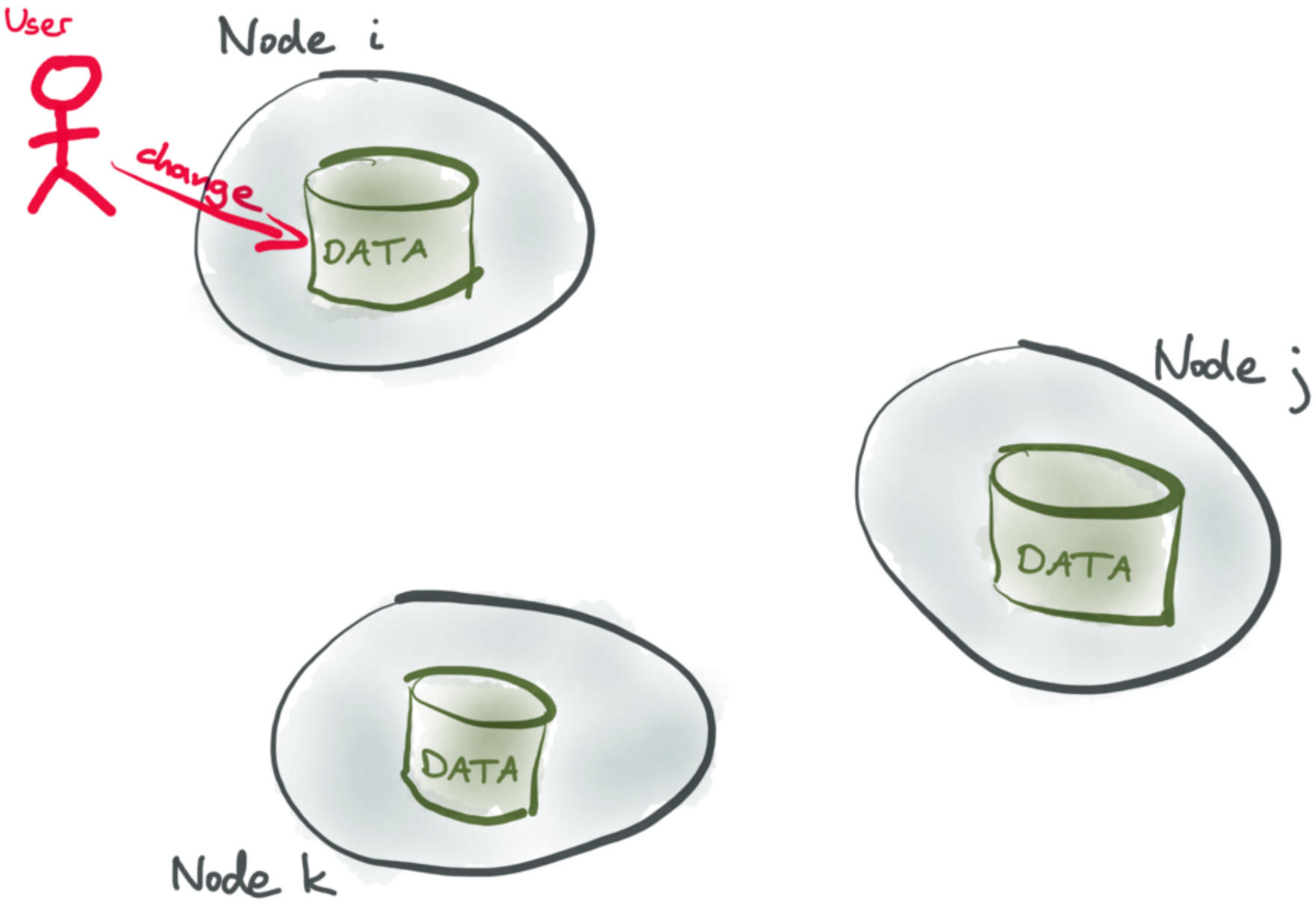

hack on code
git commit
time
git push
GITHUB
hack on code
git commit


hack on code
git commit
time
git push
GITHUB
git fetch
hack on code
git commit
git merge

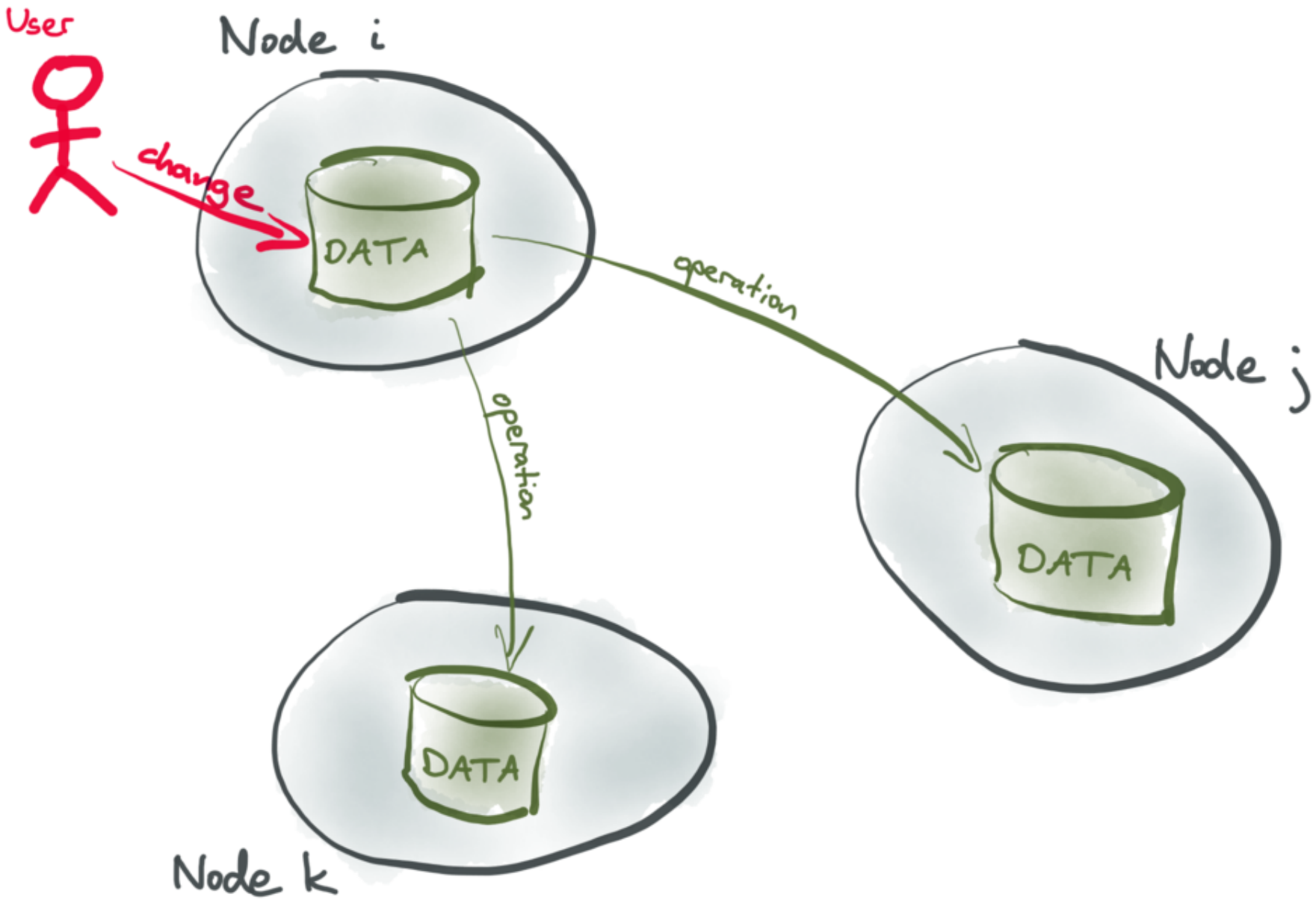
REPLICATION.



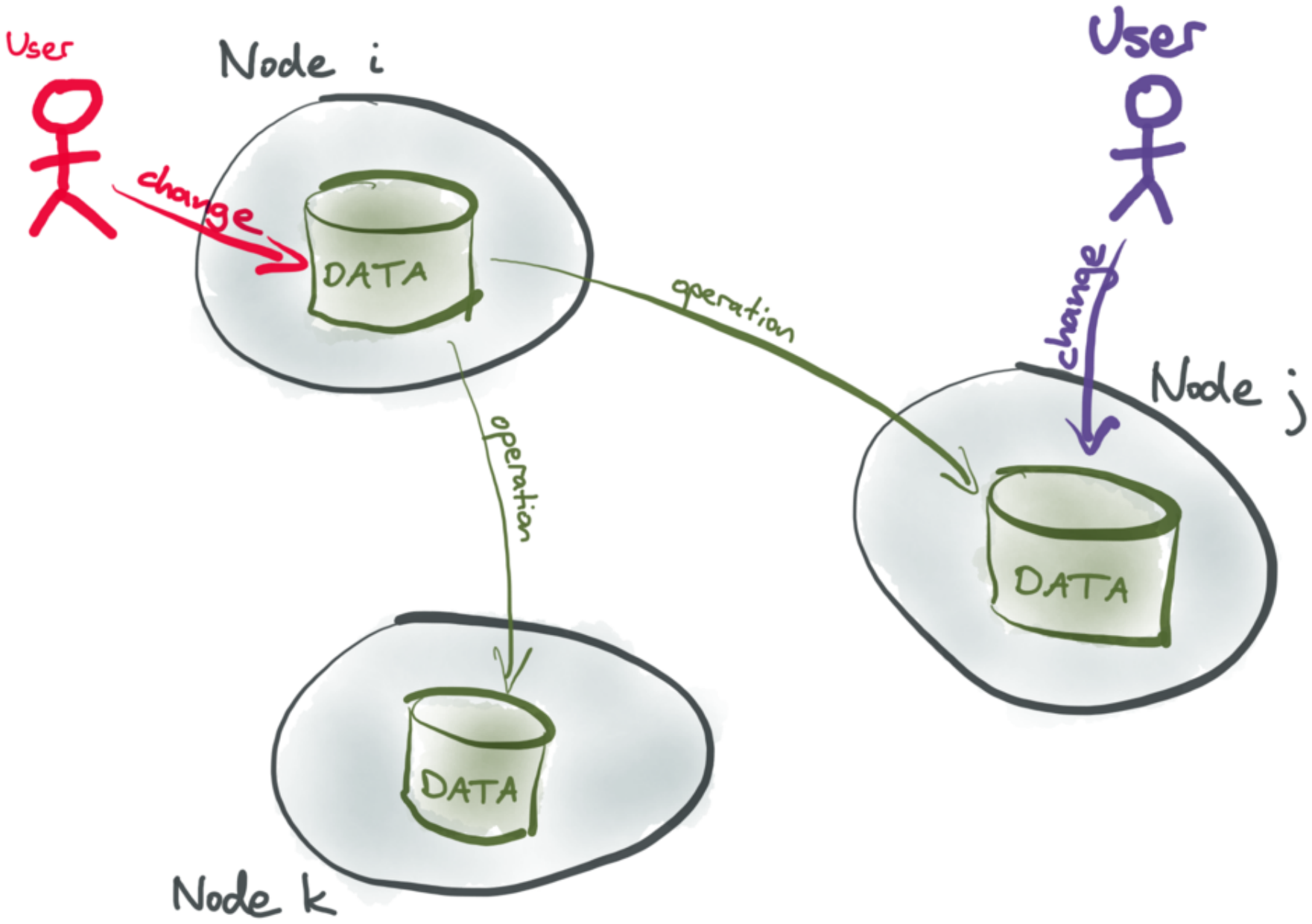
REPLICATION.



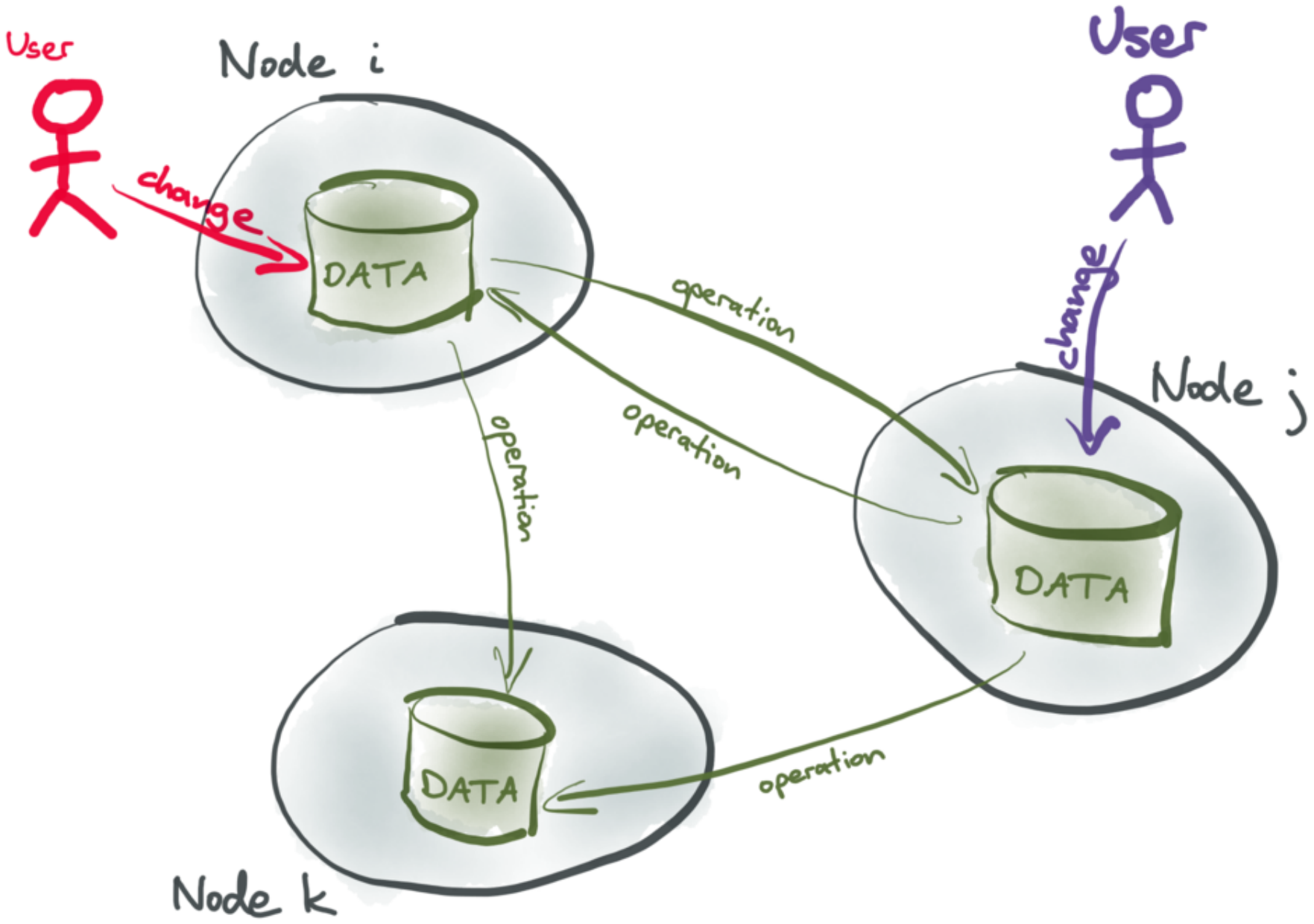
REPLICATION.



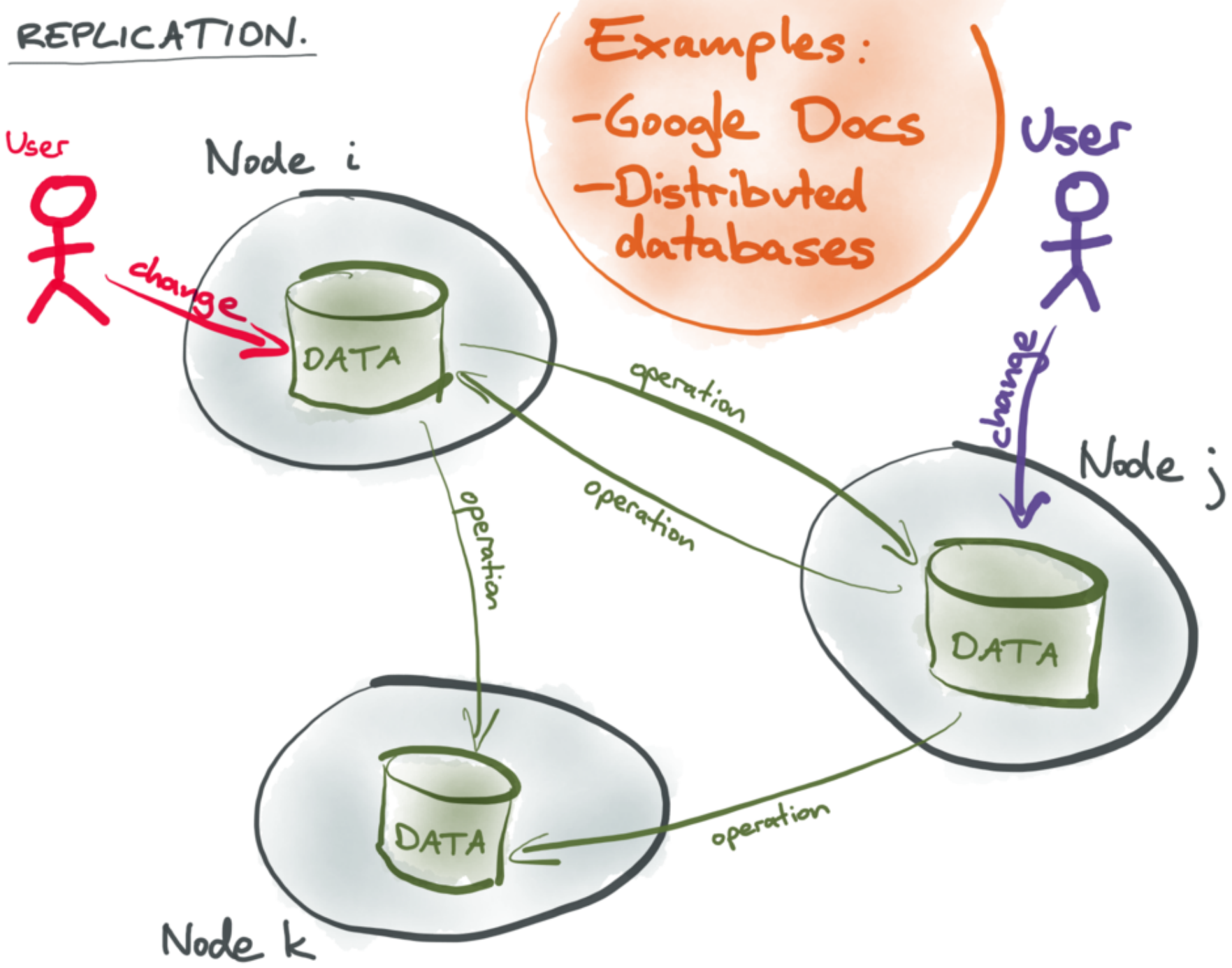
REPLICATION.

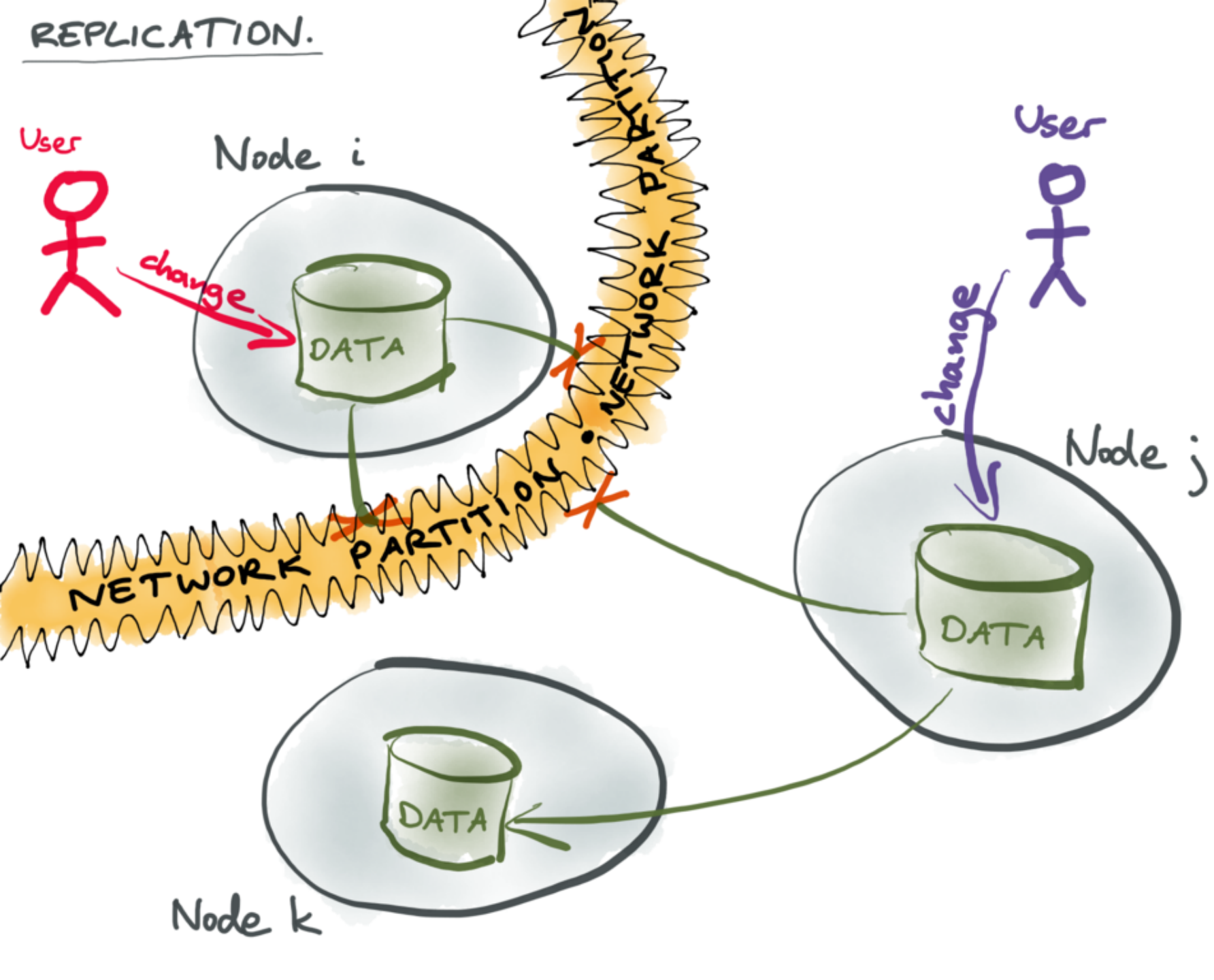


REPLICATION.



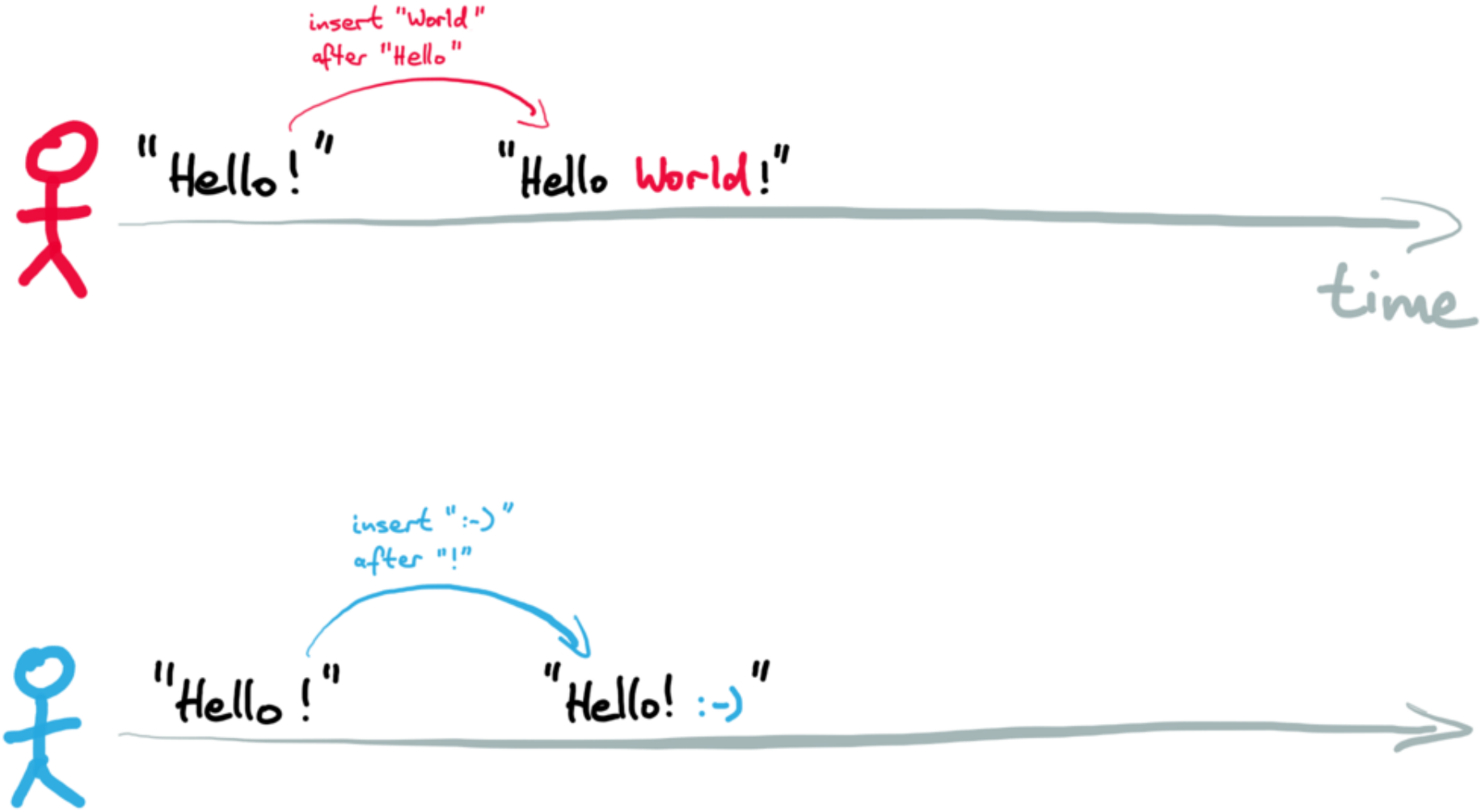
REPLICATION.



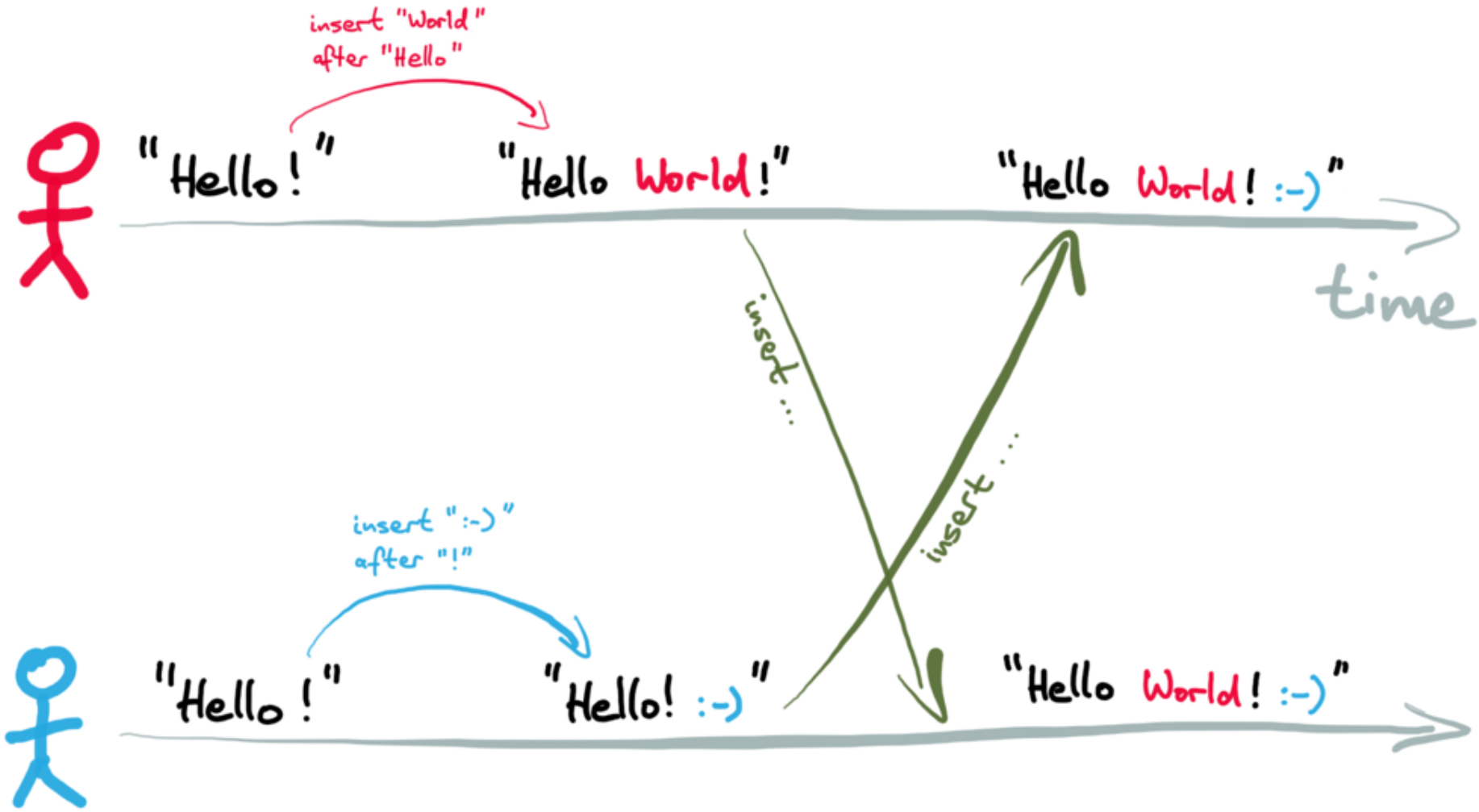

REPLICATION.
User
Node i
change
DATA
NETWORK PARTITION
NETWORK PARTITION
User
change
Node j
DATA
DATA
Node k

Example: Text editing

Example: Text editing



Example: Text editing



Example: set manipulation

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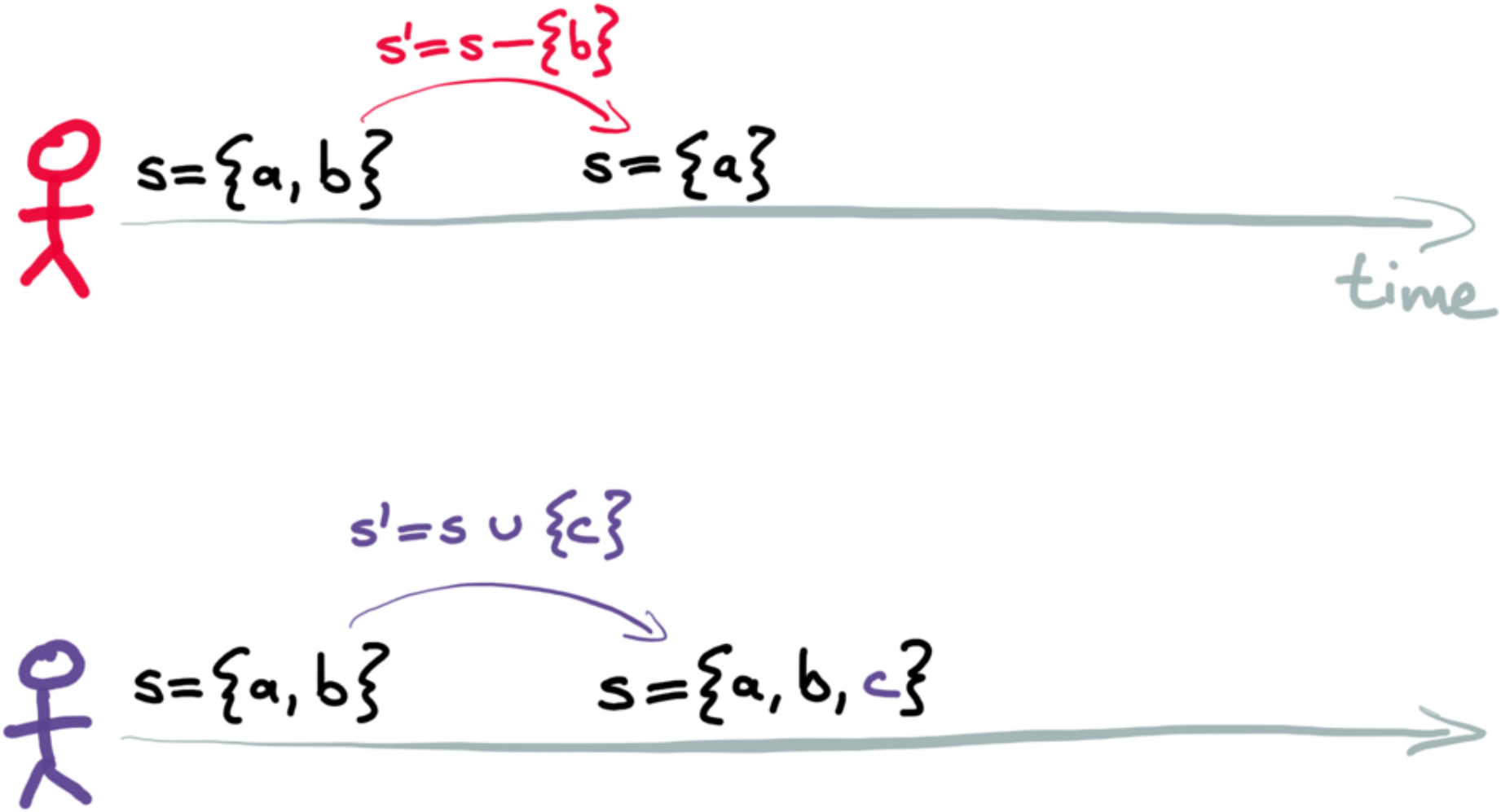

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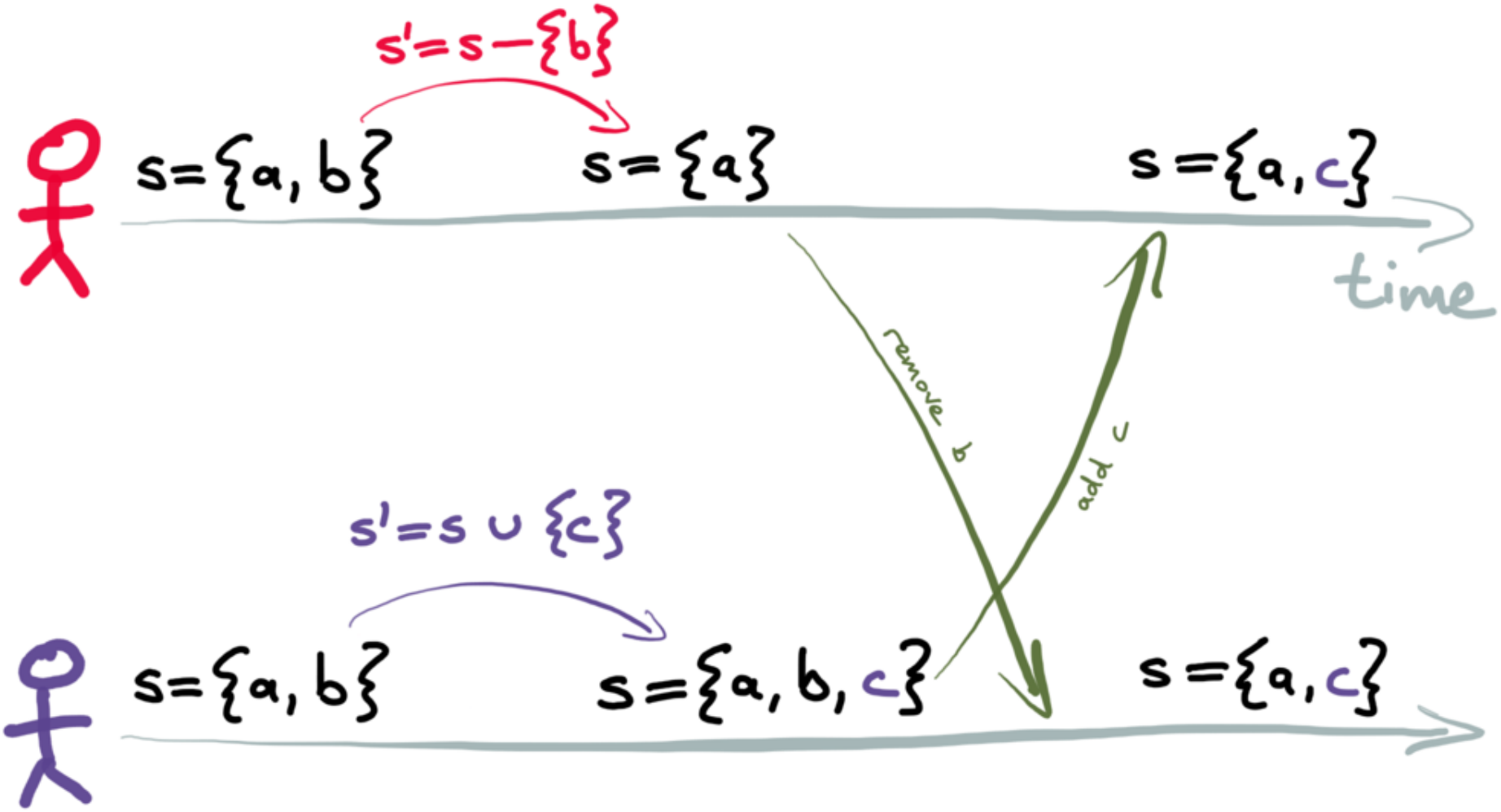

Example : counter

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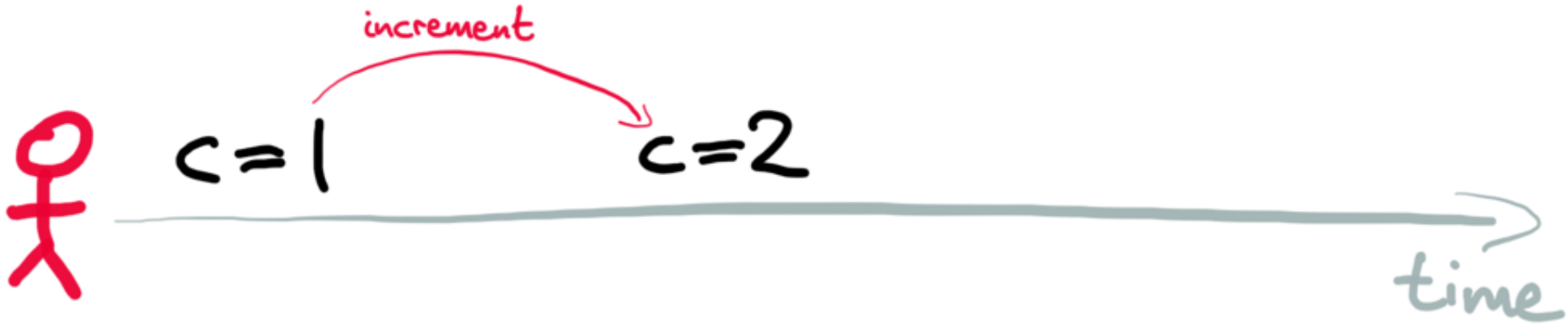

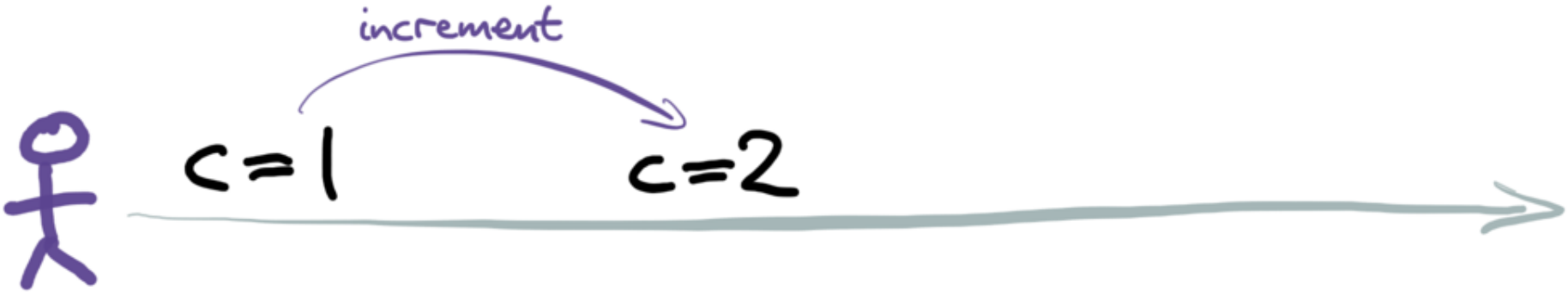

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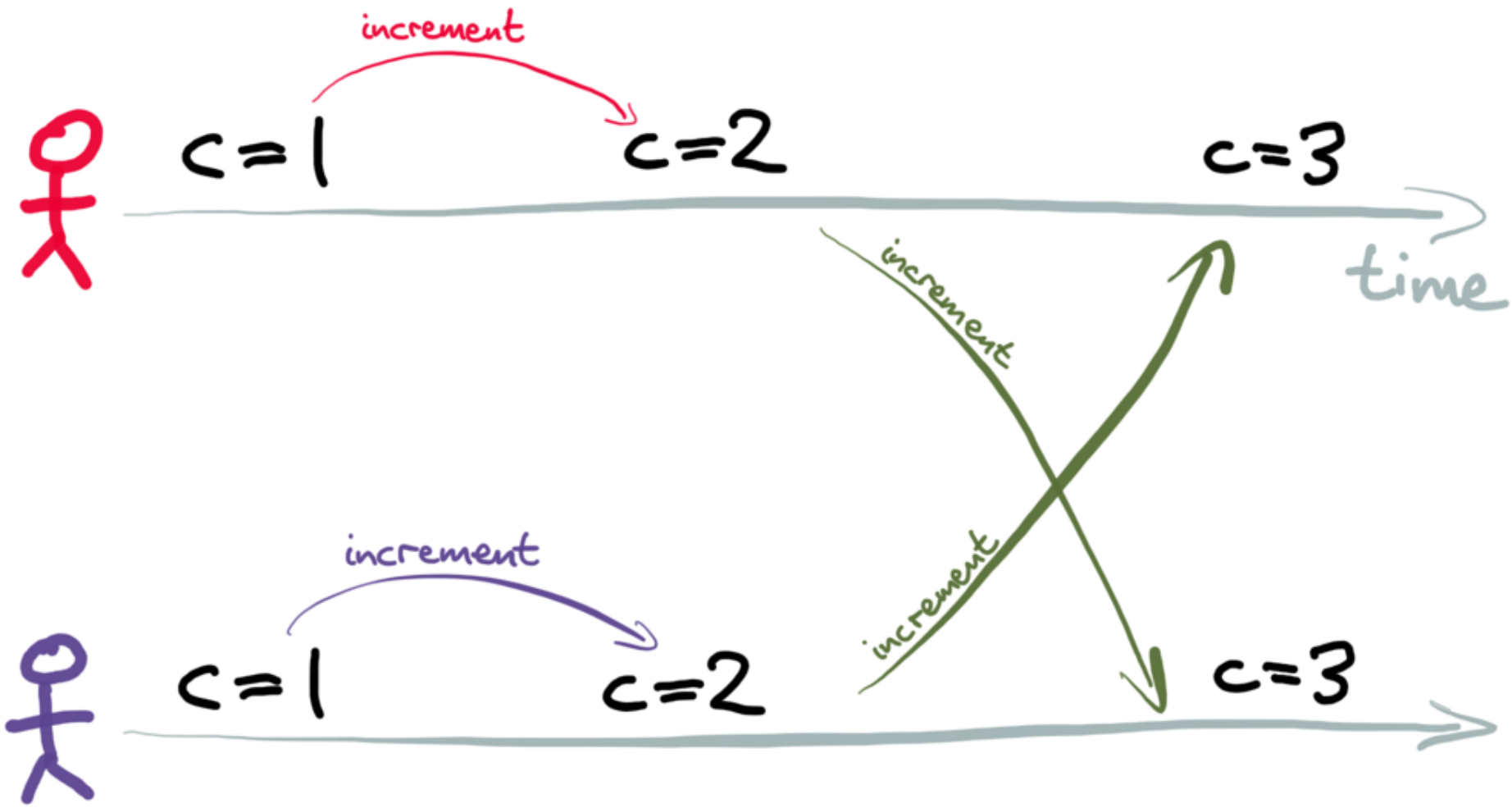

Algorithms for convergence

OPERATIONAL TRANSFORMATION (OT)

- e.g. Google Docs, MS Office Online

1989–2006

CONFLICT-FREE REPLICATED DATA TYPES (CRDTs)

- e.g. Riak, TomTom GPS, Teletype for Atom, ...

2006 – present

FAILURES OF OPERATIONAL TRANSFORM

dOPT
Ellis & Gibbs
1989

adOPTed
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IMOR
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require central server

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Suleiman et al.
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2000

TTF
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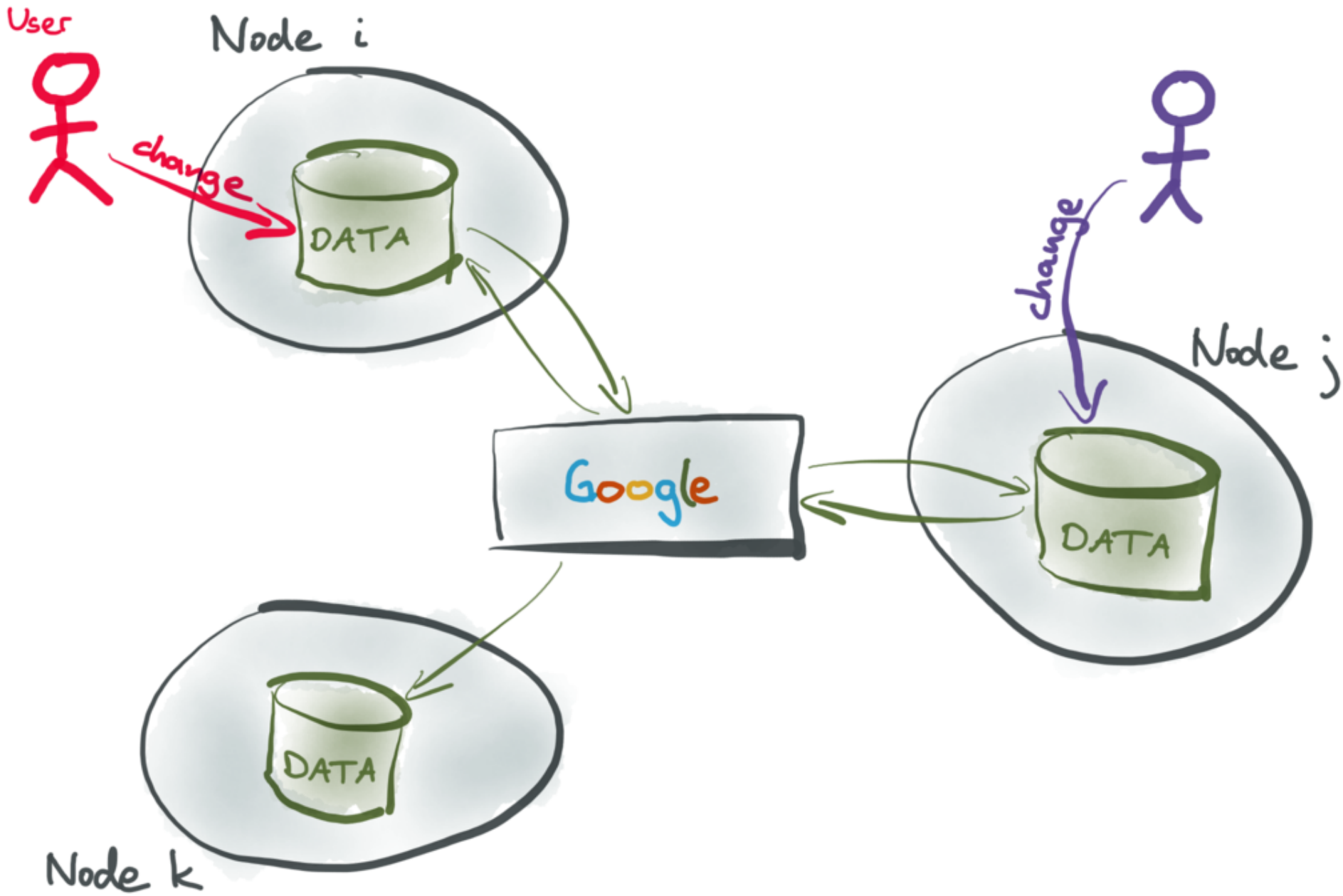
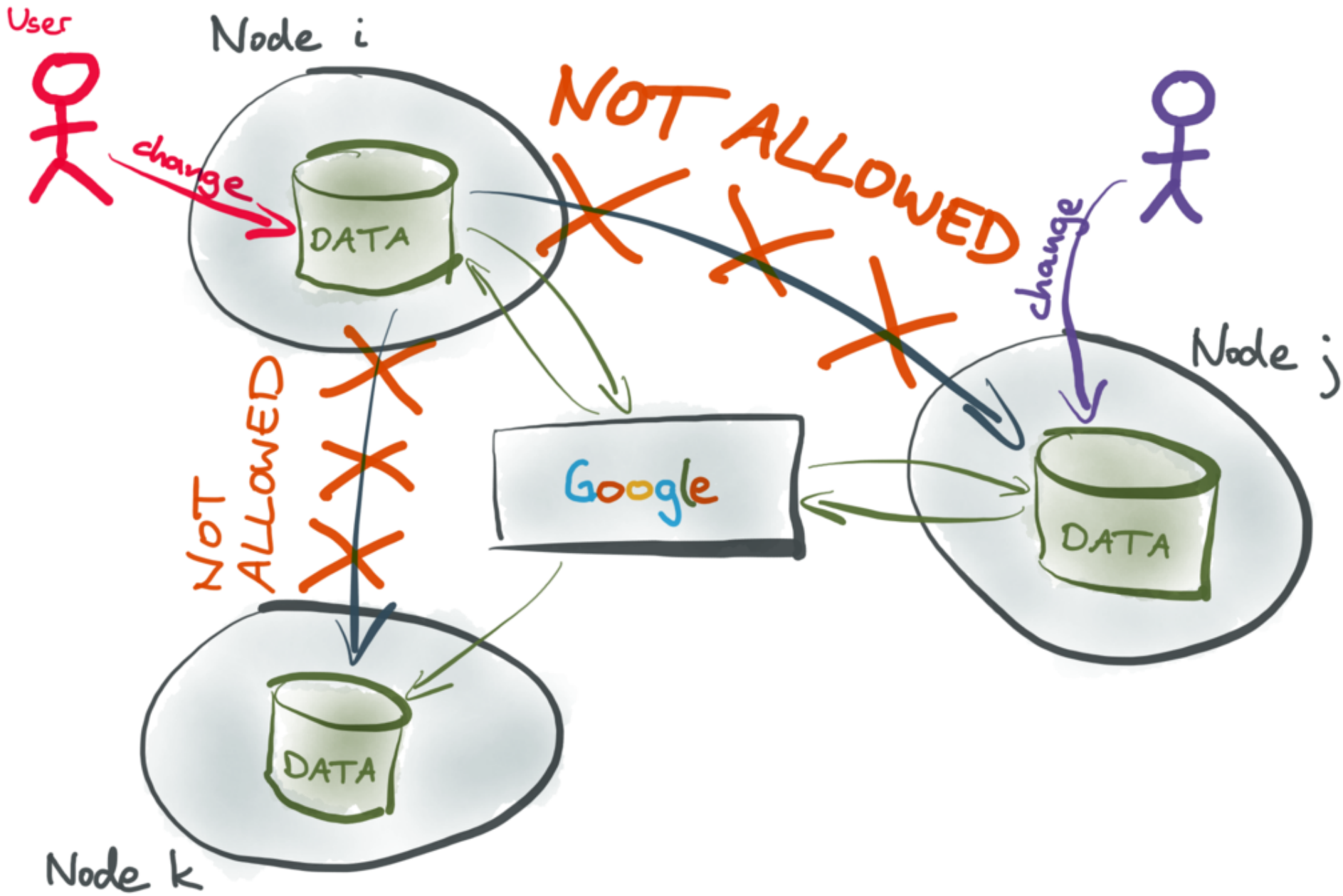
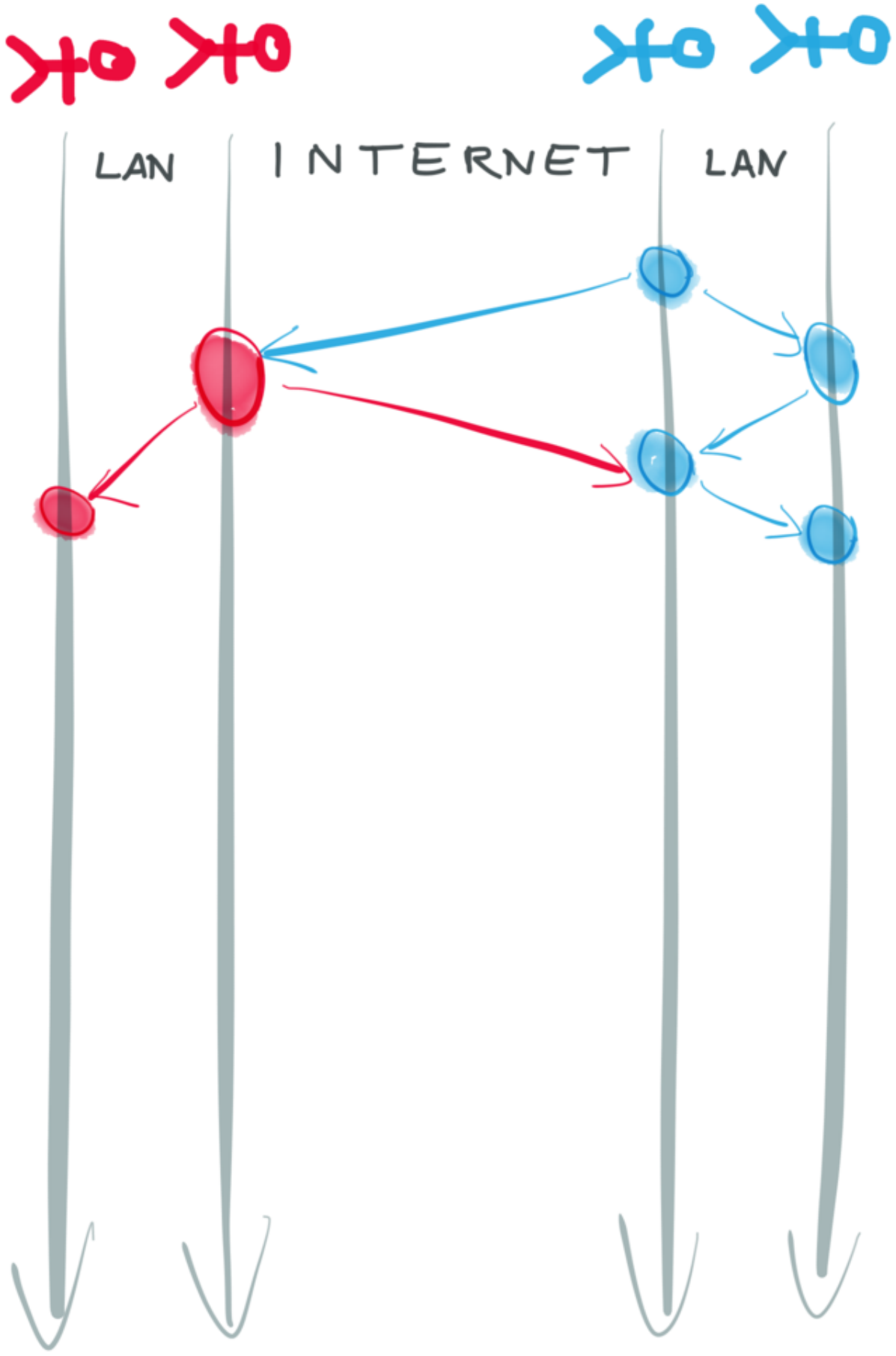
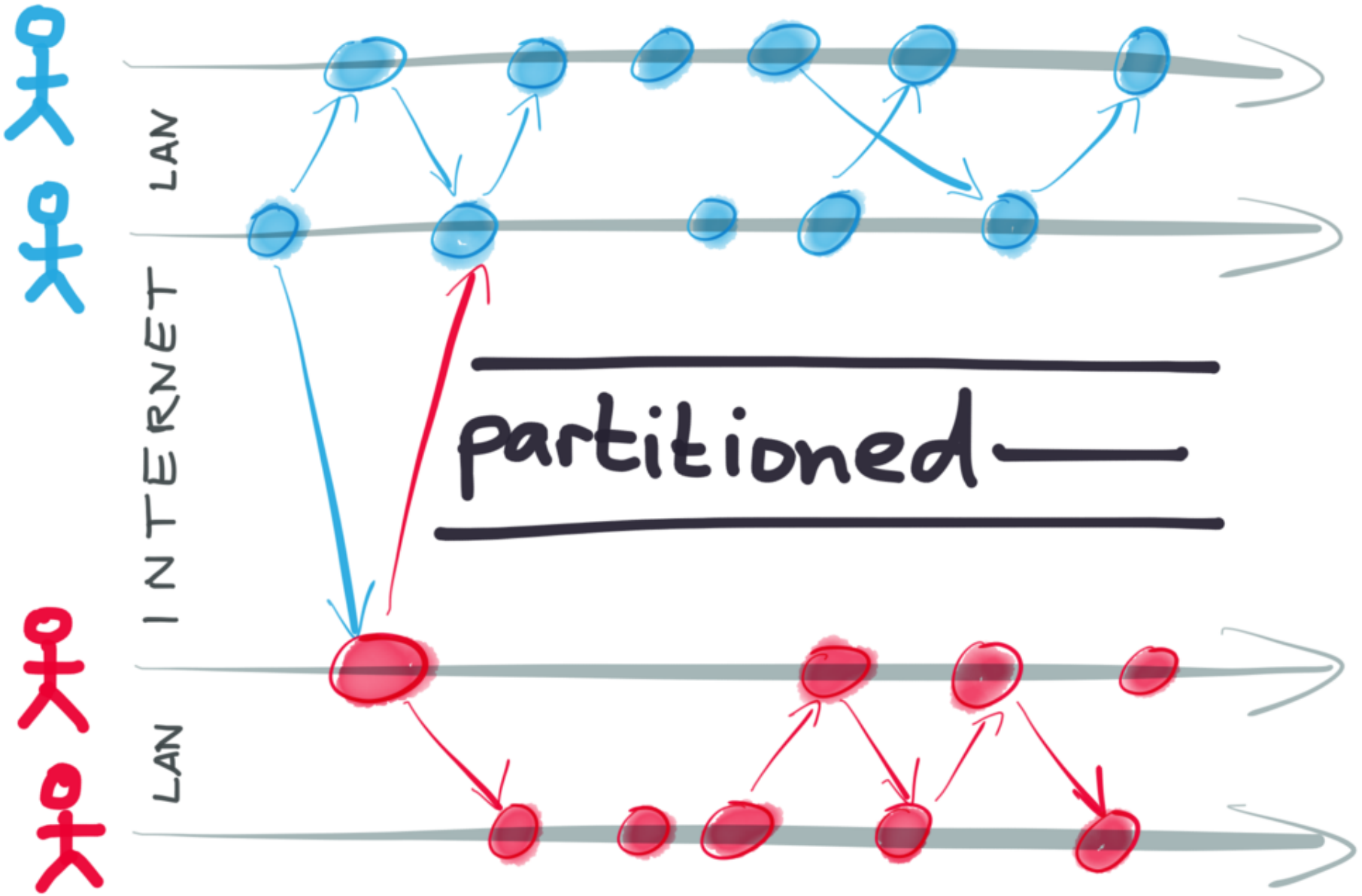
OPERATIONAL TRANSFORMATION IN GOOGLE DOCS.



OPERATIONAL TRANSFORMATION IN GOOGLE DOCS.




LAN
INTERNET
LAN


LAN
INTERNET
partitioned
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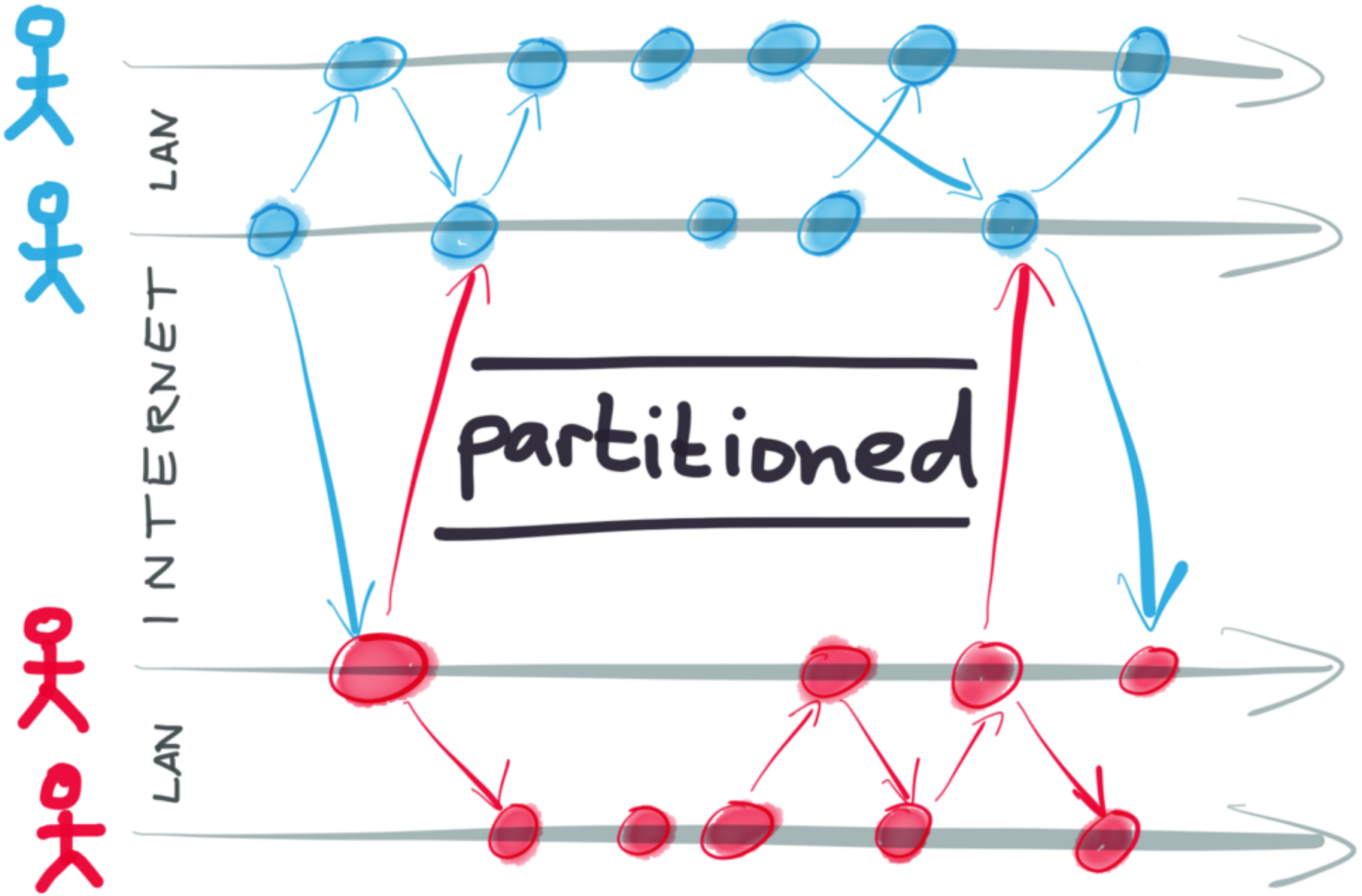
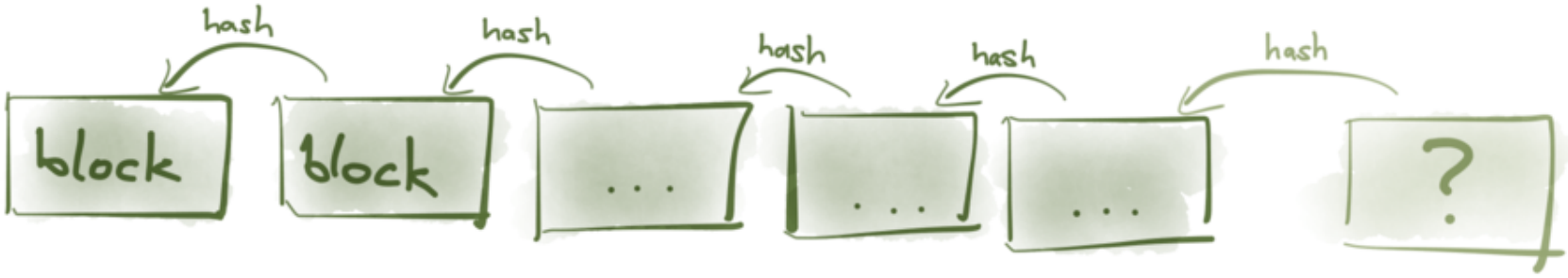

LAN
INTERNET
partitioned
LAN

DECENTRALIZATION = BLOCKCHAINS?



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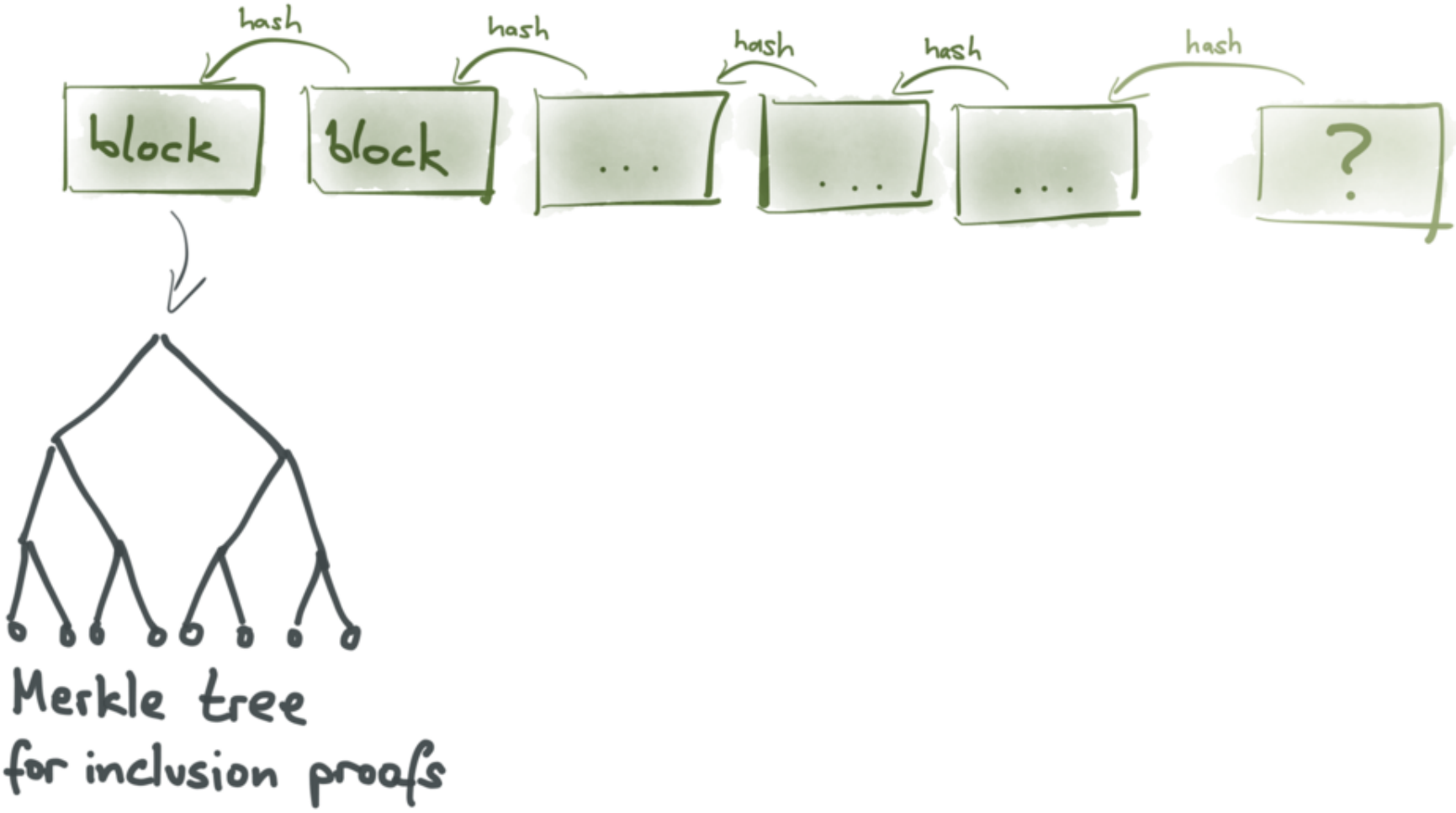

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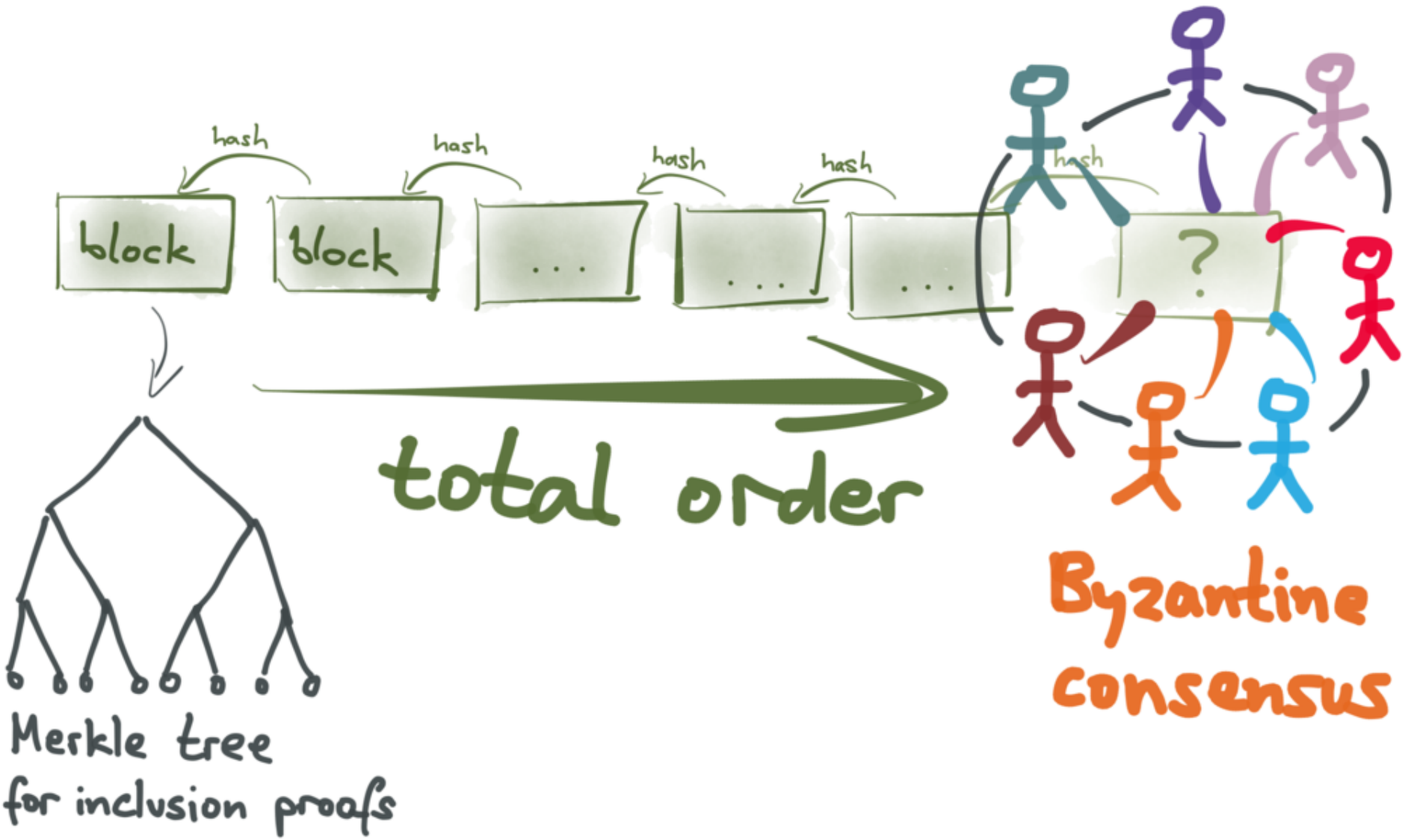

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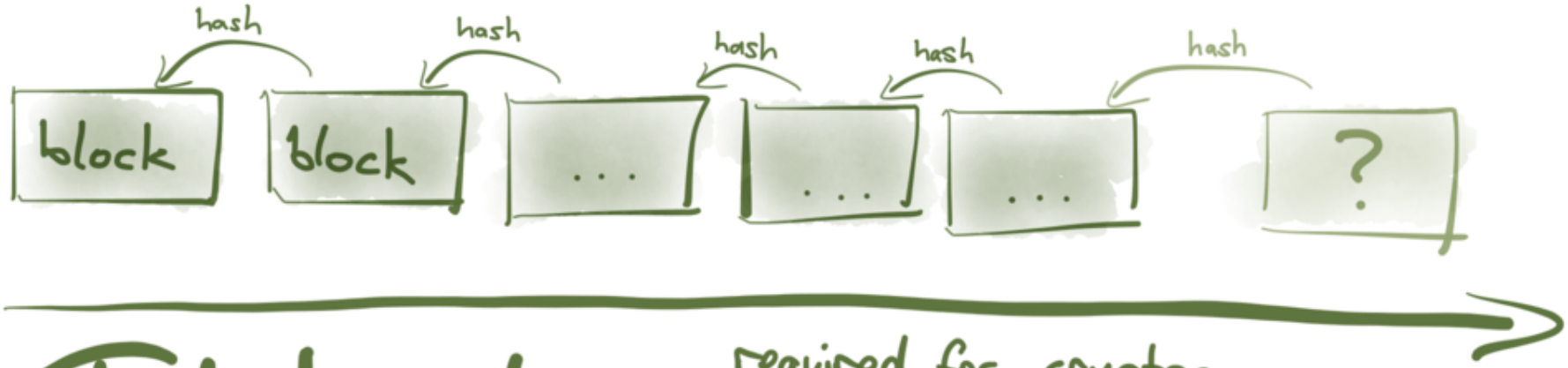
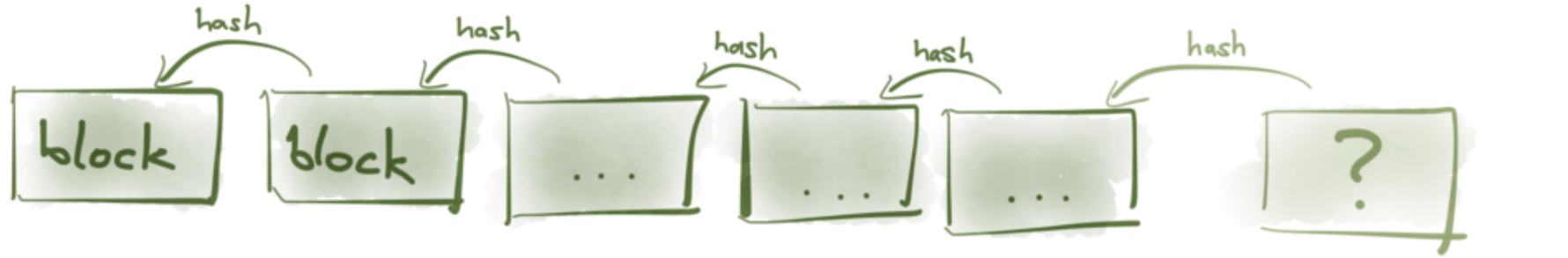


Total order

required for cryptocurrencies
(to prevent double-spending)

DECENTRALIZATION = BLOCKCHAINS?



Total order required for cryptocurrencies (to prevent double-spending)

Consensus = pick one of several proposed values

Collaboration = keep all edits and merge them

Algorithms for convergence

OPERATIONAL TRANSFORMATION (OT)

- e.g. Google Docs, MS Office Online

1989–2006

CONFLICT-FREE REPLICATED DATA TYPES (CRDTs)

- e.g. Riak, TomTom GPS, Teletype for Atom, ...

2006 – present

PROVING CRDTs CORRECT

RGA

OpSet

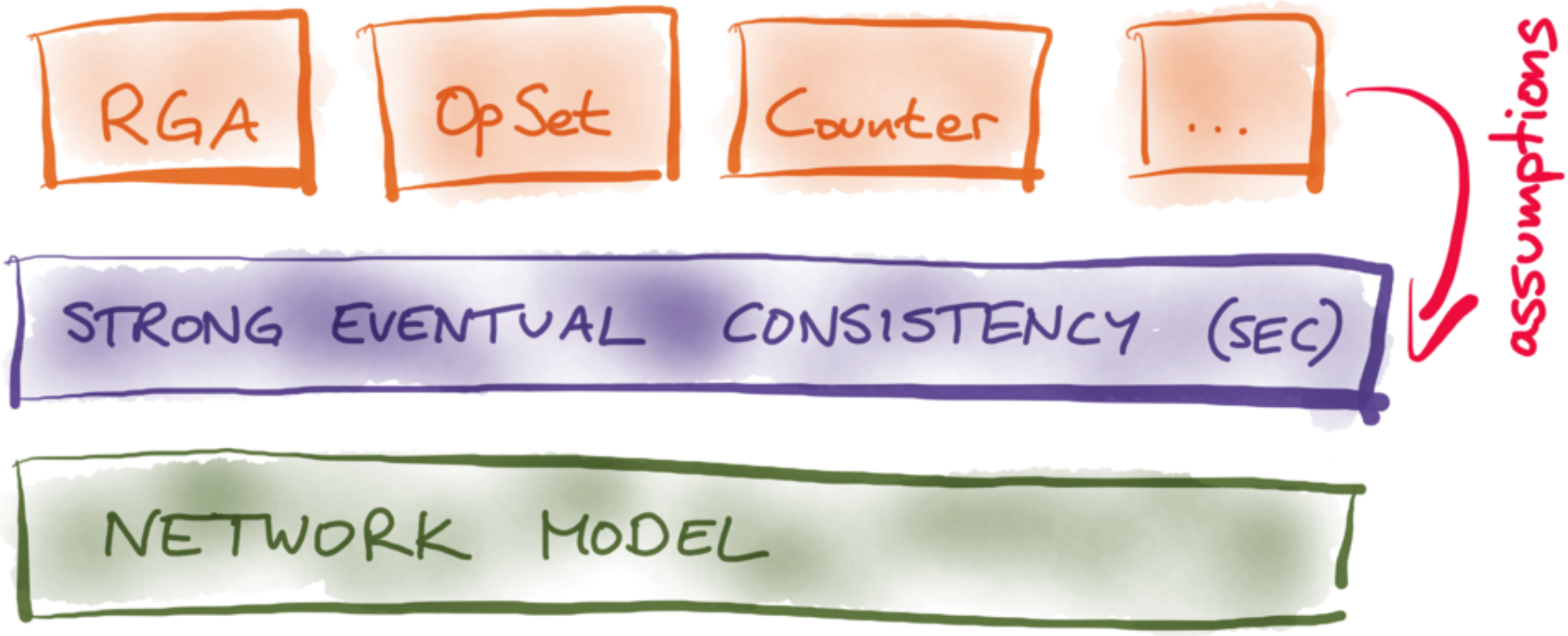
Counter

...

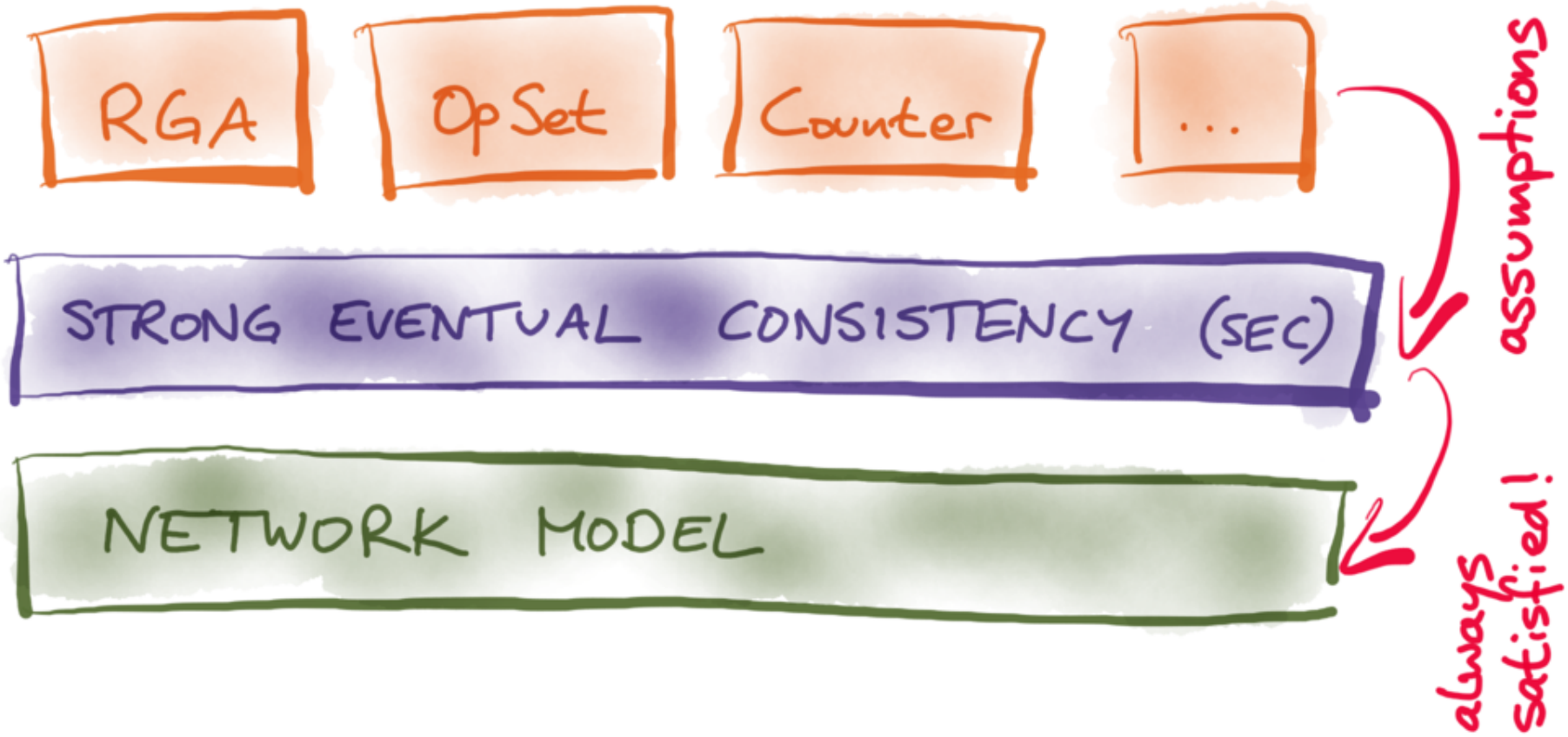
STRONG EVENTUAL CONSISTENCY (SEC)

NETWORK MODEL

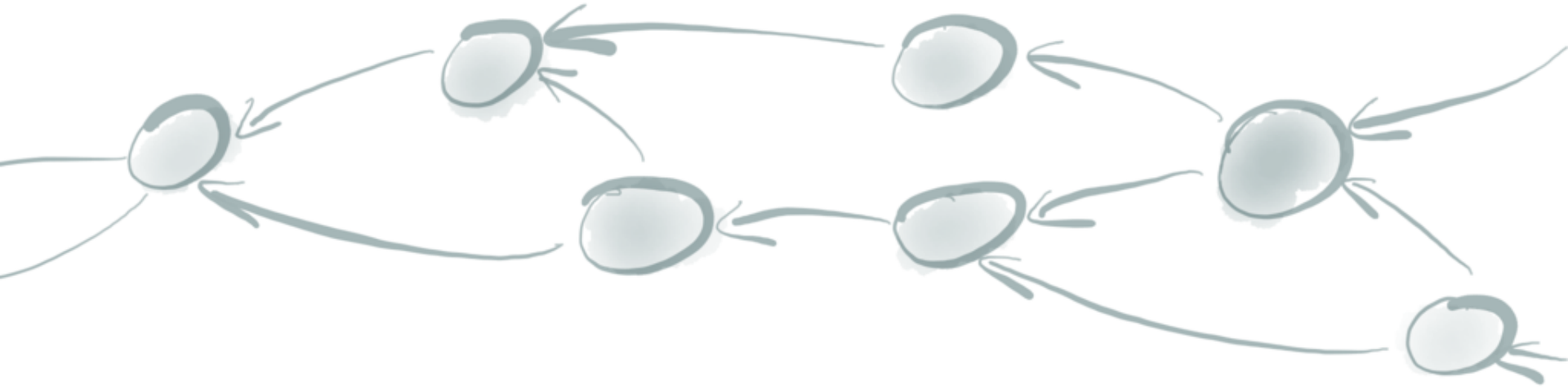
PROVING CRDTs CORRECT



PROVING CRDTs CORRECT



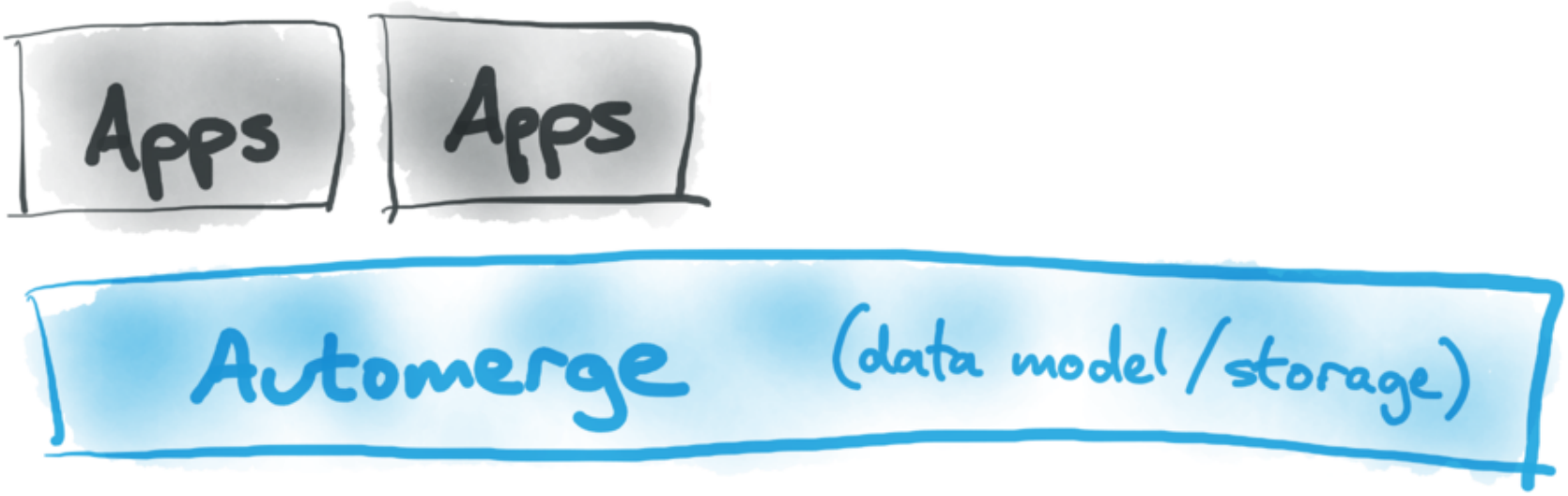
For details, see our paper at https://doi.org/10.1145/3133933
Victor B. F. Gomes, Martin Kleppmann, Dominic P. Mulligan, and Alastair R. Beresford: Verifying Strong Eventual Consistency in Distributed Systems. PACMPL 1(OOPSLA), 2017.



Automerge

https://github.com/automerge/automerge


Automerge
(data model / storage)


Apps
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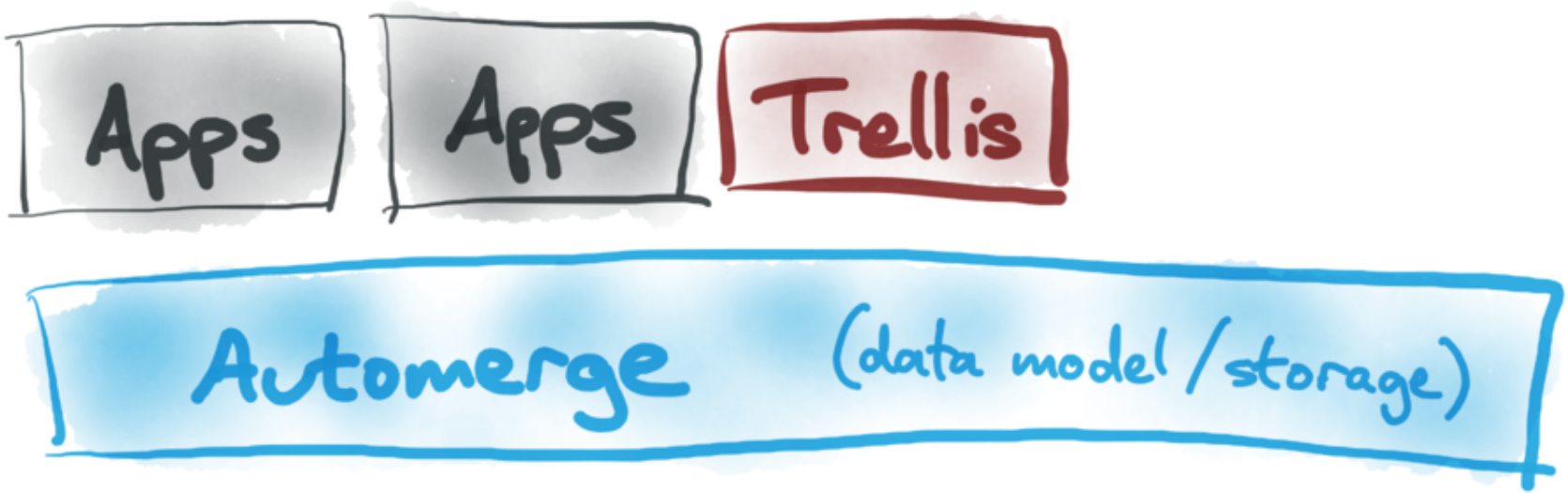


Trellis, a Trello clone based on Automerge: https://github.com/automerge/trellis
Joint work with Orion Henry, Peter van Hardenberg, Roshan Choxi, and Adam Wiggins.

The Avengers Initiative

PROSPECTS

- Spiderman
  - 1
- Doctor Strange
- Star Lord
- Groot

Add a card...

RECRUITING

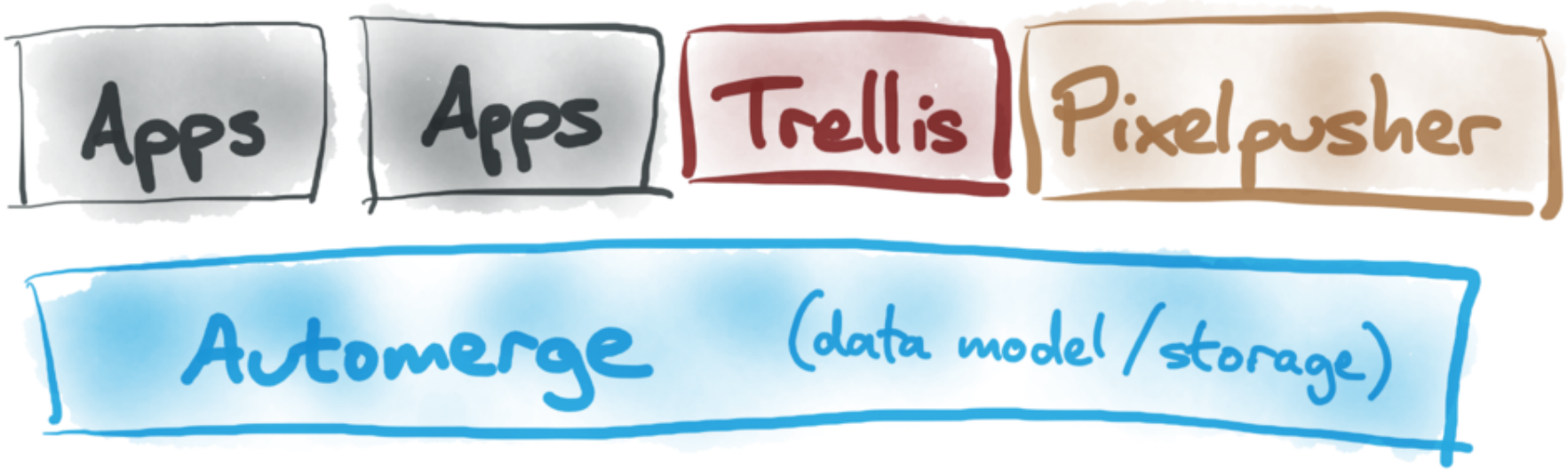
- Iron Man 

Add a card...

JOINED THE TEAM

- Black Widow 
- The Hulk
  - 1 

Add a card...



Pixelpusher, a collaborative pixel art editor: https://github.com/automerge/pixelpusher
Created by Javier Valencia, Jeff Peterson, Peter van Hardenberg, and Jim Pick.

PIXEL ART TO CSS

by JVALEN

Star 324

+ 25 50 75 100

NEW

LOAD SAVE

PREVIEW

RESET

16 + −

16 + −

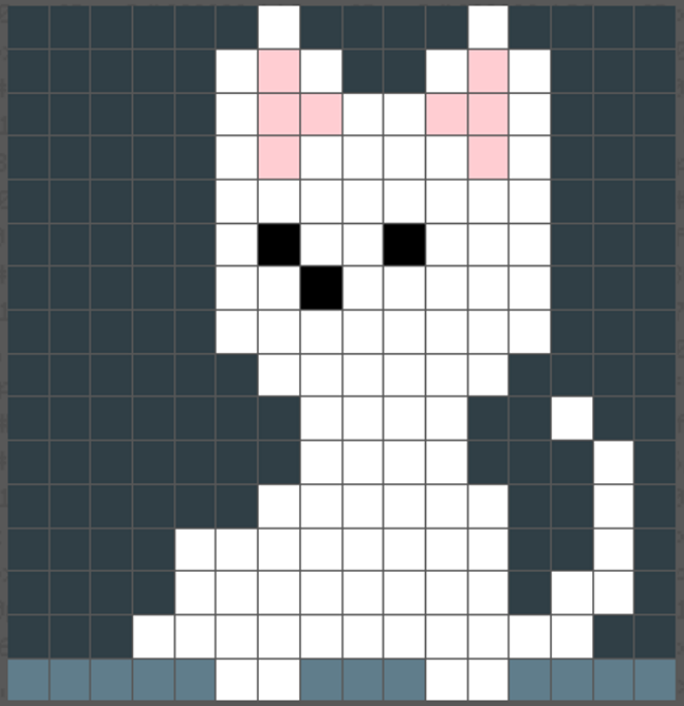
Pixel Size

10

Duration

1

CSS



PIXELPUSHER

pxlpshr://D2Sr5PkQAn7ygXyWcZFC1L9rNnaQNHeGBZgQbZqVw

Projects

Preview

Reset

Pixel Size

10

Duration

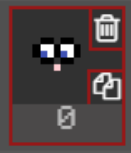
1

16 + −

16 + −

Import Image

Eyeballs

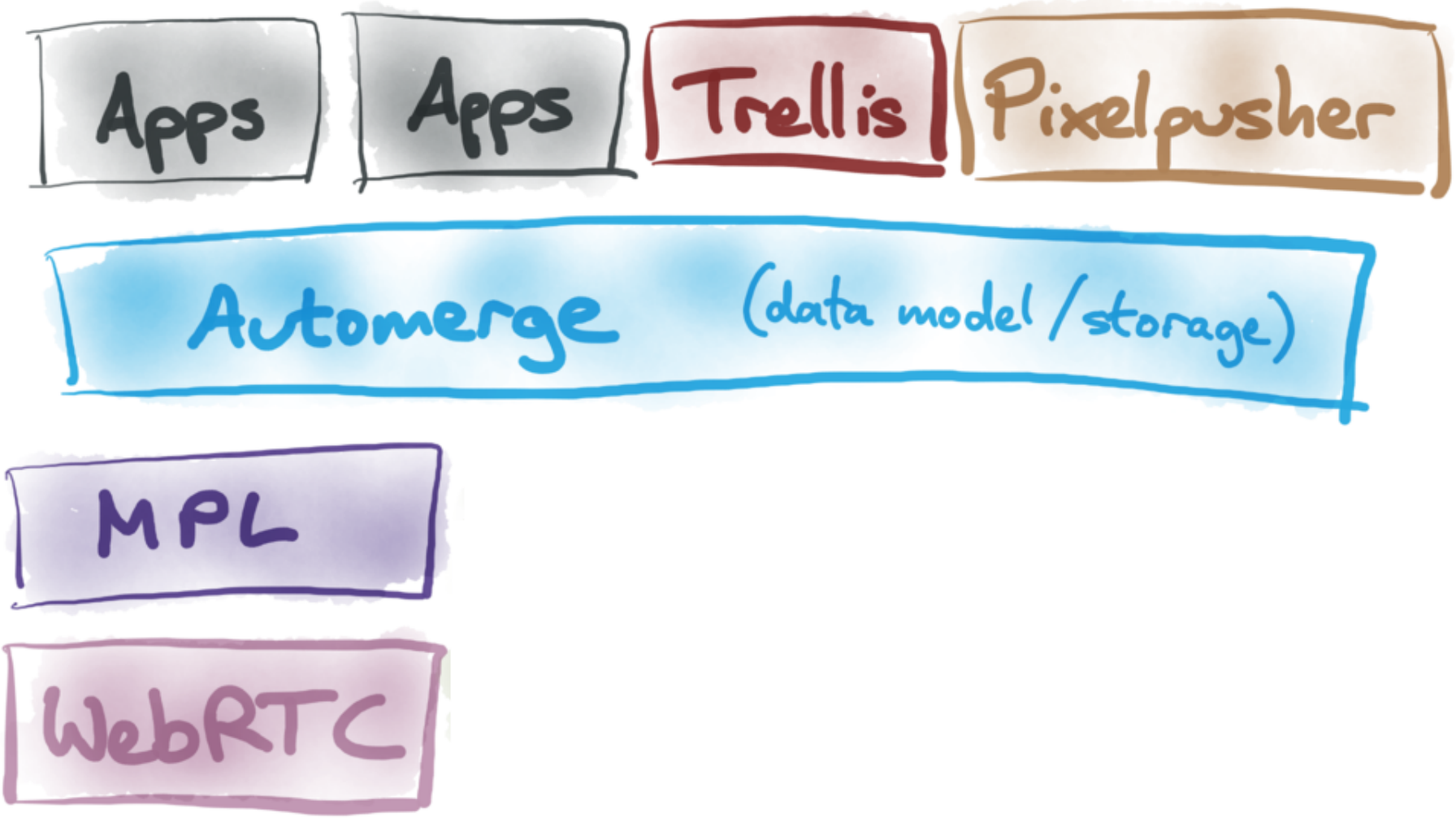


0

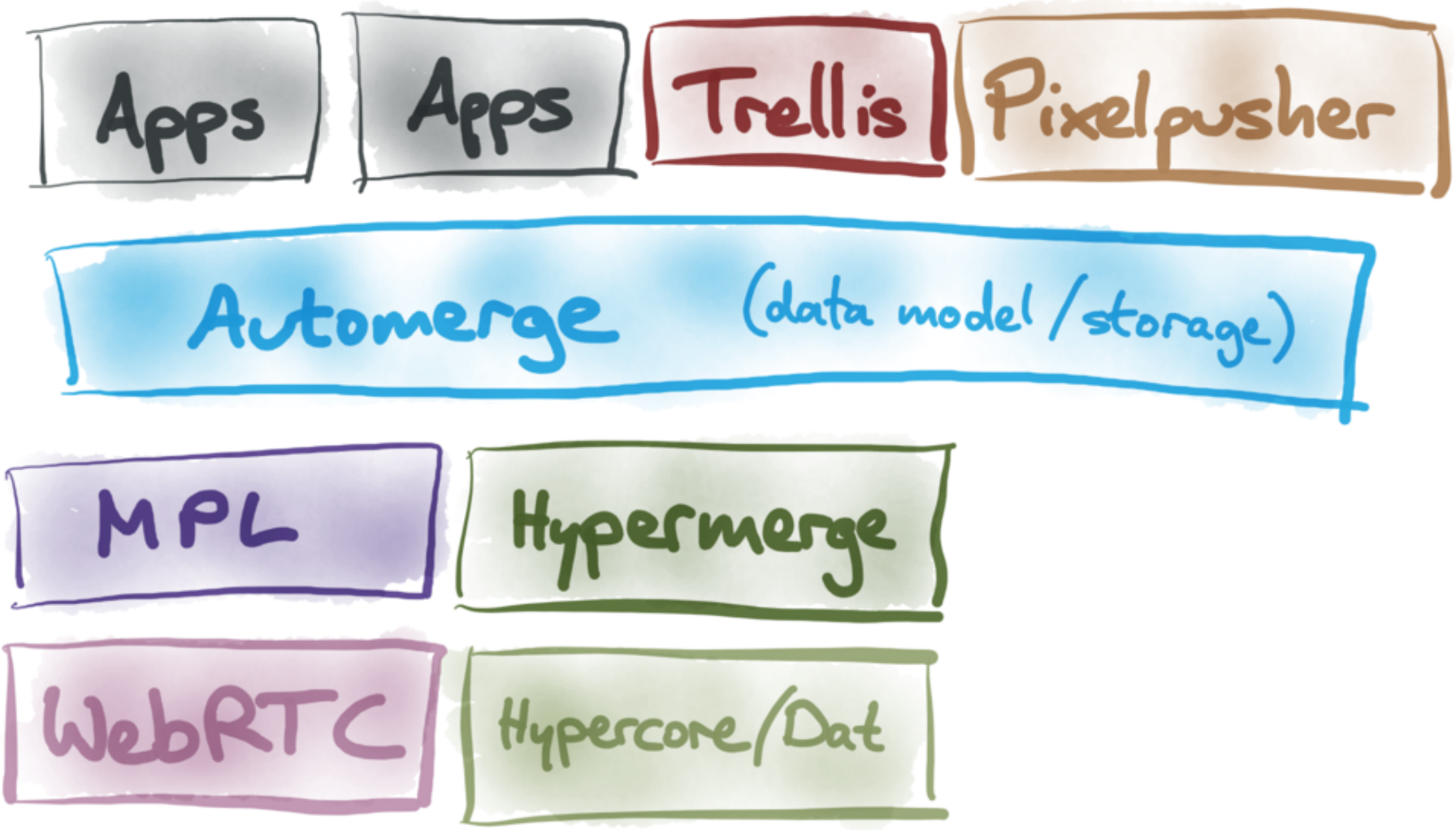
+

Versions

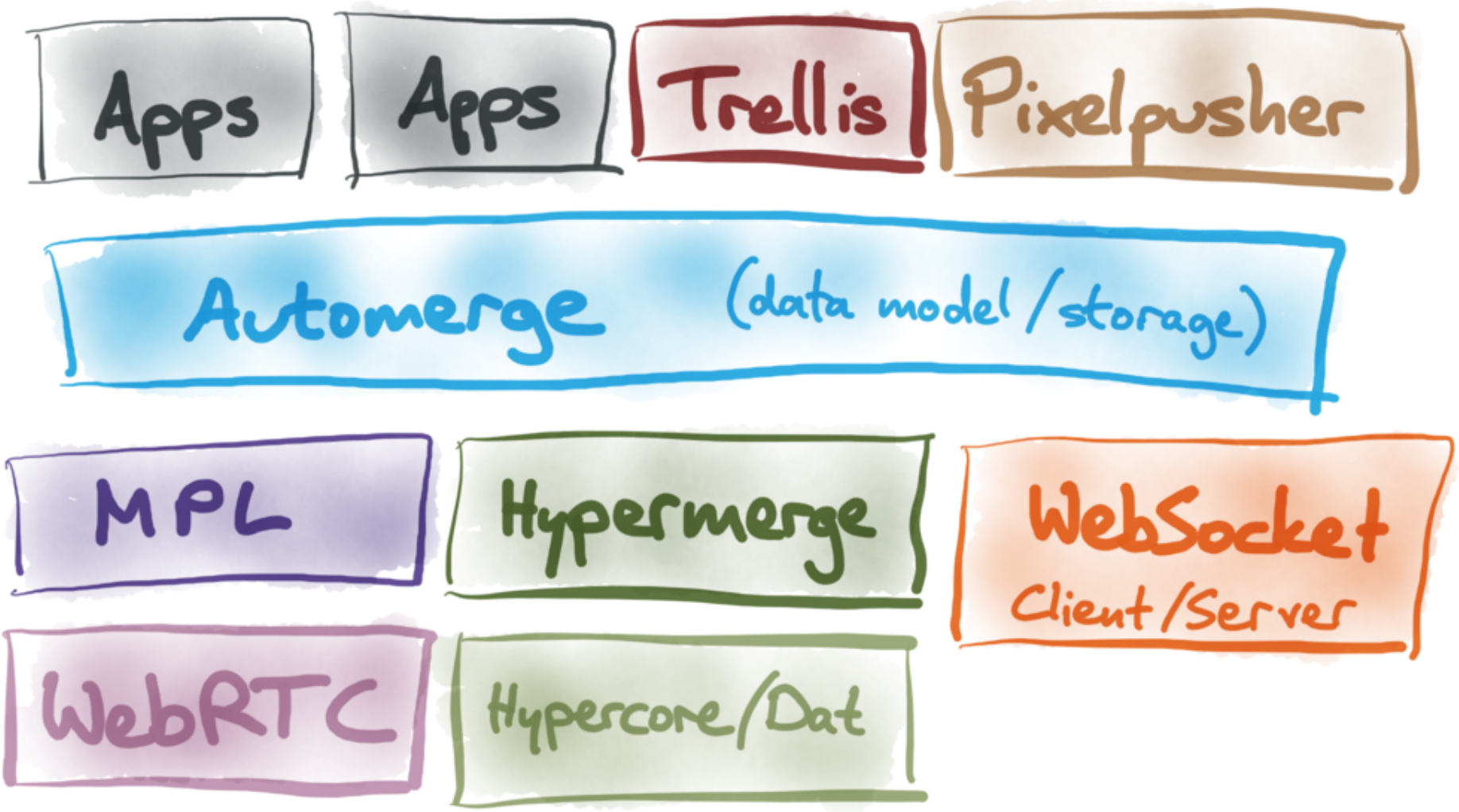
Archivers +



MPL, a WebRTC network layer for Automerge: https://github.com/automerge/mpl
Joint work with Orion Henry, Peter van Hardenberg, Roshan Choxi, and Adam Wiggins.



Hypermerge, a peer-to-peer network layer: https://github.com/automerge/hypermerge
Created by Jim Pick, Jeff Peterson, and Peter van Hardenberg.


Apps
Apps
Trellis
Pixelpusher
Automerge
(data model / storage)
MPL
Hypermerge
WebSocket
Client / Server
WebRTC
Hypercore / Dat

APPLICATION DATA (JSON)

```
{ "to-do": [
    { "title": "buy milk",
      "done": false },
    { "title": "water plants",
      "done": false }
  ],
  "settings": {"alert-sound": "ring", ...}
}
```

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ordered list

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ordered list

nested maps

EDITING OPERATIONS

```
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  ],
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}
```
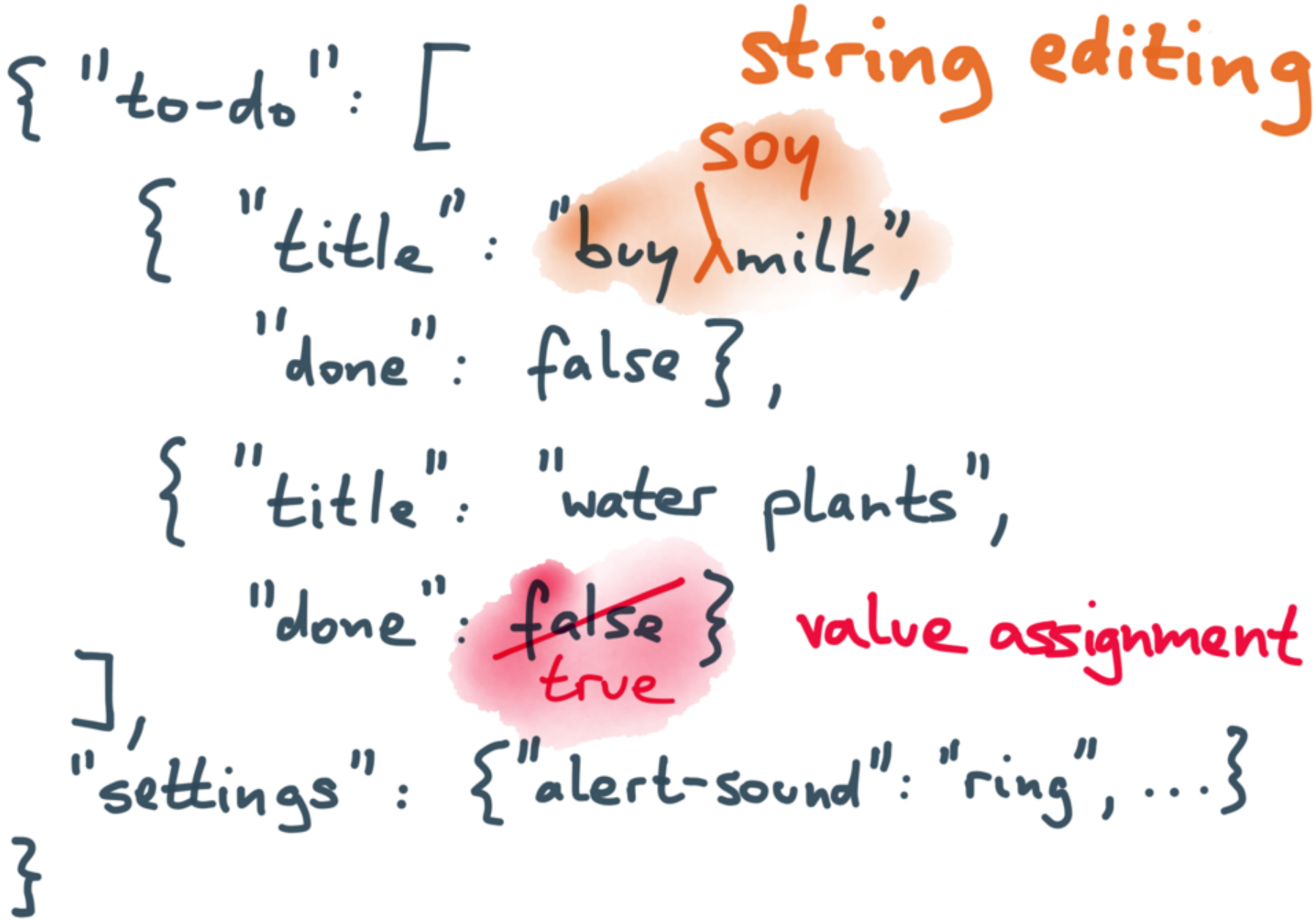
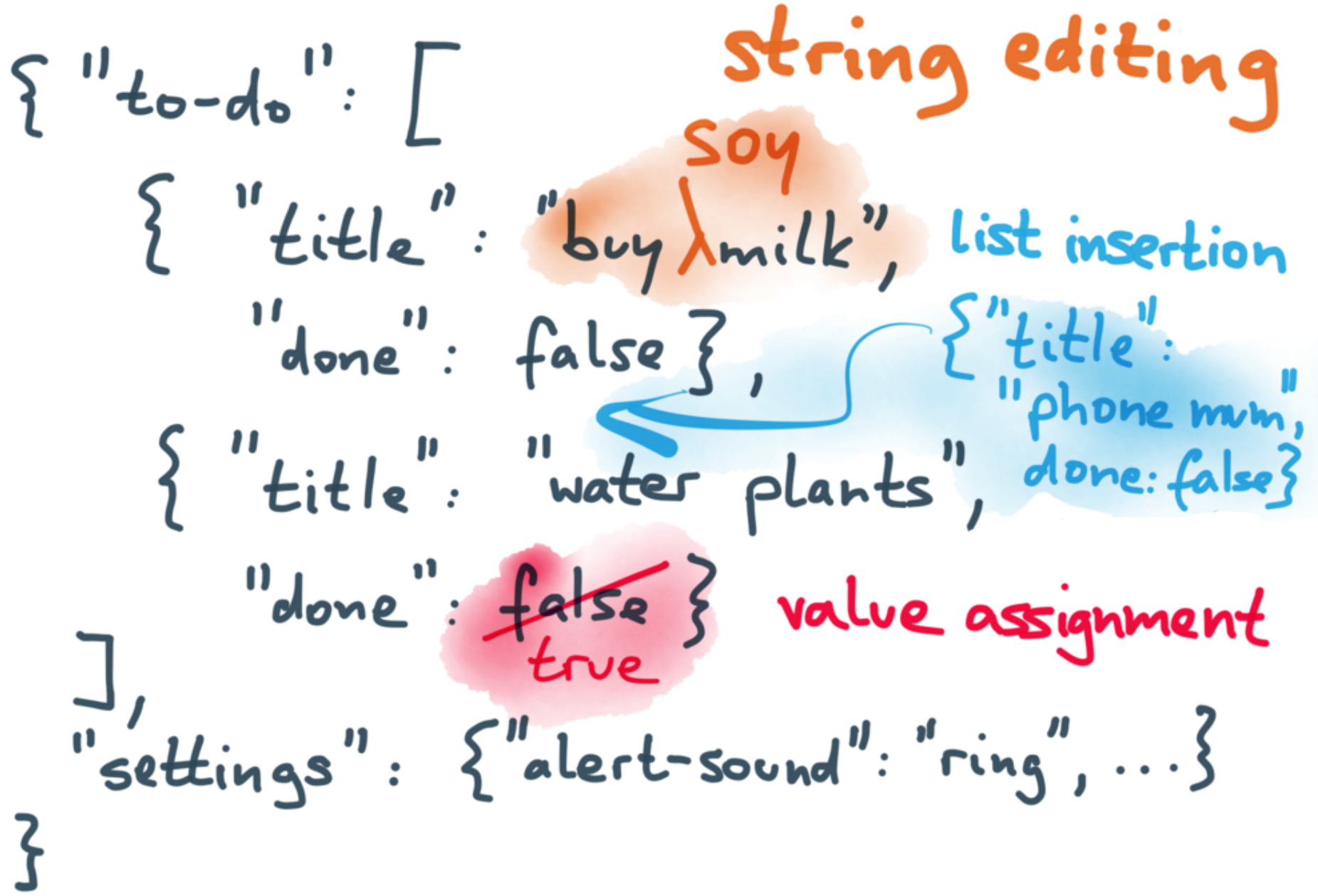

true

value assignment

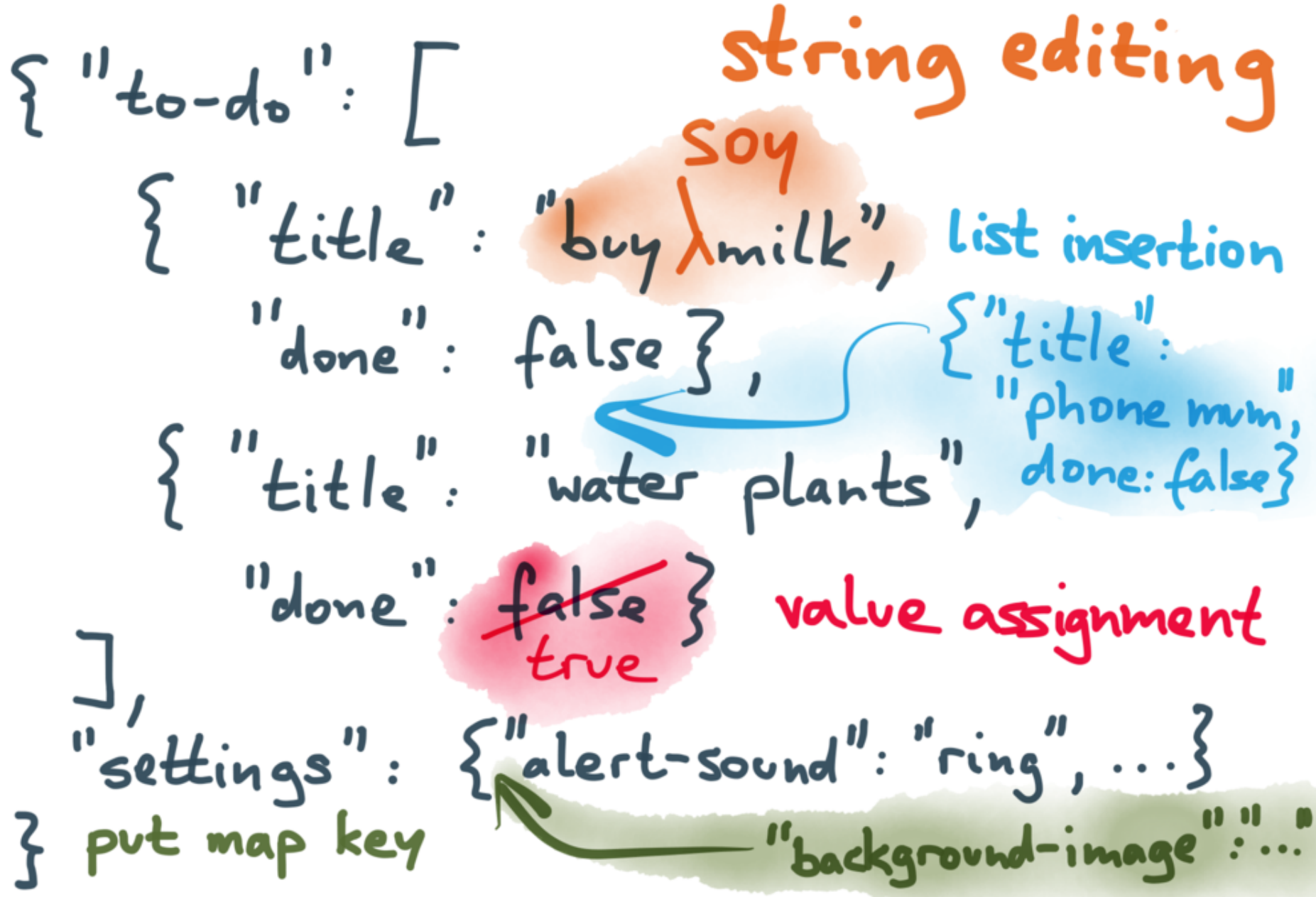
EDITING OPERATIONS



EDITING OPERATIONS



EDITING OPERATIONS



```
state = Automerge.change(state, "Add todo item",
  (doc) => {
    doc.todos.push({
      title: "Buy milk",
      done: false
    })
  })
```

state is immutable
(Automerge.change() returns
new object)

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"Commit message" (optional)

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      title: "Buy milk",
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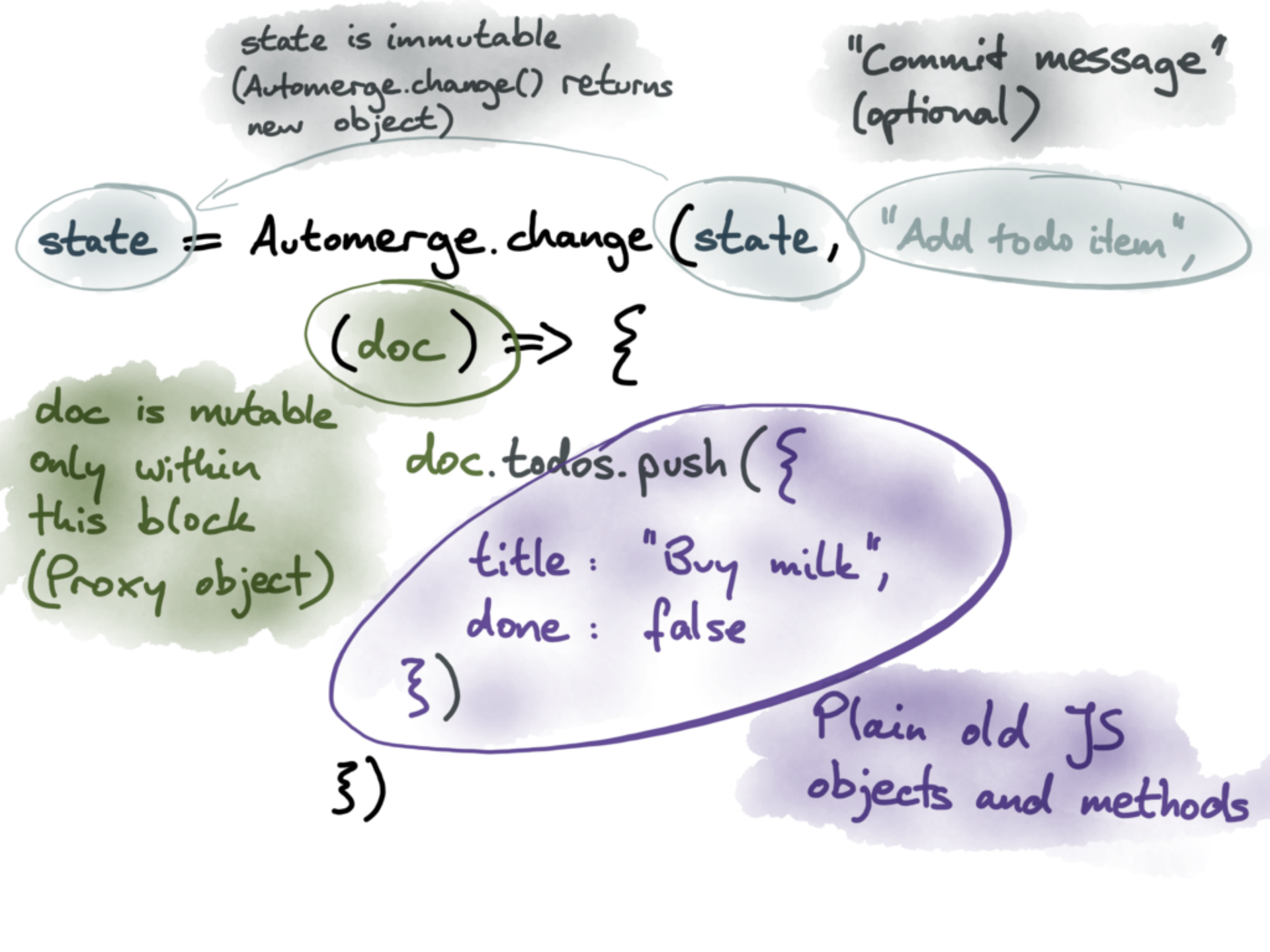
    })
  })
```

doc is mutable
only within
this block
(Proxy object)


state is immutable
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new object)
"Commit message"
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(doc) => {
doc is mutable
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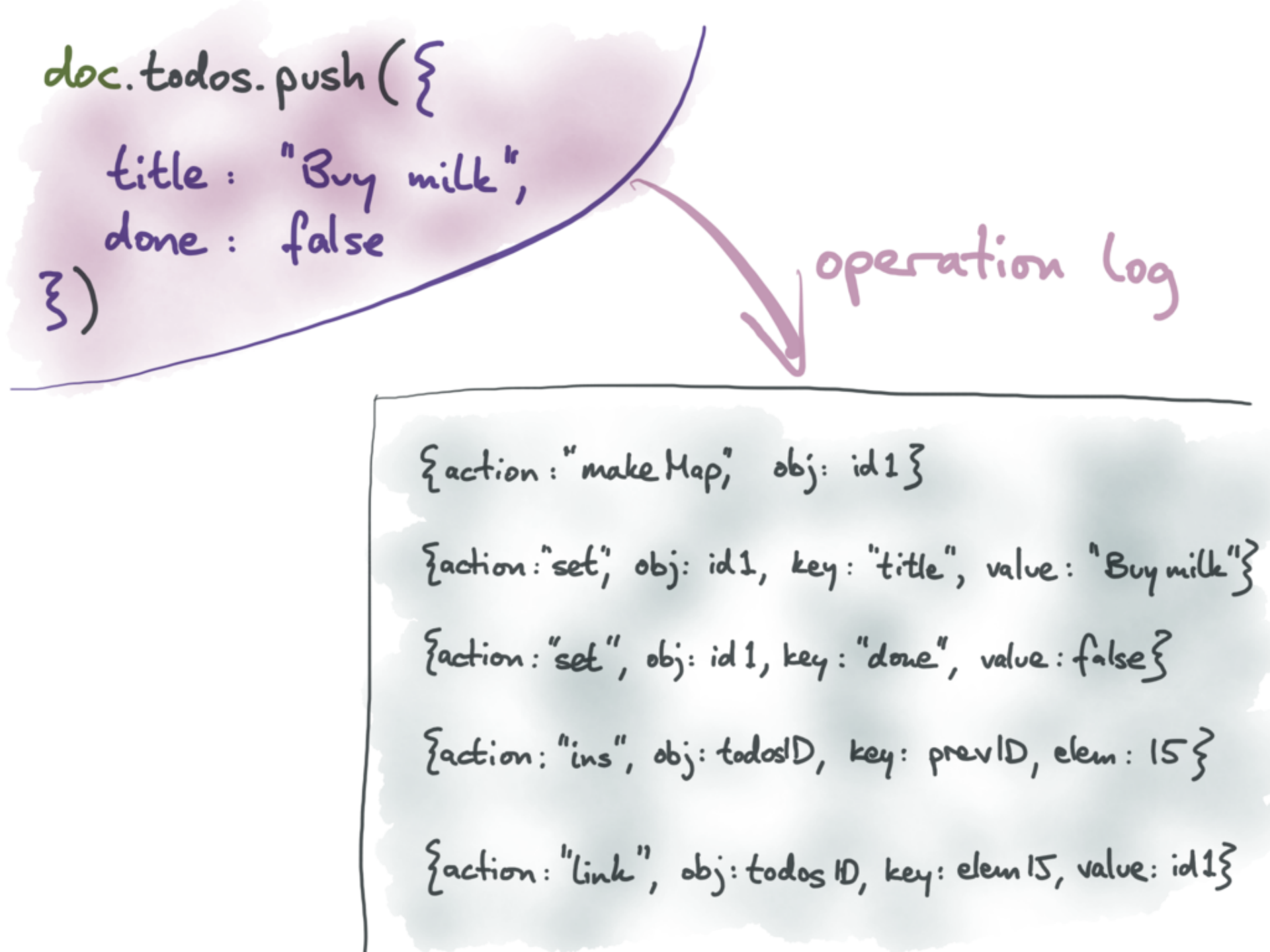
this block
(Proxy object)
doc.todos.push({
title: "Buy milk",
done: false
})
})
Plain old JS
objects and methods


doc.todos.push({
title: "Buy milk",
done: false
})
operation log
{action: "makeMap", obj: id1}
{action: "set", obj: id1, key: "title", value: "Buy milk"}
{action: "set", obj: id1, key: "done", value: false}
{action: "ins", obj: todosID, key: prevID, elem: 15}
{action: "link", obj: todos ID, key: elem 15, value: id1}

TIME TRAVEL

```
Automerge.getHistory(state)
```

TIME TRAVEL

```
Automerge.getHistory(state)

⟹ [ {change: {message: "Add todo item", ...},
      snapshot: {todos: [{title: "Buy milk", ...}, ...]}},

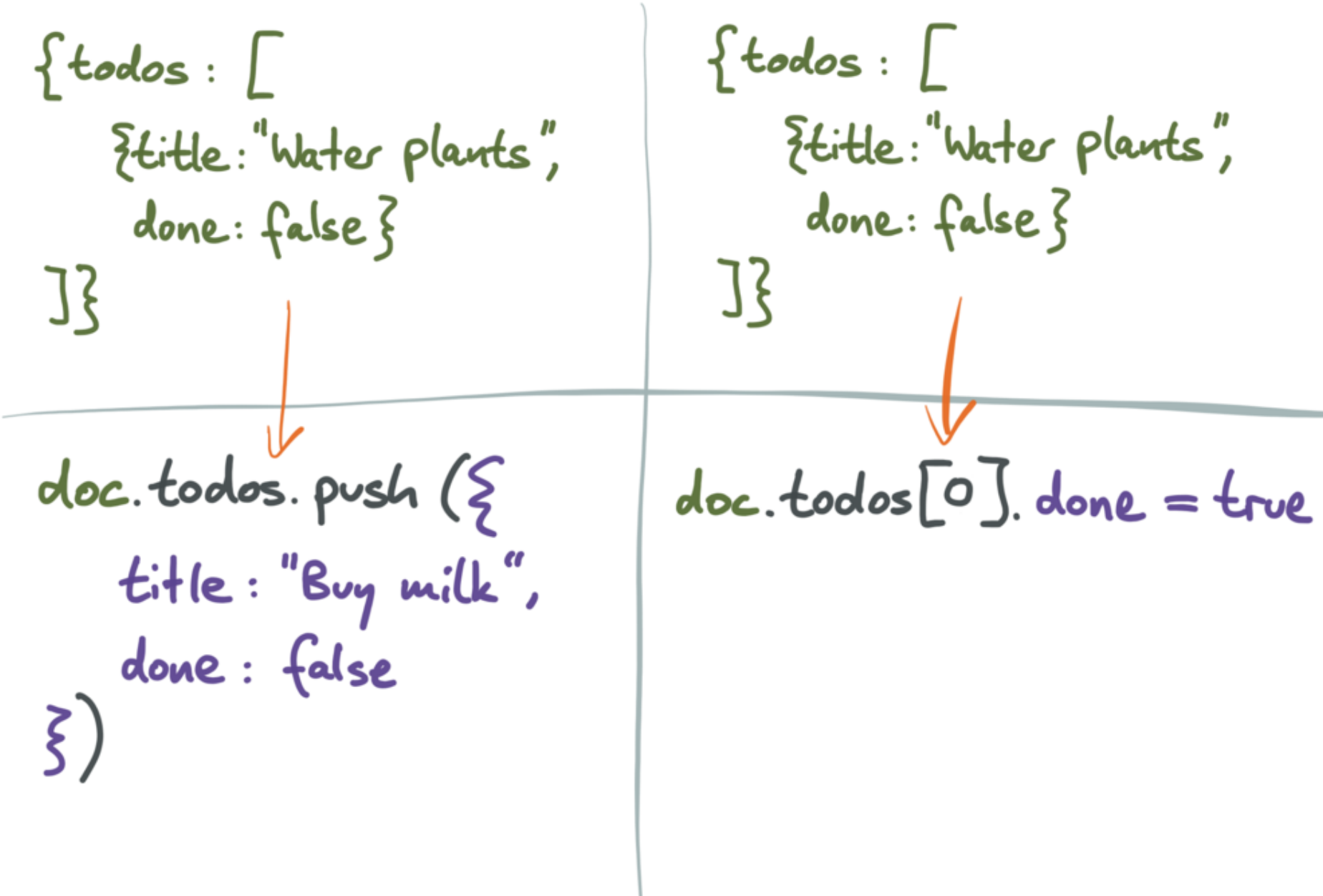
    {change: {message: "Mark item as done", ...},
     snapshot: {todos: [{title: "Buy milk", ...}, ...]}},
    ...
  ]
```

CONCURRENT CHANGES

```
{todos : [
    {title:"Water plants",
     done: false}
]}
```

```
{todos : [
    {title:"Water plants",
     done: false}
]}
```

CONCURRENT CHANGES



CONCURRENT CHANGES

```
doc.todos.push({
    title: "Buy milk",
    done: false
})
```

```
doc.todos[0].done = true
```

CONCURRENT CHANGES

```
doc.todos.push({
    title: "Buy milk",
    done: false
})
```

```
doc.todos[0].done = true
```

```
{todos: [
    {title: "Water plants",
     done: false},
    {title: "Buy milk",
     done: false}
]}
```

```
{todos: [
    {title: "Water plants",
     done: true}
]}
```

CONCURRENT CHANGES

```
doc.todos.push({
    title: "Buy milk",
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})
```

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doc.todos[0].done = true
```


```
{todos: [
    {title: "Water plants",
     done: true},
    {title: "Buy milk",
     done: false}
]}
```

```
{todos: [
    {title: "Water plants",
     done: true},
    {title: "Buy milk",
     done: false}
]}
```

Convergence guarantee:

Any two nodes have seen the same set of operations (but maybe in a different order!)

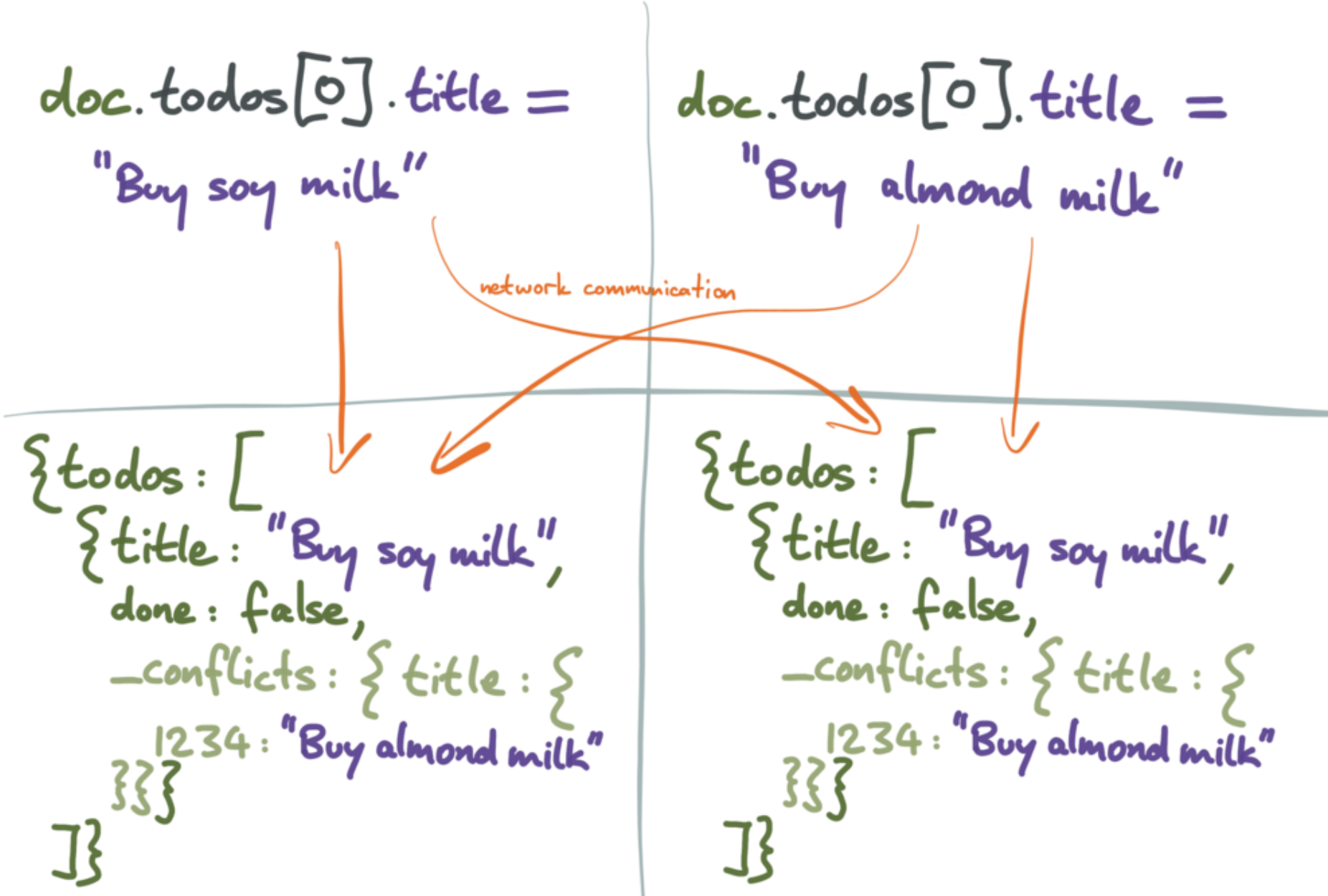
They are in the same state

CONCURRENT CHANGES

```
doc.todos[0].title =
  "Buy soy milk"
```

```
doc.todos[0].title =
  "Buy almond milk"
```

CONCURRENT CHANGES

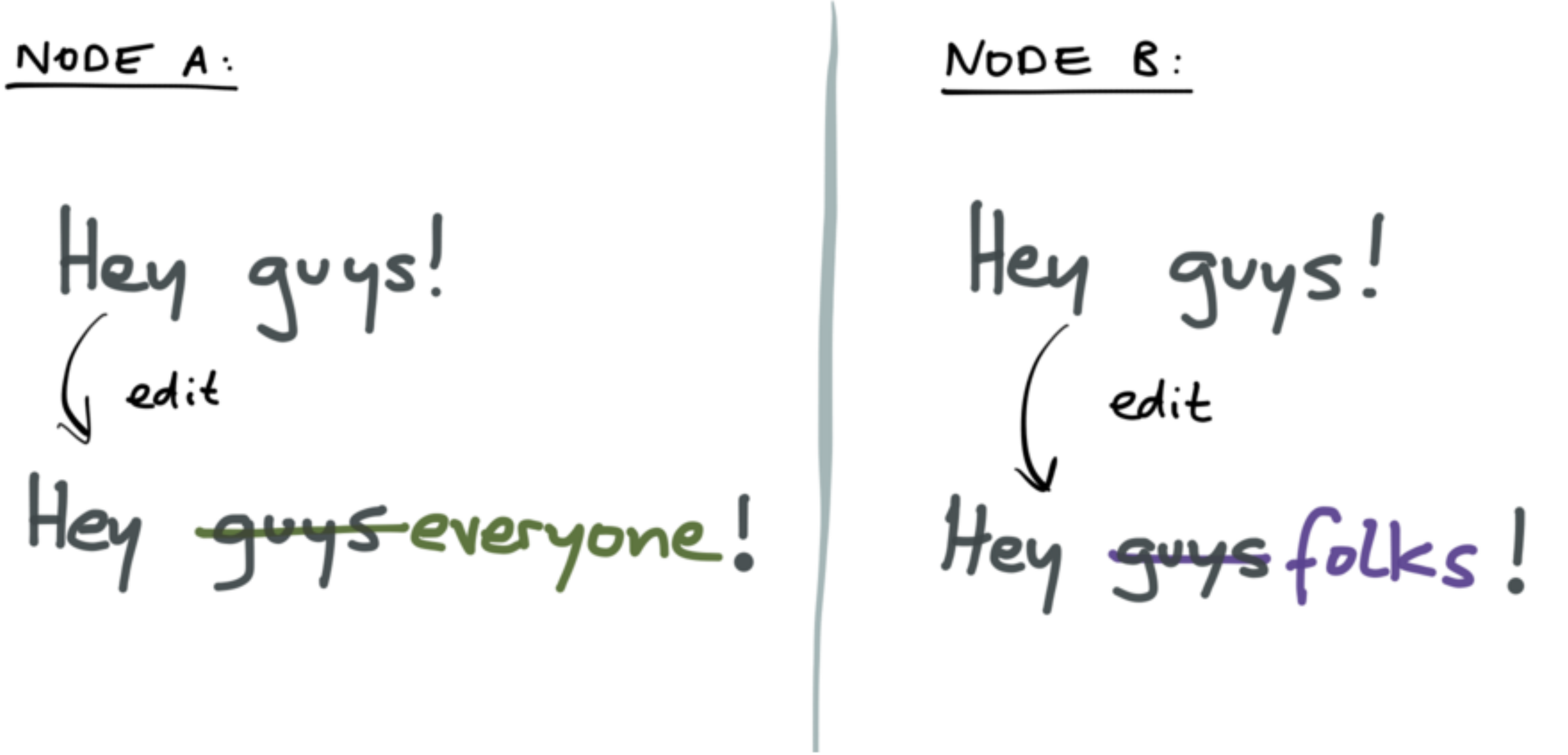


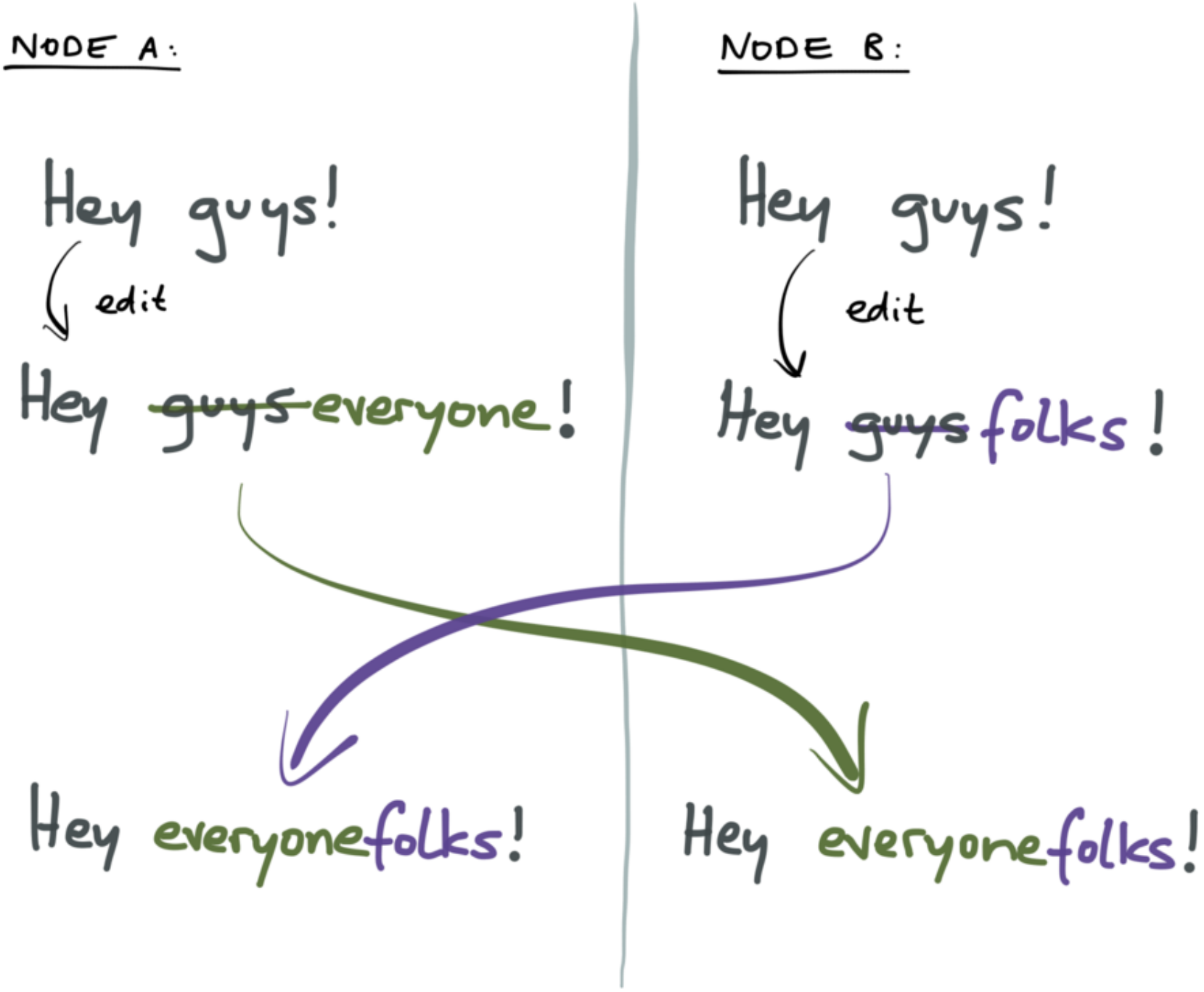
NODE A:

Hey guys!

NODE B:

Hey guys!


NODE A:
Hey guys!
edit
Hey ~~guys~~ everyone!
NODE B:
Hey guys!
edit
Hey ~~guys~~ folks!


NODE A:
Hey guys!
edit
Hey ~~guys~~ everyone!
Hey everyonefolks!
NODE B:
Hey guys!
edit
Hey ~~guys~~ folks!
Hey everyonefolks!

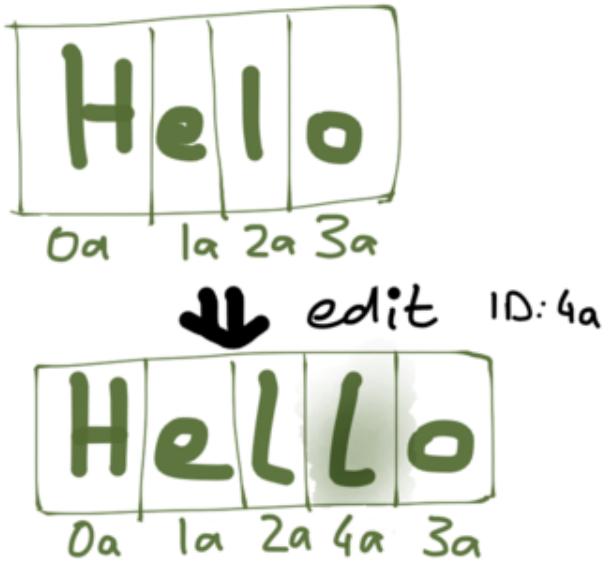
ORDERED LIST CRDT (NUTSHELL)

NODE A:

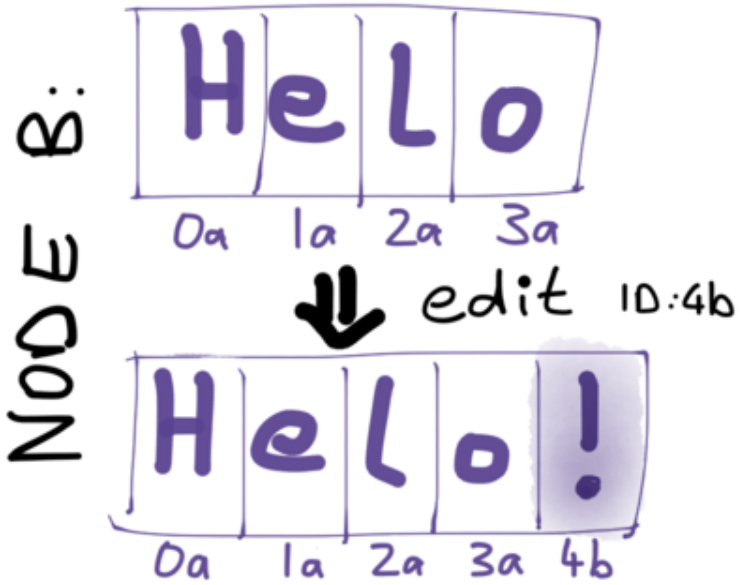
NODE B:

ORDERED LIST CRDT (NUTSHELL)

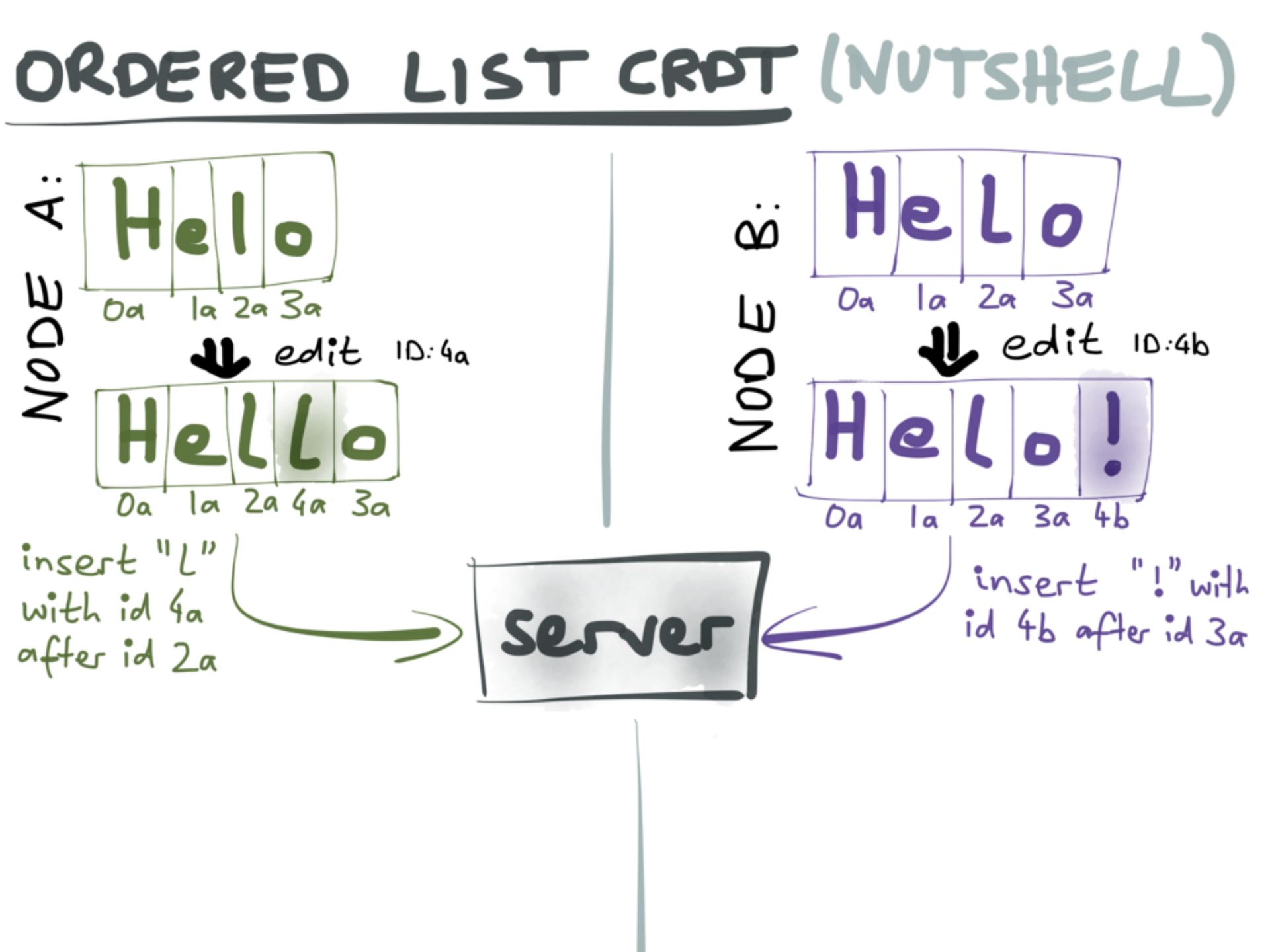
NODE A:



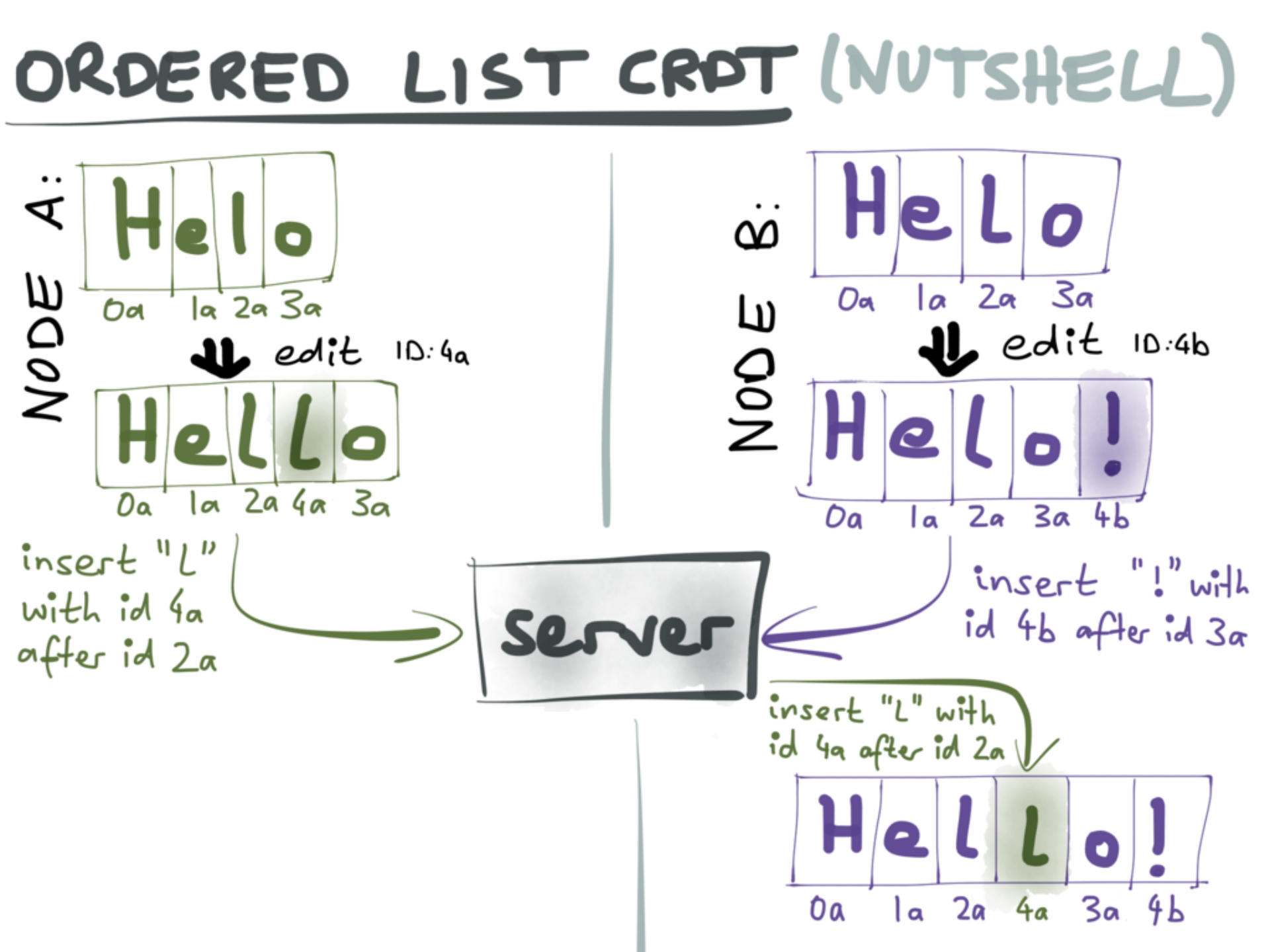
NODE B:



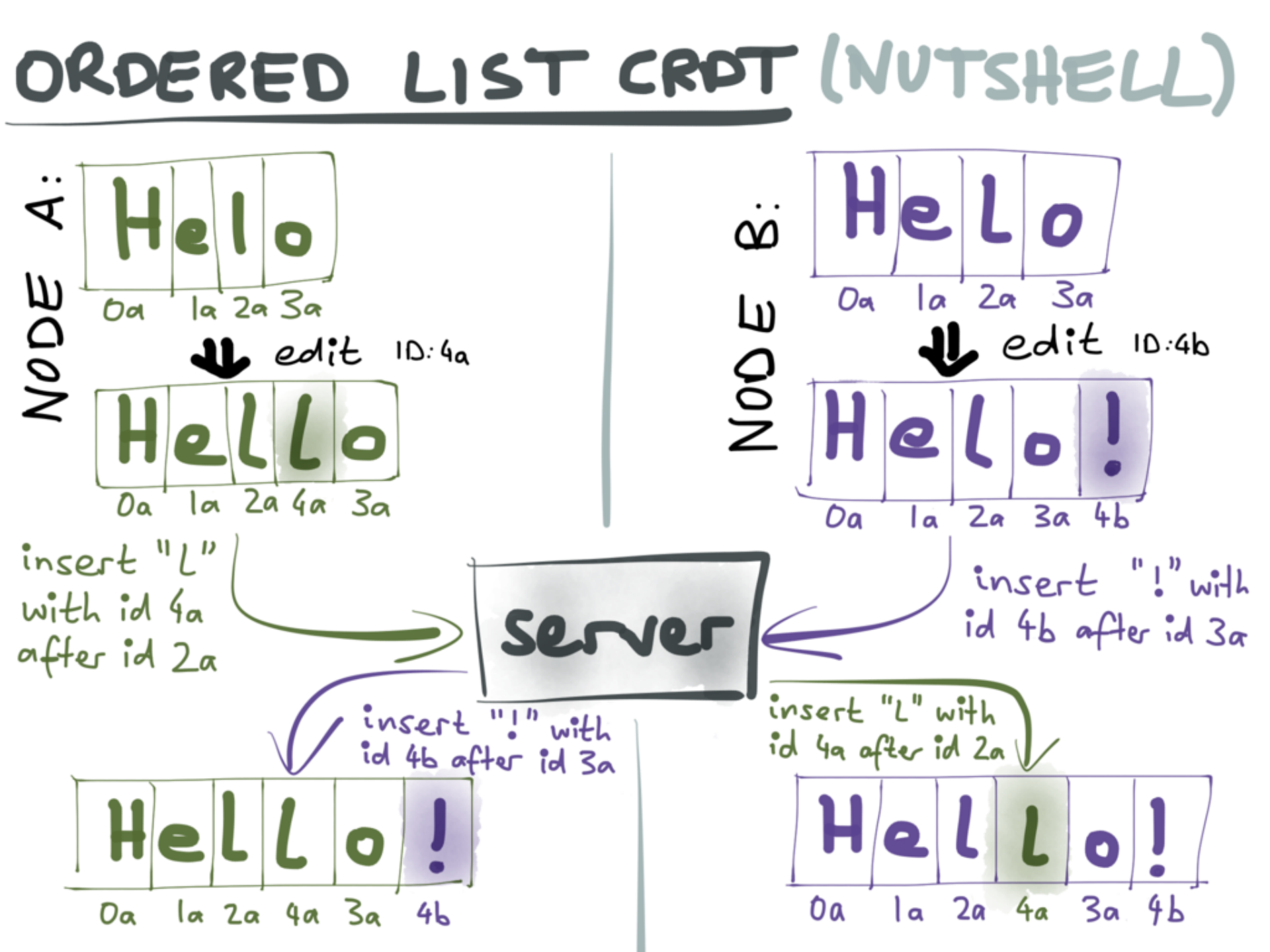
ORDERED LIST CRDT (NUTSHELL)



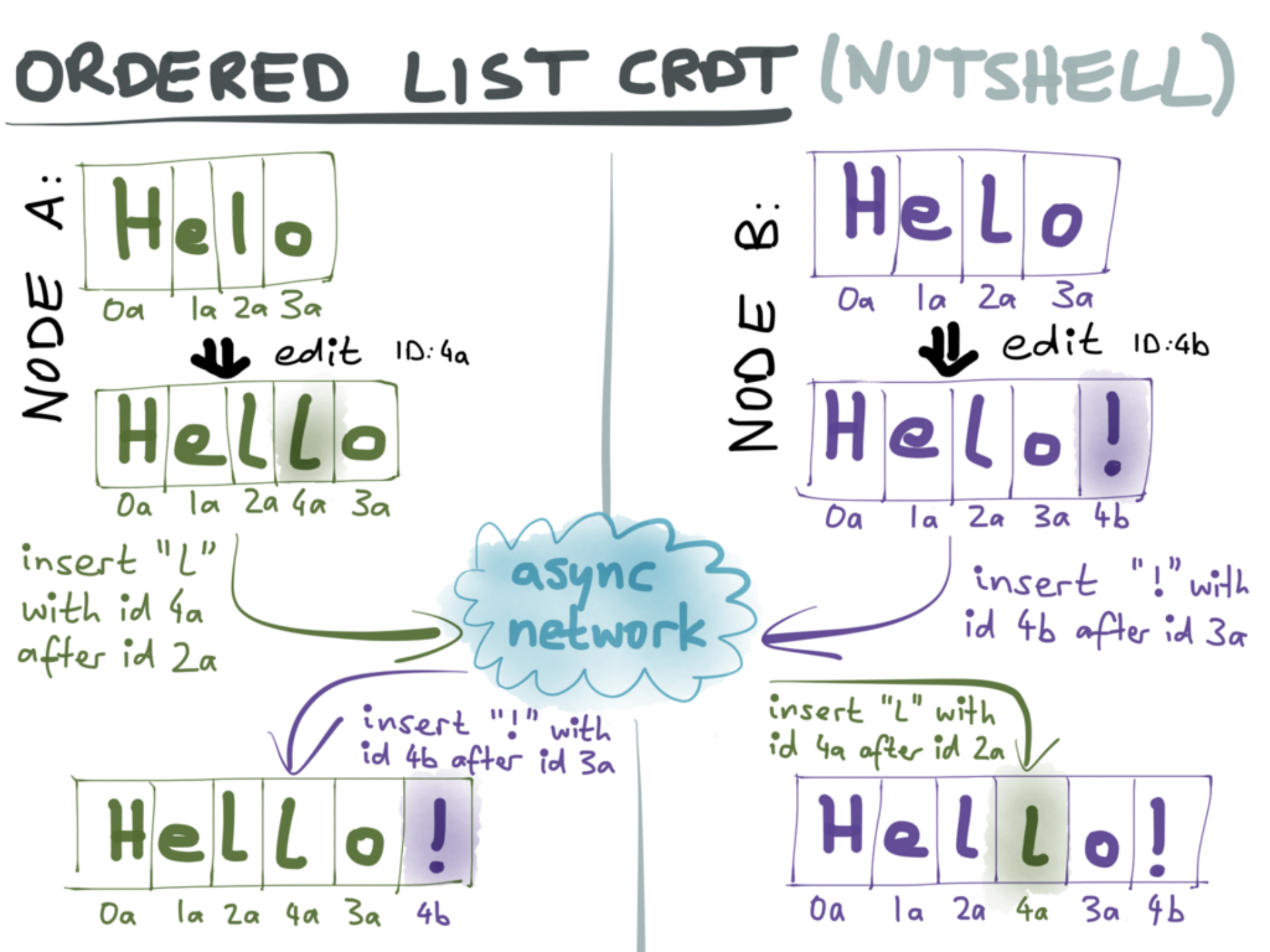
ORDERED LIST CRDT (NUTSHELL)



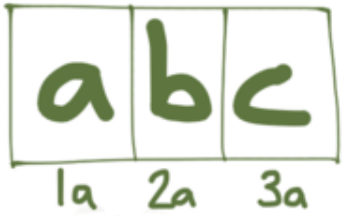
ORDERED LIST CRDT (NUTSHELL)

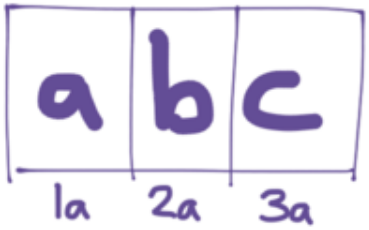


ORDERED LIST CRDT (NUTSHELL)

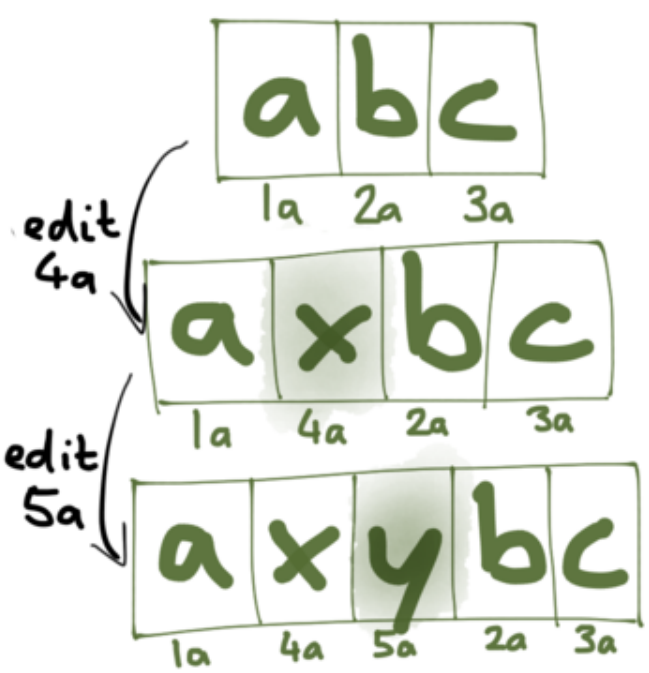


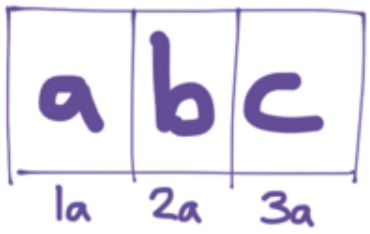
INSERTING IN THE SAME PLACE





INSERTING IN THE SAME PLACE





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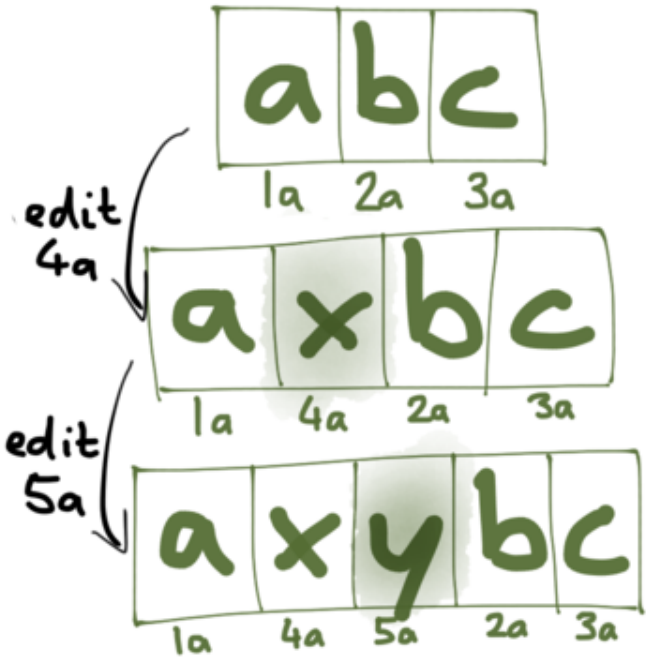

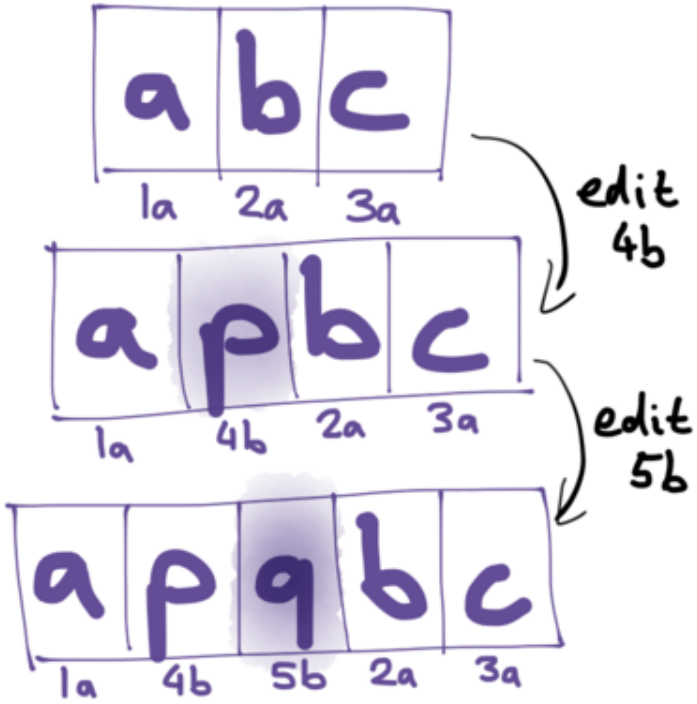

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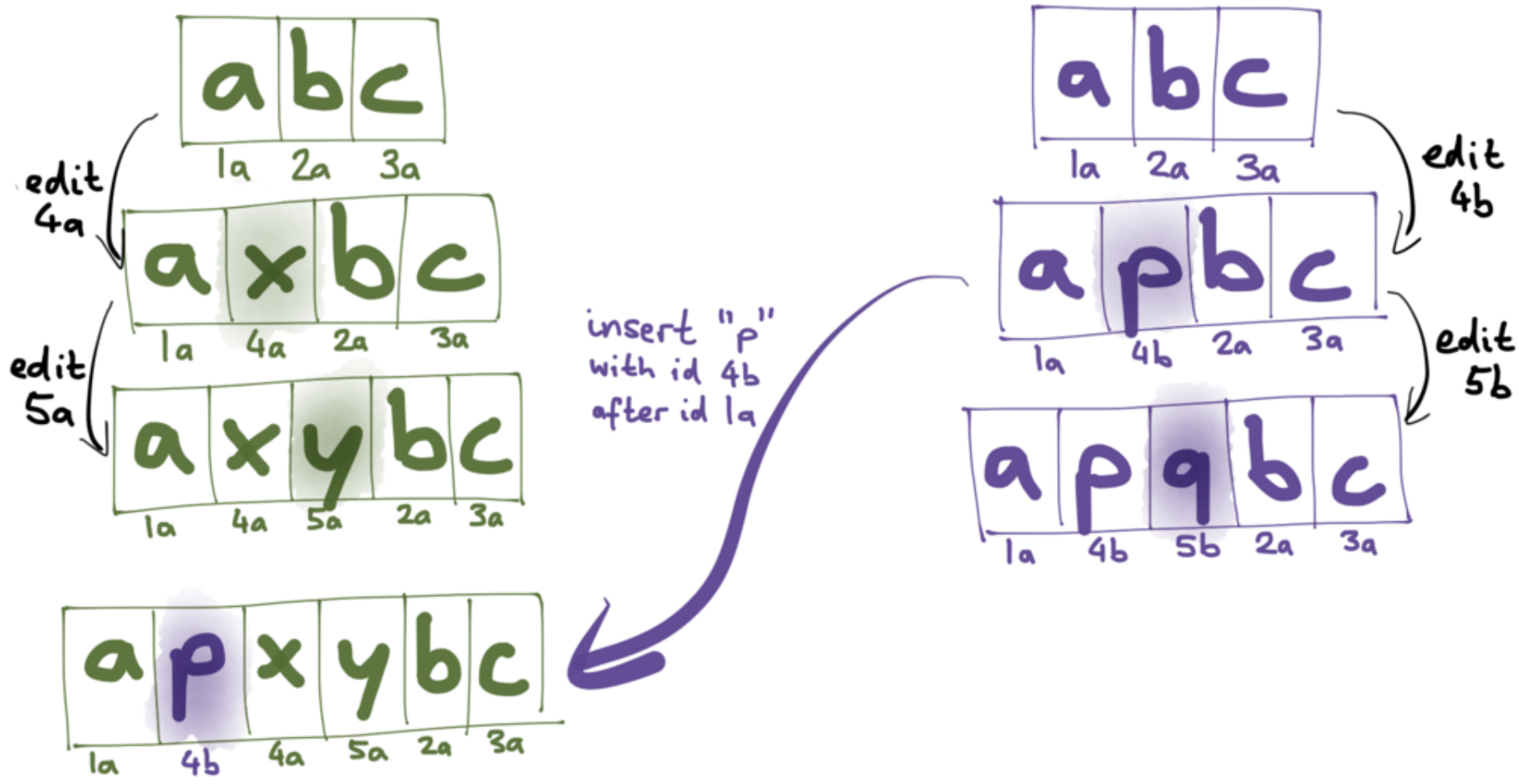

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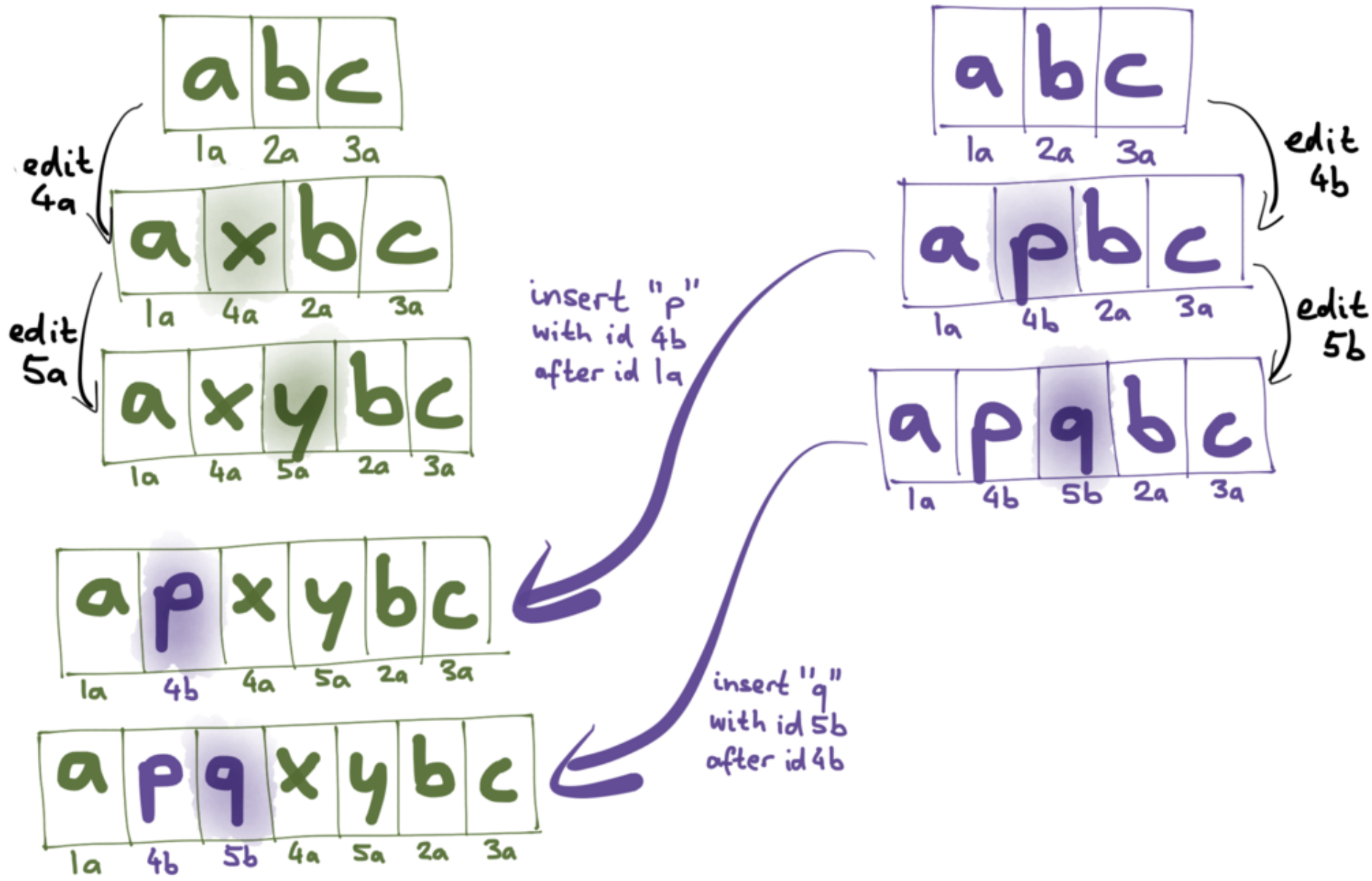

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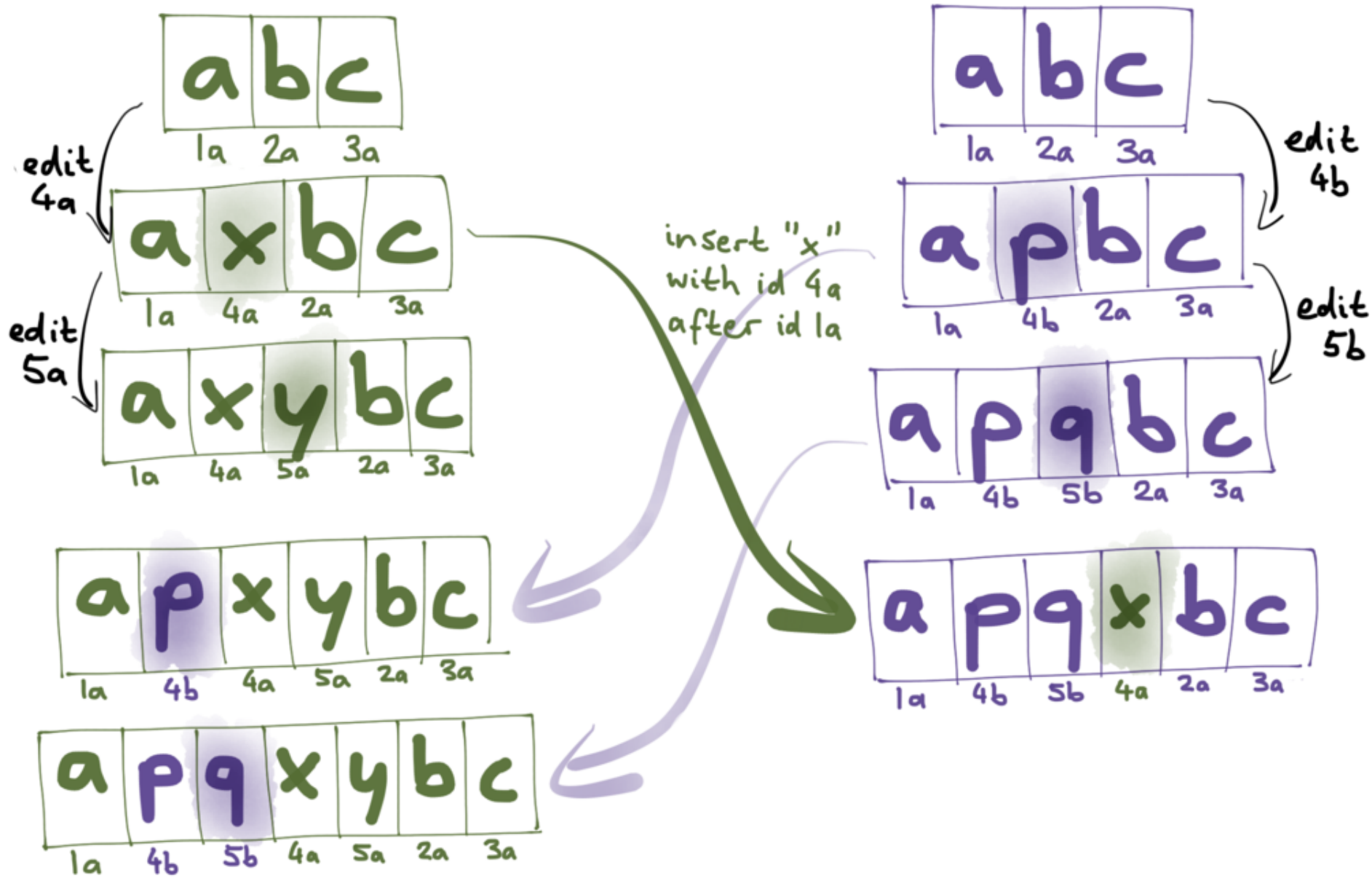

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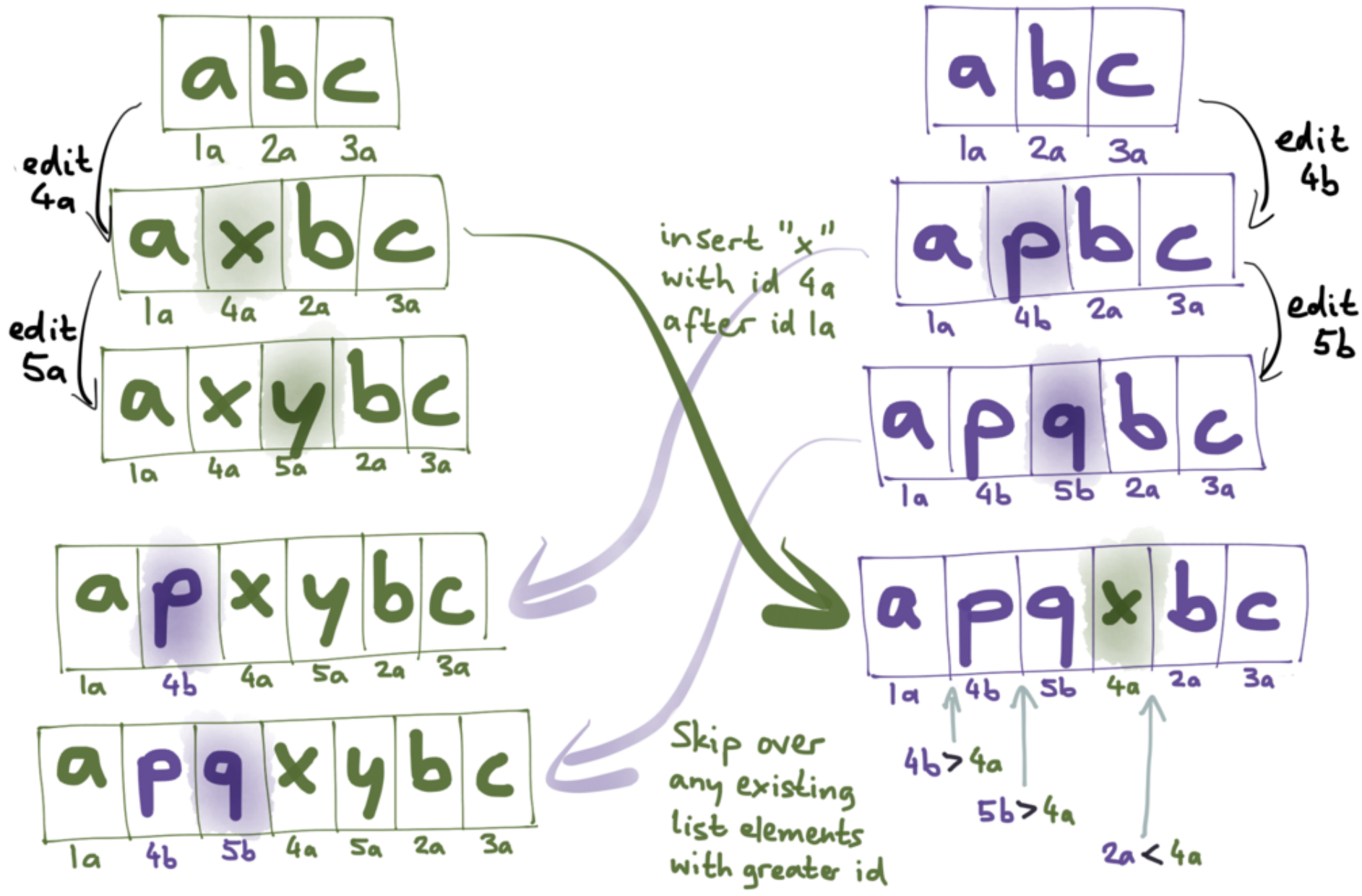

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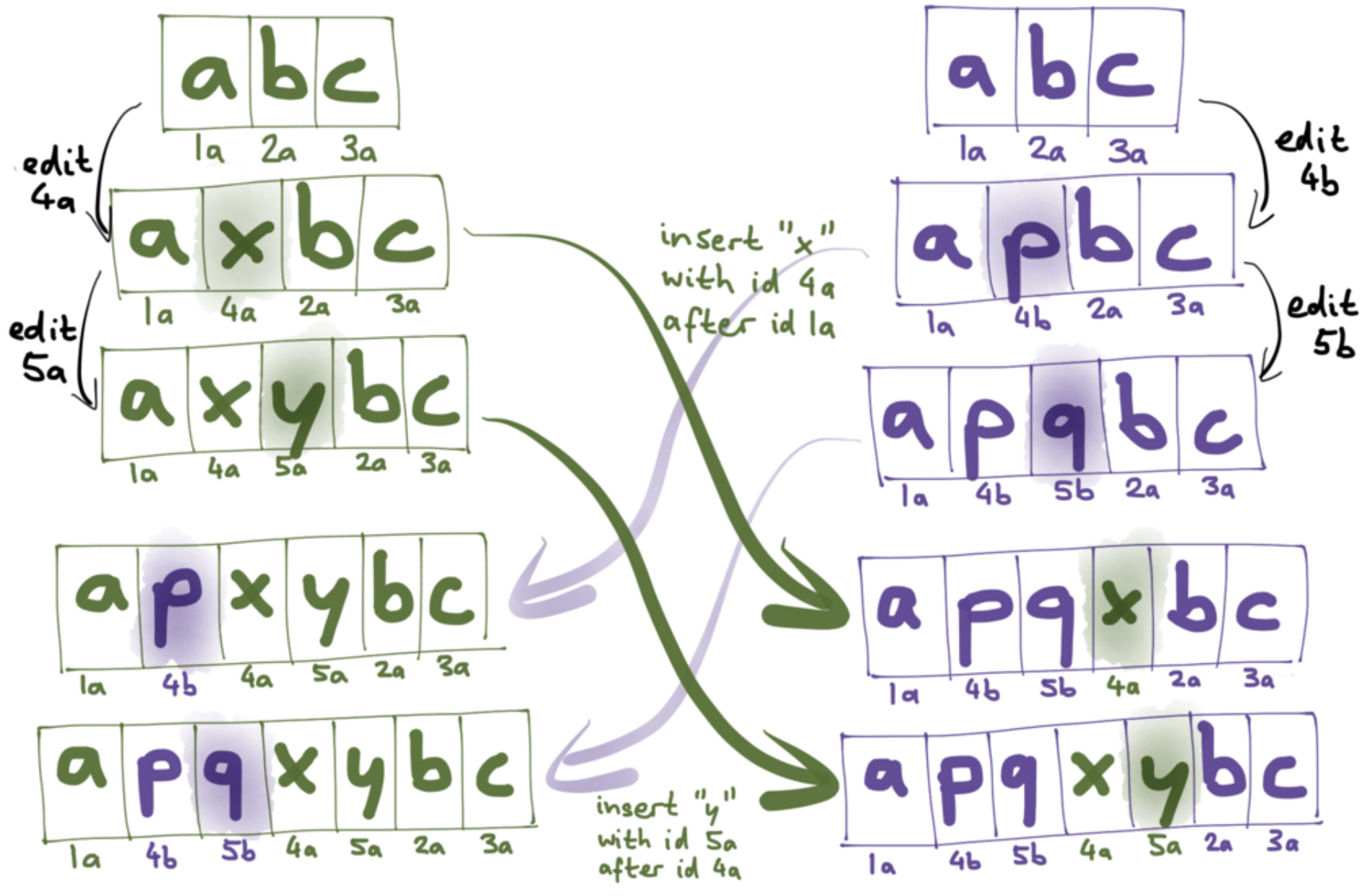

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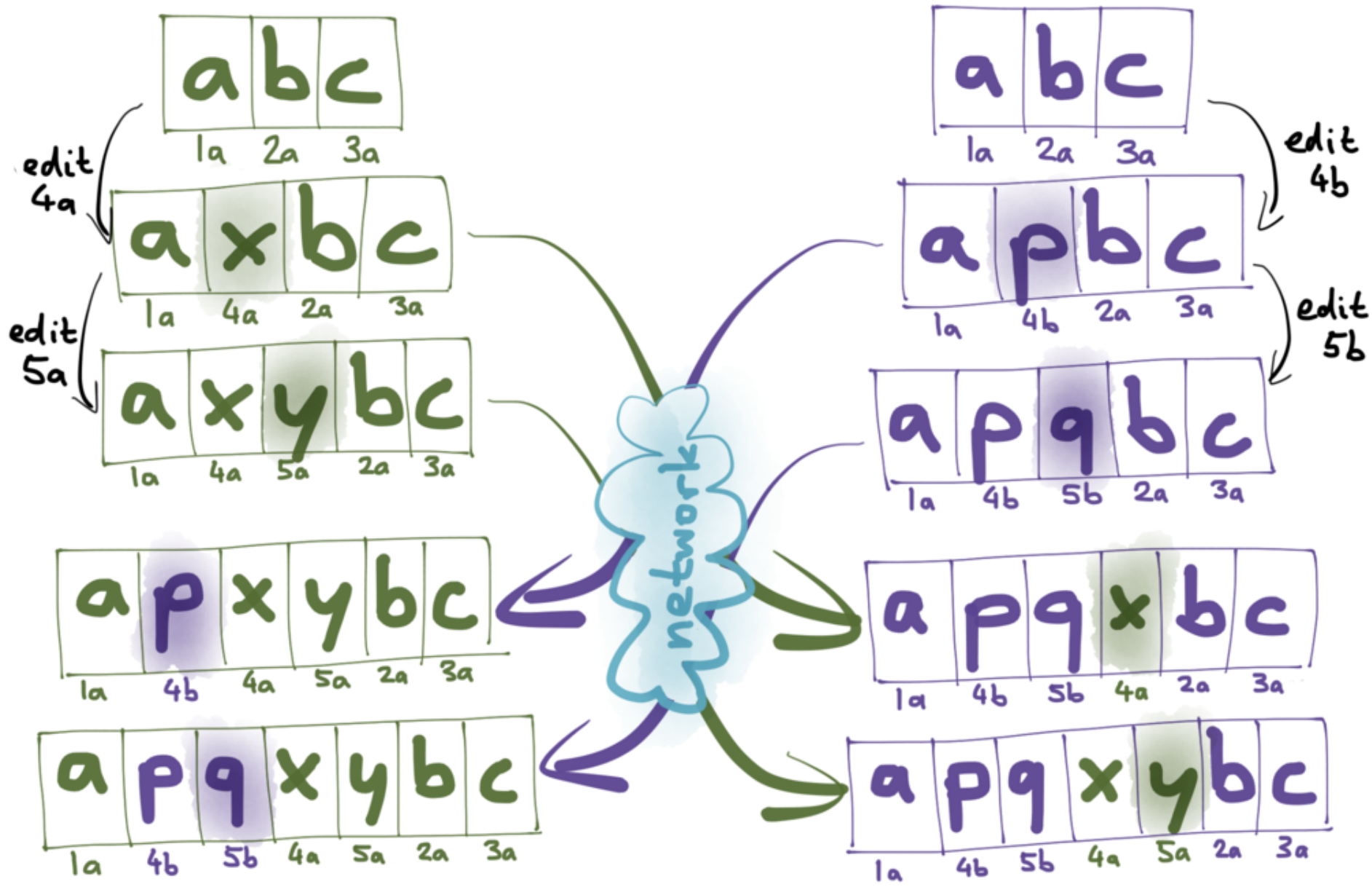
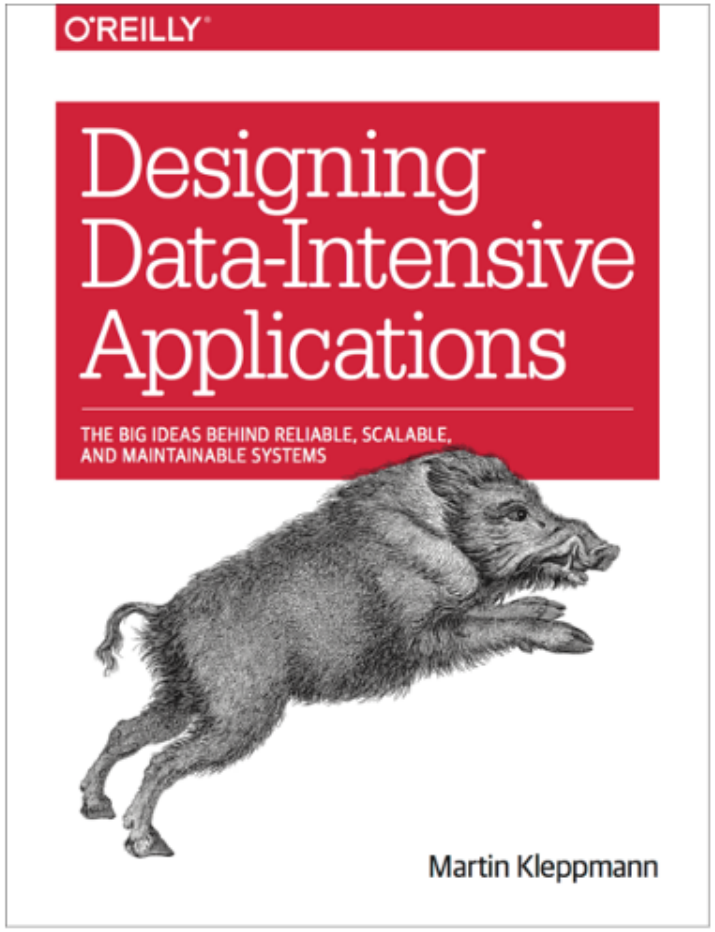


Resources

- Automerge: https://github.com/automerge/automerge
- Trellis: https://github.com/automerge/trellis
- Pixelpusher: https://github.com/automerge/pixelpusher
- MPL (WebRTC layer): https://github.com/automerge/mpl
- Hypermerge: https://github.com/automerge/hypermerge
- Dat / Hypercore: https://datproject.org/
- Proving CRDTs correct: https://doi.org/10.1145/3133933
- JSON CRDT: http://arxiv.org/abs/1608.03960
- My book: http://dataintensive.net/

dataintensive.net



@martinkl