Automerge

Making servers optional for real-time collaboration

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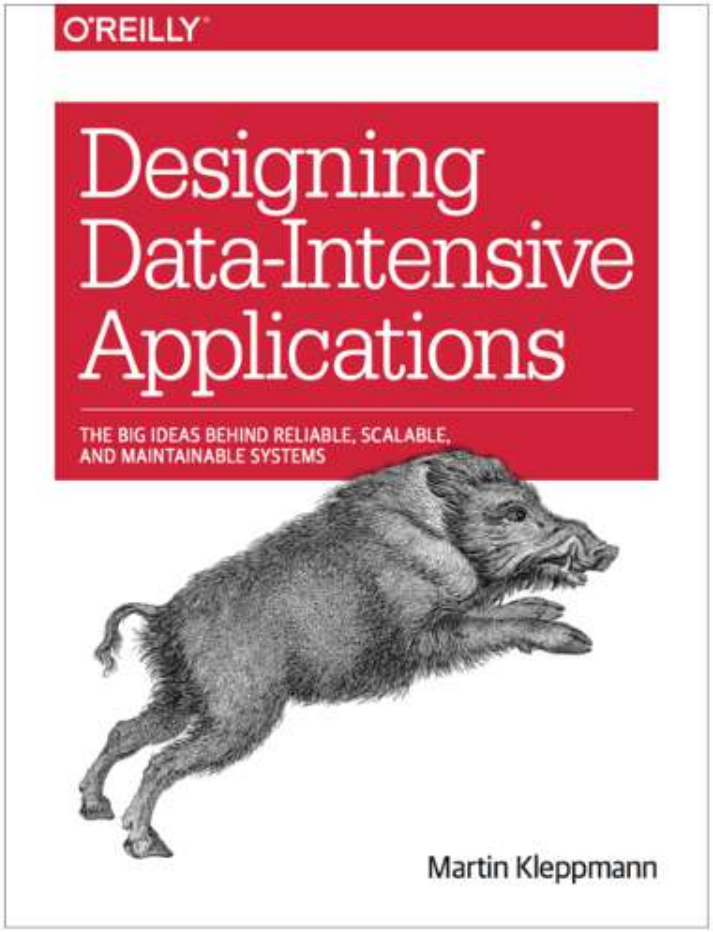
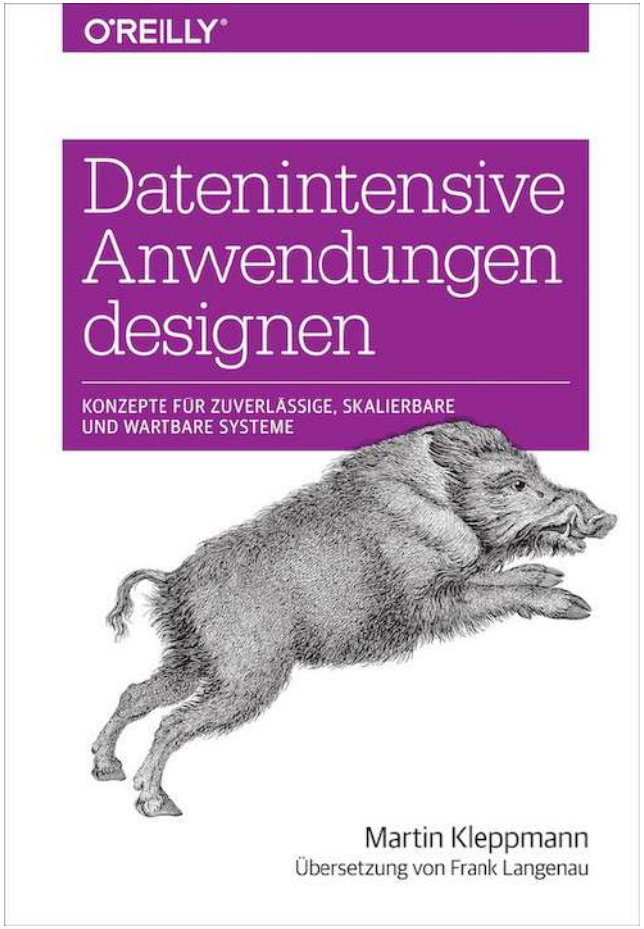
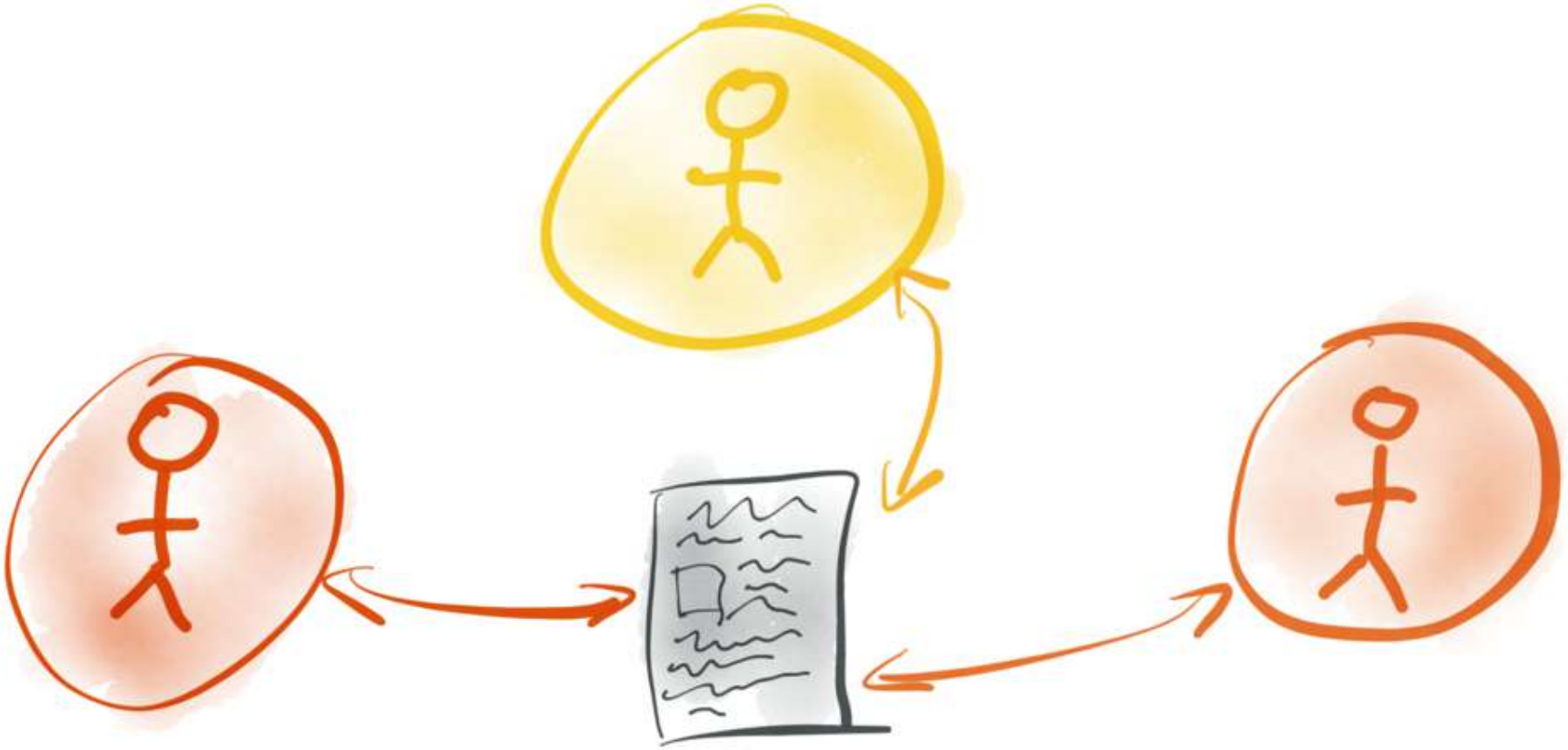
University of Cambridge

dataintensive.net





COLLABORATIVE APPLICATIONS



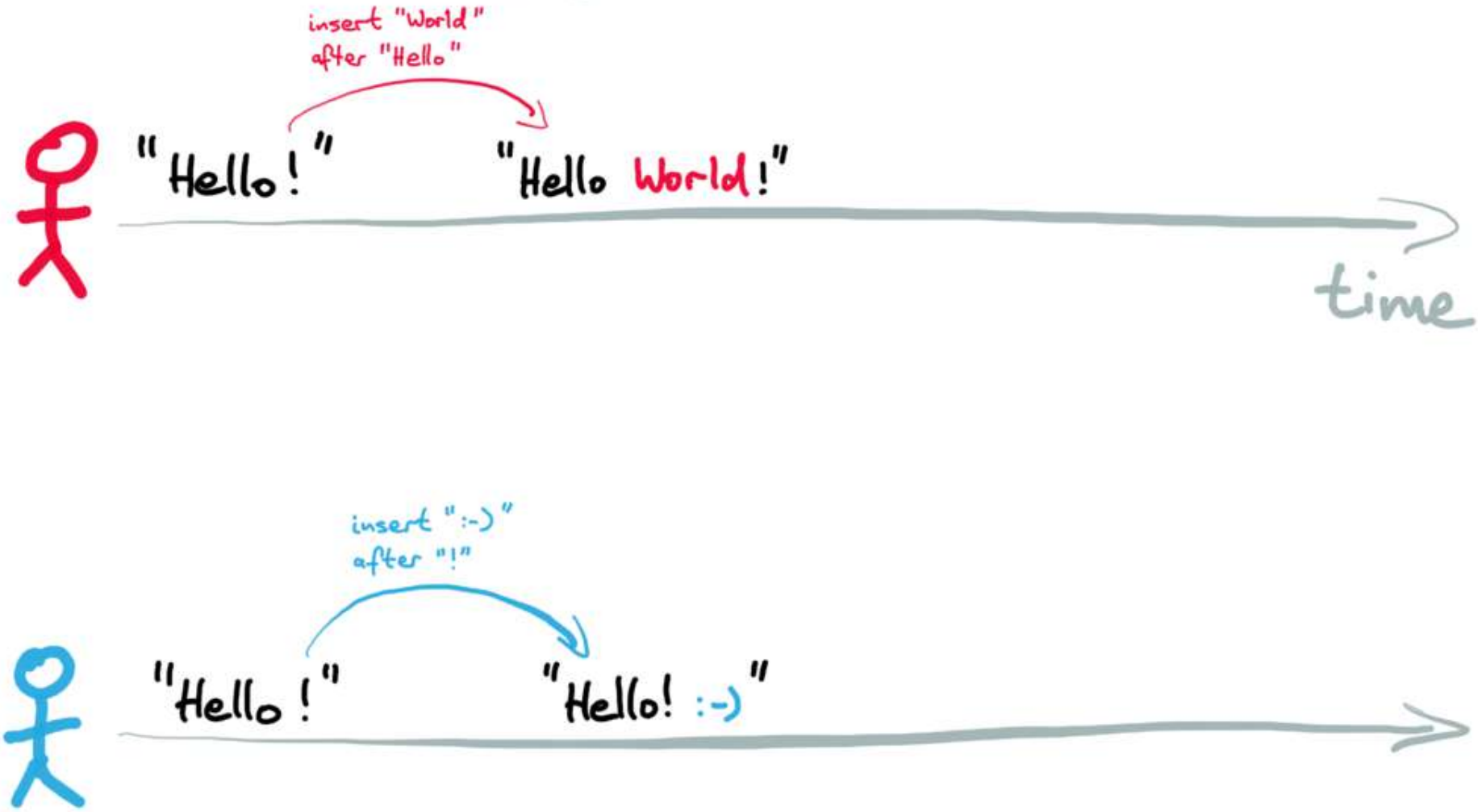
Example: Text editing

"Hello!"

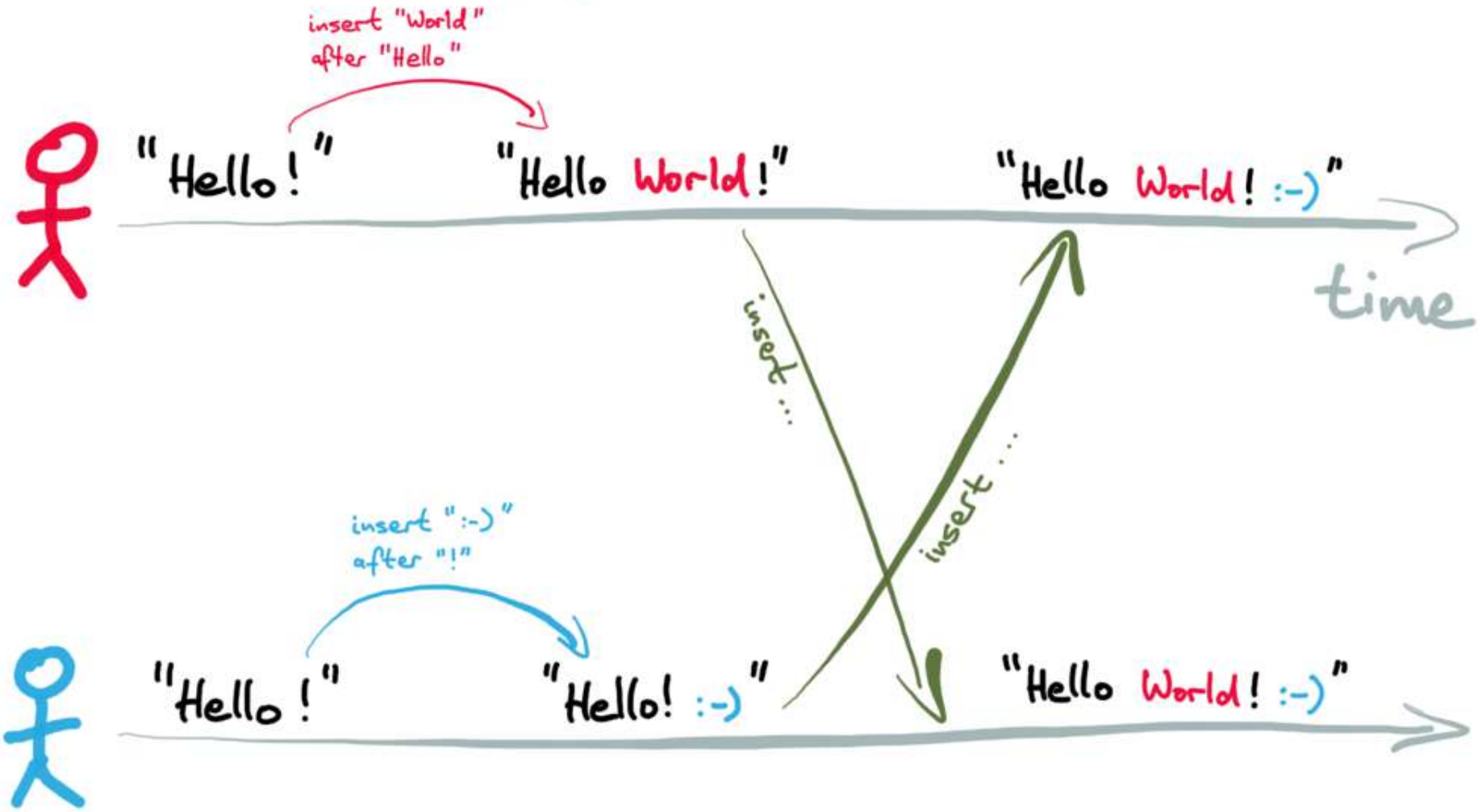
time

"Hello!"

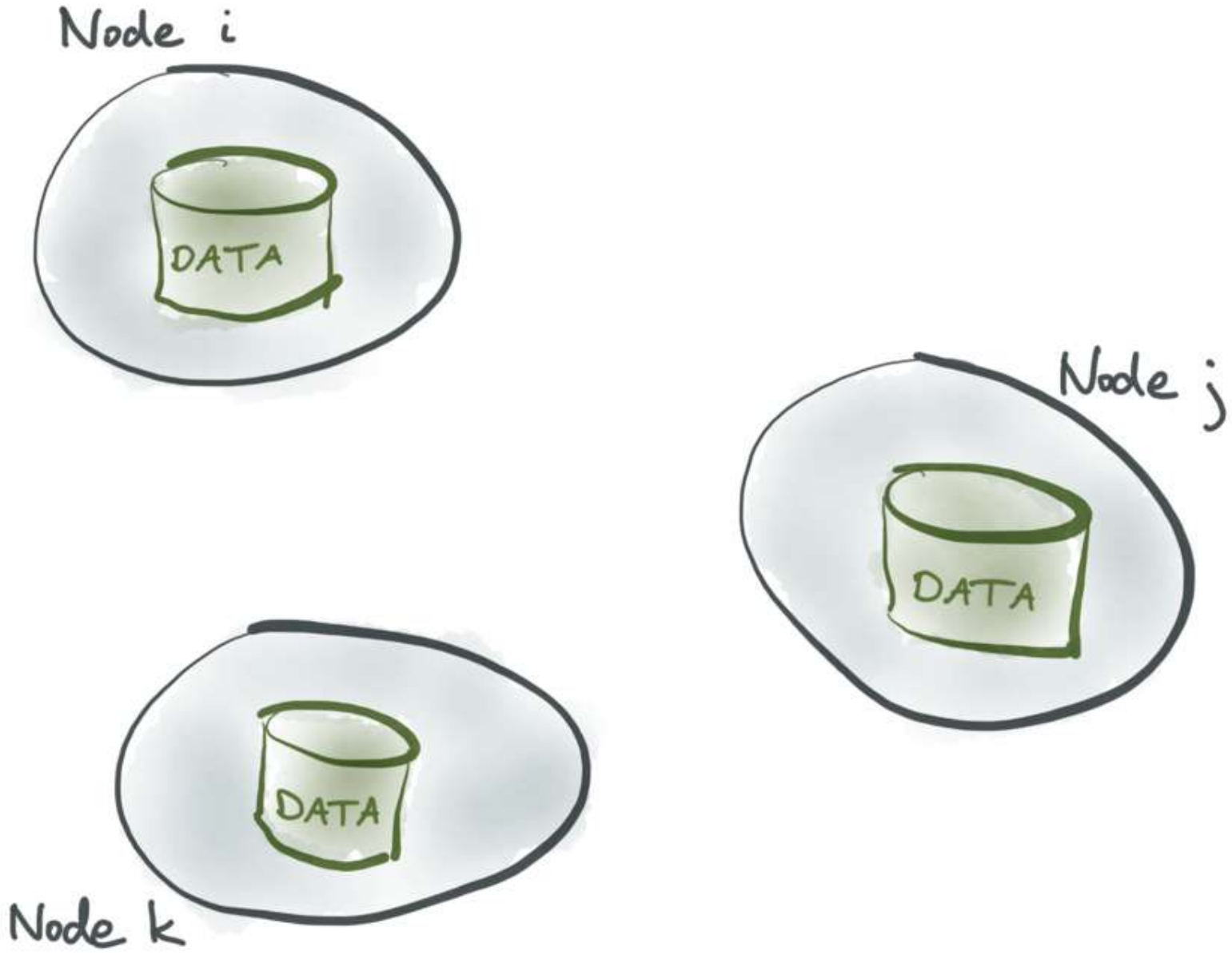
Example: Text editing



Example: Text editing



REPLICATION.



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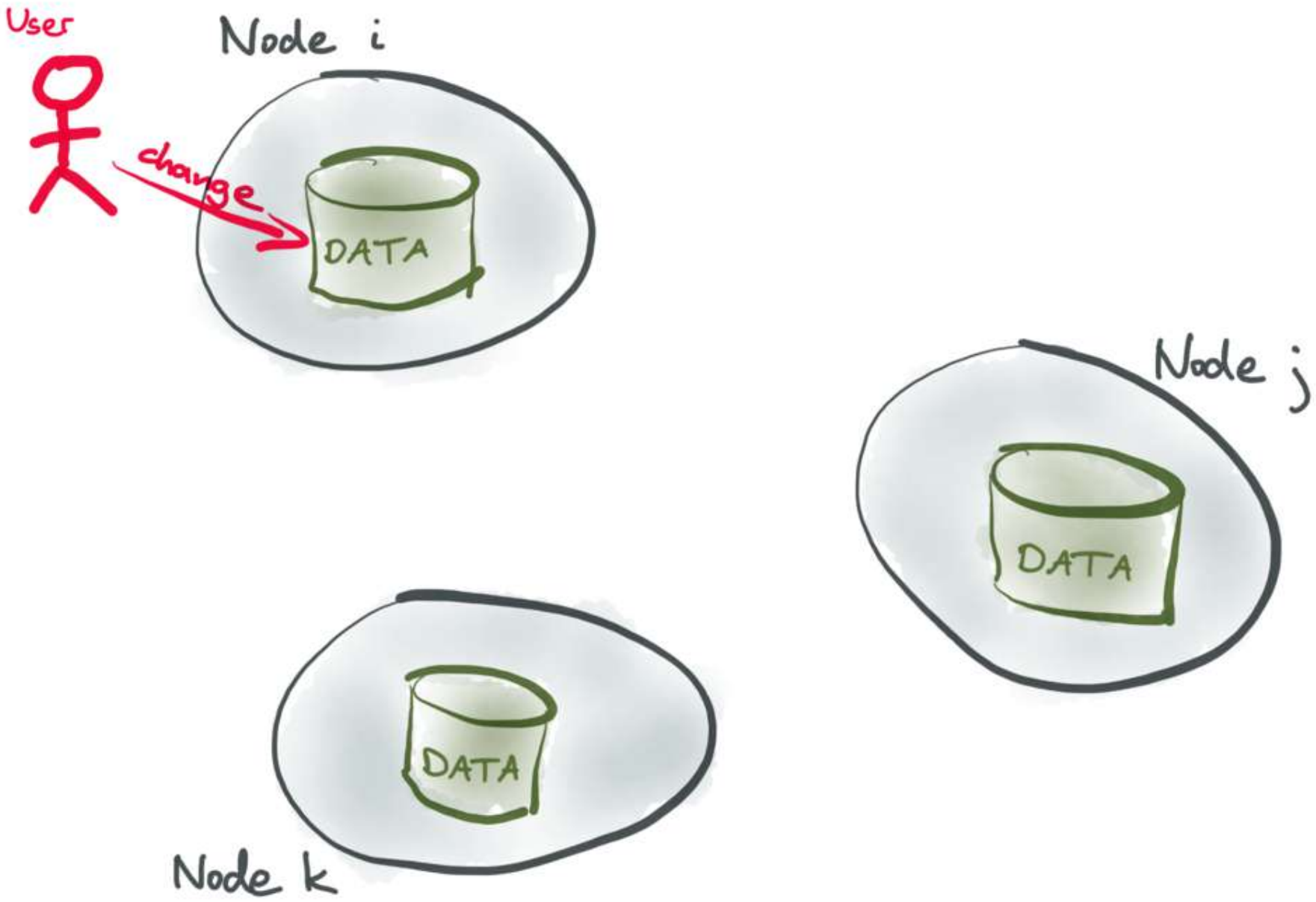

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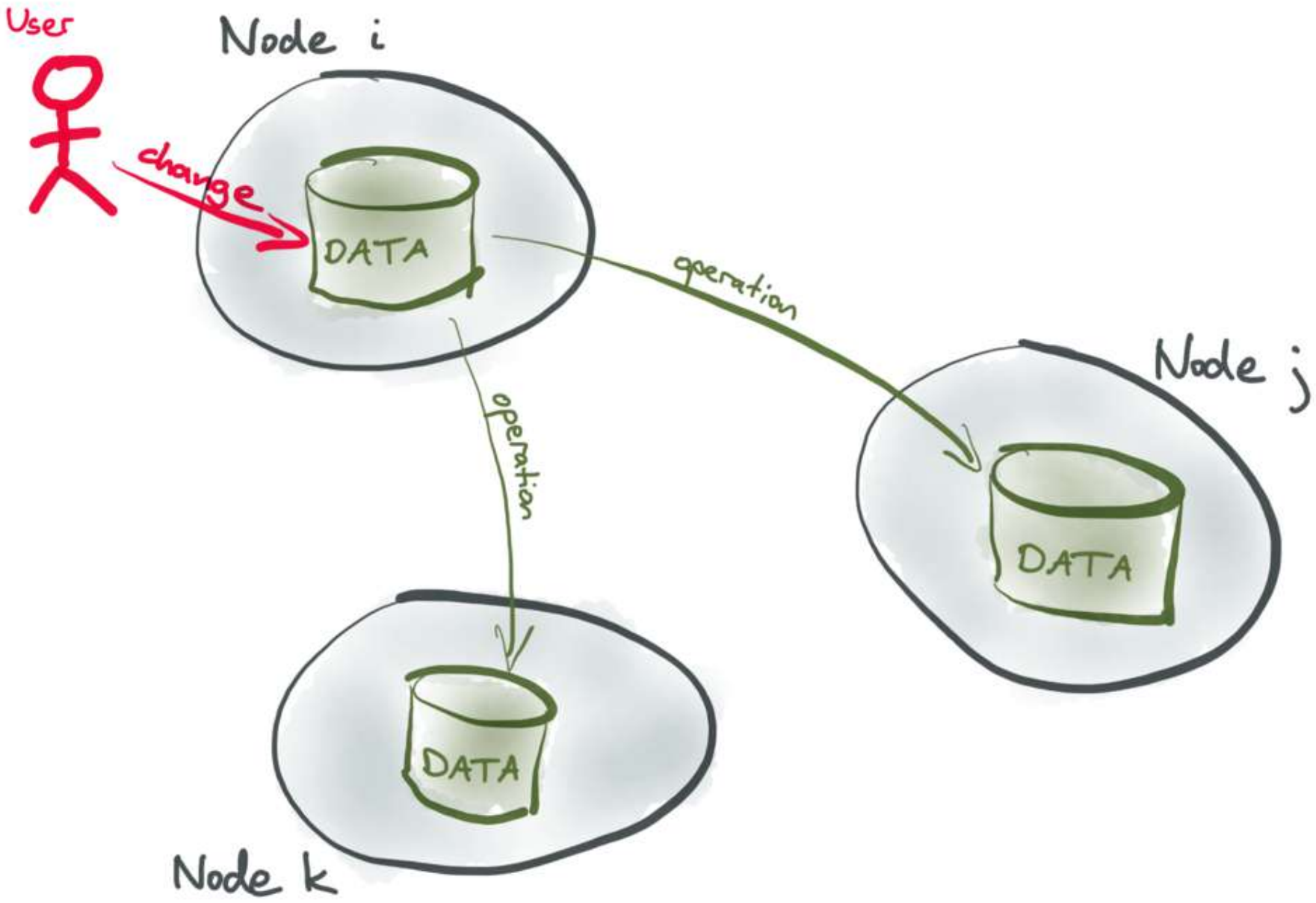

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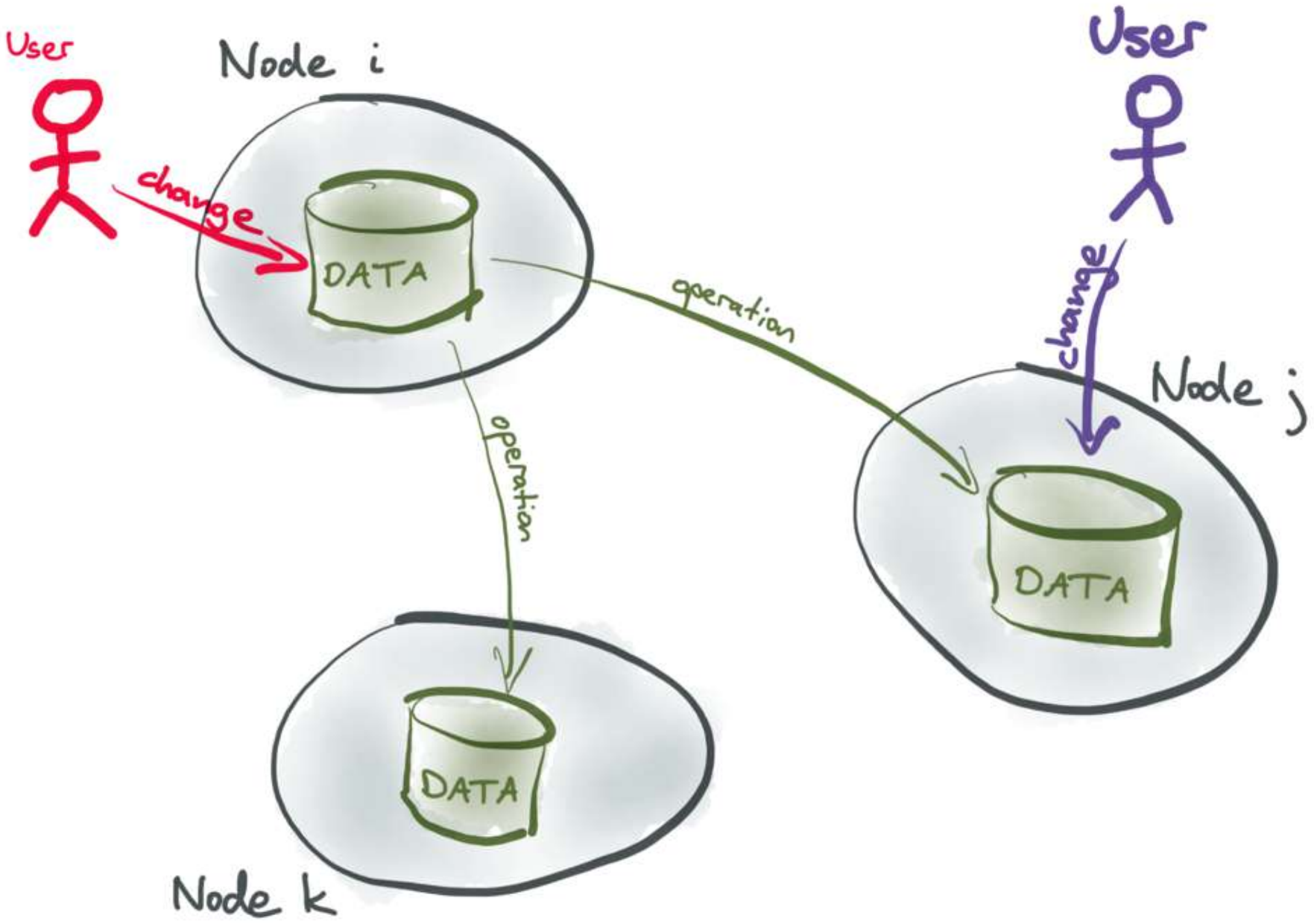

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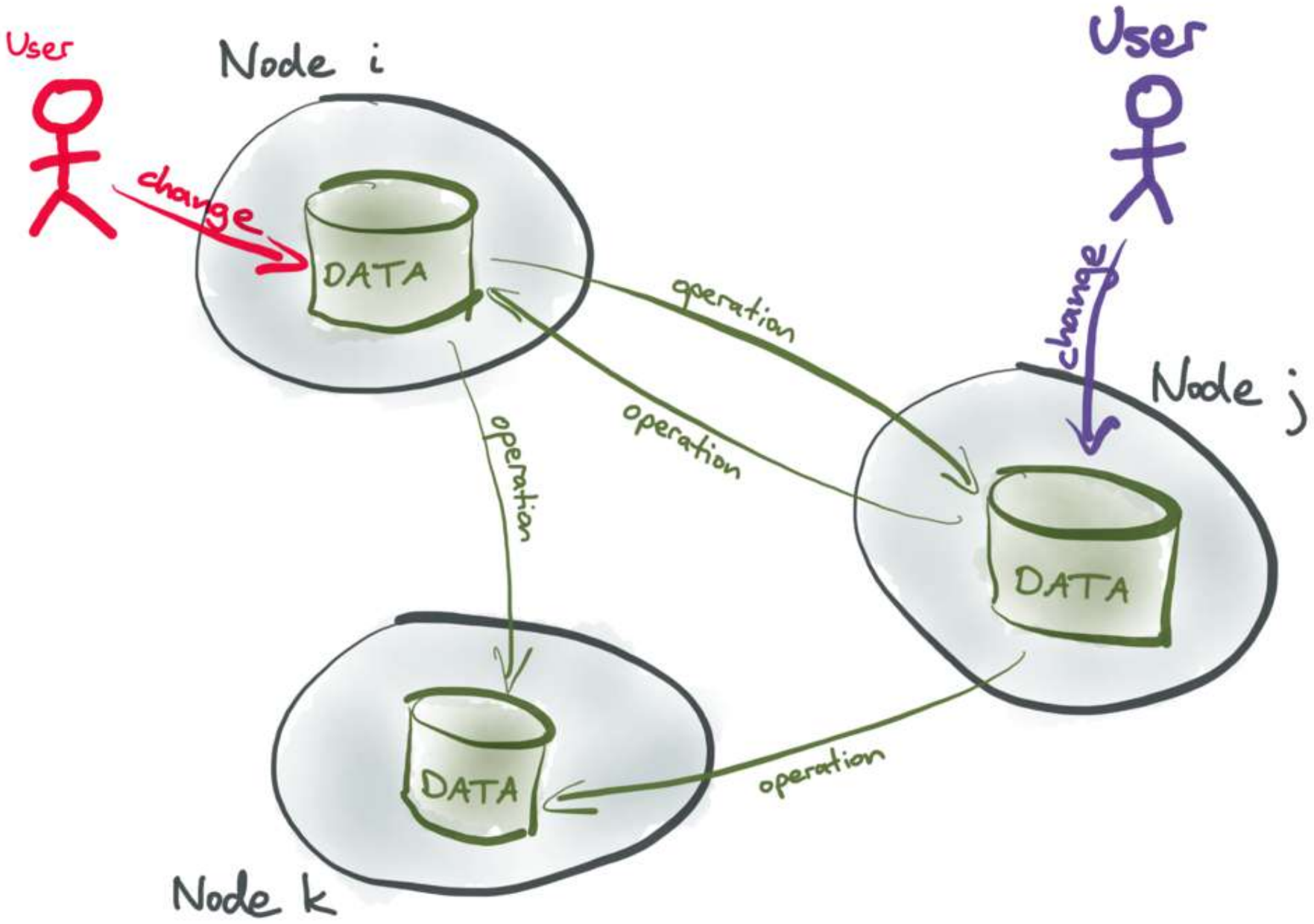
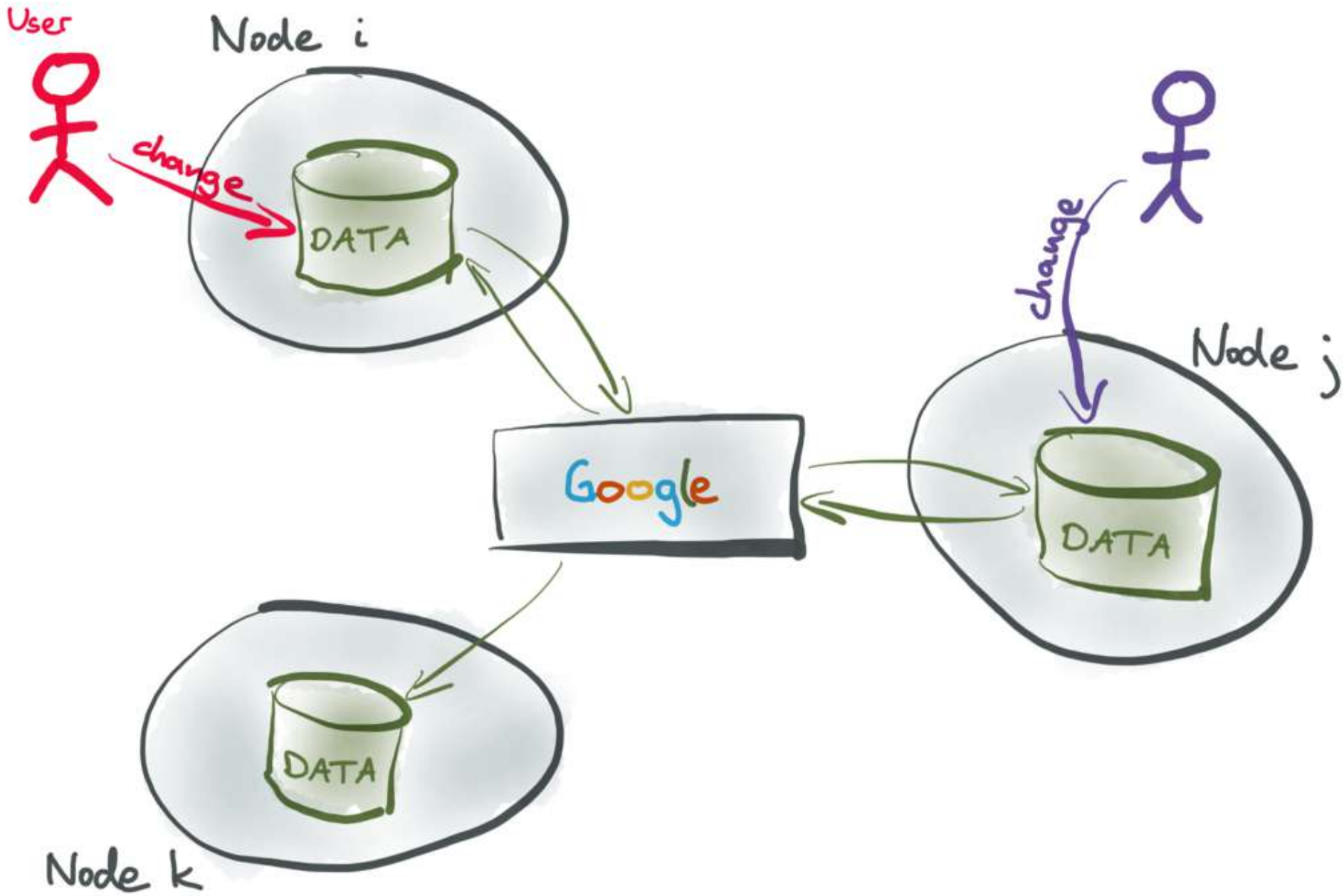



User
Node i
change
DATA
change
Node j
Google
DATA
DATA
Node k

SENSITIVE DATA

Medical records

Dissidents

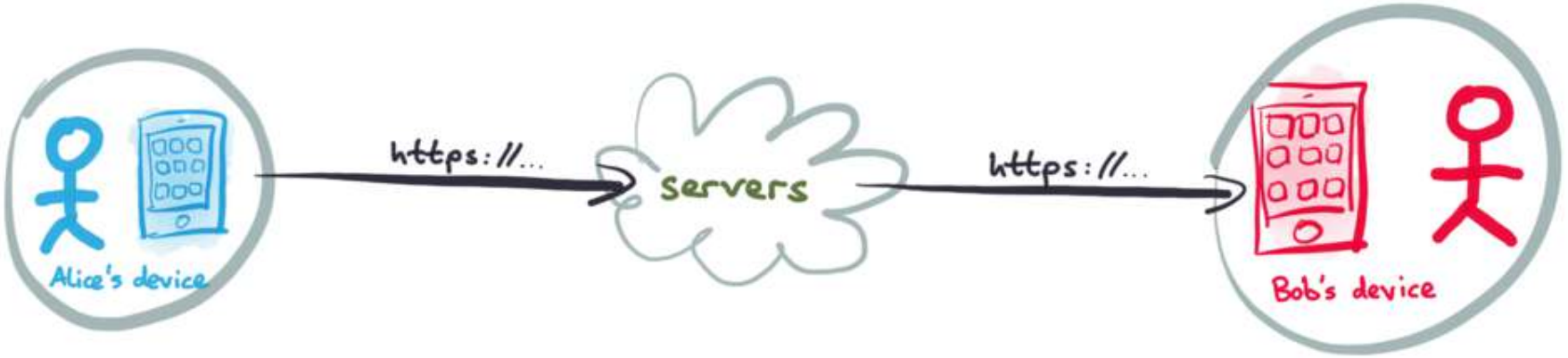
Journalists

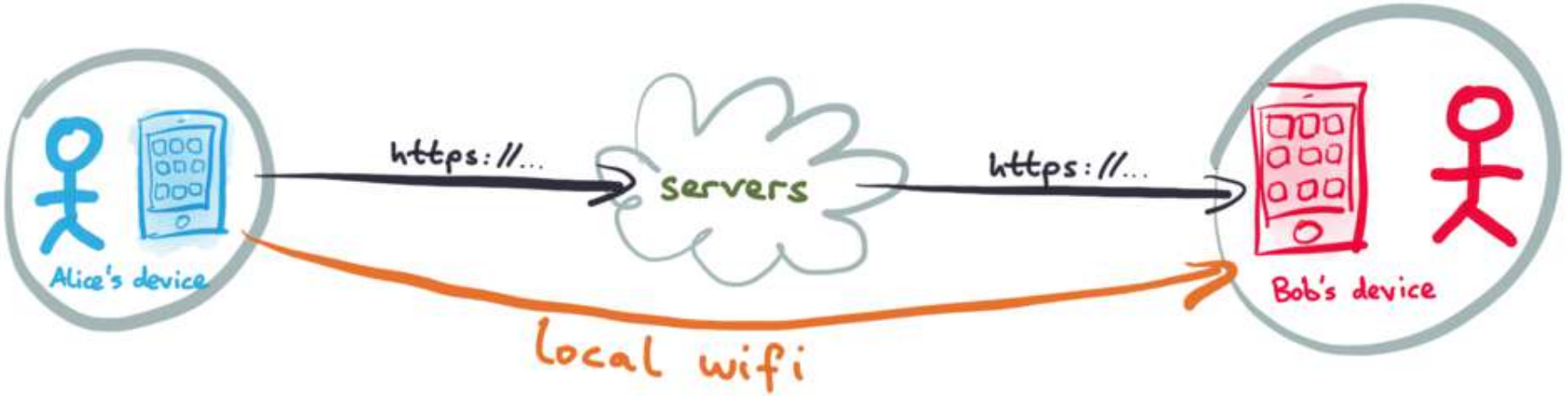
Legal / law enforcement

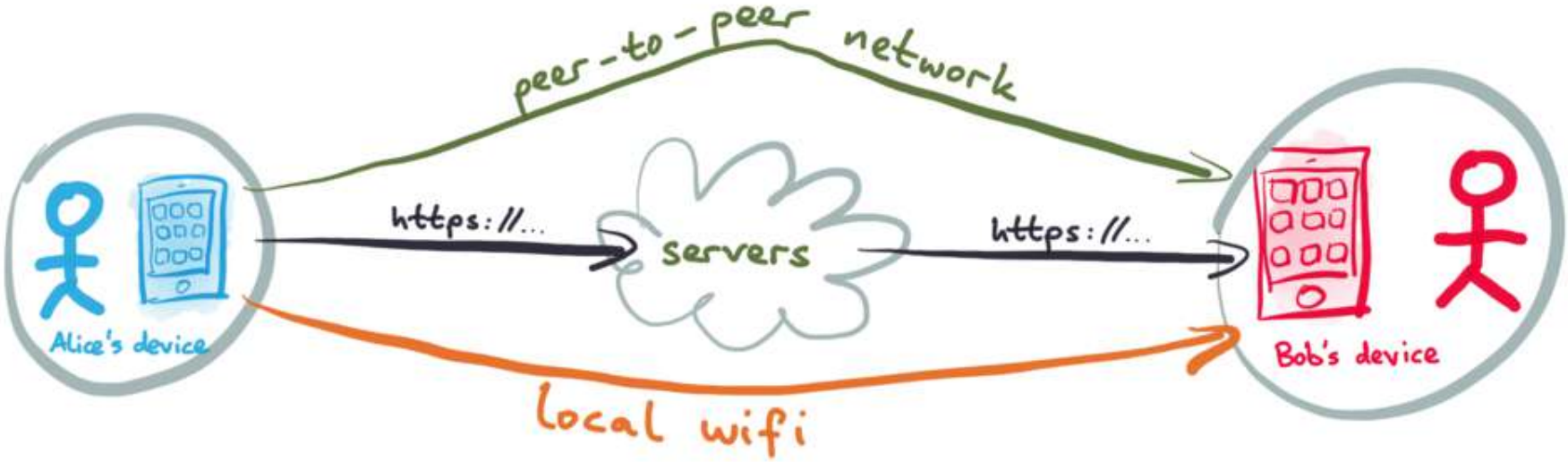
Can't just put all your data on someone else's server: regulatory compliance / confidentiality obligations / personal safety / ...

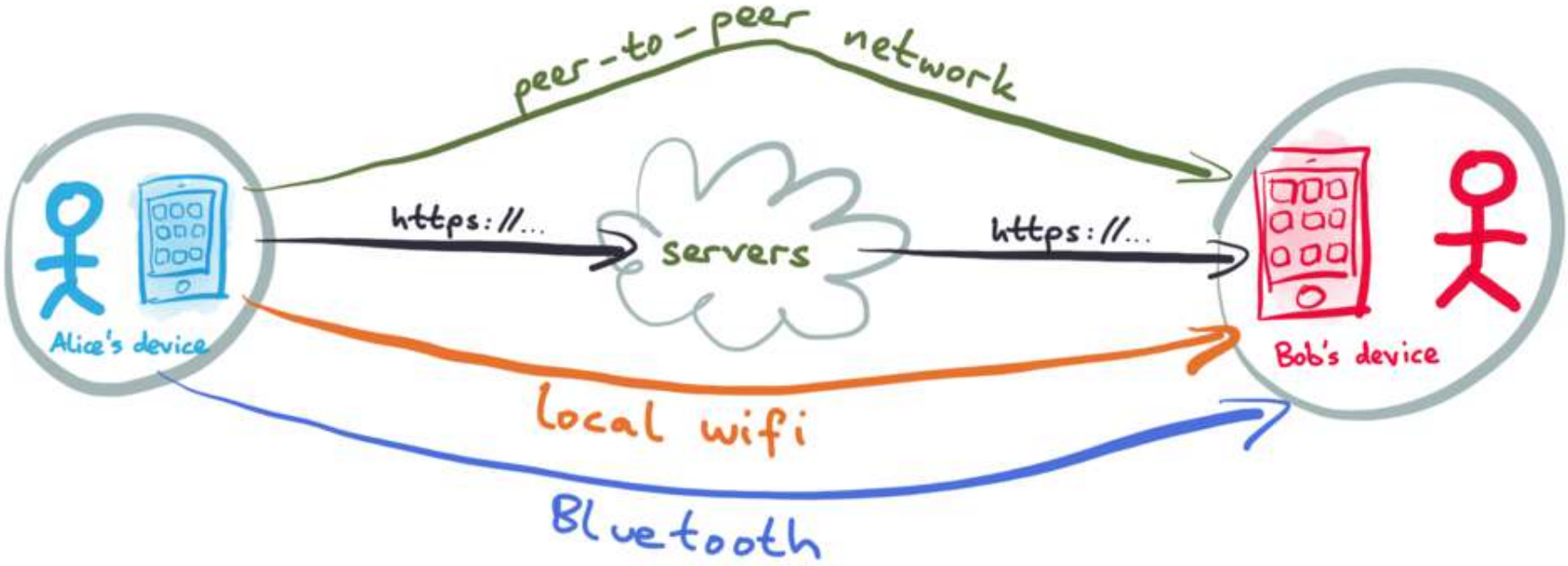
There is no cloud

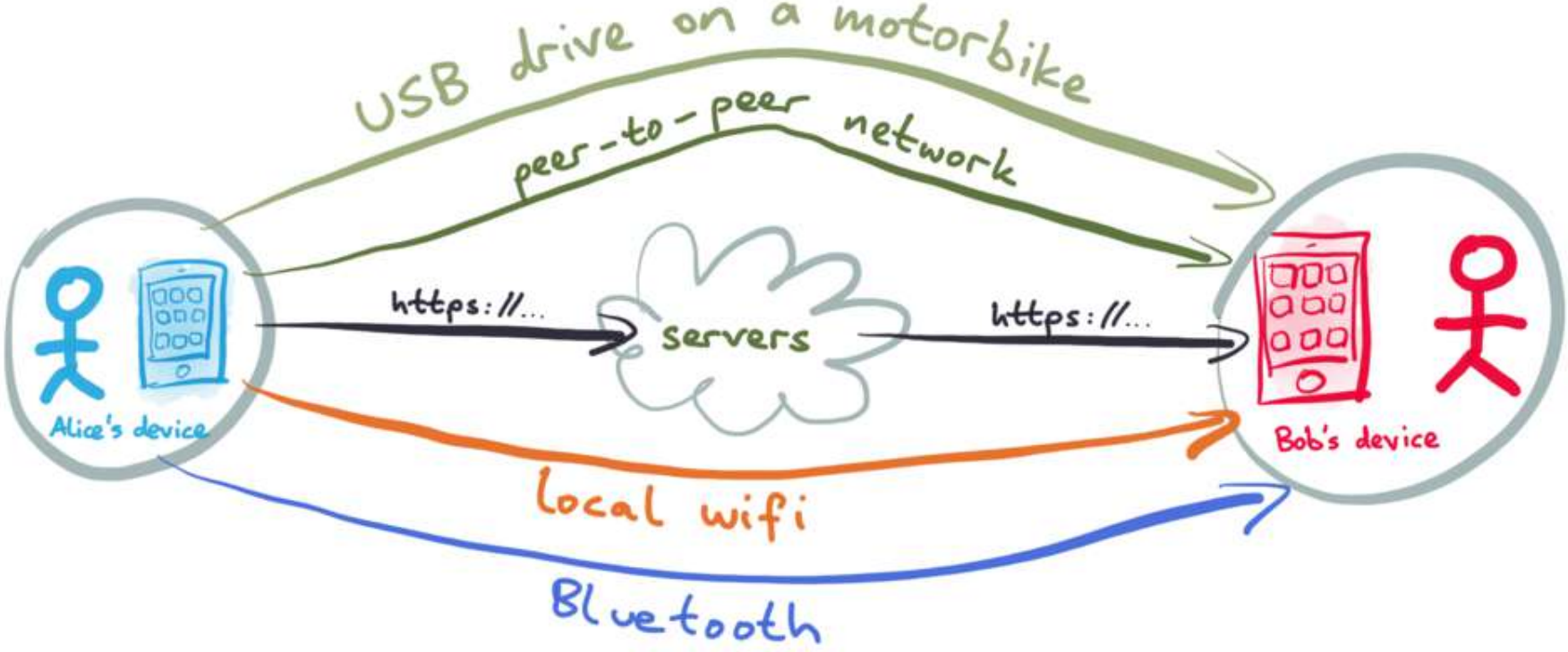
It's just someone else's computer


Alice's device
https://...
servers
https://...
Bob's device


https://...
servers
https://...
Alice's device
Bob's device
local wifi


peer-to-peer network
https://...
servers
https://...
Alice's device
Bob's device
local wifi


peer-to-peer network
https://...
servers
https://...
Alice's device
Bob's device
local wifi
Bluetooth


USB drive on a motorbike
peer-to-peer network
https://...
servers
https://...
Alice's device
Bob's device
local wifi
Bluetooth

FAILURES OF OPERATIONAL TRANSFORM

dOPT
Ellis & Gibbs
1989

adOPTed
Ressel et al.
1996

IMOR
Imine et al.
2003

Jupiter
Nichols et al.
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SOCT2
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Li & Li
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require central server

SOCT2
Suleiman et al.
1997
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Li & Li
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SOCT3/4
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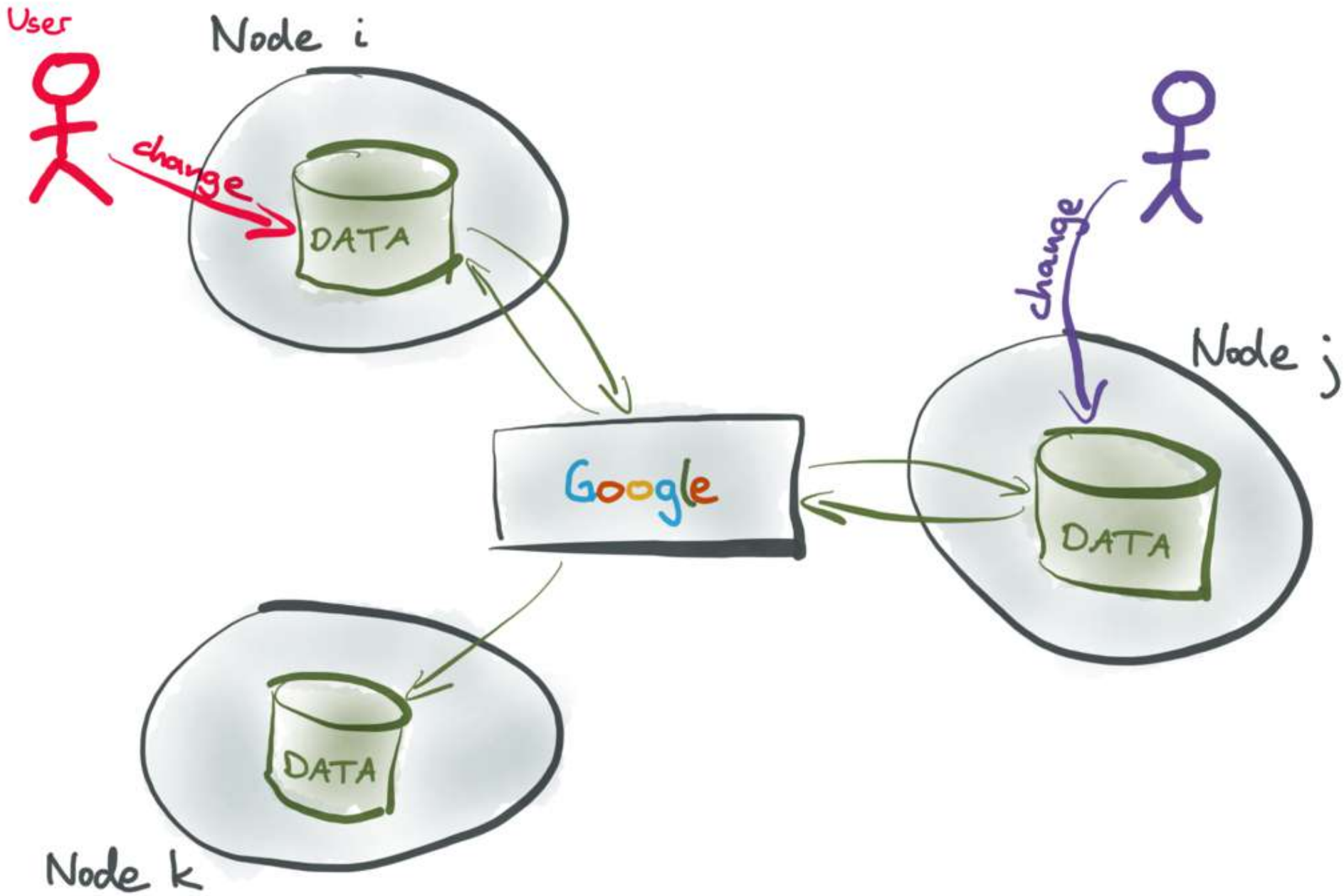
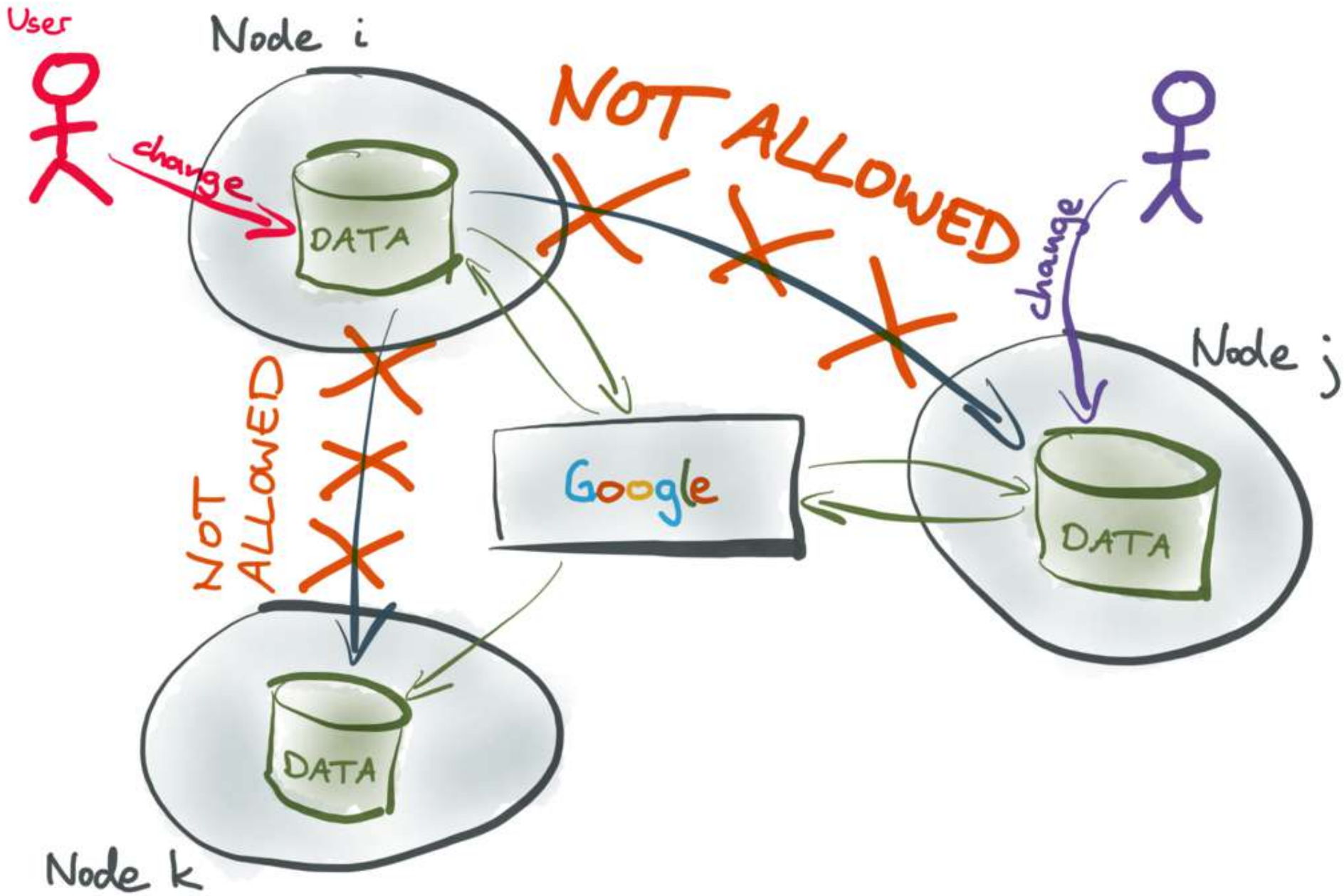
OPERATIONAL TRANSFORMATION IN GOOGLE DOCS.



OPERATIONAL TRANSFORMATION IN GOOGLE DOCS.



Algorithms for convergence

OPERATIONAL TRANSFORMATION (OT)

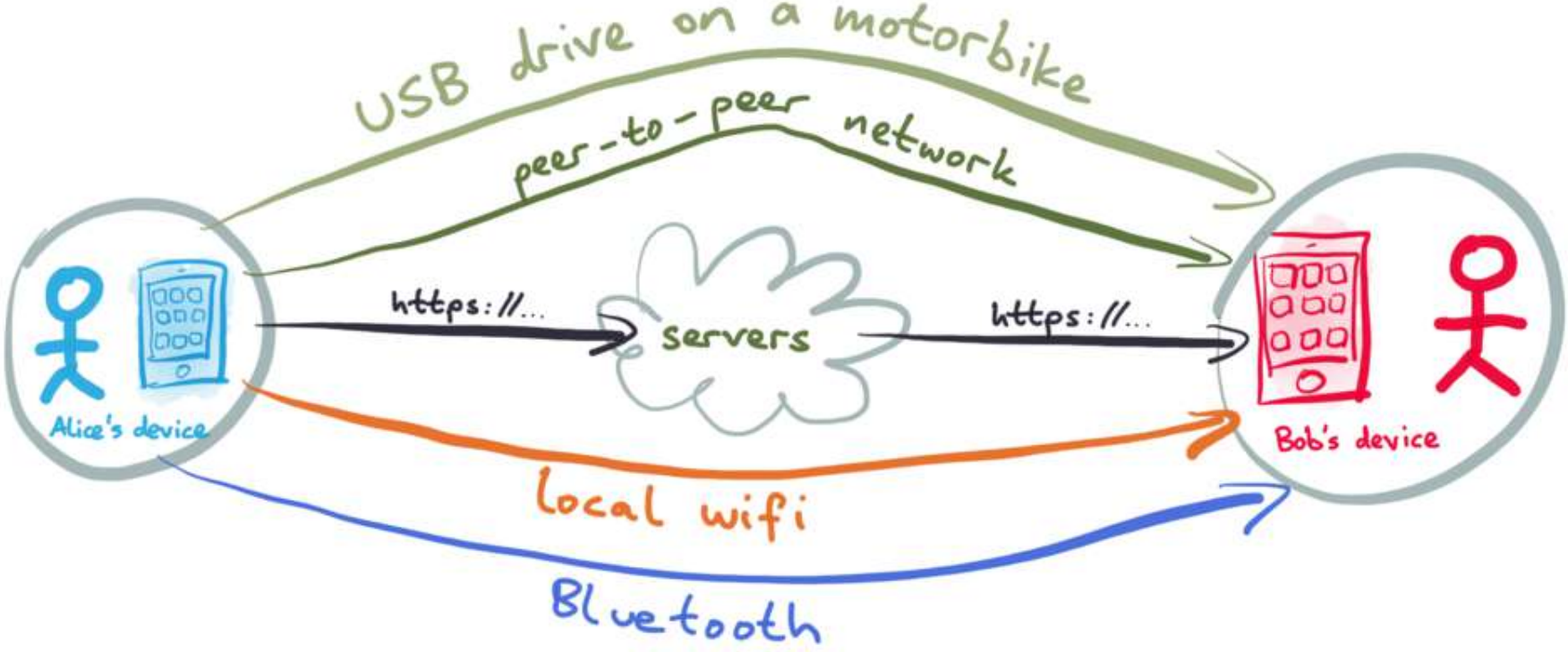
- e.g. Google Docs, MS Office Online

1989–2006

CONFLICT-FREE REPLICATED DATA TYPES (CRDTs)

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

2006 – present


USB drive on a motorbike
peer-to-peer network
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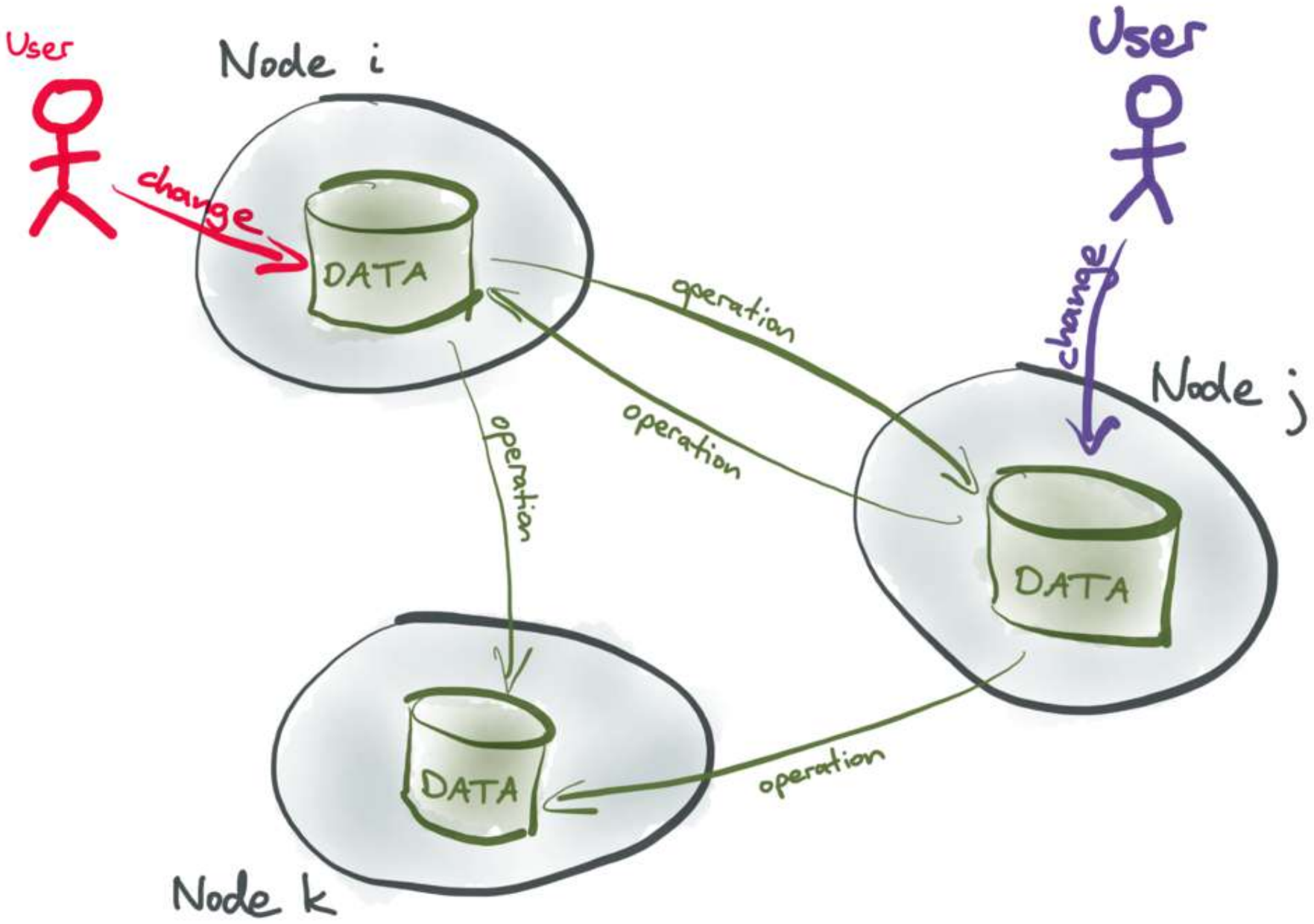
REPLICATION.



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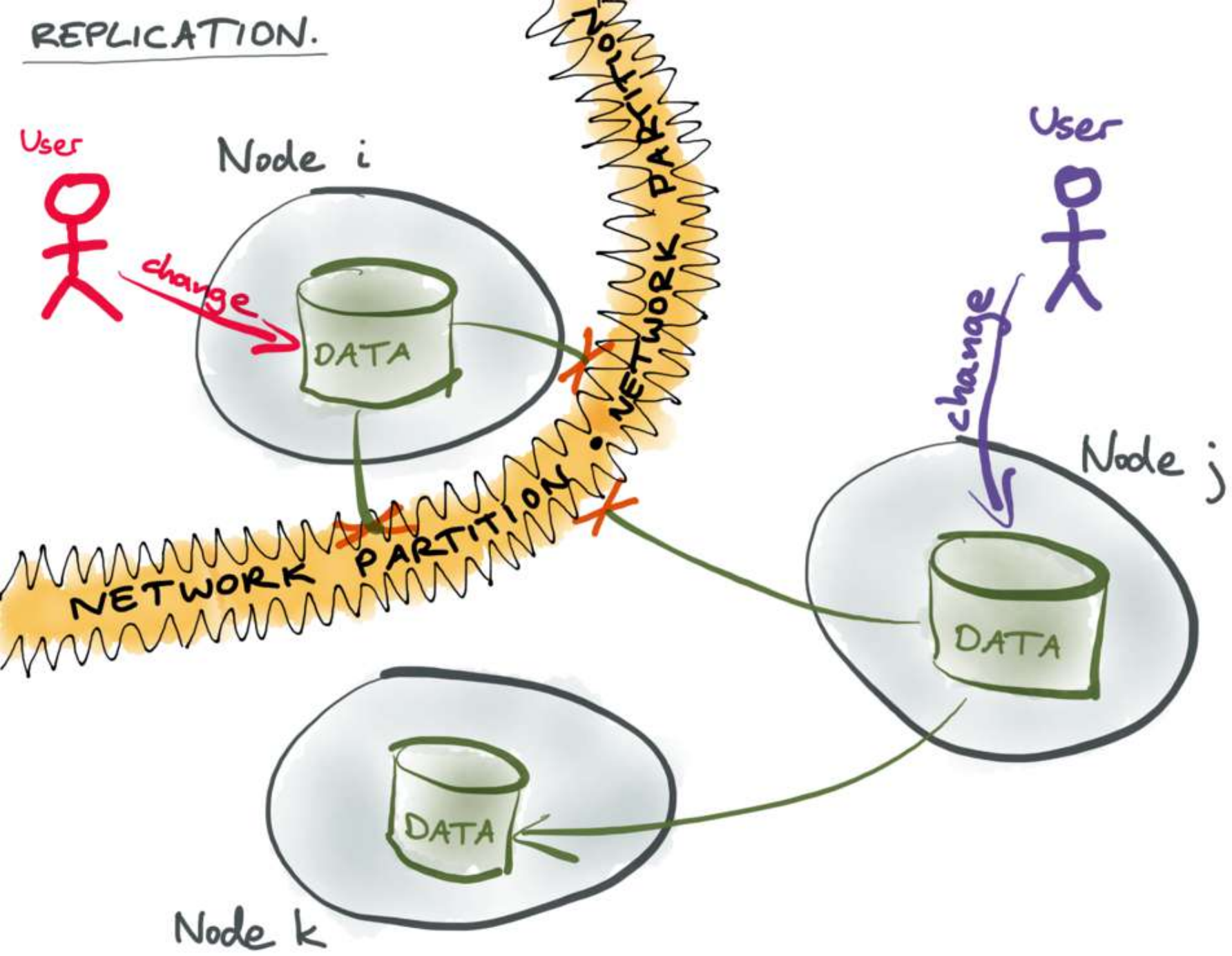


PROVING CRDTs CORRECT

RGA

ORSet

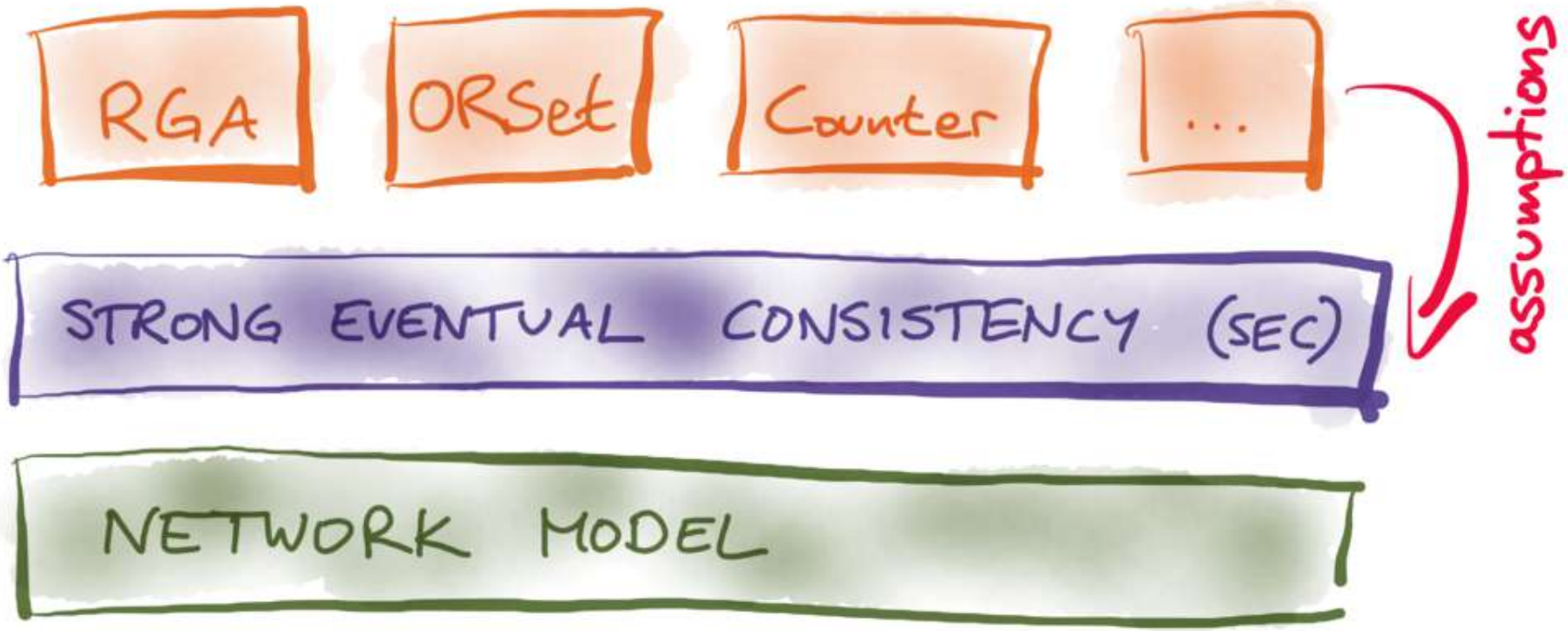
Counter

...

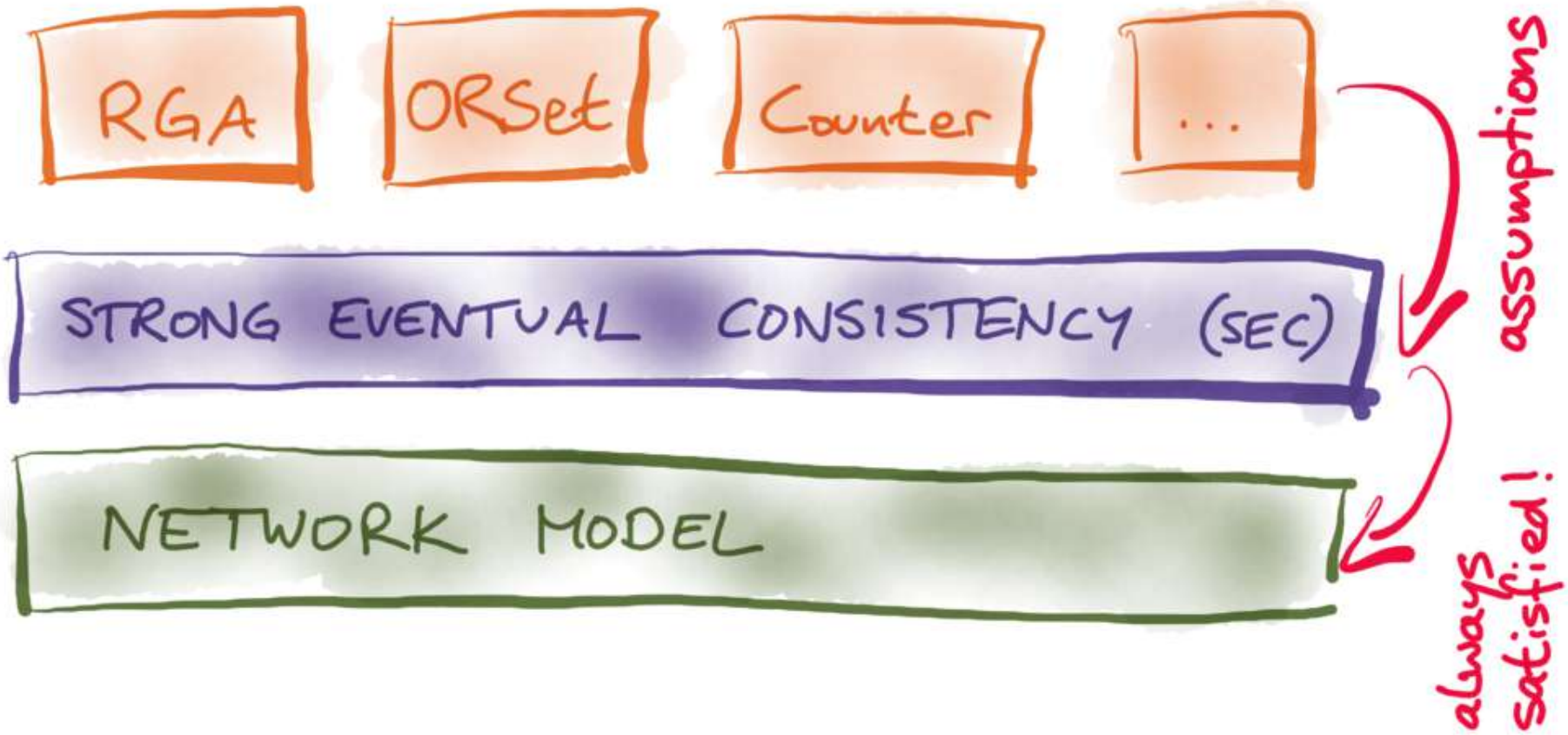
STRONG EVENTUAL CONSISTENCY (SEC)

NETWORK MODEL

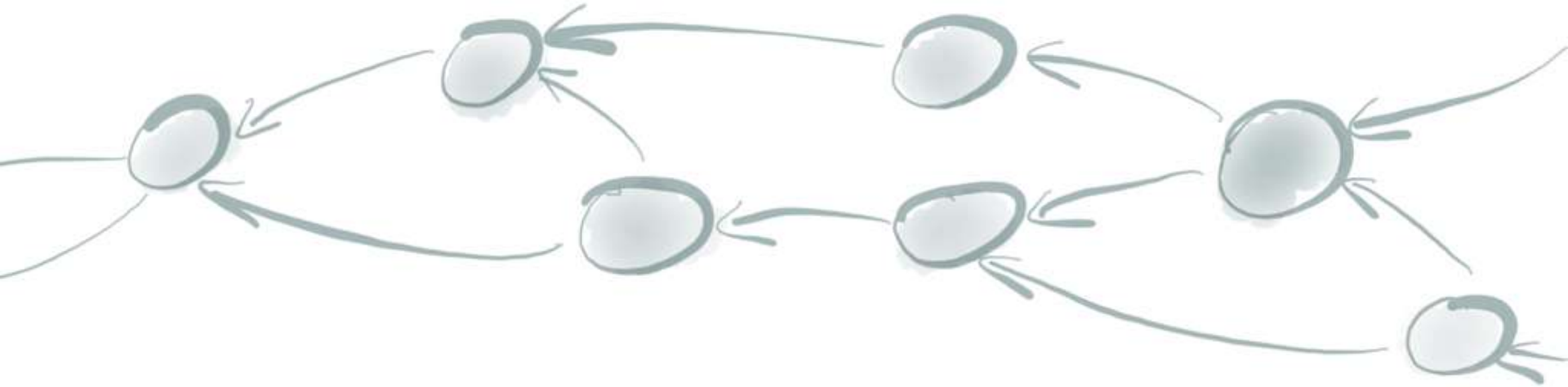
PROVING CRDTs CORRECT



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.

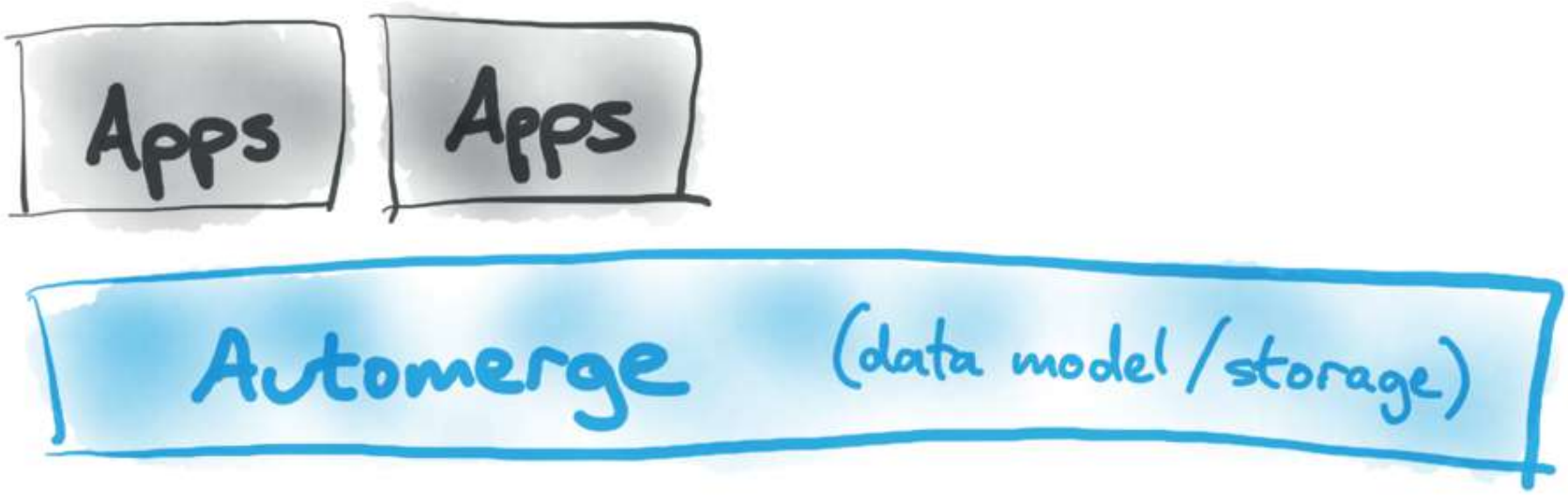


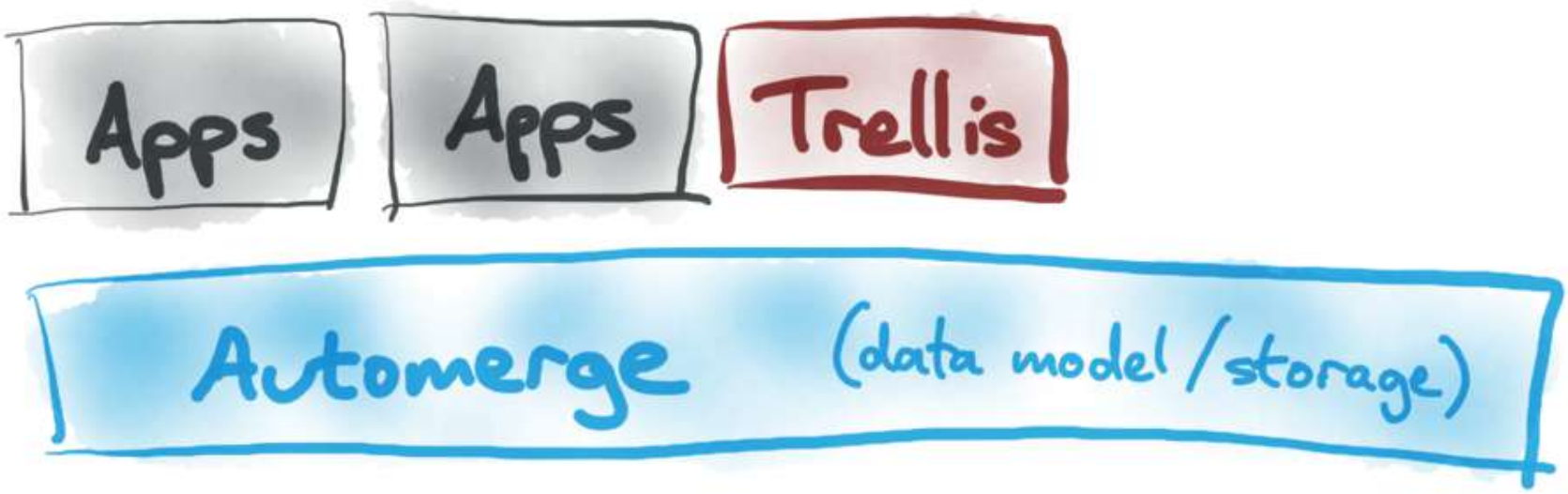
Automerge

Ink & Switch

https://github.com/automerge/automerge


Automerge
(data model / storage)


Apps
Apps
Automerge
(data model / storage)



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

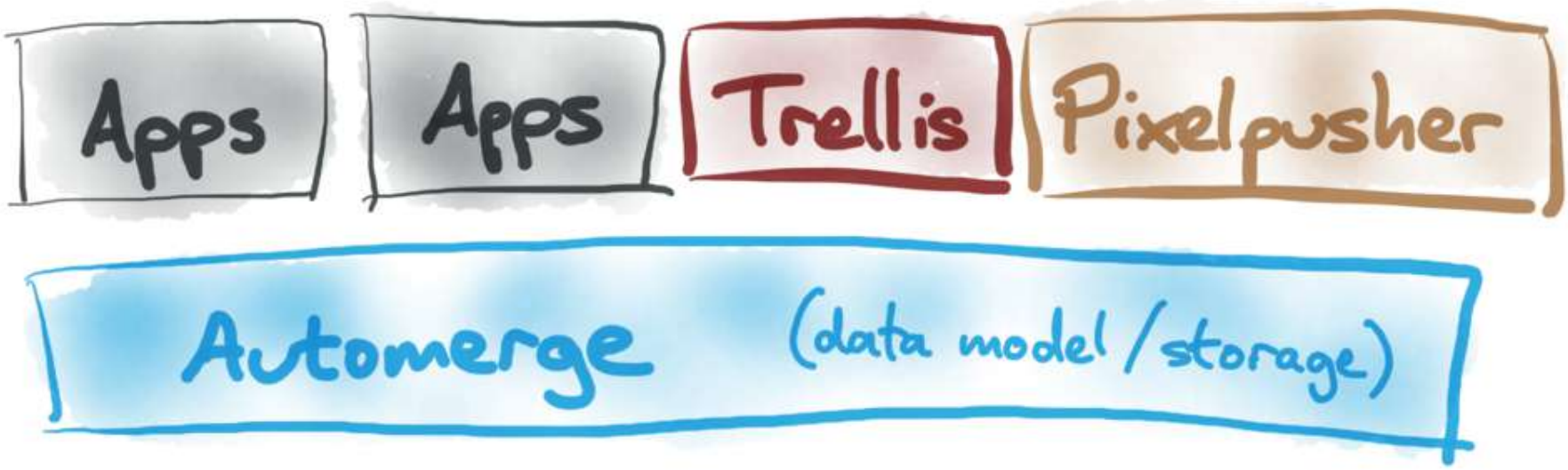
- Iron Man
  - 

Add a card...

JOINED THE TEAM

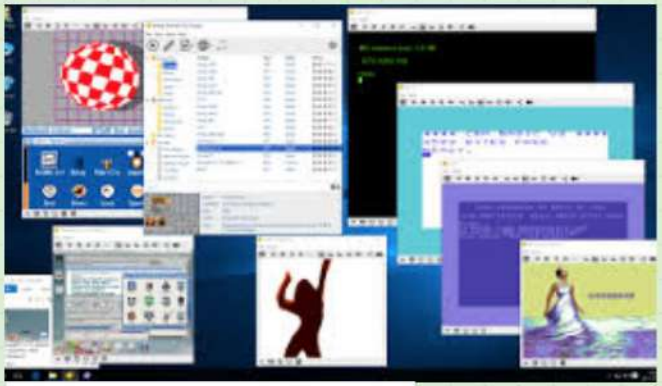
- Black Widow
  - 
- The Hulk
  - 1
  - 

Add a card...



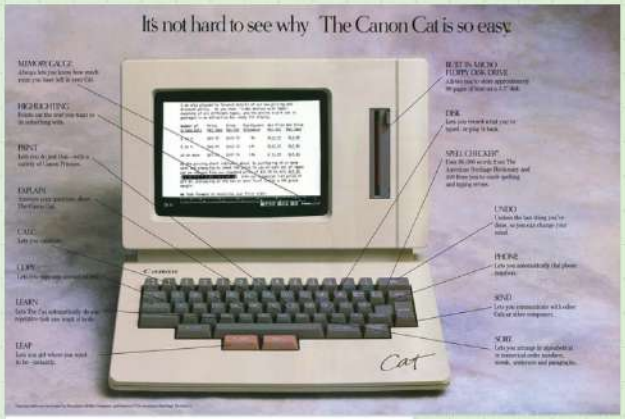
Pixelpusher, a collaborative pixel art editor: https://github.com/automerge/pixelpusher
Created by Javier Valencia, Jeff Peterson, Peter van Hardenberg, and Jim Pick.

pixelpusher client 0
PIXELPUSHER
pxlpshr://GZCp5Yt3YJ5vmFFShne9Yx4nZJpJpTFWPJoWATa4701X/3JB
Projects
Preview
Reset
Sailing Midnight
Versions
Sailing Mid...
Sailing Mi...
Archivers
+
Pixel Size
10
Duration
1
24
24
0

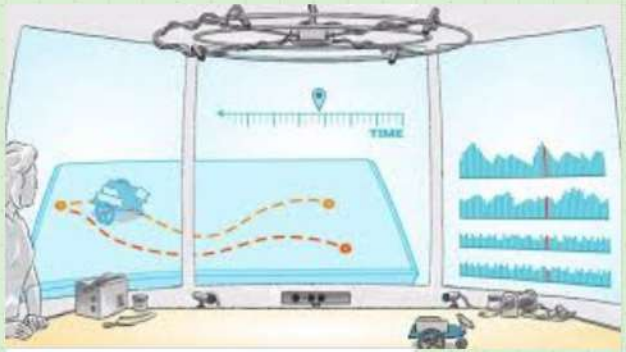


Amiga

BeOS



Canon Cat



Seeing Spaces

Inking

Nested boards

Berlin Team Summit Venues

1st choice

Hotel Oderburger

2nd choice

Gerli Apts

Others...

Hotel MANI

Mon bijou

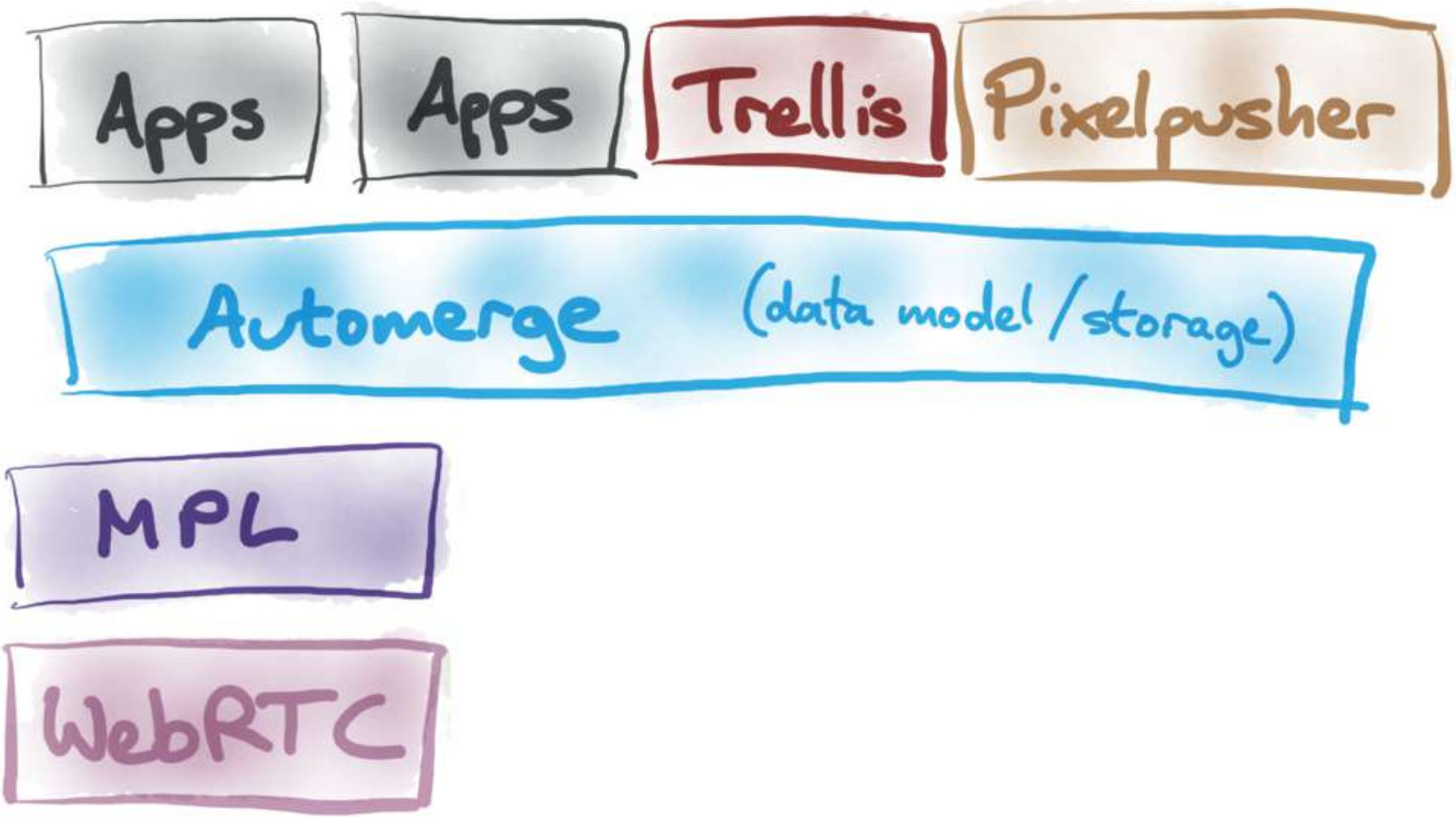
SOHO House

Unicorn coworking space

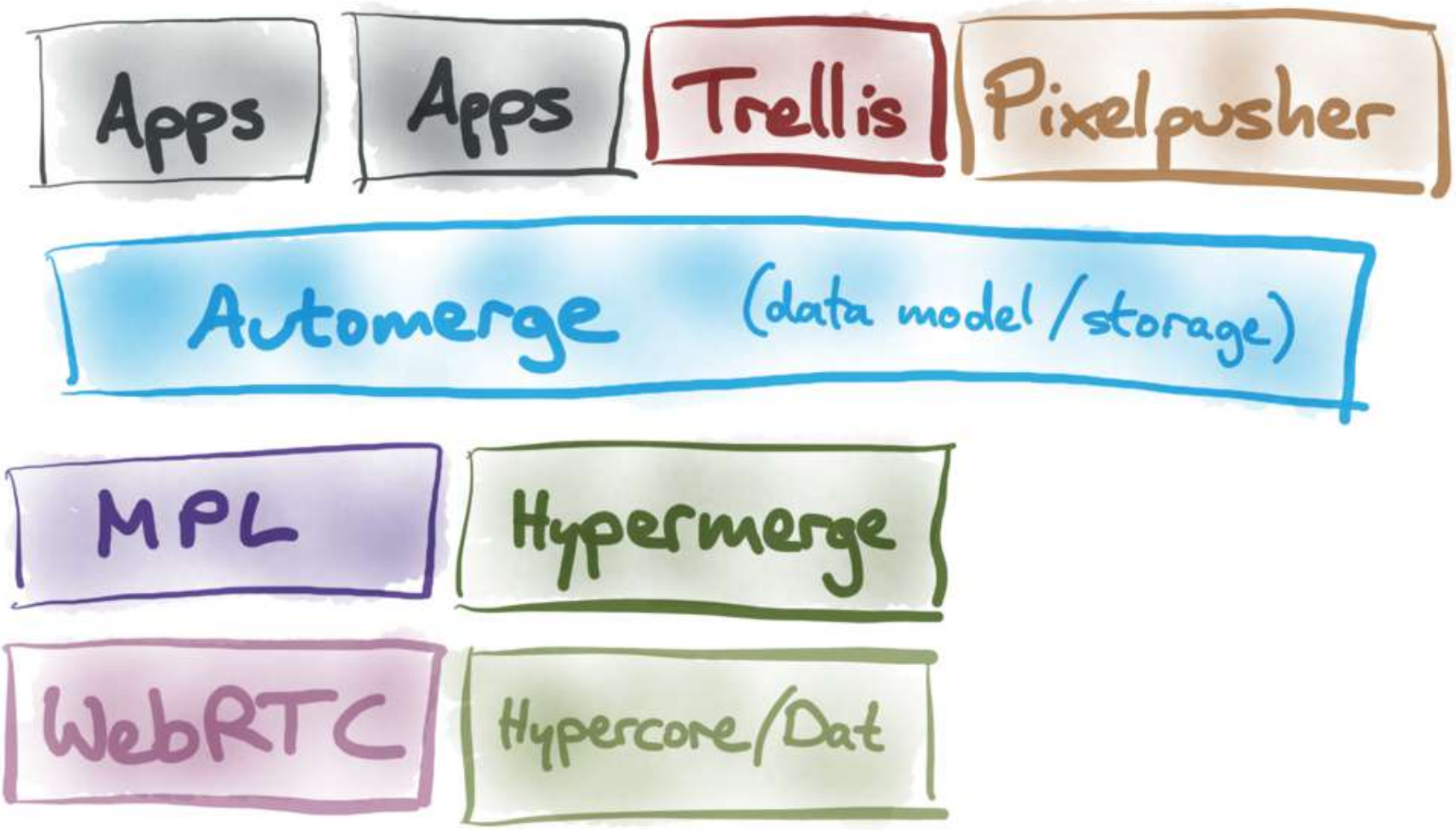
- cool space bit smallish
- Oblivon room is 1350 + VAT for the week
- not far from mauerpark and that fun stuff but not quite in it, on a somewhat boring / prtical steet

Shelf

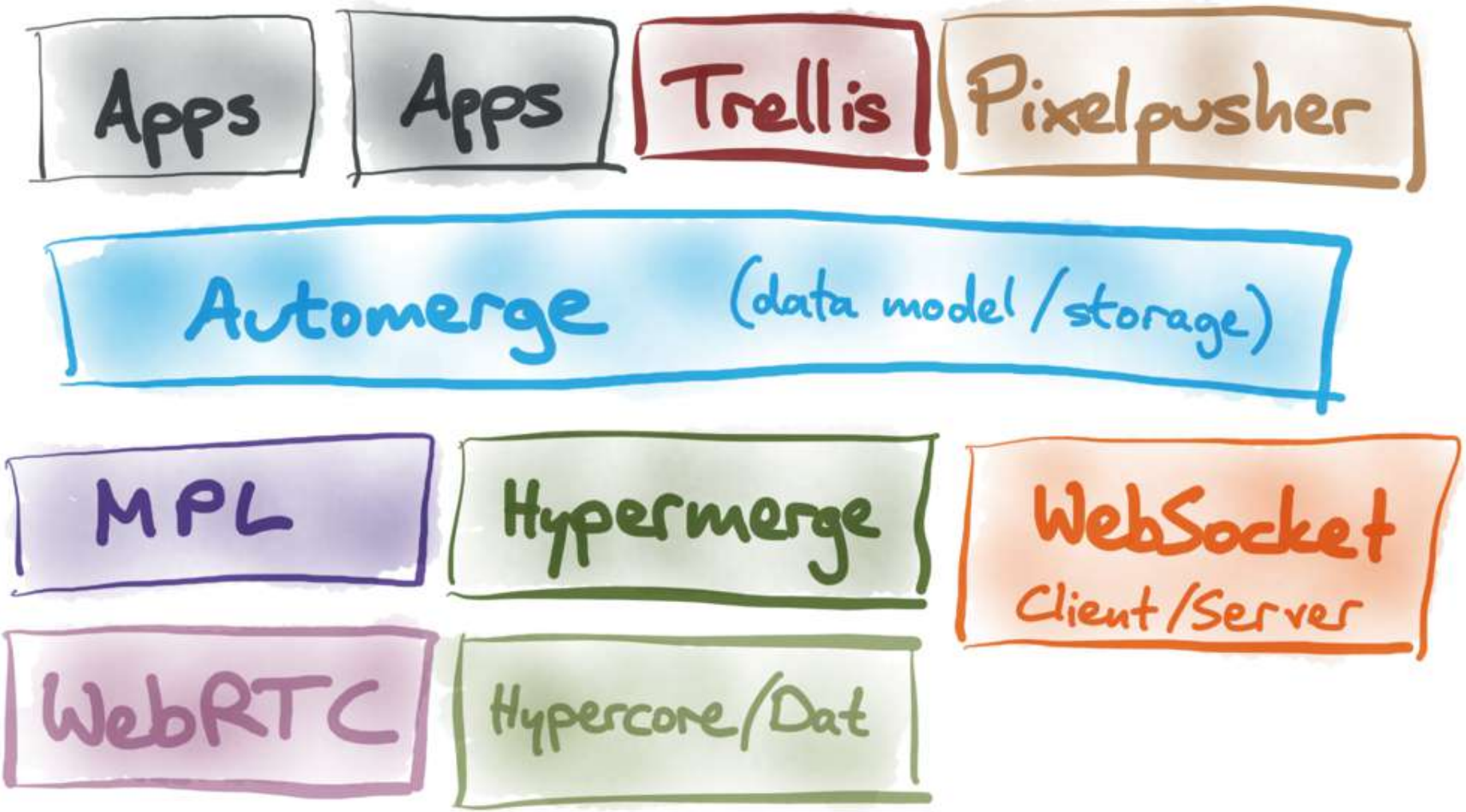
Ink/erase mode controls



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.



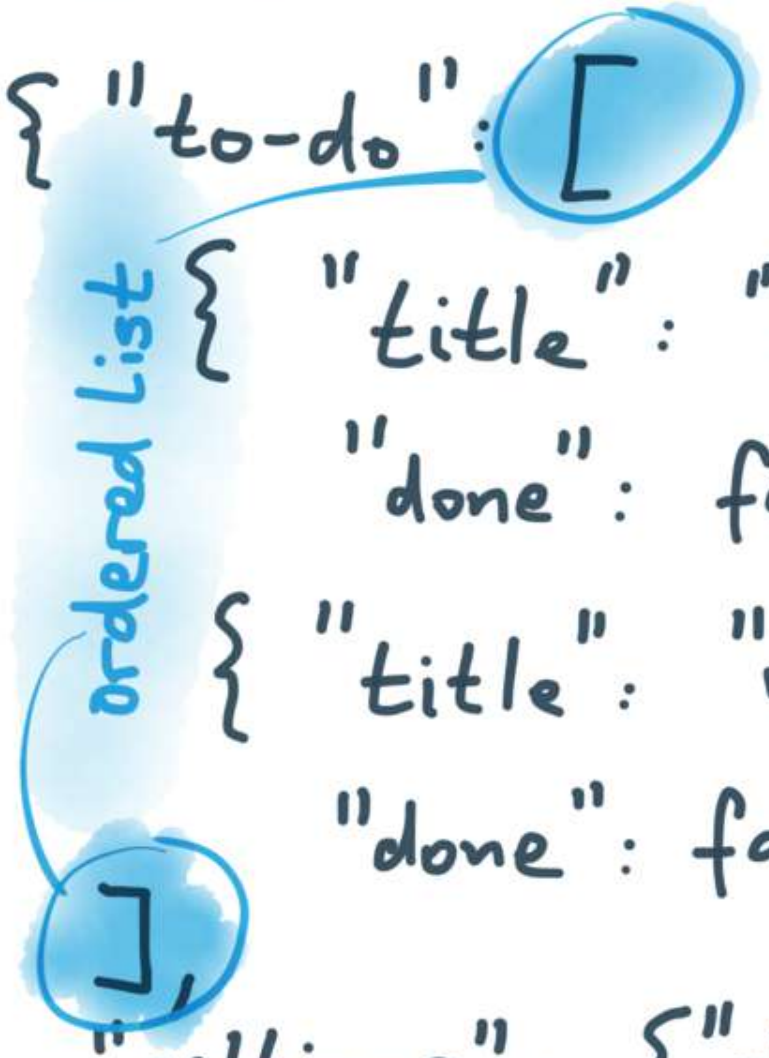
Hypermerge, a peer-to-peer network layer: https://github.com/automerge/hypermerge
Created by Jim Pick, Jeff Peterson, and Peter van Hardenberg.


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", ...}
}
```

APPLICATION DATA (JSON)

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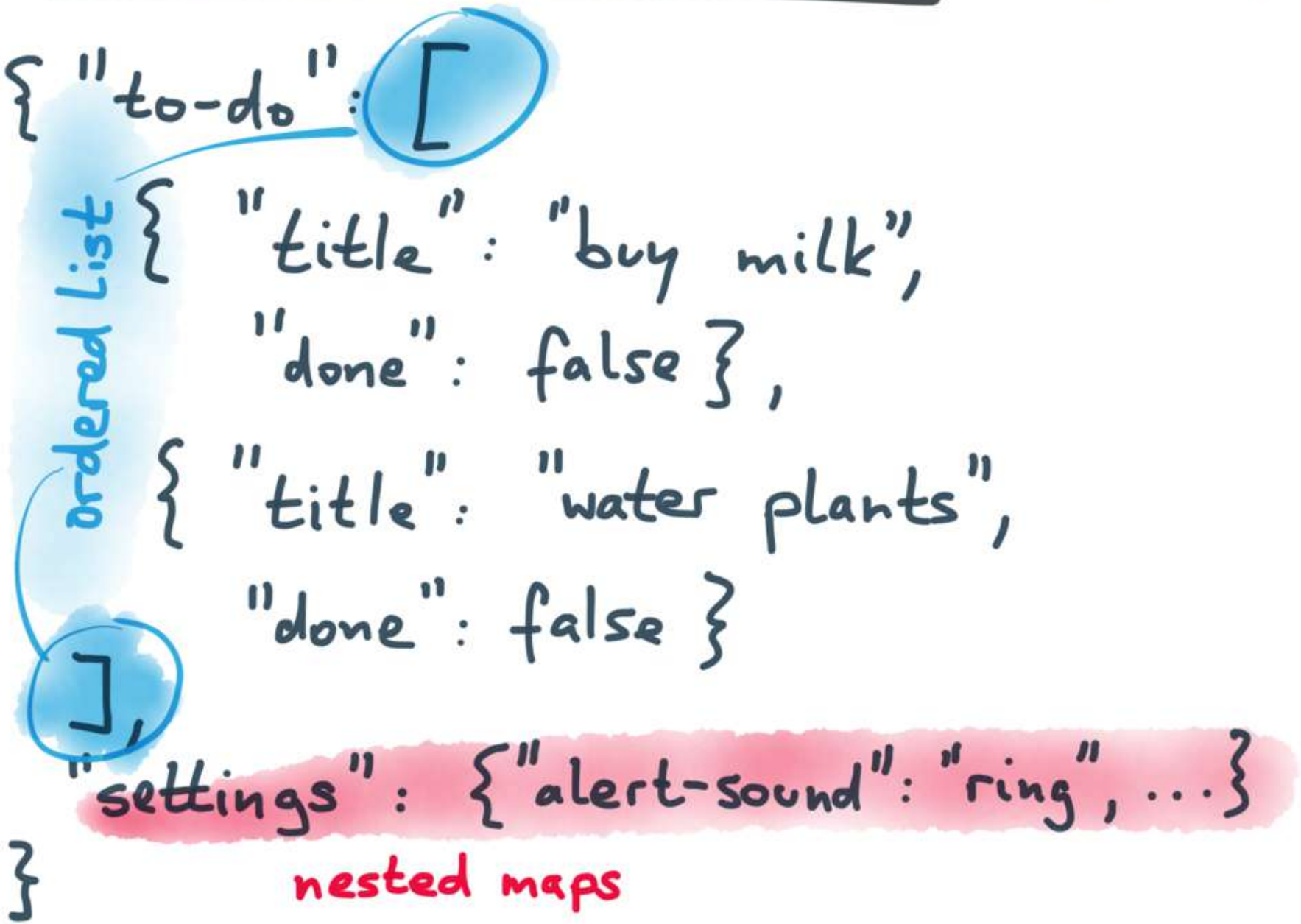

EDITING OPERATIONS

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}
```

true

value assignment

EDITING OPERATIONS

string editing

value assignment

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{ "to-do": [
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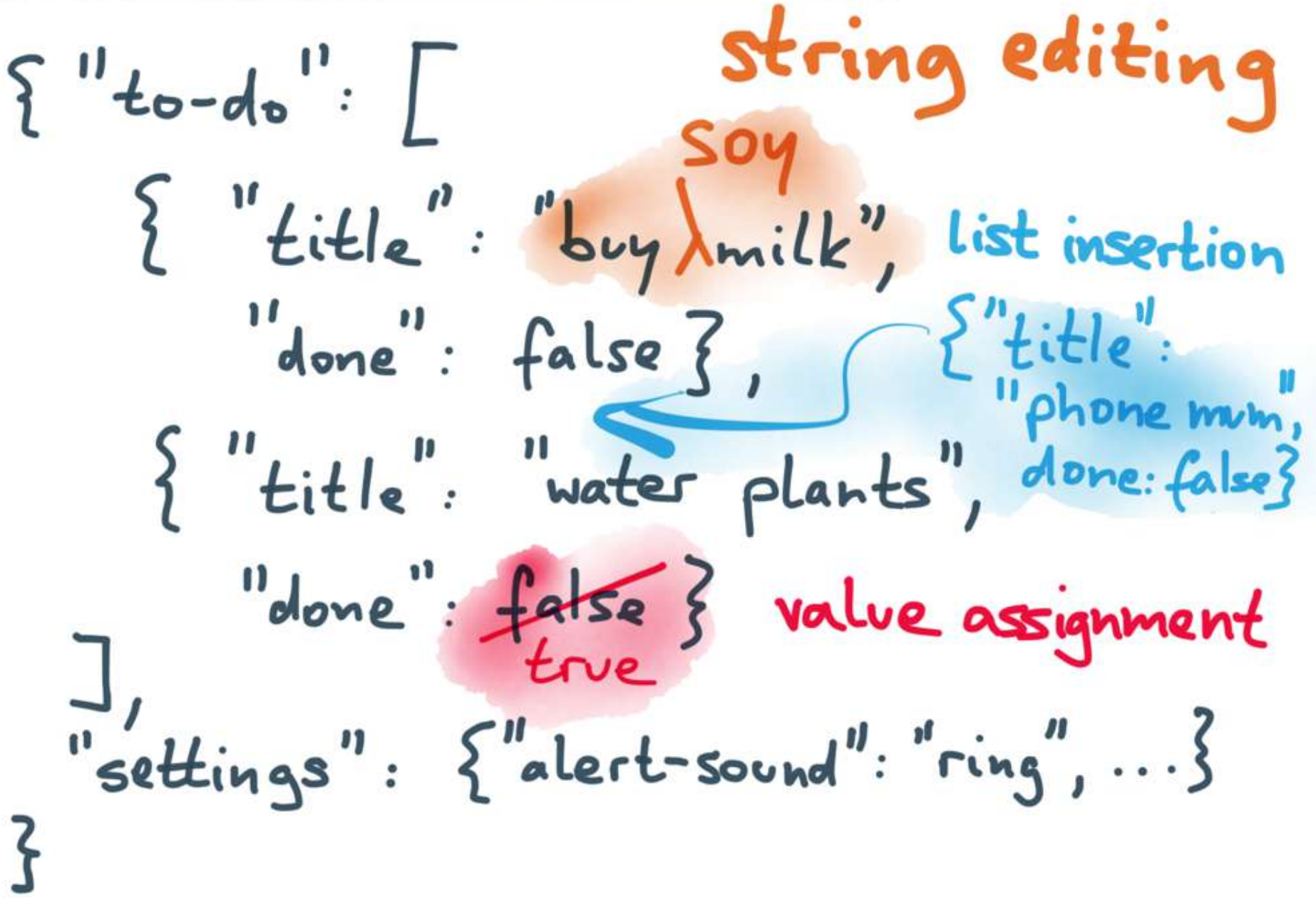
}
```

soy

λ

true

EDITING OPERATIONS



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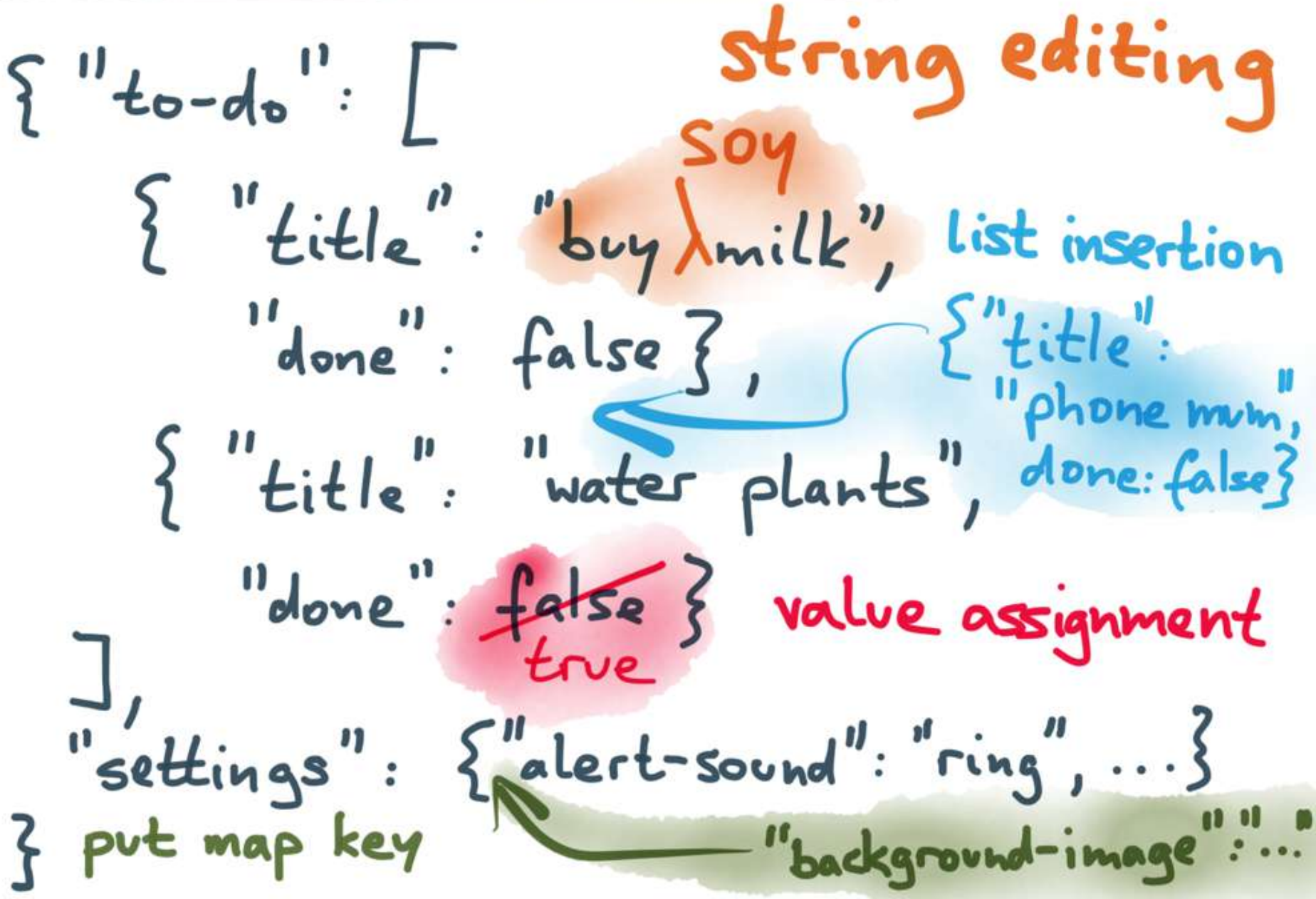

```
state = Automerge.change(state, "Add todo item",
  (doc) => {
    doc.todos.push({
      title: "Buy milk",
      done: false
    })
  })
```

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

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

"Commit message" (optional)

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

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(optional)

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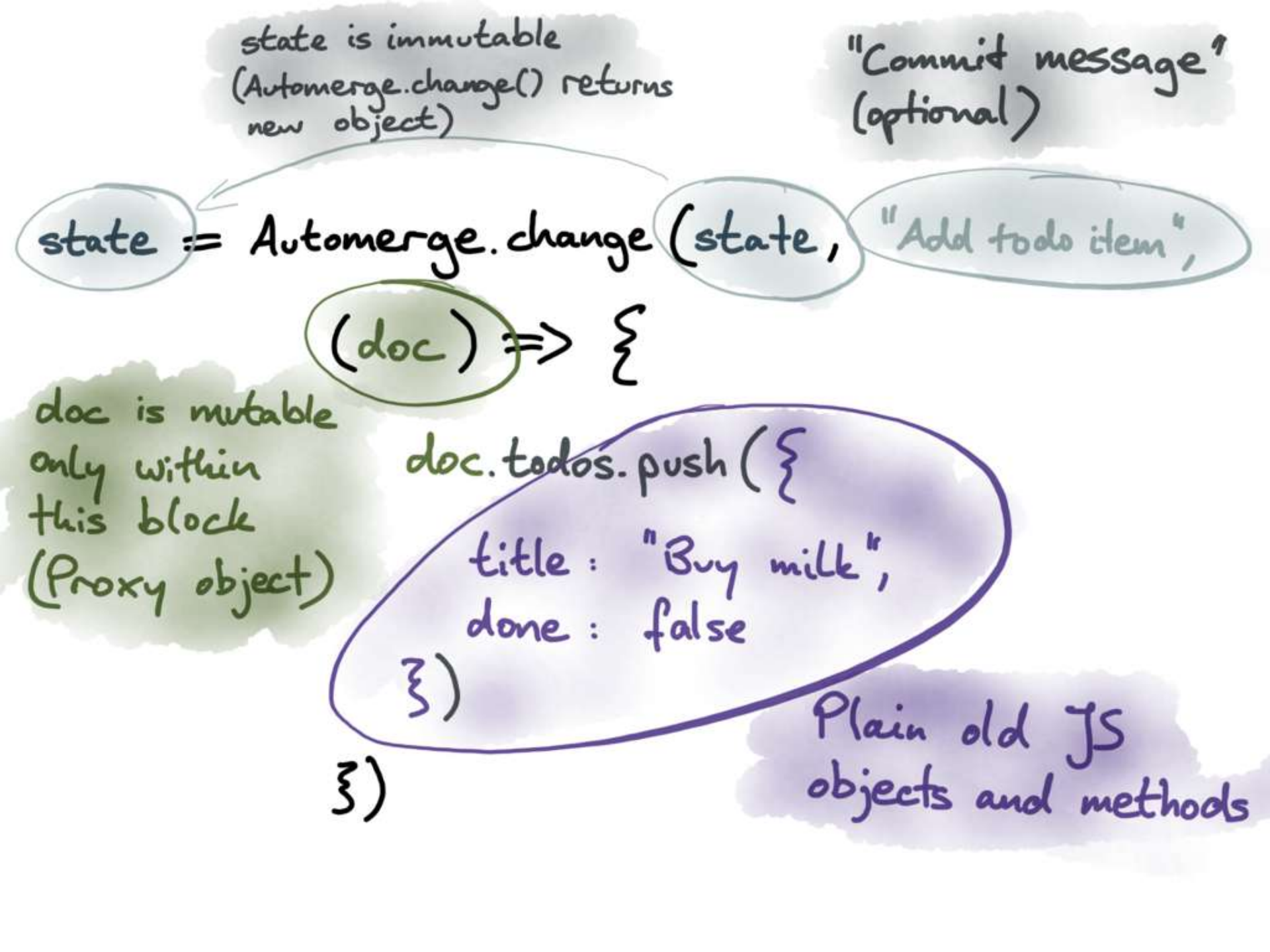
  (doc) => {
    doc.todos.push({
      title: "Buy milk",
      done: false
    })
  })
```

doc is mutable
only within
this block
(Proxy object)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(Automerge.change() returns
new object)
"Commit message"
(optional)
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doc is mutable
only within
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}
```

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

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

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

CONCURRENT CHANGES

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

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

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

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

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",
    done: false
})
```

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

network communication

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

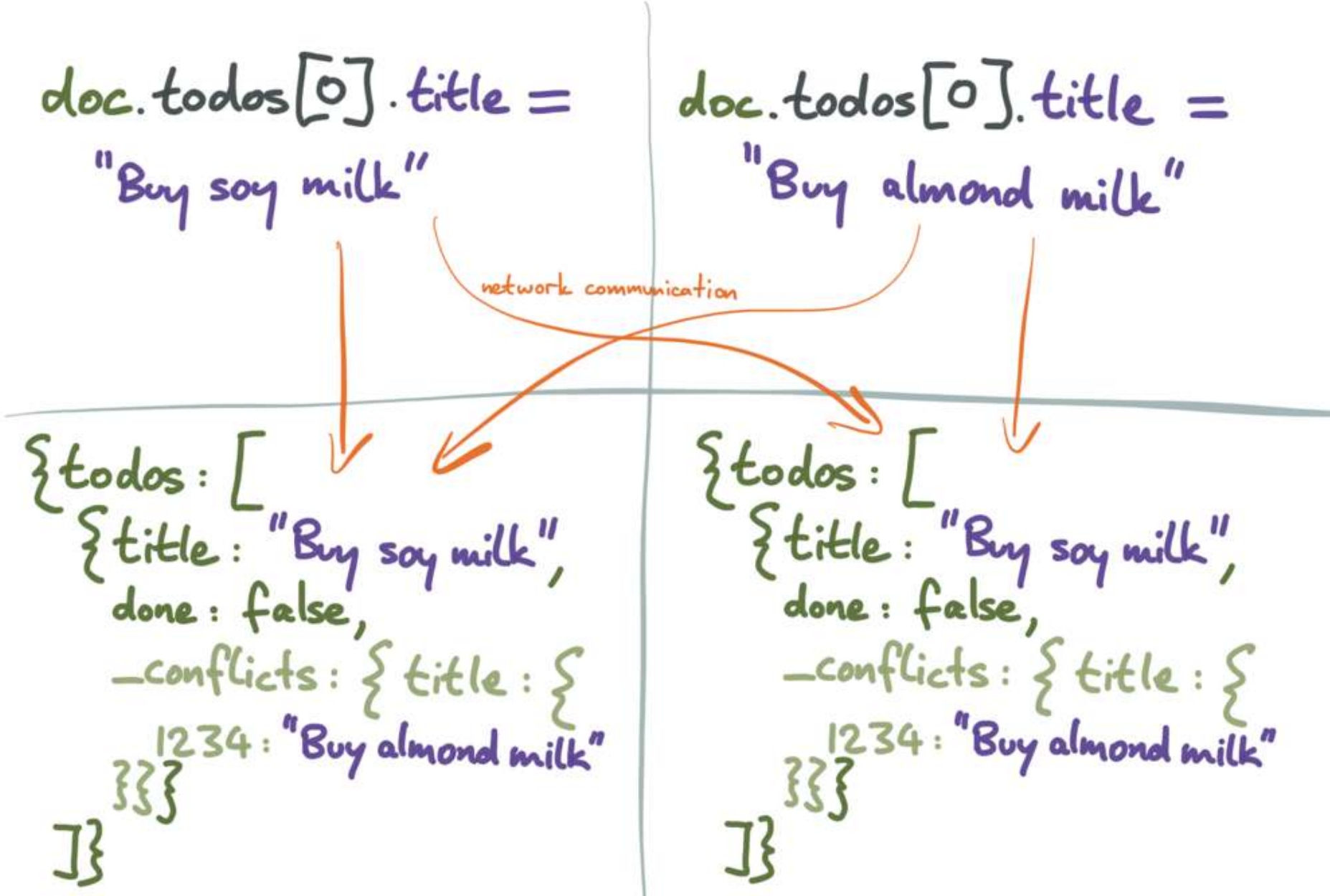
```
{todos: [
    {title: "Water plants",
     done: true},
    {title: "Buy milk",
     done: false}
]}
```

CONCURRENT CHANGES

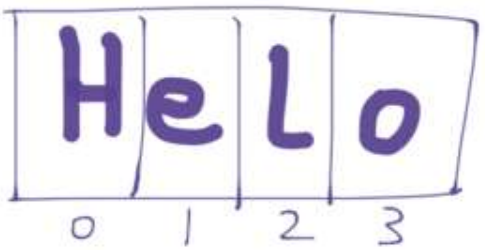
```
doc.todos[0].title =
  "Buy soy milk"
```

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

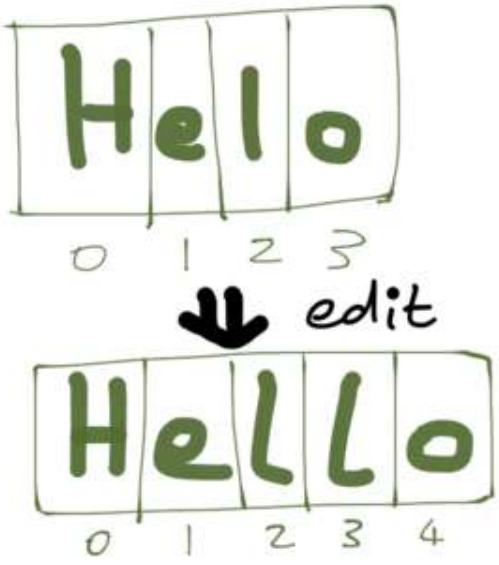
CONCURRENT CHANGES

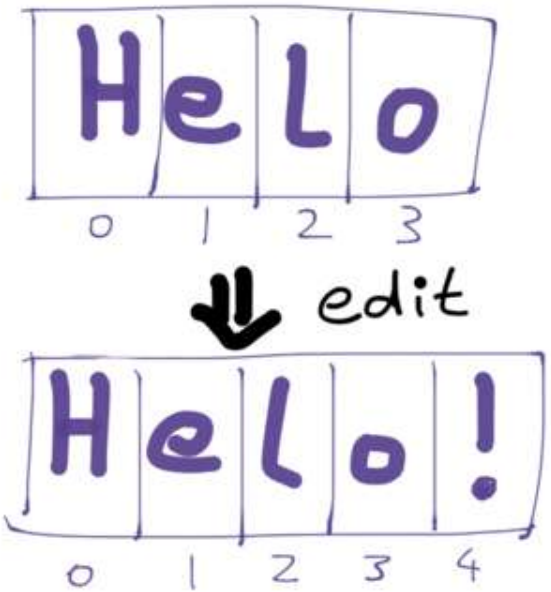


GOOGLE DOCS (NUTSHELL)



GOOGLE DOCS (NUTSHELL)





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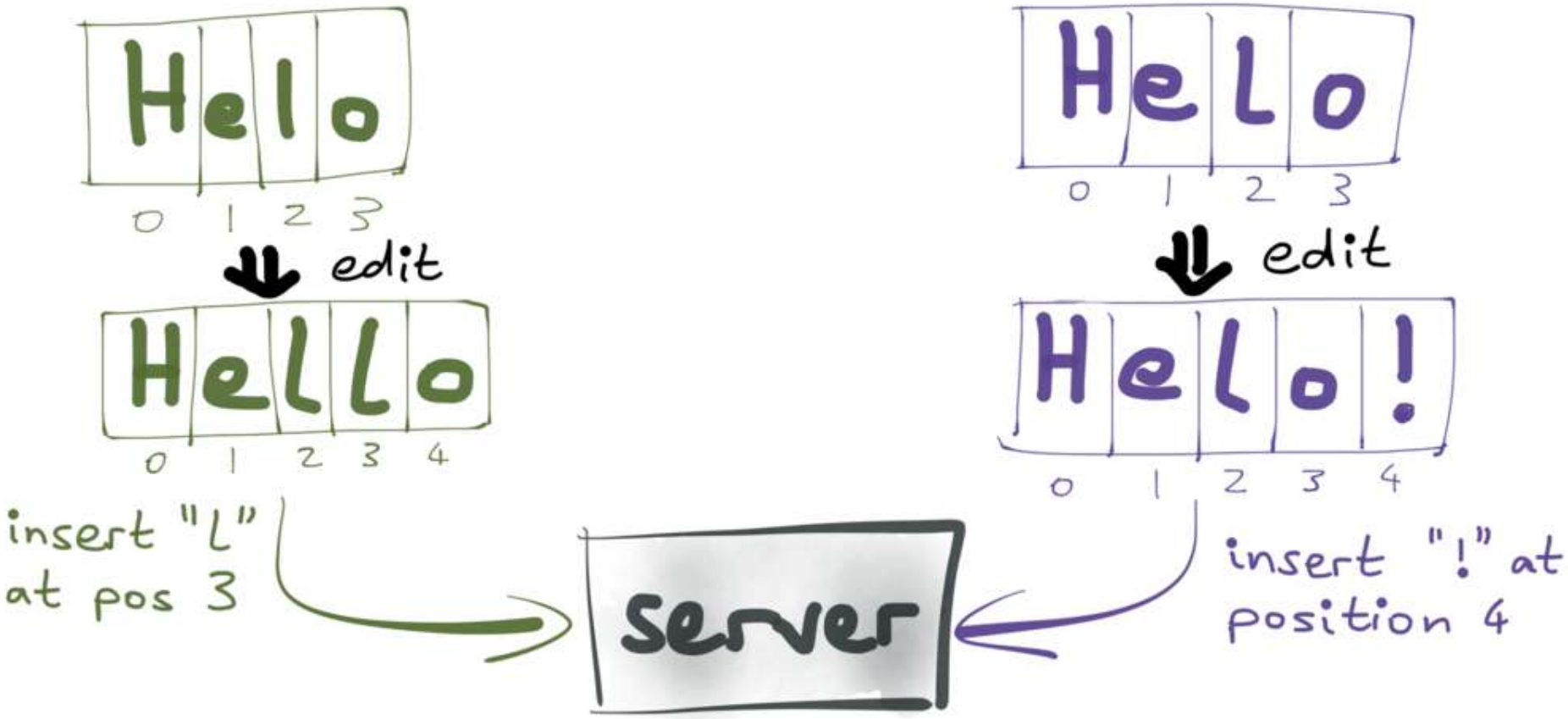
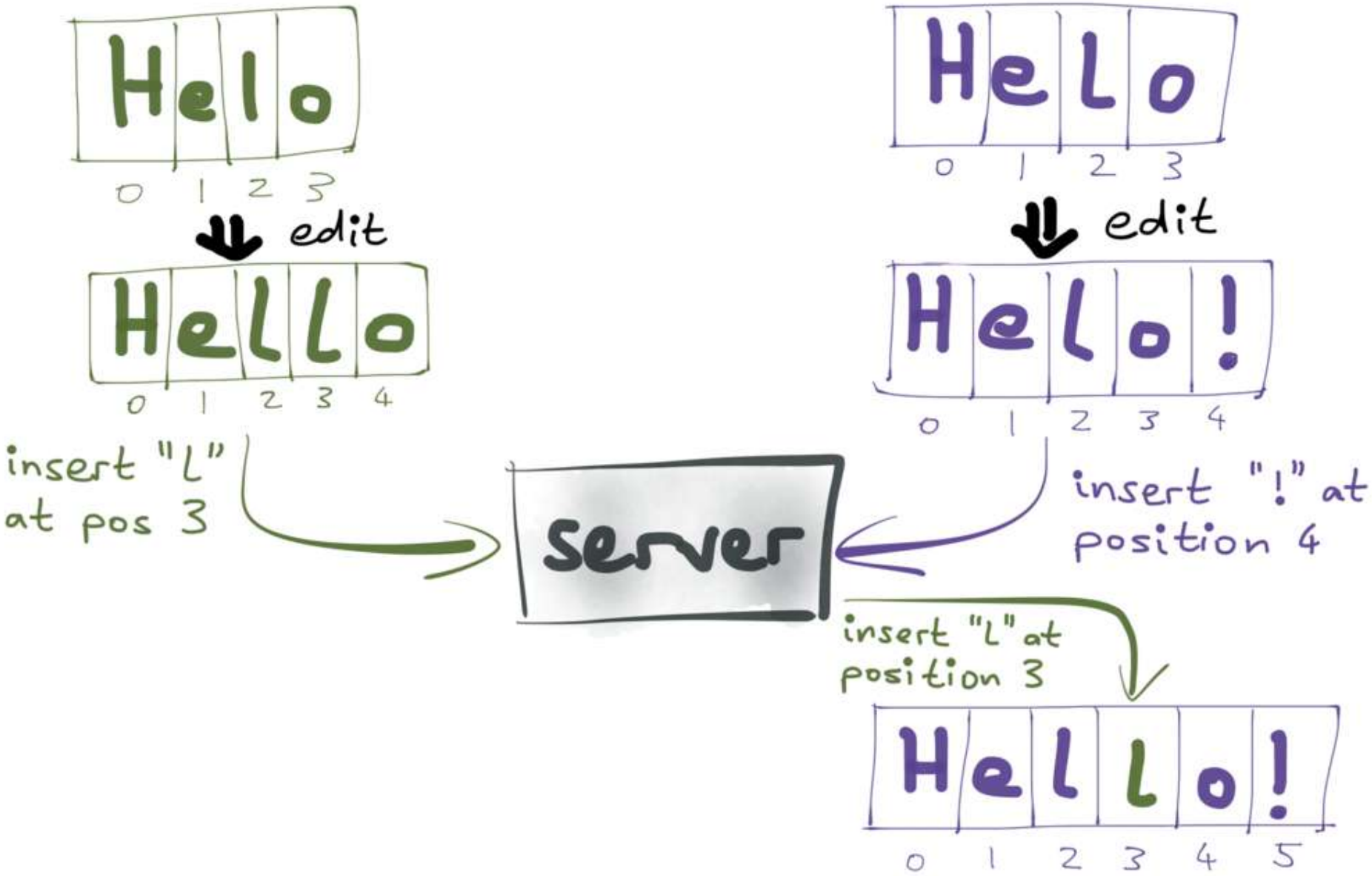
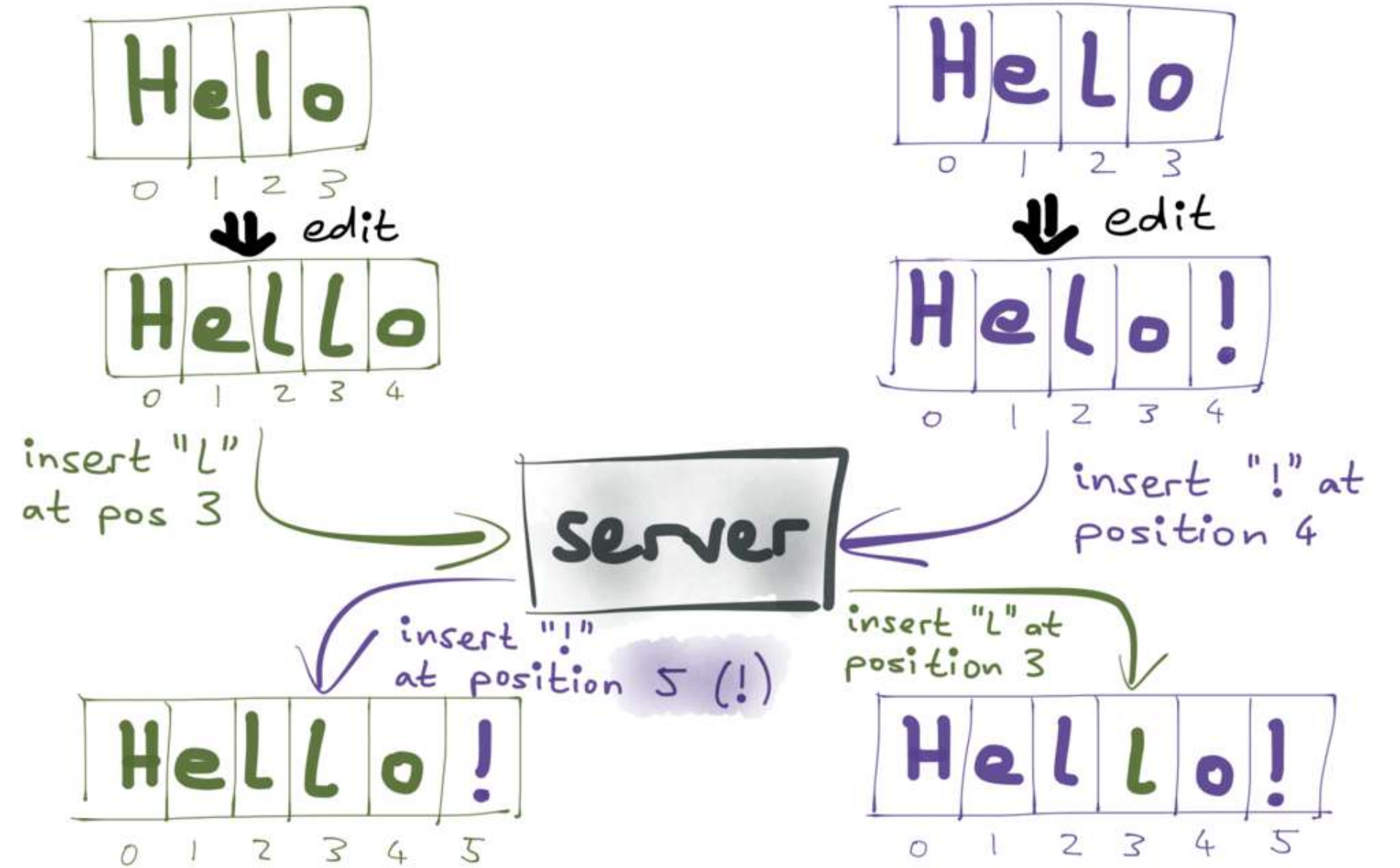


GOOGLE DOCS (NUTSHELL)



GOOGLE DOCS (NUTSHELL)

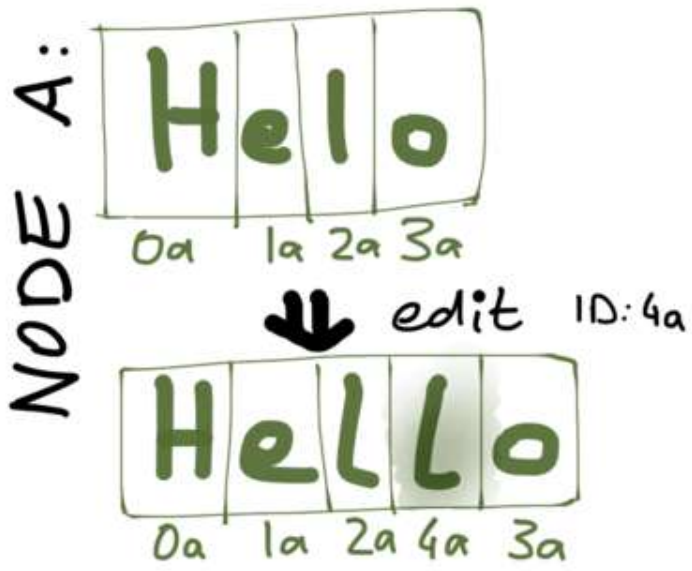


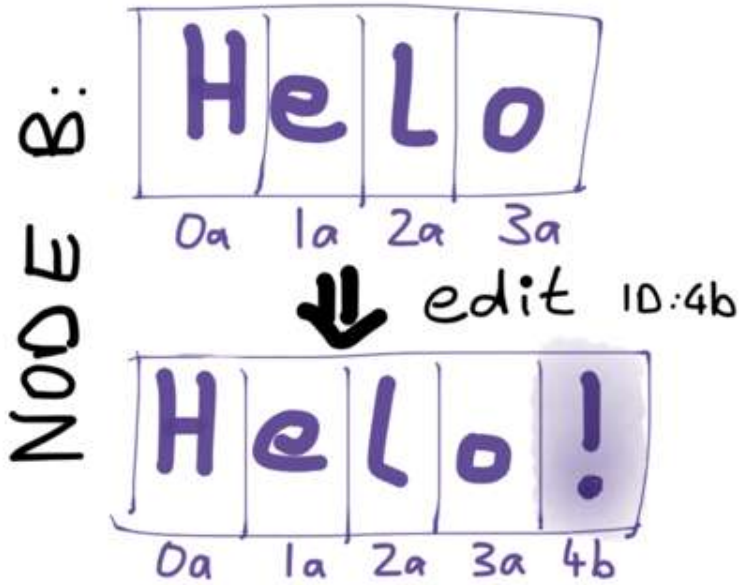
ORDERED LIST CRDT (NUTSHELL)

NODE A:

NODE B:

ORDERED LIST CRDT (NUTSHELL)





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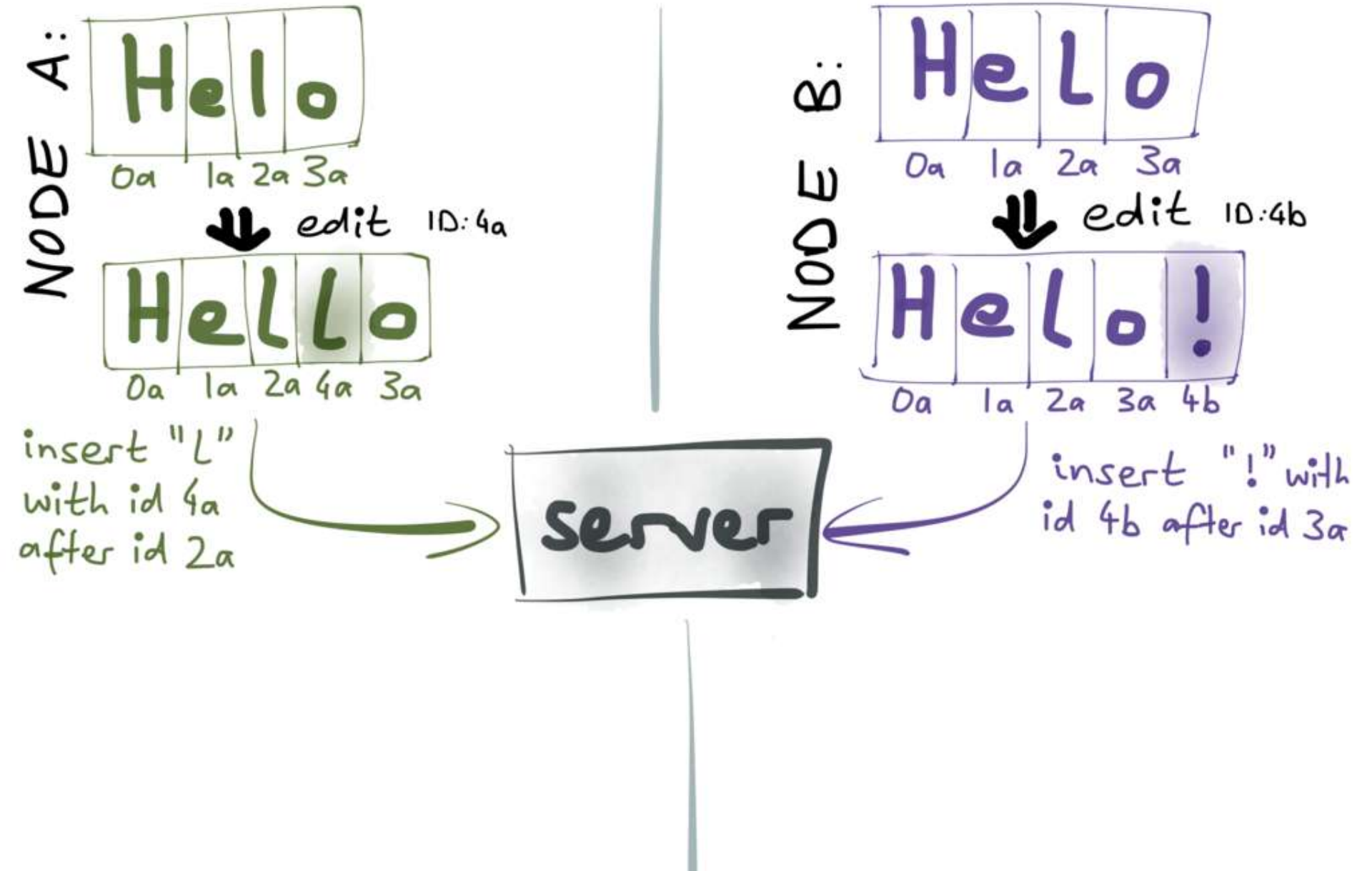
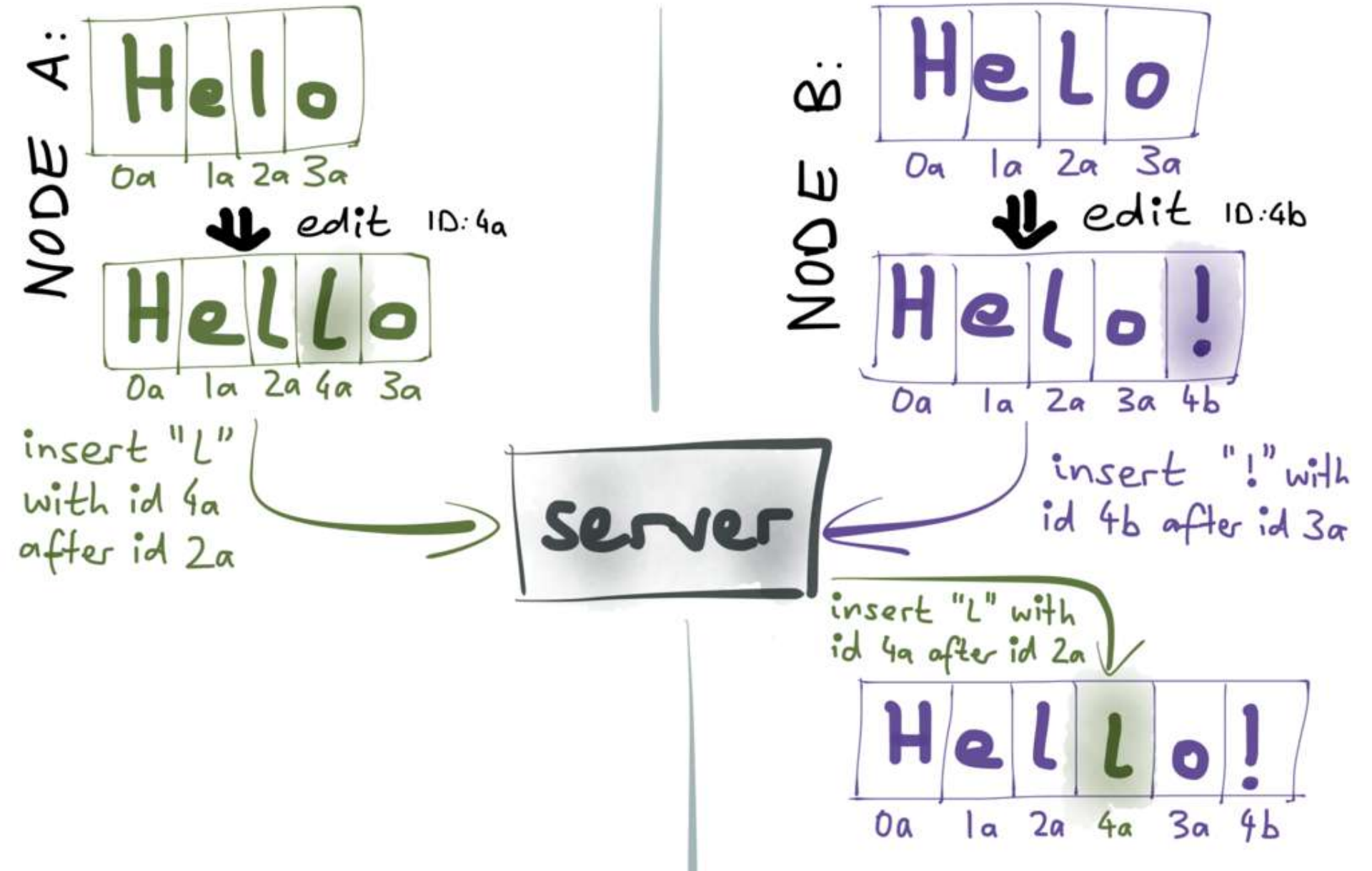
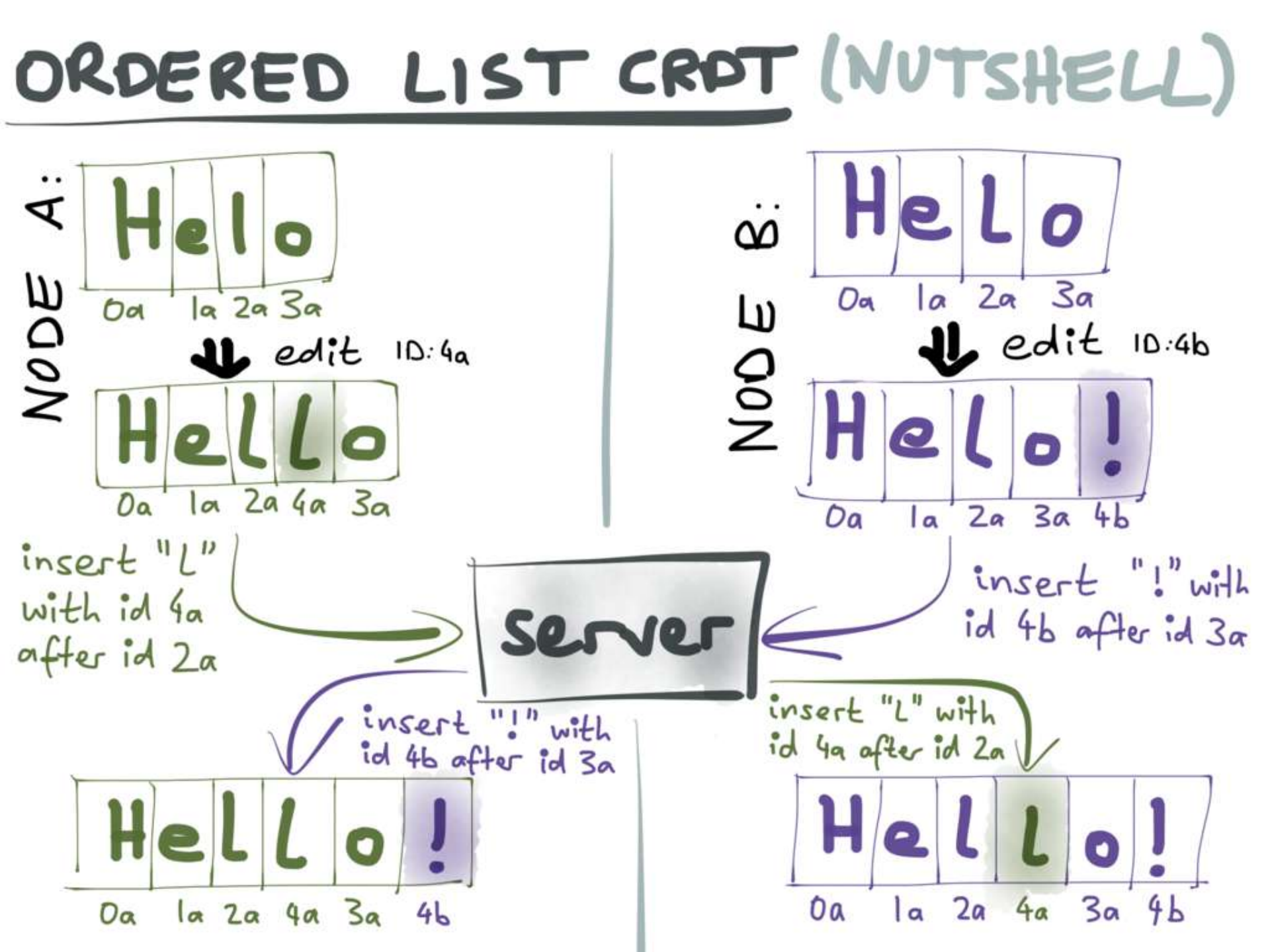


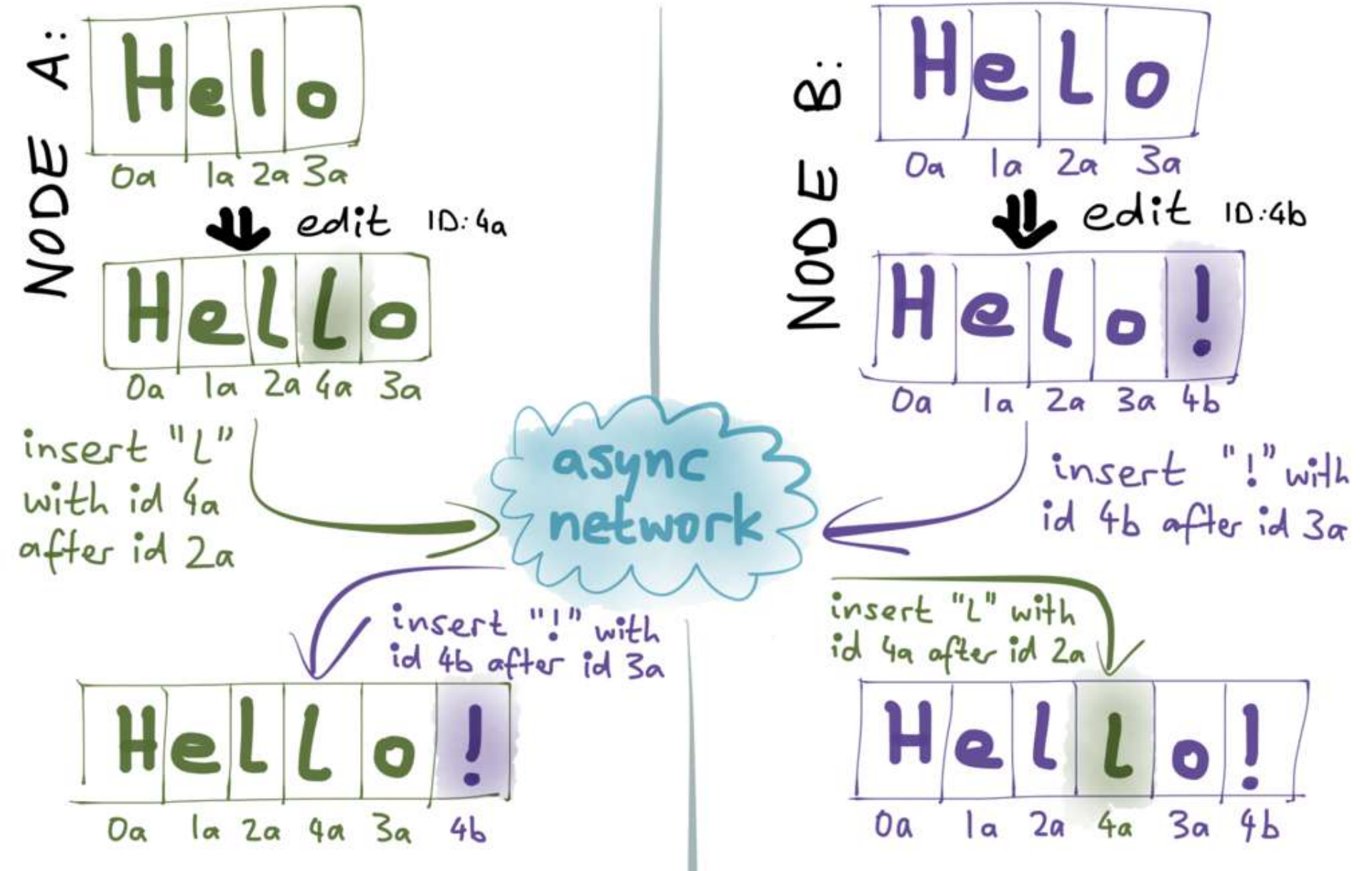
ORDERED LIST CRDT (NUTSHELL)



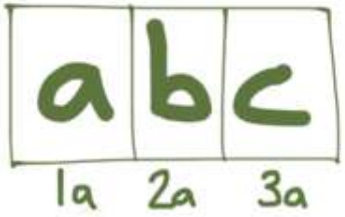
ORDERED LIST CRDT (NUTSHELL)

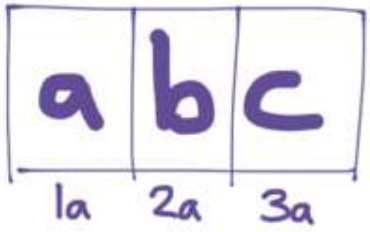


ORDERED LIST CRDT (NUTSHELL)



INSERTING IN THE SAME PLACE





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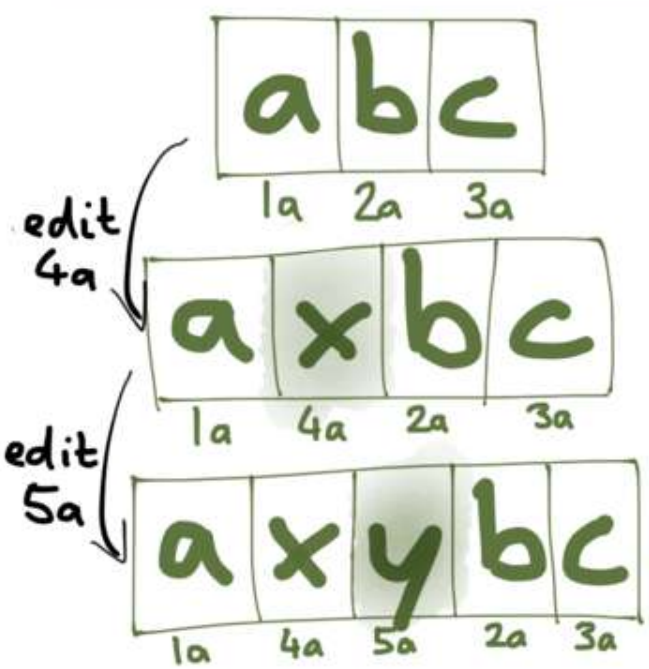

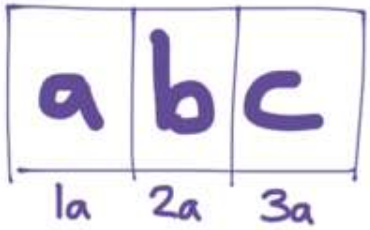

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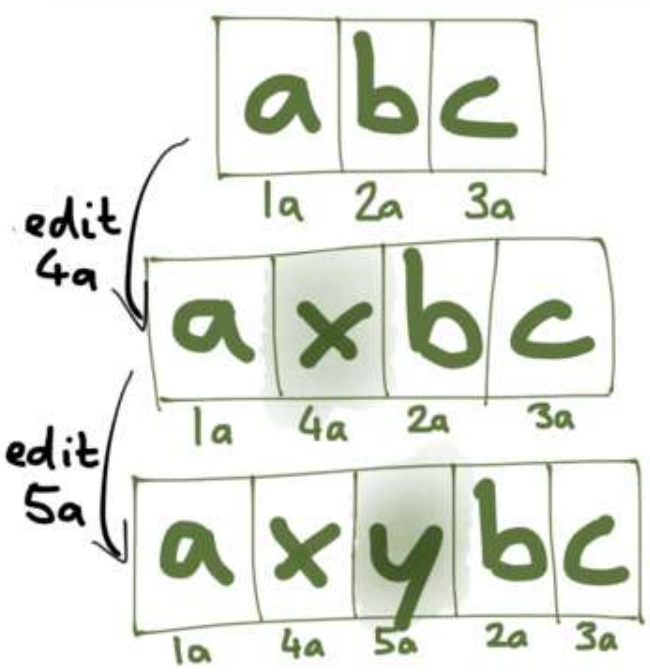

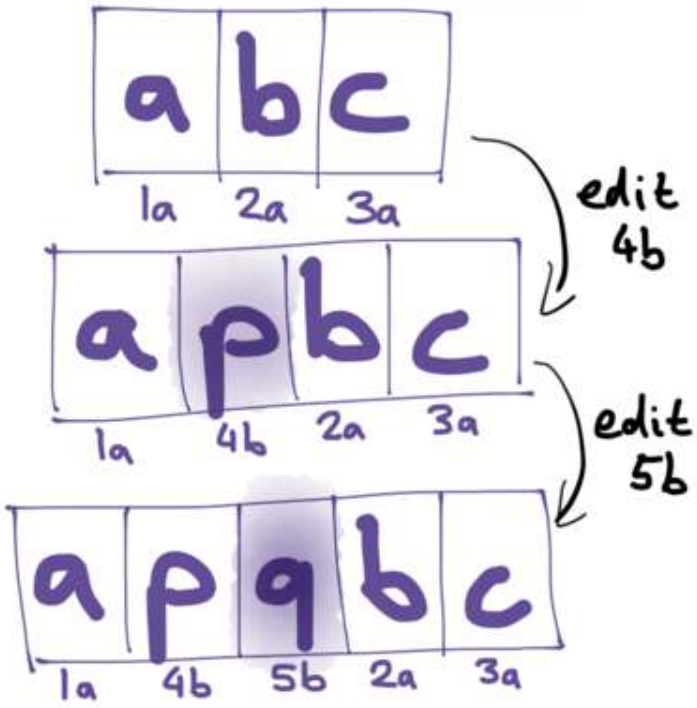

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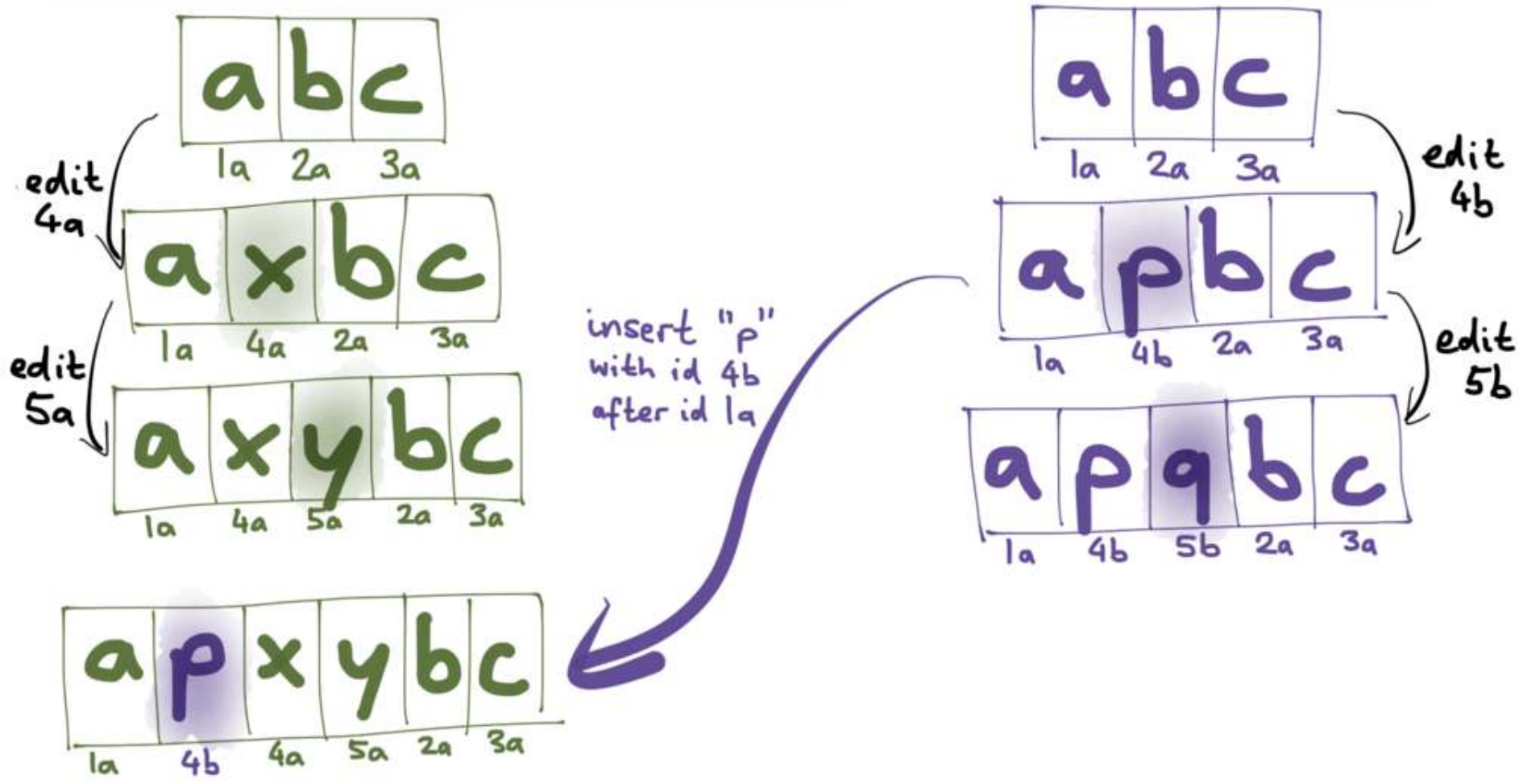

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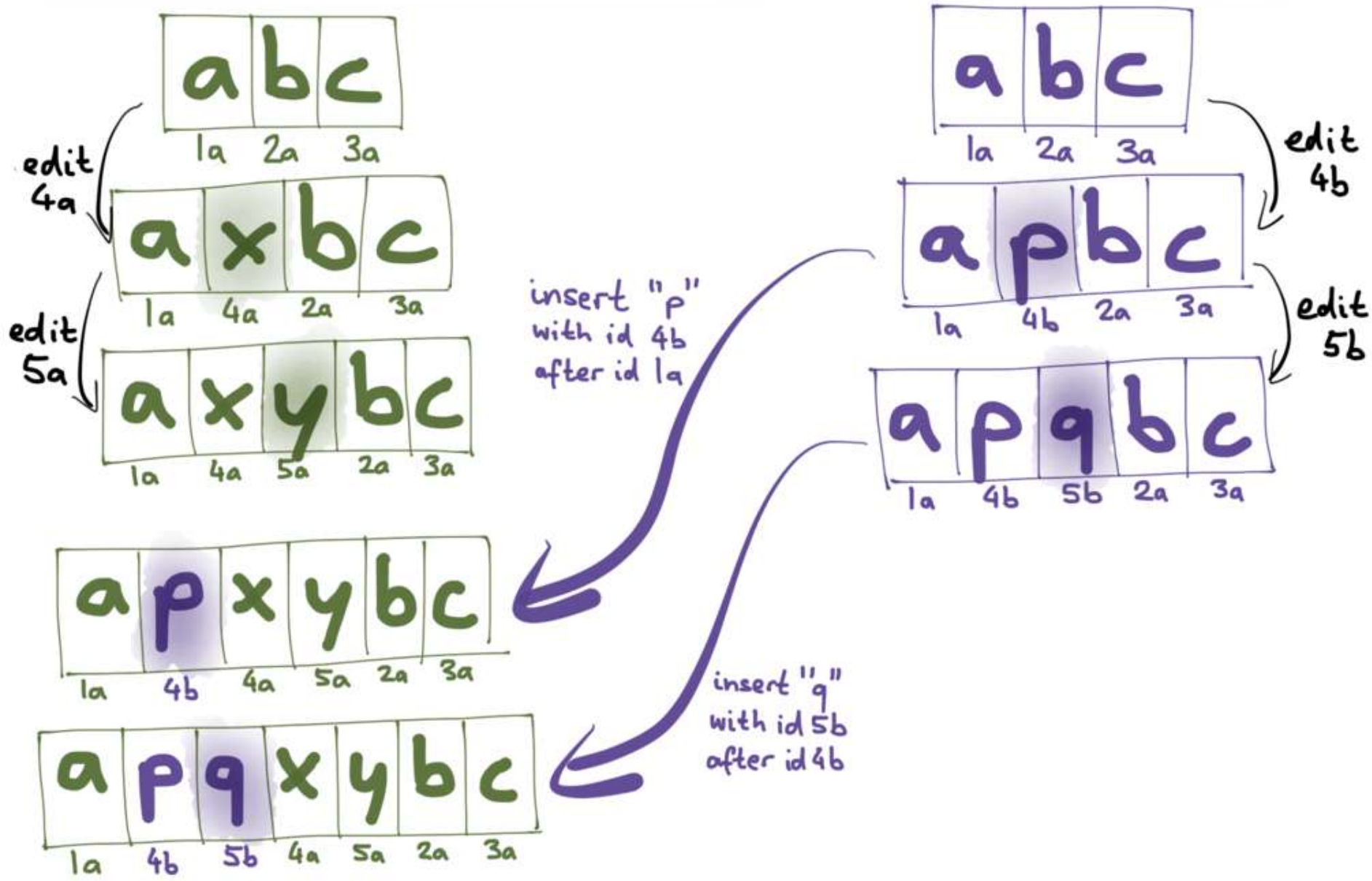

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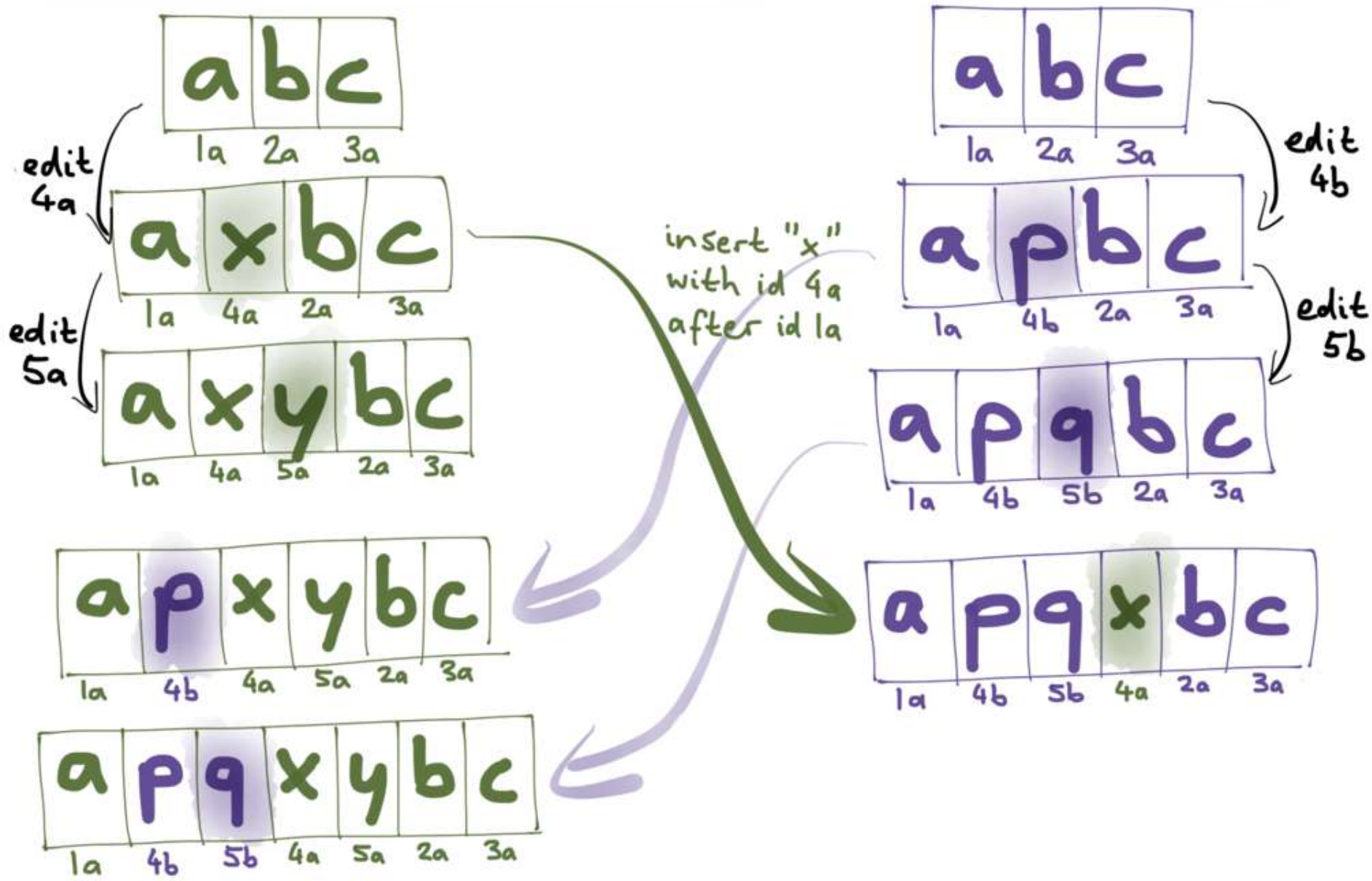

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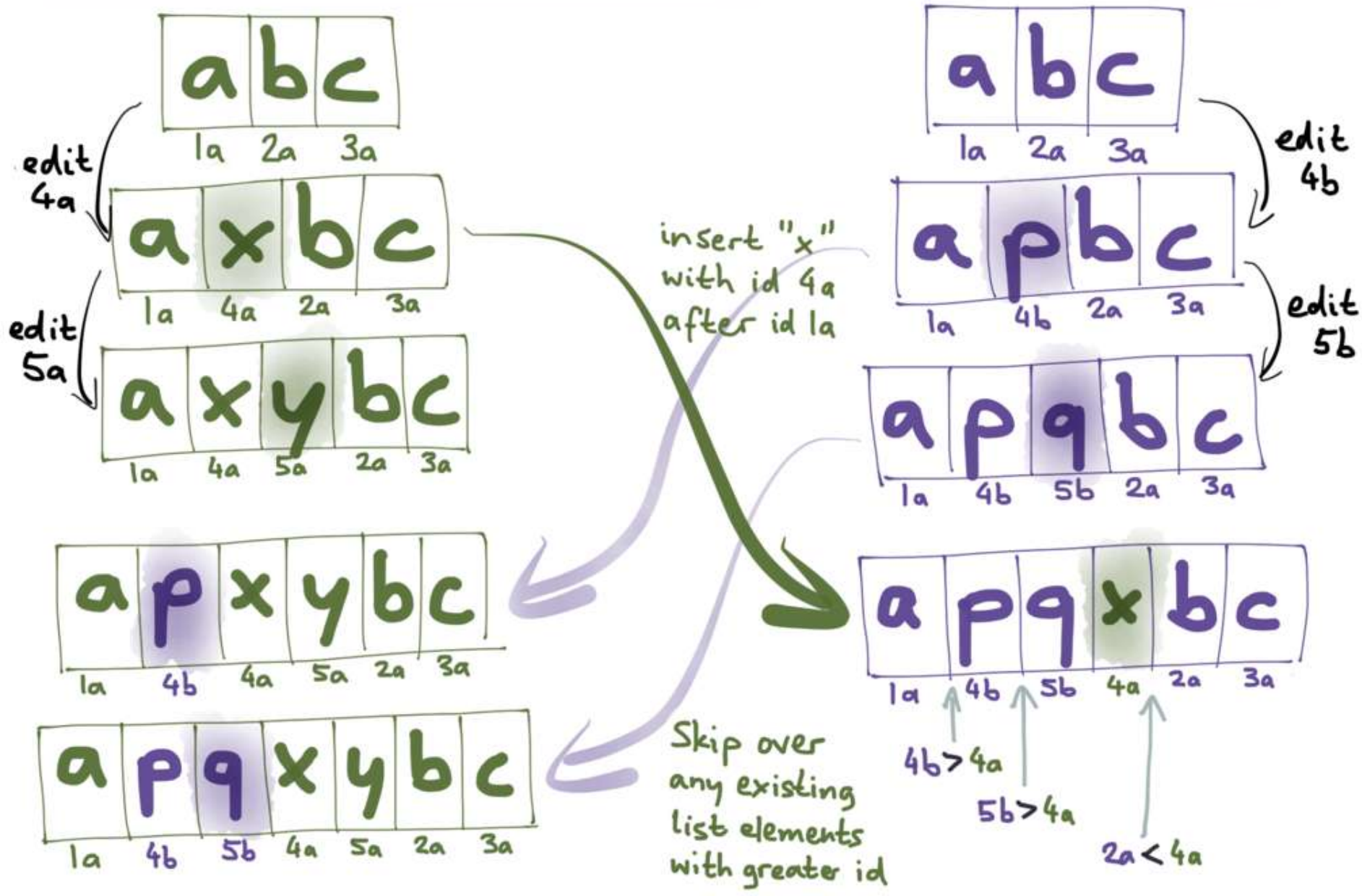

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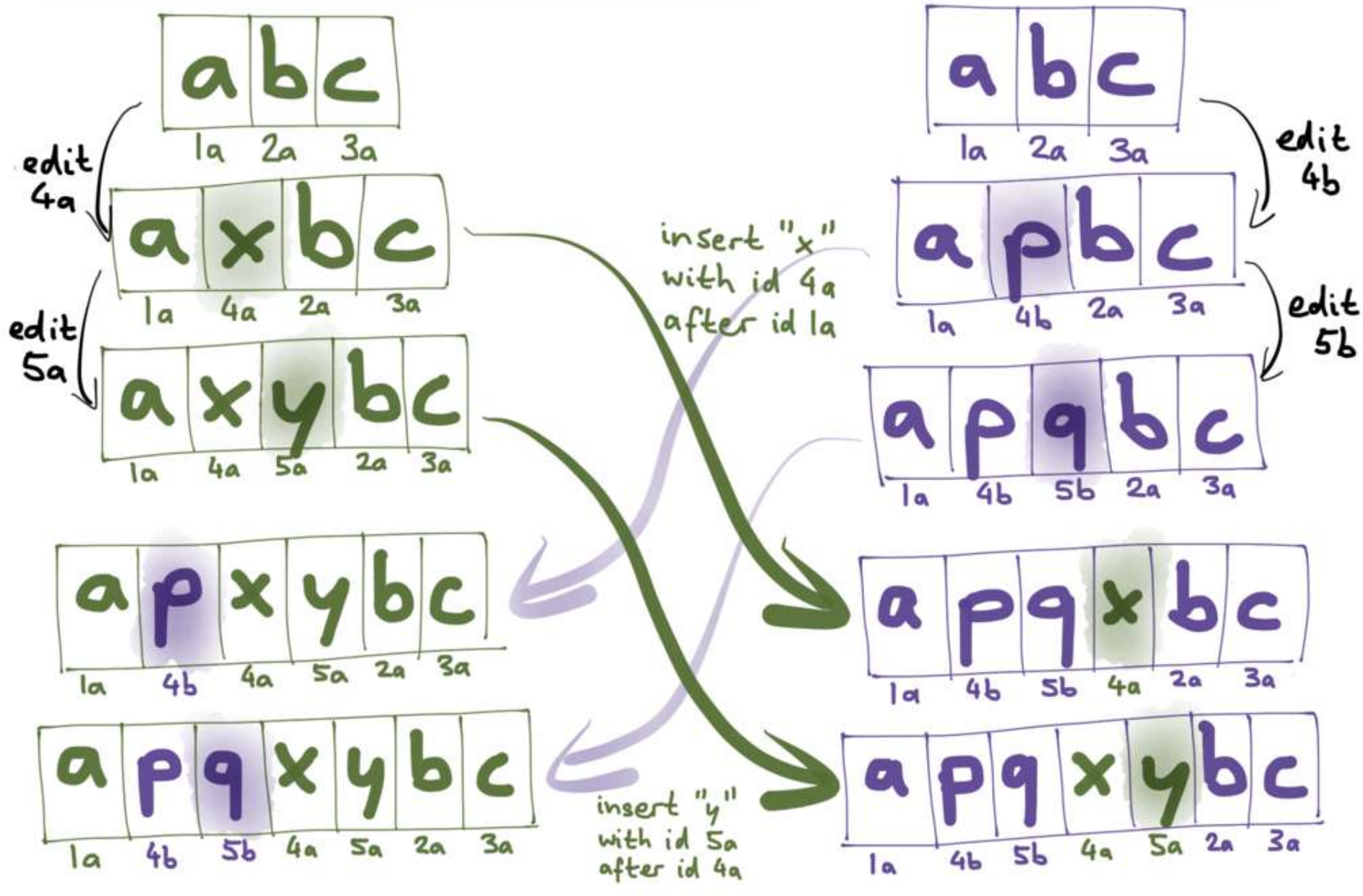

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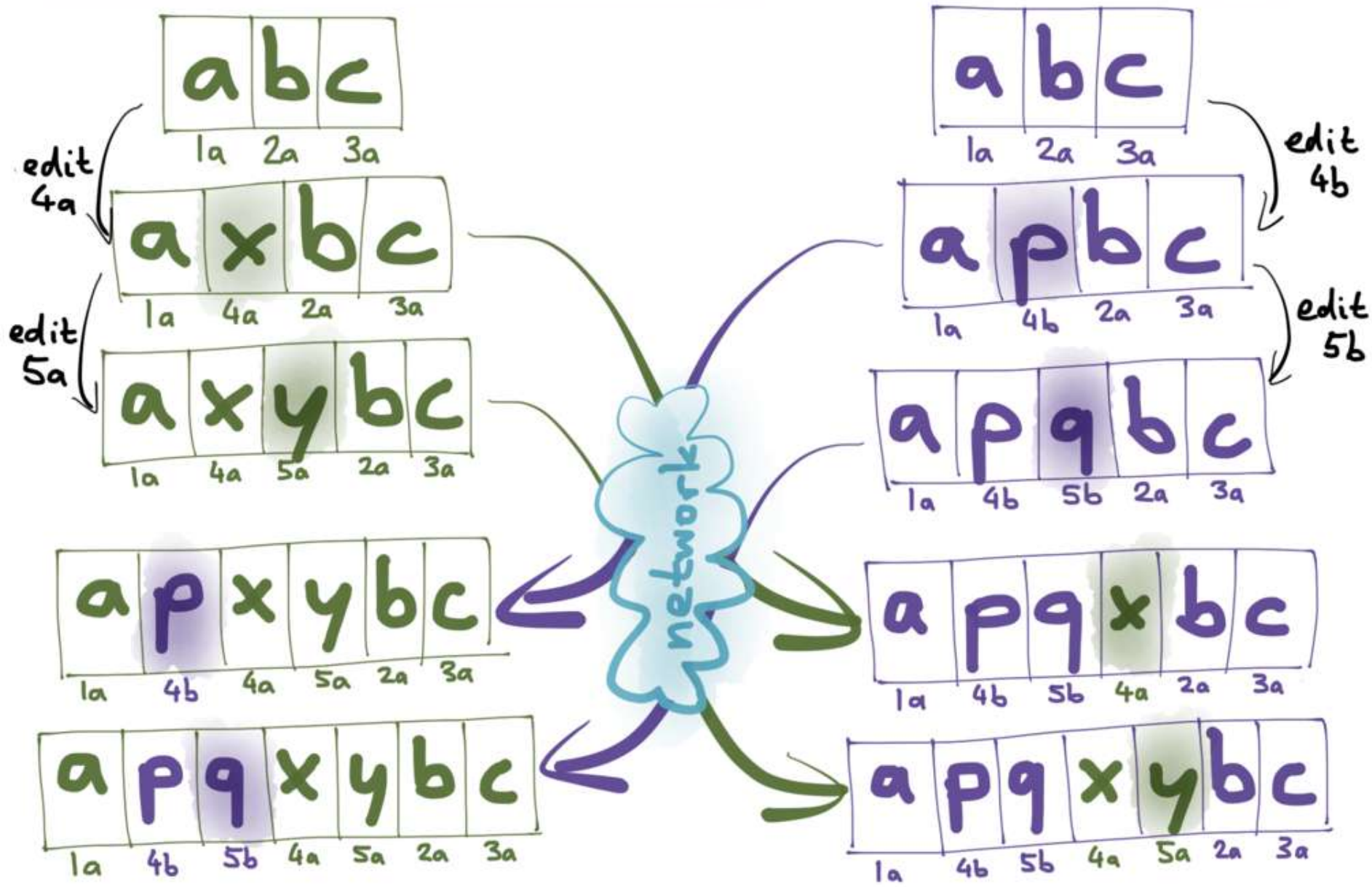

Resources

- Martin's email: mk428@cl.cam.ac.uk
- Martin on Twitter: @martinkl
- Martin's book: http://dataintensive.net/
- Automerge: https://github.com/automerge/automerge
- Trellis: https://github.com/automerge/trellis
- Pixelpusher: https://github.com/automerge/pixelpusher
- Capstone: https://www.inkandswitch.com/capstone-manuscript.html
- 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

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Ink & Switch

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