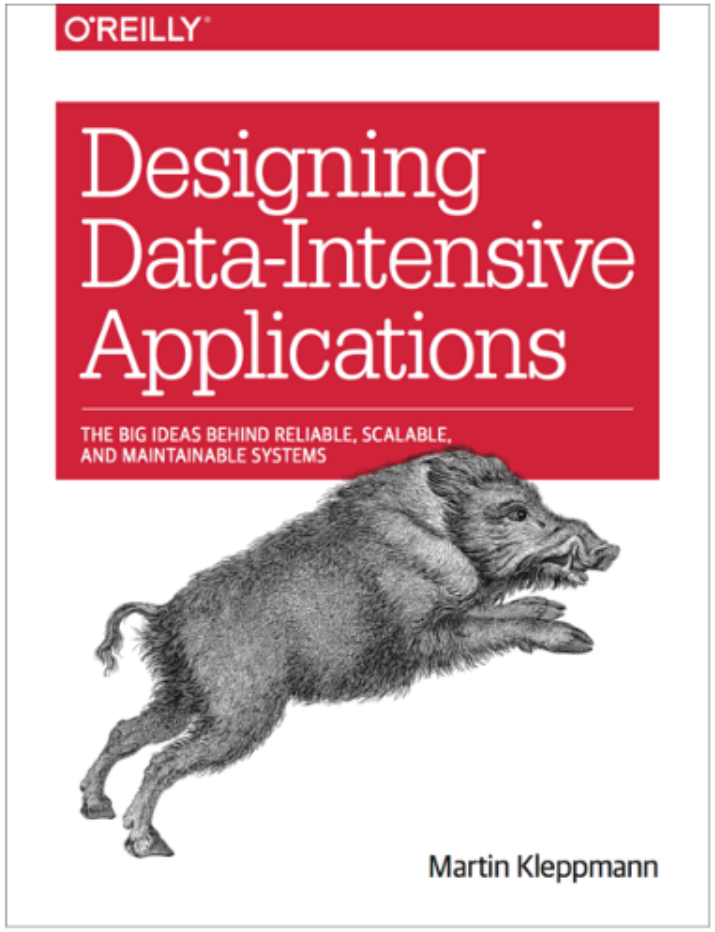
# Automerge

## Replicated data structures for peer-to-peer collaboration

Martin Kleppmann, University of Cambridge @martinkl

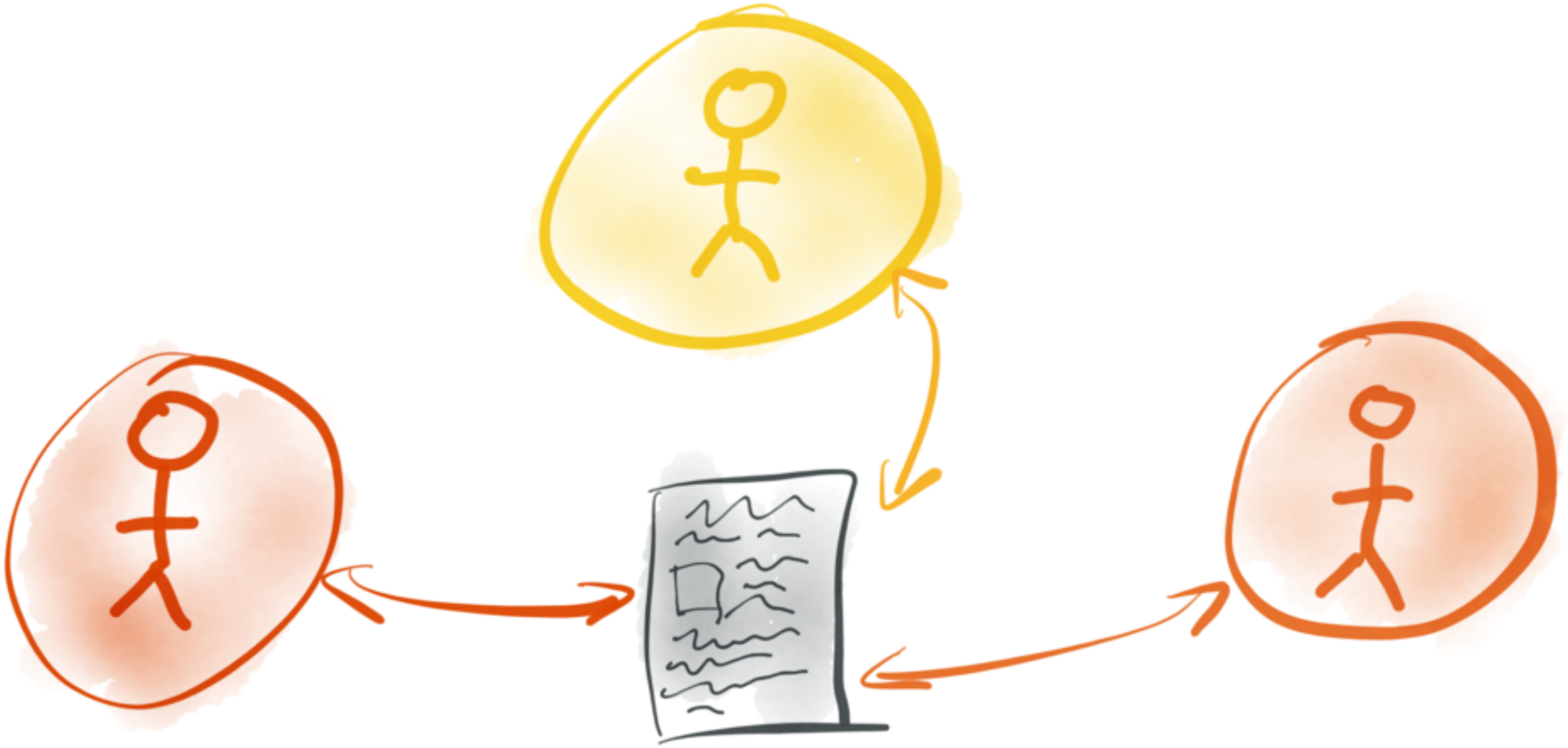
Joint work with Victor Gomes, Dominic Mulligan, Alastair Beresford, Peter van Hardenberg, Orion Henry, Adam Wiggins, Roshan Choxi, Jeff Peterson, Jim Pick, & more contributors

dataintensive.net




@martinkl

# COLLABORATIVE APPLICATIONS



# Example: Text editing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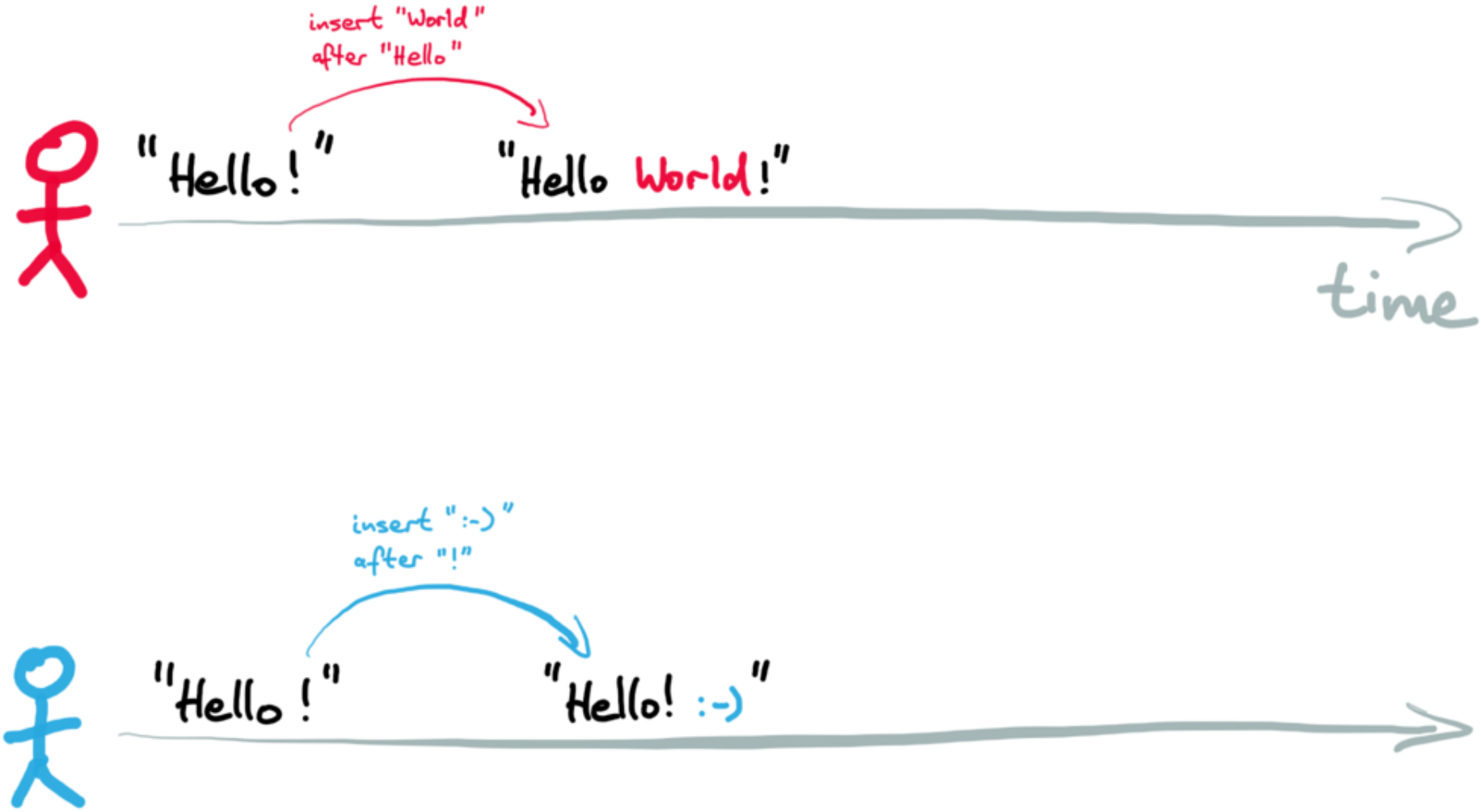
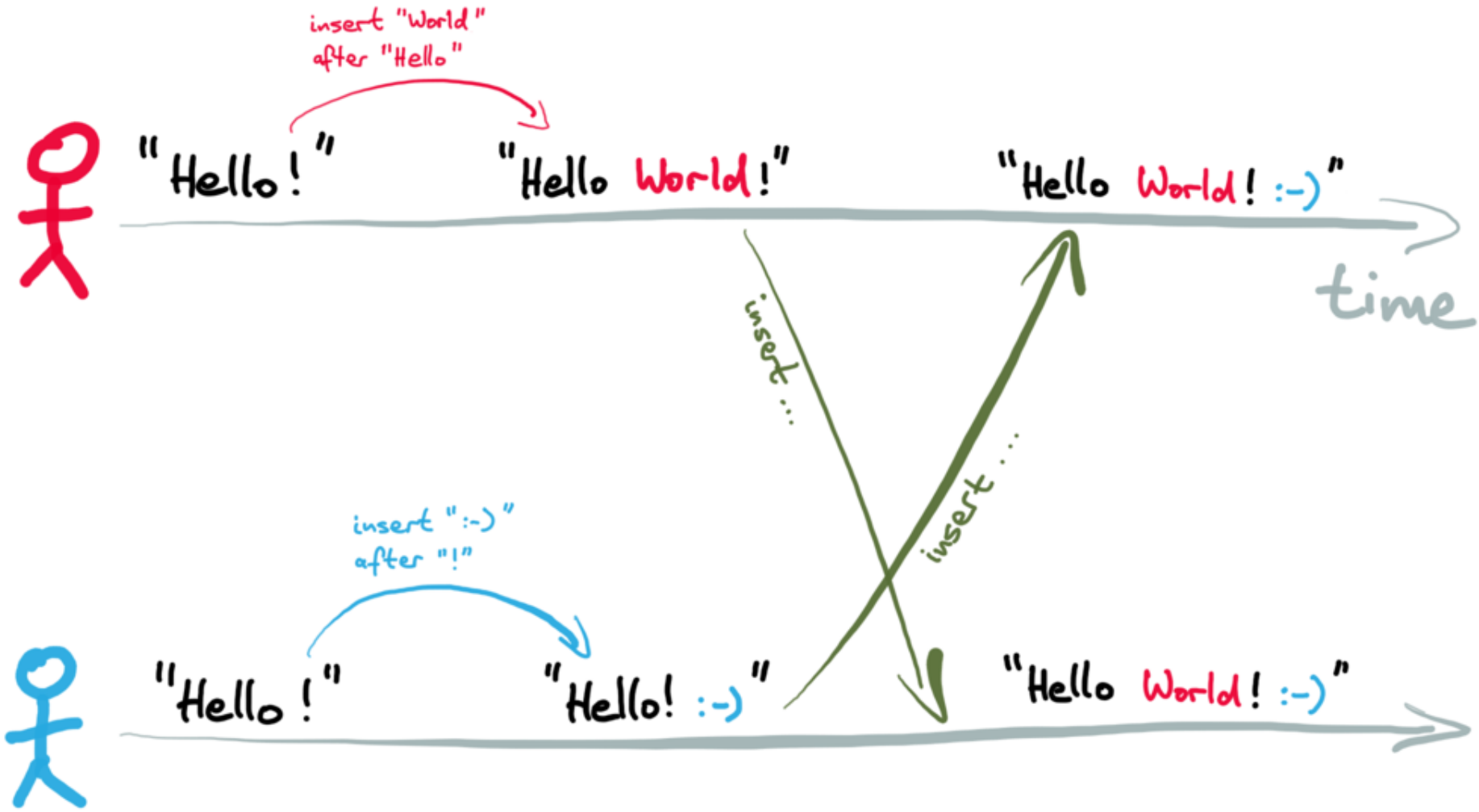


# Example: Text editing



# Algorithms for convergence

## OPERATIONAL TRANSFORMATION (OT)

- e.g. Google Docs, MS Office Online

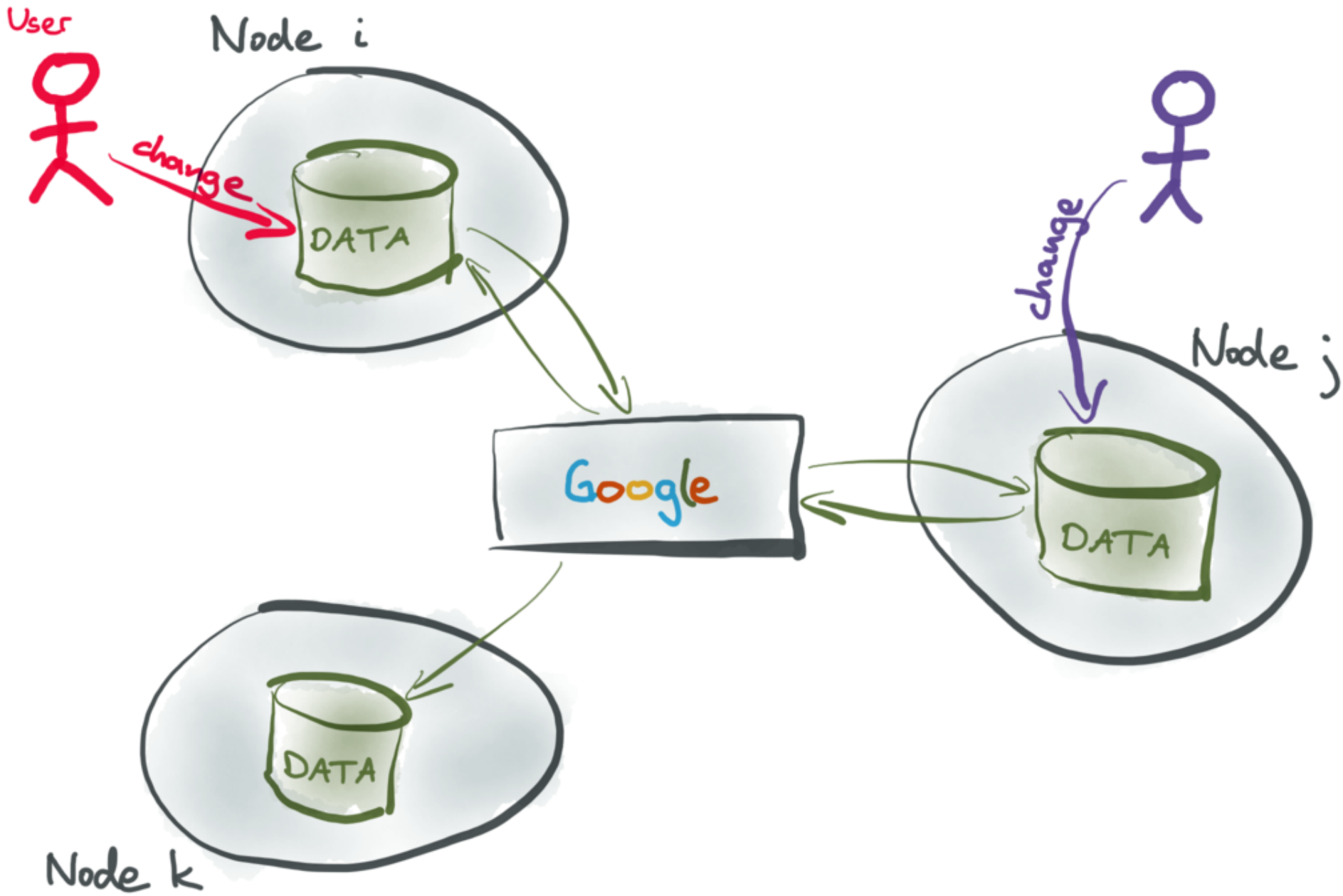
1989–2006

## CONFLICT-FREE REPLICATED DATA TYPES (CRDTs)

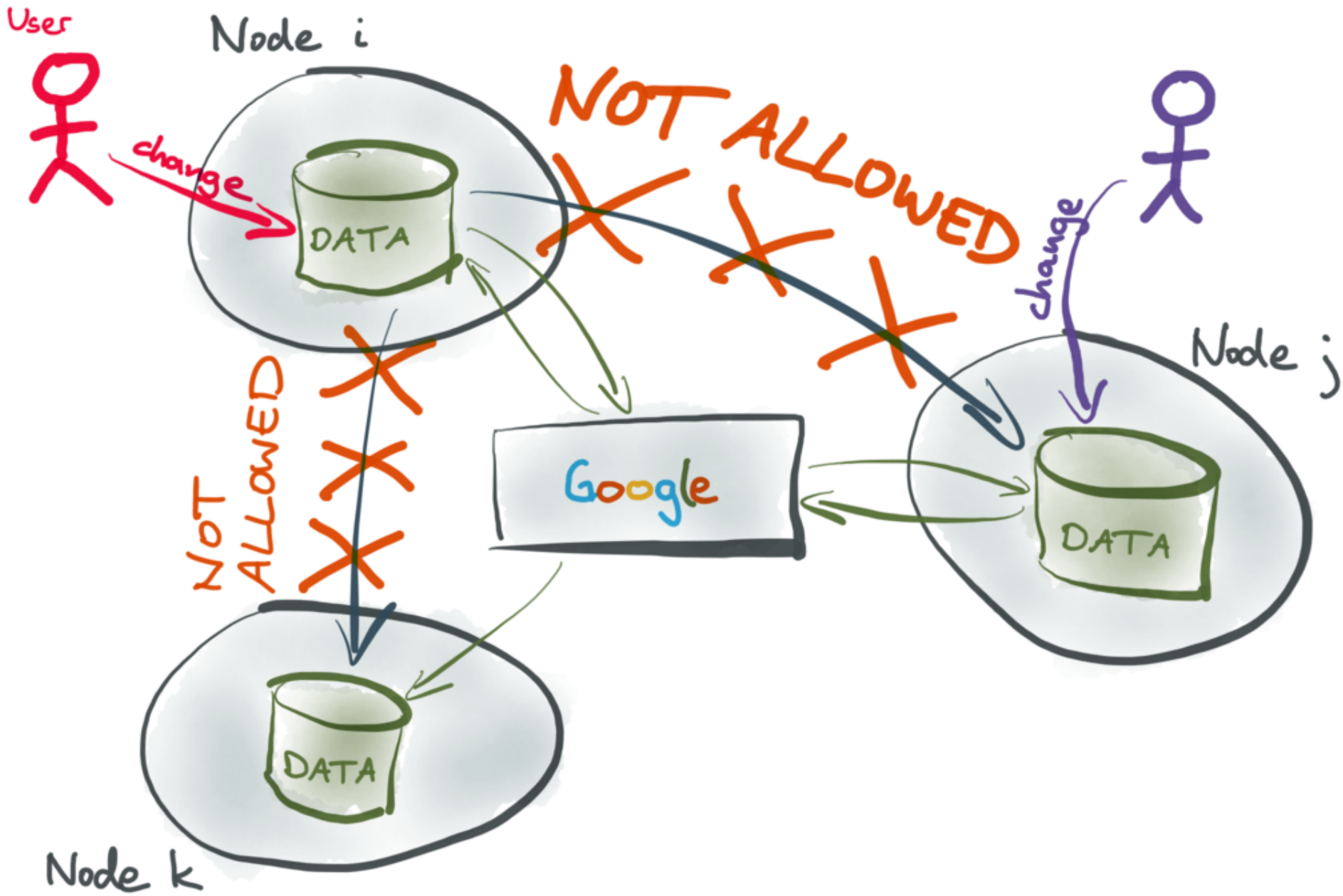
- e.g. Riak, TomTom GPS, Teletype for Atom, ...

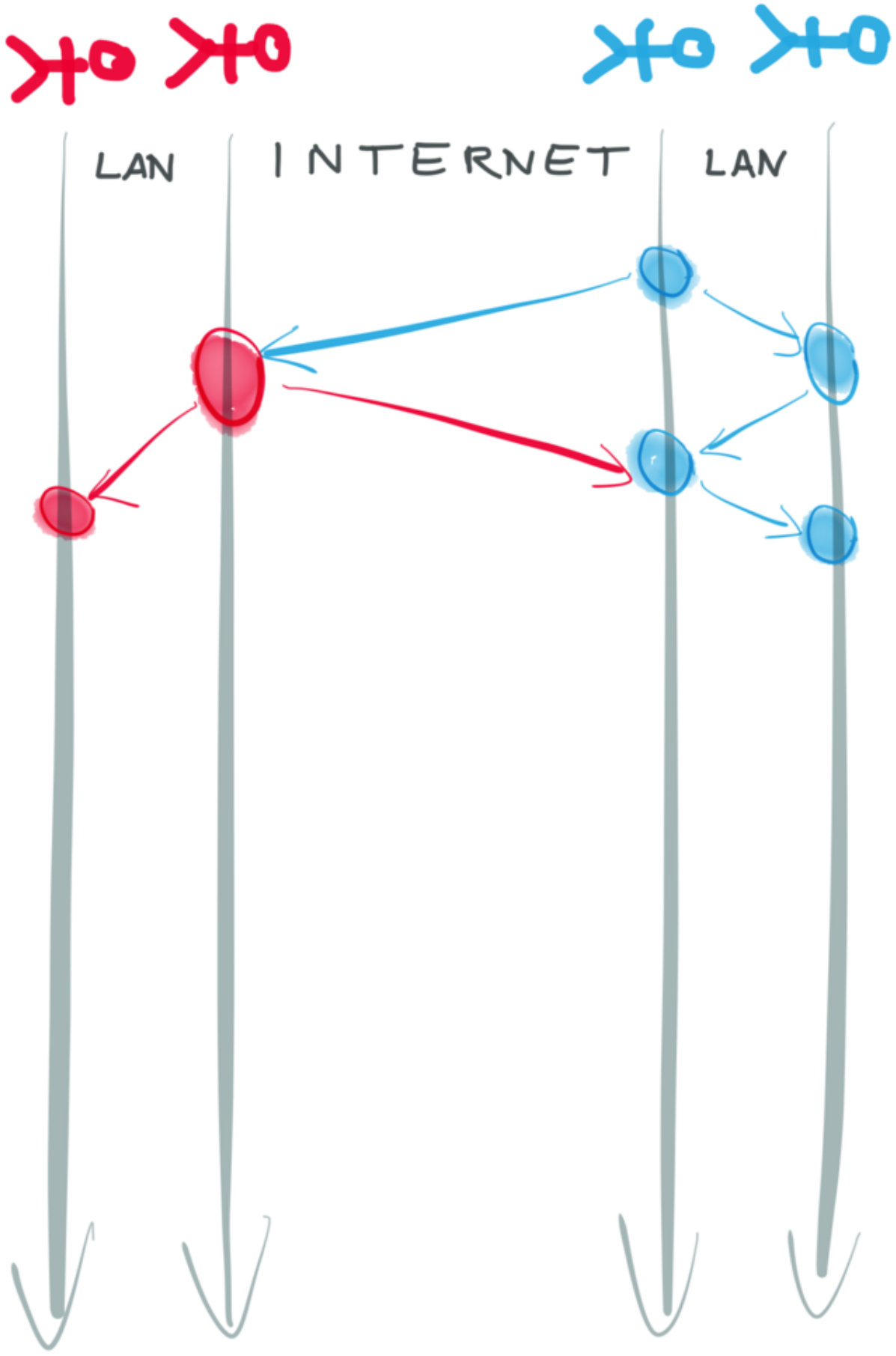
2006 – present

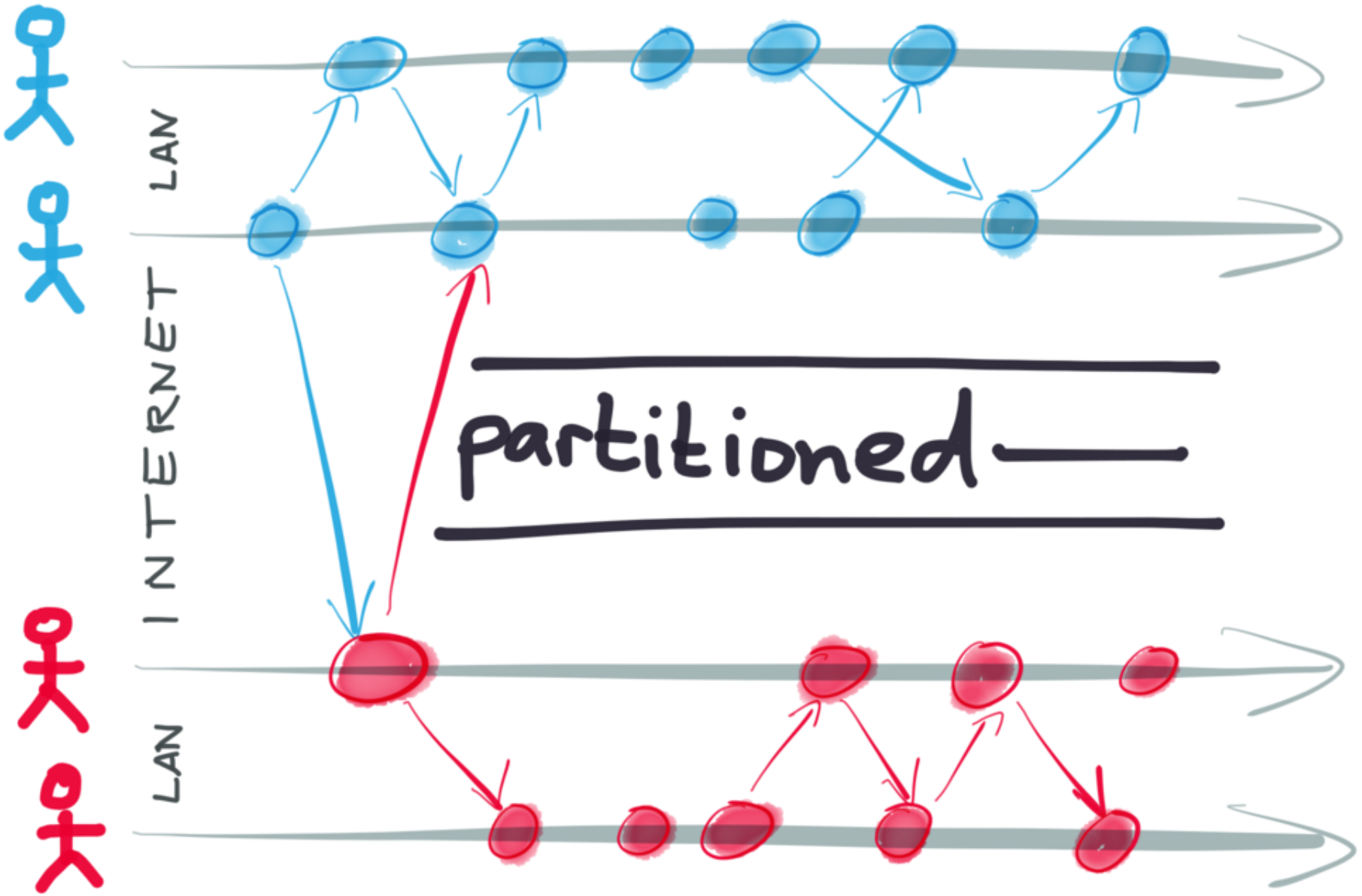
# OPERATIONAL TRANSFORMATION IN GOOGLE DOCS.

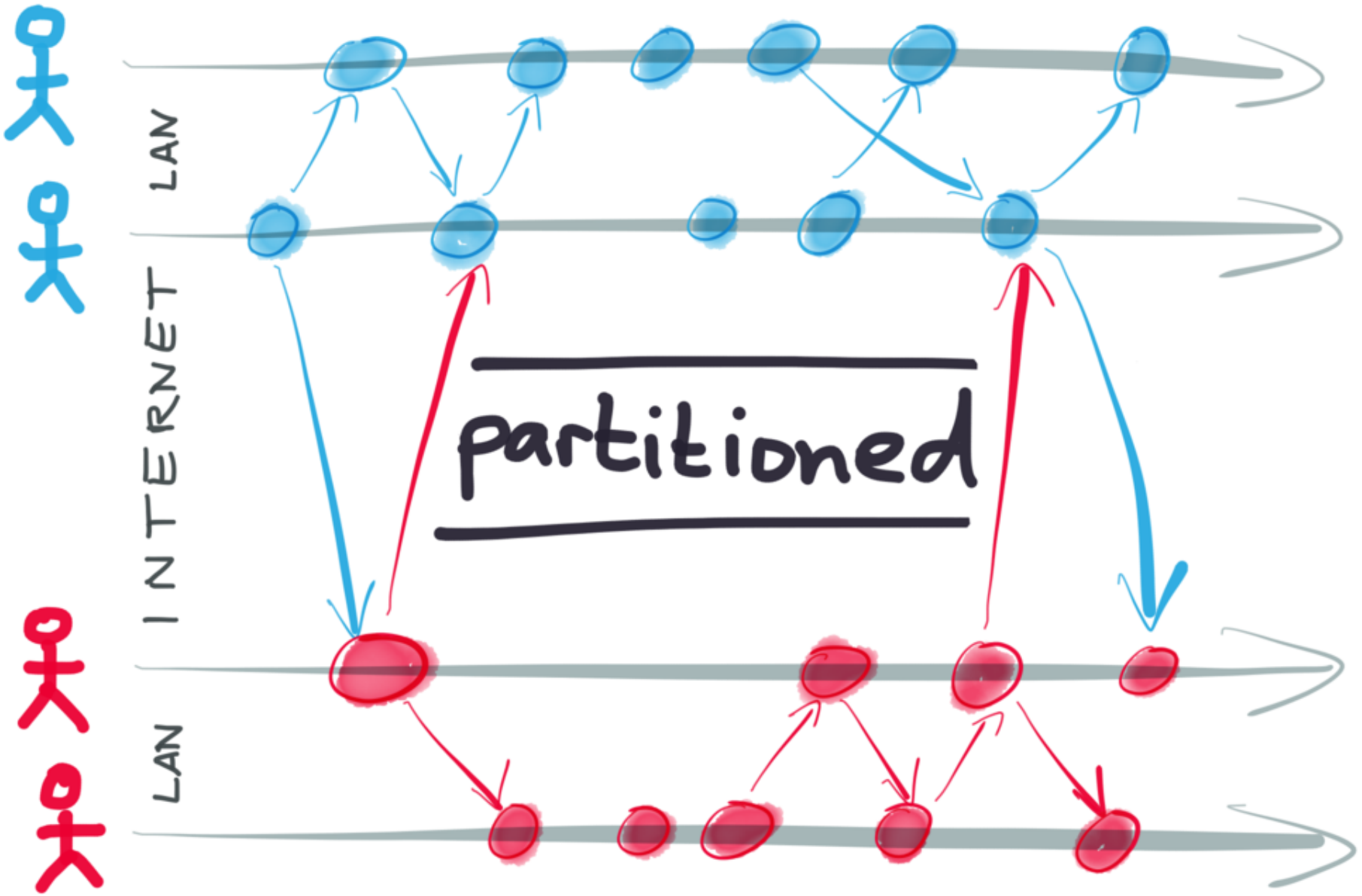


# OPERATIONAL TRANSFORMATION IN GOOGLE DOCS.




LAN
INTERNET
LAN


LAN
INTERNET
partitioned
LAN


LAN
INTERNET
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2006 – present

# PROVING CRDTs CORRECT

RGA

ORSet

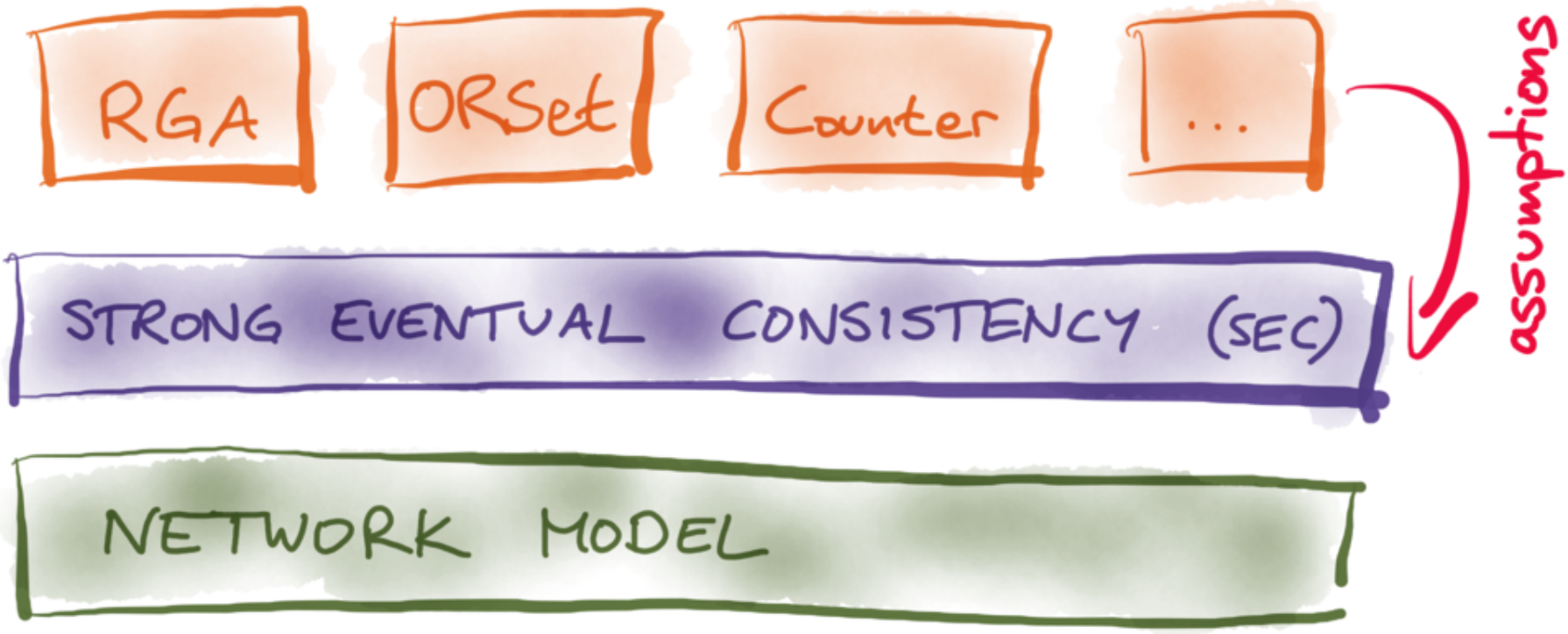
Counter

...

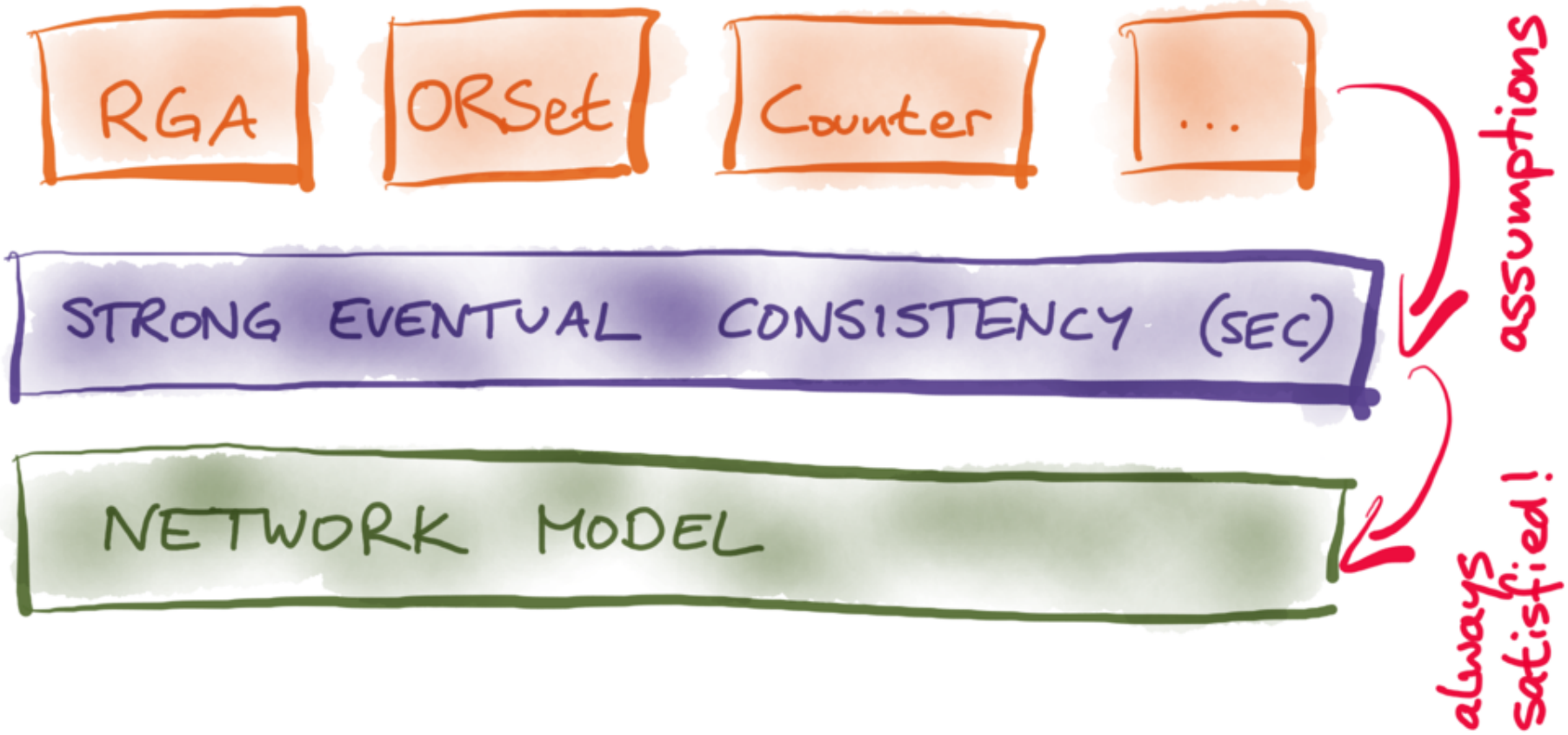
STRONG EVENTUAL CONSISTENCY (SEC)

NETWORK MODEL

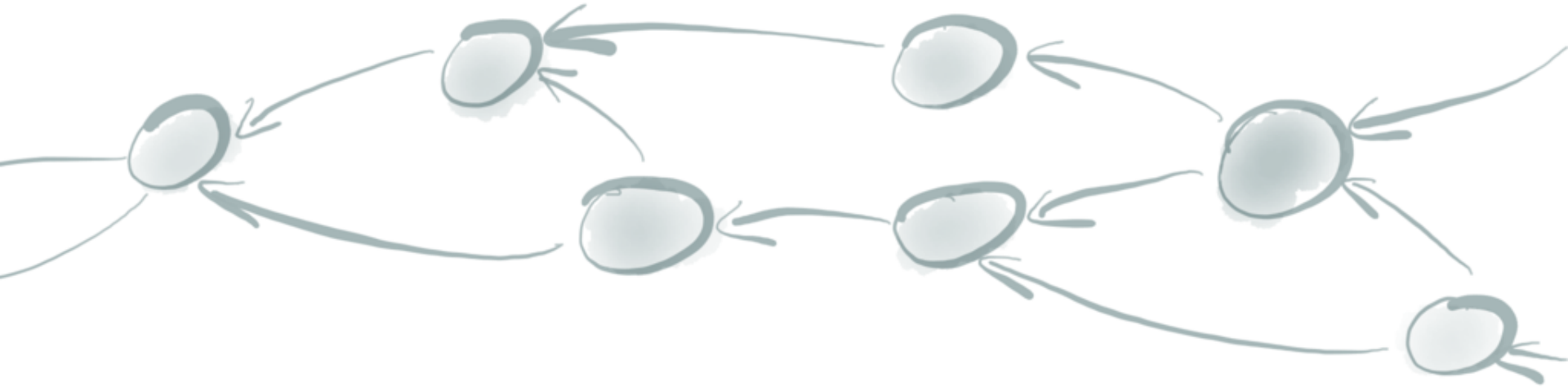
# PROVING CRDTs CORRECT




# PROVING CRDTs CORRECT



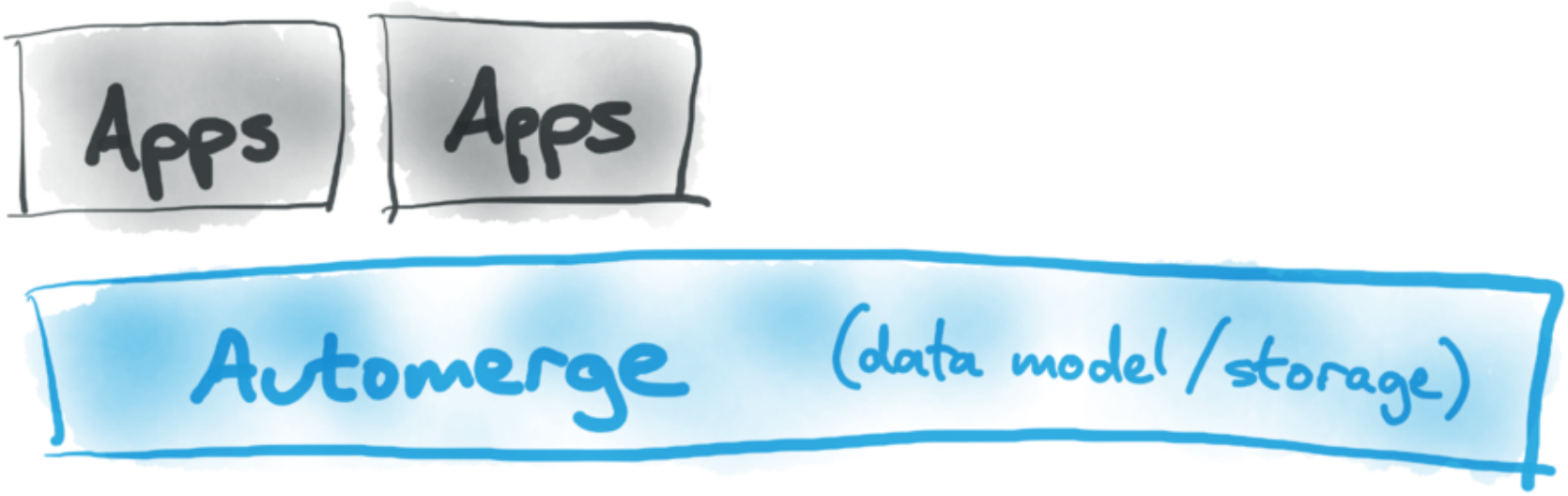

For details, see our paper at https://doi.org/10.1145/3133933
Victor B. F. Gomes, Martin Kleppmann, Dominic P. Mulligan, and Alastair R. Beresford: Verifying Strong Eventual Consistency in Distributed Systems. PACMPL 1(OOPSLA), 2017.

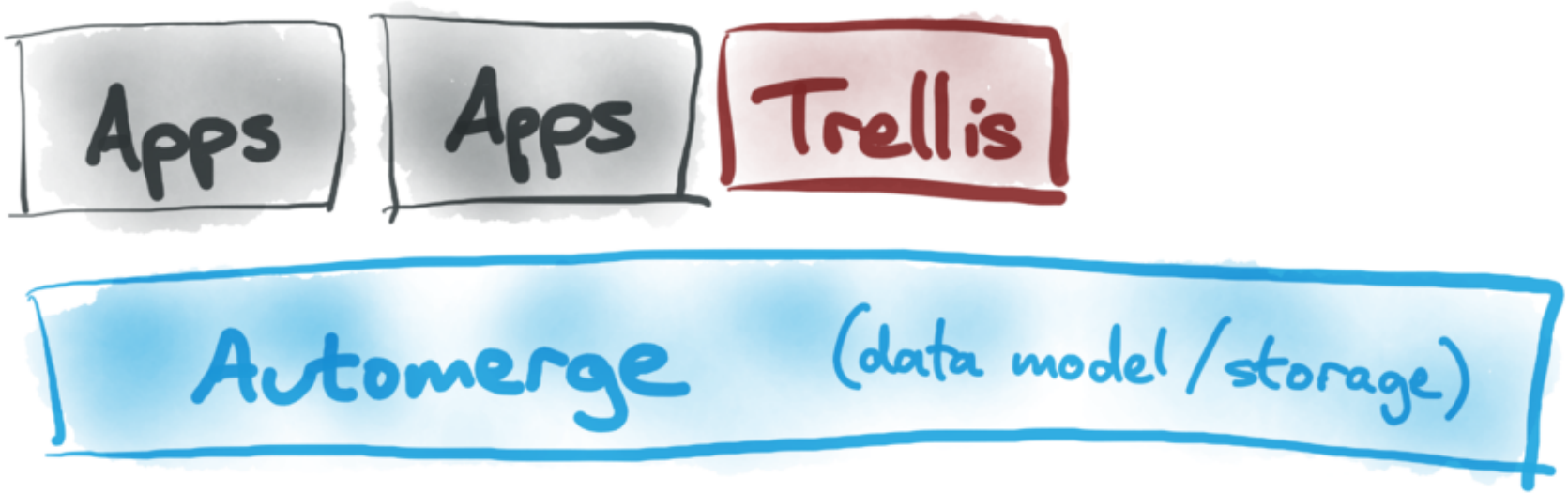


# Automerge

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

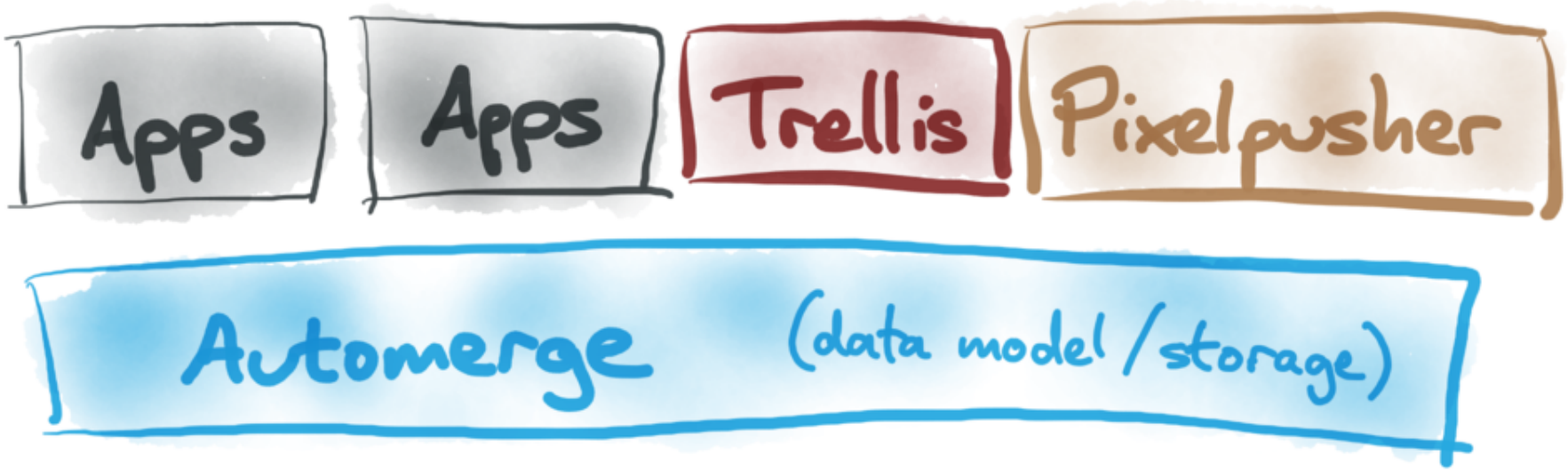
- Iron Man 

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.

# PIXEL ART TO CSS

by JVALEN

Star 324

+ | 25 | 50 | 75 | 100

NEW

LOAD | SAVE

PREVIEW

RESET

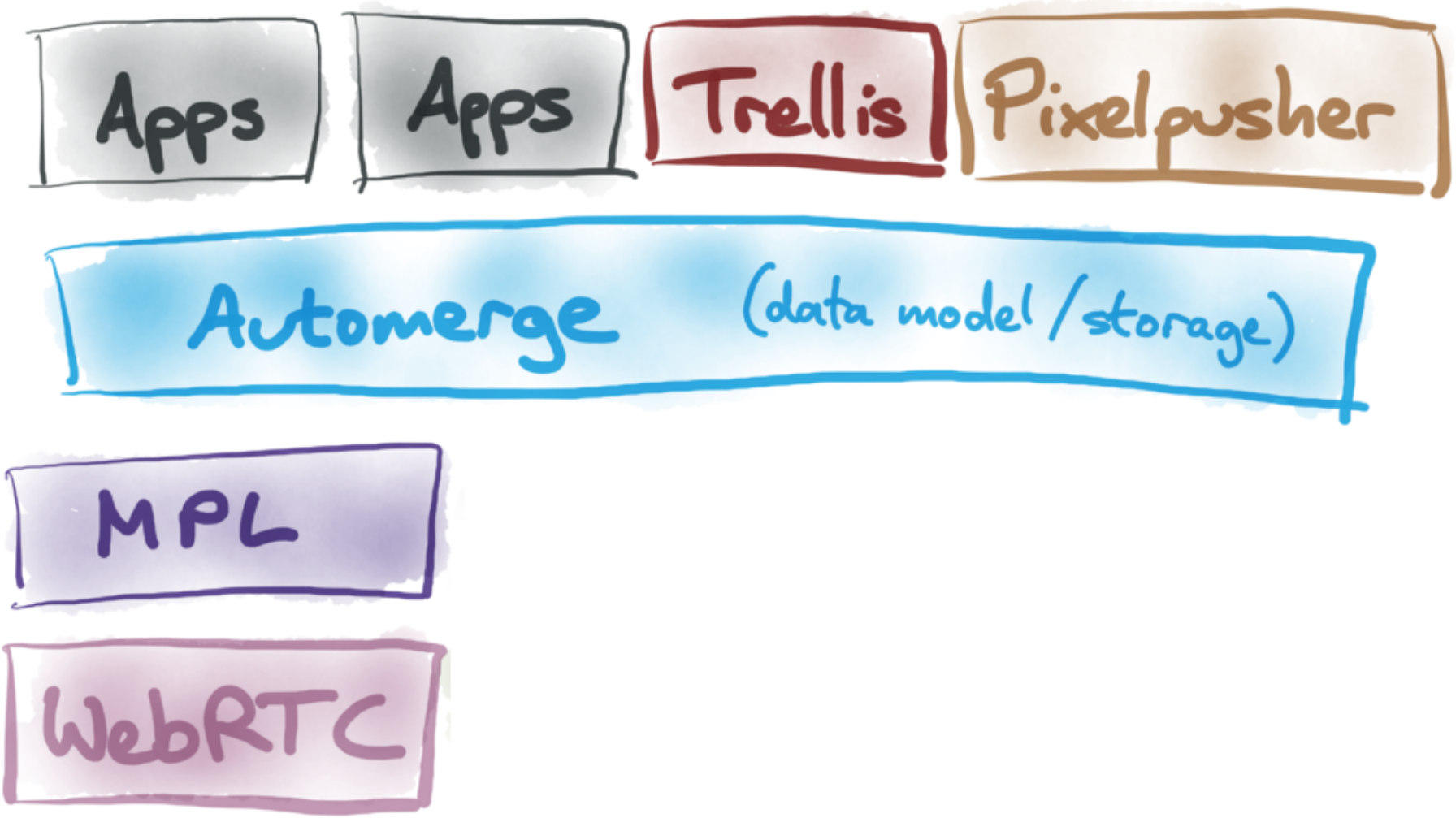
16 + −

16 + −

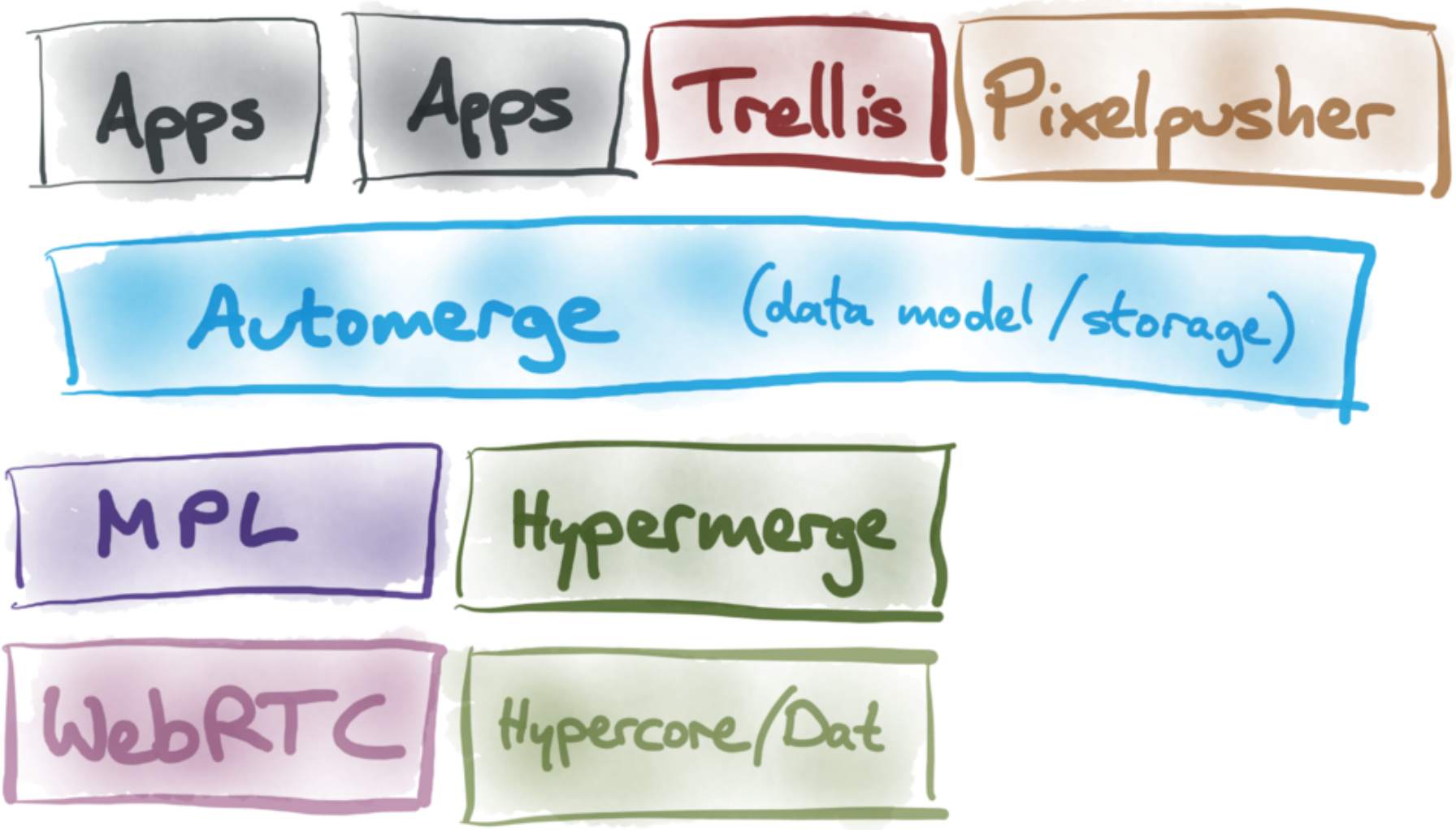
Pixel Size
10

Duration
1

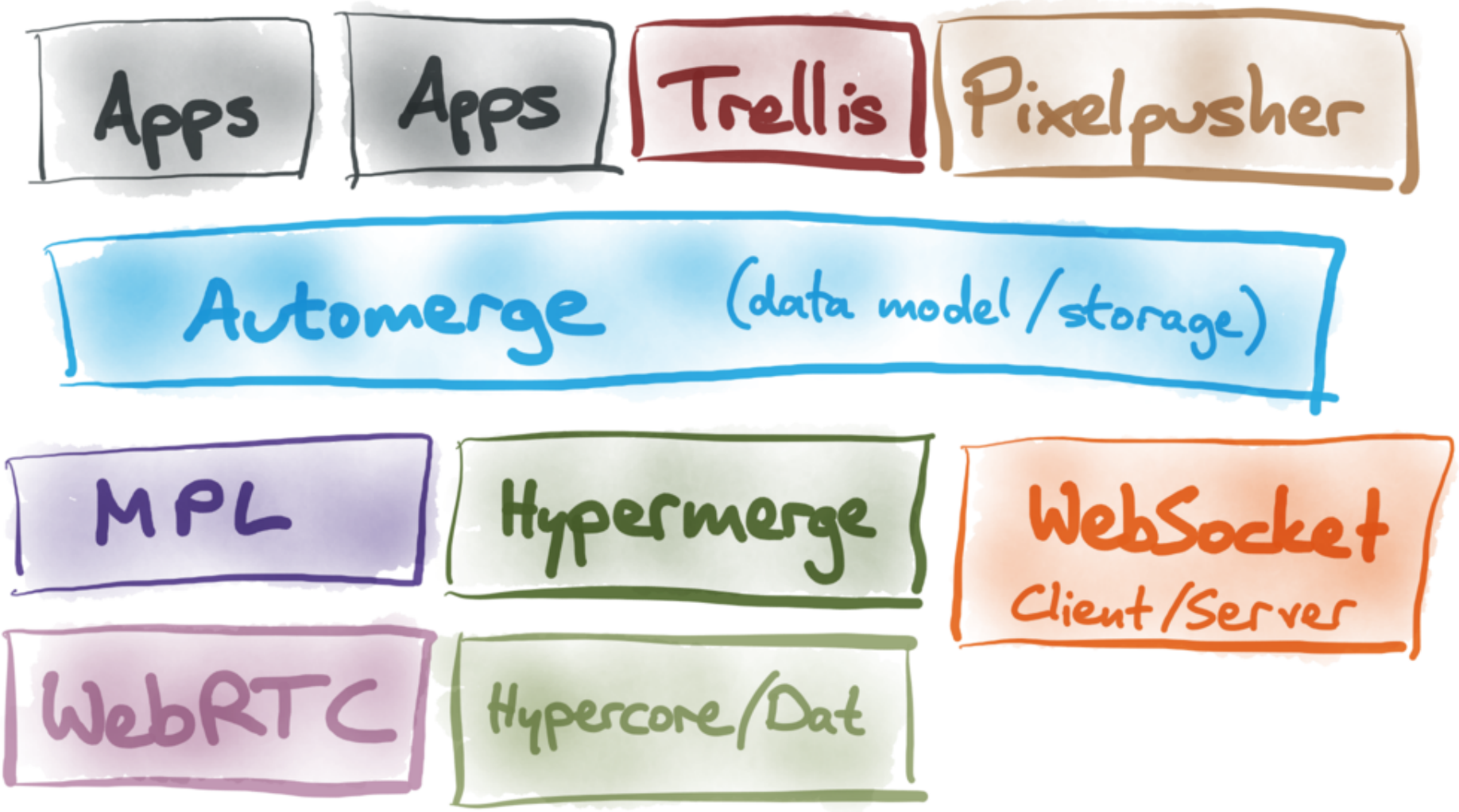
CSS




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

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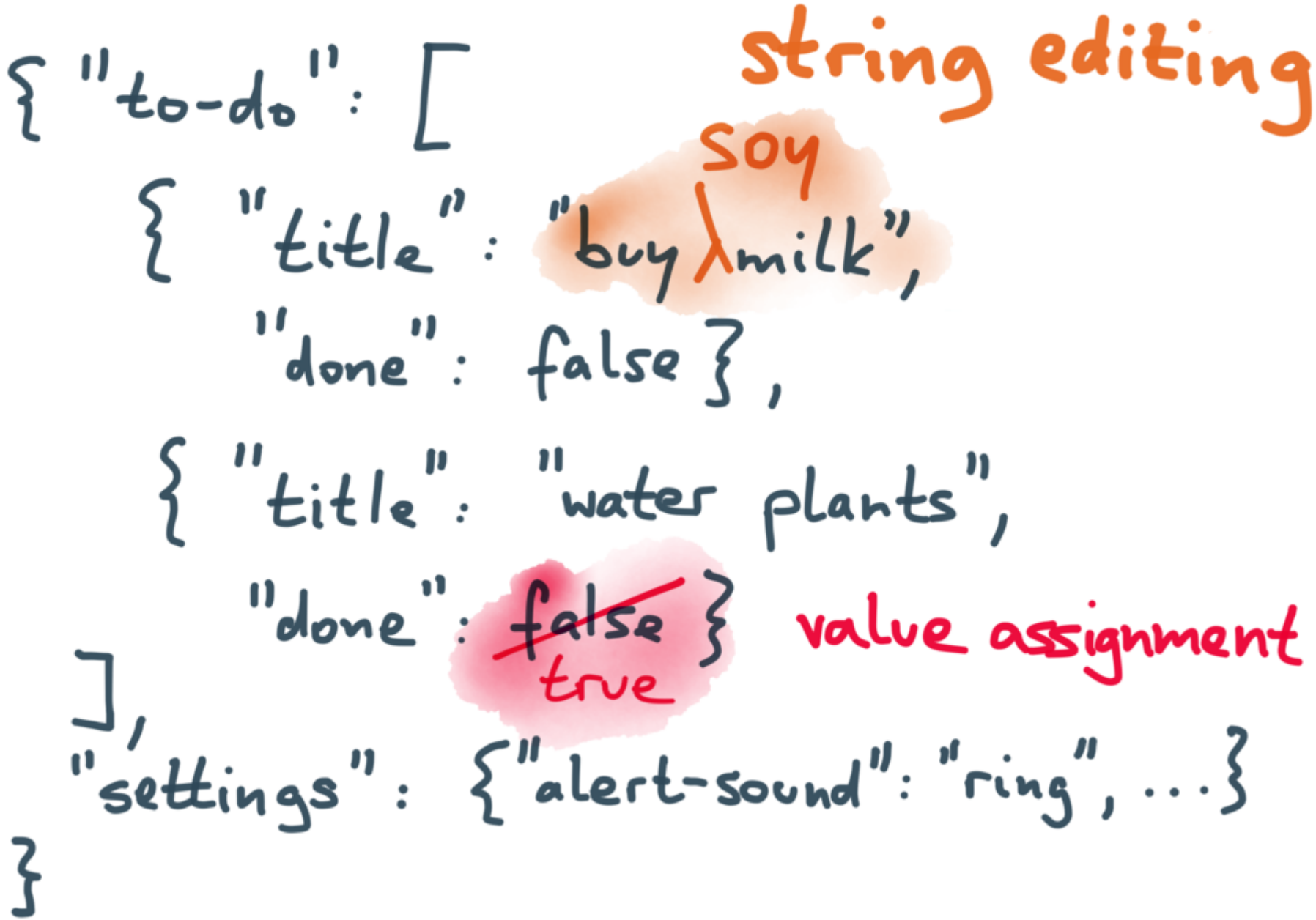

true

value assignment

# EDITING OPERATIONS



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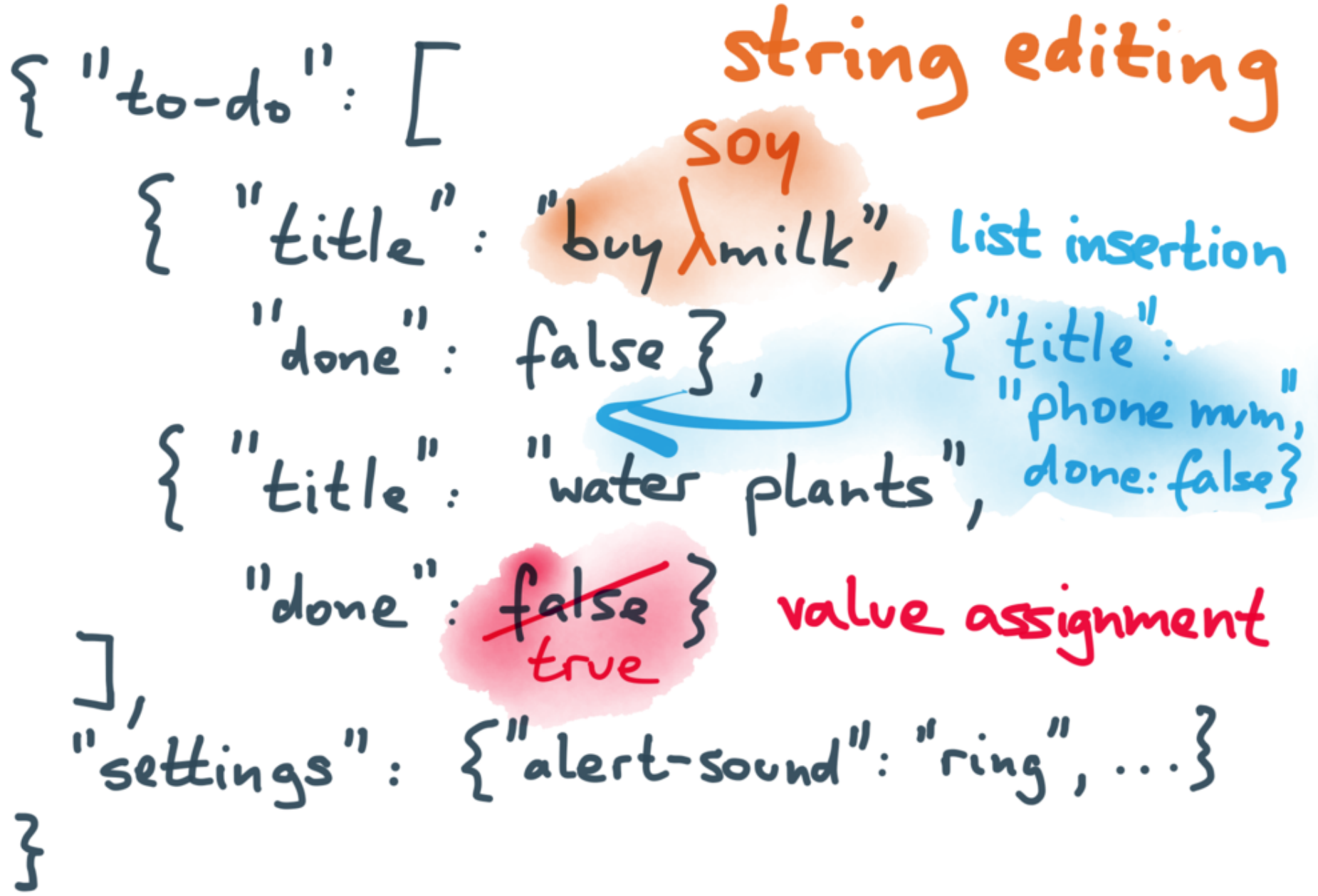

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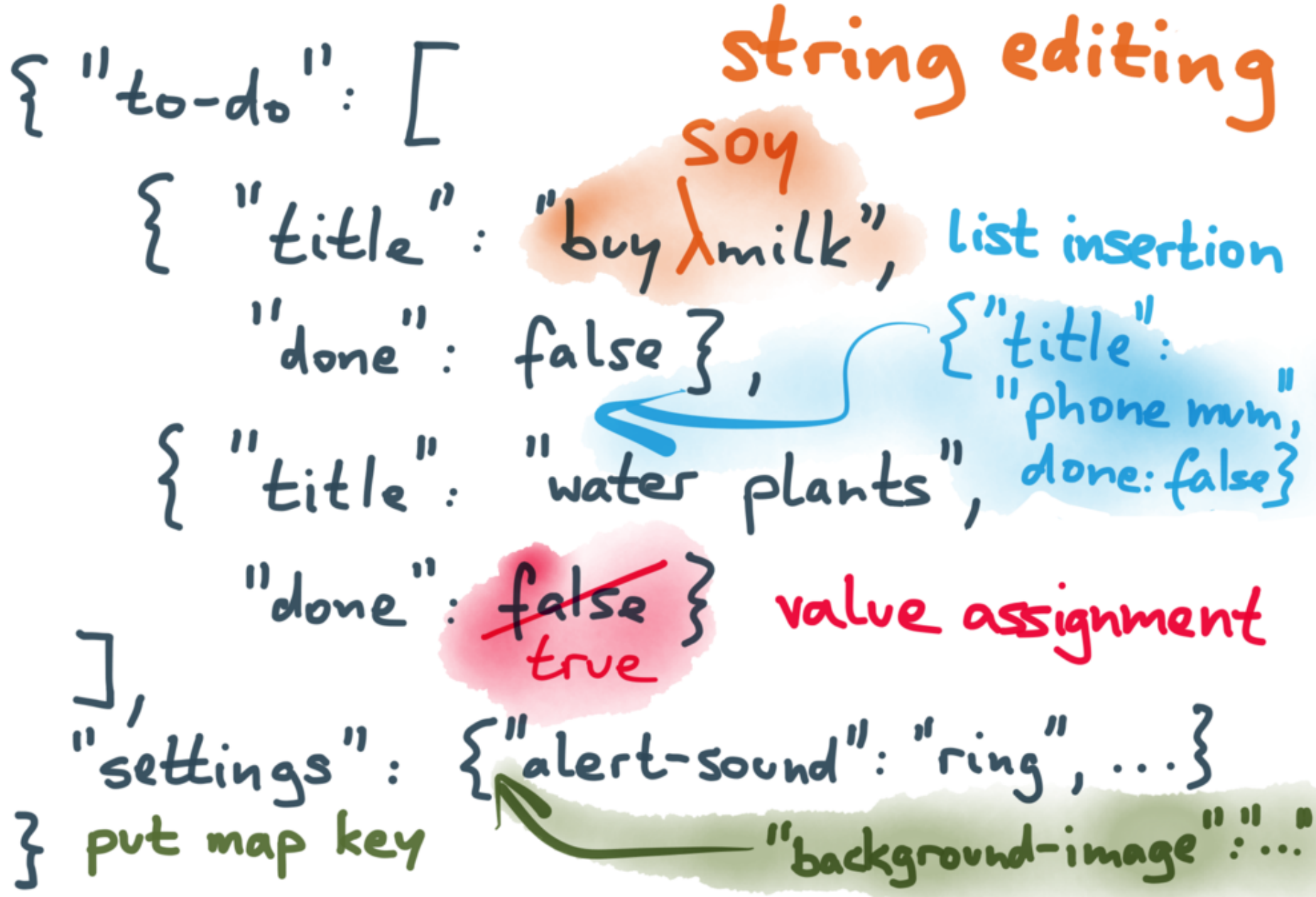

```
state = Automerge.change(state, "Add todo item",
  (doc) => {
    doc.todos.push({
      title: "Buy milk",
      done: false
    })
  })
```

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

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"Commit message" (optional)

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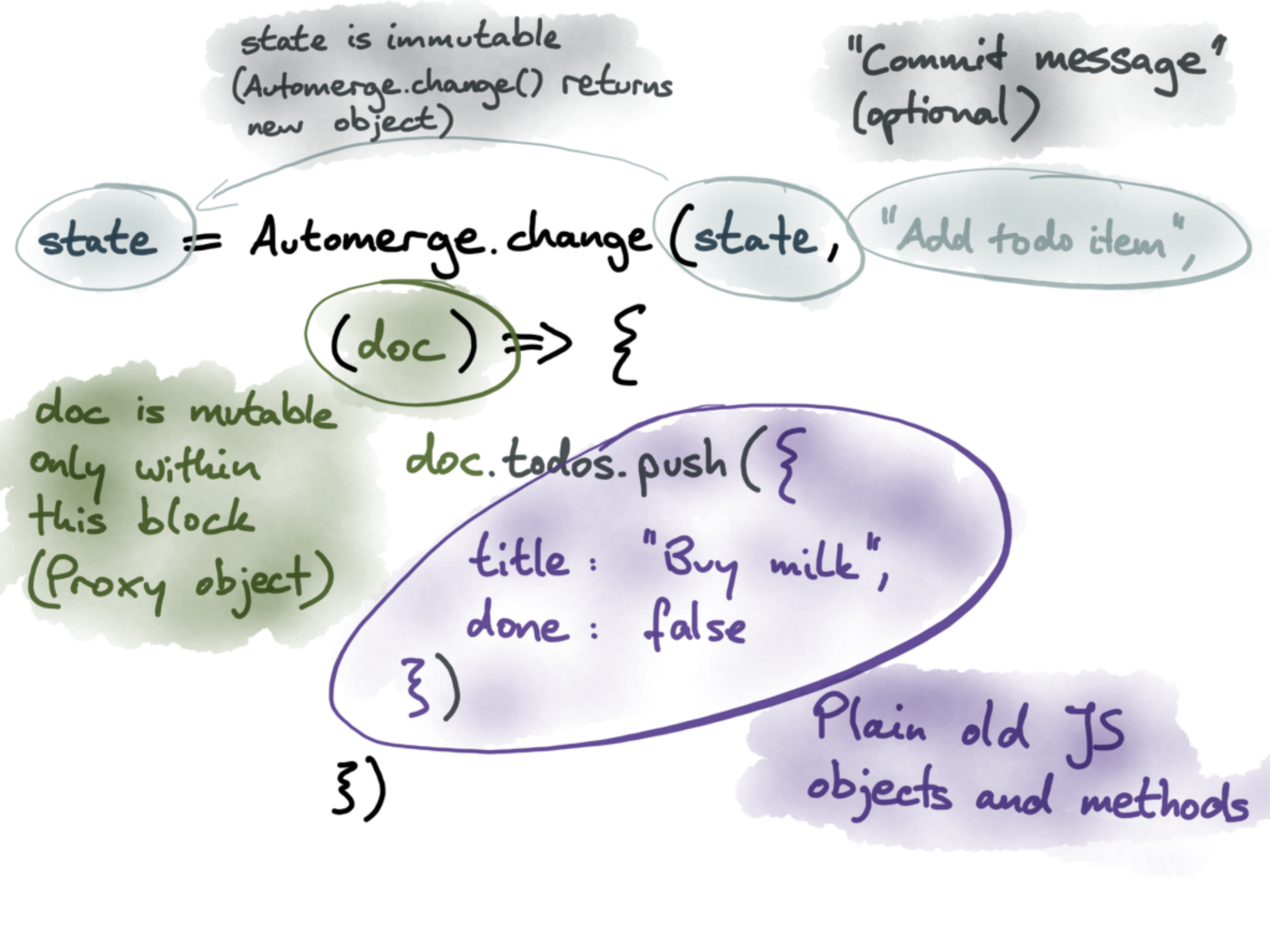
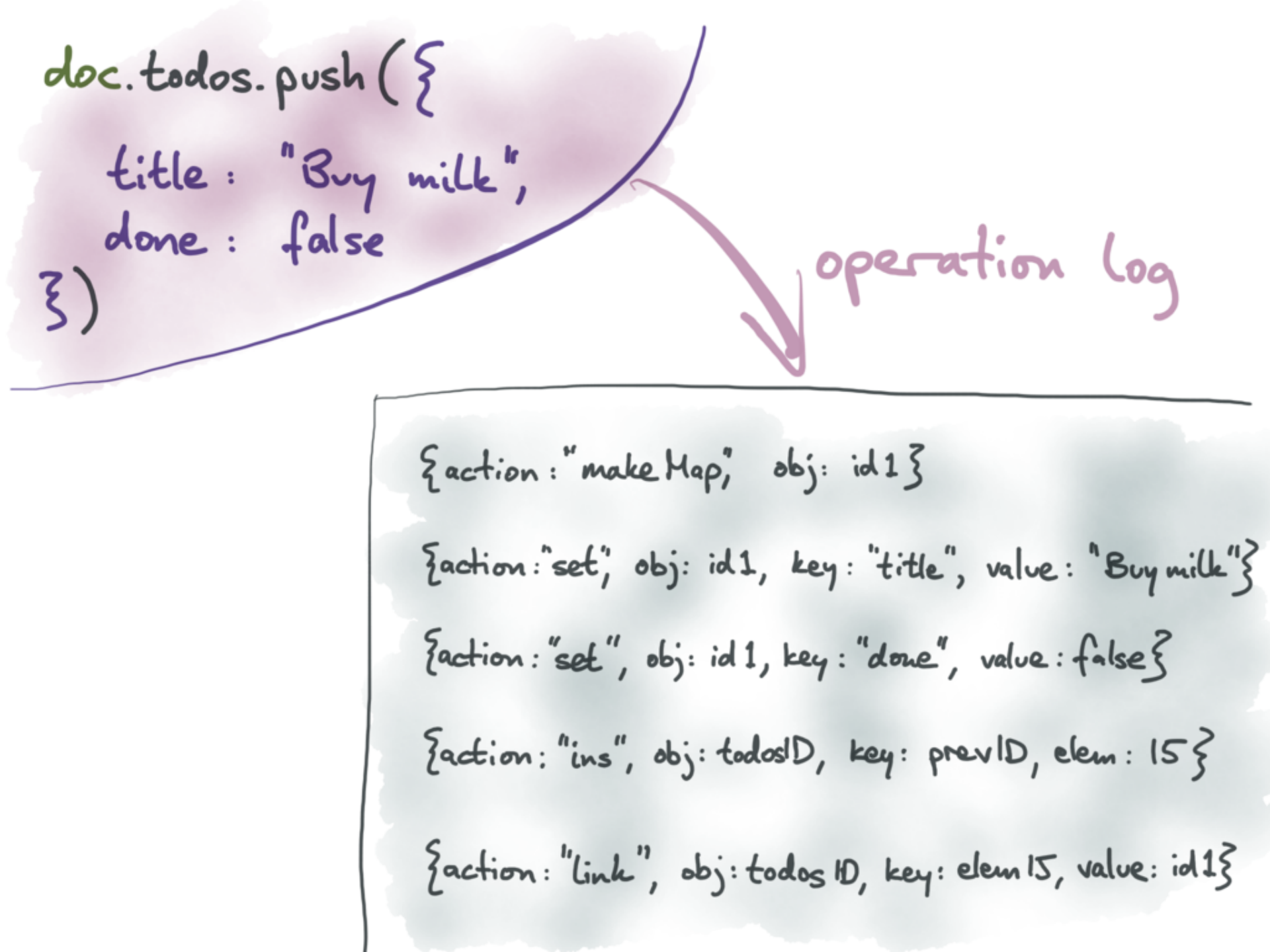
      title: "Buy milk",
      done: false
    })
  })
```

doc is mutable
only within
this block
(Proxy object)


state is immutable
(Automerge.change() returns
new object)
"Commit message"
(optional)
state = Automerge.change(state, "Add todo item",
(doc) => {
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!)

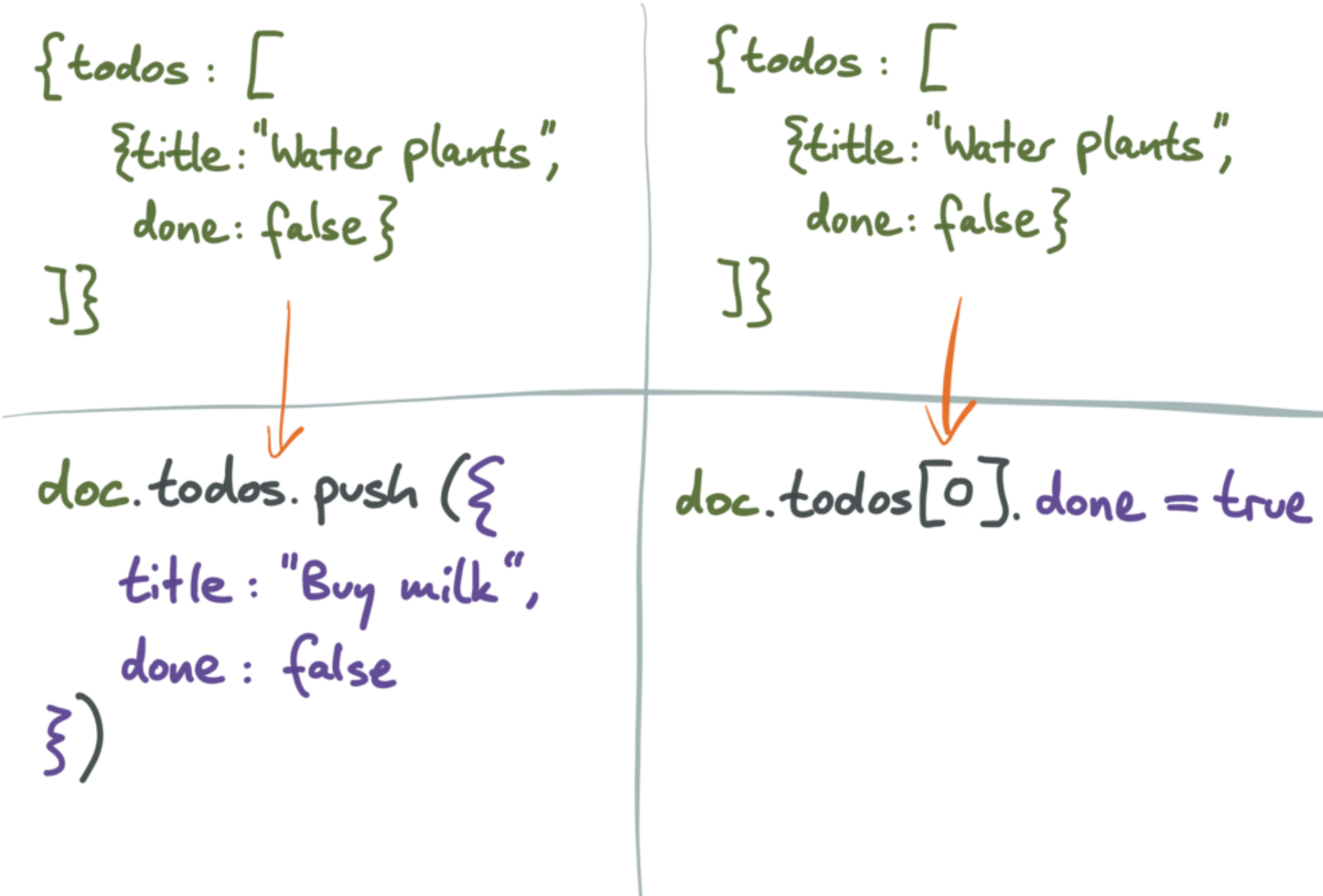
They are in the same state

# CONCURRENT CHANGES

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

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

# CONCURRENT CHANGES



# CONCURRENT CHANGES

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

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

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    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
```


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

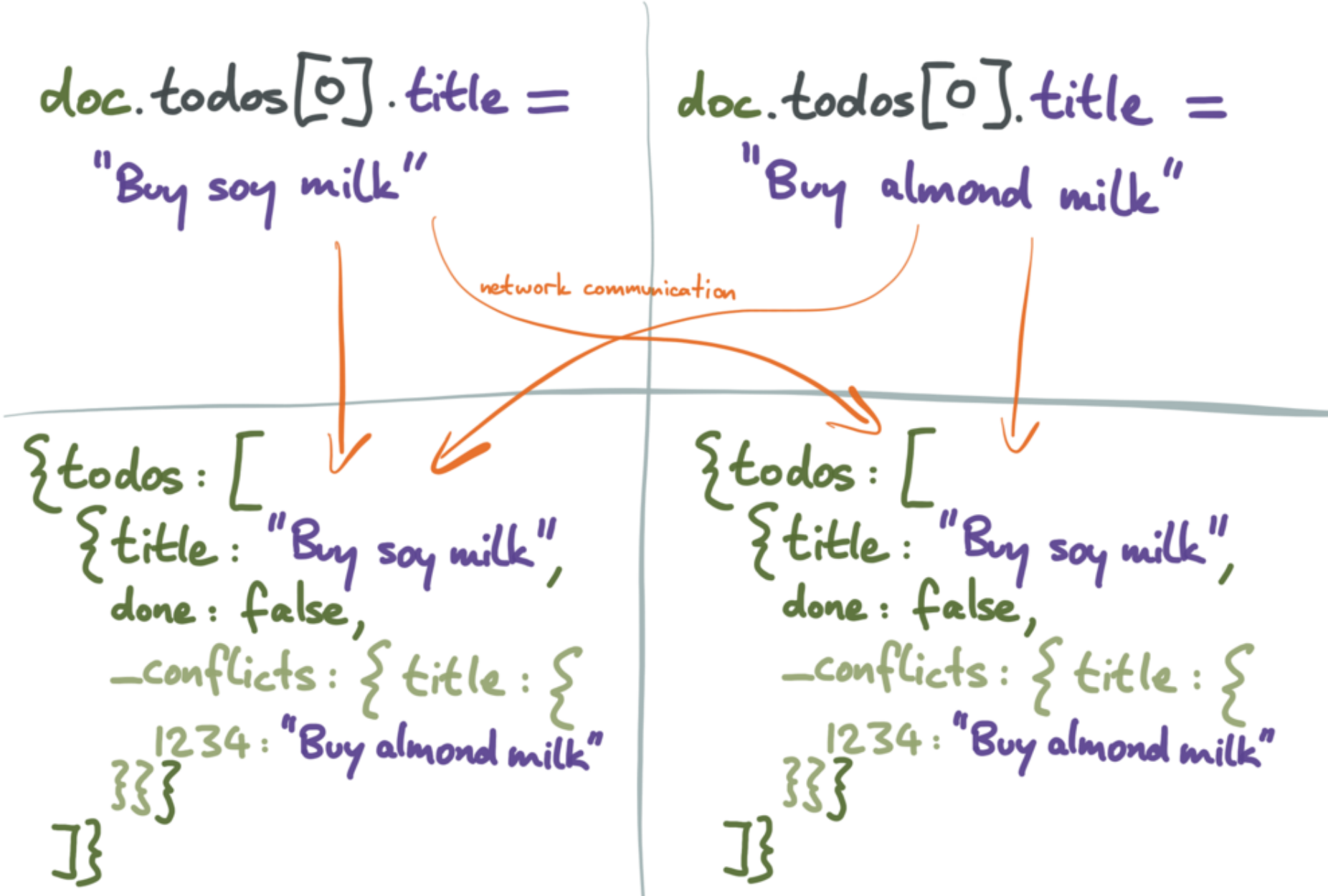
```
{todos: [
    {title: "Water plants",
     done: true},
    {title: "Buy milk",
     done: false}
]}
```

# CONCURRENT CHANGES

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

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

# CONCURRENT CHANGES



# 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", ...}, ...]}},
    ...
  ]
```

# Resources

- Martin's email: mk428@cl.cam.ac.uk
- Martin on Twitter: @martinkl
- 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
- Martin's book: http://dataintensive.net/