

# Keynote: From groupware to large-scale trustworthy distributed collaborative systems

Claudia-Lavinia Ignat

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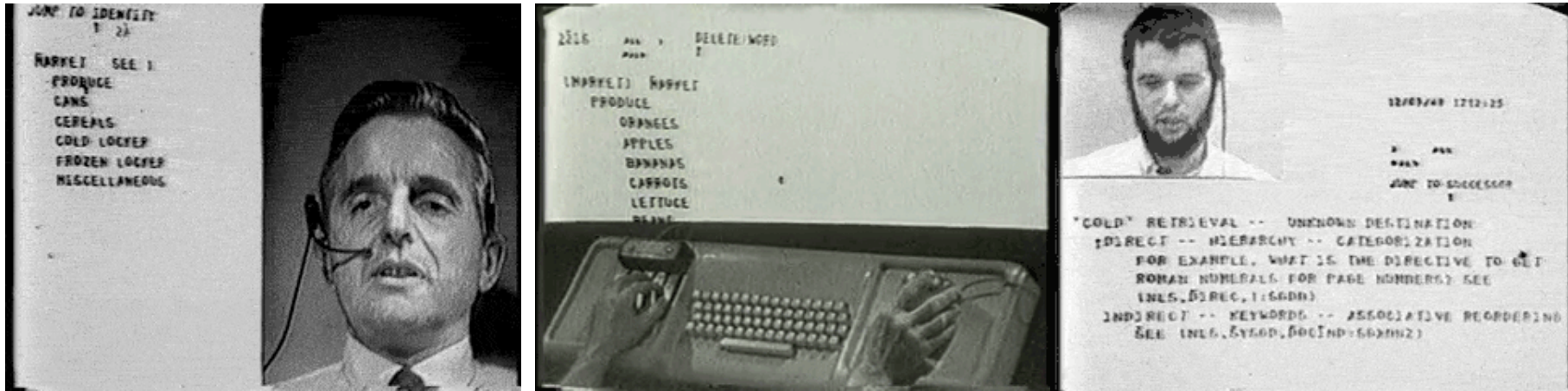


# From groupware to large-scale trustworthy distributed collaborative systems

Claudia-Lavinia Ignat, Inria, France

CRIWG 2018  
September 5, 2018  
[claudia.ignat@inria.fr](mailto:claudia.ignat@inria.fr)

# Douglas Engelbart: Augmenting Human Intellect



The Mother of all Demos, December 9, 1968



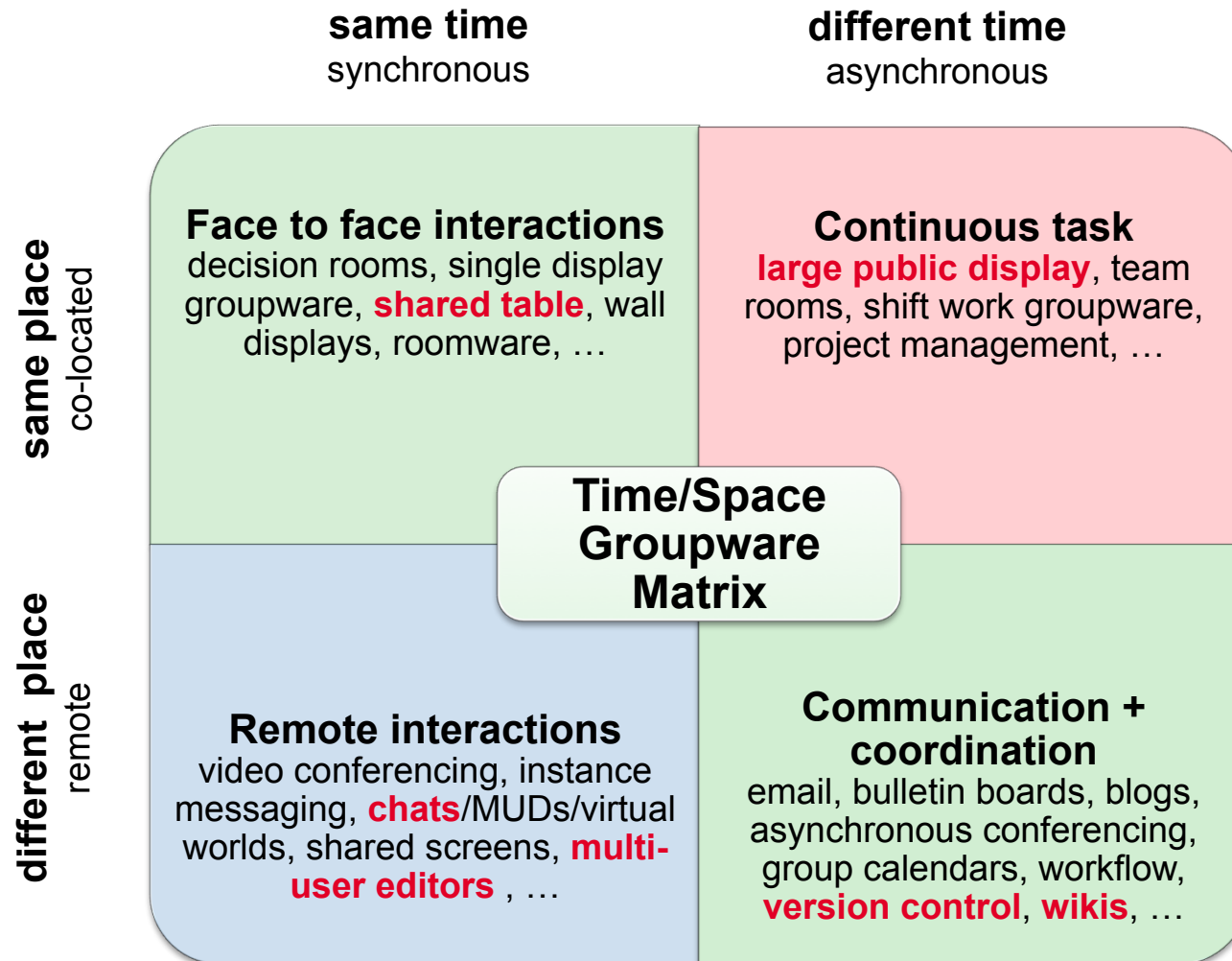
NLS: Online System

<https://archive.org/details/doungengelbartarchives>

## Groupware, early 1990s

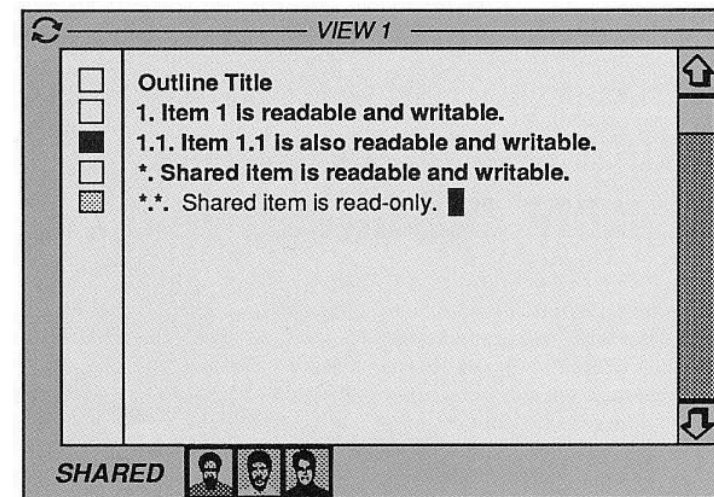
- « Computer-based systems that support groups of people engaged in a common task (or goal) and that provide an interface to a shared environment. » [EGR91]
- Lotus Notes, one of the first commercial groupware allowing remote group collaboration

# Groupware Time Space Matrix [J88]



# Groupware: supported solutions

- *Turn taking*: allow only one active participant at a time
  - e.g. *RTCAL* [SG88], *SHARE* [G90]
- *Locking*: concurrent editing allowed only if users lock and edit different objects
  - e.g. *Colab* [SFBKLS88]
- *Operational transformation*
  - e.g. *GROVE* [EG89]



# Google Drive



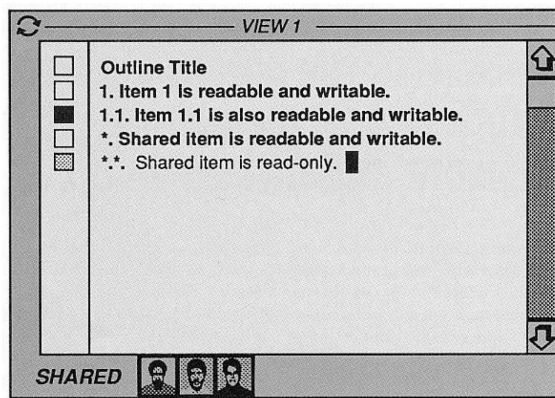


# Collaborative Systems: from users to community of users



*“Isn’t it chaotic to all edit in the same document, even the same paragraph, at the same time?”*

*“Why would a group ever want to edit in the same line of text at the same time?” [EGR91]*



GROVE, 1989



# Collaborative Systems: from users to community of users



- 2013: MOOC “Fundamentals of Online Education: Planning and Applications” with 40.000 participants
- 2016: Nuit debout, more than 70 people edit a pad
- 2018: online CSCW PC meeting with 120 members

# Collaborative Systems: from users to community of users

Real-time  
Wikipedia

The screenshot shows the Wikipedia revision history page for 'Ponte Morandi'. The page title is 'Ponte Morandi: Revision history'. The URL is 'https://en.wikipedia.org/w/index.php?title=Ponte\_Morandi&offset=20180814122400&limit=24&action=history'. The page includes a search bar for revisions, a list of 24 revisions with their dates, times, and editors, and a 'Compare selected revisions' button. The left sidebar contains navigation links for Wikipedia, including 'Main page', 'Contents', 'Featured content', 'Current events', 'Random article', 'Donate to Wikipedia', 'Wikipedia store', 'Interaction', 'Help', 'About Wikipedia', 'Community portal', 'Recent changes', 'Contact page', 'Tools', 'What links here', 'Related changes', 'Atom', 'Upload file', 'Special pages', 'Page information', 'Wikidata item', and 'Languages'.

WIKIPEDIA  
The Free Encyclopedia

Main page  
Contents  
Featured content  
Current events  
Random article  
Donate to Wikipedia  
Wikipedia store

Interaction  
Help  
About Wikipedia  
Community portal  
Recent changes  
Contact page

Tools  
What links here  
Related changes  
Atom  
Upload file  
Special pages  
Page information  
Wikidata item

Languages

## Ponte Morandi: Revision history

[View logs for this page \(view filter log\)](#)

Search for revisions

From year (and earlier): 2018 From month (and earlier): all Tag filter: Show

For any version listed below, click on its date to view it. For more help, see [Help:Page history](#) and [Help:Edit summary](#).  
External tools: [Revision history statistics](#) · [Revision history search](#) · [Edits by user](#) · [Number of watchers](#) · [Page view statistics](#) · [Fix dead links](#)

(cur) = difference from current version, (prev) = difference from preceding version, m = minor edit, → = section edit, ← = automatic edit summary  
(newest | oldest) View (newer 24 | older 24) (20 | 50 | 100 | 250 | 500)

Compare selected revisions

- [\(cur | prev\)](#) [@](#) 12:22, 14 August 2018 Pigsonthewing (talk | contribs) [m](#) . . (4,619 bytes) (-1) . . ([→top](#): [ce](#)) ([undo](#))
- [\(cur | prev\)](#) [@](#) 12:22, 14 August 2018 Pigsonthewing (talk | contribs) [m](#) . . (4,620 bytes) (-4) . . ([→References](#): [ce](#)) ([undo](#))
- [\(cur | prev\)](#) [@](#) 12:22, 14 August 2018 Pigsonthewing (talk | contribs) . . (4,624 bytes) (-44) . . ([→Collapse of the bridge](#): [redirected here](#)) ([undo](#))
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- [\(cur | prev\)](#) [@](#) 12:17, 14 August 2018 37.74.150.97 (talk) . . (4,370 bytes) (+167) . . ([cats](#)) ([undo](#))
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- [\(cur | prev\)](#) [@](#) 12:12, 14 August 2018 Prioryman (talk | contribs) . . (3,766 bytes) (+354) . . ([→Collapse of the bridge](#): [- more](#)) ([undo](#))

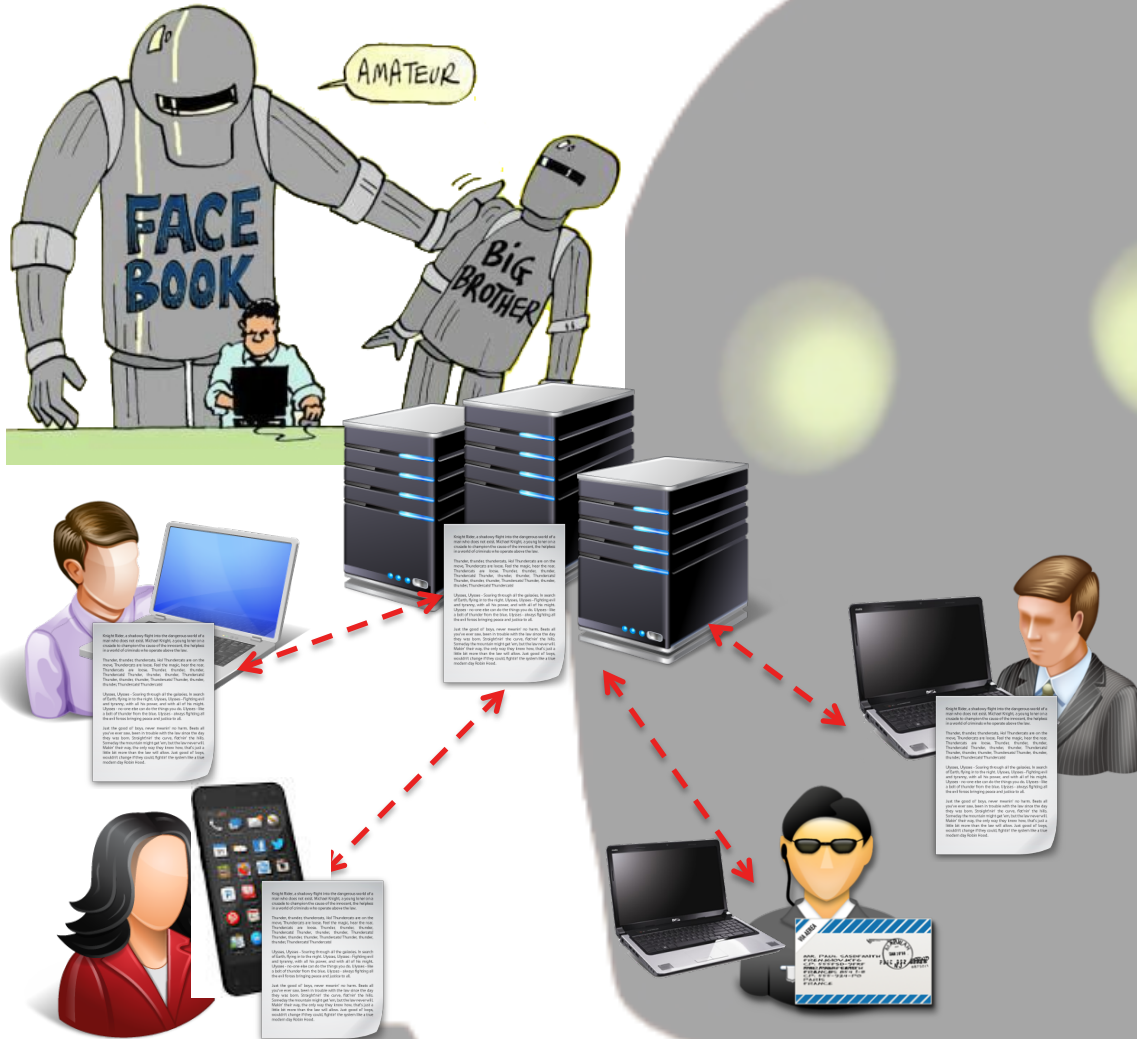
Compare selected revisions

(newest | oldest) View (newer 24 | older 24) (20 | 50 | 100 | 250 | 500)

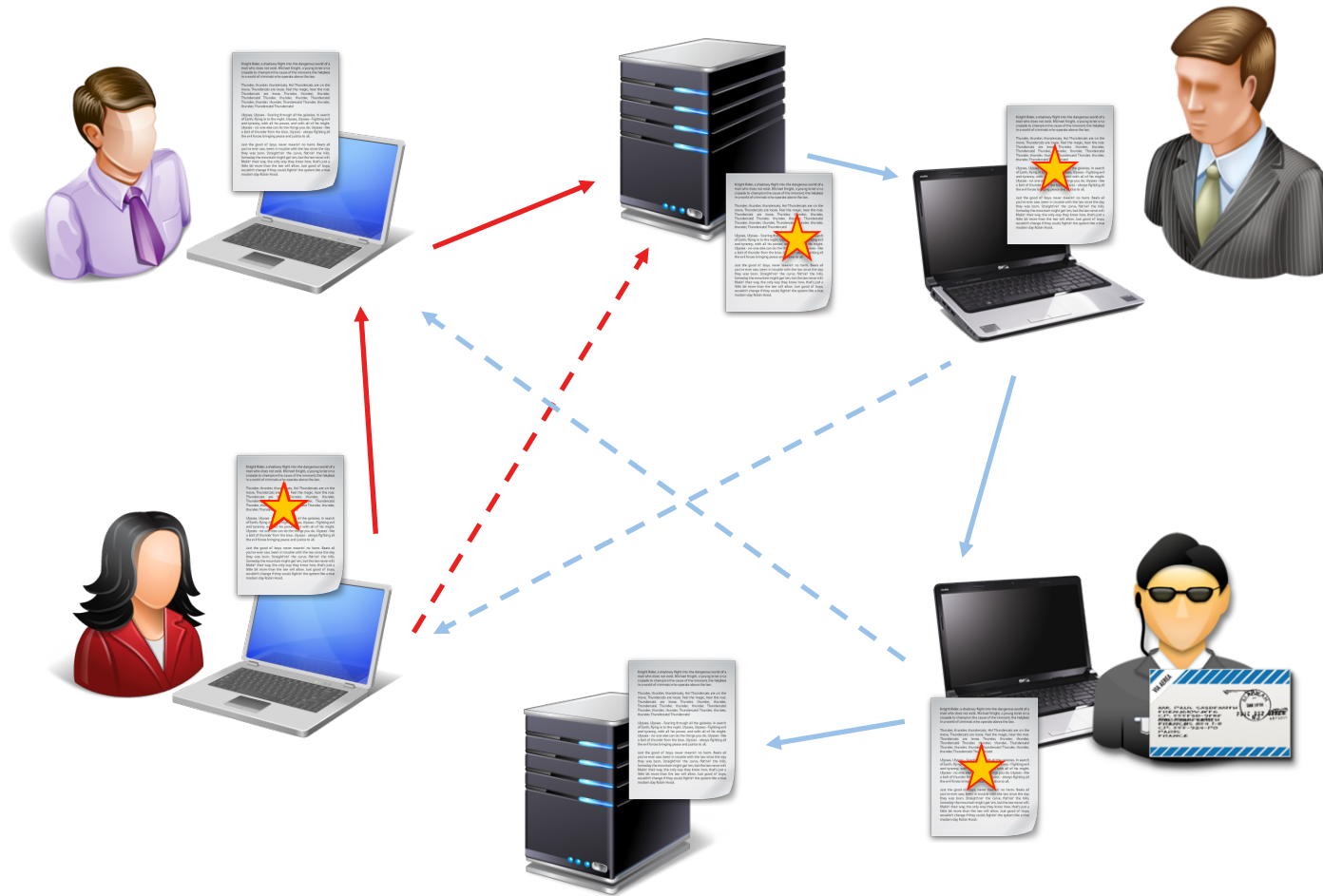
# Limitations of Central Authority Systems

SCALABILITY

PRIVACY

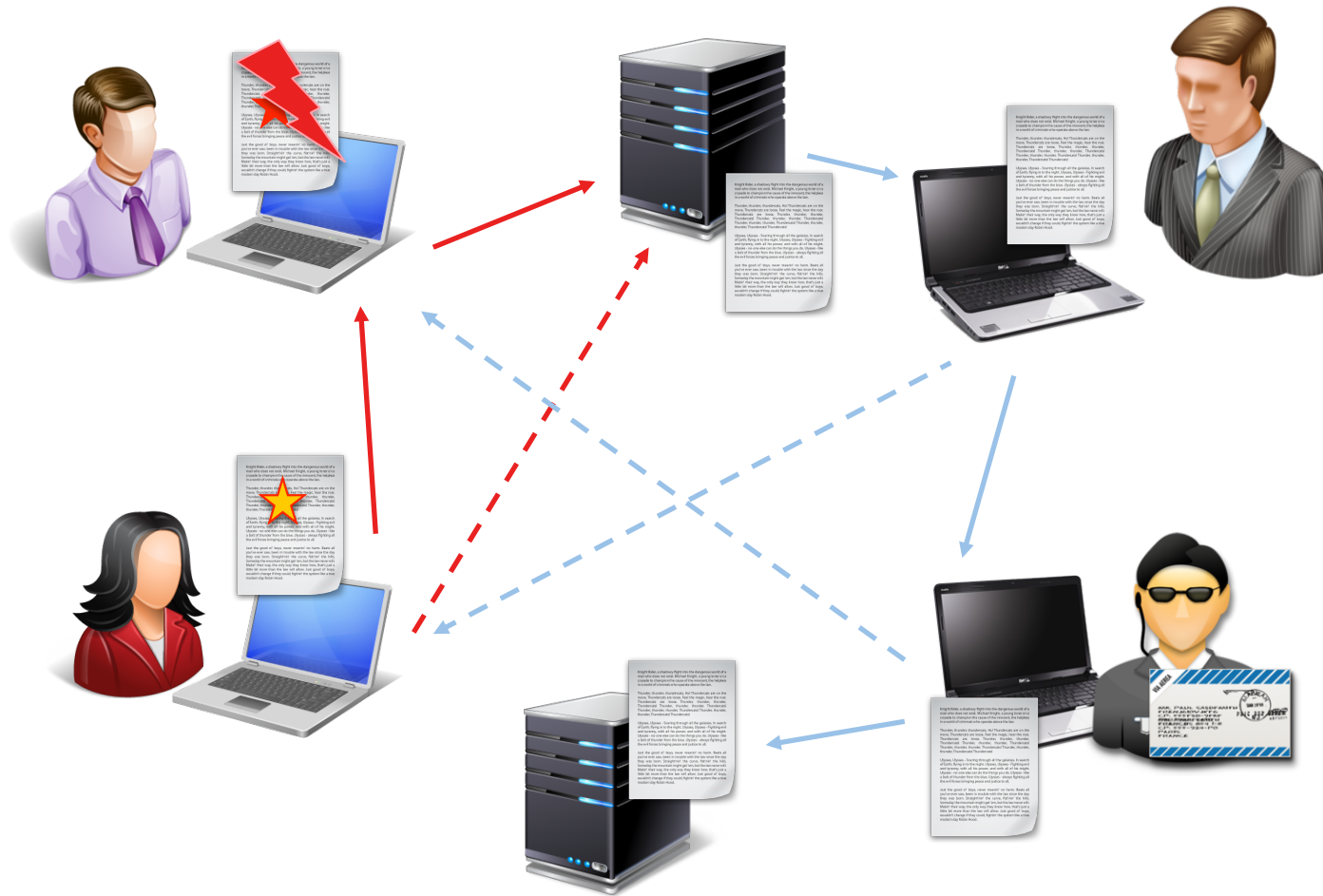


# Peer-to-Peer Collaborative Systems





# Collaboration Modes – Concurrent Changes







# Collaboration Modes – Ad-hoc Collaboration



## Research issues

- 1 How to **maintain consistency of different copies** in the face of concurrent modifications?
- 2 How to **evaluate the design of collaborative systems** and approaches?
- 3 How to **secure collaboration data**?

## Research issues

- 1 How to **maintain consistency of different copies** in the face of concurrent modifications?
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# Optimistic Replication [SS05]

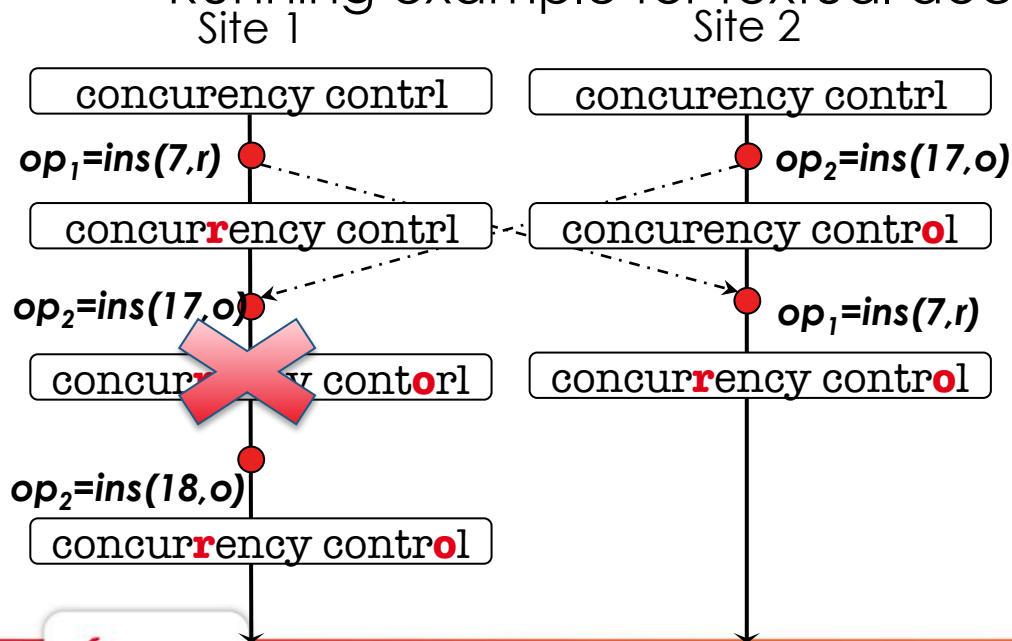
- Trade-off between consistency and availability
  - Optimistic replication : allows replicas to diverge
- Strong Eventual Consistency
  - Eventual delivery: An update executed at some correct replica eventually executes at all correct replicas
  - Strong convergence: Correct replicas that have executed the same updates have equivalent states
  - No consensus in background, no need to rollback
- Intention preservation
  - « *Effect of each operation should be observed on all copies* »

# Operational transformation (OT) [EG89]

- $n$  copies of an object hosted at  $n$  sites
- An object is modified by applying operations
- Each operation is
  - generated at a site (local execution),  
and applied immediately on the local copy
  - broadcasted to other sites
  - integrated at those sites (remote execution)
- System is correct if when it is idle all copies are identical (SEC)

# Operational transformation (OT)

- General architecture with two main components:
  - An integration algorithm (diffusion, integration)
  - A set of transformation functions (conflict resolution)
- Running example for textual document = sequence of characters



- Operations:
  - $ins(p, c)$
  - $del(p)$

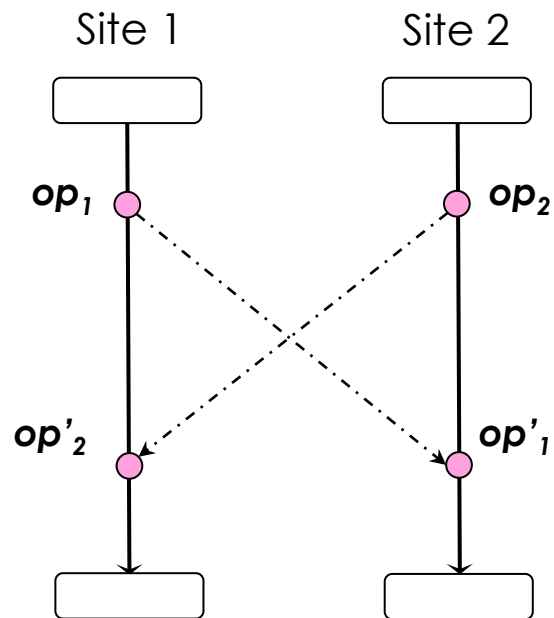
$T(ins(p_1, c_1), ins(p_2, c_2)) :-$   
 if  $(p_1 < p_2)$  return  $ins(p_1, c_1)$   
 else return  $ins(p_1 + 1, c_1)$   
 endif



# Operational transformation

## Correctness [EG89]

$$(TP1) \quad op_1 \circ T(op_2, op_1) \equiv op_2 \circ T(op_1, op_2)$$



$T(op_2: \text{operation}, op_1: \text{operation}) = op'_2$

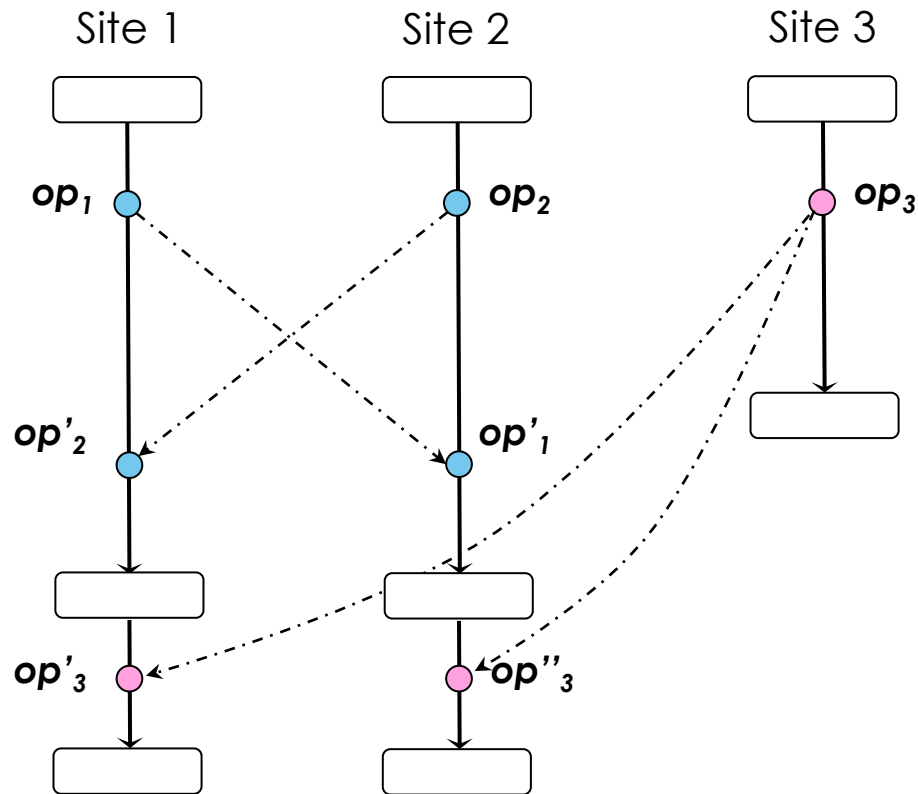
- $op_1$  and  $op_2$  concurrent, defined on a state  $S$
- $op'_2$  same effects as  $op_2$ , defined on  $S.op_1$



# Operational transformation

## Correctness [RNG96]

$$(TP2) \quad T(op_3, op_1 \circ T(op_2, op_1)) = T(op_3, op_2 \circ T(op_1, op_2))$$



# Operational transformation (OT)

## Existing approaches

- Two main families:
  - Transformation functions satisfying both TP1 and TP2: SOCT2 [SCF97] + TTF [OUMI06]
  - Control algorithms avoiding (needs of) TP2: SOCT4 [VCFS00], Jupiter [NCDL95]

# Operational transformation (OT)

## Summary

- Transforms non commuting operations to make them commute
- Genericity
- Time complexity
  - Average:  $O(H c)$      $H$ : #ops
  - Worst case:  $O(H^2)$      $c$ : avg. #conc. ops
- Difficult to write correct transformation functions
- State vectors used for detecting concurrency  $\Rightarrow$  scalability limitations
- **Not very suitable for large scale peer-to-peer**

**collaboration**

*Inria*

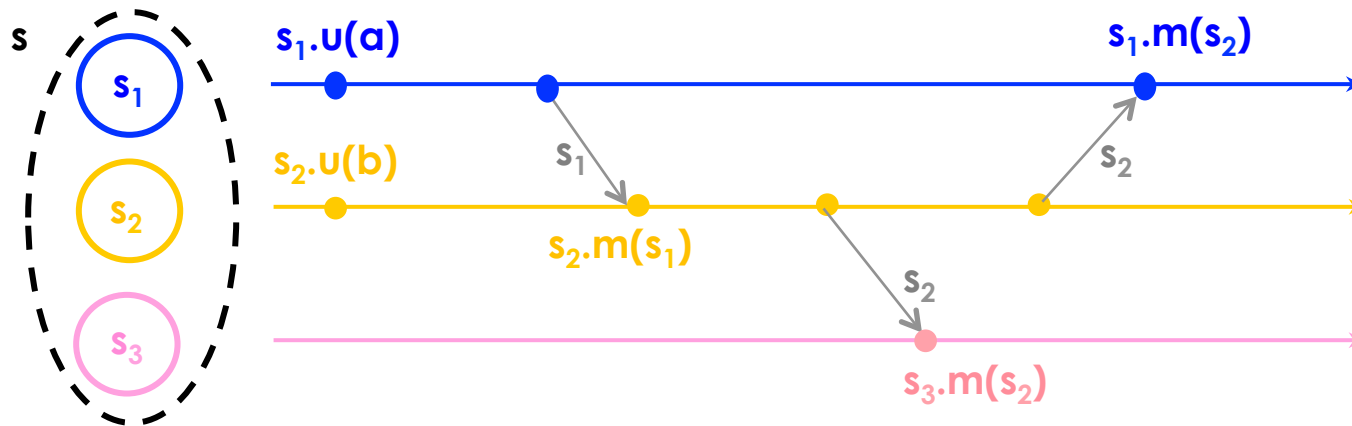
# Conflict-free Replicated Data Types (CRDT)

## [SPBZ11]

- Design operations to be commutative by construction
- Abstract data types
  - Designed to be replicated at multiple sites
  - Any replica can be modified without coordination
  - State convergence is guaranteed
- State-based and operation-based approaches

# Conflict-free Replicated Data Types (CRDT)

## State-based Replication



- Algorithm
  - Periodically, replica at  $p_i$  sends its current state to  $p_j$
  - Replica  $p_j$  merges received state into its local state by executing  $m$
- After receiving all updates (irrespective of order), each replica will have same state



# Conflict-free Replicated Data Types (CRDT)

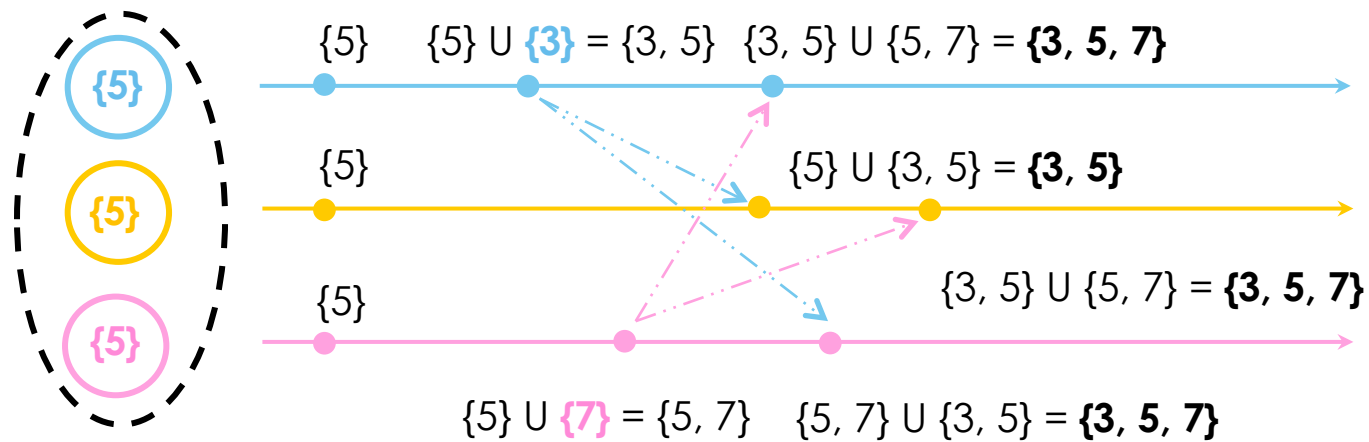
## State-based Replication

- Merge operator:
  - **Commutative:**  $x \bullet y = y \bullet x$
  - **Associative:**  $(x \bullet y) \bullet z = x \bullet (y \bullet z)$
  - **Idempotent :**  $x \bullet x = x$
- A semi-lattice is a Partial order  $\leq$  set  $S$  with a least upper bound (LUB), denoted  $\sqcup$ 
  - $m = x \sqcup y$  is a LUB of  $\{x, y\}$  under  $\leq$  if and only if  $\forall m', x \leq m' \wedge y \leq m' \Rightarrow x \leq m \wedge y \leq m \wedge m \leq m'$
  - It follows that  $\sqcup$  is commutative, associative and idempotent

# Conflict-free Replicated Data Types (CRDT)

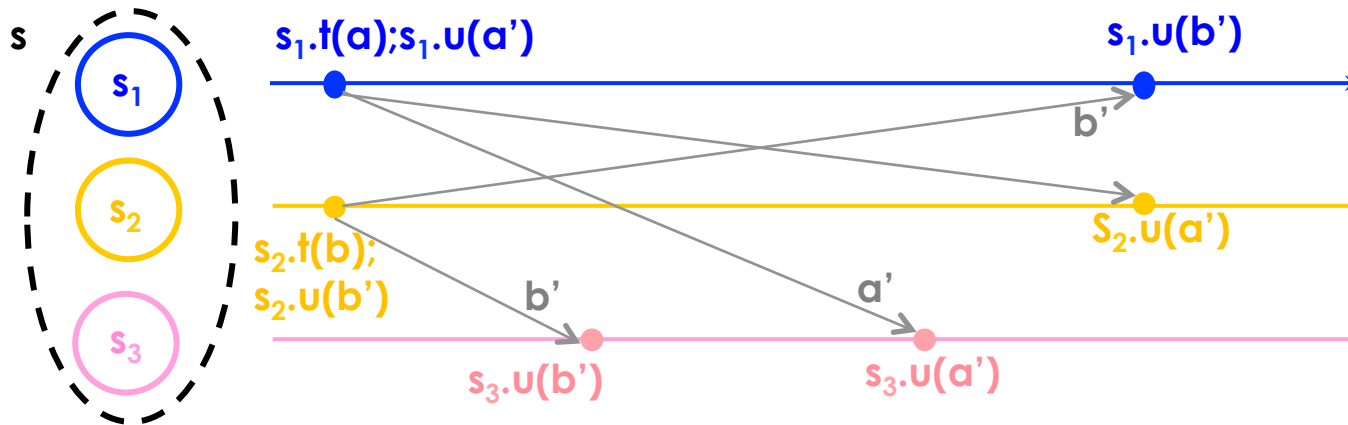
## Convergent Replicated Data Type (CvRDT)

- Example



# Conflict-free Replicated Data Types (CRDT)

## Operation-based Replication

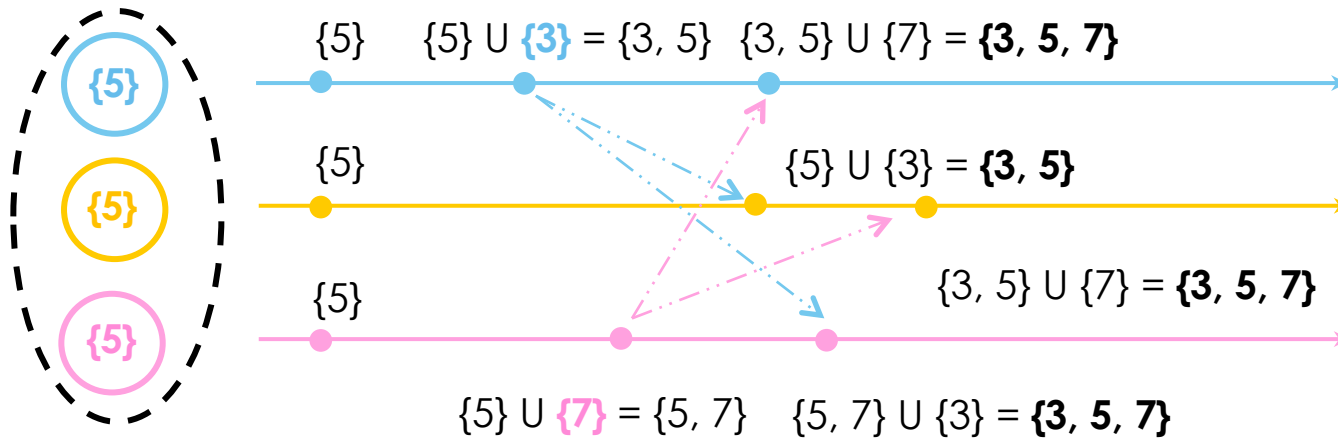


- An update split into  $(t,u)$ :  $t$  is a side-effect-free *prepare-update method* and  $u$  is an *effect-update method*
- Algorithm
  - Updates delivered to all replicas
  - Causally-ordered broadcast, every message delivered to every node exactly once w.r.t. happen-before order
- Commutativity holds for concurrent updates

# Conflict-free Replicated Data Types (CRDT)

## Commutative Replicated Data Type (CmRDT)

- Example



# Conflict-free Replicated Data Types (CRDT)

## CvRDT vs. CmRDT

- Both approaches are equivalent
  - A state-based object can emulate an operation-based object, and vice-versa
- Operation-based:
  - More efficient since you only ship small updates
  - But require exactly once causally-ordered broadcast
- State-based:
  - Only require reliable broadcast
  - Communication overhead of shipping the whole state
- Delta State-based [ASB18]:
  - Small messages
  - Dissemination over unreliable communication channels

# Consistency Maintenance

## Conflict-free Replicated Data Types (CRDT)

- Register
  - Last-Writer Wins
  - Multi-Value
- Set
  - Grow-Only
  - 2-Phase
  - Observed-Remove
  - Observed-Update-Remove

- Map
- Counter
- Graph
  - Directed
  - Monotonic DAG
  - Edit graph
- **Sequence**



# Conflict-free Replicated Data Types (CRDT) (Text) Sequence [PMSL09] [WUM09]

- Document = linear sequence of elements
  - Each element has a unique identifier
  - Identifier constant for the lifetime of the document
  - Dense total order of identifiers consistent with element order:
    - $\forall id_x, id_y: id_x < id_y \Rightarrow \exists id_z: id_x < id_z < id_y$
- Different approaches for generating identifiers:
  - TreeDoc, Logoot, LogootSplit, ...

# Conflict-free Replicated Data Types (CRDT)

## Logoot [WUM09]

- Logoot identifiers:  $\langle p_1, s_1, h_1 \rangle \langle p_2, s_2, h_2 \rangle \dots \langle p_k, s_k, h_k \rangle$

$p_i$  integer

$s_i$  site identifier

$h_i$  logical clock at site  $s_i$

$\langle 1, 2, 1 \rangle$	c
$\langle 1, 2, 2 \rangle$	o
$\langle 2, 1, 2 \rangle$	n
$\langle 3, 1, 3 \rangle$	c
$\langle 3, 1, 3 \rangle \langle 8, 4, 5 \rangle$	u
$\langle 3, 2, 5 \rangle$	r
$\langle 4, 1, 7 \rangle$	e
$\langle 4, 1, 7 \rangle \langle 9, 2, 6 \rangle$	n
$\langle 7, 2, 8 \rangle$	c
$\langle 9, 1, 7 \rangle$	y
$\langle 10, 2, 8 \rangle$	
$\langle 12, 3, 1 \rangle$	c
$\langle 12, 3, 1 \rangle \langle 6, 5, 1 \rangle$	o
$\langle 12, 3, 1 \rangle \langle 7, 8, 2 \rangle$	n
$\langle 12, 3, 1 \rangle \langle 7, 8, 2 \rangle \langle 12, 3, 5 \rangle$	t
$\langle 12, 3, 1 \rangle \langle 7, 8, 2 \rangle \langle 13, 3, 6 \rangle$	r
$\langle 12, 3, 1 \rangle \langle 7, 8, 2 \rangle \langle 14, 3, 7 \rangle$	l

ins( $\langle 3, 2, 5 \rangle \langle 13, 1, 7 \rangle$ , r)

ins( $\langle 12, 3, 1 \rangle \langle 7, 8, 2 \rangle \langle 13, 3, 6 \rangle \langle 7, 2, 9 \rangle$ , o)

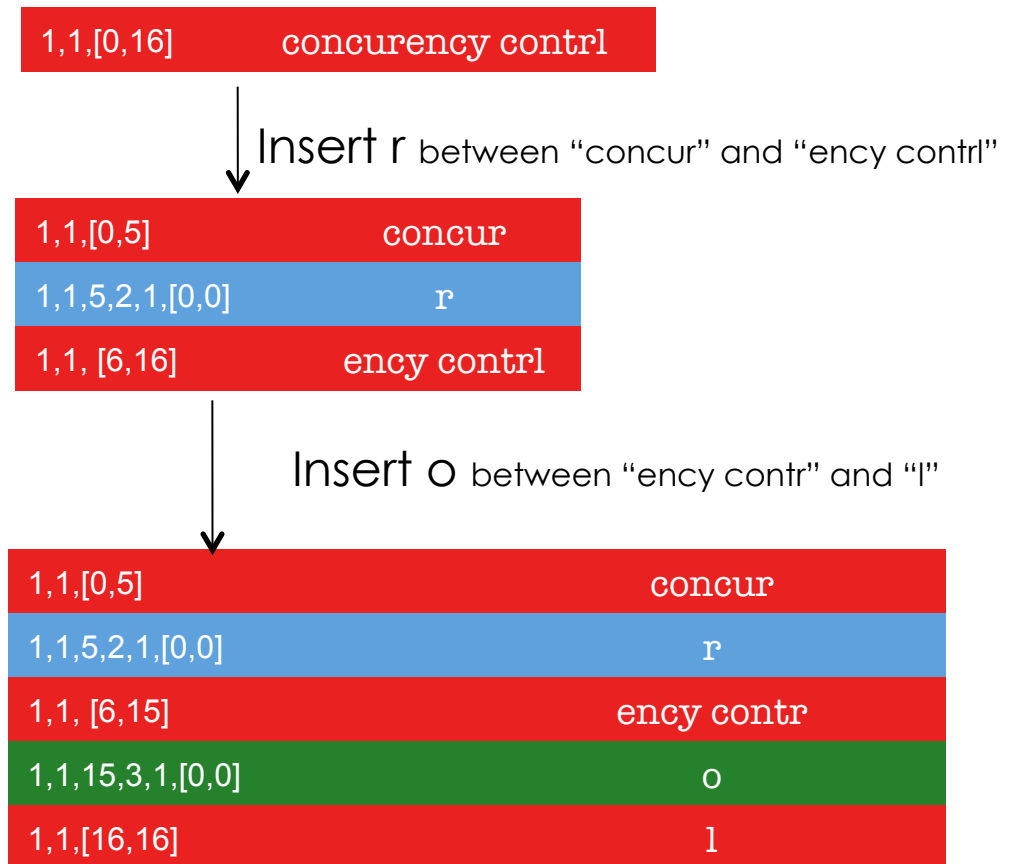
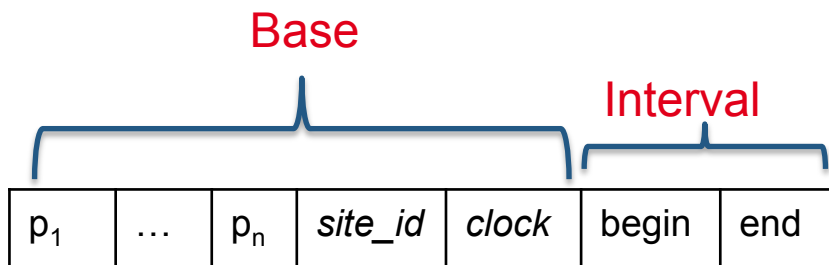
- Time complexity
  - Average:  $O(k \log(n))$
  - Worst case:  $O(H * \log(H))$
  - H: #ops
  - n: doc. size (non deleted chars.)
  - k: avg. size of Logoot identifier
- No need for concurrency detection
- Identifiers storage cost
- New design for each data type
- Suitable for large-scale collaboration**



# Conflict-free Replicated Data Types (CRDT)

## LogootSplit [AMO13]

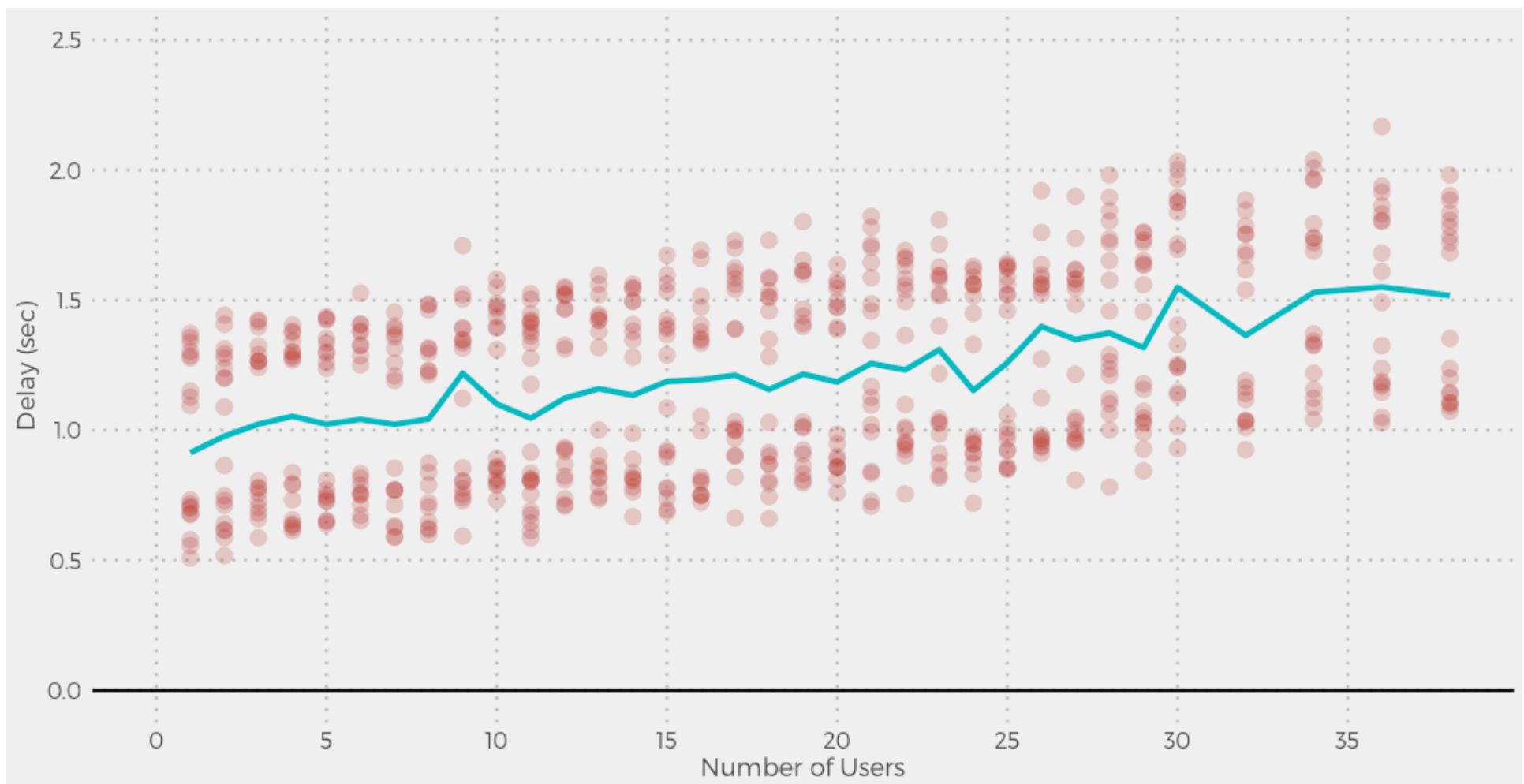
LogootSplit identifiers



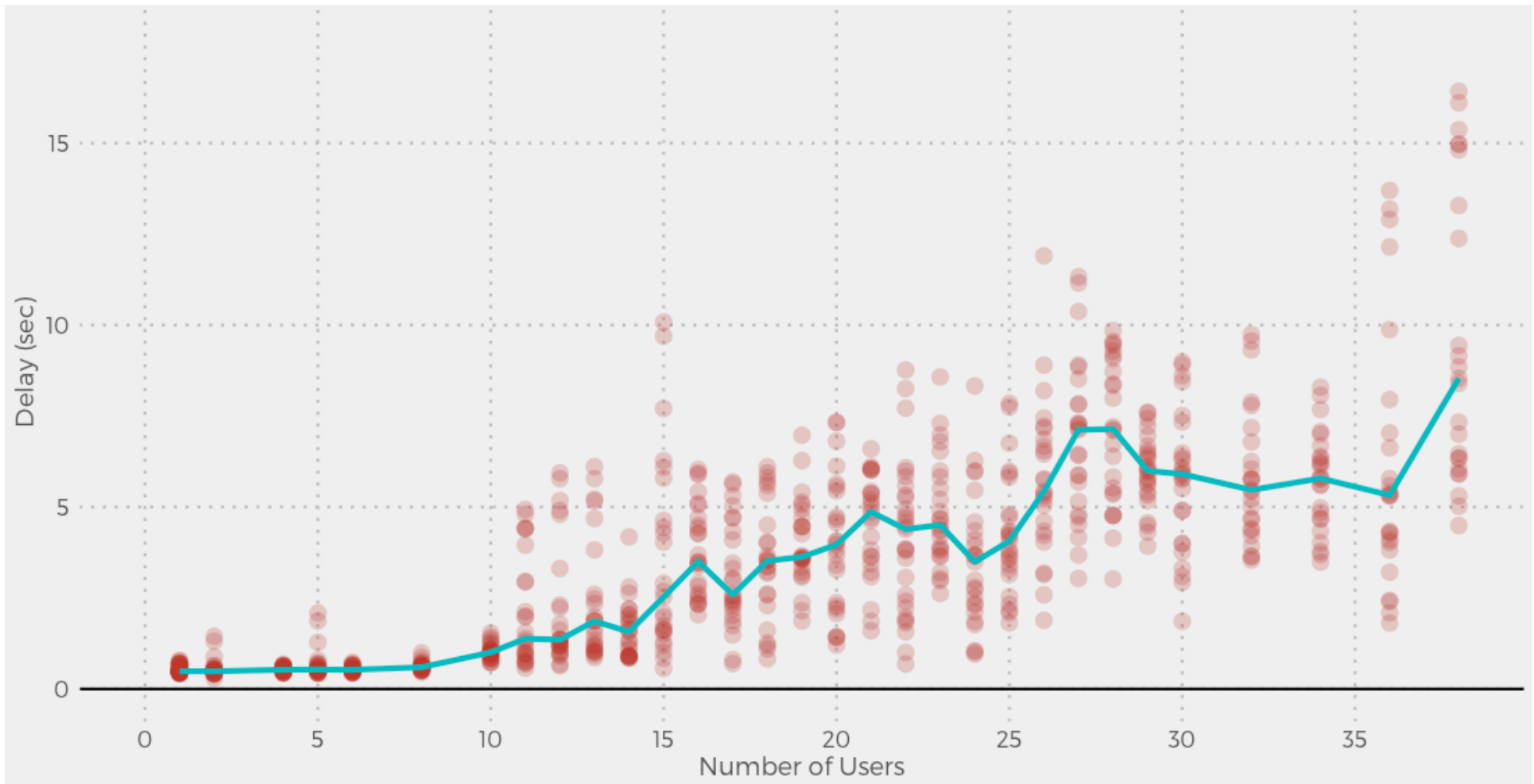
## OT vs. operation-based CRDT

- CRDT: more formalised approach
- OT: more generic and guided
  - Generic concurrency control algorithm
  - Operation transformations specific to application domain
- CRDT: different solutions for concurrency handling for different data types
- CRDT: Metadata overhead

# Delays in MUTE [NEOIC17] <https://coedit.re/>



# Delays in GoogleDocs [DI16]

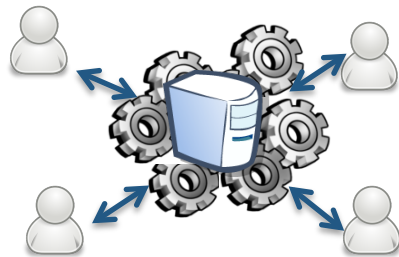


# Research issues

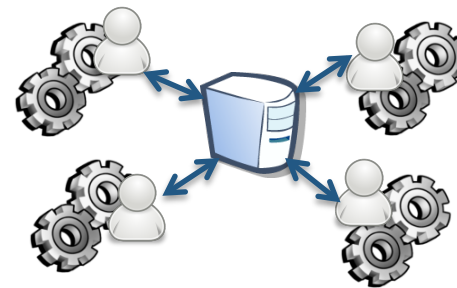
- 1 How to **maintain consistency of different copies** in the face of concurrent modifications?
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- 3 How to **secure collaboration data**?

## User Study: The effect of delay on users

- Delays in seeing modifications of other users
  - Network delay
  - Time complexity of consistency maintenance algorithms
  - Types of architecture



Thin client architecture



Thick client architecture

- How does **delay influence group performance?**

# Experiment design

- 20 groups of 4 students
  - Perform several collaborative editing tasks
    - A proofreading task
    - A sorting task
    - **A note taking task**
  - Use the provided collaborative editor (Etherpad) + chat
  - Each group experienced a **certain delay** (0, 4, 6, 8, 10 s)
- Registration of user keyboard inputs
- Video recording of user activities on desktop



# Note-taking [IOFSC15]

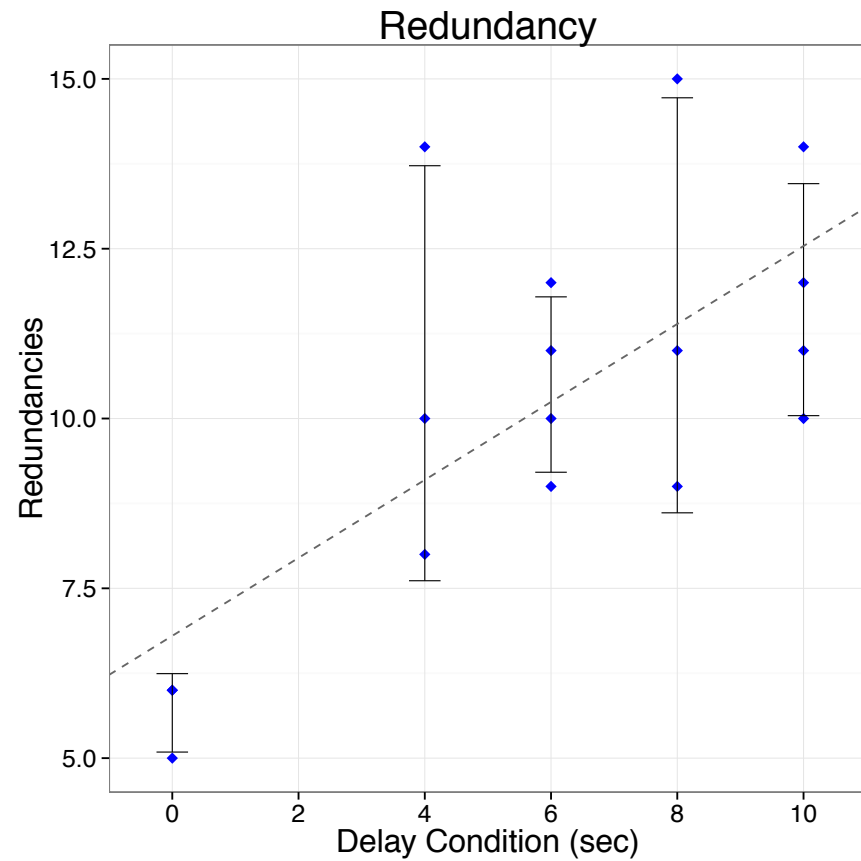
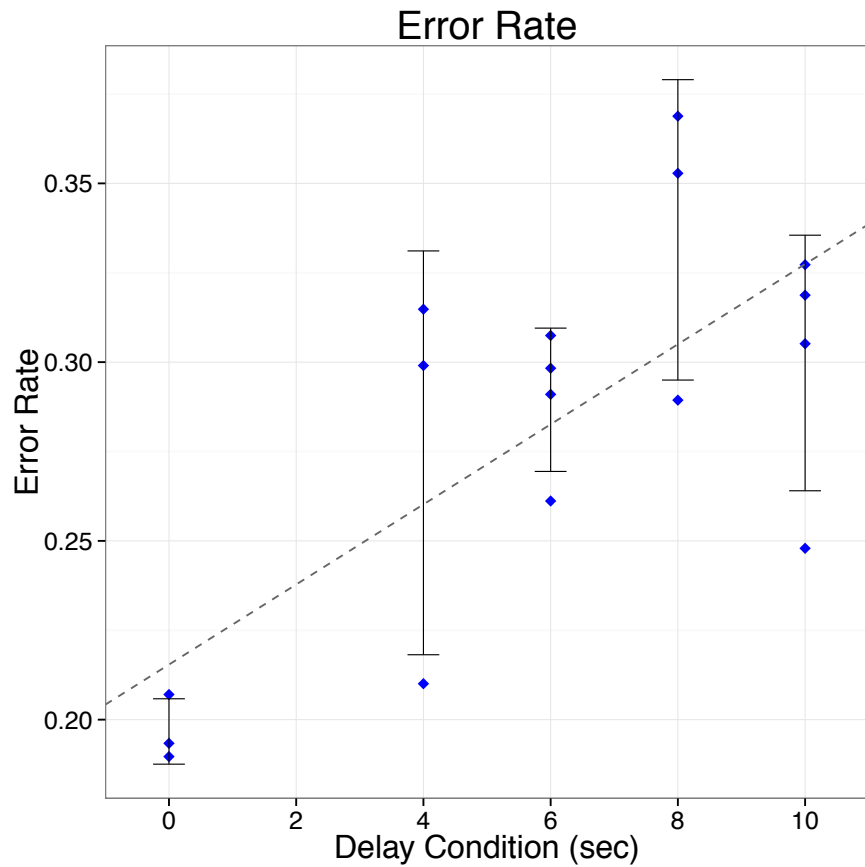
The image shows a screenshot of a web browser displaying a note-taking application. The browser's address bar shows the URL `ec2-184-72-75-76.compute-1.amazonaws.com/p/notes005`. The note-taking interface includes a toolbar with various editing tools and a list of notes. A black box labeled "Editing zone" points to a highlighted section of text in the notes. A "Chat dialogue" window is visible in the bottom right corner, showing a list of messages from different users. Three circular callouts are present: one pointing to the text "un data matérialisé", another pointing to "demateriali", and a third pointing to "matérialisé".

**Editing zone**

**Chat dialogue**

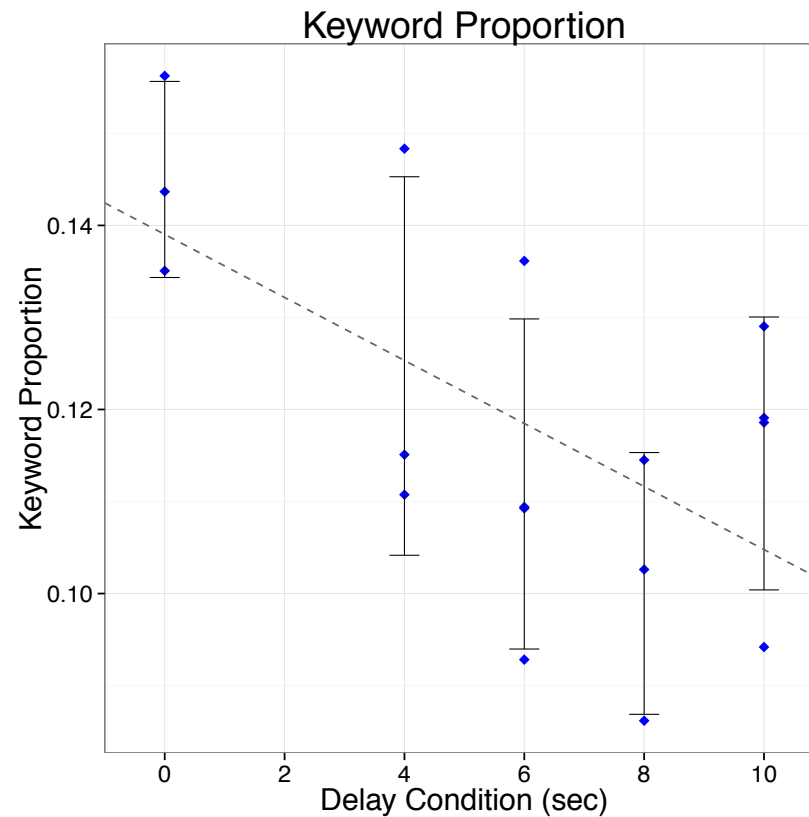
Chat	
user4: test	16:15
user2: test user 2	16:15
user2: great	16:15
user3: test	16:15

# Delay reduces Group Performance



- Delay increases error rate and redundancy

# Delay reduces Group Performance



- Delay decreases proportion of keywords

## Design implications

- Reduce the delay by the choice of the architecture and synchronisation algorithms
- Make users aware of existing delays such that they can compensate for the delay by coordination strategies
- Analyse real collaboration traces to understand collaboration patterns and behavior [NI18]

## Research issues

- 1 How to **maintain consistency of different copies** in the face of concurrent modifications?
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# Security in peer-to-peer collaboration



- How to learn and verify the other party's key ?
- Trust-based access control

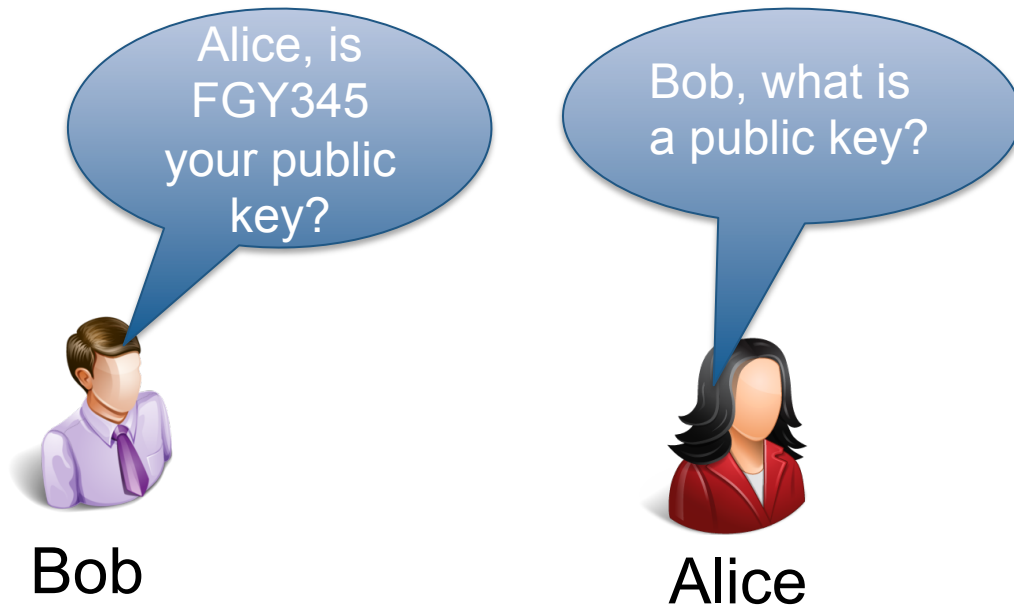
# Trust establishment

- How to learn and verify the other party's key before establish a secure communication channel ?
  - Out of band trust establishment
  - Trust establishment by the provider



# Out of band trust establishment

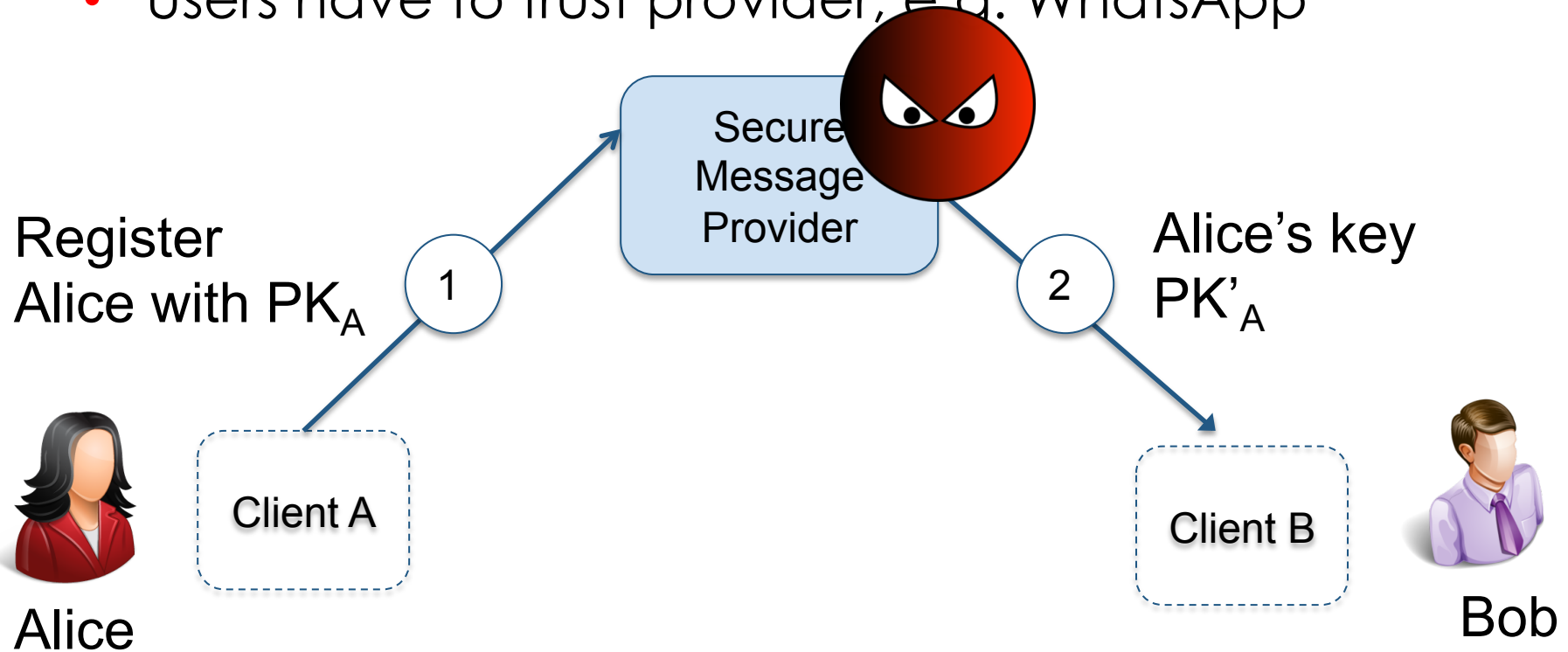
- Unintuitive, error-prone



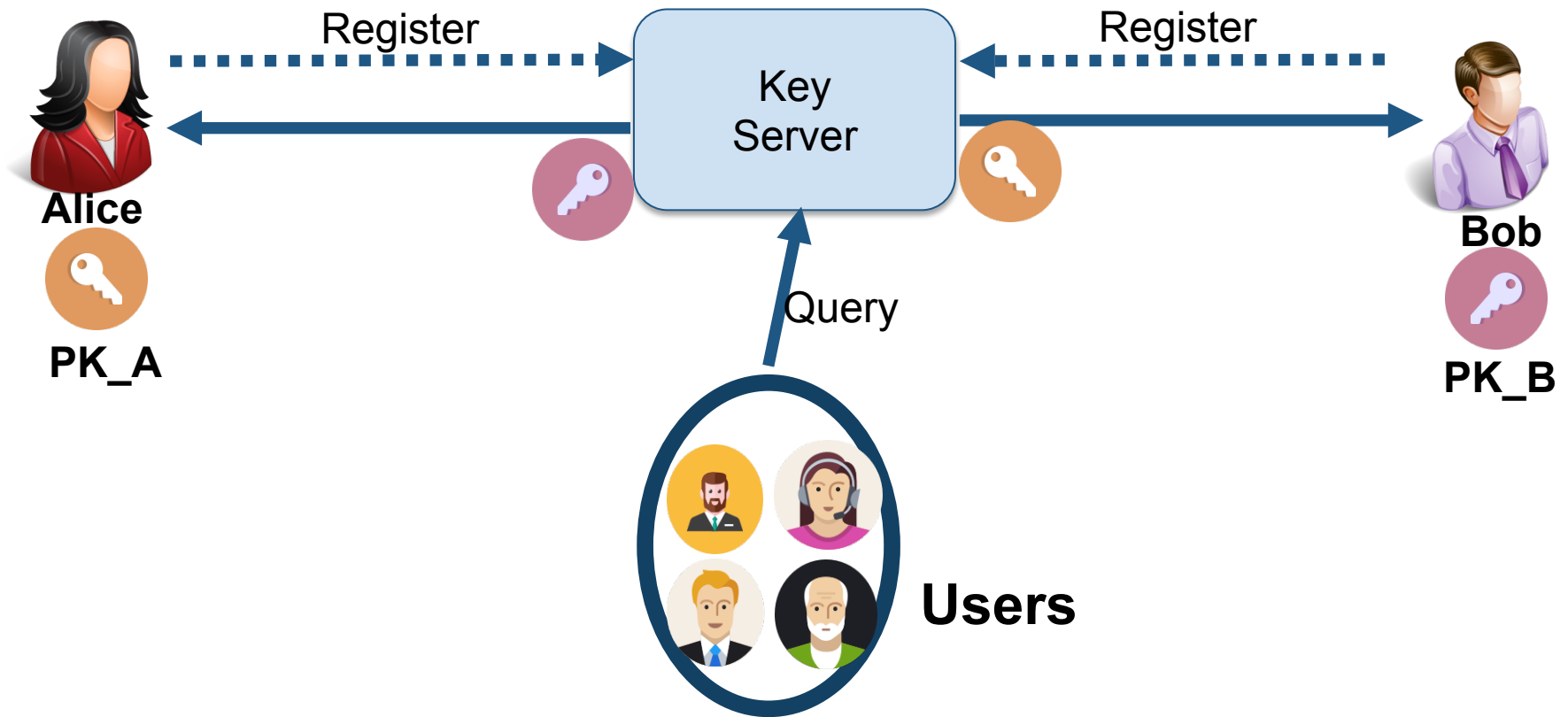
# Trust establishment by the provider

## Centralized key server

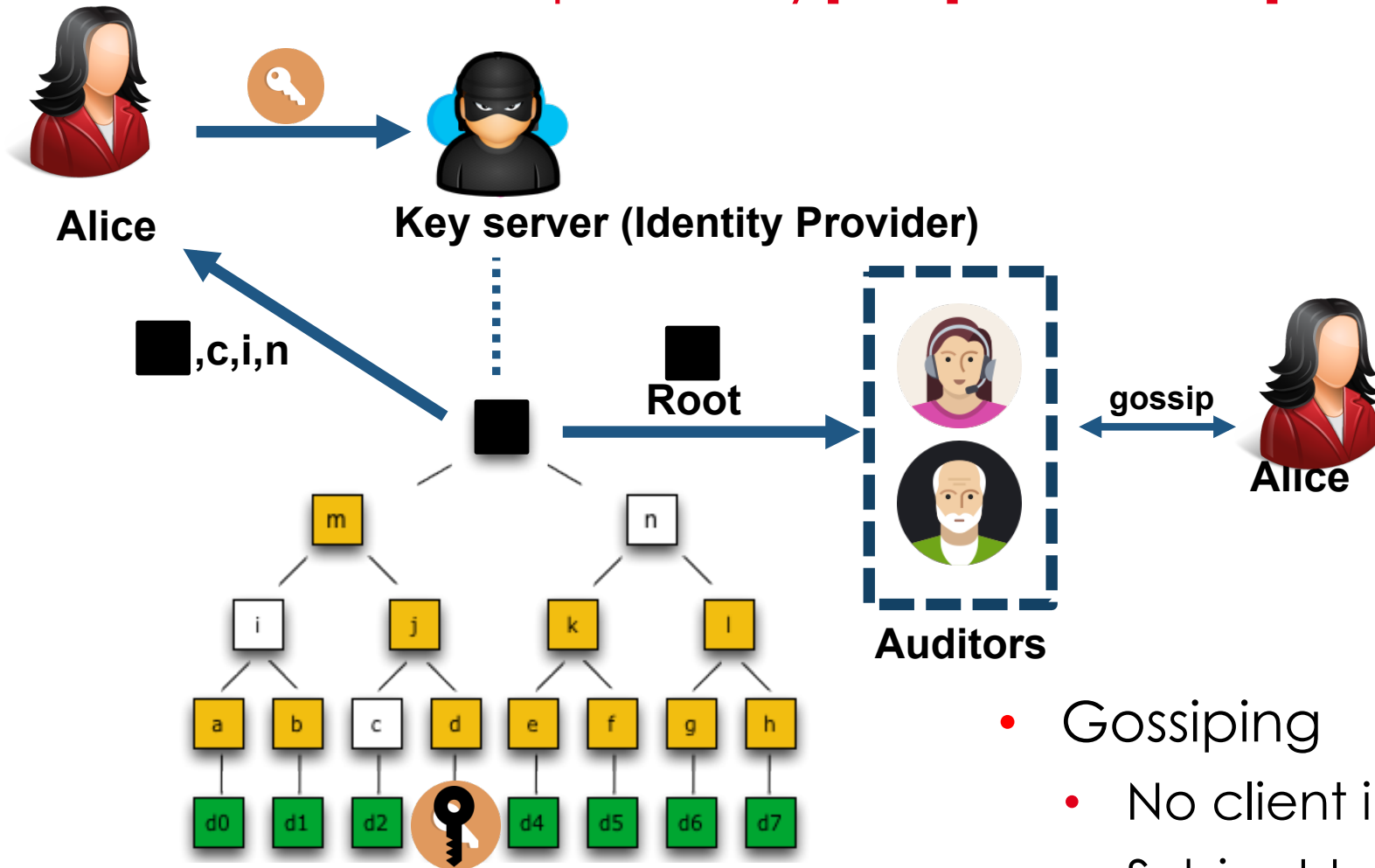
- Clients query providers for keys of other users
- Users have to trust provider, e.g. WhatsApp



# Transparent log

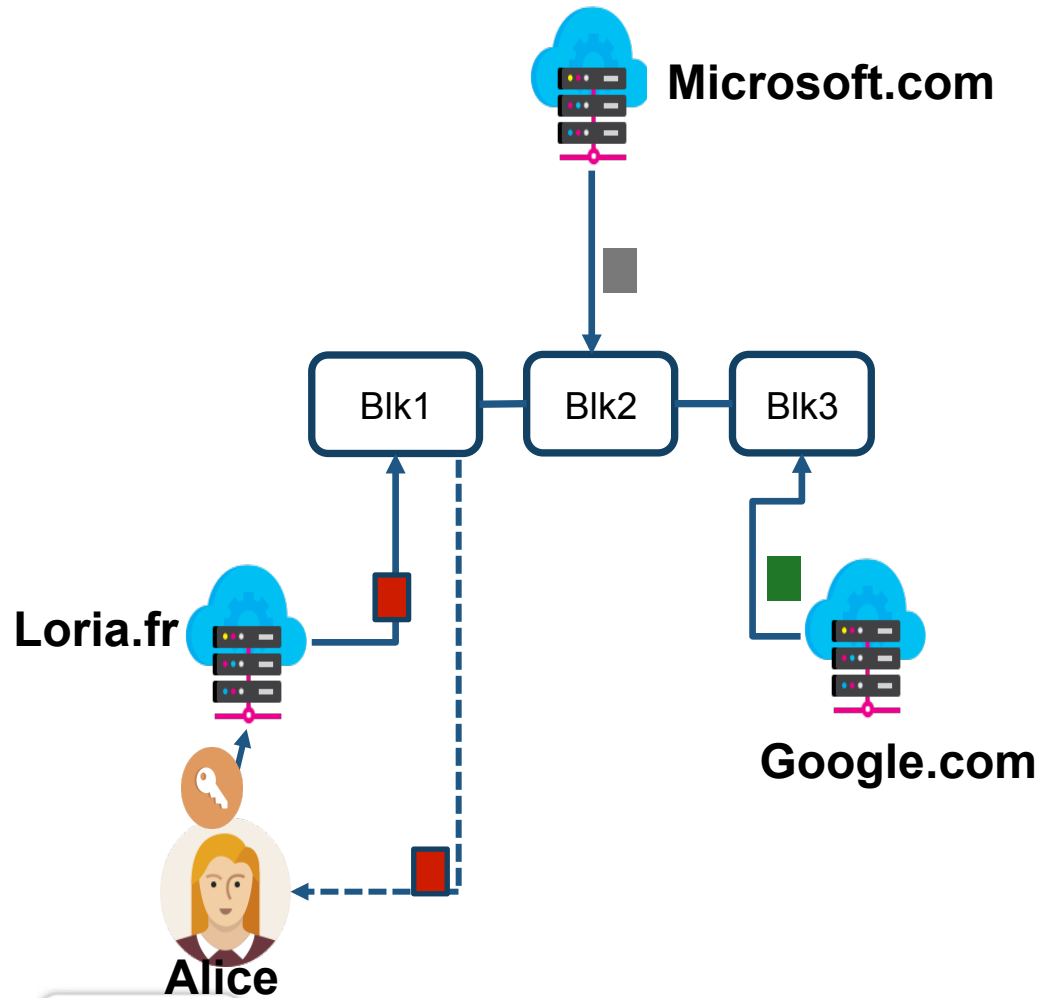


# Certificate transparency[L14]/CONIKS [MBBFF15]



- Gossiping
  - No client incentive
  - Subject to Sybil and Eclipse attacks

# Trusternity: Blockchain-based Auditing of Transparent Log Servers [NEIP18]

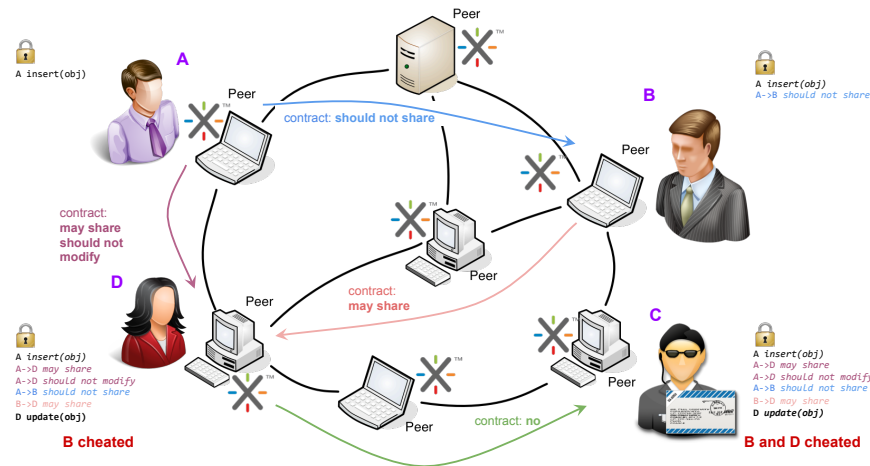


## Trust-based access control

- Dynamic trust values among users
- How to **define an access control based on trust** and how to **compute trust based on collaborative experience?**

# Trust computation

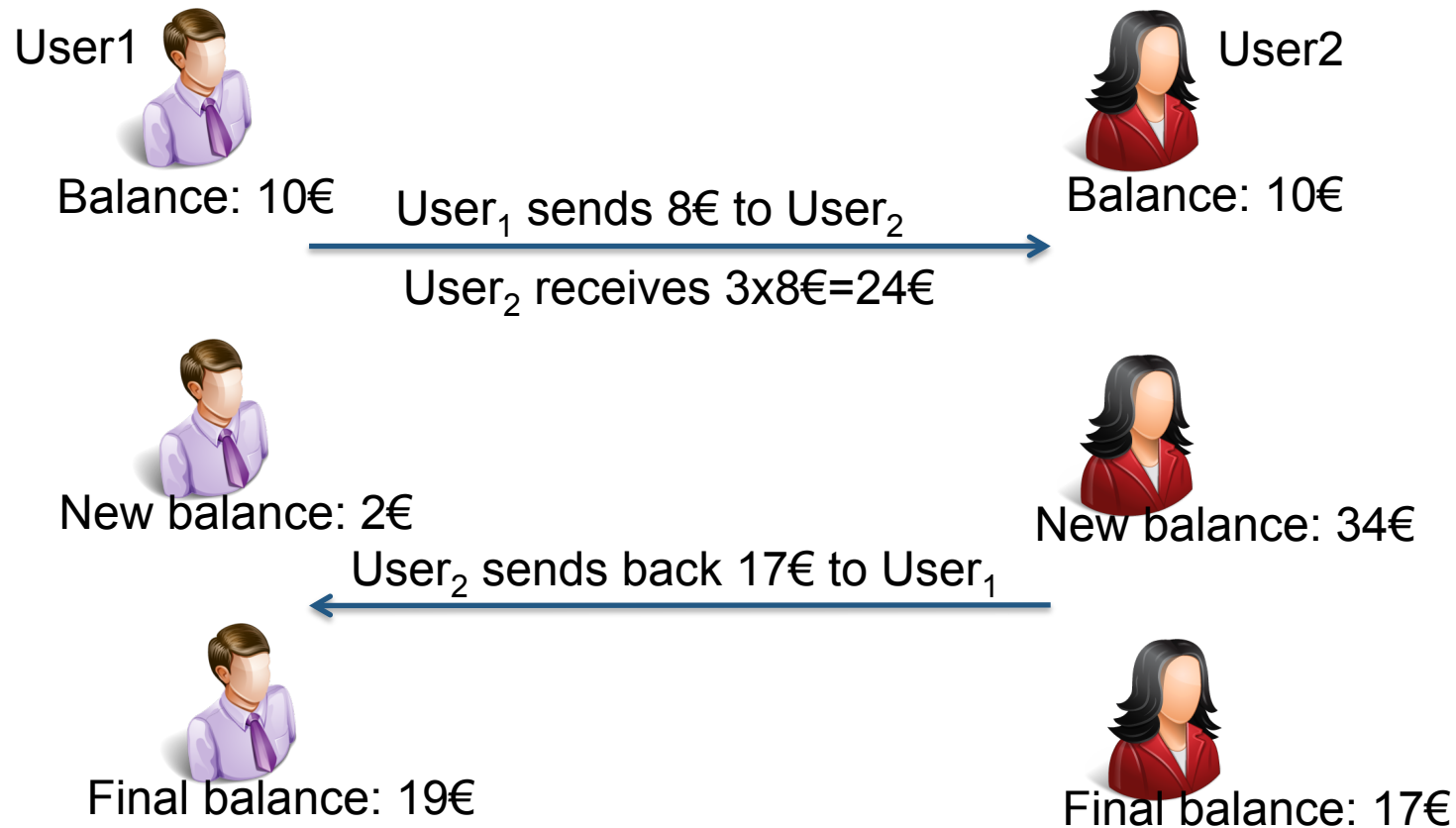
- Respect/Violation of contracts
  - Contracts in collaborative editing (share, edit)



- Reporting of fake news in Facebook
- Quality of user contributions

# Validation of trust-based collaboration

- Using game theory (trust game) [BDM95]





# Validation of trust-based collaboration

- Proposal of a trust metric reflecting user behavior [DI16]
- User studies on various trust game variations
  - Trust can replace knowing the identity of collaborators
  - People take into account the trust value of the partner in their future collaboration

# Large-scale trustworthy distributed collaborative systems

- New uses and new practices due to large scale adoption
- New challenges
  - Consistency of replicated data
  - User studies
  - Trust and Security

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# modifications operation-based

documents  
management  
modification  
friend-to-friend  
operation-based  
work  
granularity  
conflicts

web-based  
push-pull-time  
compro  
mising  
increasing  
round-free  
securing  
development

networks  
assessment  
peer-to-peer  
awareness  
environments  
peer-to-peer  
collaborative

undo  
framework  
analysis  
development

undo  
studying  
multi-mode

web  
cdrts  
changes  
analysis  
xml

adaptable  
wiki  
push-pull  
text  
history

xml

editing  
structures  
repositories  
awareness

data  
contract  
tree-based  
editor  
model  
tree  
graphical  
distributed

real-time  
data  
user  
resolution  
grouping  
multi-level

algorithms  
processes  
annotation  
concurrent  
trust

merging  
drawing  
editing  
algorithm  
hi story  
multi-part

real-time  
data  
user  
resolution  
grouping  
multi-level

algorithms  
processes  
annotation  
concurrent  
trust

writing  
information  
log  
multi-pair  
model  
authoring  
communication

changes  
software  
note  
delay  
content  
evaluating  
optimistic  
authenticating

consistency  
slices  
wiki  
information  
log  
multi-pair  
model  
authoring  
communication

framework  
state-based  
privacy  
massive-scale  
hierarchical  
draw-together

# documents systems multi-level

grouping  
asynchronous

performance  
inter-document  
co-authoring

# Thank you

## COAST Team

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