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Keynote: Large-scale trustworthy distributed collaborative systems - challenges and prospective solutions

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Loria



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DE LORRAINE



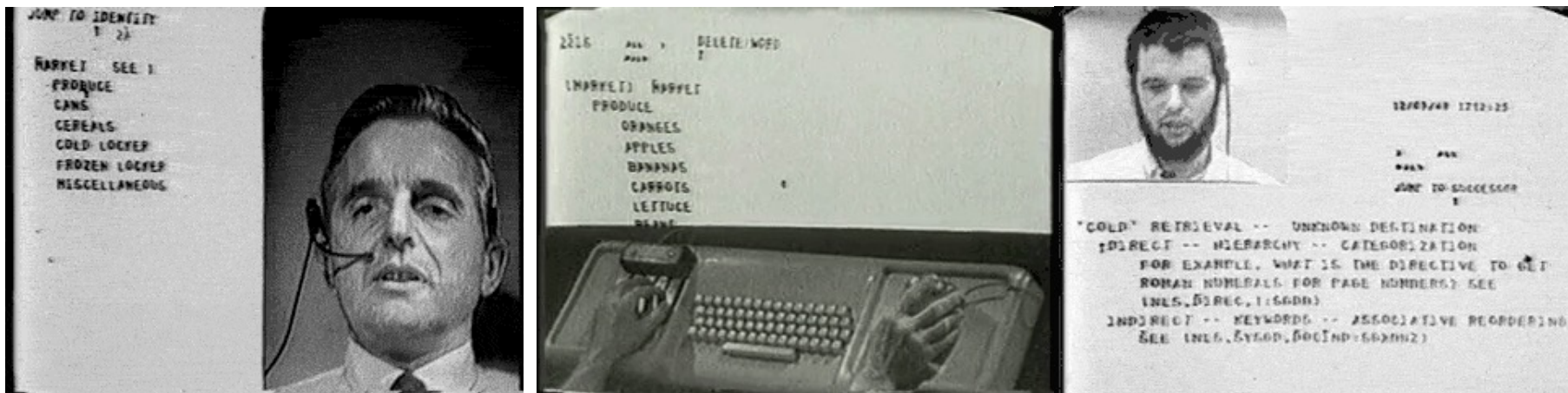
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Large-scale trustworthy distributed collaborative systems: challenges and prospective solutions

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Inforsid 2024
May 30, 2024
claudia.ignat@inria.fr

Douglas Engelbart: Augmenting Human Intellect



The Mother of all Demos, December 9, 1968



NLS: Online System

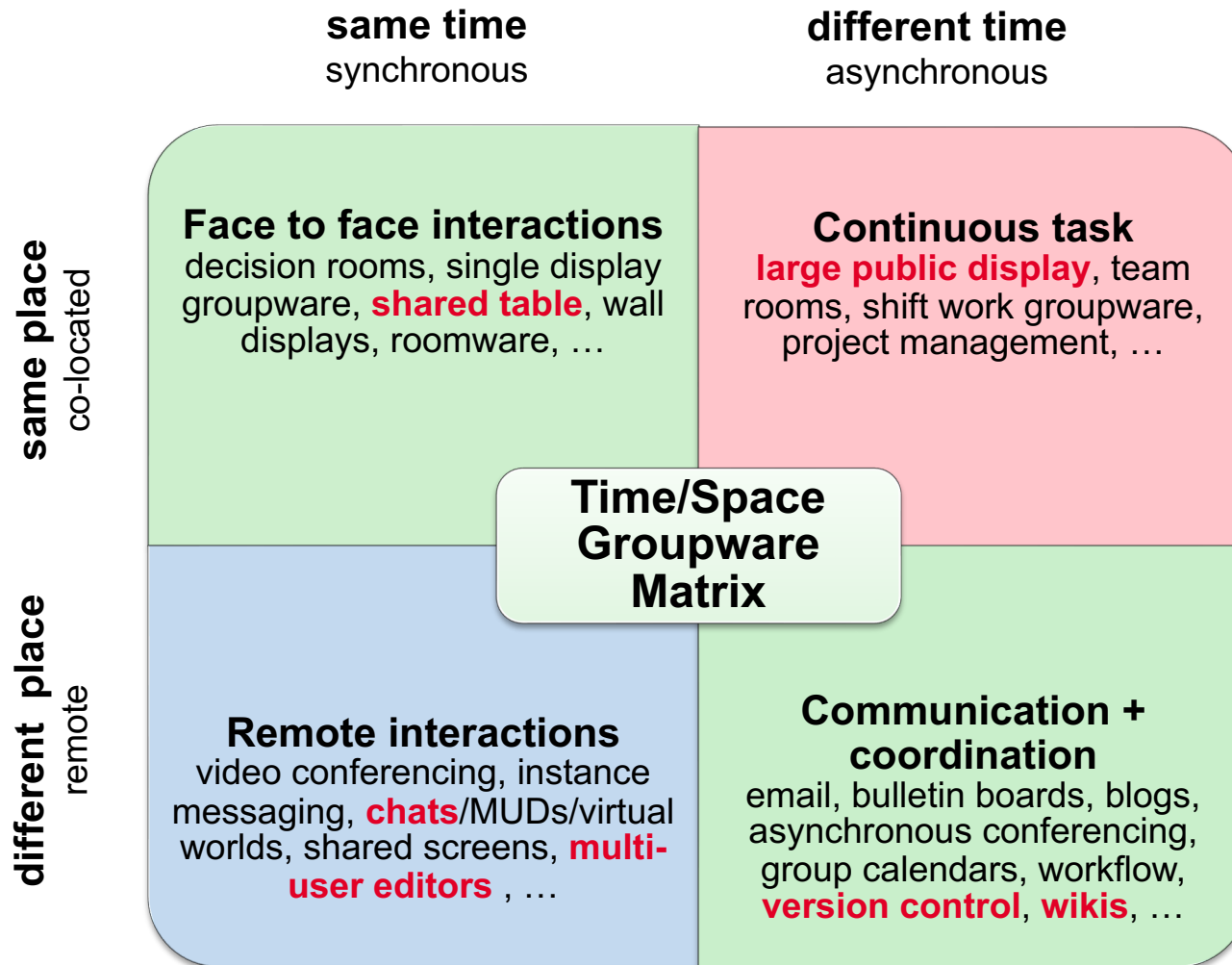
<https://archive.org/details/dougengelbartarchives>

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 (HCL Notes today), one of the first commercial groupware allowing remote group collaboration

Groupware Time Space Matrix [J88]

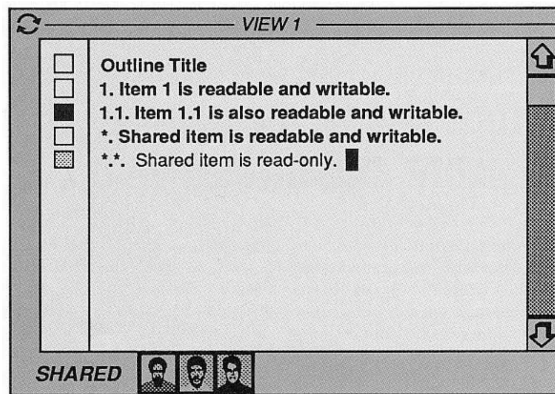


Collaborative Systems: from users to community of users



“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

From users to community of users: new practices



Main page
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Current events
Random article
About Wikipedia
Contact us
Donate

Contribute
Help
Learn to edit
Community portal
Recent changes
Upload file

Tools
What links here
Related changes
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Special pages
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- [\(cur | prev\)](#) [22:56, 6 January 2021](#) [Sleyece \(talk | contribs\)](#) [...](#) (83,551 bytes) [\(+96\)](#) [..](#) (*Be Concise*) ([undo](#))
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From users to community of users: new practices

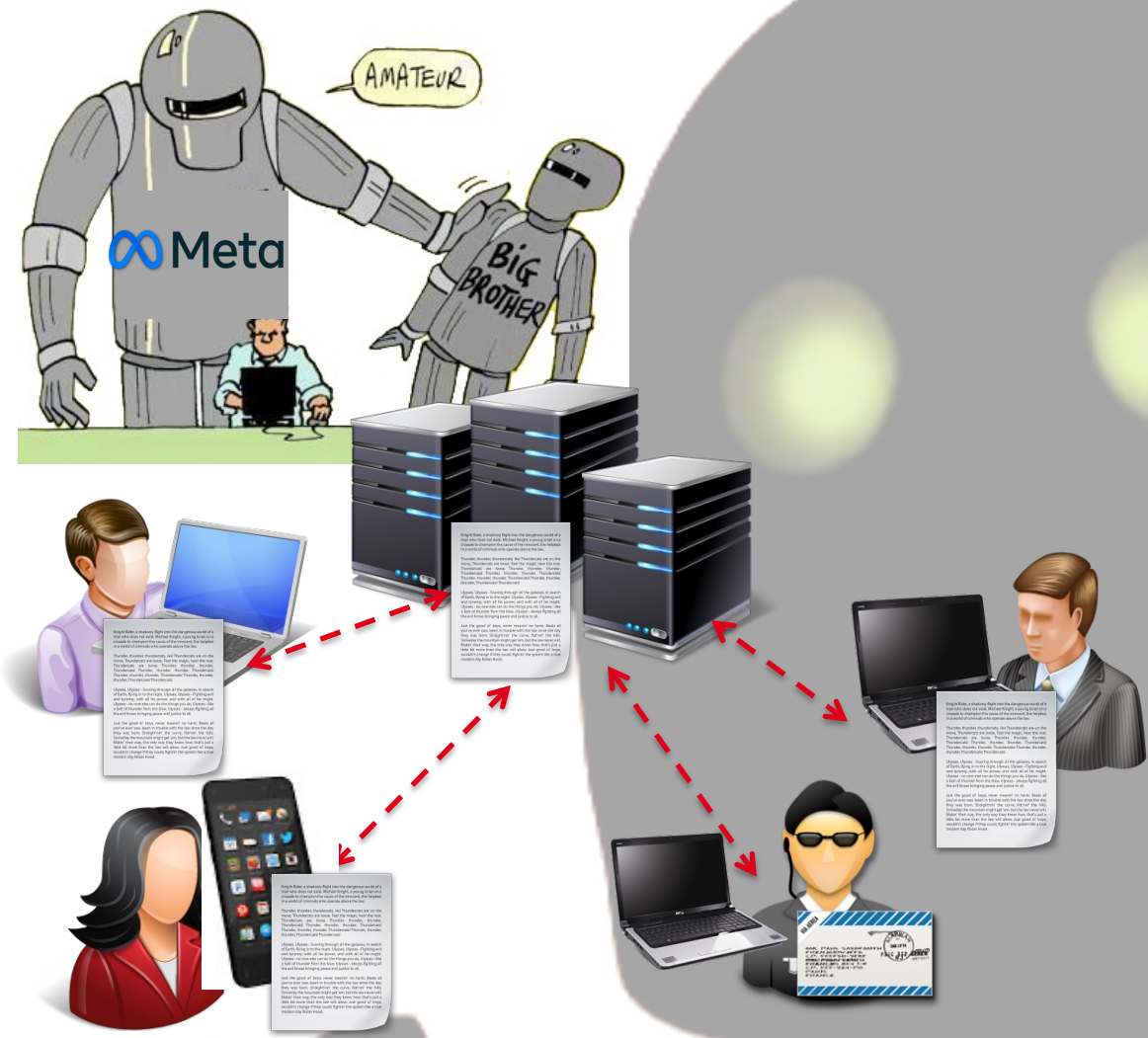


Example: Intergovernmental Panel Climate Change (IPCC) assessment report editing

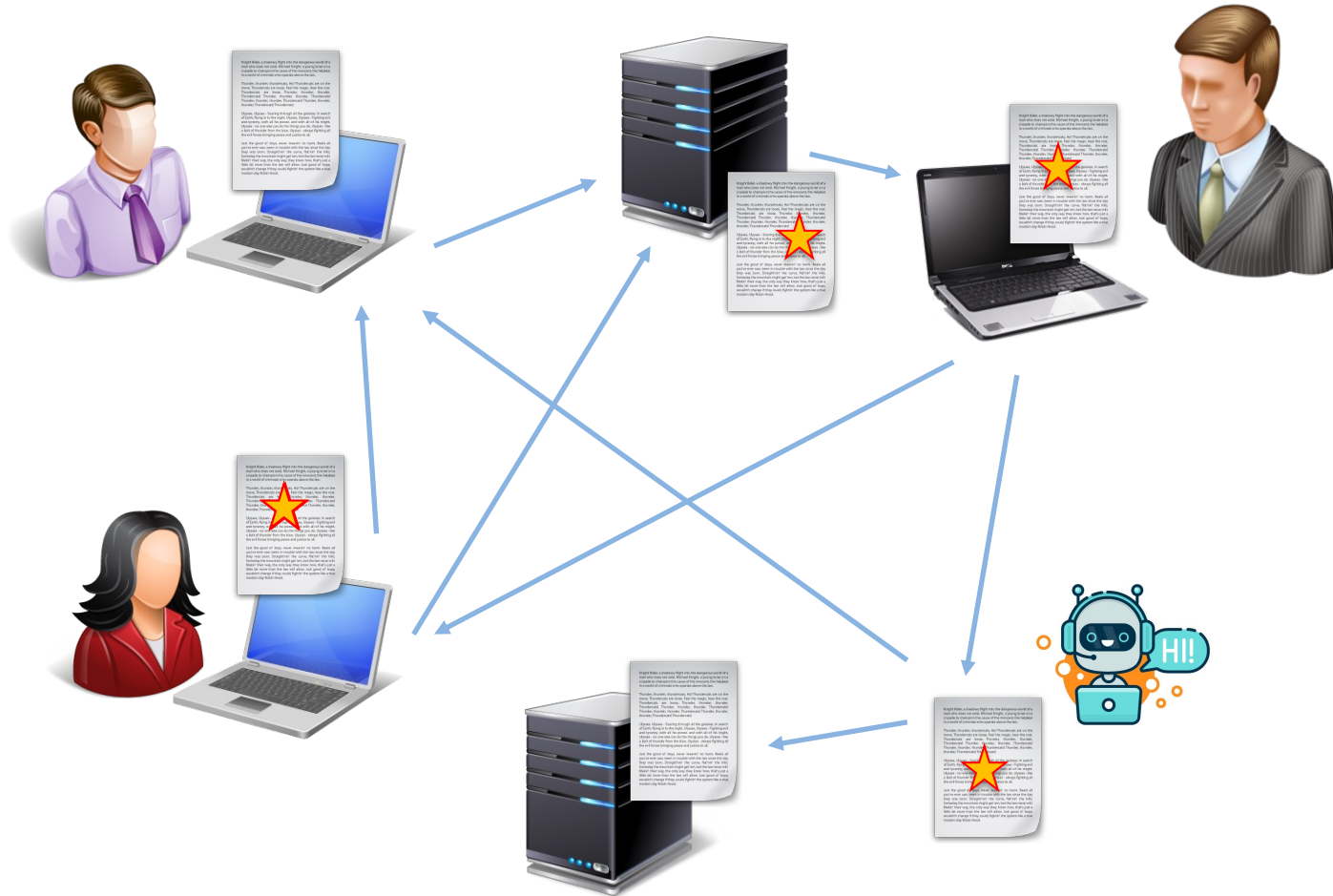
- Expert contributions: hundreds of scientists from different countries
- Review stages by experts and governments
- Approval sessions: government delegates and lead authors
- Editing teams: review editors

SCALABILITY

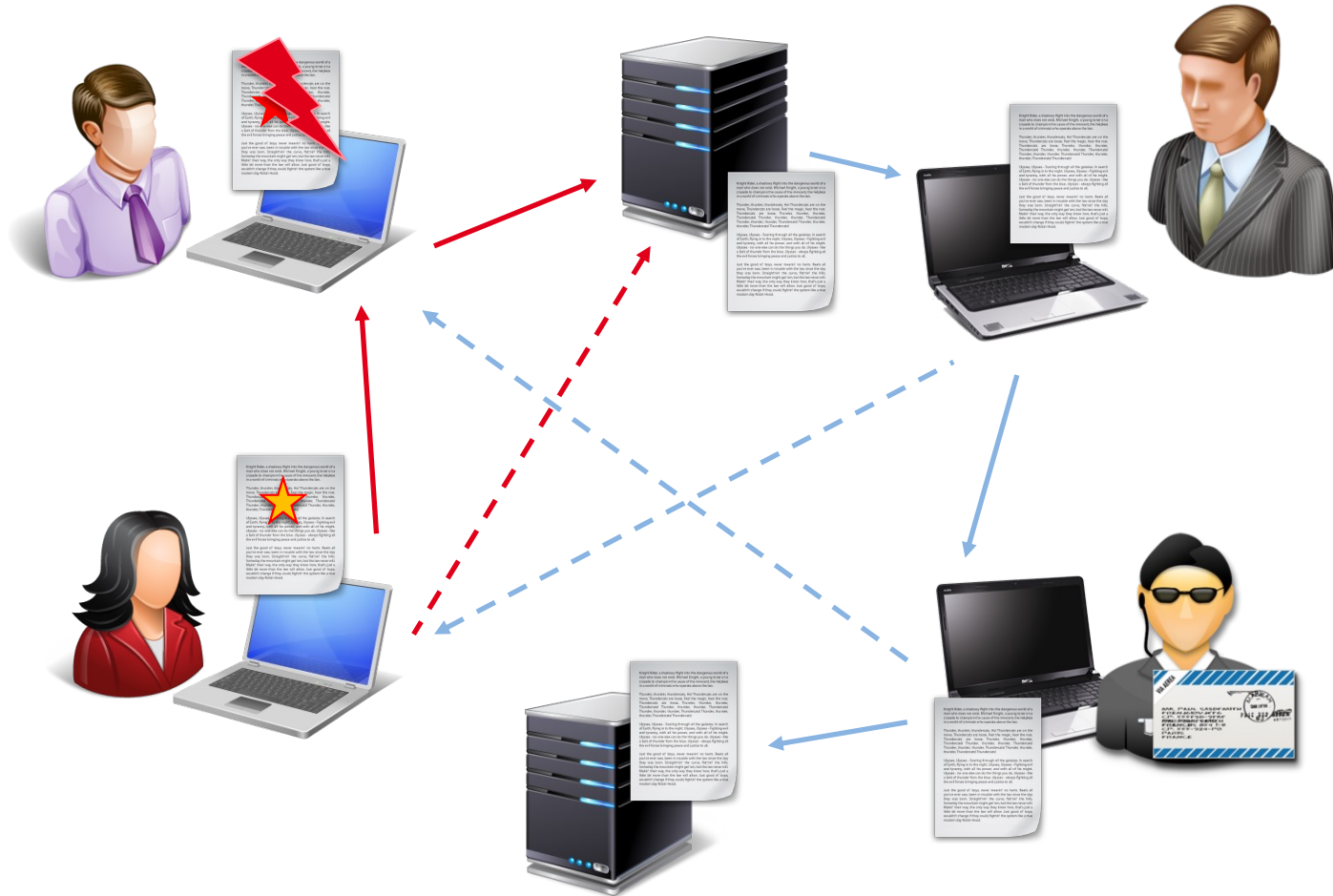
PRIVACY



Vision: 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 **secure collaboration data**?
- 3 How to make a collaboration **trustworthy**?

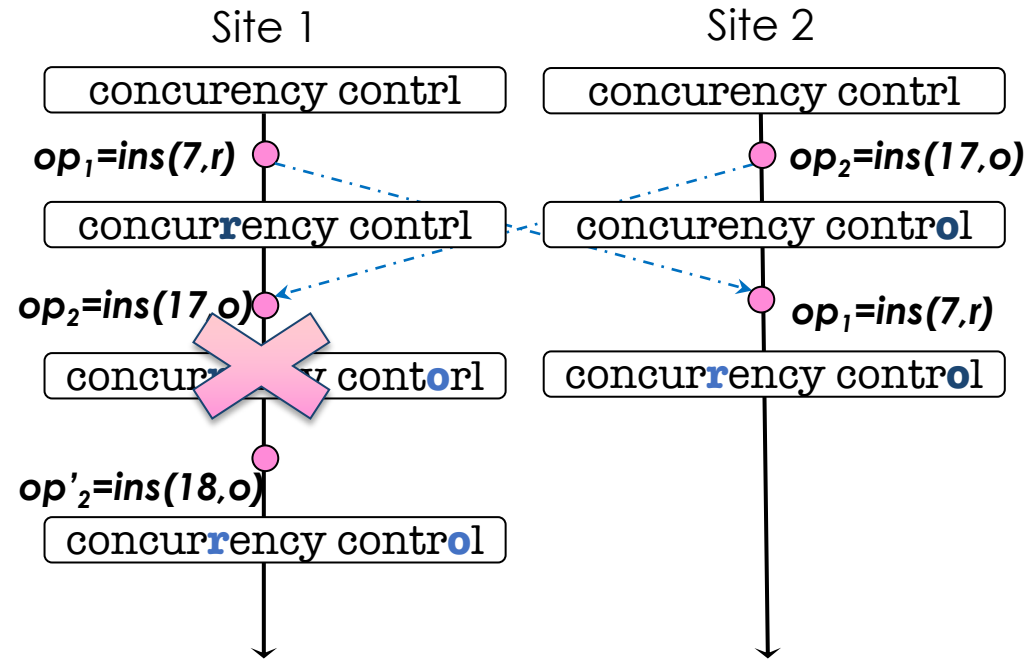
Research issues

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

CAP Theorem [B00]

- Properties of shared-data systems
 - Data consistency
 - System availability
 - Tolerance to network partition
- Only two out of three properties can be achieved at a given time
- **Relax consistency for availability** in the presence of network partitions

Operational transformation (OT) [EG89]



```

T(ins(p1,c1), ins(p2,c2)) :-
  if (p1 < p2) return ins(p1,c1)
  else return ins(p1+1,c1)
  endif
  
```

- Transforms non commuting operations to make them commute
- Genericity
- Time complexity

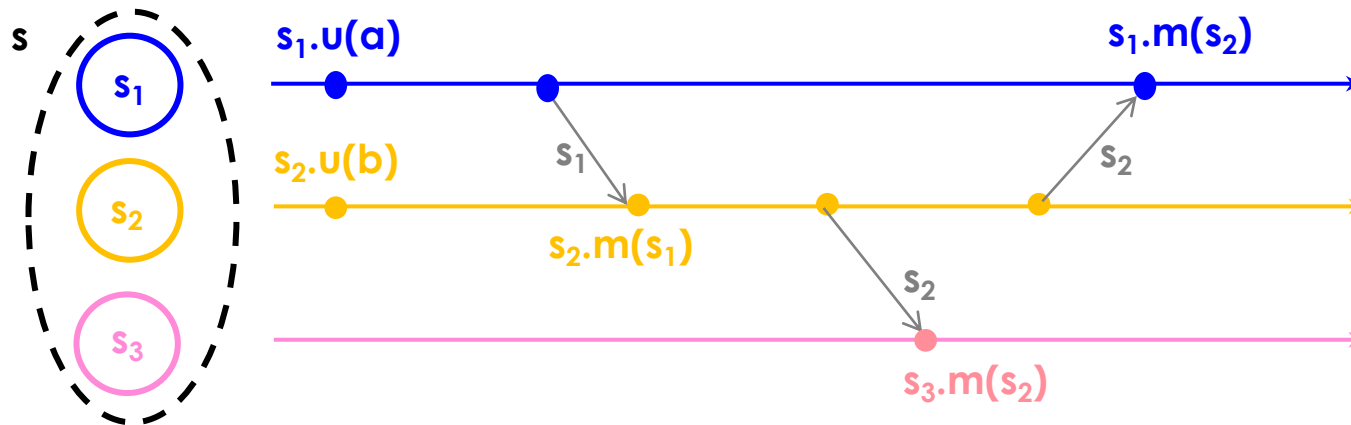
Average: $O(H \cdot c)$	H: #ops
Worst case: $O(H^2)$	c: avg. #conc. ops
- Difficult to write correct transformation functions
- State vectors used for detecting concurrency \Rightarrow scalability limitations
- **Not very suitable for large scale peer-to-peer collaboration**

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

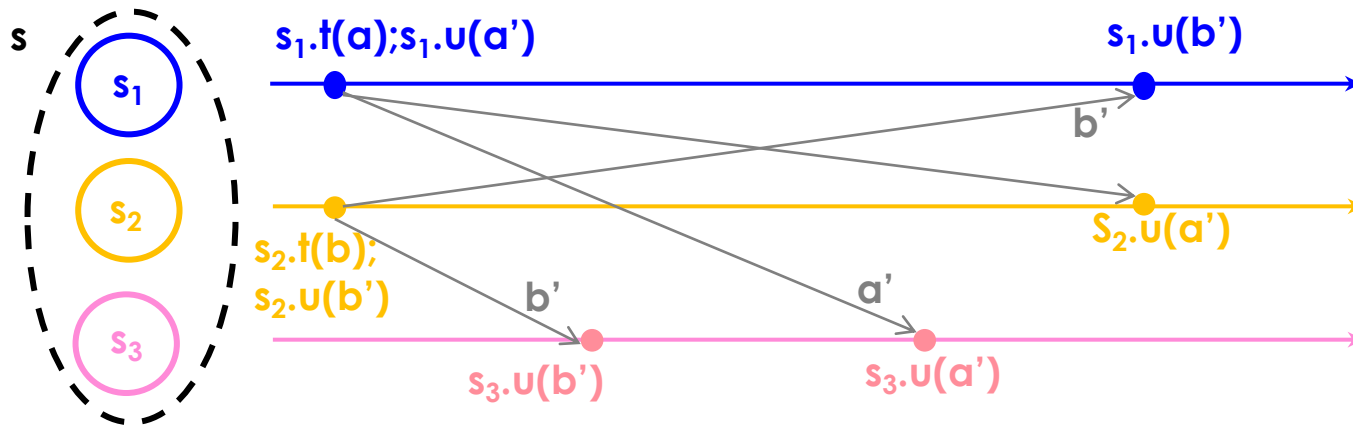
Conflict-free Replicated Data Types (CRDT)

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)

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) Operation vs. State-based Replication

- 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

<1,2,1>	c
<1,2,2>	o
<2,1,2>	n
<3,1,3>	c
<3,1,3><8,4,5>	u
<3,2,5>	r
<4,1,7>	e
<4,1,7><9,2,6>	n
<7,2,8>	c
<9,1,7>	y
<10,2,8>	
<12,3,1>	c
<12,3,1><6,5,1>	o
<12,3,1><7,8,2>	n
<12,3,1><7,8,2><12,3,5>	t
<12,3,1><7,8,2><13,3,6>	r
<12,3,1><7,8,2><14,3,7>	l

ins(<3,2,5><13,1,7>, r)

ins(<12,3,1><7,8,2><13,3,6><7,2,9>, o)

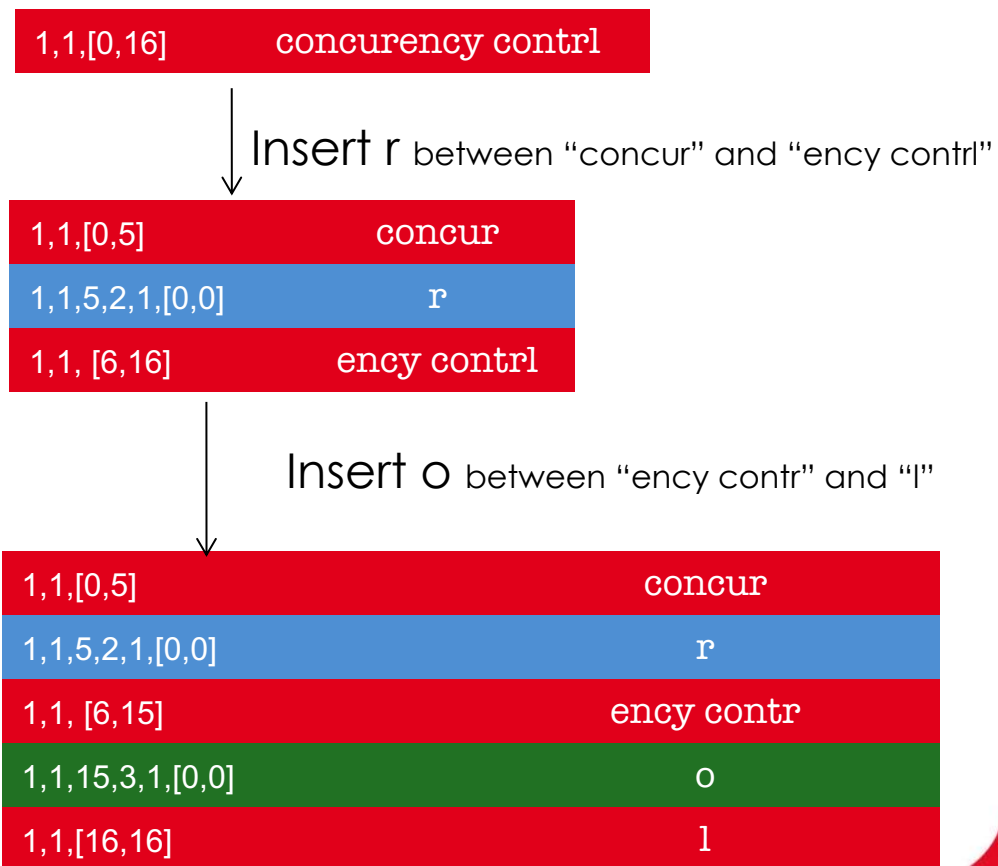
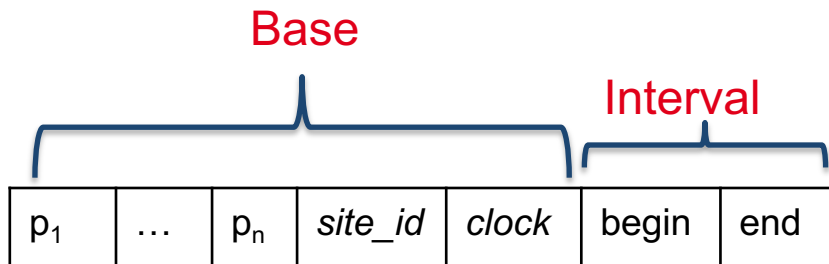
- Time complexity
 - Average: $O(k \log(n))$
 - Worst case: $O(H \cdot \log(H))$
 - H: #ops
 - n: doc. size (non deleted chars.)
 - k: avg. size of Logoot identifier
- No need for concurrency detection
- Identifiers storage cost
- New design for each data type
- Suitable for large-scale collaboration**

Conflict-free Replicated Data Types (CRDT)

LogootSplit [AM0113]

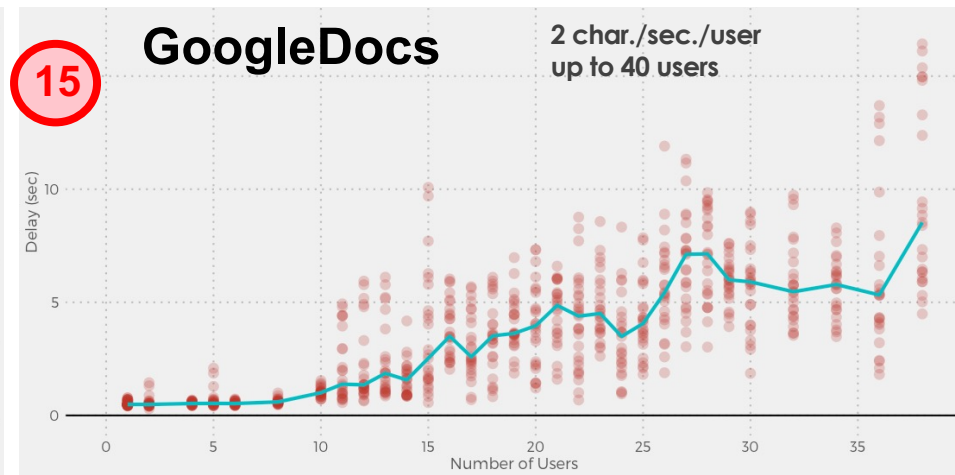
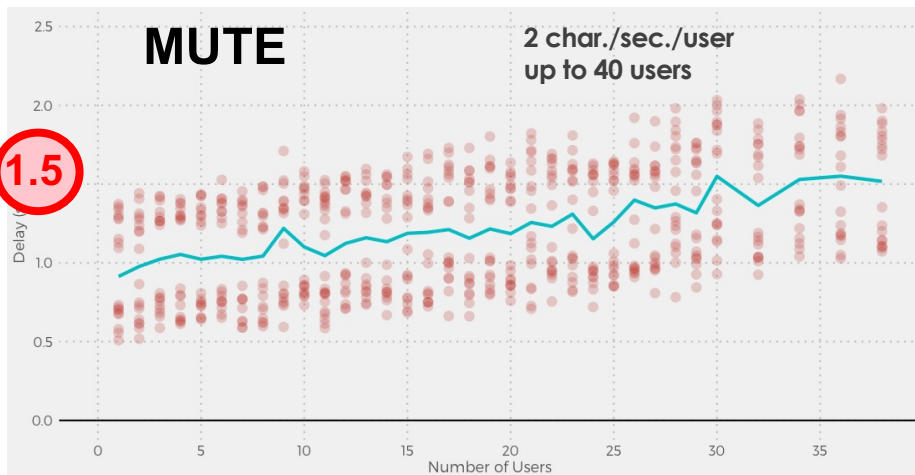
Aggregation of elements to limit metadata

LogootSplit identifiers



Conflict-free Replicated Data Types (CRDT) LogootSplit - Impact

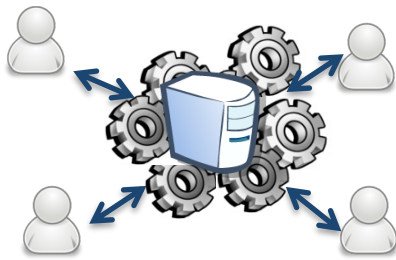
- Implemented in MUTE P2P collaborative editor [NEOIC17] [github.com/coast-team/mute, OpenPaaS::NG, ADT MUTE]
- Better performances than GoogleDocs [DI16a]



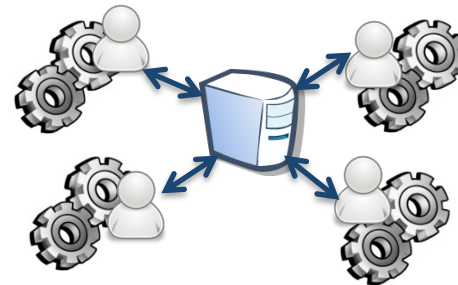
- Related approach on wikis transferred to XWiki [IA021]

User Study: The effect of delay on users [IOFSC15]

- 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

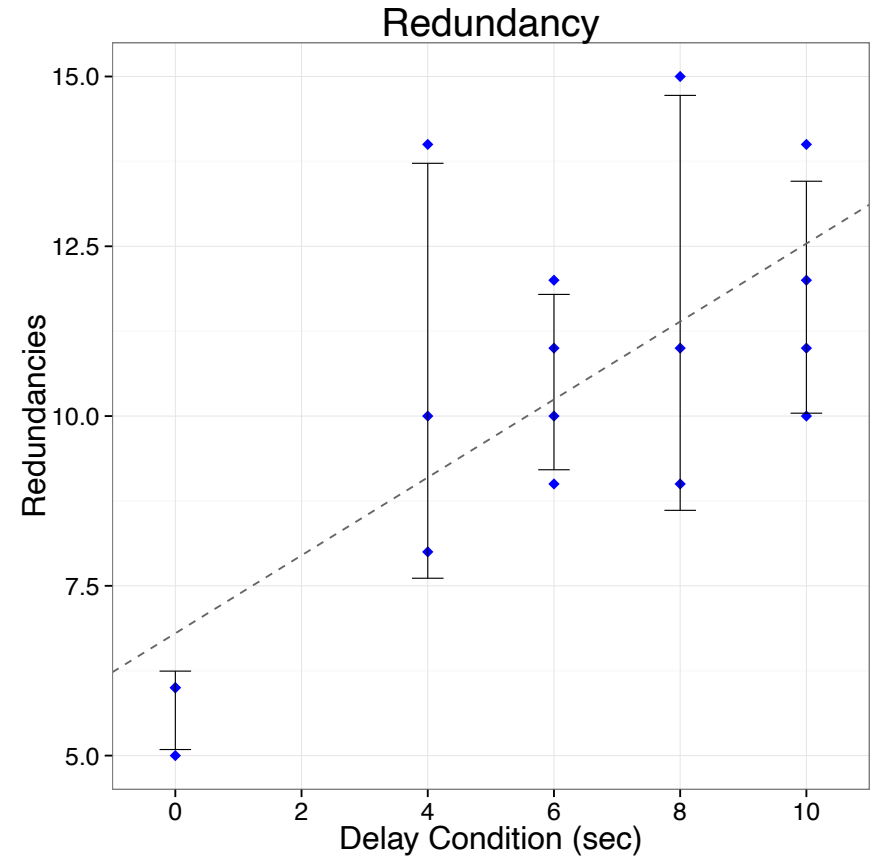
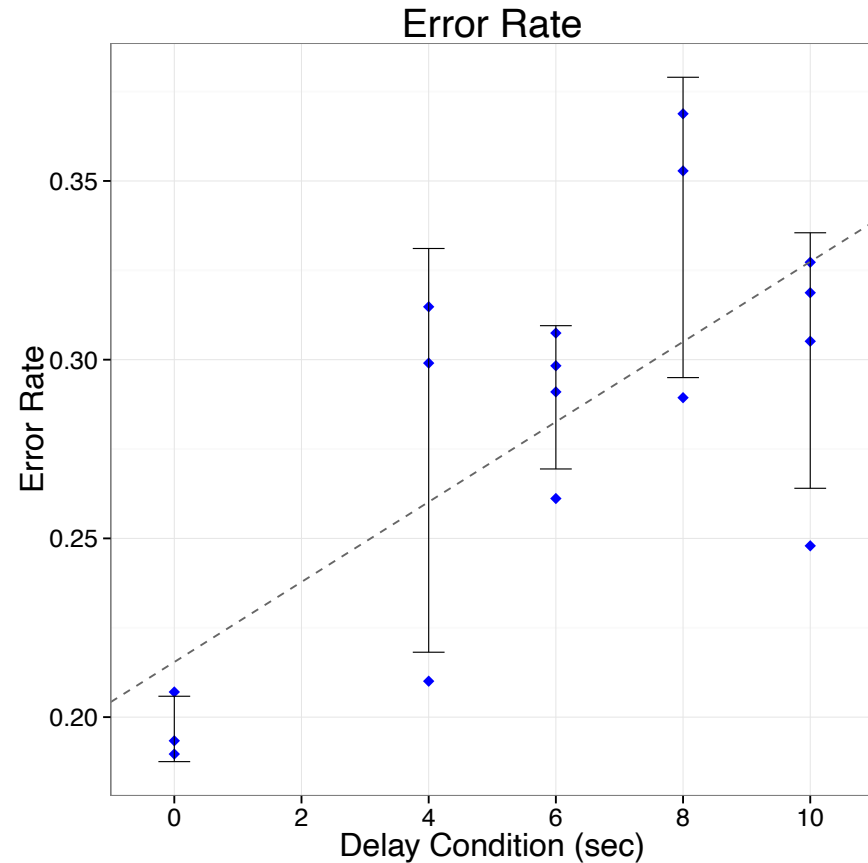
- 20 groups of 4 students
 - Perform several collaborative editing tasks
 - A proofreading task
 - A sorting task
 - **A note taking task**
 - Use the provided collaborative editor (Etherpad) + chat
 - Each group experienced a **certain delay** (0, 4, 6, 8, 10 s)
- Registration of user keyboard inputs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

Note-taking [IOFSC15]

The image shows a screenshot of a web browser window displaying a document with several lines of text. The browser's address bar shows the URL `ec2-184-72-75-76.compute-1.amazonaws.com/p/notes005`. The document content includes a list of items, with several lines highlighted in purple, blue, and yellow. A black box with the text "Editing zone" is overlaid on the first few lines of the document. Three circular callouts are drawn around specific text elements: one around "un data", one around "dematerialise", and one around "matérialisé". A black box with the text "Chat dialogue" is overlaid on the bottom right of the document. In the bottom right corner, a chat window is visible, showing a list of messages:

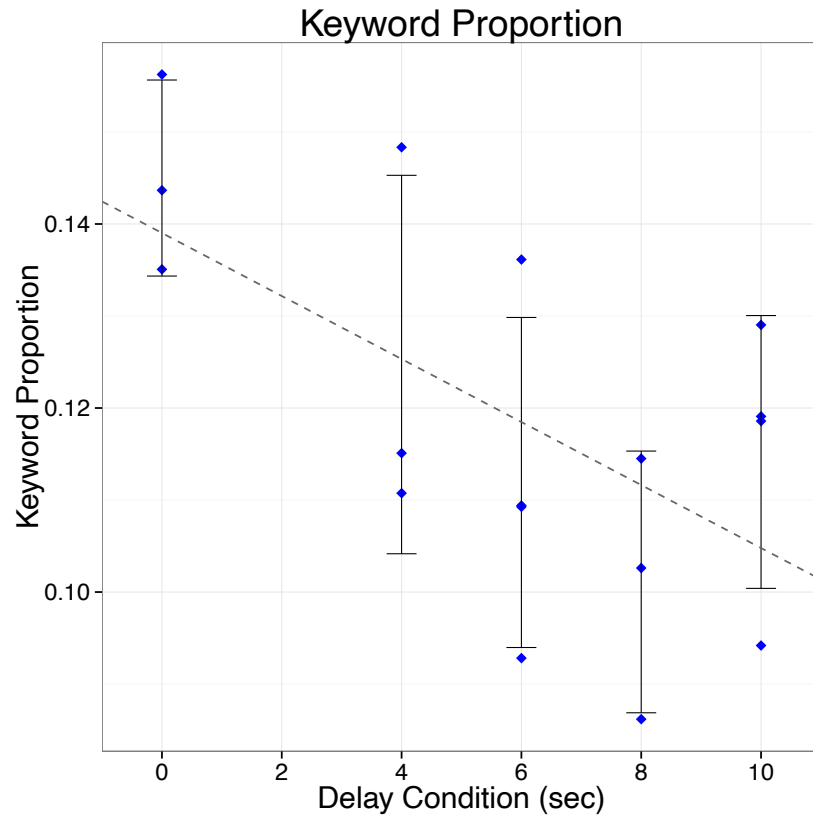
Chat	
user4: test	16:15
user2: test user 2	16:15
user2: great	16:15
user3: test	16:15

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]

Perspectives – Replication for complex data

- Composition of replication mechanisms for simple data
 - Maintaining global invariants (e.g. integrity constraints) over CRDTs for replicated relational databases [IEB24]
 - Replication mechanisms for P2P cloud storage [AII23]
 - Automated approach to combine CRDTs meeting expressed constraints
- Validate with users the defined merge semantics

Research issues

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

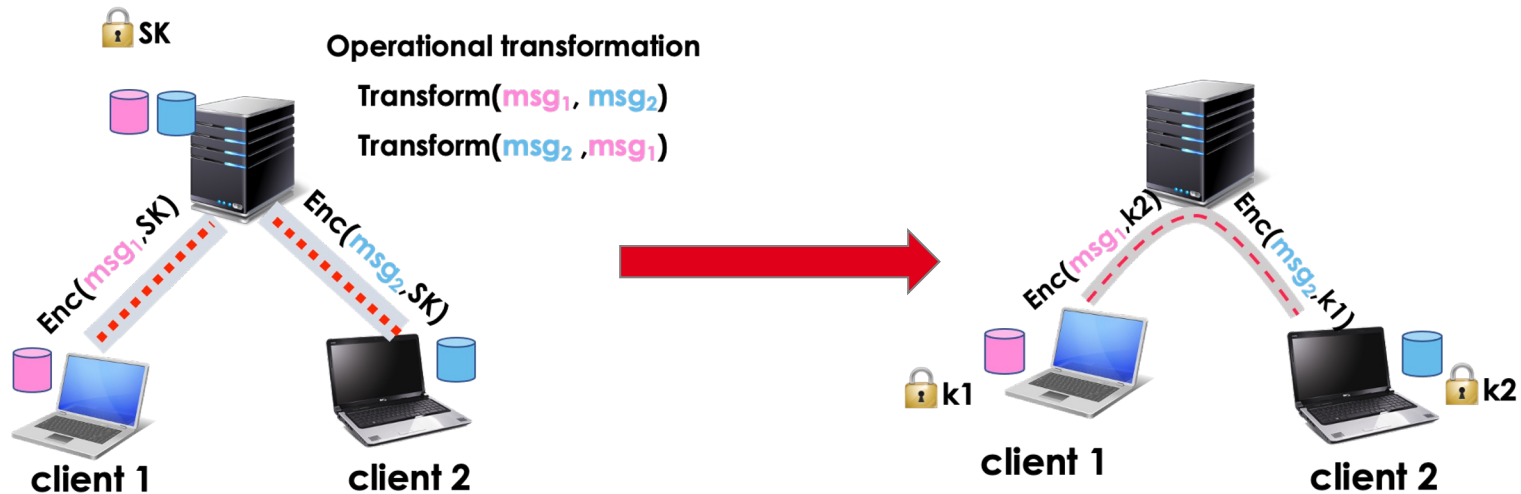
Security in peer-to-peer collaboration



- Client-side E2E encryption
- Group key management
- Access control without central authority

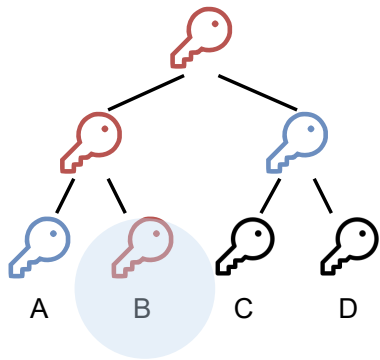
Encryption for mutable data by means of CRDTs

- CRDTs suitable for client-side E2E encryption

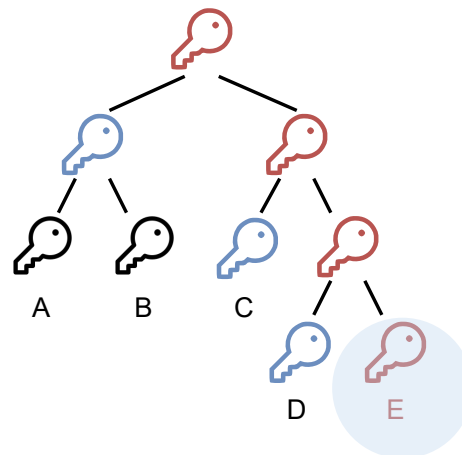


Group key management for large and dynamic groups

- TreeKEM - Message Layer Security (MLS) RFC 9420
 - Operations: Add, Remove and Update



Updating member B



Adding member E



Modified/updated keys



Keys on co-path, used to encrypt new keys to subgroups

- Delivery Service: a central server that resolves conflicts among operations
- **Goal: Distribute the Delivery Service** [PIFTI23]
 - Use of reliable broadcast protocols for operation delivery
 - Use consensus between group members for operation commits

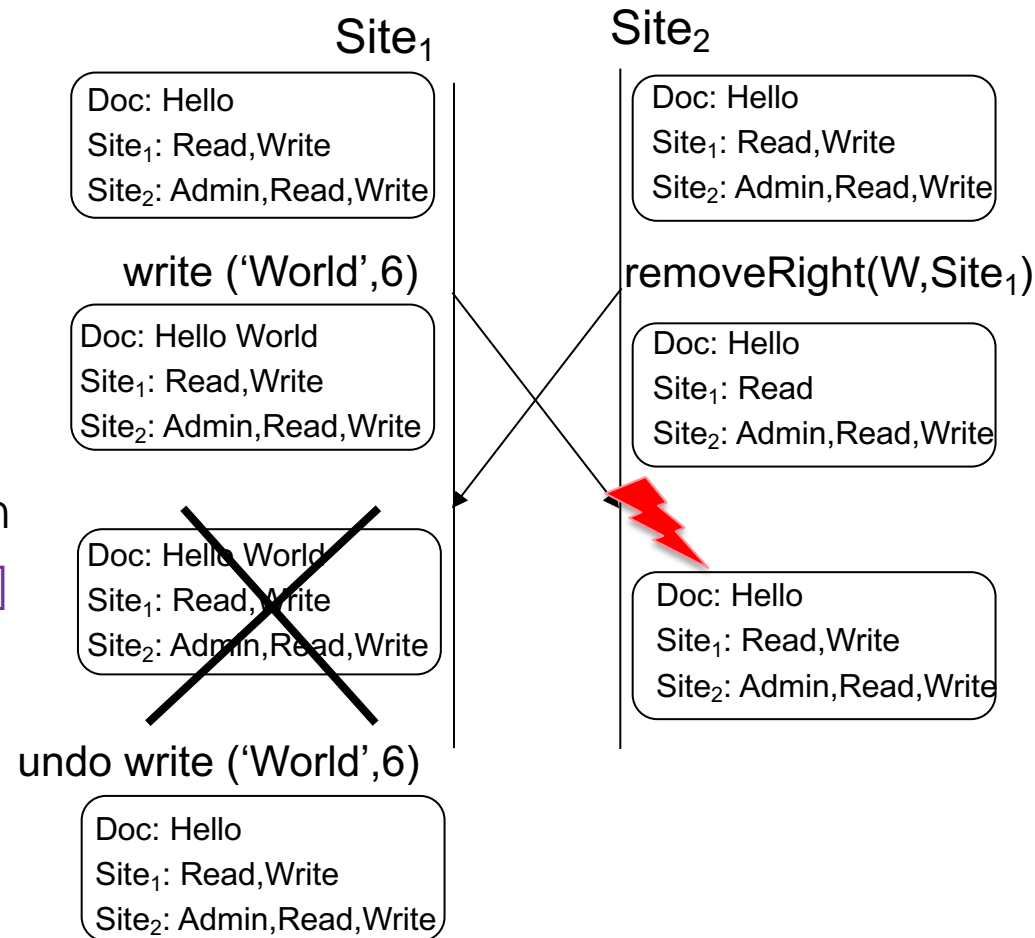
Access control for peer-to-peer systems without central authority

Goals

- Replicated data
- Replicated access rights
- Multiple administrators

Approach

- Compose CRDTs for data with CRDTs for access rights [RIP23]
- Dependencies
 - Between access rights operations
 - Between document and access rights



P2P Cloud Storage – Défi Alvearium with hive Replication and security mechanisms application

- A distributed peer-to-peer cloud exploiting unused capacity of computers
 - +20% of computing resources remain unused
 - Allows users to share these computing resources
 - Builds a virtual cloud to offer compute and **storage services**



- Sustainable
- Secure & private
- Data sovereignty
- Affordable

P2P Cloud Storage – collaboration with hive

Research topics

- How to place data in the peer-to-peer storage in order to ensure high availability?
- How to manage data that can be modified by different peers?
- How to deal with Byzantine nodes? How to handle Sybil attacks?
- How to define a peer-to-peer security mechanism (manage access rights, client-side E2E encryption, group key management)

Research issues

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

Trust in collaborative tools [L21]

- Crisis management – issues on information sharing
- Technical issues: tools' complexity, network delay, no interoperability
- Communicational issues



Peer-to-peer user trust

- Prediction of future collaborative user behavior based on the quality of user contributions

Should I Trust You?

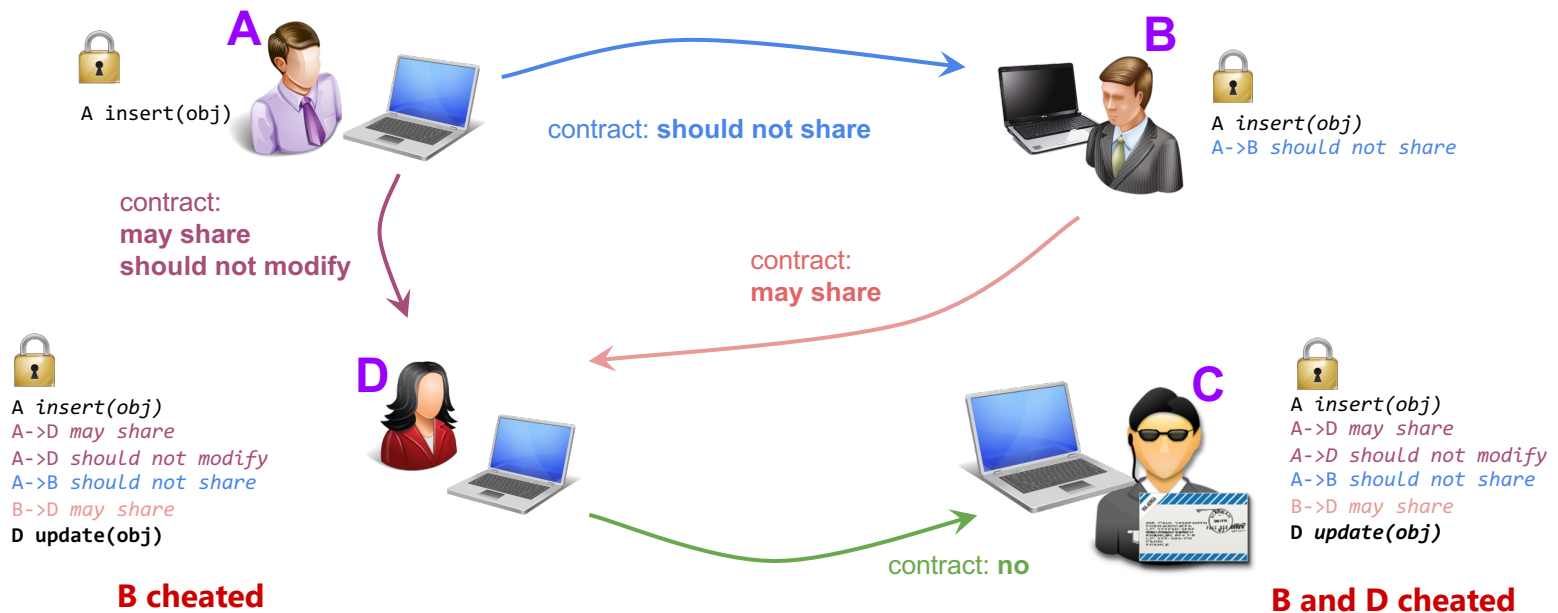


Trust computation - contribution

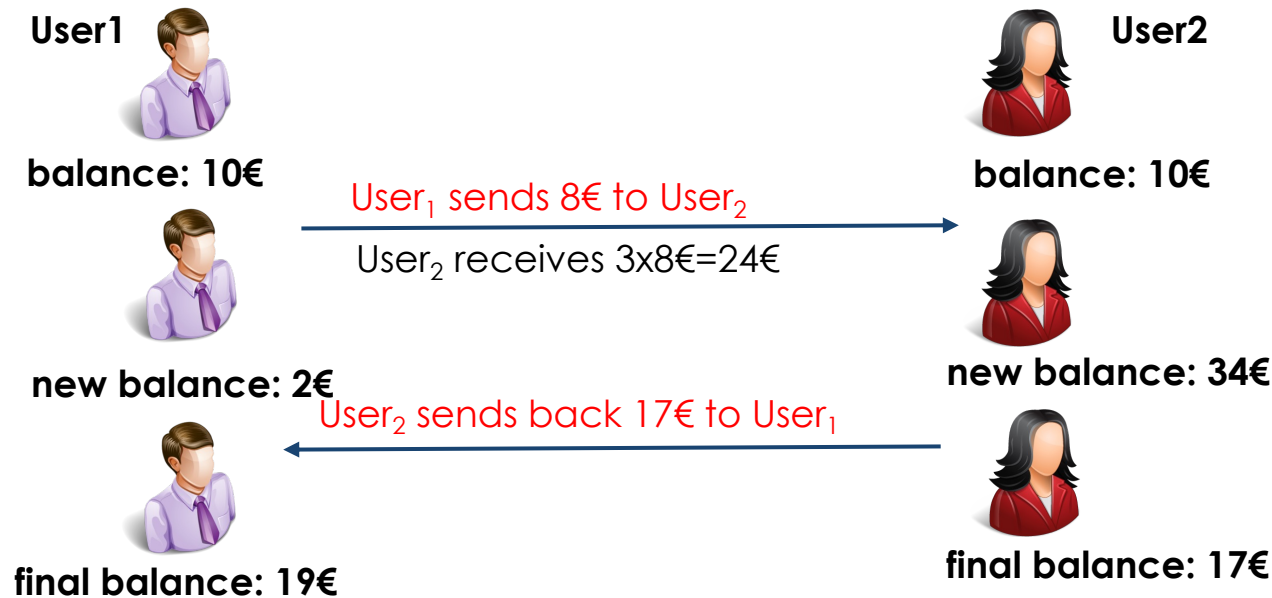
- Evaluate collaborators trust based on their past behavior
 - Contract-based collaborative editing
 - Trust game

Trust computation in collaborative editing

- Respect/Violation of contracts [TI11, TIBM11, TIM12, ID21]



Peer-to-peer trust metric in trust game [BDM95]



- **Design a trust metric** dealing with fluctuating user behaviour [DI16a]

- For a round: $current_trust_t = \log(send_proportion_t * (e - 1) + 1)$

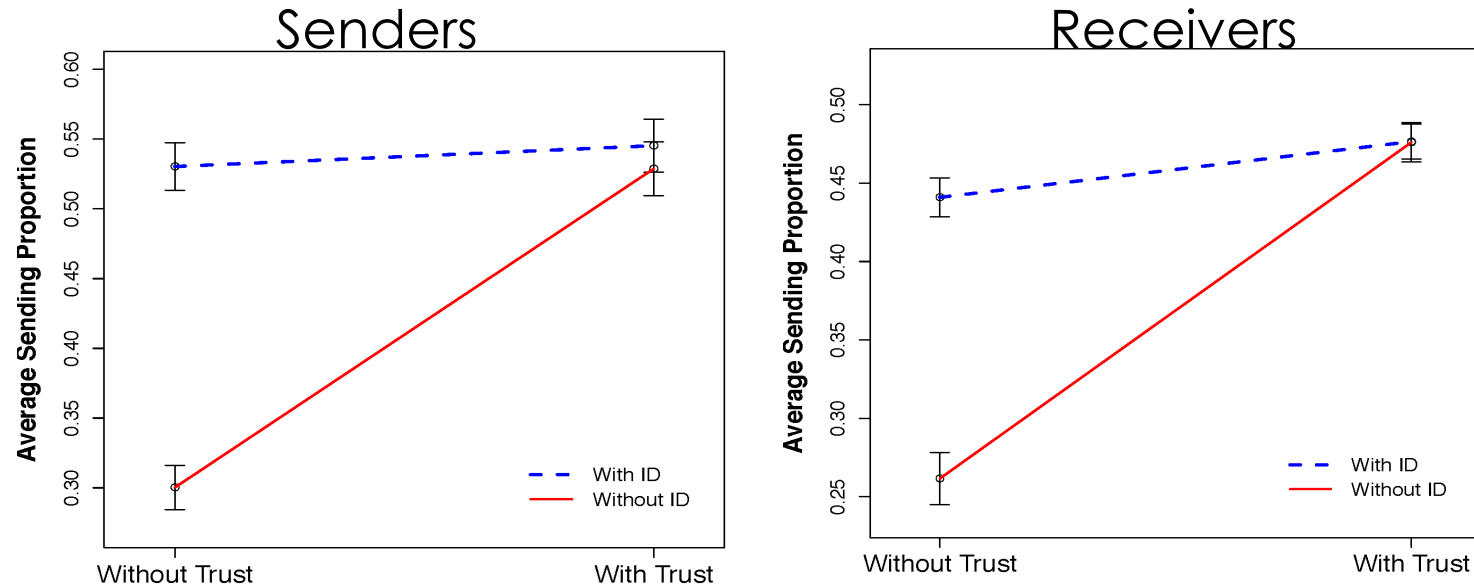
$$send_proportion_t = \frac{sending_amount_t}{max_sending_amount}$$

- For accumulated rounds:

$$aggregate_trust_t = \alpha_t * current_trust_t + (1 - \alpha_t) * aggregate_trust_{t-1}$$

Validation of the trust metric – experimental design [IDS19]

- **Experiment with users** on 4 trust games: Simple Game, Identity Game, Score game and Combine game



- Showing either trust score or identity improves the measure
- Showing both of them does not change the measure
- **Trust-based systems can be a replacement of identity-based systems**
- Collaboration with Department of Psychology Wright State University

PEPR eNSEMBLE (<https://pepr-ensemble.fr/>)

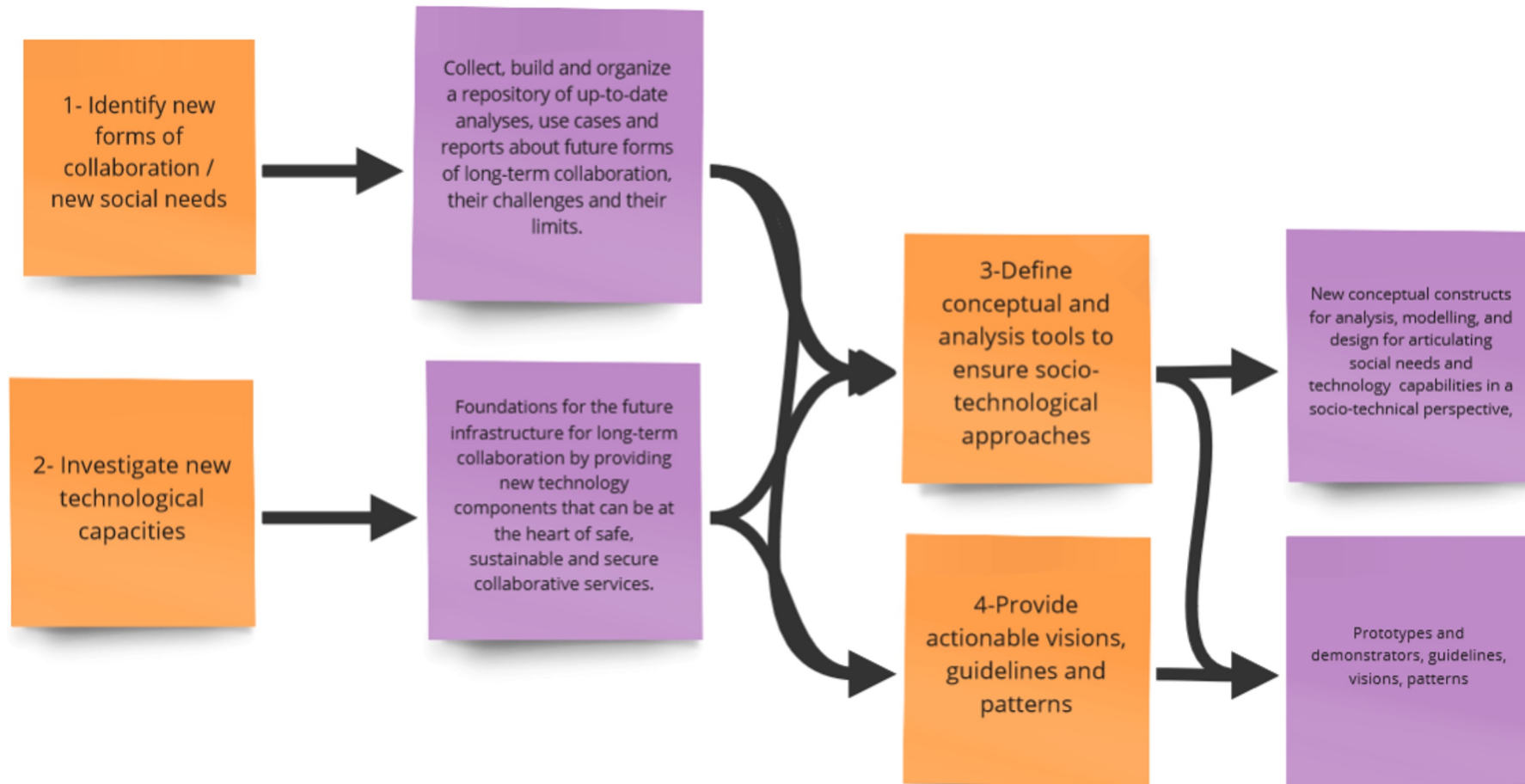
PILOT – Practices and infrastructure for long term collaboration

- Socio-technical models for long-term collaboration
- Multi-organizational, sovereign, secure, interoperable collaboration platforms promoting trust and digital well-being
- Coordinators
 - Claudia-Lavinia Ignat, Inria
 - François Charoy, Université de Lorraine
 - Myriam Lewkowicz, Université de Technologie de Troyes

PILOT – Project axes

- Axis 1: Understanding current and future forms of long-term collaboration
- Axis 2: Open technical frameworks and protocols for long-term collaboration
- Axis 3: Conceptual Frameworks for long-term collaboration
- Axis 4: Actionable guidelines and demonstrators for long term collaboration

PILOT architecture



PILOT – Resources

- Budget: 5 M€
- Period: 7 years (Sept. 2023 – Aug. 2030)
- Non permanent resources
 - 18 PhD theses
 - 4 postdocs of 2 years
 - 2 engineers of 4 years
 - 12 internships of 6 months
- 14 partner institutions: Inria, CNRS, Univ. Paris-Saclay, Univ. Grenoble Alpes, Sorbonne Univ., IMT, UTT, INSA Lyon, UCB, Nantes Université, ENSAM, Univ. de Lille, Univ. de Toulouse

Large-scale trustworthy distributed collaborative systems

- New uses and new practices due to large scale adoption
- New challenges
 - Consistency of replicated complex data
 - Security mechanisms without a central authority
 - Trust in collaborative platforms and trust among collaborators

Thank you

COAST Team

<http://team.inria.fr/coast/>

modifications operation-based

documents
management
operations-based
work
granularity
conflicts

web-based
compro-mising
round-free
securing
development

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

awareness

undo
studying
multi-mode
web
cdrts
adaptable
wiki
push-pull
text
repository
structures

editing

xml

contract
tree-based
writing
model
editor
real-time
graphical
distributed

data
user
resolution
multi-level
processes
annotation
concurrent
trust

organisations
auditing
merging
drawing
editing
algorithms
hi story
multi-part

information
log
multi-pair
model
authoring
communication

changes
software
note
evaluating
optimistic
authenticating

consistency
slices
delay
content

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

documents systems multi-level

un-grouping
asynchronous

multiple-granularity
programmability

performance
inter-document
co-authoring

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