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

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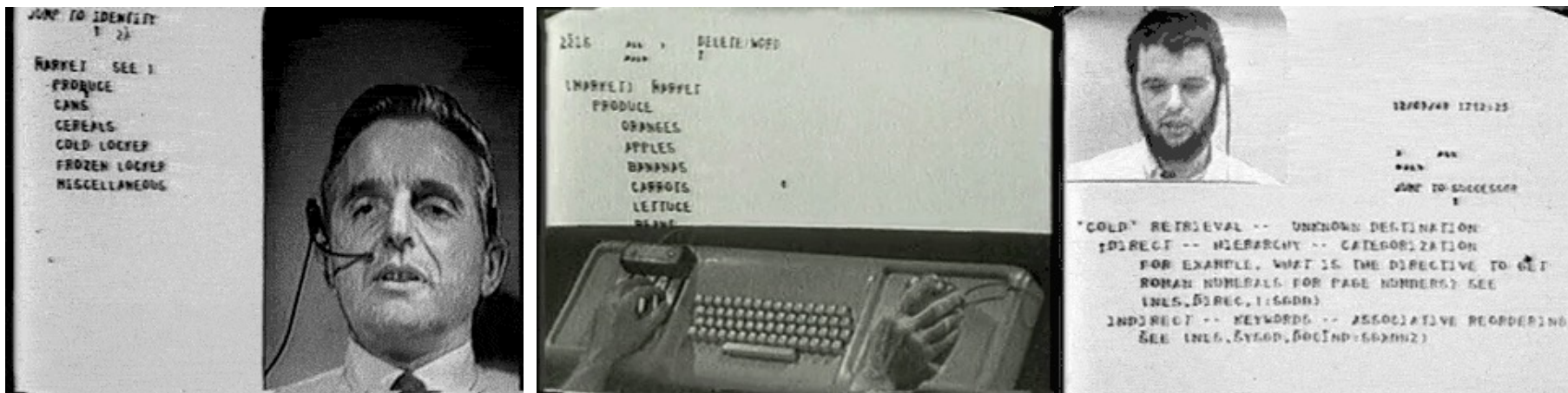
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informatics mathematics

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

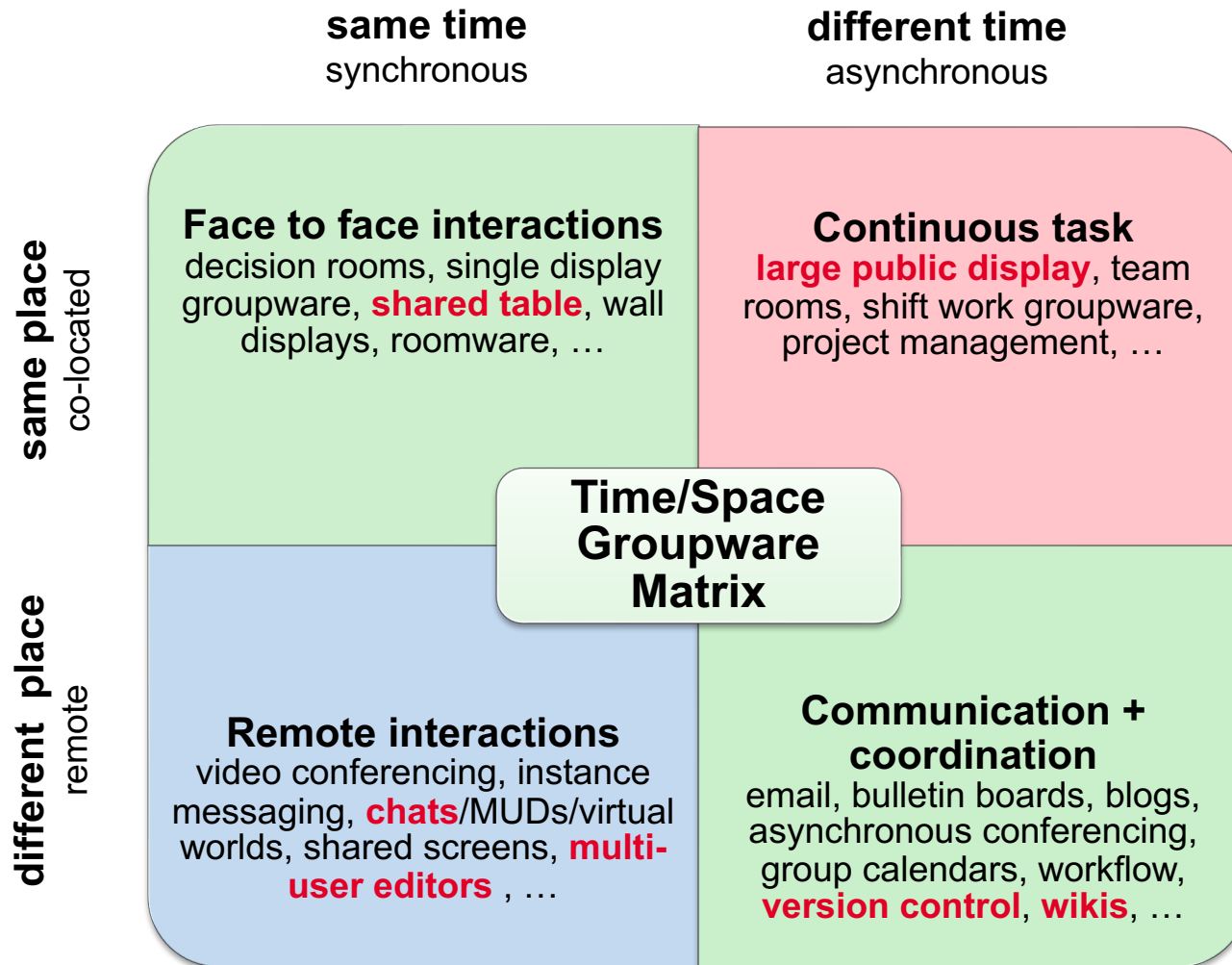
<https://archive.org/details/dougengelbartarchives>

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]

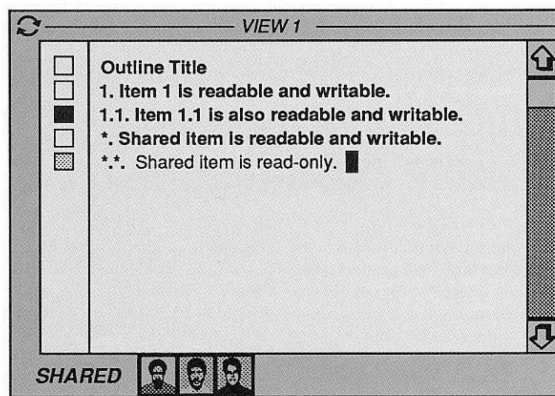


Collaborative Systems: from users to community of users



“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
Contents
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
Atom
Special pages
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m = [minor edit](#), → = [section edit](#), ← = [automatic edit summary](#)

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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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- [\(cur | prev\)](#) [22:39, 6 January 2021](#) [ClueBot NG \(talk | contribs\)](#) [m](#) [...](#) (83,243 bytes) (-47) [..](#) (*Reverting possible vandalism by 2603:9001:4903:D811:9052:EFE:155C:2134 to version by 81.167.188.42. Report False Positive? Thanks, ClueBot NG. (3860441) (Bot)*) ([undo](#)) ([Tag: Rollback](#))
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- [\(cur | prev\)](#) [22:35, 6 January 2021](#) [81.167.188.42 \(talk\)](#) [...](#) (83,243 bytes) (+40) [..](#) ([undo](#))
- [\(cur | prev\)](#) [22:34, 6 January 2021](#) [72.217.56.18 \(talk\)](#) [...](#) (83,203 bytes) (-58) [..](#) (*person shot has not been reported dead as of yet!*) ([undo](#))
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- [\(cur | prev\)](#) [22:31, 6 January 2021](#) [2603:8000:8e42:cb00:55ec:35dc:94e4:c9be \(talk\)](#) [...](#) (83,188 bytes) (+1) [..](#) ([undo](#)) ([Tag: Possible vandalism](#))
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From users to community of users: new practices



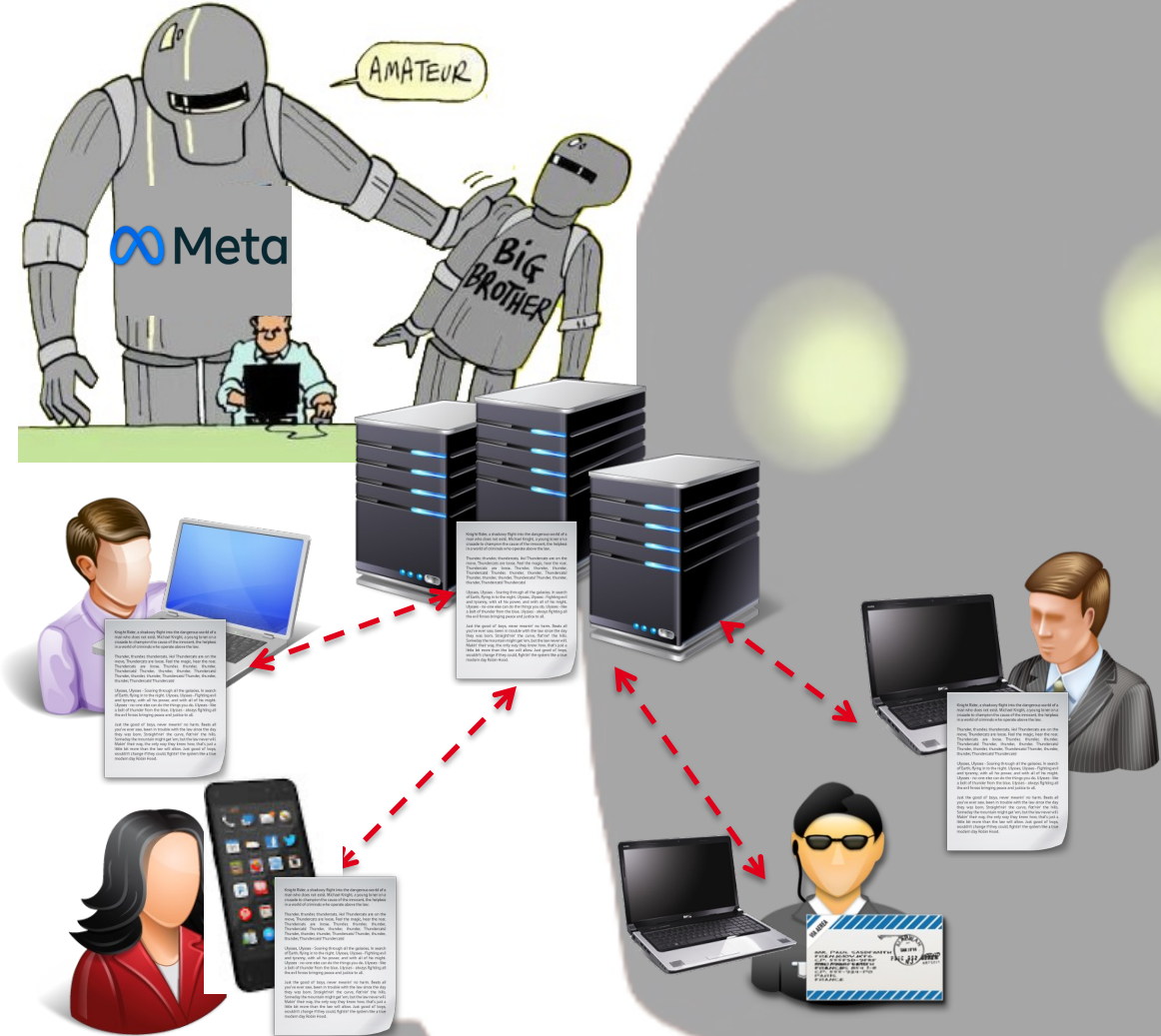
Example: Intergovernmental Panel Climate Change (IPCC) assessment report editing

- 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

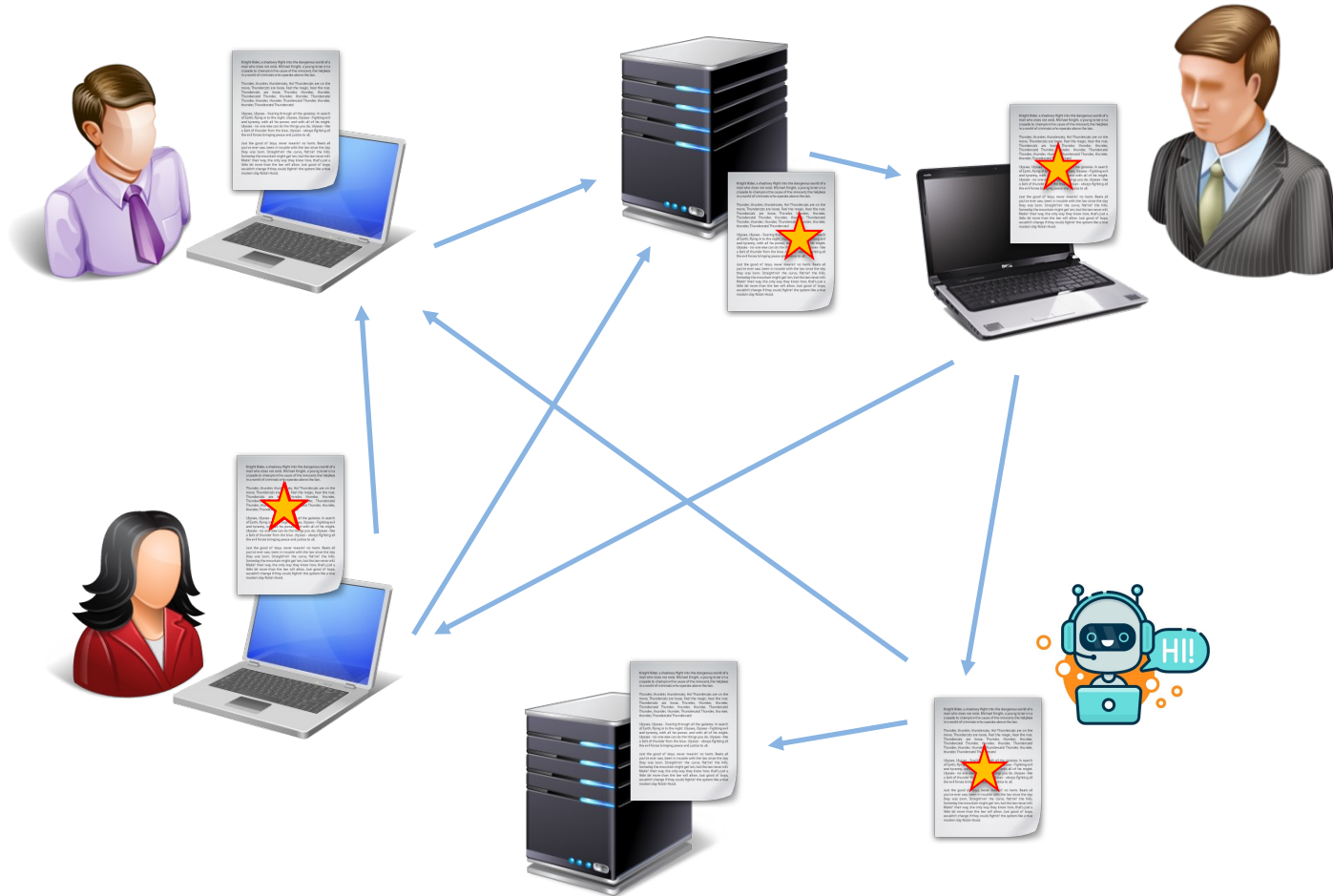
Limitations of Central Authority Systems

SCALABILITY

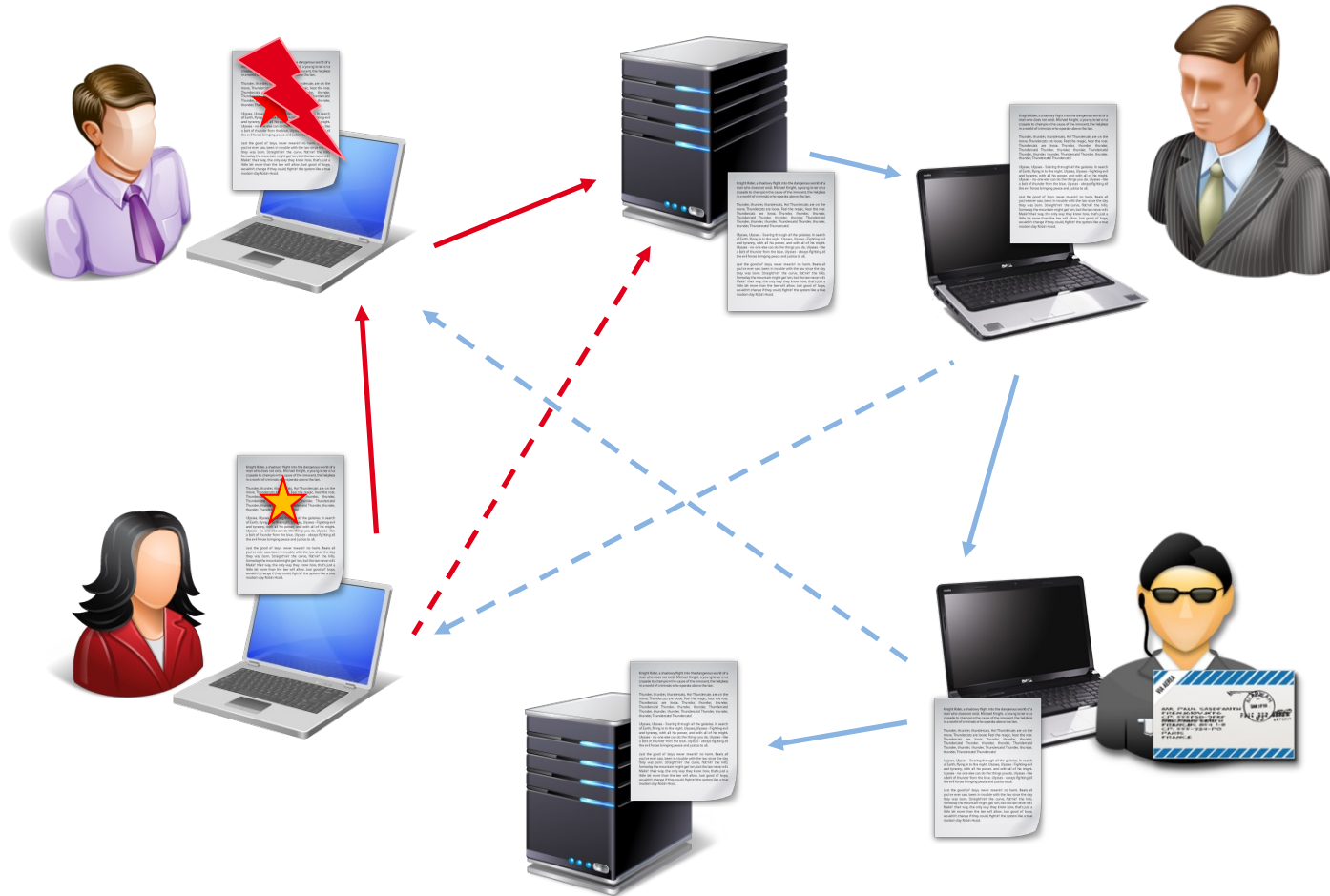
PRIVACY



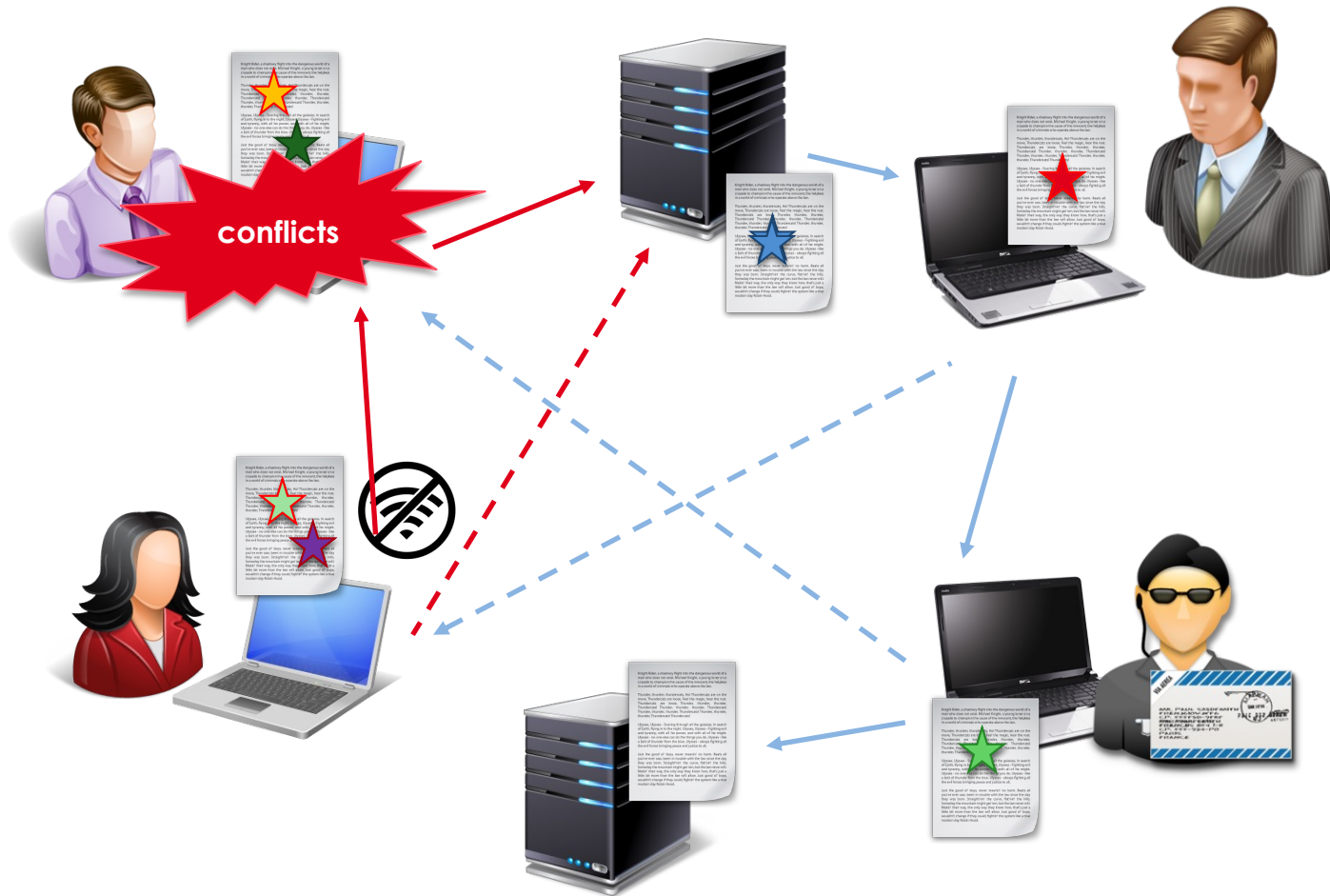
Vision: Peer-to-Peer Collaborative Systems



Collaboration Modes – Concurrent Changes



Collaboration Modes – Offline Work



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**?

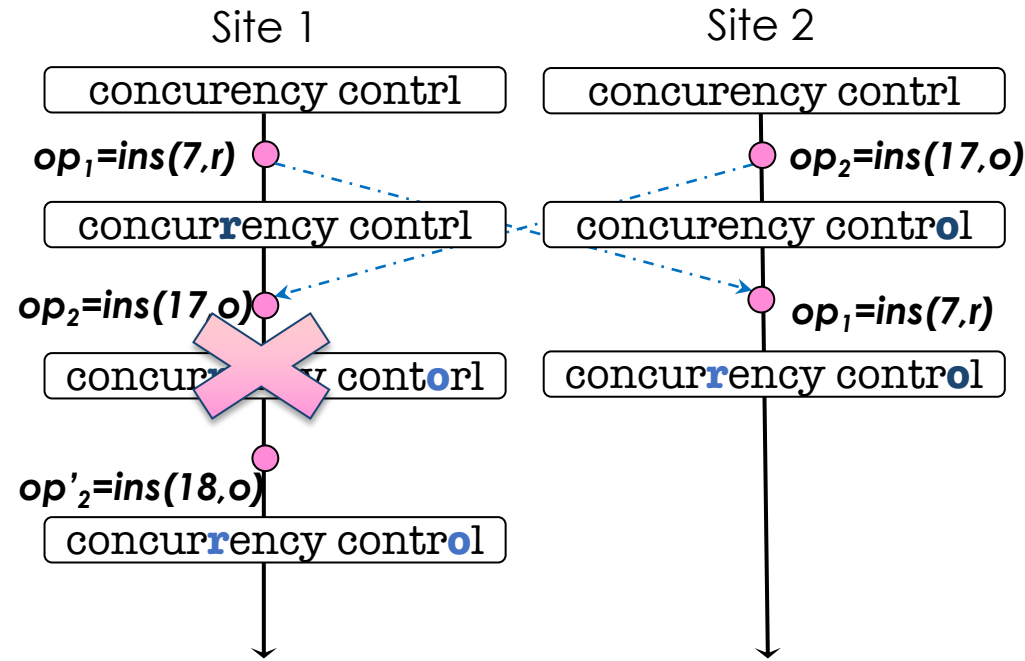
Research issues

- 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

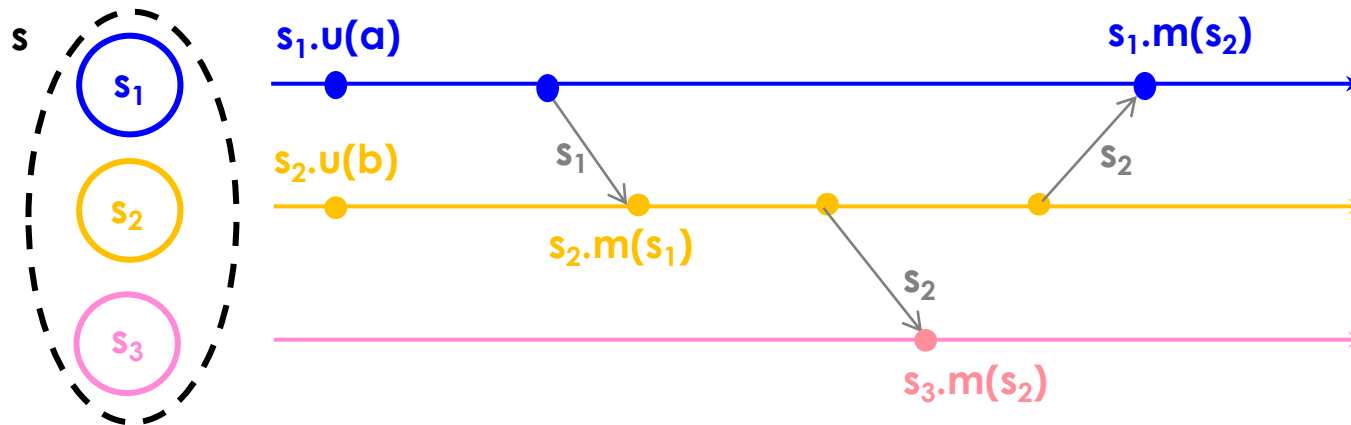
Average: $O(H.c)$	H: #ops
Worst case: $O(H^2)$	c: avg. #conc. ops
- Difficult to write correct transformation functions
- State vectors used for detecting concurrency \Rightarrow scalability limitations
- **Not very suitable for large scale peer-to-peer collaboration**

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

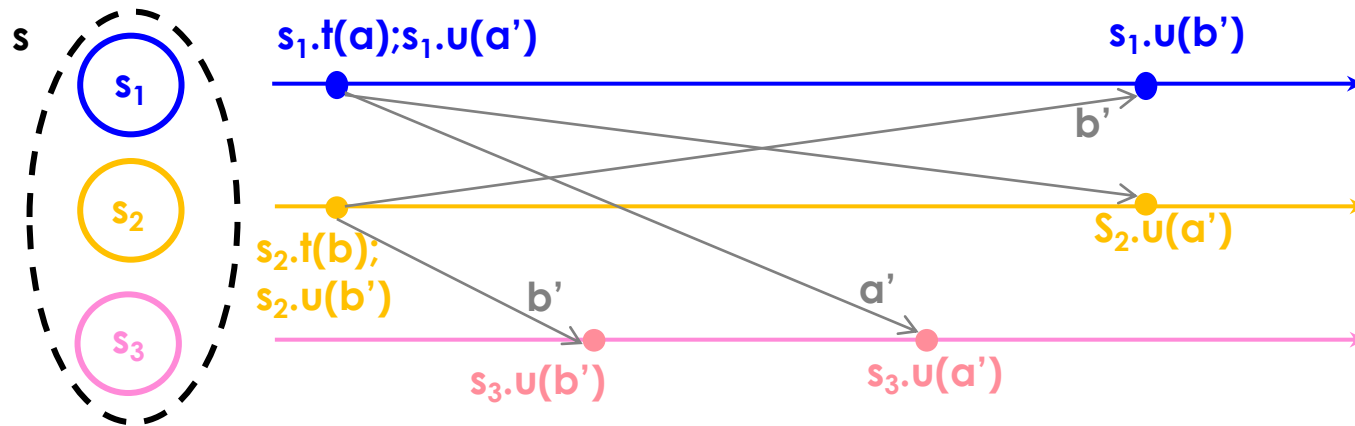
Conflict-free Replicated Data Types (CRDT)

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

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)

$\langle 1, 2, 1 \rangle$	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

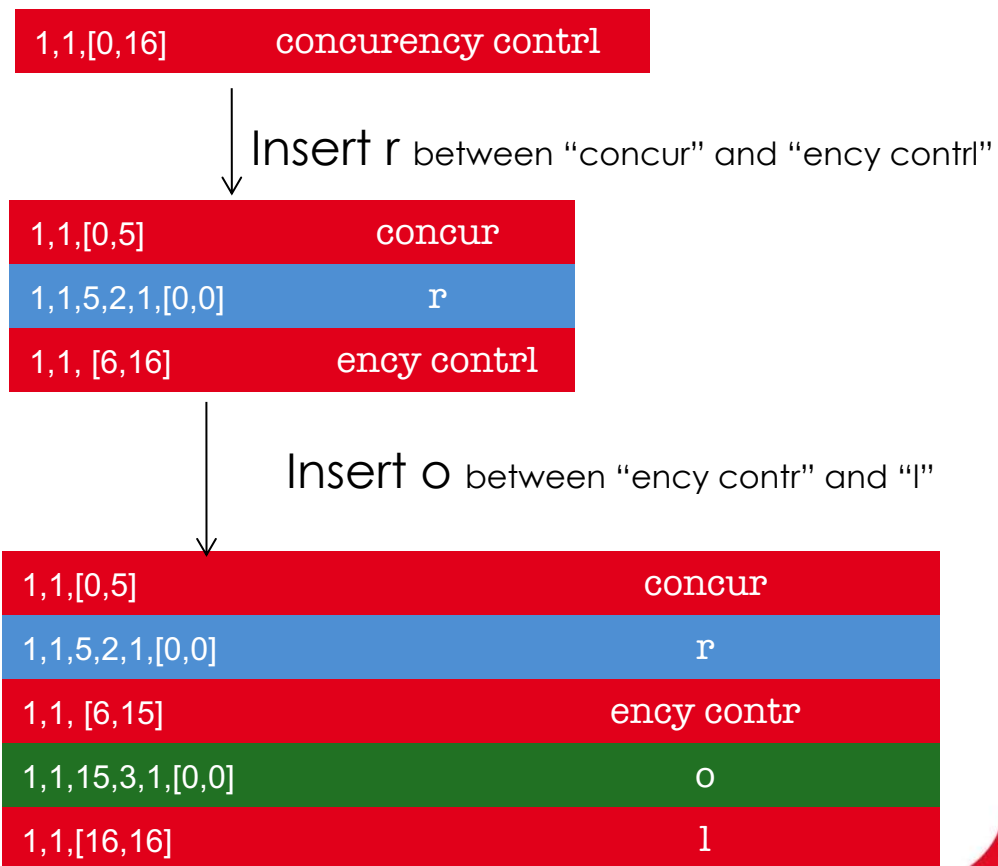
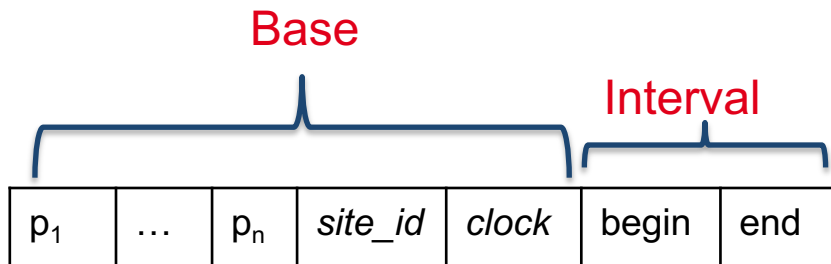
- Time complexity
 - Average: $O(k \log(n))$
 - Worst case: $O(H * \log(H))$
 - H: #ops
 - n: doc. size (non deleted chars.)
 - k: avg. size of Logoot identifier
- No need for concurrency detection
- Identifiers storage cost
- New design for each data type
- Suitable for large-scale collaboration**

Conflict-free Replicated Data Types (CRDT)

LogootSplit [AM0113]

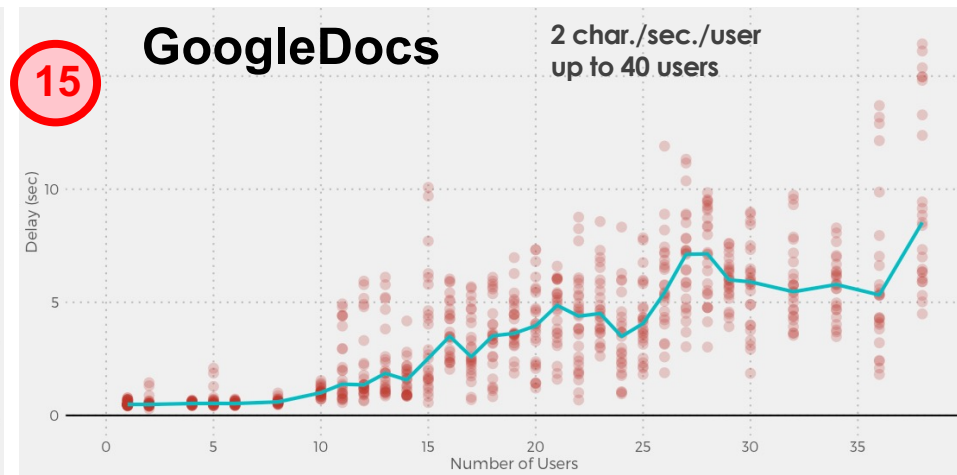
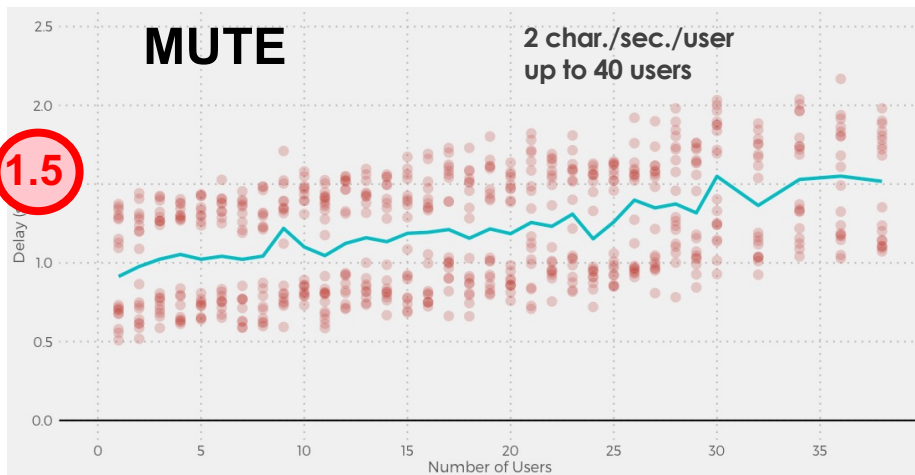
Aggregation of elements to limit metadata

LogootSplit identifiers



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

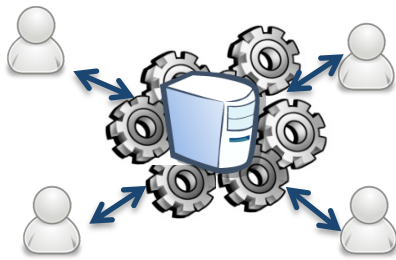
- Implemented in MUTE P2P collaborative editor [NEOIC17] [github.com/coast-team/mute, OpenPaaS::NG, ADT MUTE]
- Better performances than GoogleDocs [DI16a]



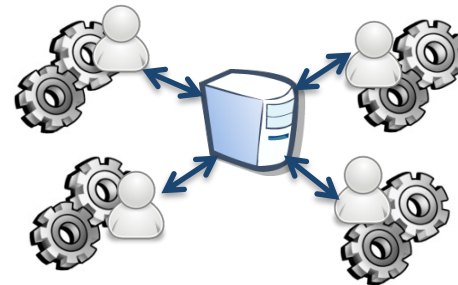
- Related approach on wikis transferred to XWiki [IA021]

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]

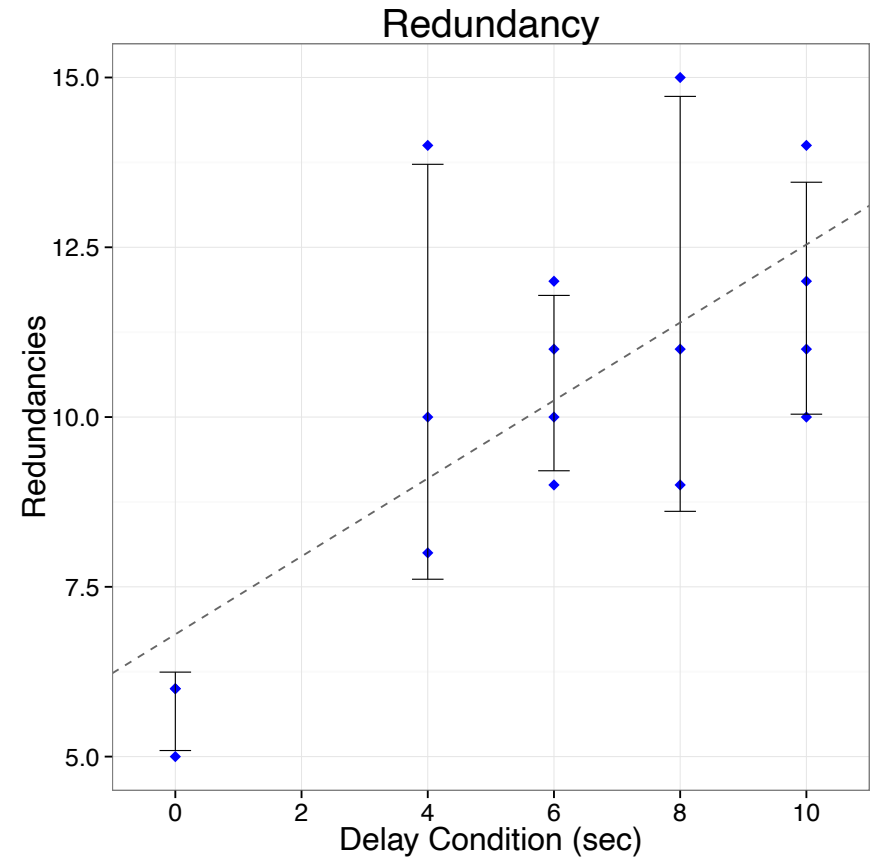
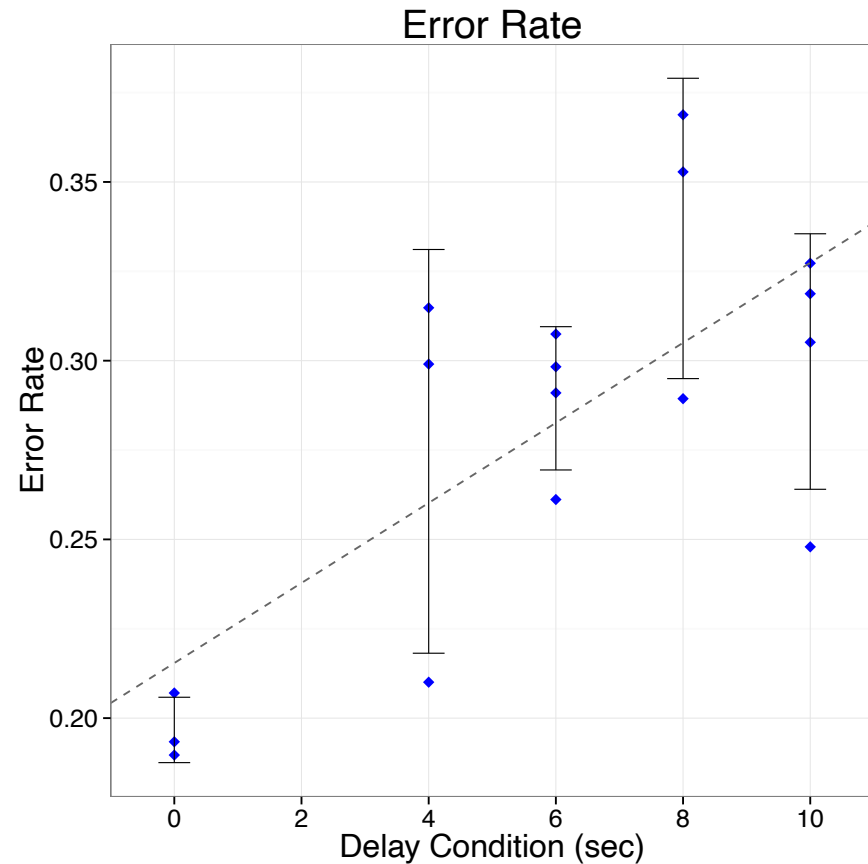
The image shows a screenshot of a web browser window displaying a document. The browser's address bar shows the URL `ec2-184-72-75-76.compute-1.amazonaws.com/p/notes005`. The document content is a list of notes about cloud computing, with several lines highlighted in purple, blue, and yellow. A black box with the text "Editing zone" is overlaid on the document. Three circular callouts are connected to the document by lines, highlighting specific text: "un data matérialisé", "le cloud représente un marché gigantesque", and "matérialisé". A black box with the text "Chat dialogue" is overlaid on the bottom right, pointing to a chat window. The chat window shows a list of messages:

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

The document content includes the following text:

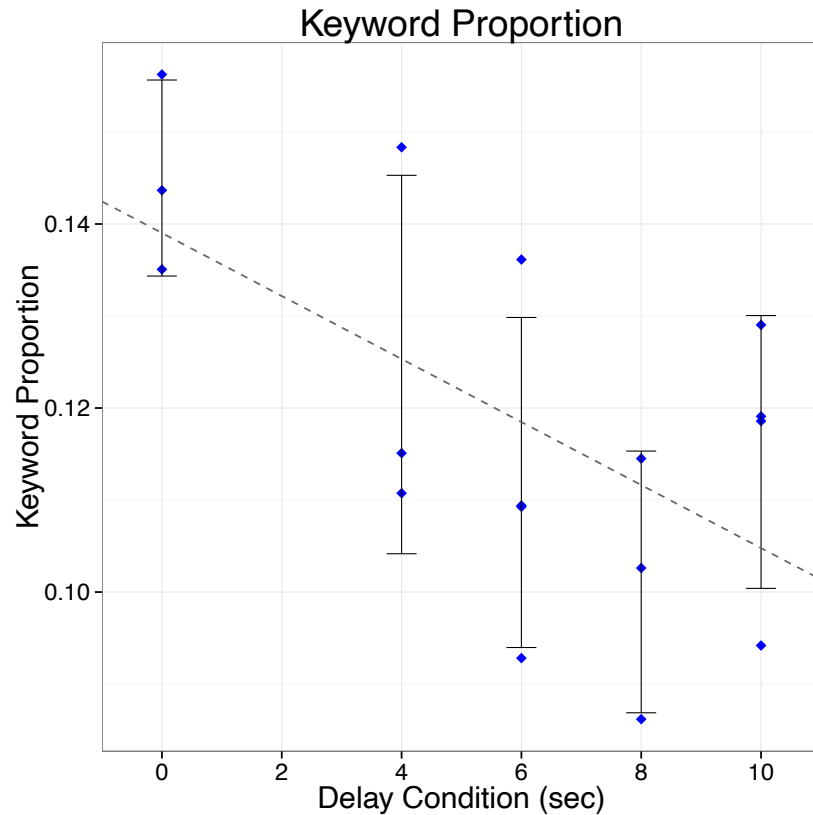
1. Cloud computing (Utilisateur 1 + Utilisateur 2)
enjeu
100 milliards de dollars
accès via internet via un simple navigateur à des ressources énormes
même fiabilité qu'un data center
Informatique dématérialisée (U)
le cloud représente un marché gigantesque
accès à des ressources infinies : réseau calcul stockage
représentation d'internet sous forme de nuage complexité disparé dematerialisati
informatique dématérialisé
2. Différents types de clouds et de clients (Utilisateur 3 + Utilisateur 4)
3. Les avantages de cloud (Utilisateur 1 + Utilisateur 2)
4. Les inconvénients de cloud (Utilisateur 3 + Utilisateur 4)
5. Sujets de recherche en cloud computing (Utilisateur 1 + Utilisateur 2)

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**?

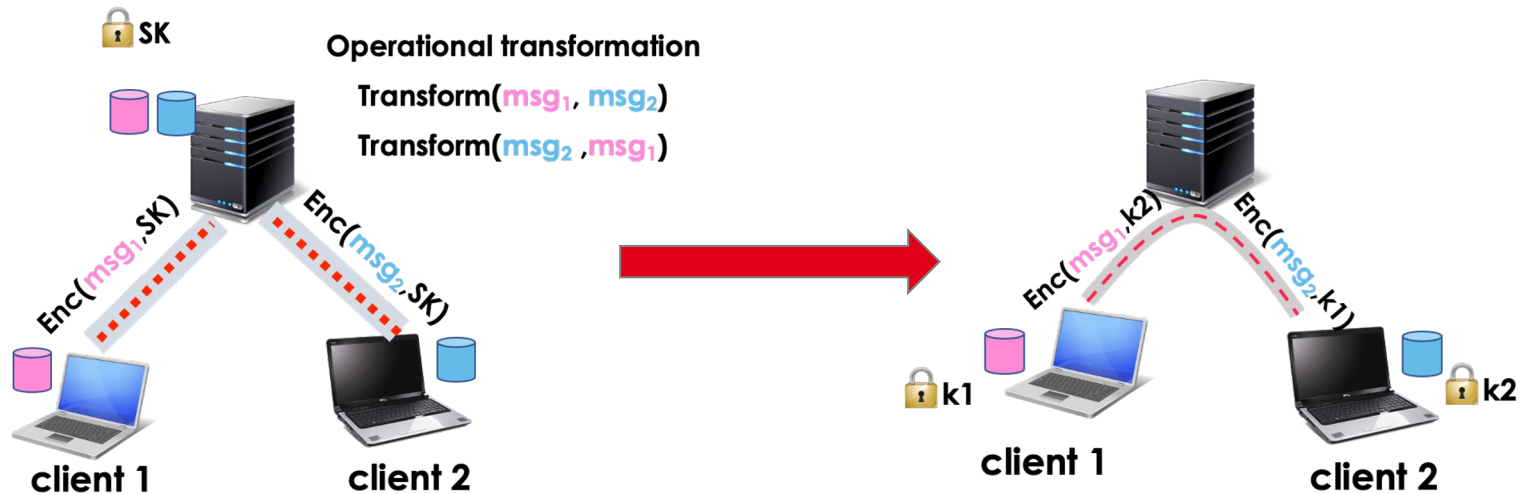
Security in peer-to-peer collaboration



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

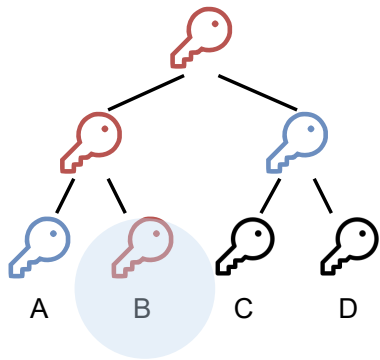
Encryption for mutable data by means of CRDTs

- CRDTs suitable for client-side E2E encryption

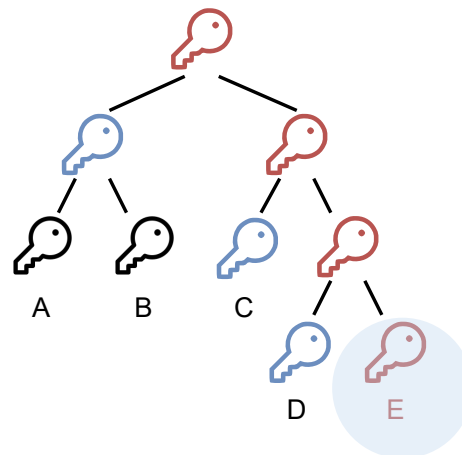


Group key management for large and dynamic groups

- 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

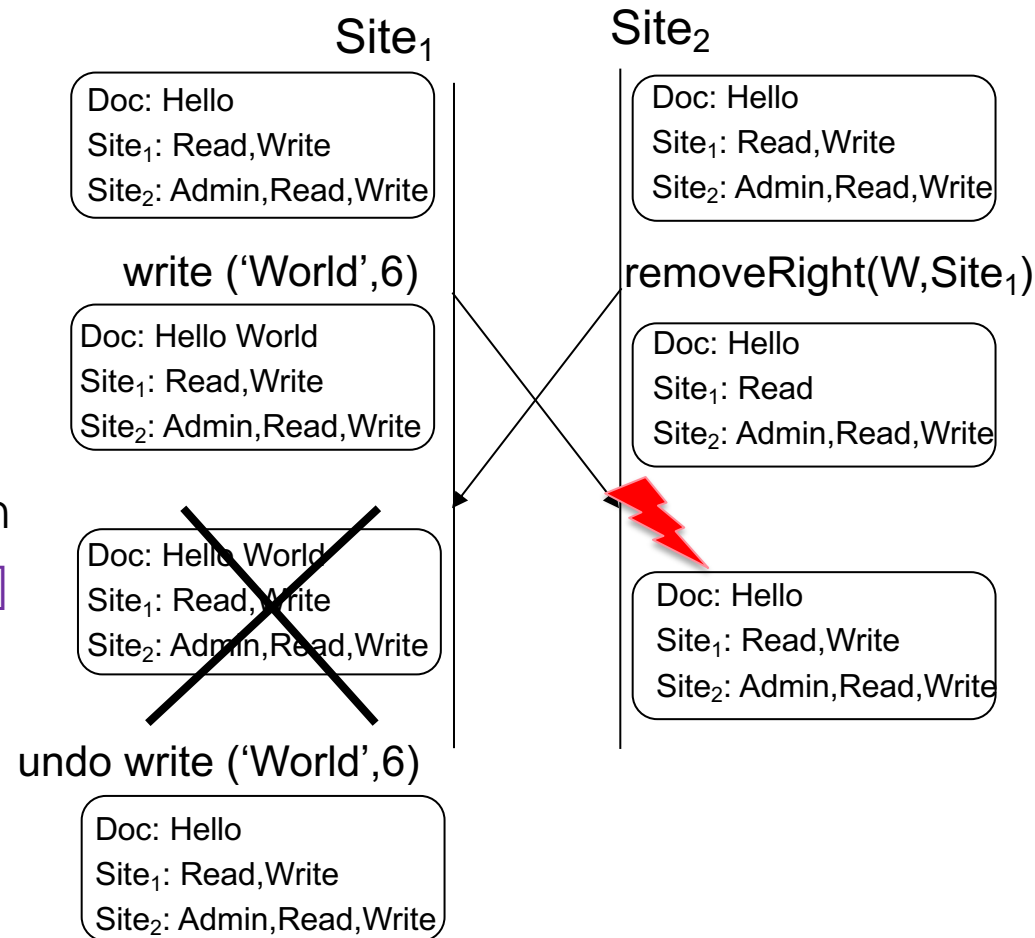
Access control for peer-to-peer systems without central authority

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?

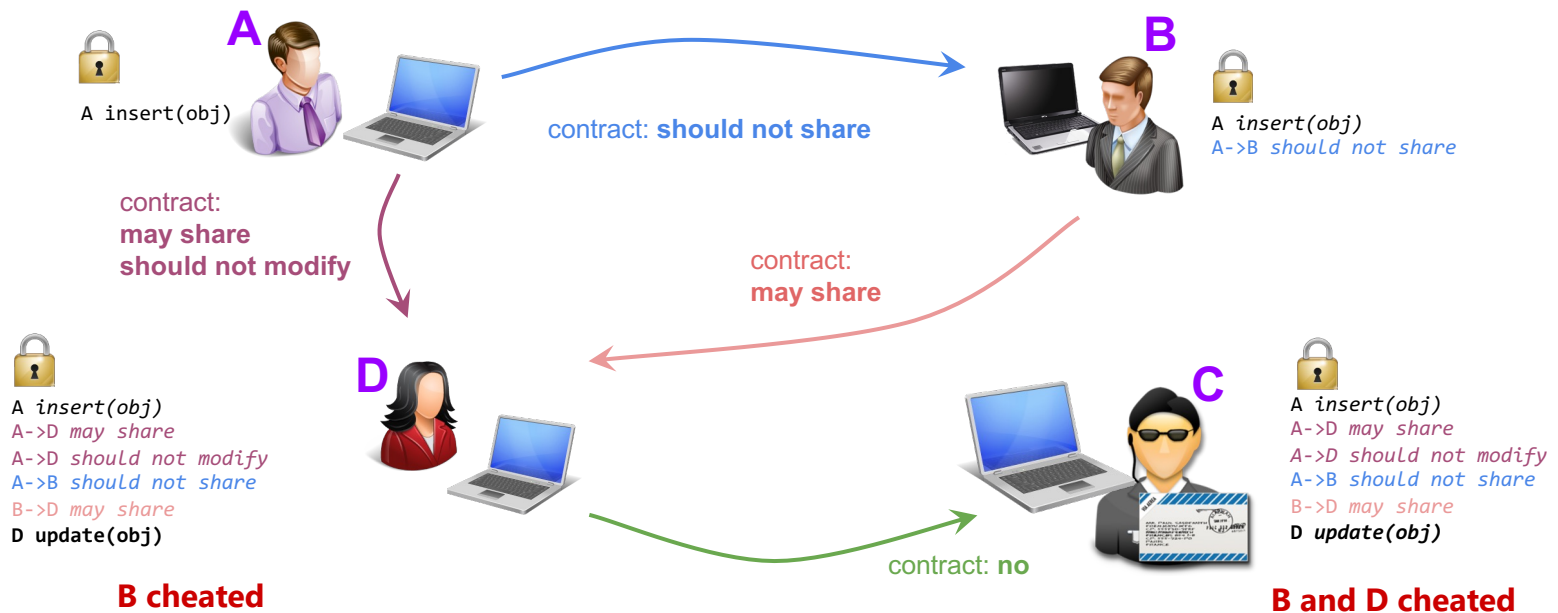


Trust computation - contribution

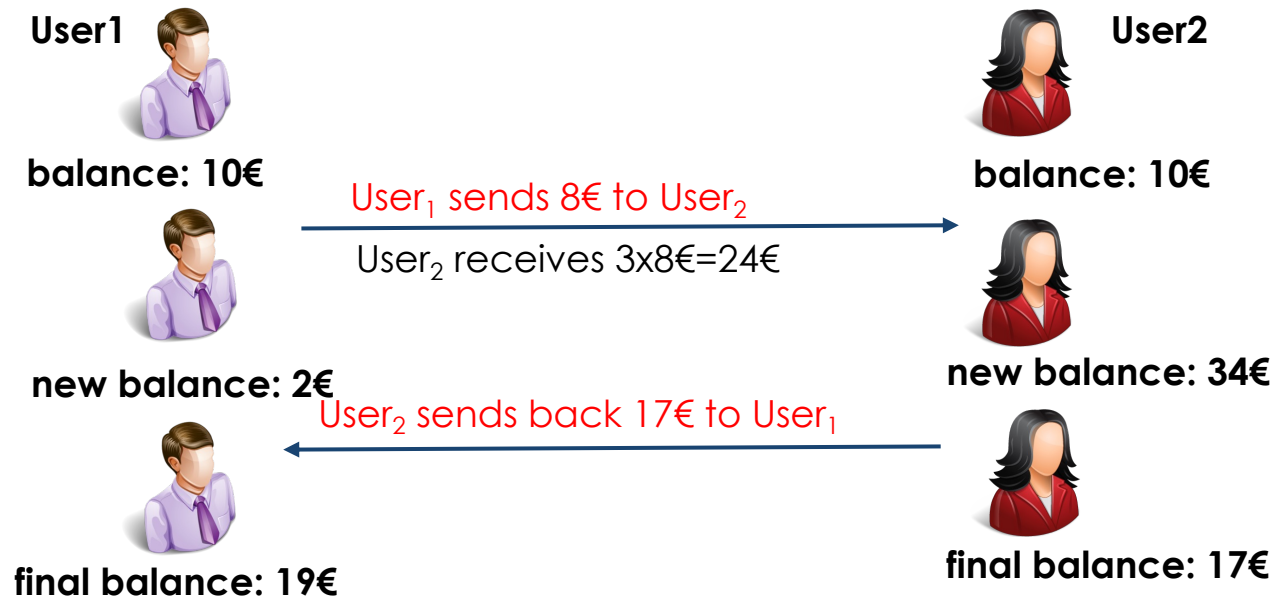
- Evaluate collaborators trust based on their past behavior
 - Contract-based collaborative editing
 - Trust game

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

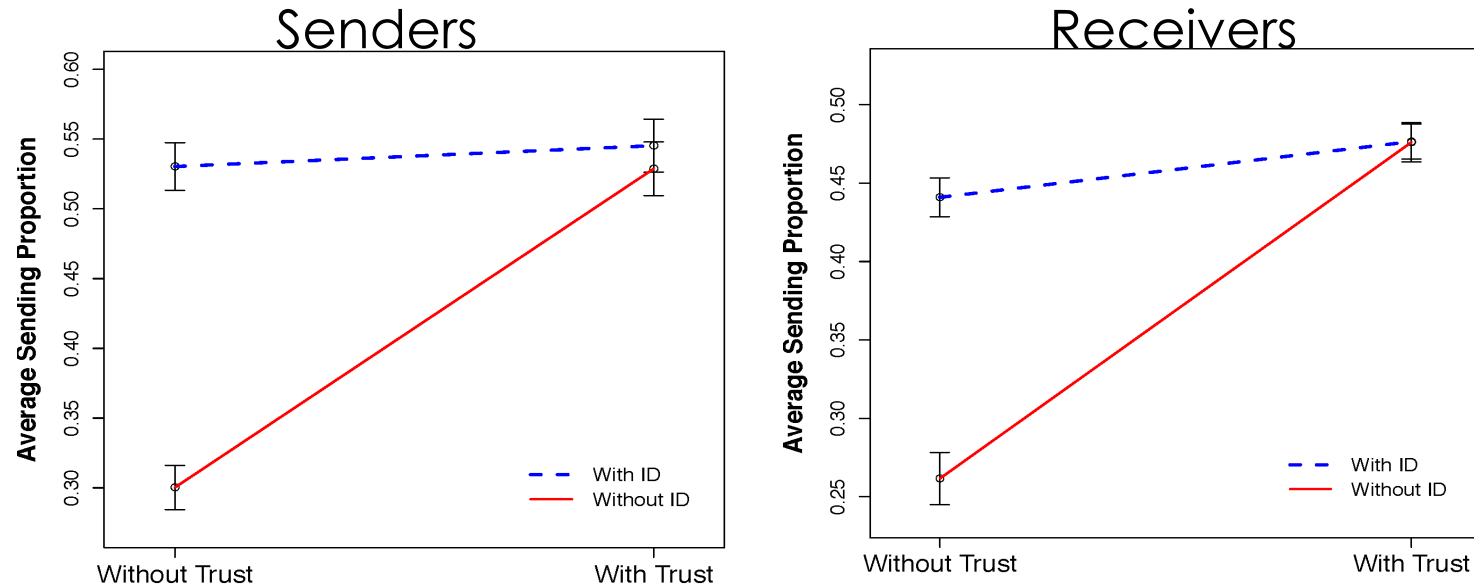
$$send_proportion_t = \frac{sending_amount_t}{max_sending_amount}$$

- 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/>)

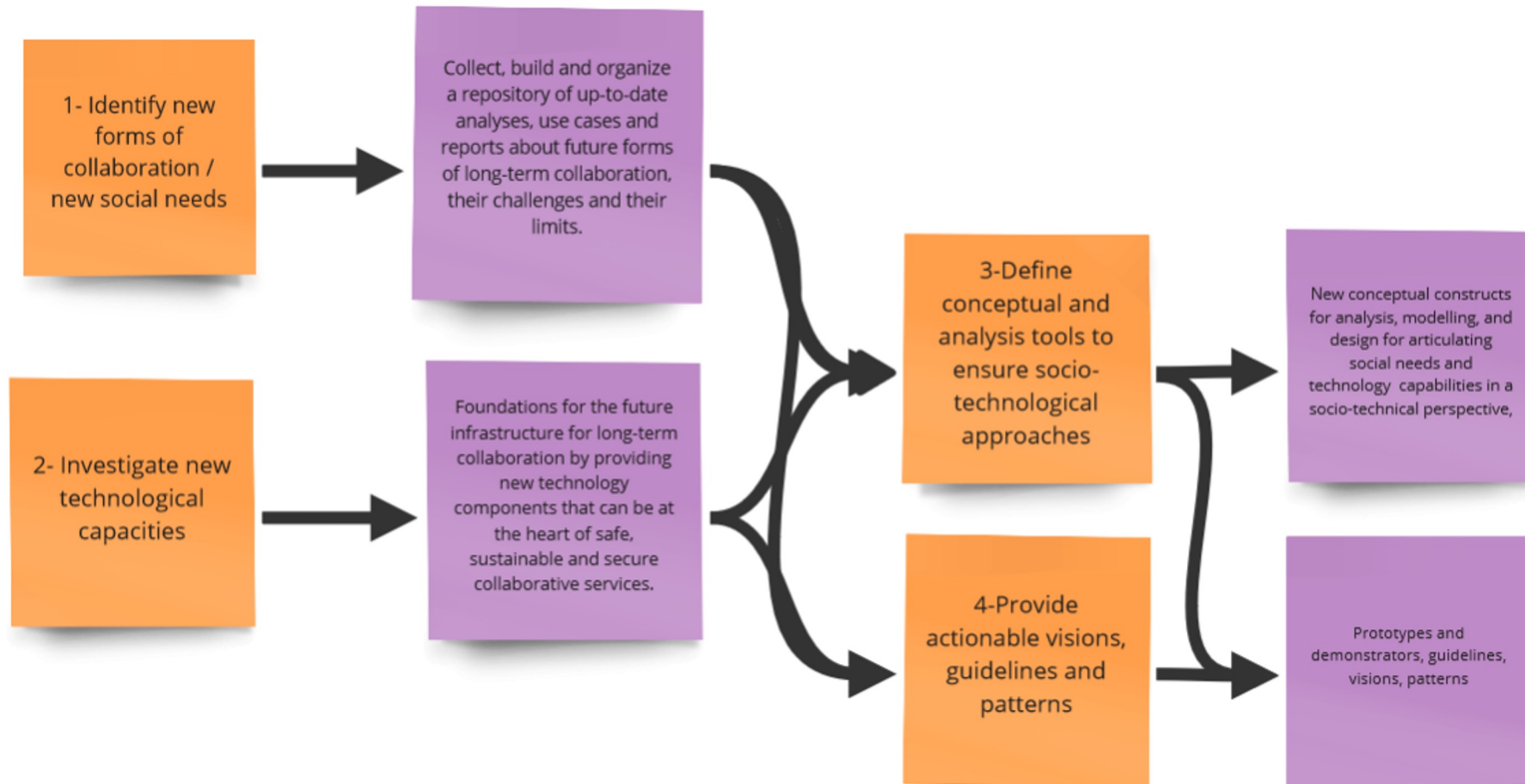
PILOT – Practices and infrastructure for long term collaboration

- 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

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

xml
editing
structures
repositories
structures

contract
tree-based
writing
model
editor
real-time
distributed

data
user
resolution
multi-level
processes
annotation
concurrent
trust

algorithms
merging
drawing
editing
algorithms
hi story
multi-part

organisations
auditing
reconciliation
adaptable
drawing
partitioning
recovery

writing
information
log
multi-pair
model
authoring
communication

changes
software
note
evaluating
optimistic
authenticating

consistency
slices
delay
content

framework
state-based
privacy
massive-scale
draw-together

documents
systems
multi-level

performance
inter-document
co-authoring

framework
state-based
privacy
massive-scale
draw-together

References

- **[AI123]** Quantifying the Performance of Conflict-free Replicated Data Types in InterPlanetary File System. Q. Acher, C.-L. Ignat, S. Ibrahim. DICG@Middleware 2023
- **[AMO113]** Supporting Adaptable Granularity of Changes for Massive Scale Collaborative Editing. L. André, S. Martin, G. Oster, C.-L. Ignat. CollaborateCom 2013.
- **[ASB18]** Delta state replicated data types. P. S. Almeida, A. Shoker, C. Baquero. Journal of Parallel and Distributed Computing, 2018
- **[B00]** Brewer, E.A. “Towards robust distributed systems”. In Proc. of PODC, 2000.
- **[BDM95]** Trust, social history, and reciprocity. J. Berg, J. Dickhaut, and K. McCabe, Games and Econ. Behav.1995.
- **[DI16a]** Performance of real-time collaborative editors at large scale: User perspective. Q. V. Dang, C.-L. Ignat. Networking 2016
- **[DI16b]** Computational Trust Model for Repeated Trust Games. Q. V. Dang, C.-L. Ignat. Trustcom 2016
- **[EG89]** Concurrency Control in GroupWare Systems, C.A. Ellis and S.J. Gibbs. ACM SIGMOD Record 18(2), 1989.
- **[EGR91]** Groupware: Some issues and experiences, C.A. Ellis, S. J. Gibbs and G. Rein, Communications of the ACM,1991

References

- **[IAO21]** Enhancing rich content wikis with real-time collaboration. C.-L. Ignat, L. André, G. Oster. *Concurr. Comput. Pract. Exp.* 2021
- **[ID21]** Users trust assessment based on their past behavior in large scale collaboration. C.-L. Ignat, Q.-V. Dang. *ICCP* 2021
- **[IDS19]** The influence of trust score on cooperative behavior. C.-L. Ignat, Q.-V. Dang, and V. L. Shalin. *ACM Trans. Internet Technol.* 2019
- **[IEB24]** Synql: A CRDT-based Approach for Replicated Relational Databases with Integrity Constraints. C.-L. Ignat, V. Elvinger, H. Ba. *DAIS* 2024
- **[IOFSC15]** How Do User Groups Cope with Delay in Real-Time Collaborative Note Taking. C.-L. Ignat, G. Oster, O. Fox, V. L. Shalin, F. Charoy. *ECSCW* 2015
- **[J88]** GroupWare: Computer Support for Business Teams. R. Johansen. The Free Press, New York, NY, USA, 1988.
- **[L21]** Confiance dans les situations de travail collaboratifs médiatisés par des environnements numériques. B. Linot. Thèse de doctorat, Univ. de Lorraine, 2021
- **[NEOIC17]** MUTE: A Peer-to-Peer Web-based Real-time Collaborative Editor. M. Nicolas, V. Elvinger, G. Oster, C.-L. Ignat, F. Charoy. *ECSCW*, 2017

References

- **[NI18]** An Analysis of Merge Conflicts and Resolutions in Git-Based Open Source Projects. H. L. Nguyen, C.-L. Ignat. Journal of CSCW, 2018
- **[PIFTI23]** Design of an Efficient Distributed Delivery Service for Group Key Agreement Protocols. L. Paillat, C.-L. Ignat, D. Frey, M. Turuani, A. Ismail. FPS 2023
- **[PMSL09]** A commutative replicated data type for cooperative editing, N. Preguica, M. Joan, M. Shapiro, and M. Letia. ICDCS 2009.
- **[RIP23]** Access control based on CRDTs for Collaborative Distributed Applications. P.-A. Rault, C.-L. Ignat, O. Perrin. TrustCom 2023
- **[SPBZ11]** Conflict-free Replicated Data Types, M. Shapiro, N. Preguica, C. Baquero, M. Zawirski. Research Report, RR-7687, INRIA, 2011
- **[TI11]** H. T. T. Truong, C.-L. Ignat. Log Auditing for Trust Assessment in Peer-to-Peer Collaboration. ISPDC 2011
- **[TIBM11]** A contract-extended push-pull-clone model. H. T. T. Truong, C.-L. Ignat, M.-R. Bouguelia, P. Molli. CollaborateCom 2011
- **[TIM12]** Authenticating operation-based history in collaborative systems. H. T. T. Truong, C.-L. Ignat, P. Molli. GROUP 2012
- **[WUM09]** Logoot : a Scalable Optimistic Replication Algorithm for Collaborative Editing on P2P Networks, S. Weiss, P. Urso and P. Molli. ICDCS 2009.