Large-scale trustworthy distributed collaborative systems

Claudia-Lavinia Ignat
Coast team
Inria Nancy-Grand Est

Habilitation defense
April 23, 2021

claudia.ignat@inria.fr

Education and work experience

Technical University
Cluj-Napoca Romania

- Master thesis ETH Zurich, June 2000
- Engineer diploma, July 2000

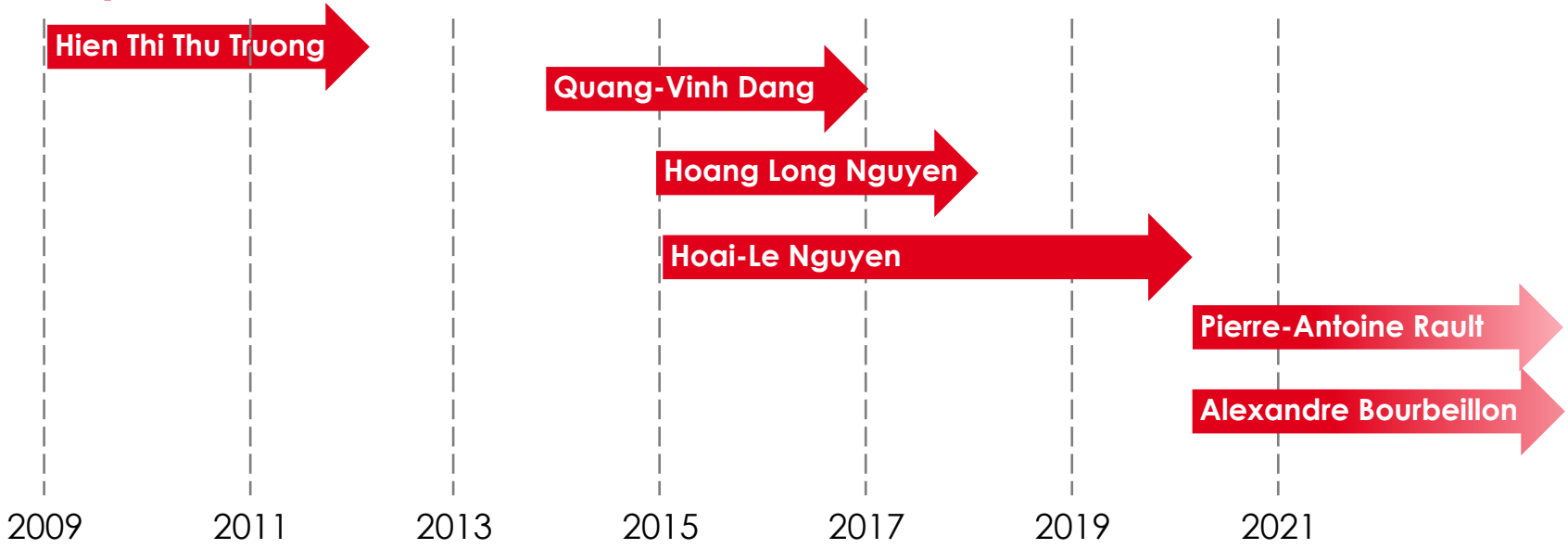
ETH Zurich
Switzerland

- Research and teaching assistant
- PhD thesis July 2006

Inria Nancy-Grand Est
France

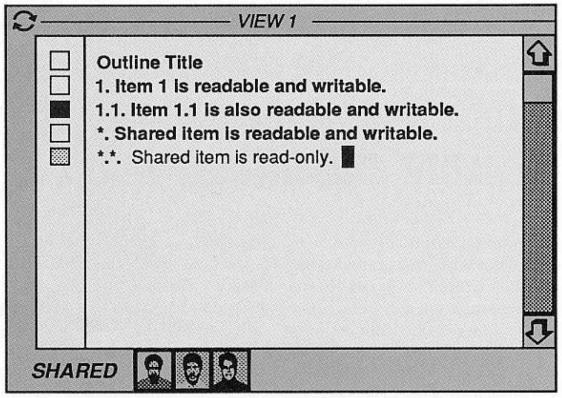
- Postdoc 2006-2007
- Research scientist since 2007

PhD Supervision



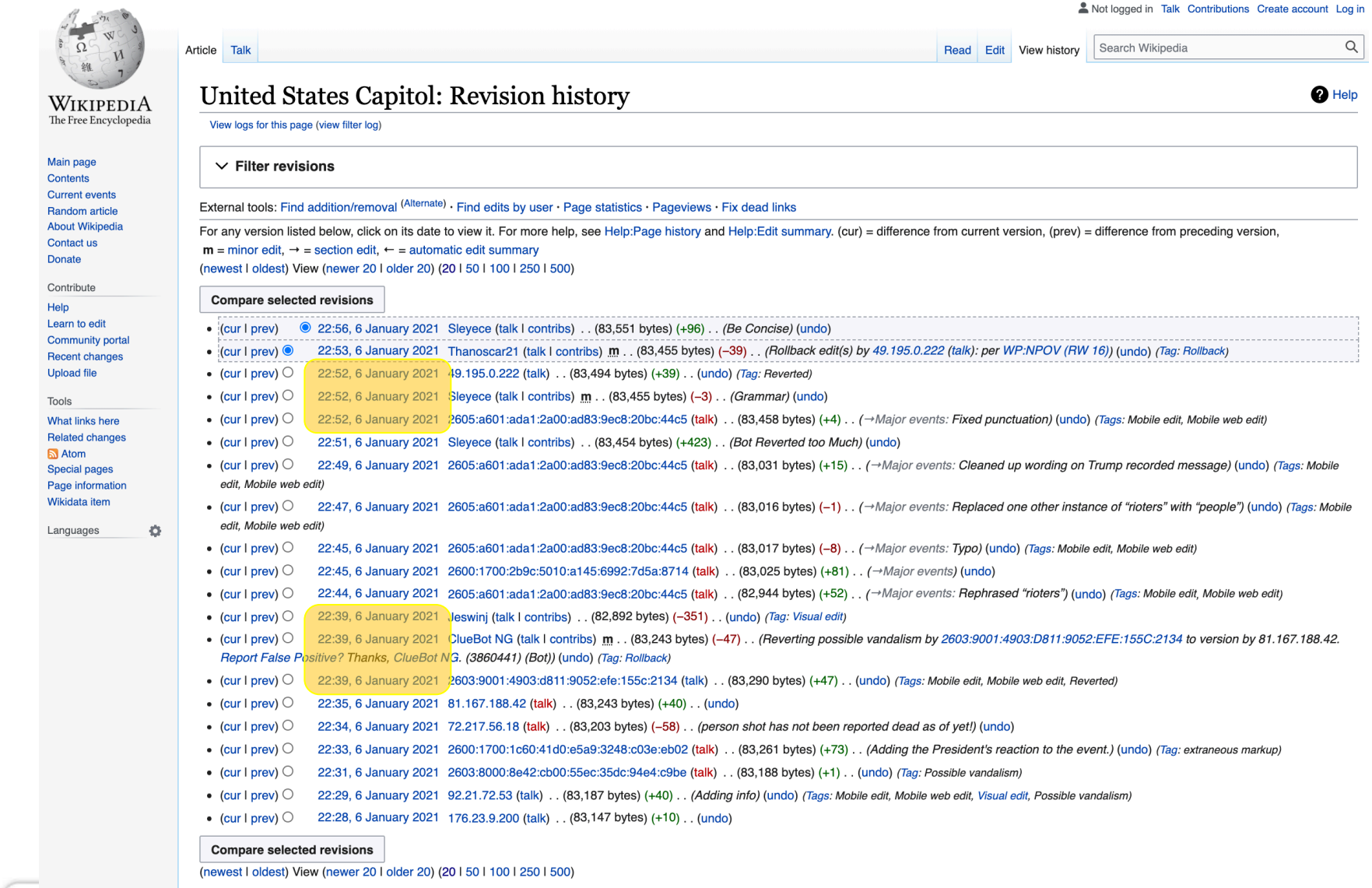
Collaborative Systems: from users to community of users

GROVE, 1989



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

From users to community of users: new practices



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- (cur | prev) 22:56, 6 January 2021 Sleyece (talk | contribs) . . (83,551 bytes) (+96) . . *(Be Concise)* (undo)
- (cur | prev) 22:53, 6 January 2021 Thanoscar21 (talk | contribs) **m** . . (83,455 bytes) (−39) . . *(Rollback edit(s) by 49.195.0.222 (talk): per WP:NPOV (RW 16))* (undo) *(Tag: Rollback)*
- (cur | prev) 22:52, 6 January 2021 49.195.0.222 (talk) . . (83,494 bytes) (+39) . . (undo) *(Tag: Reverted)*
- (cur | prev) 22:52, 6 January 2021 Sleyece (talk | contribs) **m** . . (83,455 bytes) (−3) . . *(Grammar)* (undo)
- (cur | prev) 22:52, 6 January 2021 2605:a601:ada1:2a00:ad83:9ec8:20bc:44c5 (talk) . . (83,458 bytes) (+4) . . *(→Major events: Fixed punctuation)* (undo) *(Tags: Mobile edit, Mobile web edit)*
- (cur | prev) 22:51, 6 January 2021 Sleyece (talk | contribs) . . (83,454 bytes) (+423) . . *(Bot Reverted too Much)* (undo)
- (cur | prev) 22:49, 6 January 2021 2605:a601:ada1:2a00:ad83:9ec8:20bc:44c5 (talk) . . (83,031 bytes) (+15) . . *(→Major events: Cleaned up wording on Trump recorded message)* (undo) *(Tags: Mobile edit, Mobile web edit)*
- (cur | prev) 22:47, 6 January 2021 2605:a601:ada1:2a00:ad83:9ec8:20bc:44c5 (talk) . . (83,016 bytes) (−1) . . *(→Major events: Replaced one other instance of "rioters" with "people")* (undo) *(Tags: Mobile edit, Mobile web edit)*
- (cur | prev) 22:45, 6 January 2021 2605:a601:ada1:2a00:ad83:9ec8:20bc:44c5 (talk) . . (83,017 bytes) (−8) . . *(→Major events: Typo)* (undo) *(Tags: Mobile edit, Mobile web edit)*
- (cur | prev) 22:45, 6 January 2021 2600:1700:2b9c:5010:a145:6992:7d5a:8714 (talk) . . (83,025 bytes) (+81) . . *(→Major events)* (undo)
- (cur | prev) 22:44, 6 January 2021 2605:a601:ada1:2a00:ad83:9ec8:20bc:44c5 (talk) . . (82,944 bytes) (+52) . . *(→Major events: Rephrased "rioters")* (undo) *(Tags: Mobile edit, Mobile web edit)*
- (cur | prev) 22:39, 6 January 2021 Jeswinj (talk | contribs) . . (82,892 bytes) (−351) . . (undo) *(Tag: Visual edit)*
- (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)*
- (cur | prev) 22:39, 6 January 2021 2603:9001:4903:d811:9052:efe:155c:2134 (talk) . . (83,290 bytes) (+47) . . (undo) *(Tags: Mobile edit, Mobile web edit, Reverted)*
- (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)
- (cur | prev) 22:33, 6 January 2021 2600:1700:1c60:41d0:e5a9:3248:c03e:eb02 (talk) . . (83,261 bytes) (+73) . . *(Adding the President's reaction to the event.)* (undo) *(Tag: extraneous markup)*
- (cur | prev) 22:31, 6 January 2021 2603:8000:8e42:cb00:55ec:35dc:94e4:c9be (talk) . . (83,188 bytes) (+1) . . (undo) *(Tag: Possible vandalism)*
- (cur | prev) 22:29, 6 January 2021 92.21.72.53 (talk) . . (83,187 bytes) (+40) . . *(Adding info)* (undo) *(Tags: Mobile edit, Mobile web edit, Visual edit, Possible vandalism)*
- (cur | prev) 22:28, 6 January 2021 176.23.9.200 (talk) . . (83,147 bytes) (+10) . . (undo)

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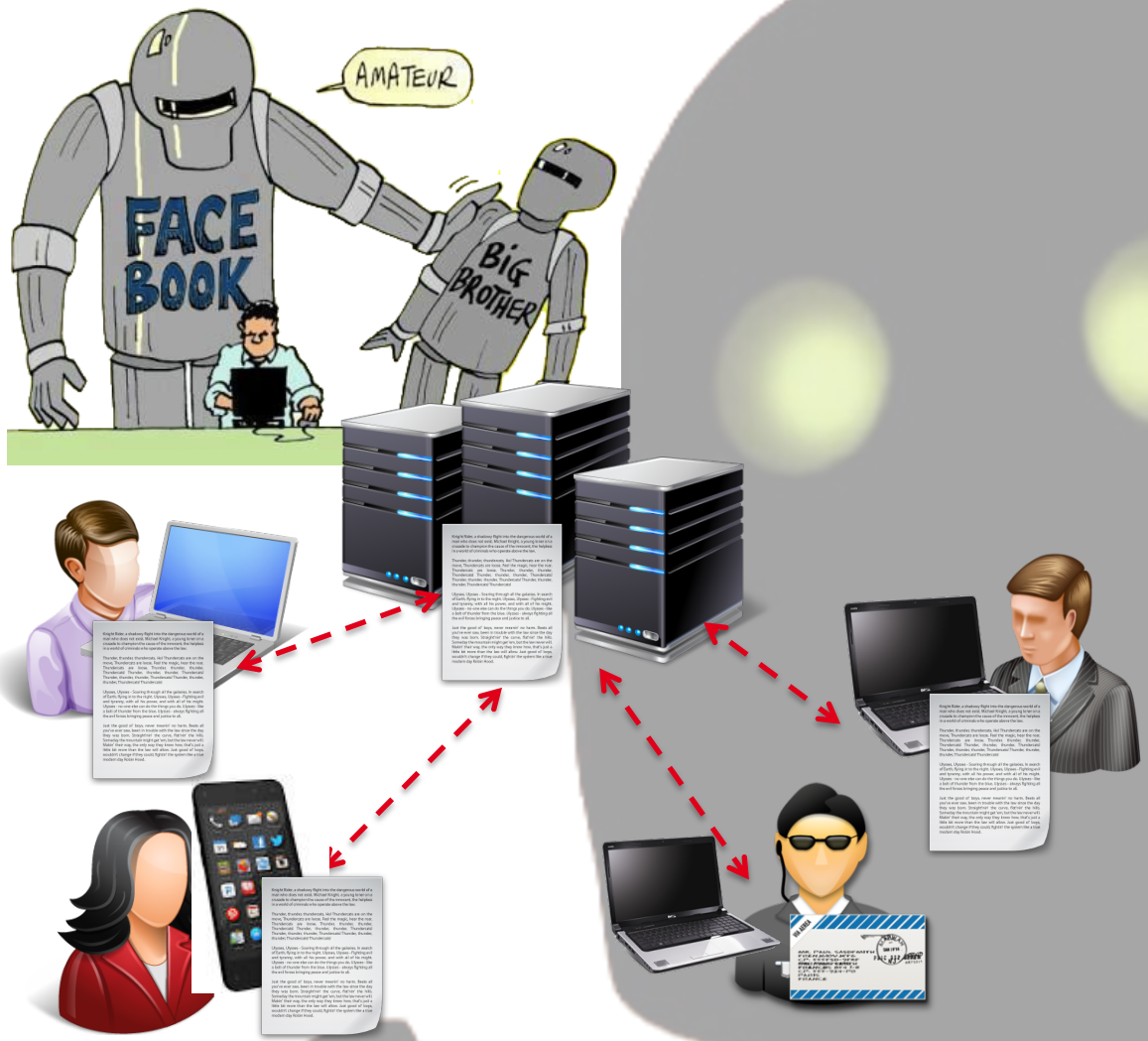
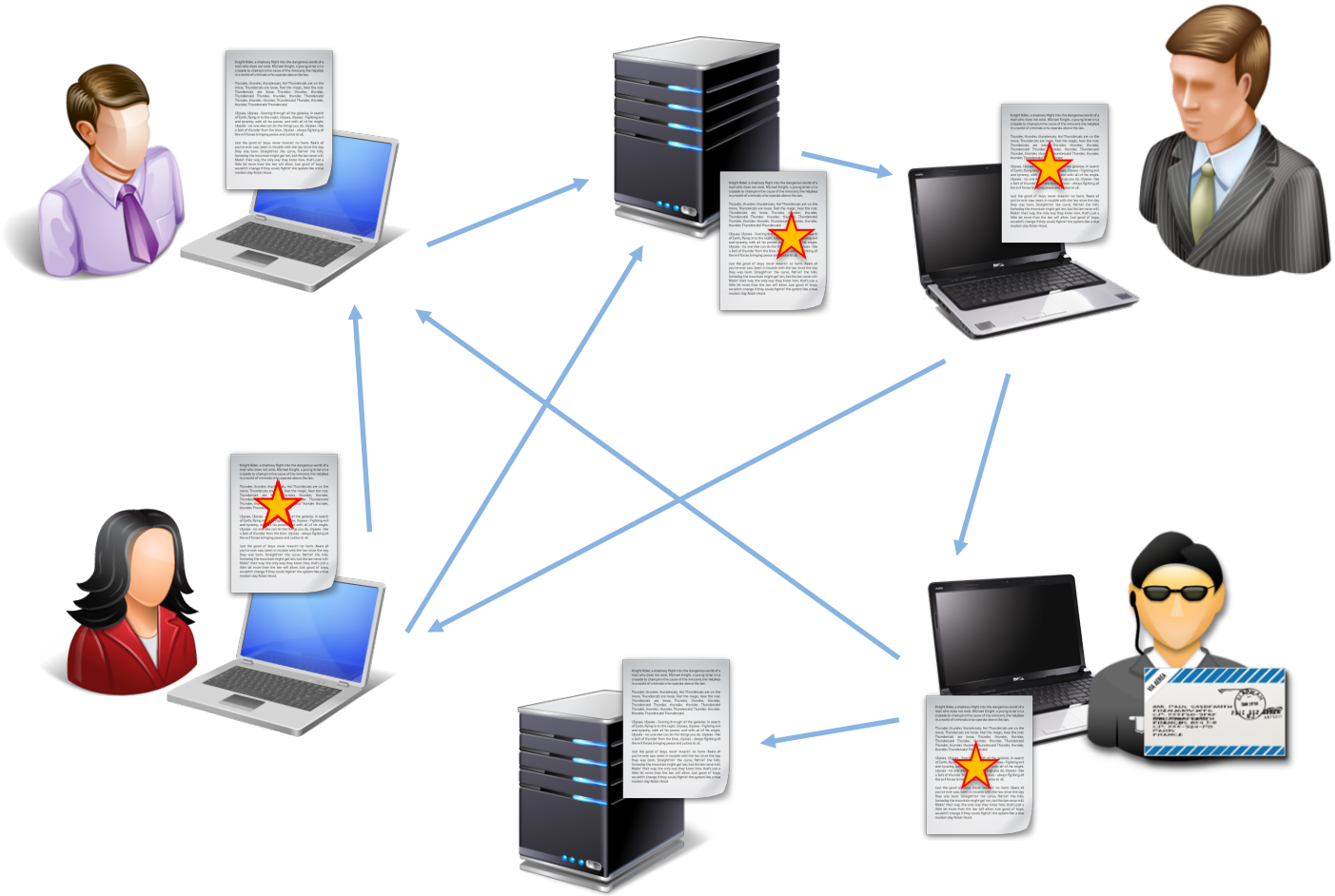
Limitations of Central Authority Systems

SCALABILITY

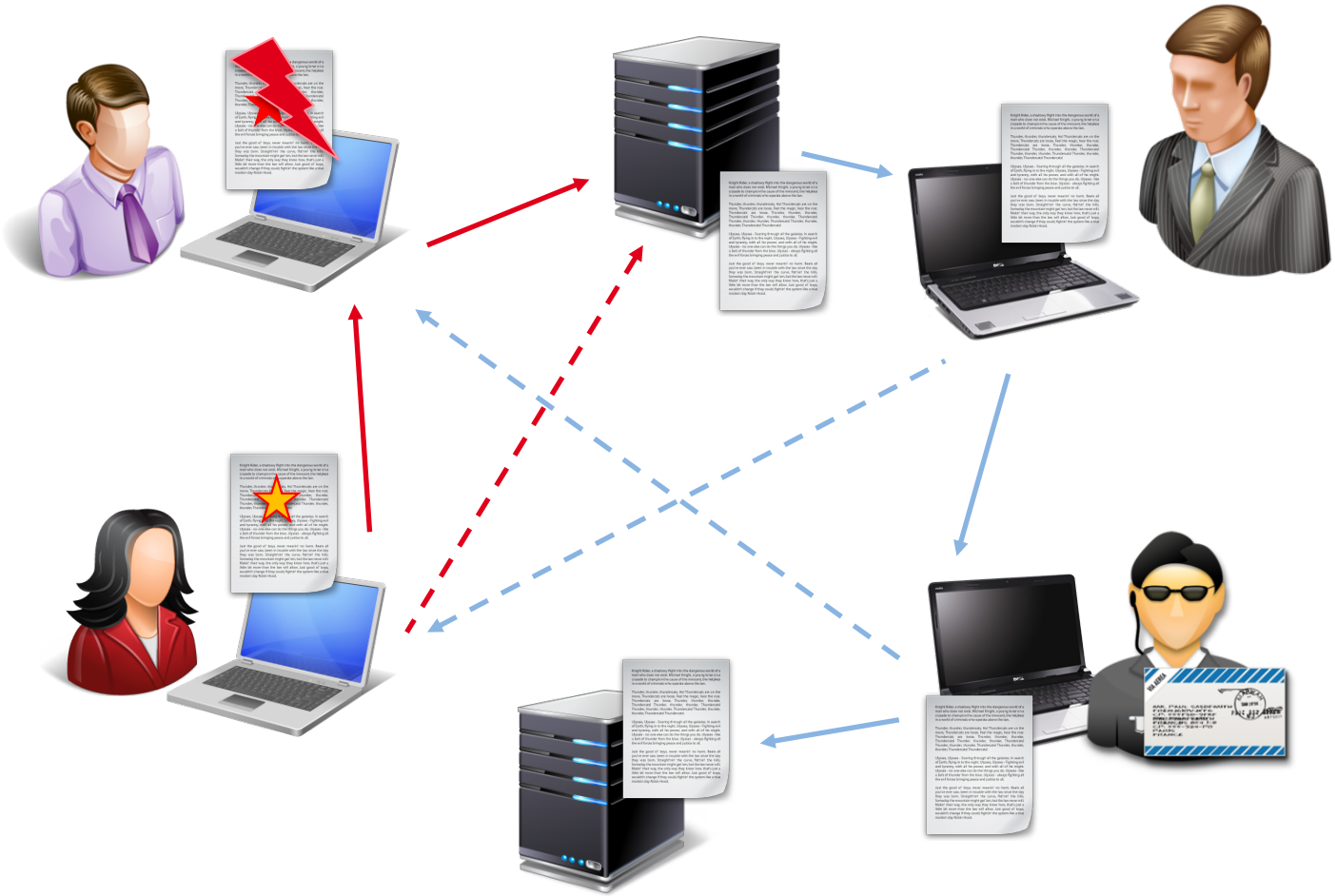
PRIVACY



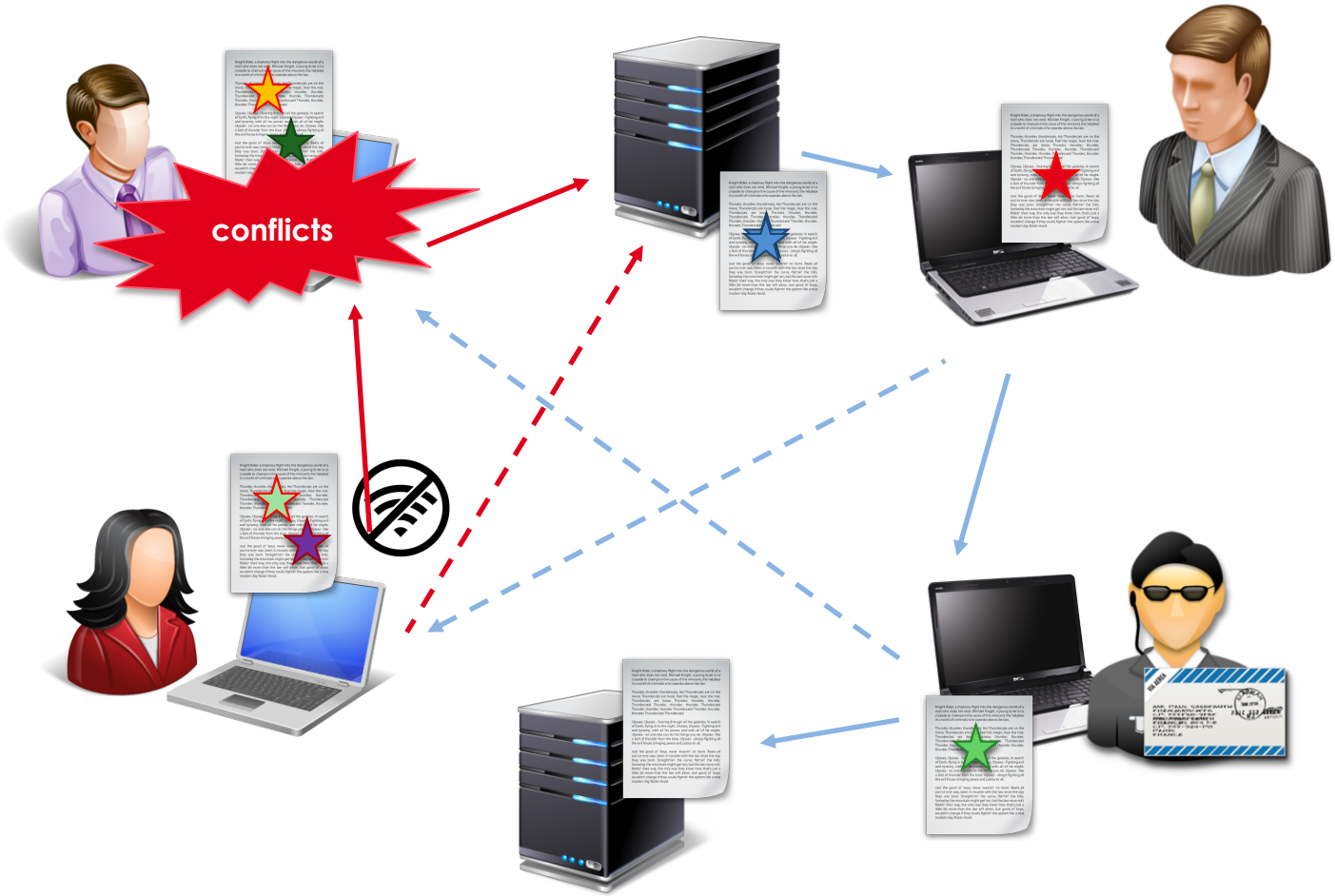
Peer-to-Peer Collaborative Systems



Collaboration Modes – Concurrent Changes

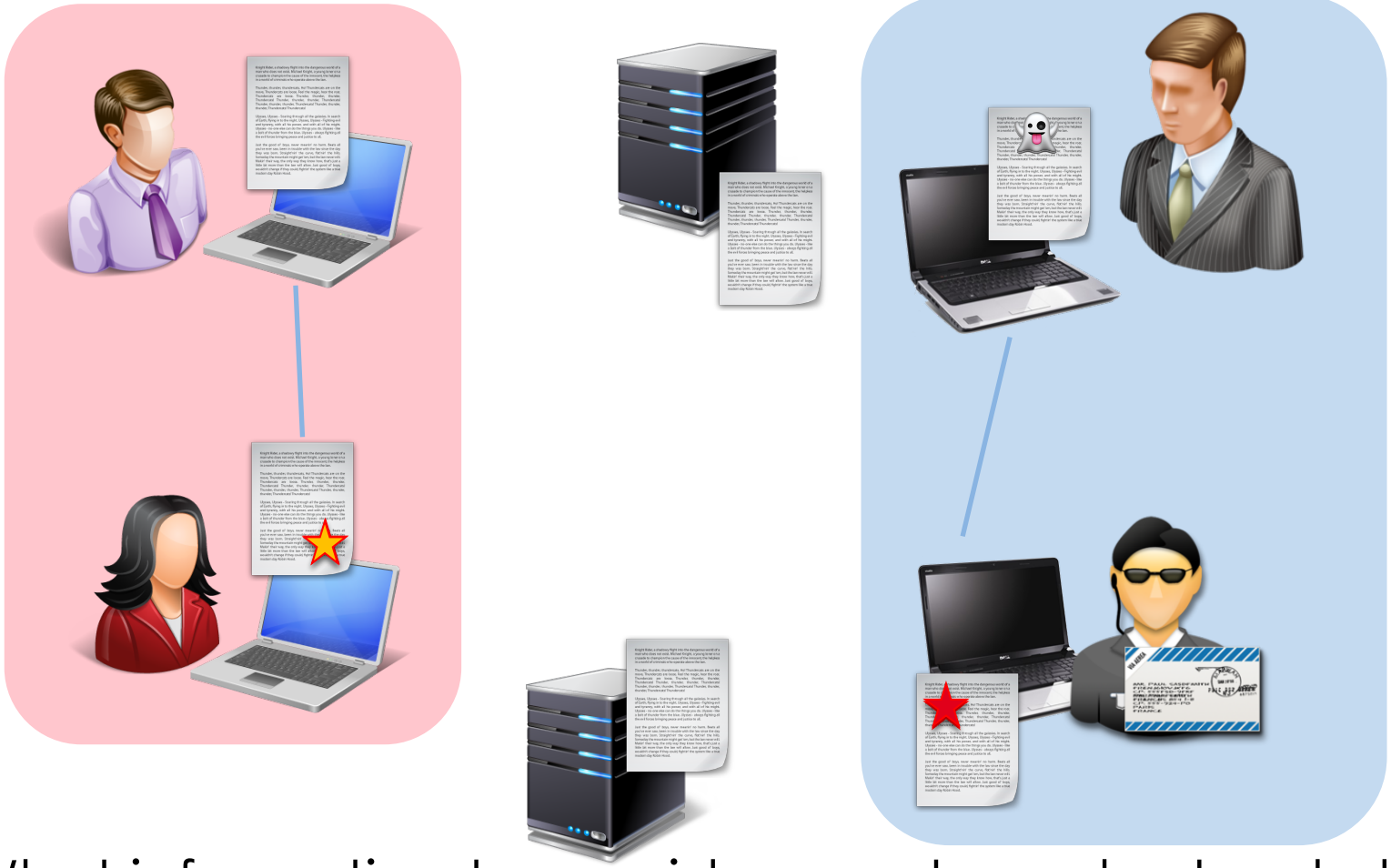


Collaboration Modes – Offline Work



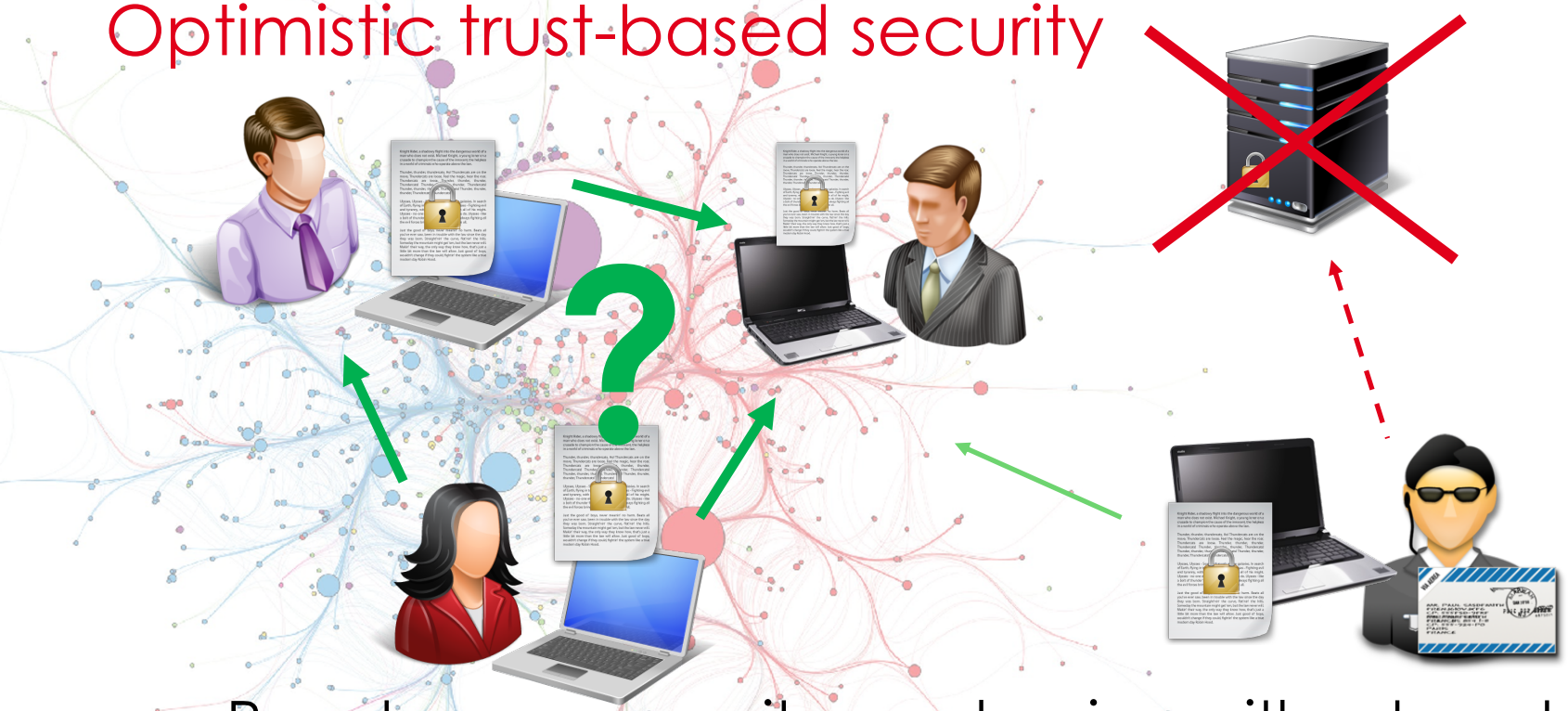
Collaboration Modes – Ad-hoc Collaboration

Group Awareness



What information to provide users to understand changes of other users and prevent conflictual changes?

Optimistic trust-based security



- Peer-to-peer security mechanism without central authority, scalable and easy-to-use
- Soft security: give access to data without control but with a-posteriori verified restrictions
- Trust-based data access with dynamic trust based on collaborative experience

Research Axes

1. Collaborative Data Management
   - Reliable, scalable and explainable replication algorithms
   - Evaluation: collaboration traces and user studies
   - Group awareness mechanisms

2. Trustworthy Collaboration
   - Evaluate collaborators trust based on their past behavior
   - Evaluation: game theory and user studies

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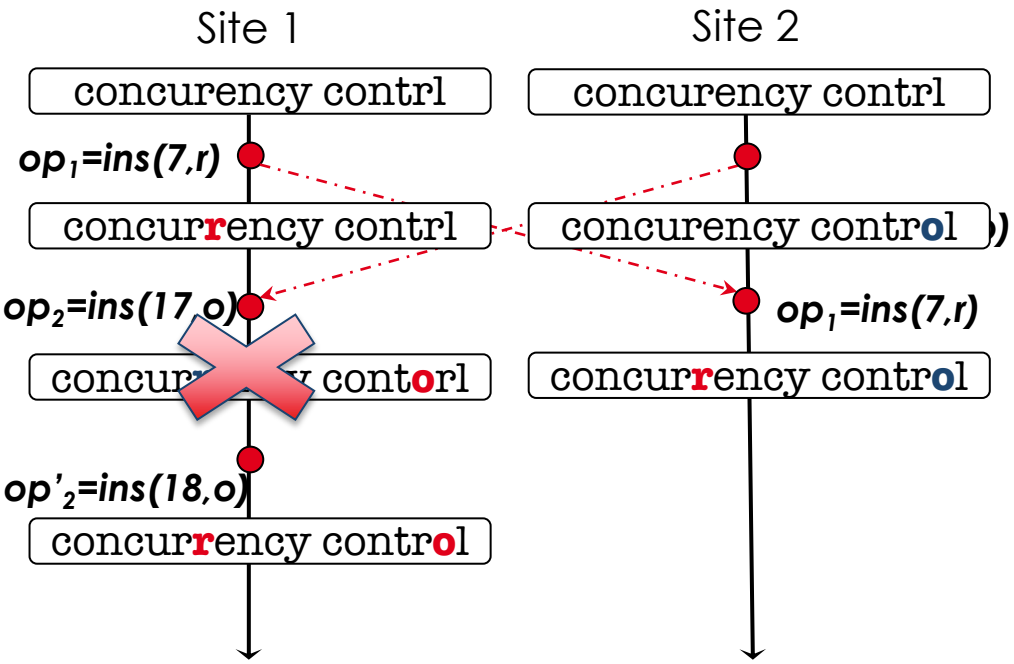
Operational transformation (OT) [EG89]



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 ⇒ 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
- 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

Conflict-free Replicated Data Types (CRDT)
Logoot [WUM09]

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

  p_i position

  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*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**

My Contributions

- Algorithms design
  - OT algorithms for complex data such as hierarchical text documents [IN08], XML [IO07] and wikis [IA017]
  - A CRDT approach for strings that limits metadata [AMOI13]
  - An undo mechanism based on CRDT [YAI15,YEI19]

- Algorithms evaluation
  - Evaluation of OT and CRDT algorithms [IOMC07,AIOR11]
  - Measurement of delays in real-time collaborative editing systems [DI16a] and their influence on users [IOFS15]

- Conflicts prevention and resolution
  - Awareness mechanisms for source code [IO08] and textual documents that considers user privacy [IPON08]
  - Conflict analysis in git-based projects [NI18] and real-time collaborative editing [NI20]

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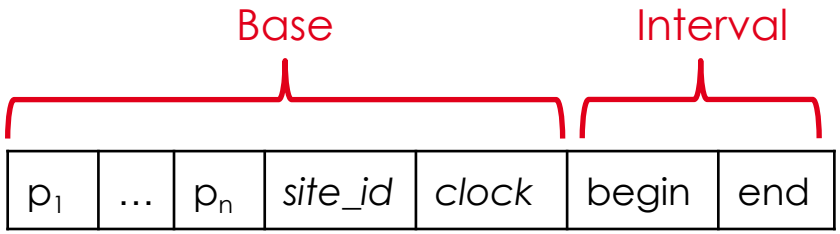
Conflict-free Replicated Data Types (CRDT)
LogootSplit [AMOI13]

LogootSplit identifiers



1,1,[0,16]	concurency contrl

Insert r between "concur" and "ency contrl"

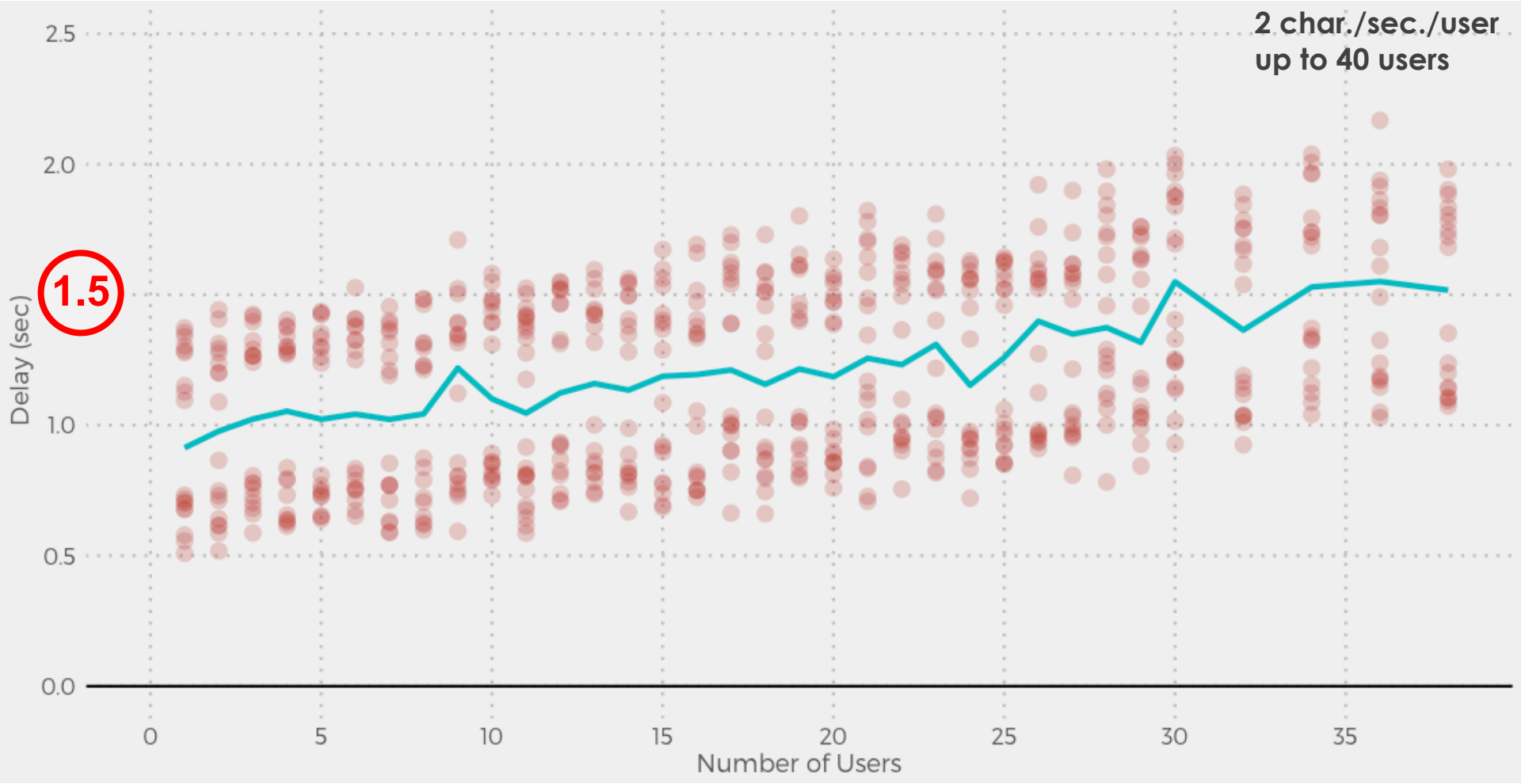
1,1,[0,5]	concur
1,1,5,2,1,[0,0]	**r**
1,1, [6,16]	ency contrl

Insert o between "ency contr" and "l"

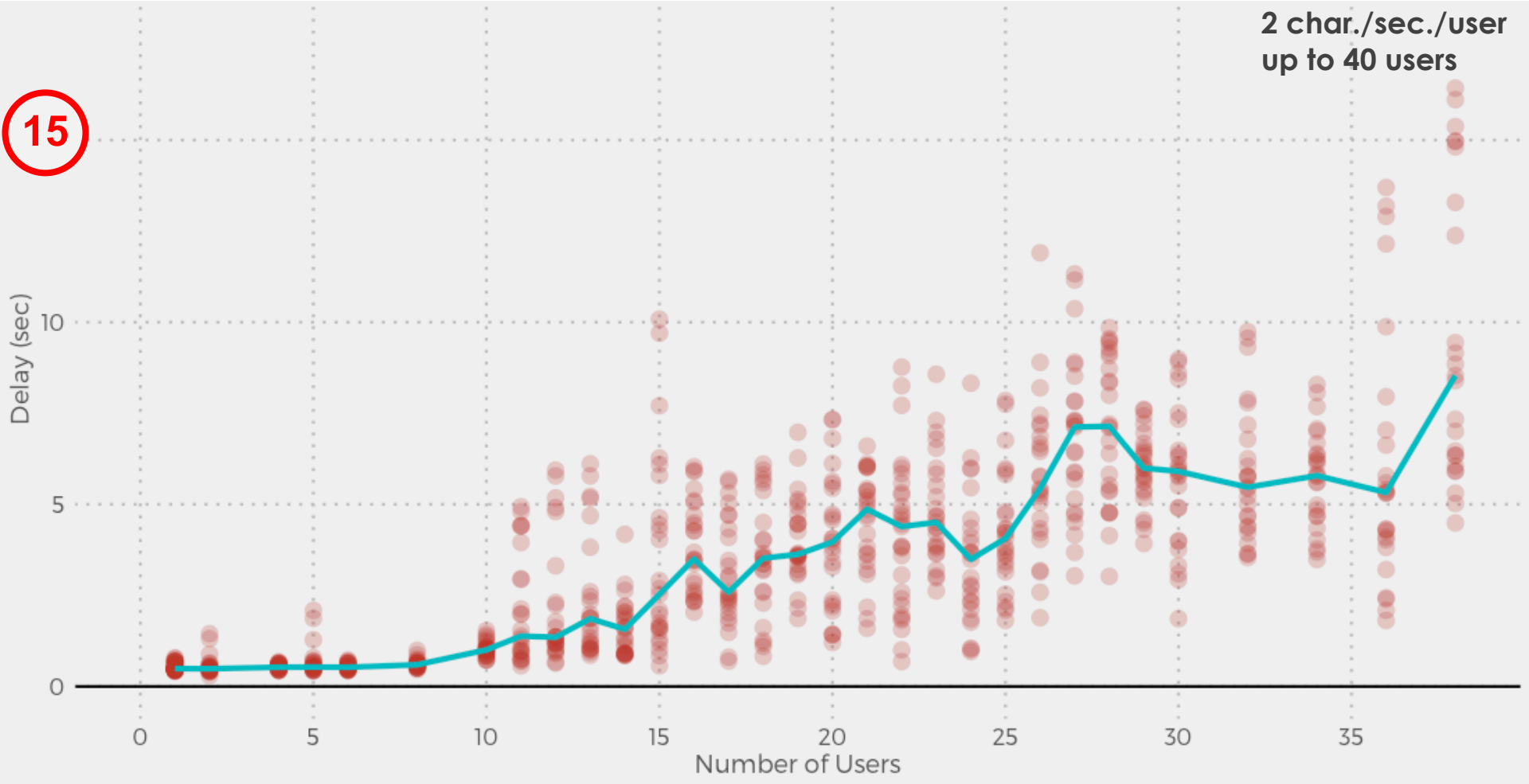
1,1,[0,5]	concur
1,1,5,2,1,[0,0]	**r**
1,1, [6,15]	ency contr
1,1,15,3,1,[0,0]	**o**
1,1,[16,16]	l

Delays in MUTE [NEOIC17]

https://coedit.re/



Delays in GoogleDocs [DI16a]

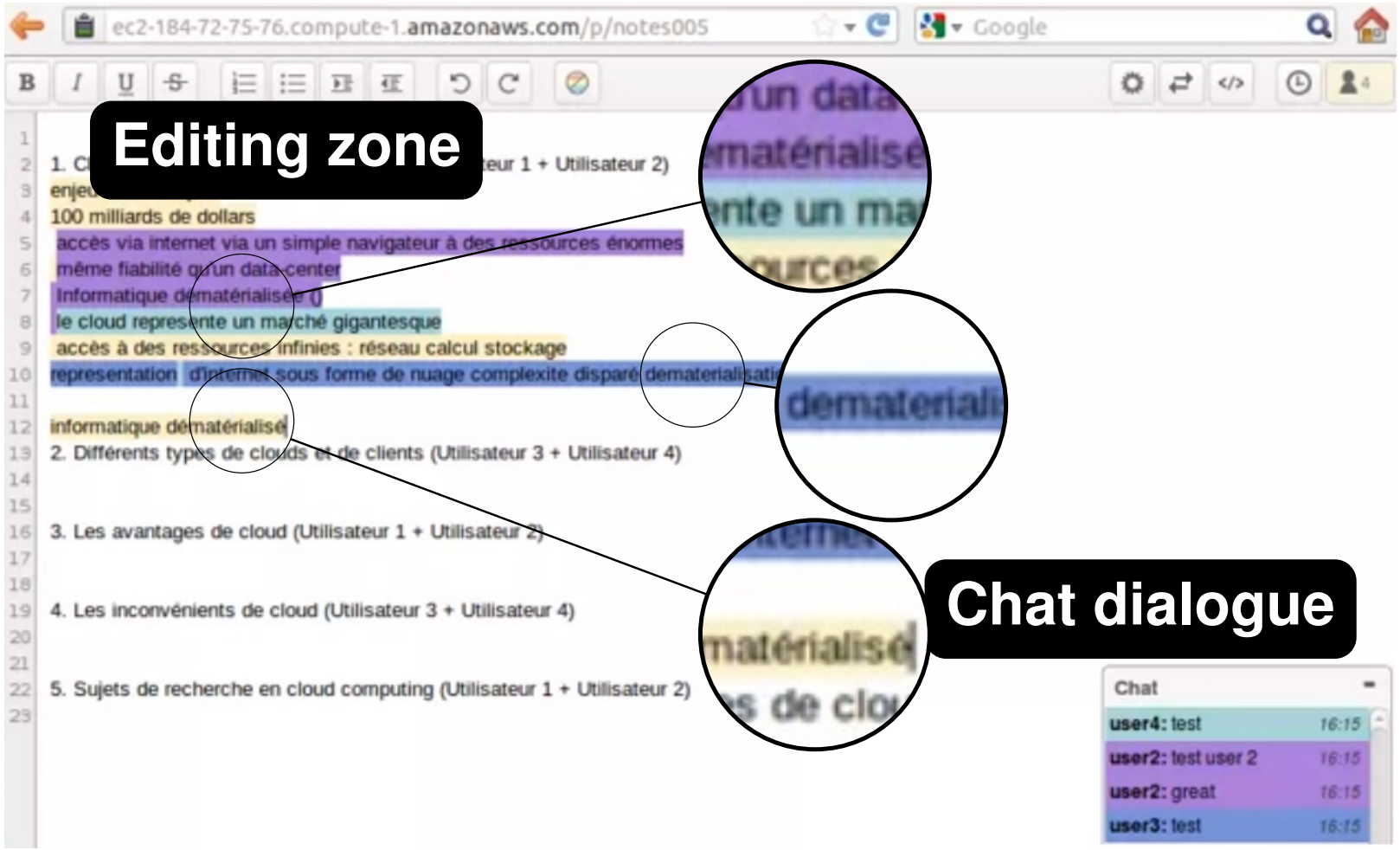


Experimental design: The effect of delay on users

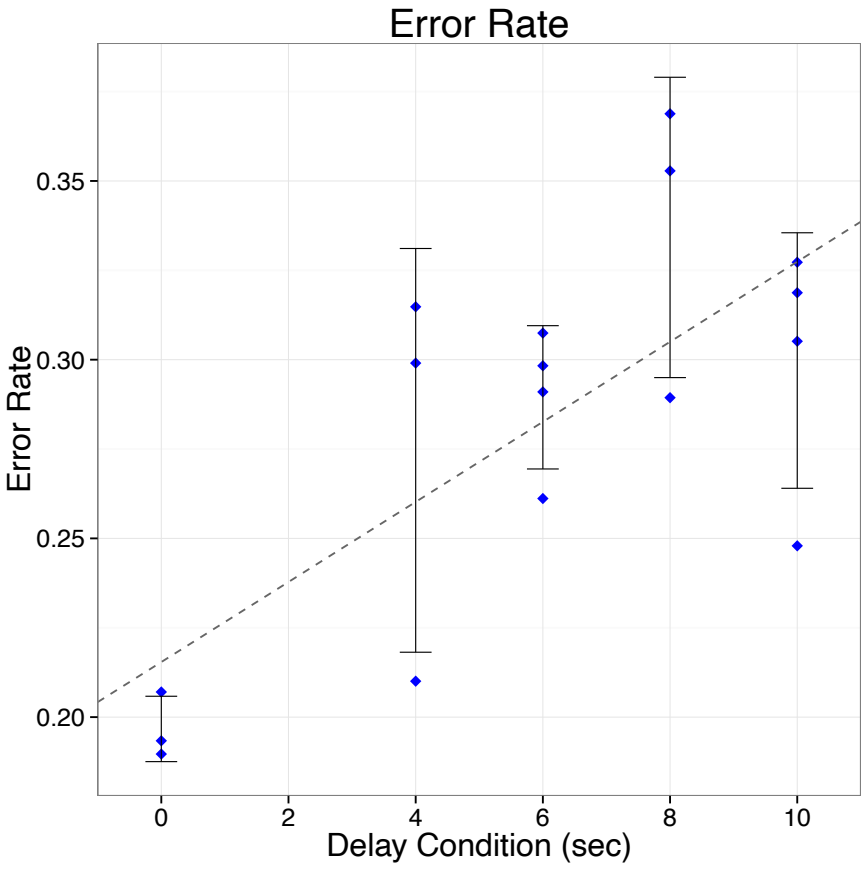
- 20 groups of 4 students
  - Perform several collaborative editing tasks
    - A proofreading task
    - A sorting task
    - **A note taking task**
  - Use the provided collaborative editor (Etherpad) + chat
  - Each group experienced a **certain delay** (0, 4, 6, 8, 10 s)

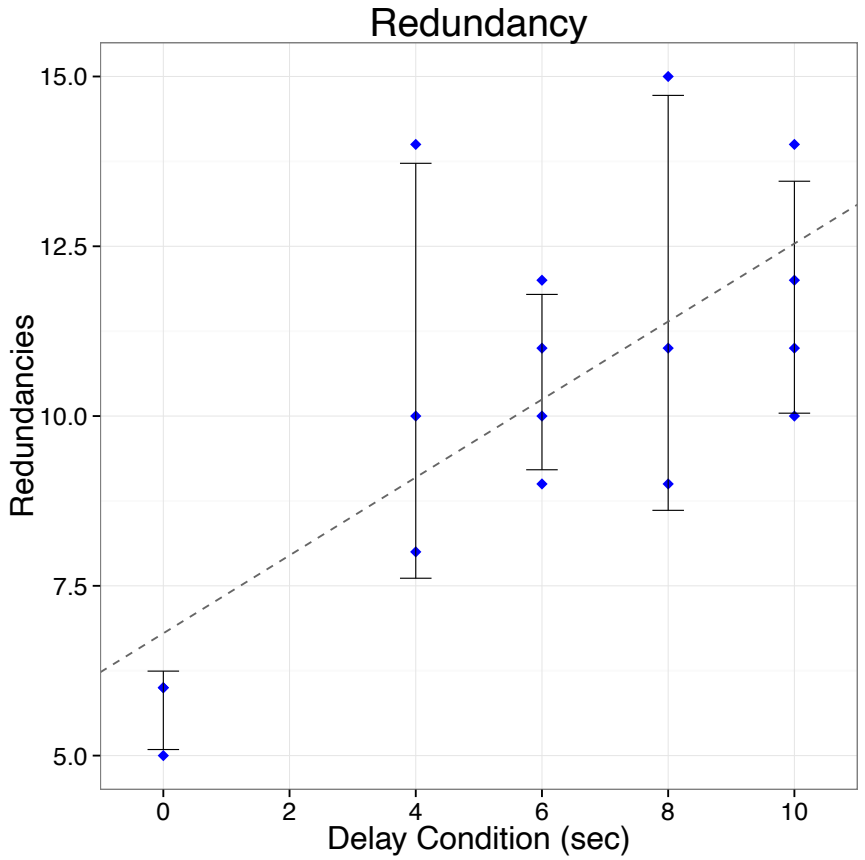
- Collaboration with Department of Psychology Wright State University, Inria USCoast associate team

Note-taking [IOFSC15]



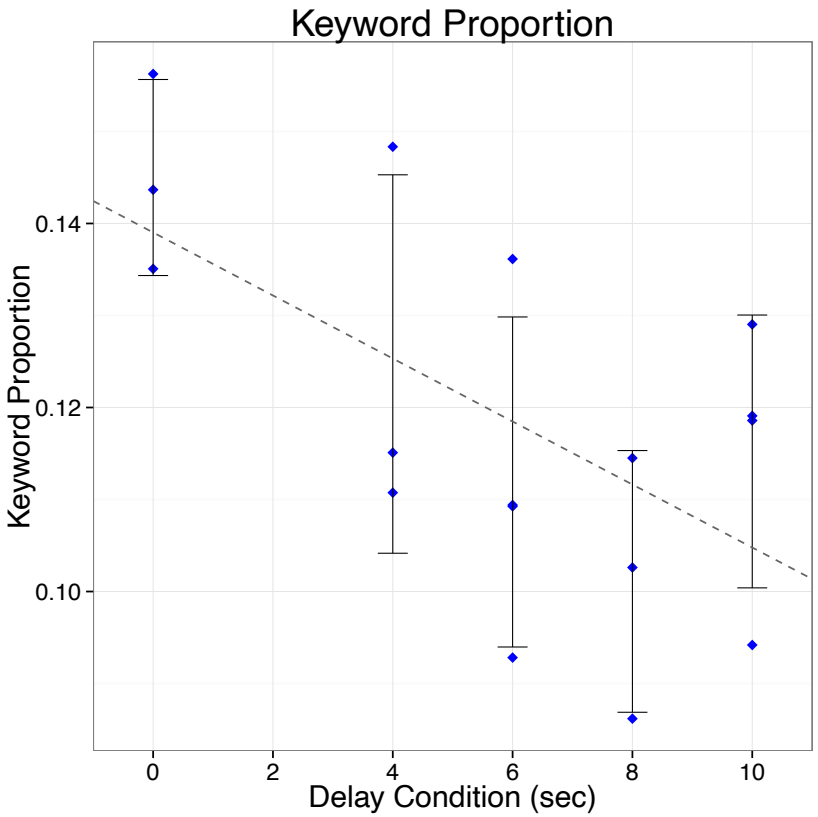
Delay reduces Group Performance





- 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

Collaborative Data Management - summary

- Contributions ranging from OT and CRDT **algorithms design** to their **evaluation** (theoretical/simulations/real collaboration traces) and study of their **impacts on users**

- Contributions ranging from the **study of conflicts** in real collaboration traces to **design** and **prototype** of **awareness** mechanisms

Research Axes

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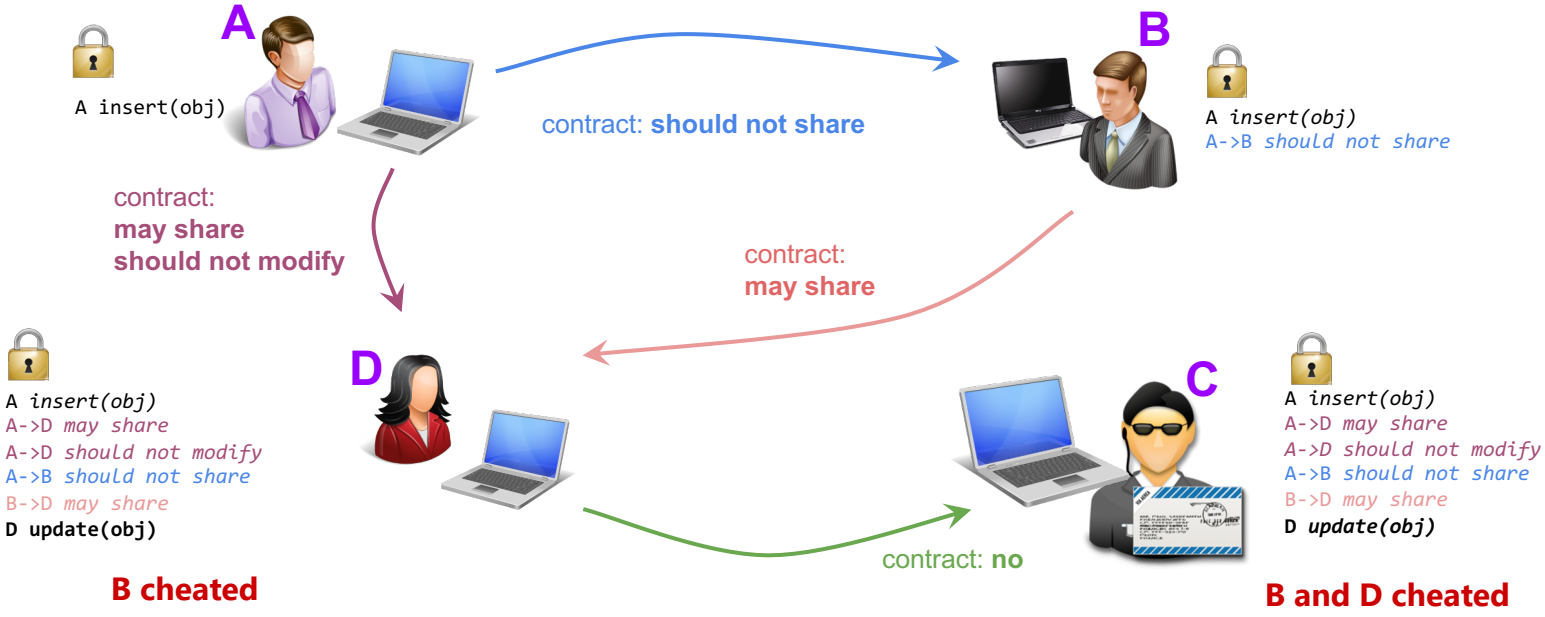
2. Trustworthy Collaboration
   - Evaluate collaborators trust based on their past behavior
   - Evaluation: game theory and user studies

Trustworthy collaboration

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

Trust computation – my contributions

- Respect/Violation of contracts
  - Collaborative editing contracts(share/edit)[TIM12b,TIBM11]



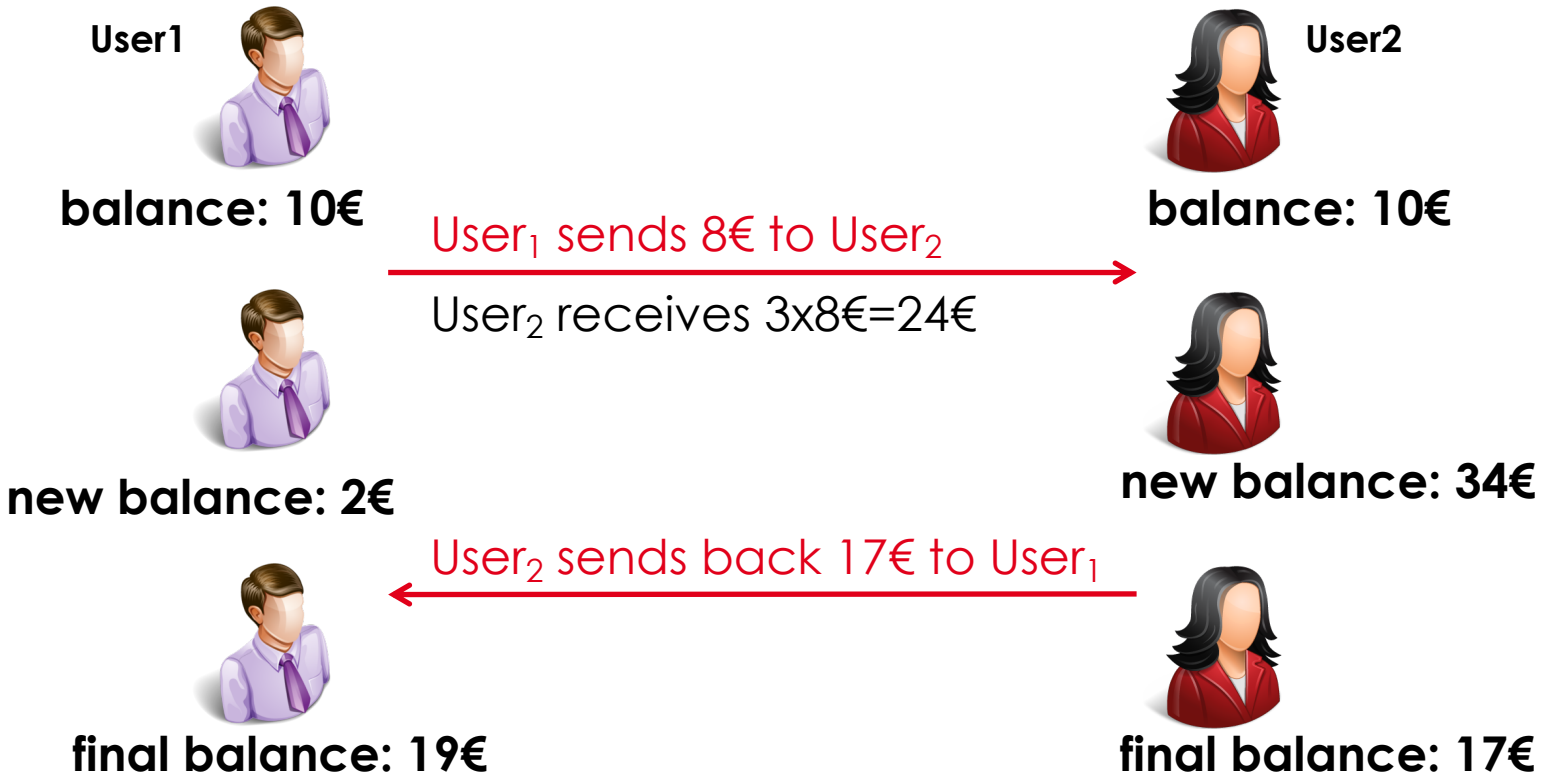
  - Log auditing [TI11,TIM12]
  - Hash-chain based authenticators for log tampering[TIM12a]

Trust computation – my contributions

- Quality assessment of Wikipedia articles
  - Manual feature engineering: extension of ORES (random forest + 11 article features) with readability scores [DI16d]
  - Deep-learning mechanisms: Doc2Vec + DNN [DI16c], RNN-LSTM [DI17]
- Predict trust relations between users that did not interact in the past [DI18]
- Experimental design for testing the proposed trust-based collaboration [IDS19]

Validation of trust-based collaboration

- Using game theory (trust game) [BDM95]



- Collaboration with Department of Psychology Wright State University, Inria USCoast associate team

Trust metric based on user behavior [DI16b]

- For a round:

$$current\_trust_t = \log(send\_proportion_t * (e-1)+1)$$

$$send\_proportion_t = \frac{sending\_amount_t}{\max\_sending\_amount}$$

- For an accumulated number of rounds

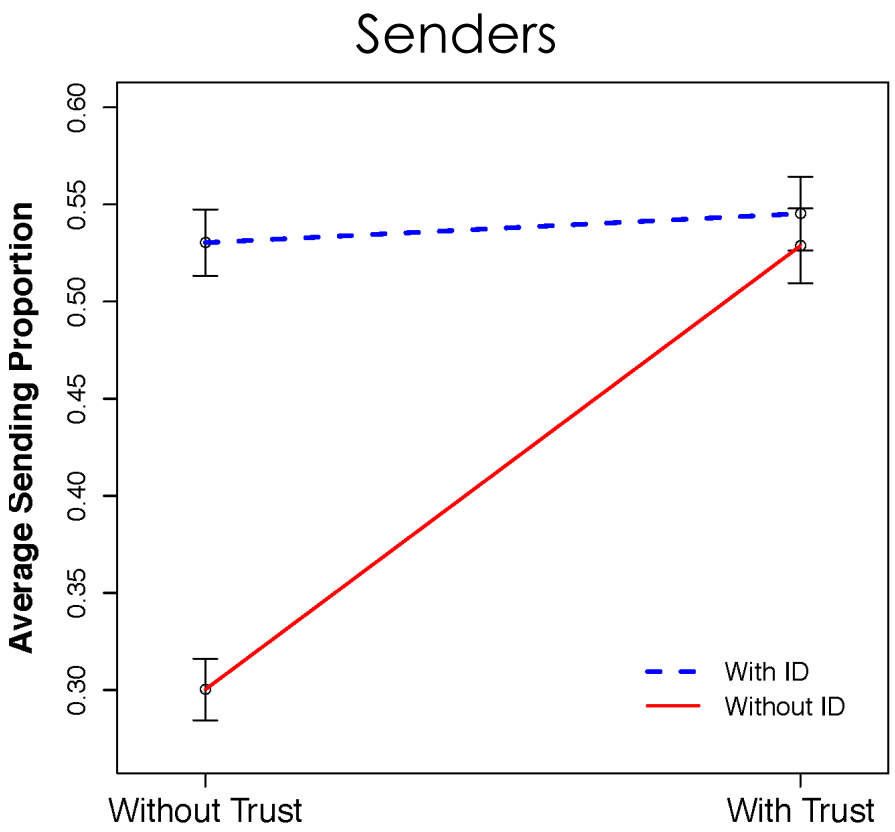
$$aggregate\_trust_t = \alpha_t * current\_trust_t + (1-\alpha_t) * aggregate\_trust_{t-1}$$

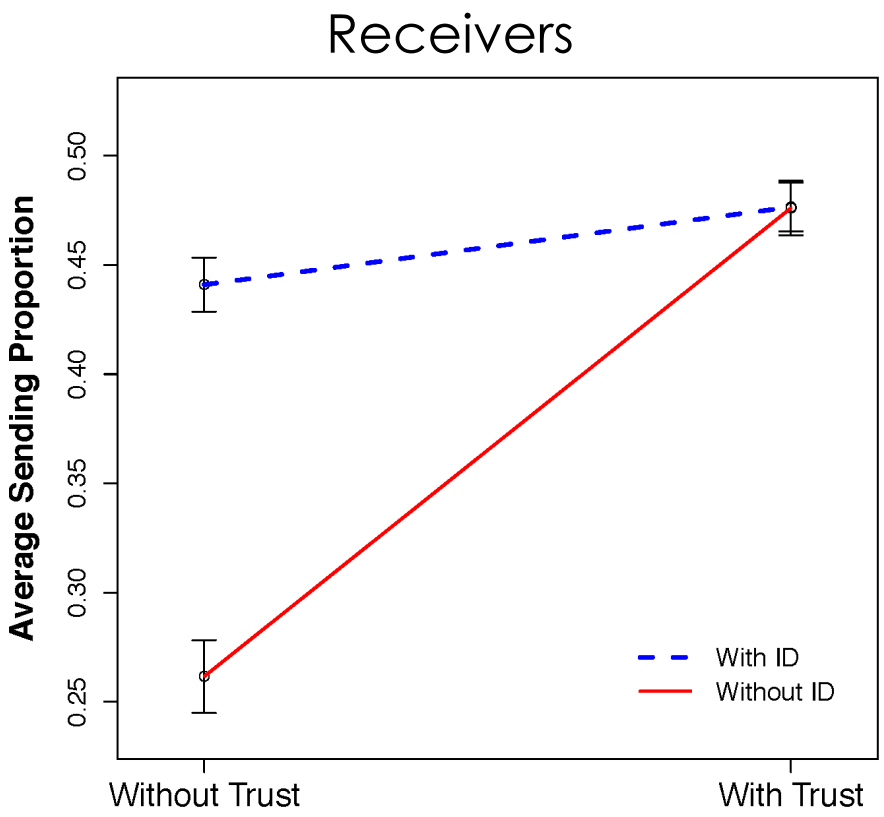
- The trust metric deals with fluctuating user behavior

Experiment design [IDS19]

- 5 sessions with 6 participants each
  - Play 4 trust games
    - Simple Game
    - Identity Game
    - Score Game
    - Combine Game
  - Use z-tree for trust games implementation
  - Each participant received a 10 euro gift card
  - Participant with highest gain received an extra card

Effect of trust and identity





- Showing either trust score or nickname improves the measure
- Showing both of them does not change the measure relative to one of them

Validation of trust-based collaboration - findings

- Trust score or ID availability could significantly improve the level of cooperation between users
- Trust-based systems could be a replacement of identity-based systems especially in the context of large scale collaboration

Trustworthy collaboration - summary

- Contributions towards an **optimistic trust-based security** for large scale peer-to-peer collaboration
  - Modeling of **contract-based collaboration**
  - **Computation** of **users trust** based on their past behavior and **prediction** of their future behavior
  - **Evaluation** using **game theory** and **user studies**

Future directions – Secure and trustworthy distributed collaborative systems

- Security for distributed collaboration without central authority
- Users trust evaluation based on past contributions
- Replication mechanisms for complex data

Security for distributed collaboration without central authority

- Access control without central authority
- End-to-end encryption with group key management

Users trust evaluation based on past contributions

- In Wikipedia
  - Use the proposed trust metric: User contributions throughout article revisions are similar to user interactions in the trust game
  - Need of quality metrics: how long an edit of a user persists

- BPI Deeptech project with Fair&Smart (2020-2023)
  - Computing trust among clients and enterprises for a personal data management platform that respects GDPR

Replication mechanisms for complex data

- Composition of state-based CRDT, operation-based CRDT and operational transformation
- CRDT for relational database [YI20]
- Maintaining global invariants for CRDT such as integrity constraints (uniqueness, reference integrity, numeric constraints) for relational databases

Large-scale trustworthy distributed collaborative systems

- New uses and new practices due to large scale adoption
- New challenges
  - Consistency of complex replicated data in large scale collaboration
  - Large scale group awareness
  - Large scale group user studies
  - Trust and Security without a central authority

List of co-authors

Luc André
Mehdi Ahmed-Nacer
Lamia Benmouffok
Mohamed-Rafik Bouguelia
Jean-Michel Busca
Michèle Cart
François Charoy
Quang-Vinh Dang
Victorien Elvinger
Jean-Philippe Eisenbarth
Jean Ferrié
Olivia Fox
Rachid Guerraoui
Anne-Marie Kermarrec
Stéphane Martin
Pascal Molli
Meagan Newman
Matthieu Nicolas
Moira Norrie
Hoang-Long Nguyen
Hoai-Le Nguyen
Gérald Oster
Stavroula Papadopoulou
Olivier Perrin
Charbel Rahhal
Hyun-Gul Roh
Valerie Shalin
Marc Shapiro
Hala Skaf-Molli
Pierre Sutra
Hien Thi Thu Truong
Pascal Urso
Weihai Yu

Thank You

ANY QUESTIONS?

Claudia Ignat

Habilitation defense
April 23, 2021
claudia.ignat@inria.fr

References

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