Large-scale trustworthy distributed collaborative systems

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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

Hien Thi Thu Truong
2009

Quang-Vinh Dang
2013

Hoang Long Nguyen
2015

Hoai-Le Nguyen
2017

Pierre-Antoine Rault
2019

Alexandre Bourbeillon
2021
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
Limitations of Central Authority Systems
Peer-to-Peer Collaborative Systems
Collaboration Modes – Concurrent Changes
Collaboration Modes – Offline Work

conflicts
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]

- Transforms non commuting operations to make them commute
- Genericity
- Time complexity
  Average: $O(H \cdot c)$
  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**

$T(\text{ins}(p_1,c_1), \text{ins}(p_2,c_2))$:
if $(p_1 < p_2)$ return $\text{ins}(p_1,c_1)$
else return $\text{ins}(p_1+1,c_1)$
endif
• 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:
    • $\forall \text{id}_x, \text{id}_y: \text{id}_x < \text{id}_y \Rightarrow \exists \text{id}_z: \text{id}_x < \text{id}_z < \text{id}_y$

• Different approaches for generating identifiers
Conflict-free Replicated Data Types (CRDT)

Logoot [WUM09]

- Logoot identifiers: \(<p_1,s_1,h_1>,<p_2,s_2,h_2>, \ldots, <p_k,s_k,h_k>\)
  
  \(p_i\) position

  \(s_i\) site identifier

  \(h_i\) logical clock at site \(s_i\)

- 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

- Base
- Interval

| p₁ | … | pₙ | site_id | clock | begin | end |

1,1,[0,16] concurrency 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/

2 char./sec./user up to 40 users
Delays in GoogleDocs [DI16a]

2 char./sec./user up to 40 users

Number of Users

Delay (sec.)

0 5 10 15 20 25 30 35

0 5 10 15 20 25 30 35 40 45 50
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]

The participants ranged in age from 21 – 27. All participants used French in their daily activities. An electronic announcement solicited participation. One of the researchers organized interested participants into sets of 4 and scheduled the session. All participants received a 10 Euro gift certificate for their participation.

2.2 Apparatus

The experiment was conducted using four GNU/Linux desktop computers in a classroom setting. Participants were separated by partitions and could not directly observe other team members while they worked, although typing activity was audible. The server running the Etherpad application was hosted on an Amazon Elastic Compute Cloud (EC2) instance located in the US East (Northern Virginia) Region. Each desktop ran the Mozilla Firefox web browser executing the Etherpad web client application. Etherpad hosted the task stimuli and a Chat dialogue facility (see Figure 2). User operations appeared color-coded in both the text and chat. Etherpad relies on a client-server architecture where each client/user edits a copy of the shared document. When a user performed a modification it was immediately displayed on the local copy of the document and then sent to the server. The server merged the change received from the user with other user changes and then transmitted the updates to the other users. When a user edited a sequence of characters, the first change on the character was immediately sent to the server, while the other changes were sent at once only upon reception of an acknowledgement from the server. With each change sent to the server, it created a new version of the document. Gstreamer software enabled the video recording of user activity. We also instrumented Etherpad to register all user keyboard inputs on the client side and to introduce delays on the server-side. The editor window displayed 50 lines of text. Users editing above the field of view of a collaborator could cause the lines within the collaborator's view to “jump” inexplicably. Such a property is consistent with...
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
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.
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Trustworthy collaboration

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

Should I Trust You?
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:

\[
\text{current\_trust}_t = \log(\text{send\_proportion}_t * (e - 1) + 1)
\]

\[
\text{send\_proportion}_t = \frac{\text{sending\_amount}_t}{\text{max\_sending\_amount}}
\]

• For an accumulated number of rounds

\[
\text{aggregate\_trust}_t = \alpha_t \times \text{current\_trust}_t + (1 - \alpha_t) \times \text{aggregate\_trust}_{t-1}
\]

• 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
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Thank You

ANY QUESTIONS?

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References


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YEI19 A Generic Undo Support for State-Based CRDTs. Weihai Yu, Victorien Elvinger, Claudia-Lavinia Ignat. OPODIS 2019

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