Analyzing Multiparty Interaction using Conversation Types

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Motivation

- Software systems often rely on the collaboration between multiple parties to realize their tasks

  e.g., web-service applications

  How can we ensure protocol safety and progress in such a decentralized and dynamic setting?

- Sessions [Honda93,Honda et al.98] have been widely used to model typeful binary interaction

  How can we extend classical sessions so as to address dynamic multiparty interaction?

Sessions and Conversations

- Session type theory

  Systems modeled in the π-calculus

  Types describe the behavior of a single participant
  (≈ local types [HondaYoshidaCarbone07-08])

  progress analysis based on well-founded ordering of channels
  [Dezani et al.07]

- Conversation type theory (this talk)

  Systems modeled in the π-calculus extended with labels
  (to support distinguished interaction in a single medium)

  Types describe the behavior of a subset of participants
  (mixing global and local type specifications)

  progress analysis based on well-founded ordering of events
  and its propagation in communication

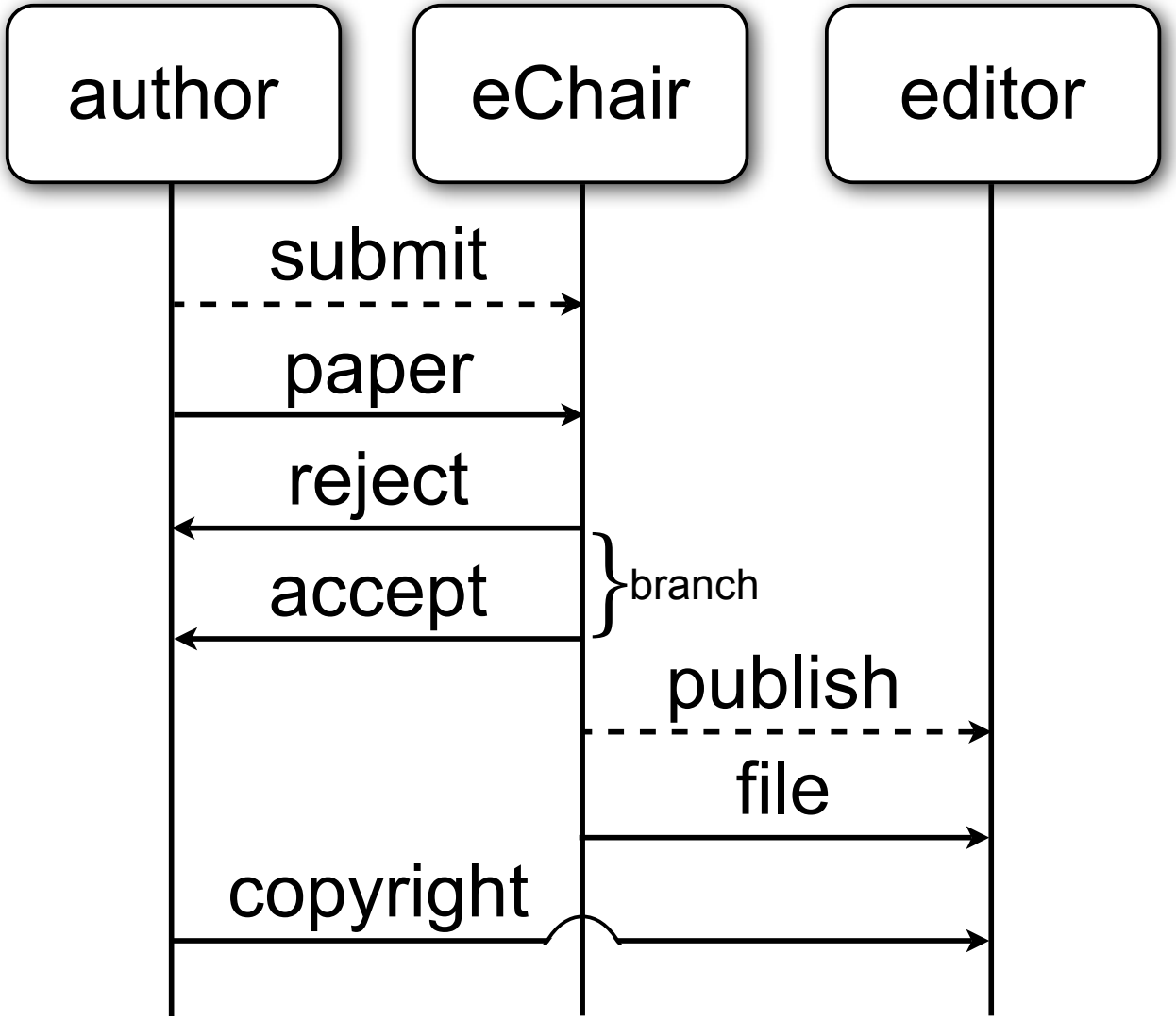
π−calculus + labels

π−calculus + labels

P :: =	$\mathbf{0}$	(Inaction)
	$\mid P \mid Q$	(Parallel Composition)
	$\mid (\boldsymbol{\nu} a)\, P$	(Name Restriction)
	$\mid$ **rec** $X.P$	(Recursion)
	$\mid X$	(Variable)
	$\mid \Sigma_{i \in I}\, \alpha_i.P_i$	(Prefix Guarded Choice)
α :: =	$n \bullet \text{label}?(x_1,\ldots,x_k)$	(Input)
	$\mid n \bullet \text{label}!(n_1,\ldots,n_k)$	(Output)

The eChair System

The eChair System



eChair System Code

```
(νchat)
(eChair • submit!(chat).
      chat • paper!(pdf).
      (chat • reject?()
       +
       chat • accept?(). chat • copyright!()))
|
*eChair • submit?(x).
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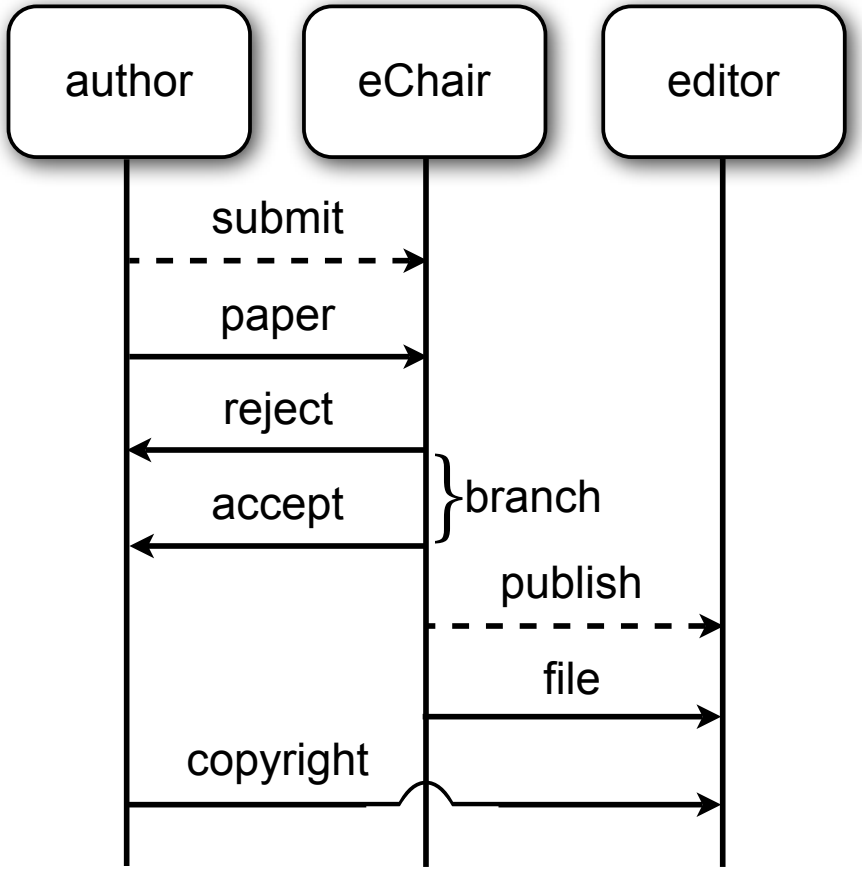

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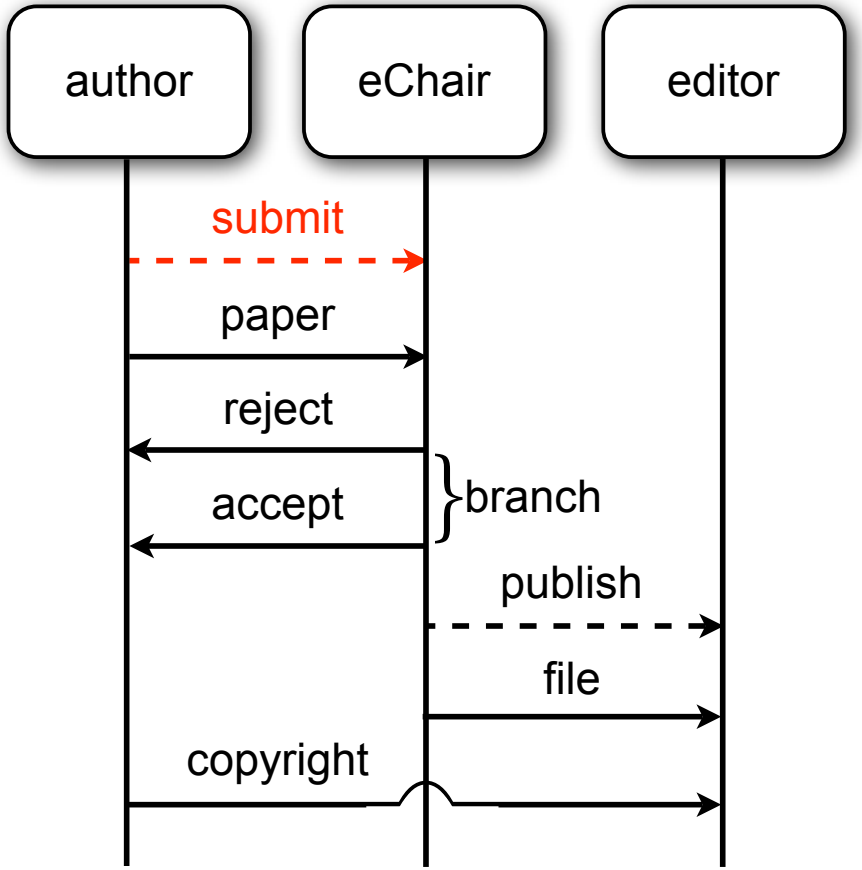

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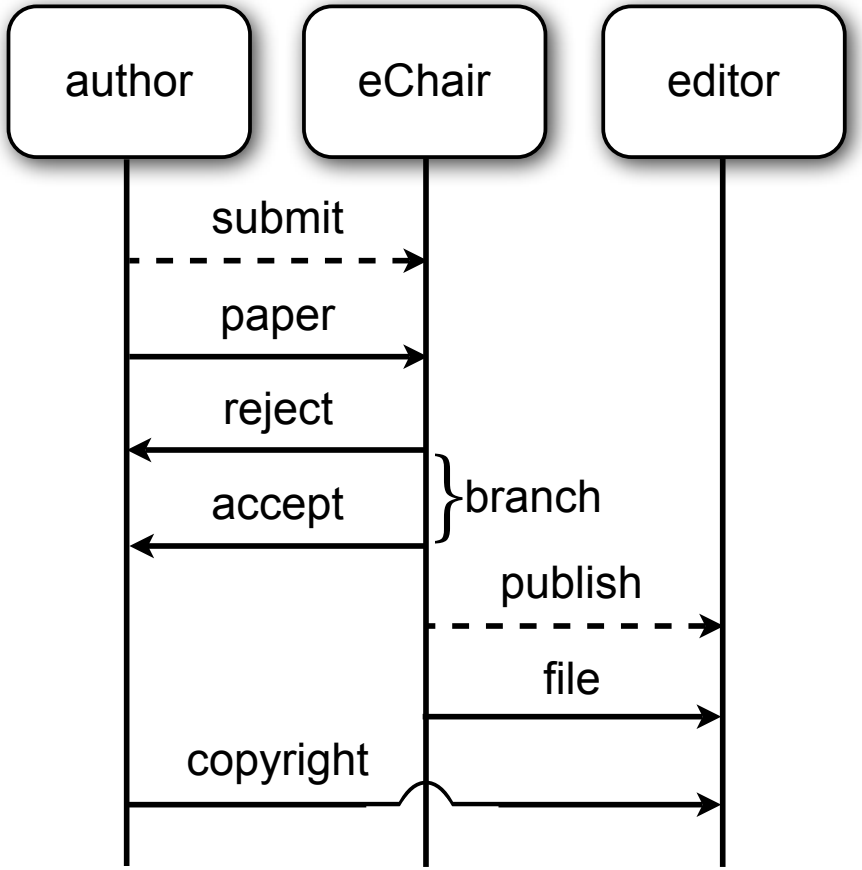

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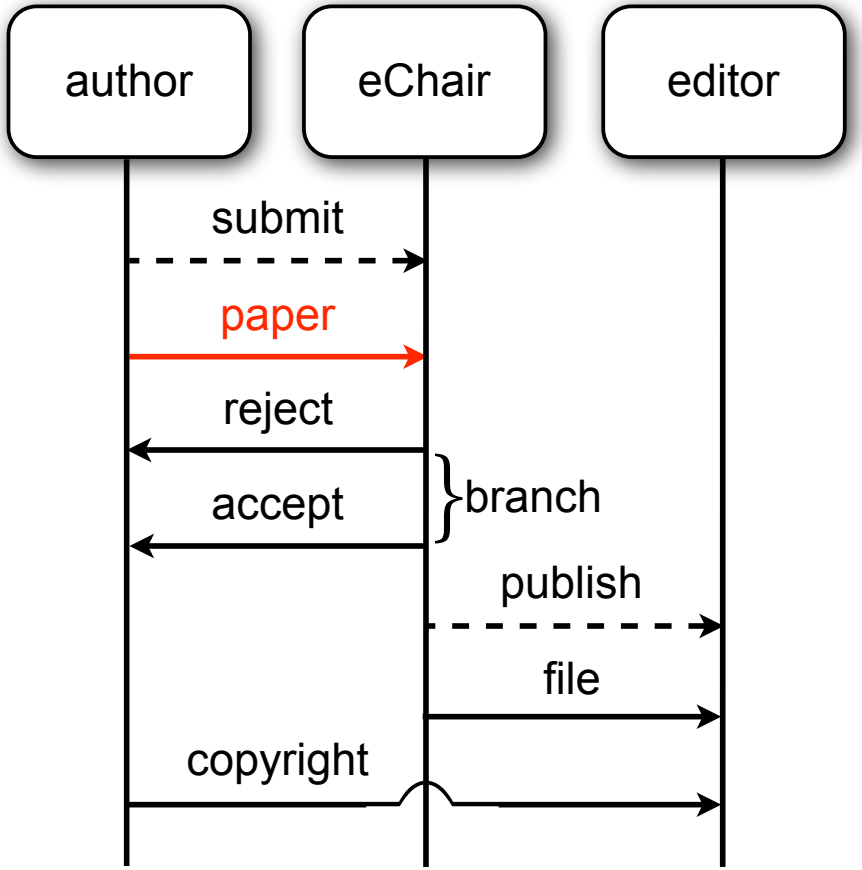

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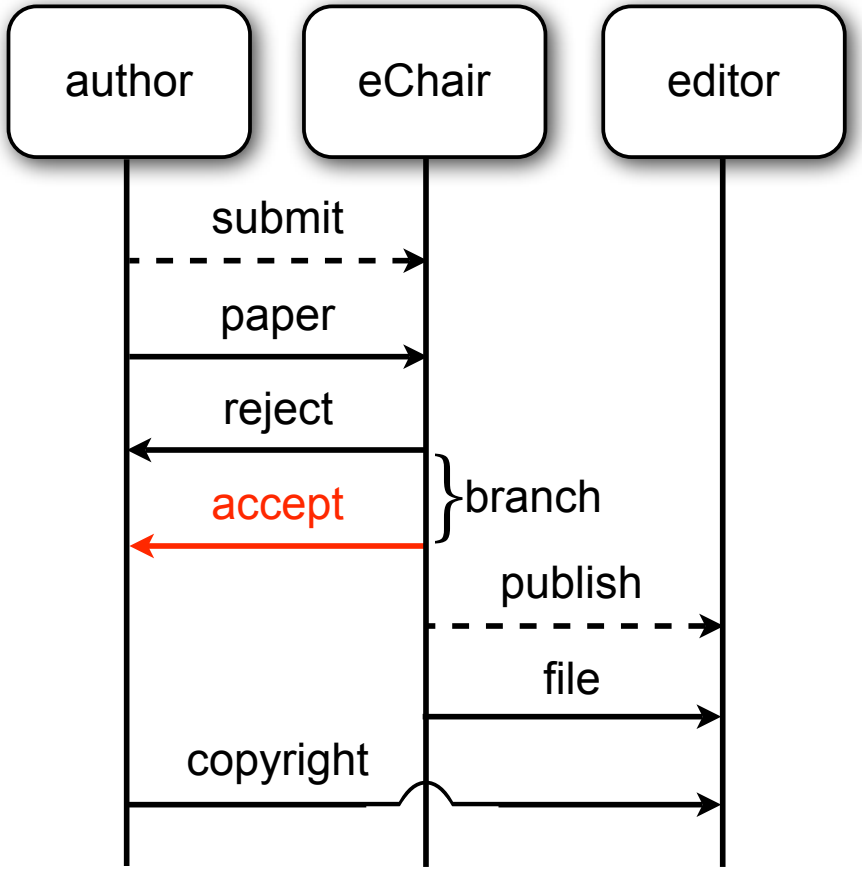

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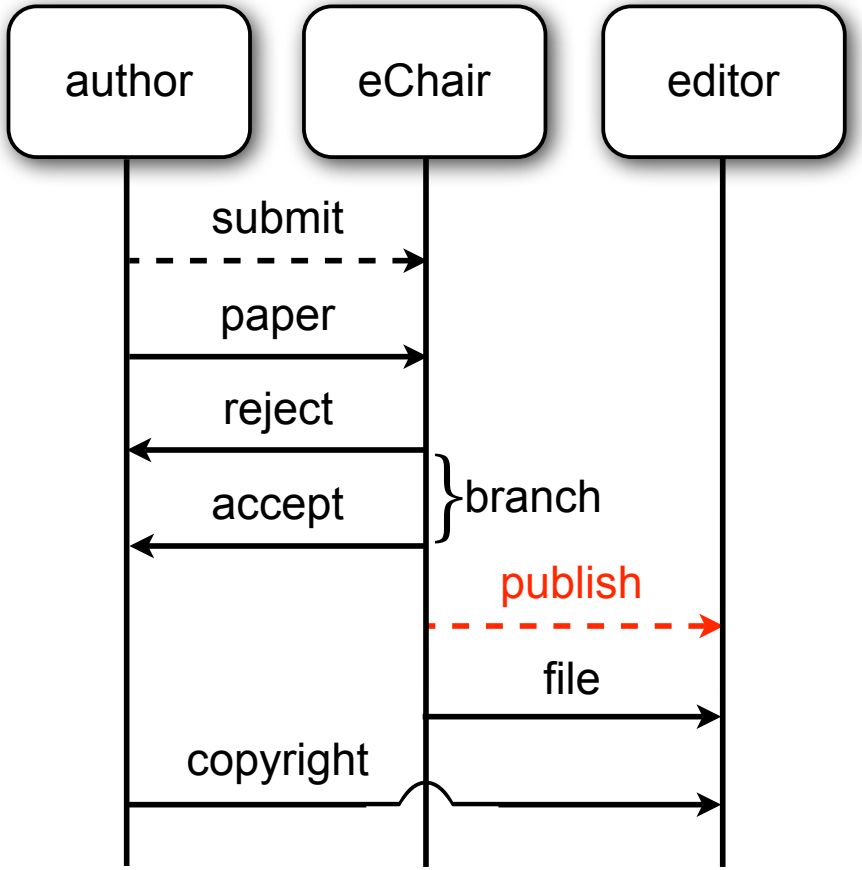

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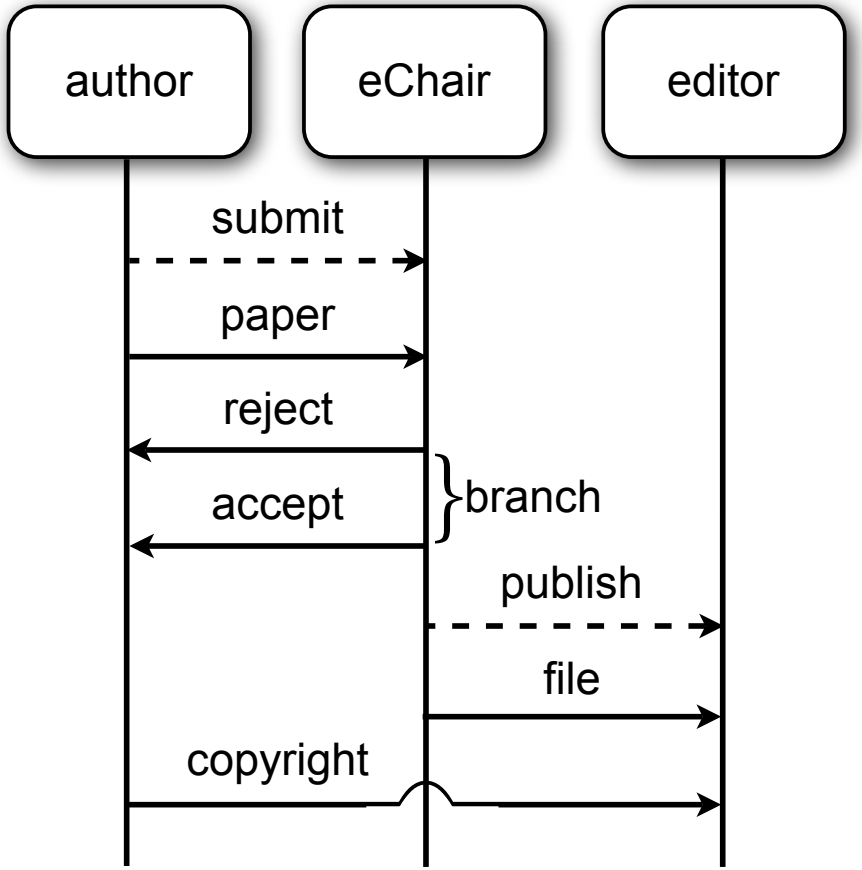

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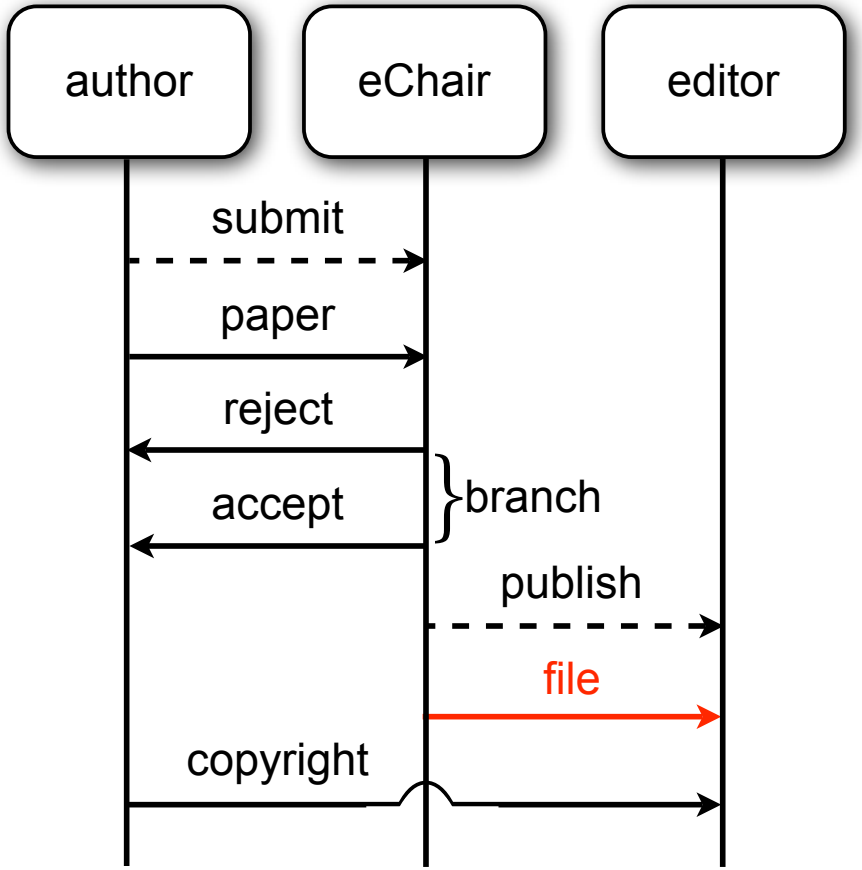

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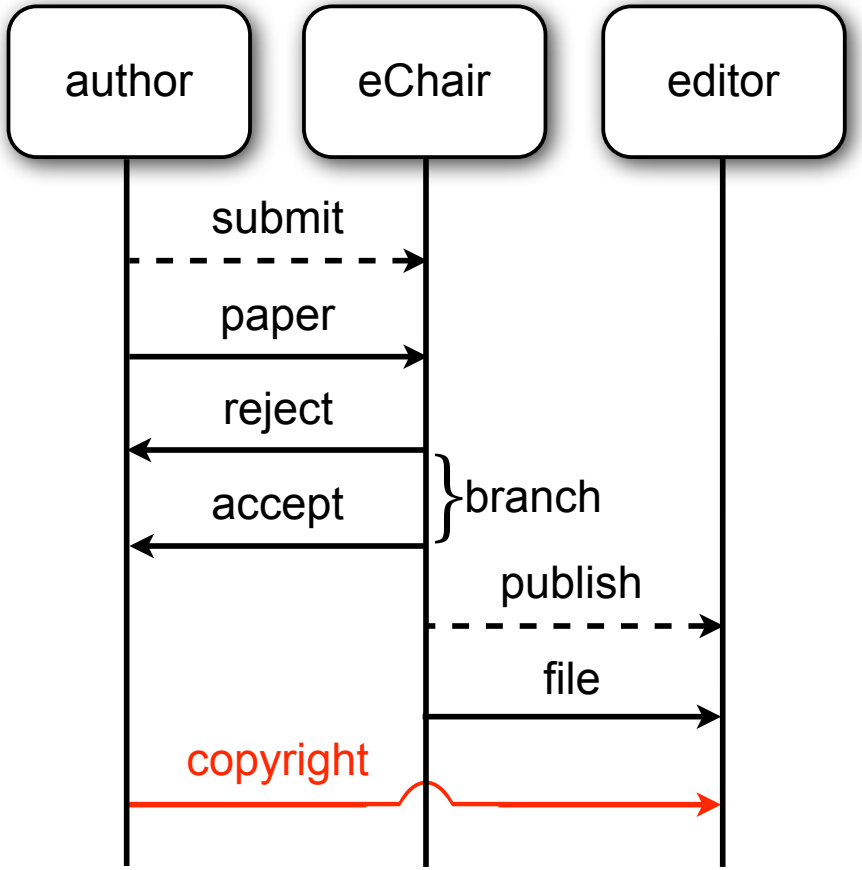

Conversation Types

Conversation Types

- Typing judgement

$$P :: n_1{:}B_1 \mid n_2{:}B_2 \mid \ldots \mid n_k{:}B_k$$

says P interacts in n_i accordingly to the B_i spec

- Behavioral types (B) extend session types:

$$B ::= B_1 \mid B_2 \mid \mathbf{0} \mid \text{rec } X.B \mid X \mid \&_{i \in I}\{M_i.B_i\} \mid \oplus_{i \in I}\{M_i.B_i\}$$

Message types (M) are labeled and describe both external and internal message exchanges

$$M ::= p\ label(B) \qquad p ::= ! \mid ? \mid \tau$$

Typing *chat* Conversation

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chat:

τ paper(T_{pdf}).
  $\oplus$ { τ reject();
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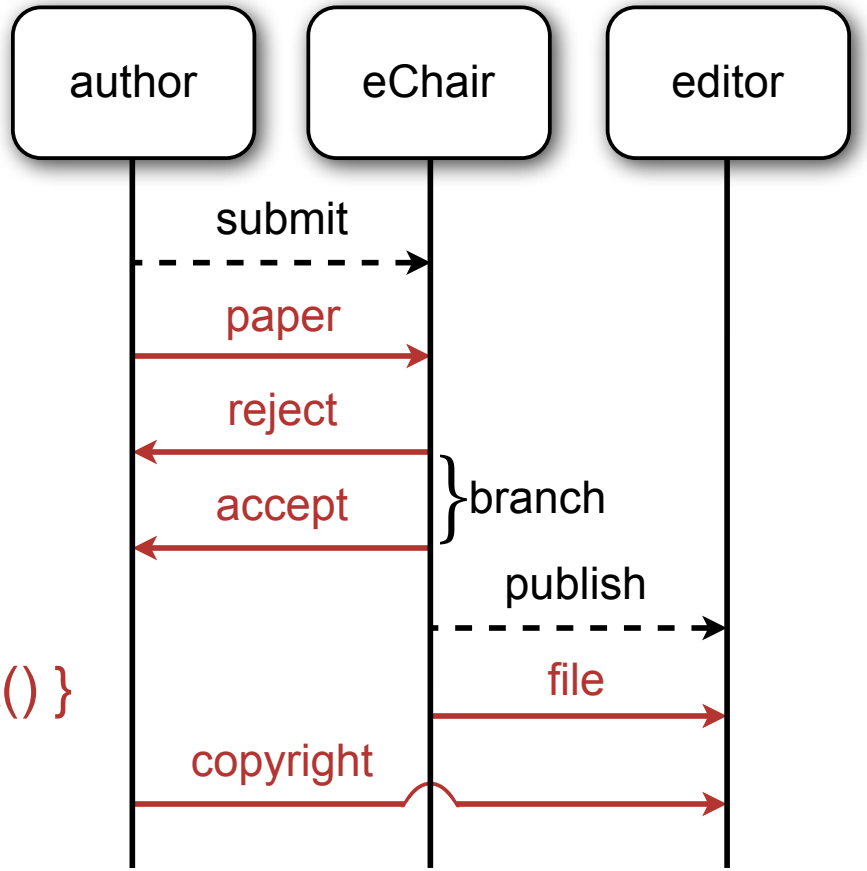

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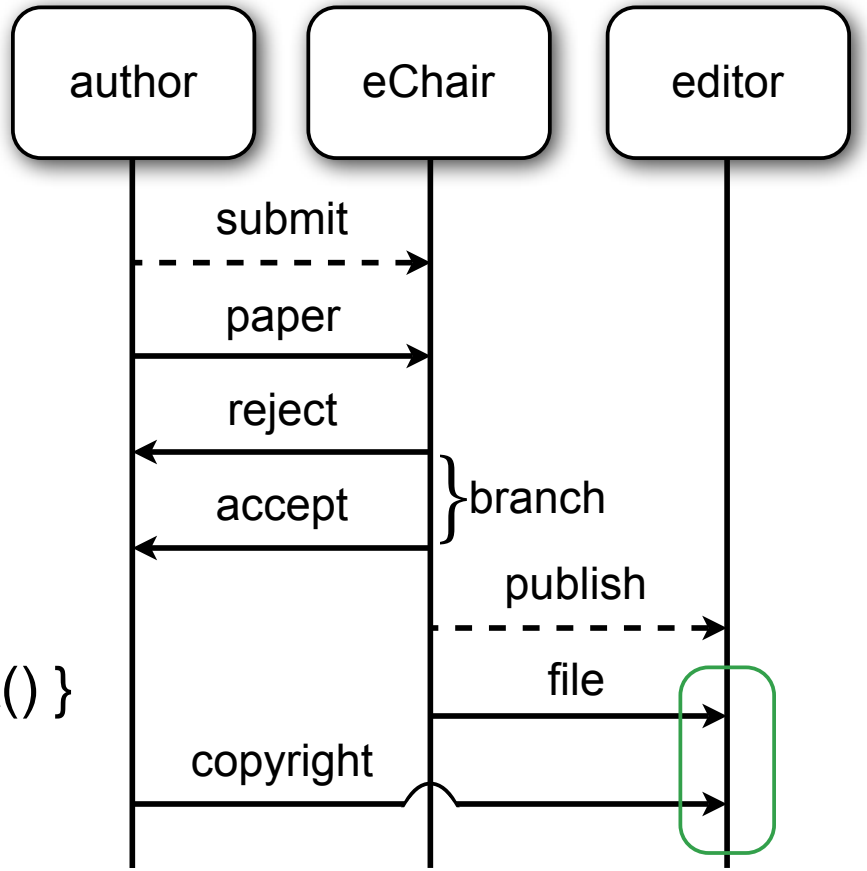

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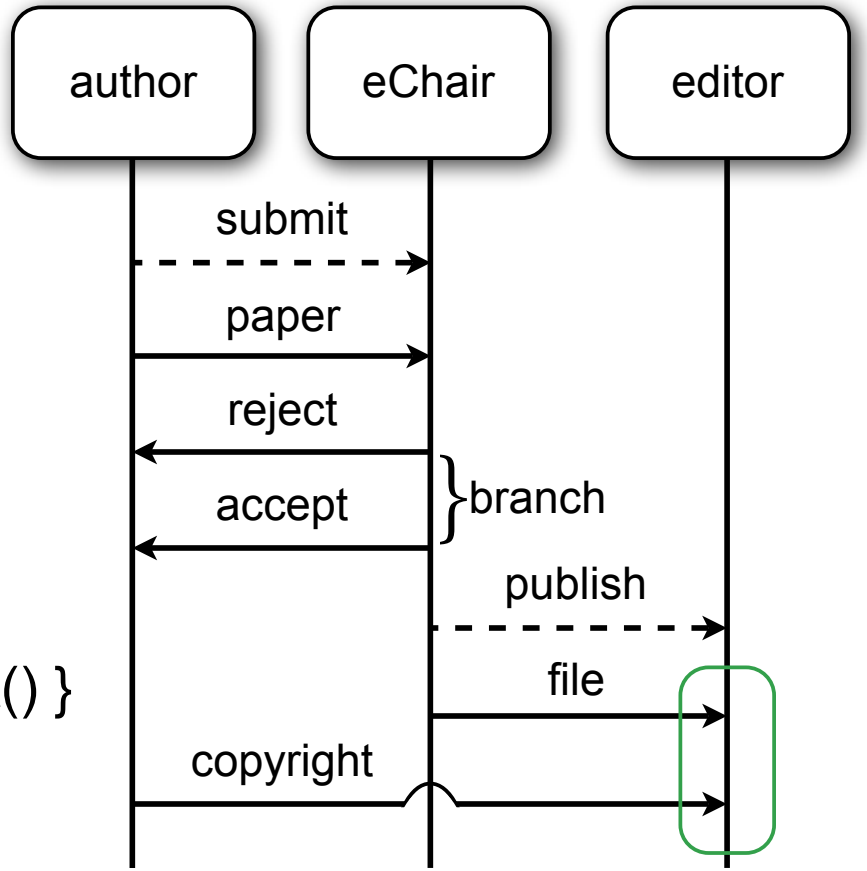

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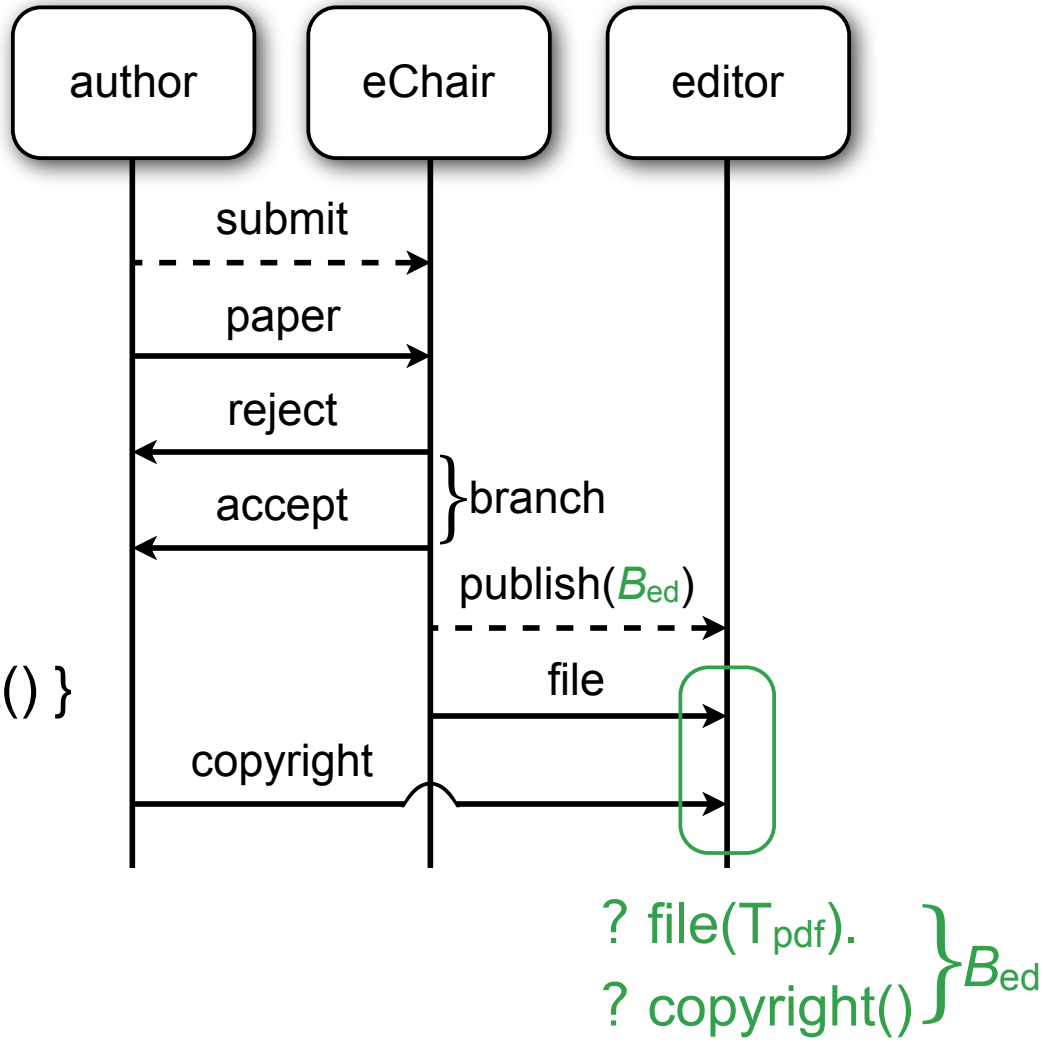

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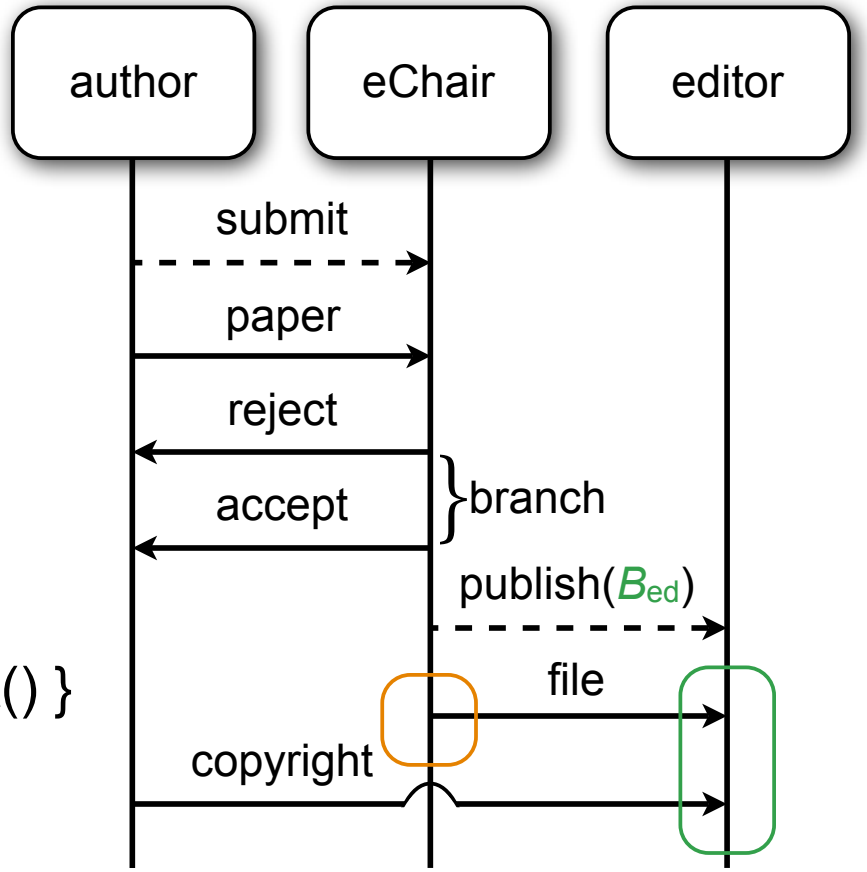

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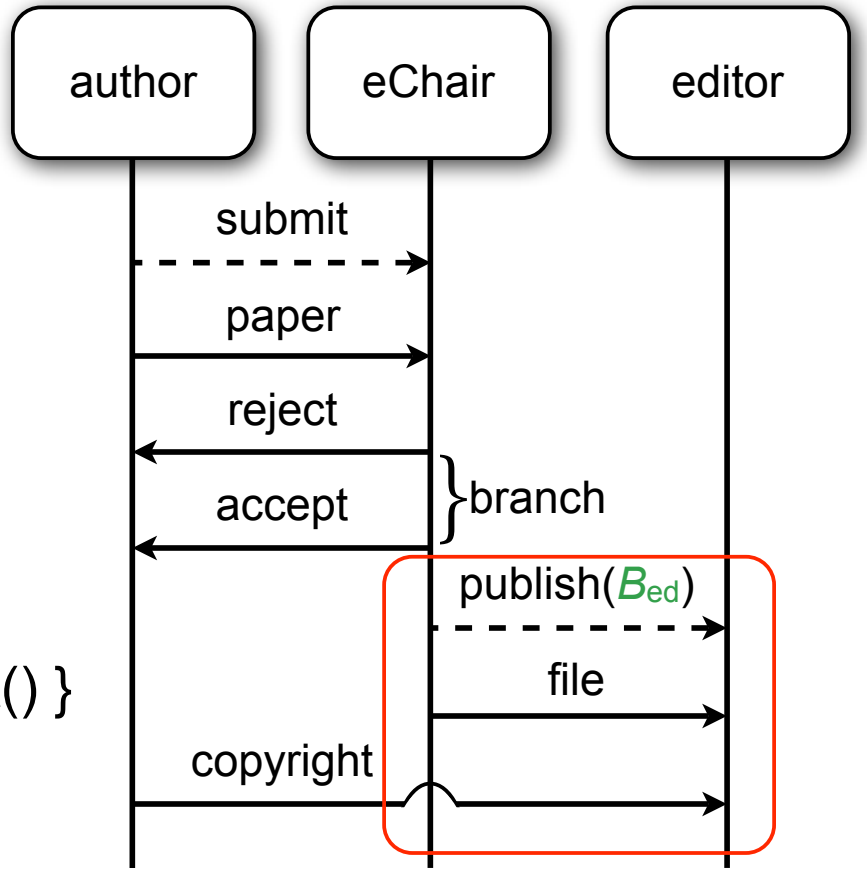

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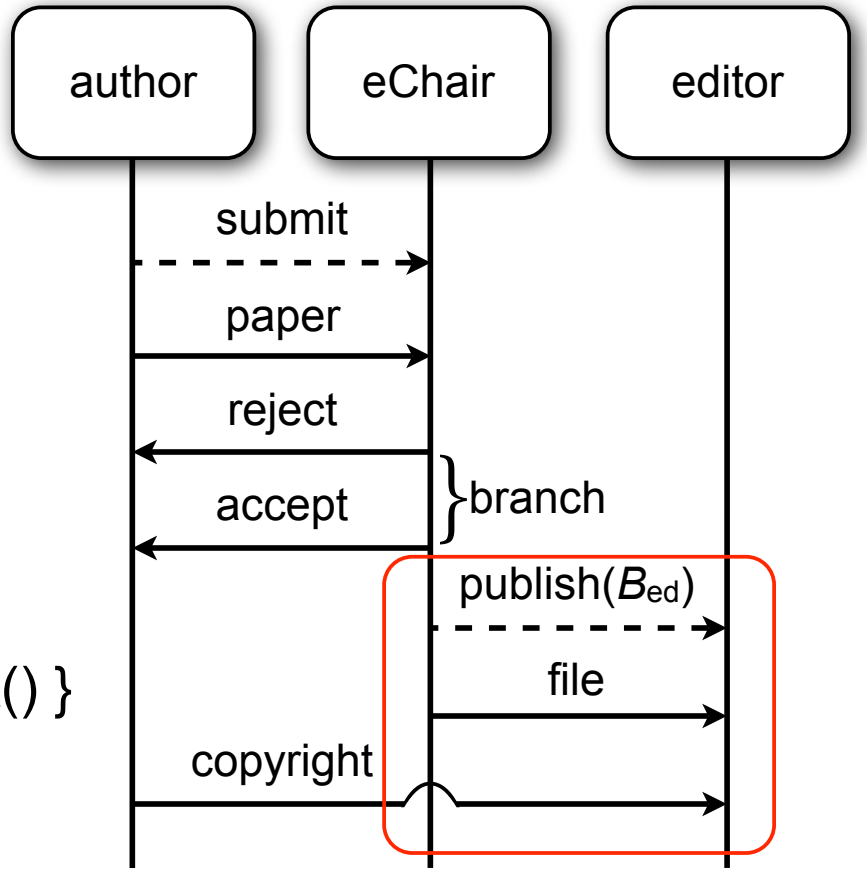

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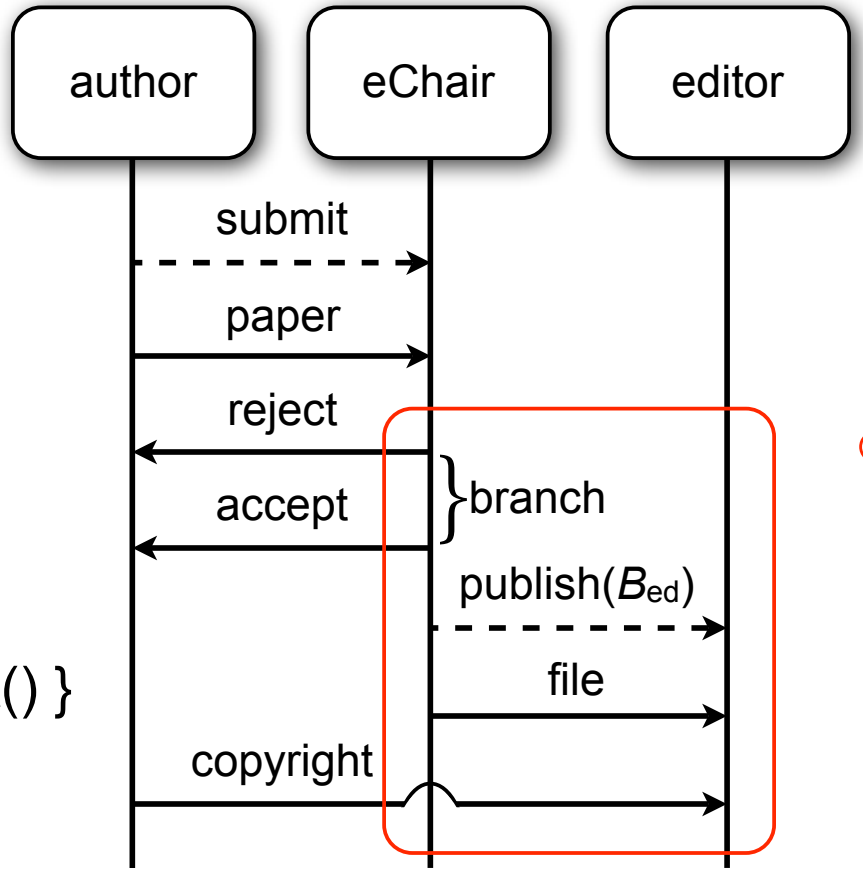

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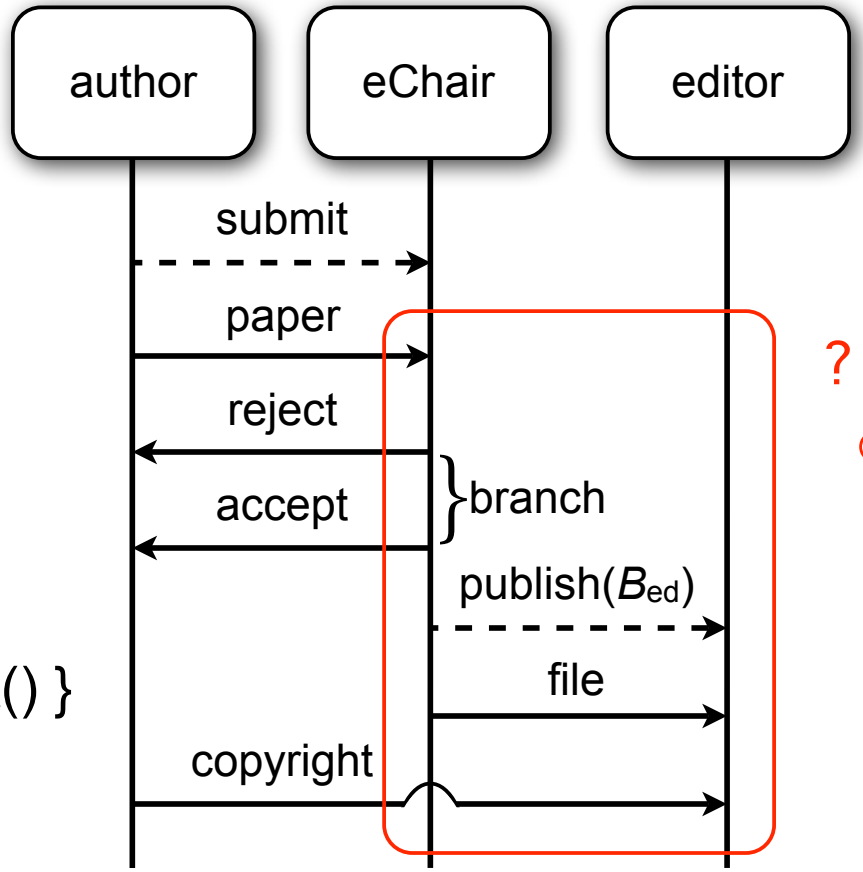

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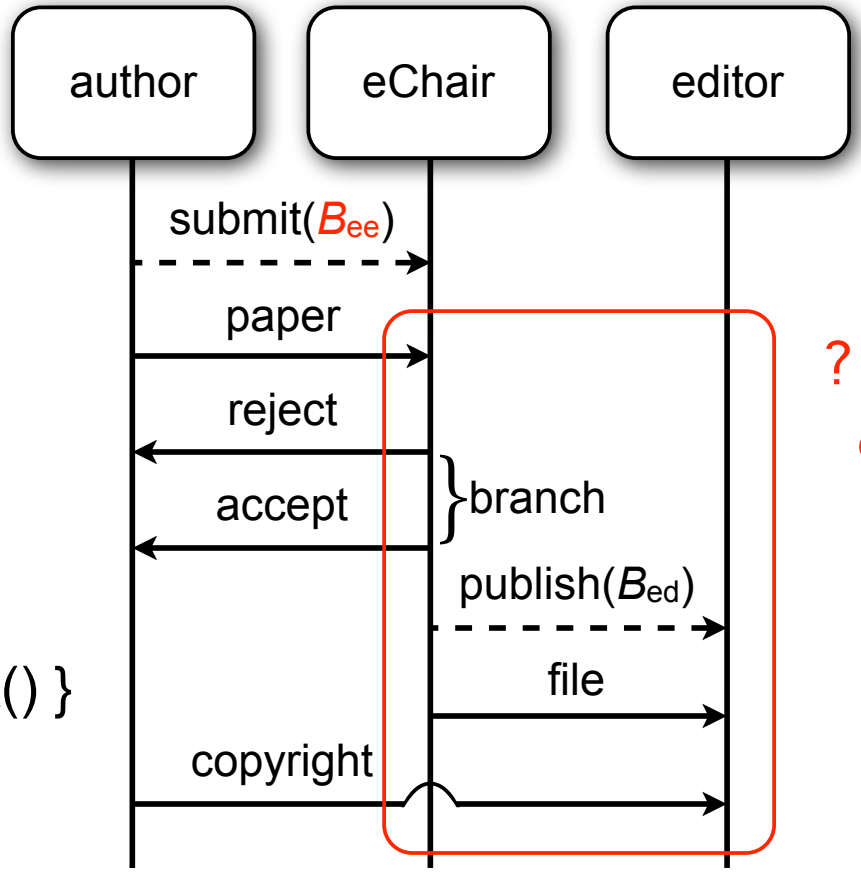

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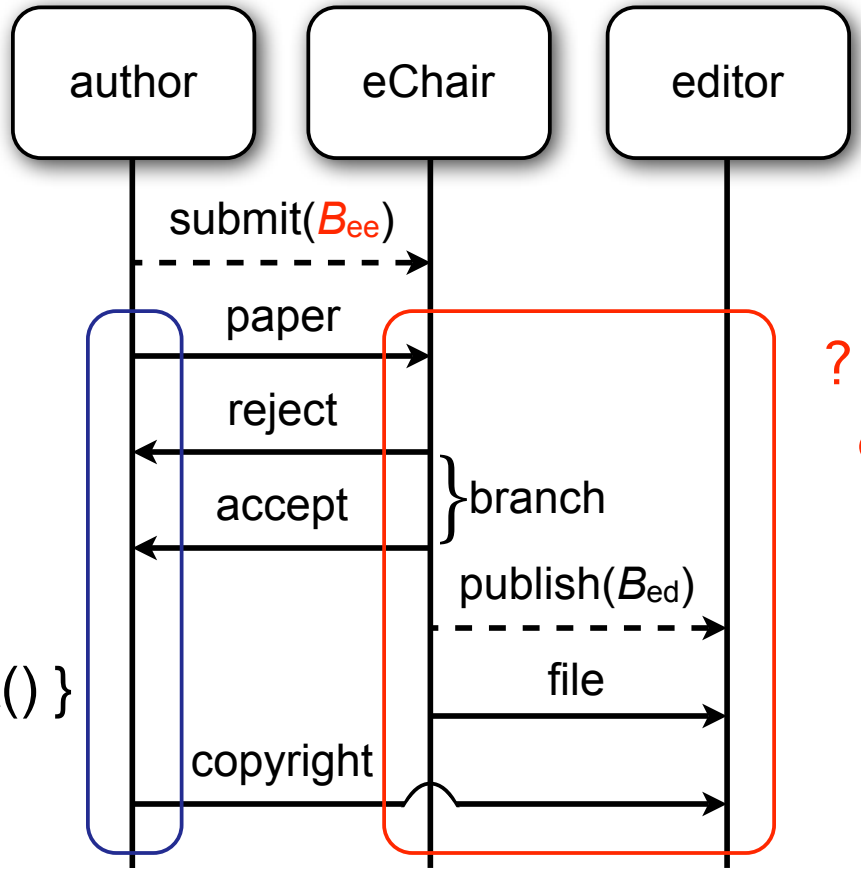

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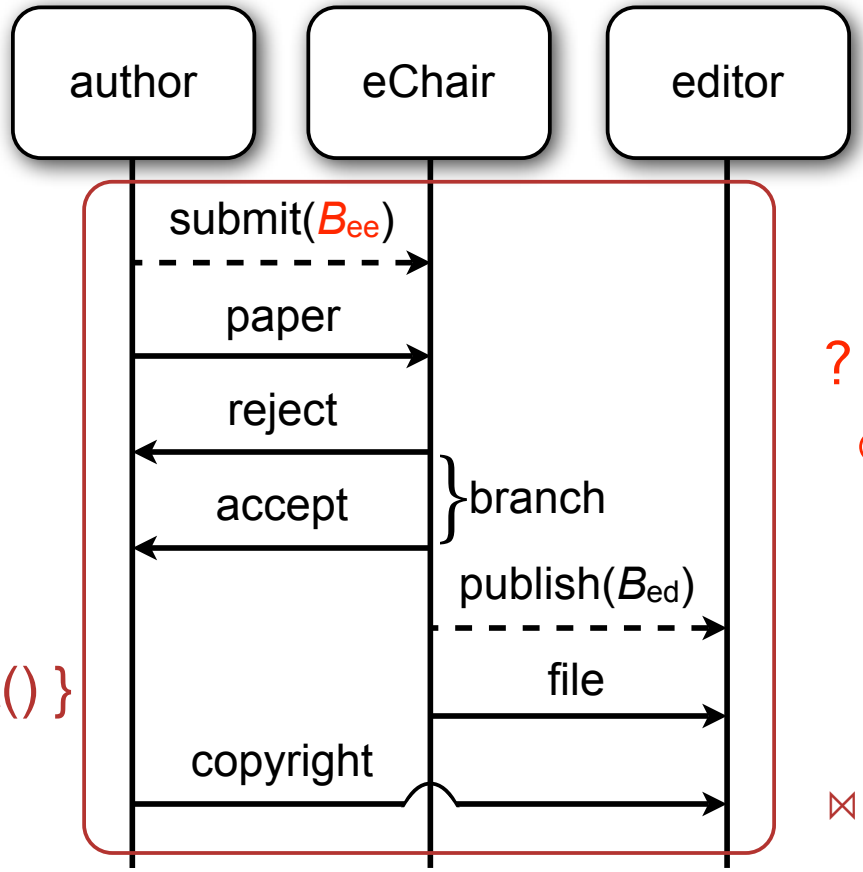

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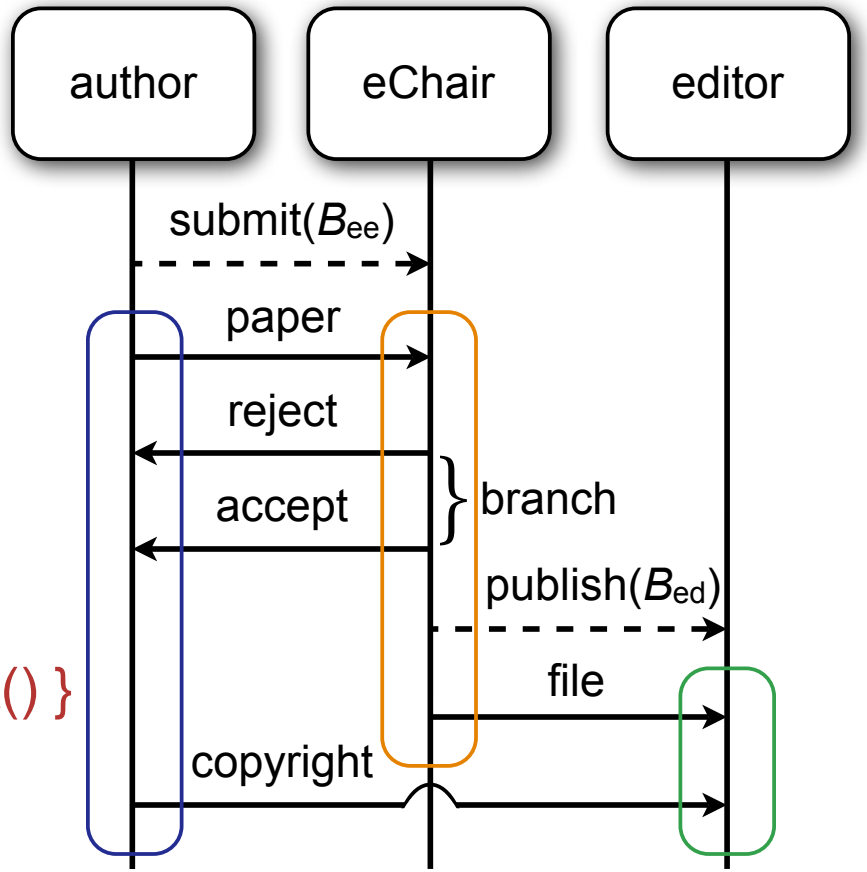

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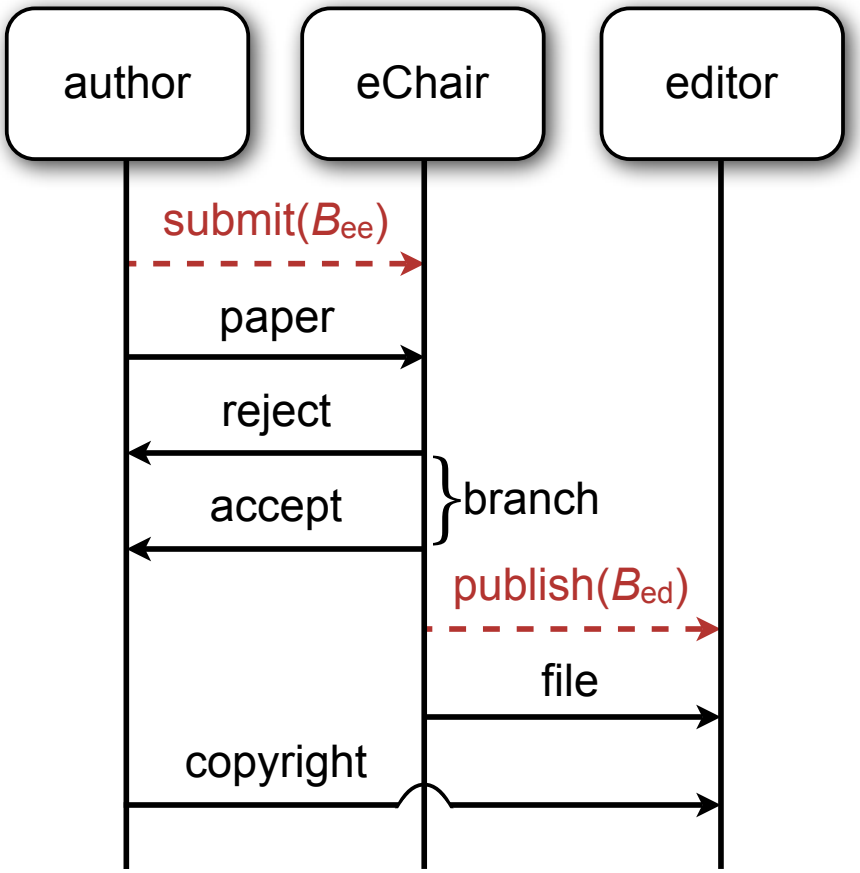

Results

Results

Theorem (Subject Reduction)

Let P be a well-typed process, $P :: T$.

If $P \rightarrow Q$ then there is T' such that $T \rightarrow T'$ and $Q :: T'$.

Proposition (Error Freeness)

Let P be a well-typed process. Then P is not an *error:*

P has no communication errors; P has no illegal message races

Corollary (Type Safety)

Let P be a well-typed process. If $P \rightarrow^* Q$ then Q is not an *error*.

Corollary (Conversation Fidelity)

Let P be a well-typed process, $P :: T$.

Then all conversations in P follow the protocols prescribed by T.

Proving Progress of Conversations

Proving Progress of Conversations

- We complement conversation typing with a proof system to ensure deadlock absence.

  As traditional methods (Lynch80, Kobayashi06, Dezani et al.07) we rely on imposing an ordering on **events.**

- Judgement $\Gamma;\Delta \vdash P$

  Events in *P* follow a well-founded order determined by $\Gamma;\Delta$.

- Events (*channel.*label.$(x)\Gamma$) are synchronizations in labeled channels passing channel references

  Each event has associated the ordering admissible $(x)\Gamma$ for the channel which is to be passed in the message

  received/sent channels must comply with the prescribed order

Ordering eChair System Events

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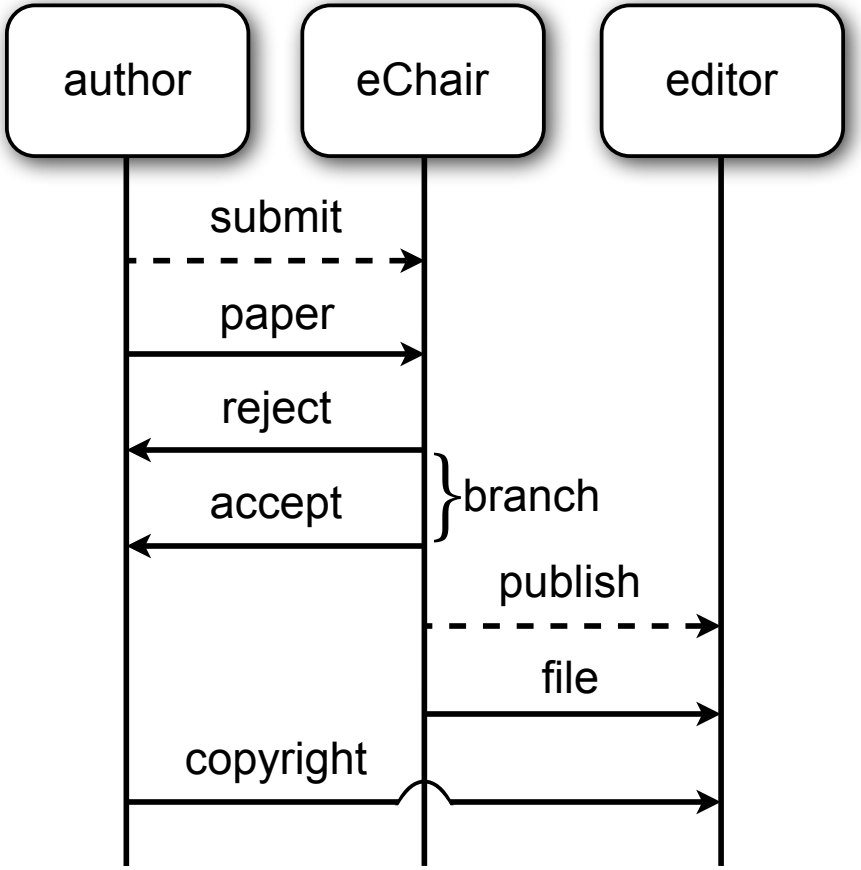

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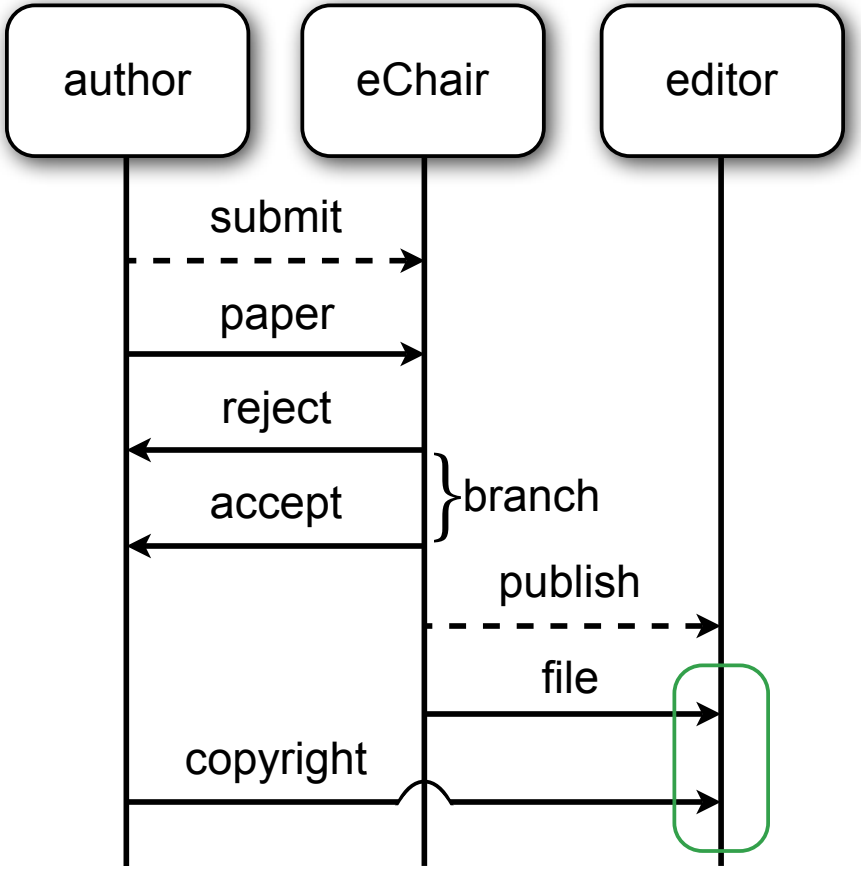

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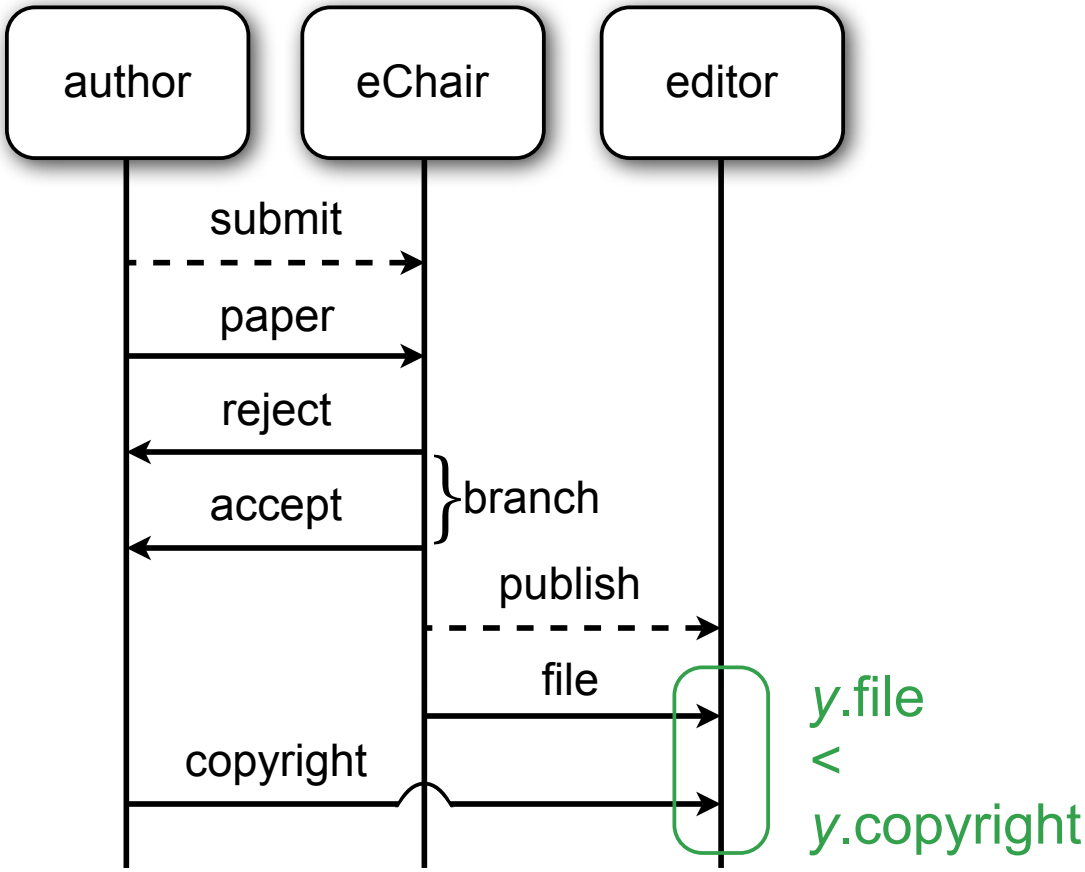

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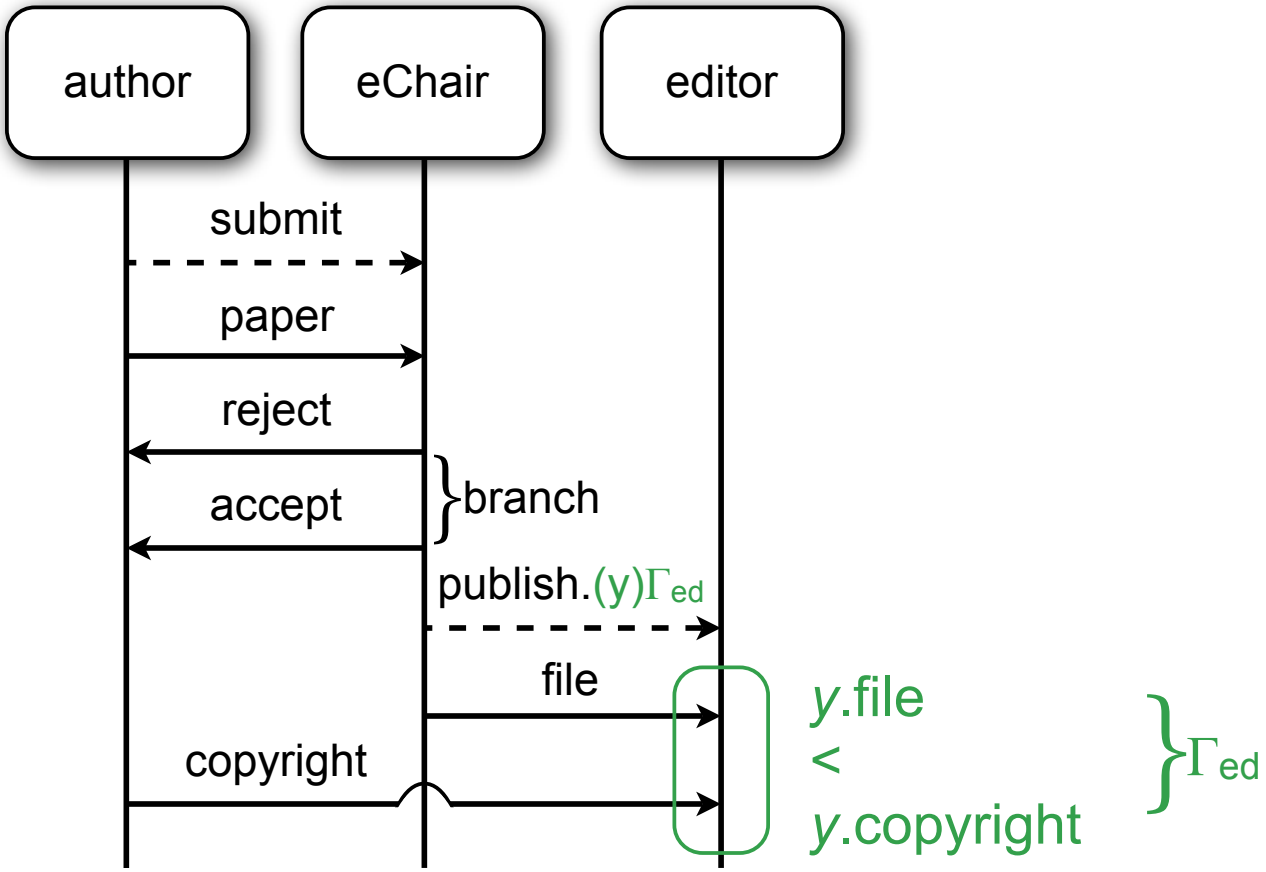

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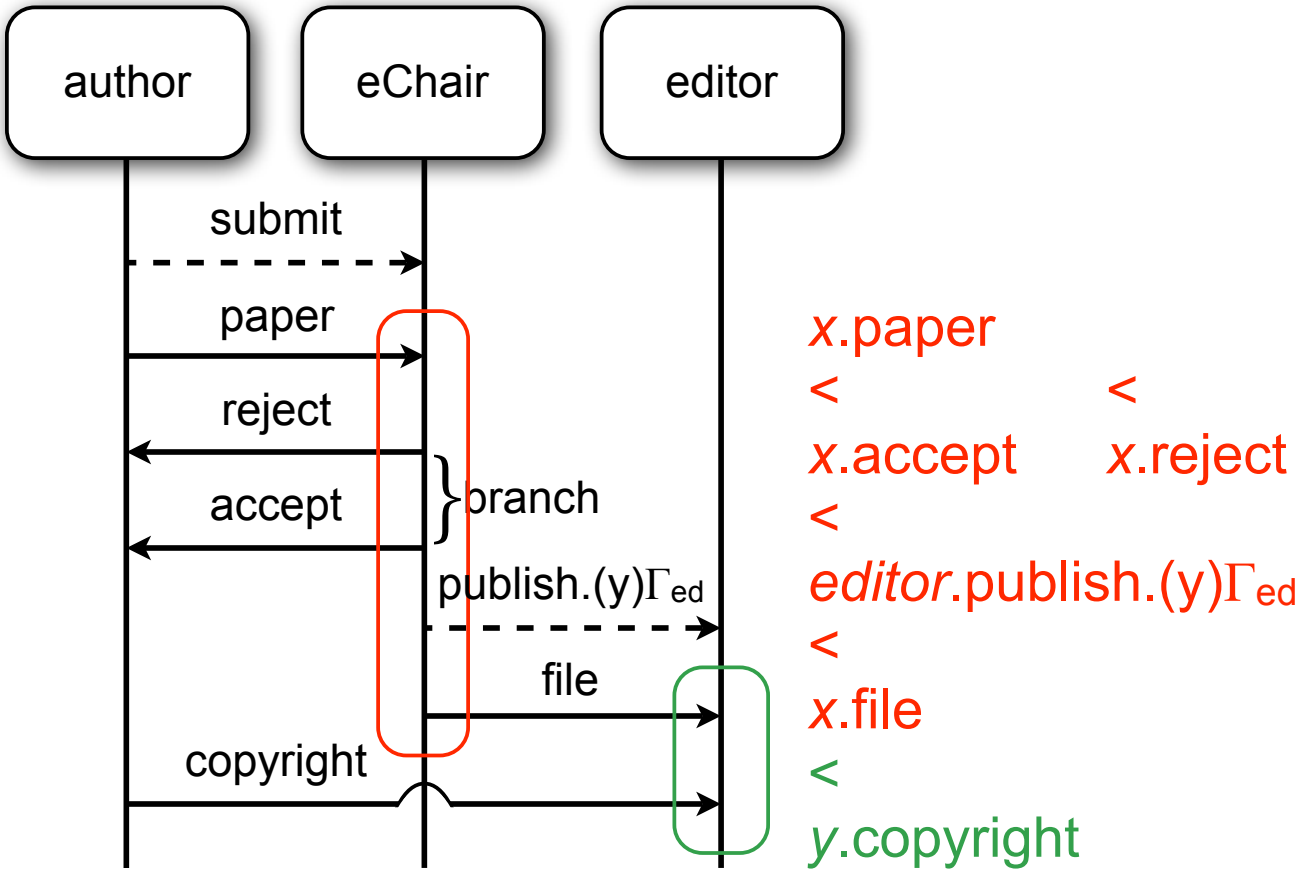

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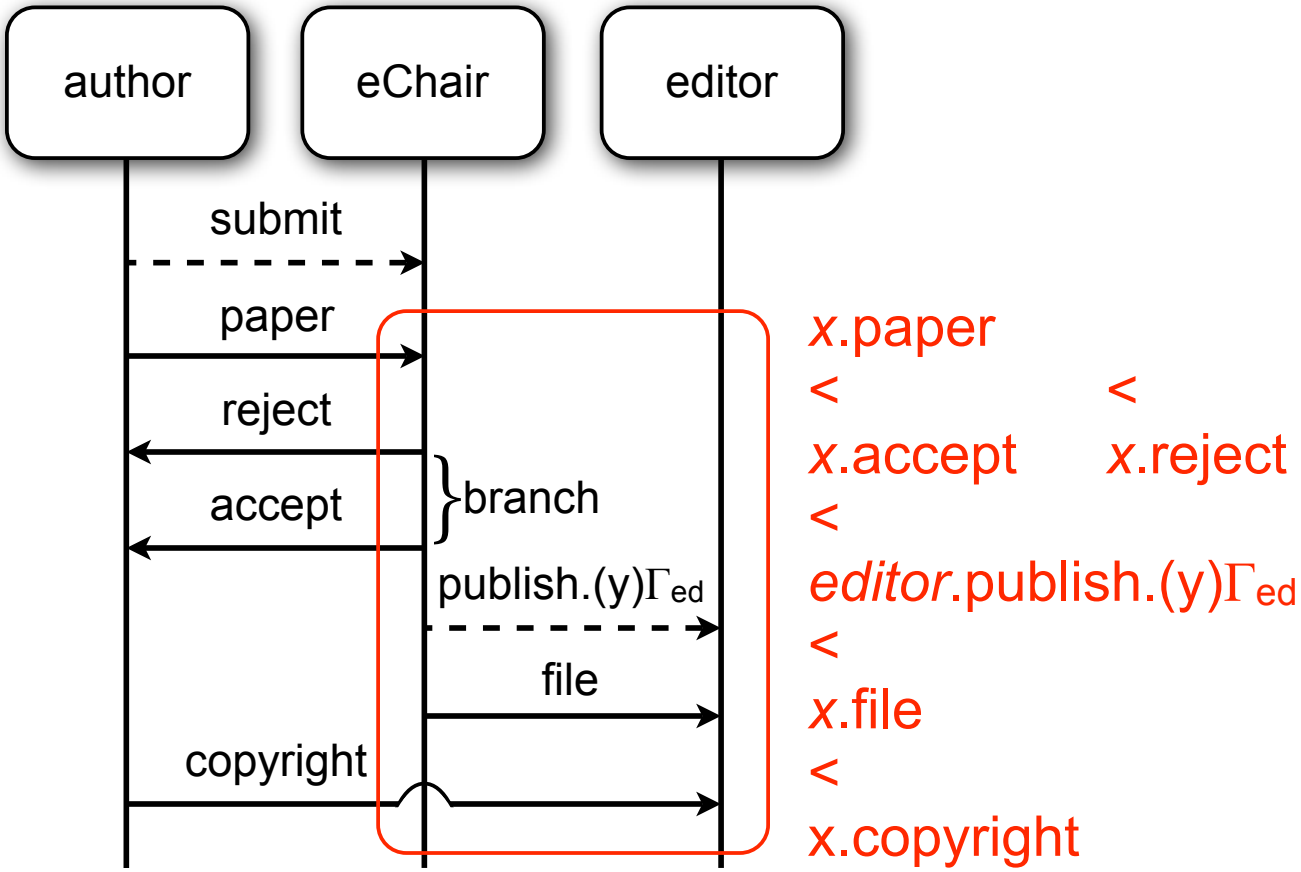

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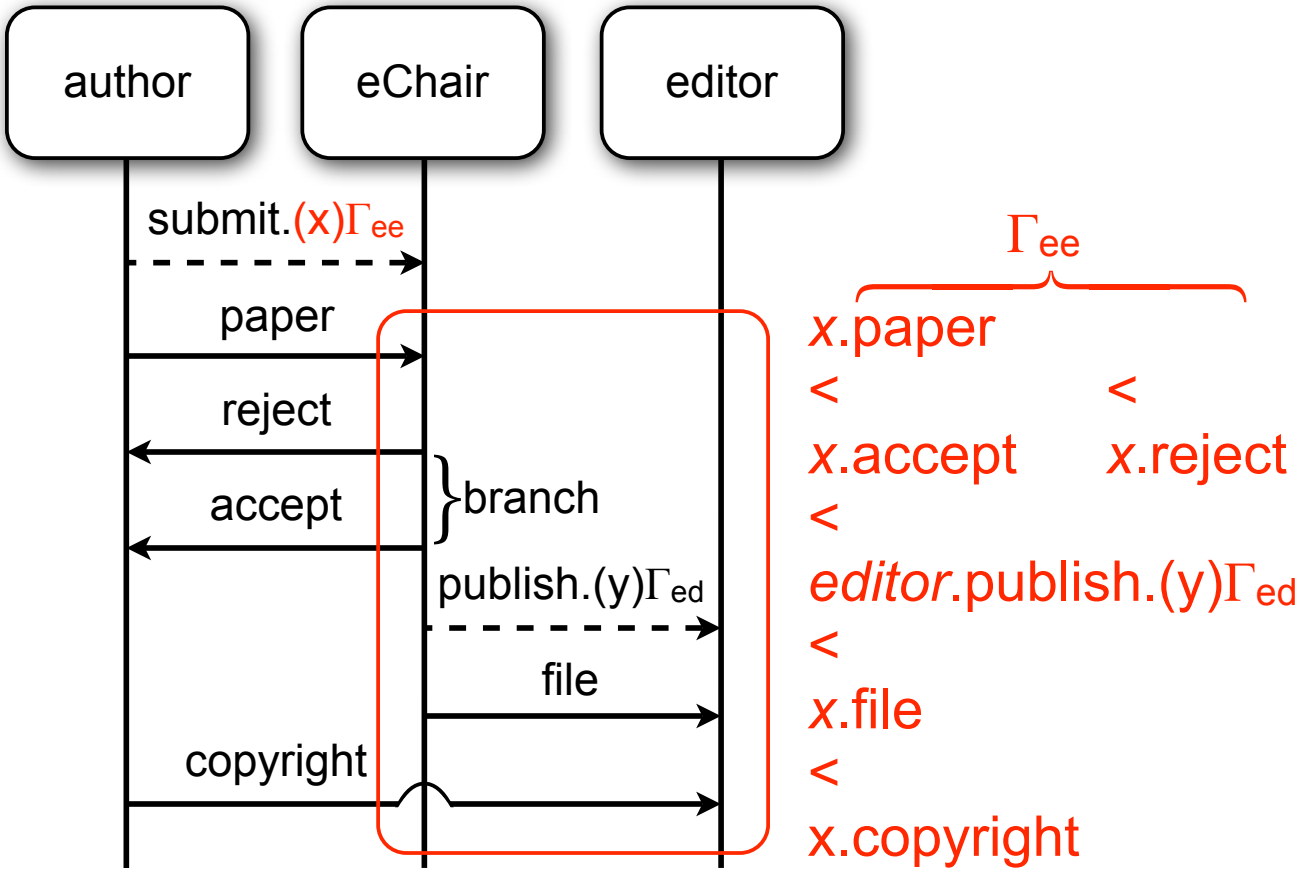

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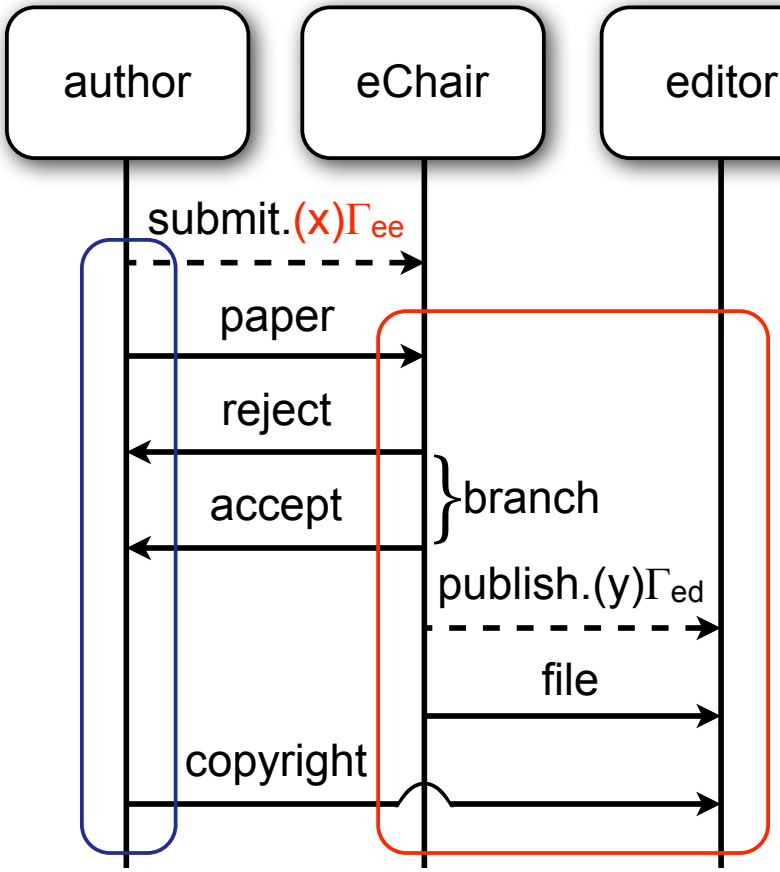

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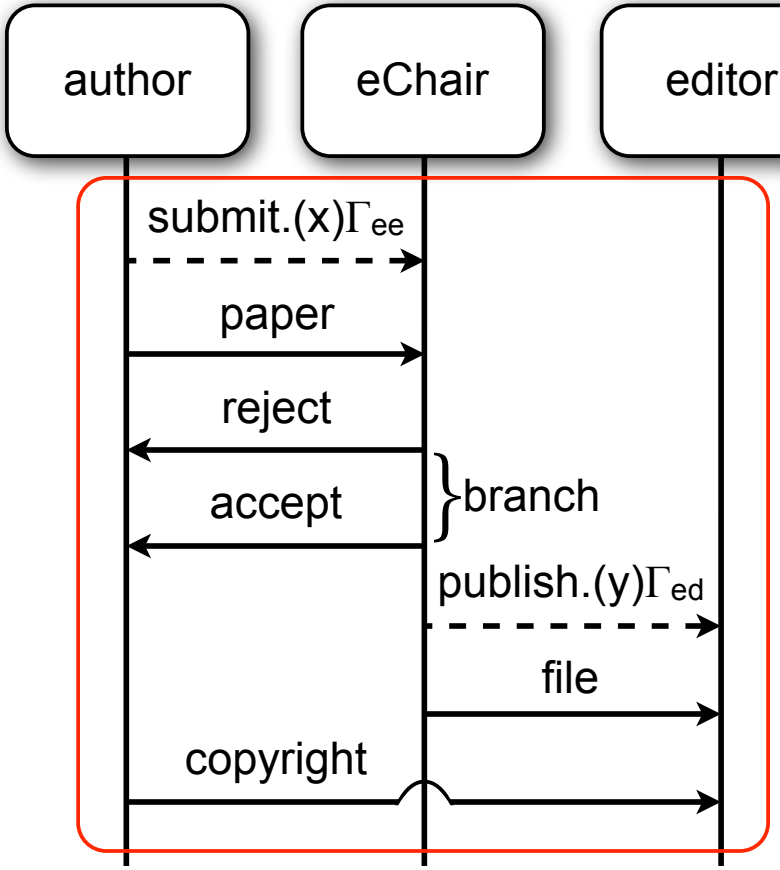
chat.copyright

Ordering eChair System Events



eChair.submit.(*x*)Γee
<
chat.paper
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chat.accept *chat*.reject
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editor.publish.(y)Γed
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chat.file
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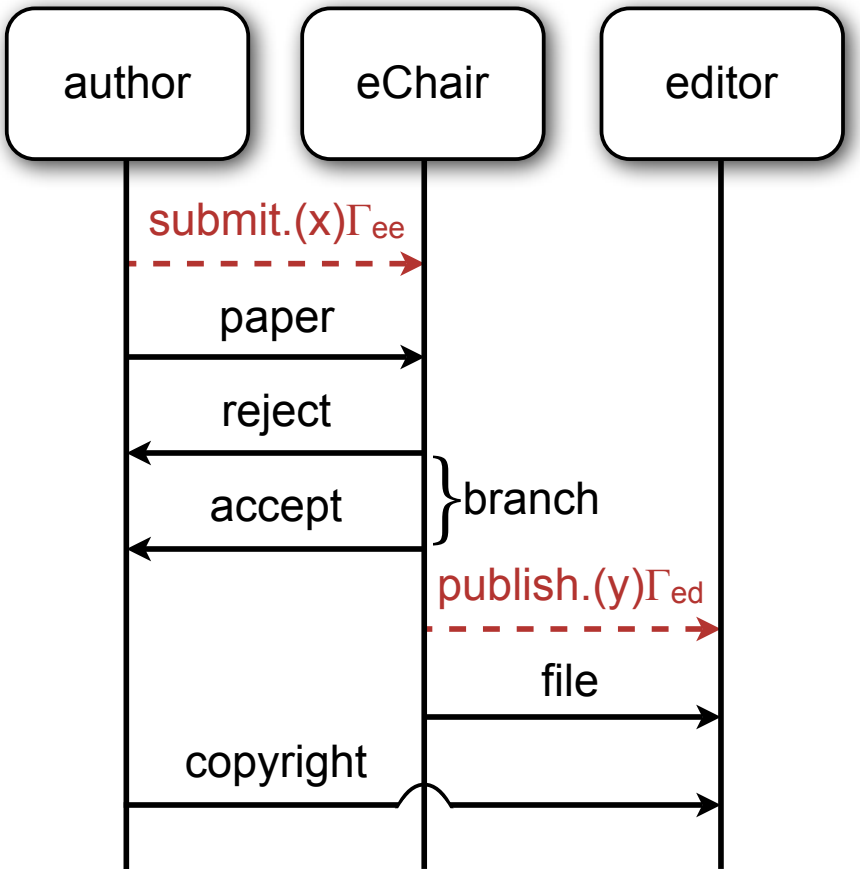
chat.copyright

Typing eChair System

$eChair.\mathrm{submit}.(x)\Gamma_{ee}$
$< editor.\mathrm{publish}.(y)\Gamma_{ed}$
$\vdash$

(**ν***chat*)
(*eChair* • submit!(*chat*).
  chat • paper!(*pdf*).
  (*chat* • reject?()
   +
   chat • accept?(). *chat* • copyright!()))
|
eChair • submit?(*x*).
  x • paper?(*pdf*).
  (*x* • reject!()
   +
   x • accept!().
    editor • publish!(*x*). *x* • file!(*pdf*))
|
editor • publish?(*y*).
  y • file?(*pdf*). *y* • copyright?()



Results

Results

Theorem (Preservation of Event Ordering)

Let P be well-formed and $\Gamma;\Delta \vdash P$. If $P \rightarrow Q$ then $\Gamma';\Delta,\Delta' \vdash Q$.

Theorem (Lock Freeness)

Let P be a process s.t. $P :: T$ and $\Gamma;\Delta \vdash P$. If *closed*(T) and P is not a *finished* process then there is Q such that $P \rightarrow Q$.

A type T is *closed* if (roughly) $T = \tau(T)$.

Finished processes only exhibit shared inputs (e.g., persistent services).

Corollary (Progress)

Let P be a process s.t. $P :: T$ and $\Gamma;\emptyset \vdash P$ and *closed*(T).

If $P \rightarrow^* Q$ and Q is not a finished process then $Q \rightarrow R$.

Related Work

- Multiparty Sessions (HondaYoshidaCarbone08)

  Created via multicast atomic service requests, each having multiple channels; support a constant number of participants; global types specify who does what.

  In our approach, a single medium supports a dynamic number of multiple participants, interacting via labeled messages.

- Progress in Multiparty Sessions (Bettini et al.08)

  Builds on (HondaYoshidaCarbone08) improving on the progress result;

  Does not address the interleaving of delegated sessions.

- Dynamic Multirole Sessions (DeniélouYoshida11)

  Multicast atomic service request, multiple session channels; Dynamic number of participants, constant number of roles.

  Our approach addresses systems with dynamic “roles”

Concluding Remarks

- Conversation types

  Simple extension of the session type notion

  Multiparty conversations in a single communication medium

  Unify local and global behavioral specs at the same level

  Unantecipated participants may join / leave a conversation, as long as the “projection invariant” is preserved

  $$P_1 \bowtie P_2 \bowtie \ldots \bowtie P_k = G_\tau$$

  Progress result on systems where processes interact in multiple conversations, supporting repeated accesses to several interleaved, possibly delegated, conversations

- Ongoing work

  Analysis of role based conversation using conversation types