Decentralized Operation-based Graph Versioning to support **Collaborative Blended Modeling** and **Live Modeling**

ENSTA Bretagne, Brest
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Overview

- **Part 1: Collaborative Blended Modeling**
  - Background
    - Versioning
      - “Classic” text-based versioning (git) and its limitations
      - Going beyond git
      - Versioning in Model-Driven Engineering
    - Blended Modeling
  - Research question
  - Running example
  - Solution (top→down)
- **Part 2: Collaborative Live Modeling**
  - Background: live modeling
  - Research question
  - Running example
  - Solution

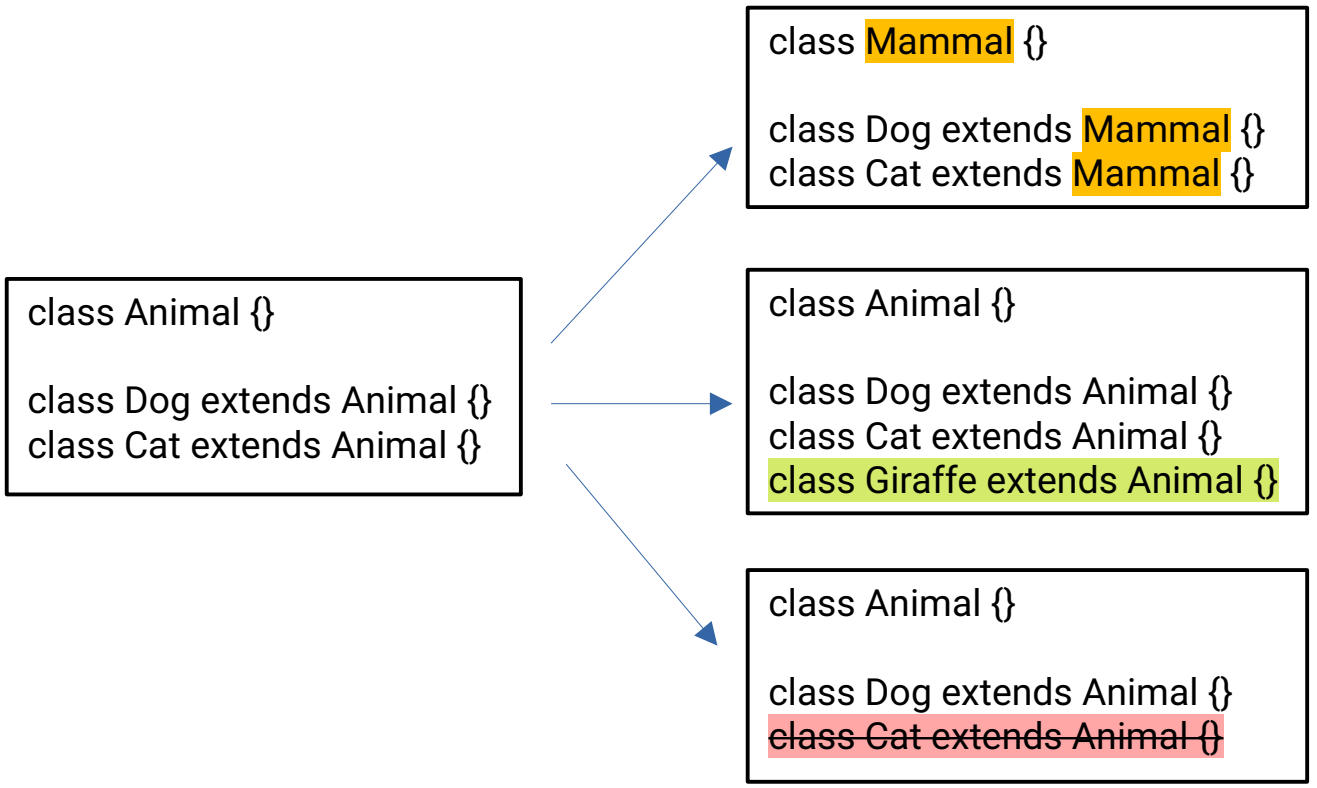
Part 1: Collaborative Blended Modeling

Versioning

= ***Central piece of technology*** in any kind of collaborative work

- programming
- modeling

“Classic” text-based + snapshot-based versioning (e.g., git)



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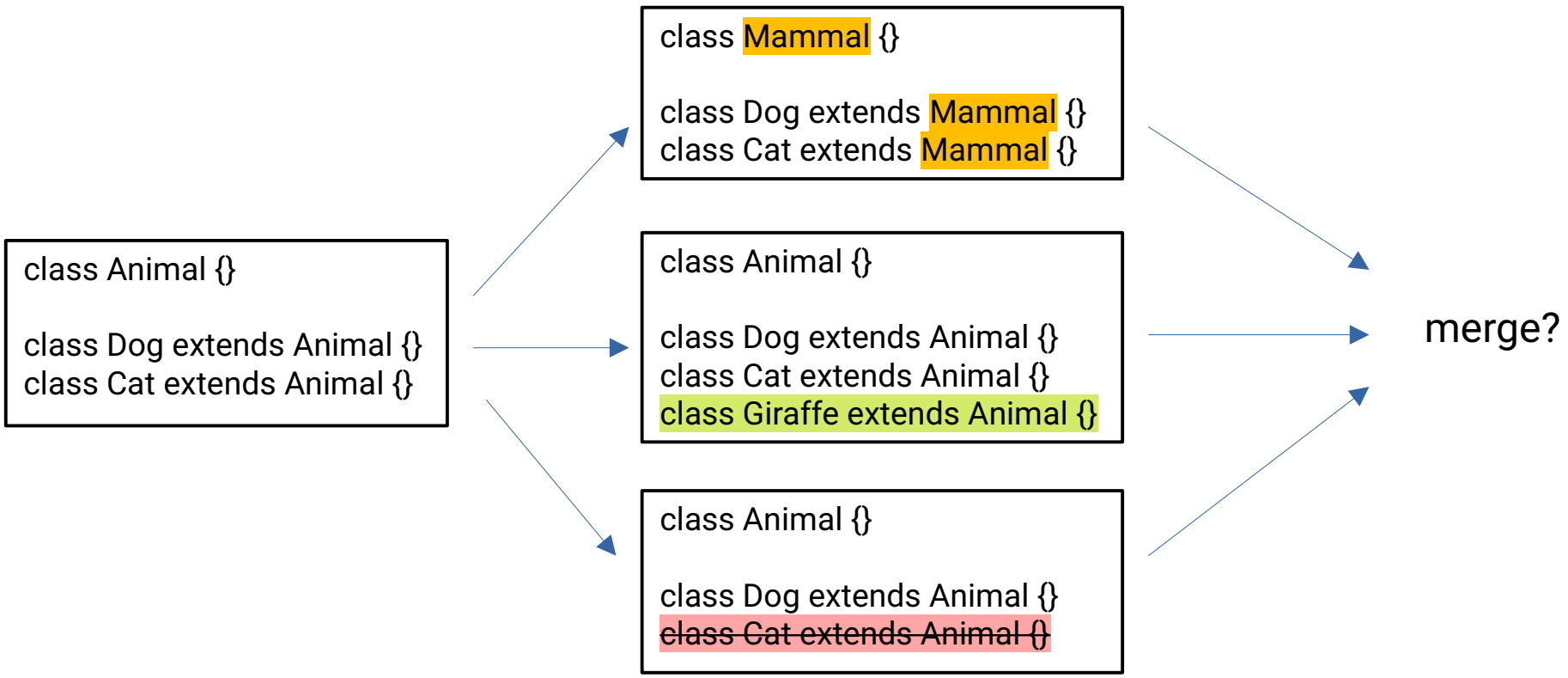

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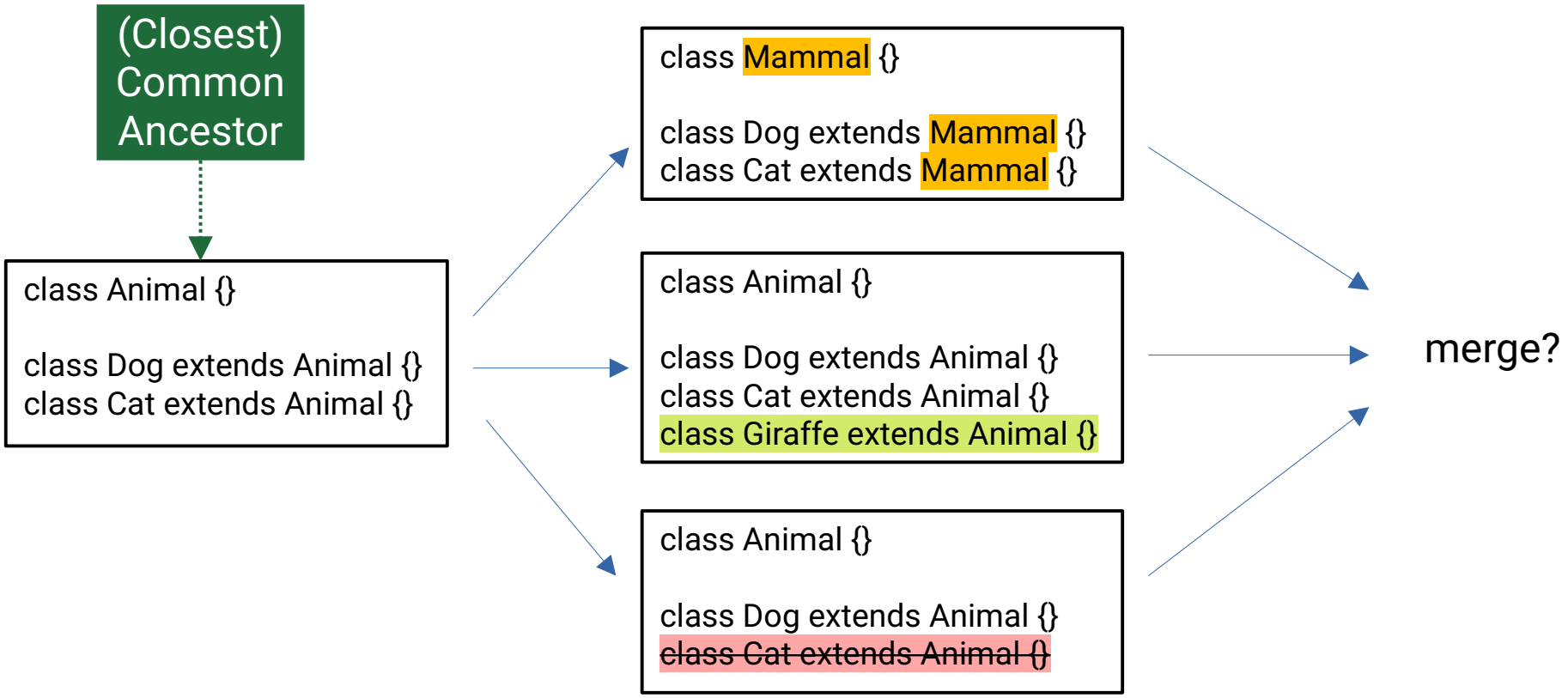

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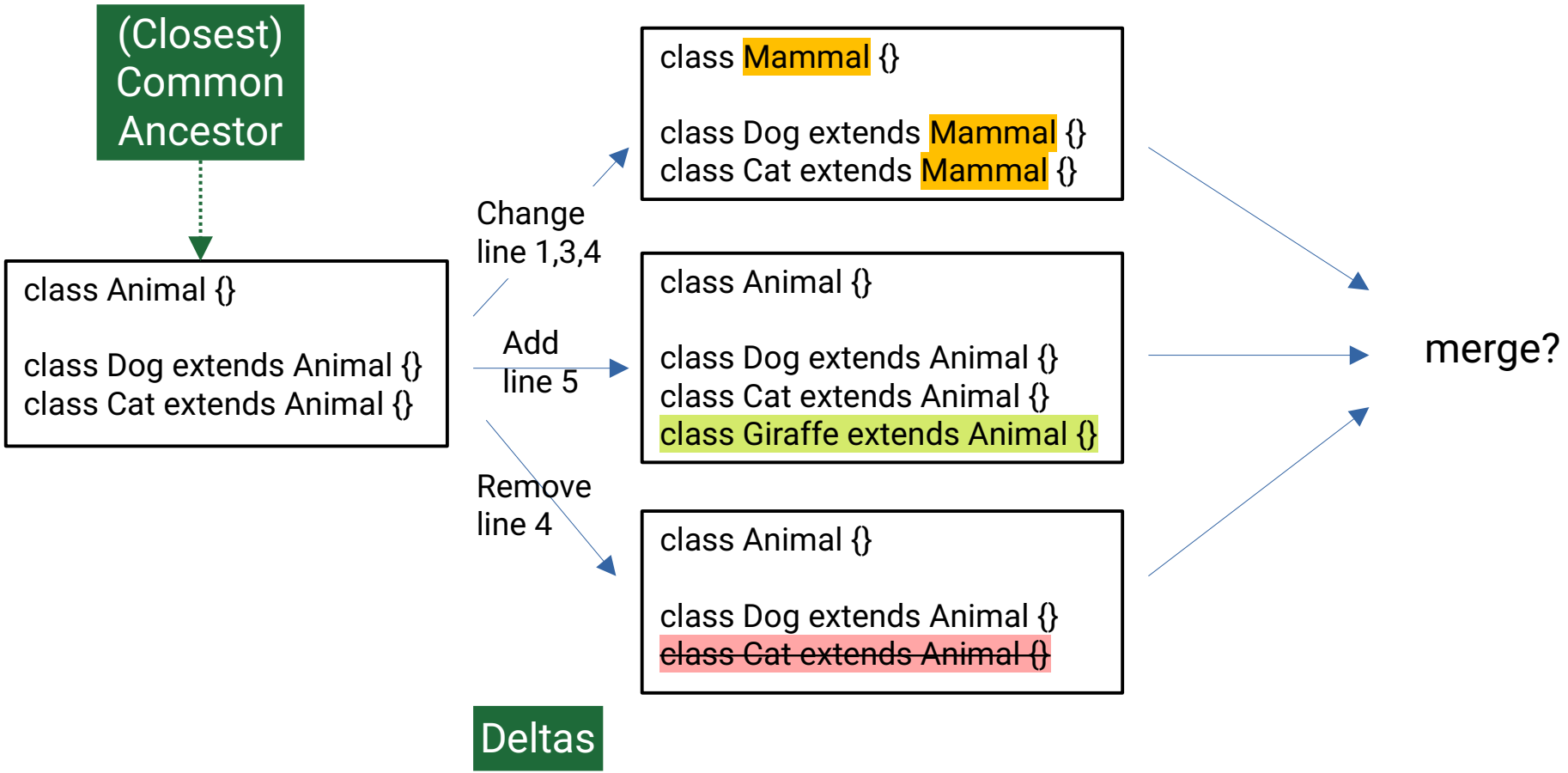

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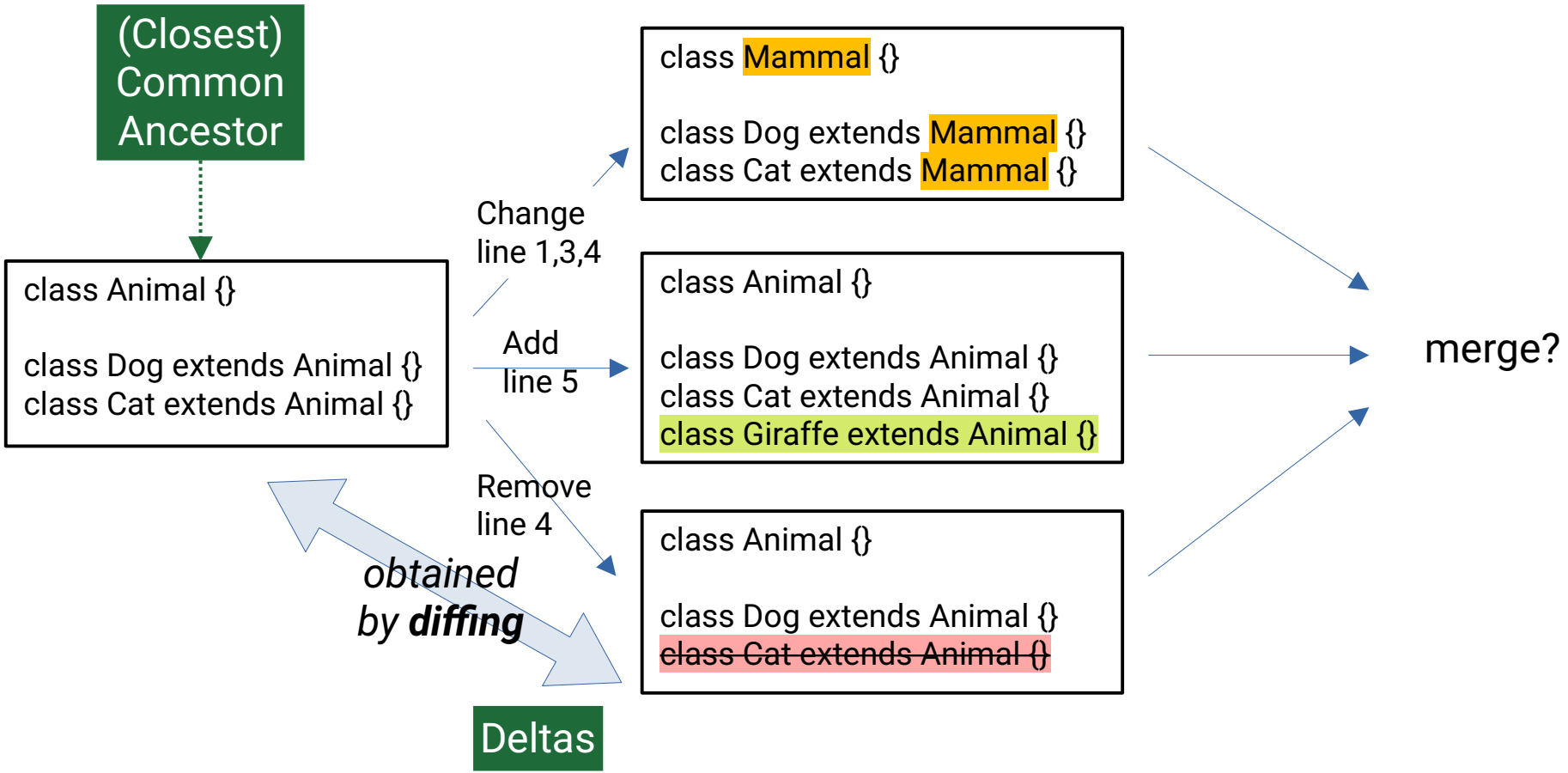

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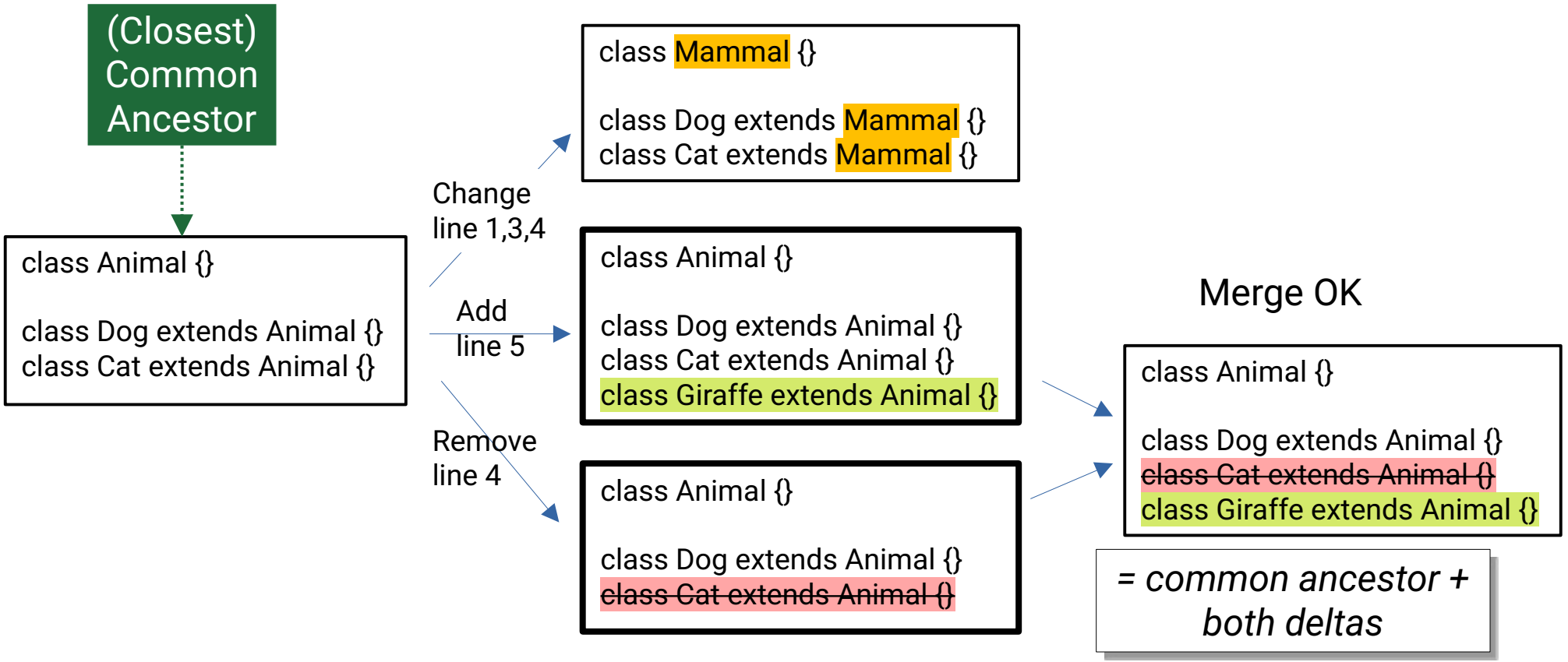

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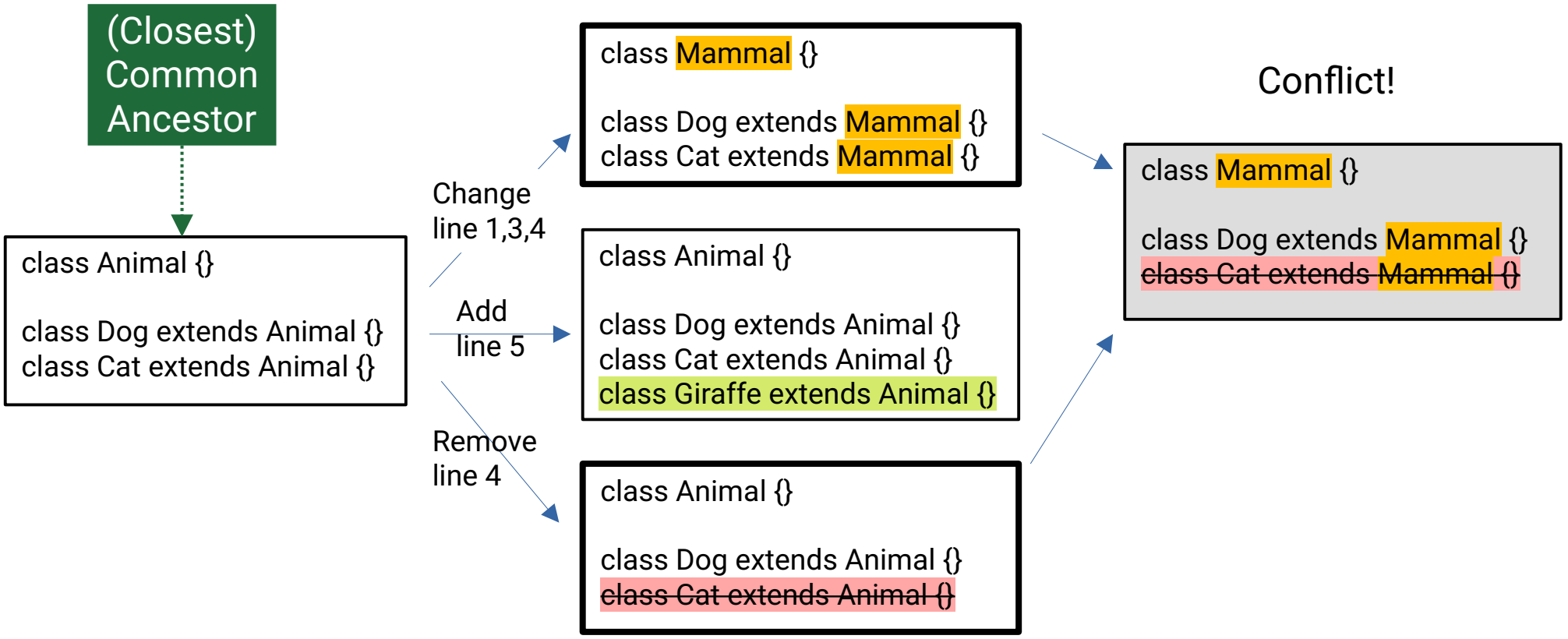

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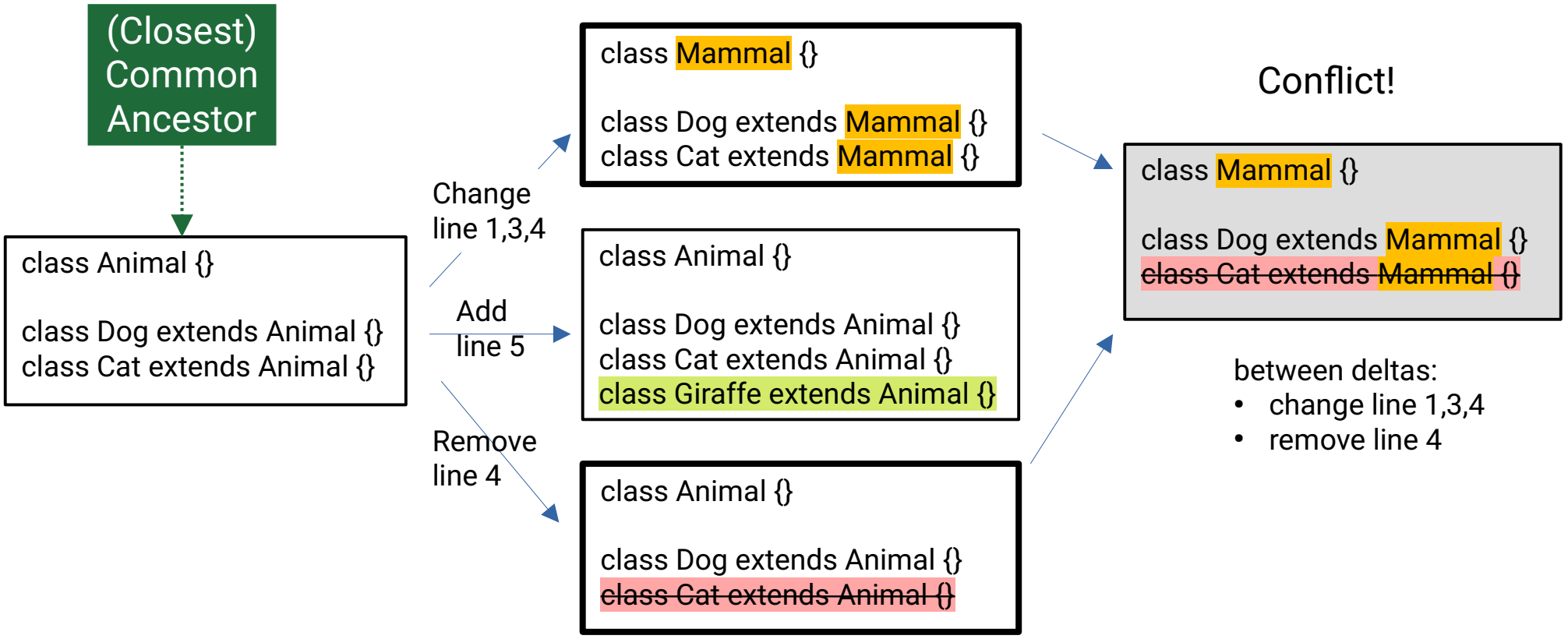

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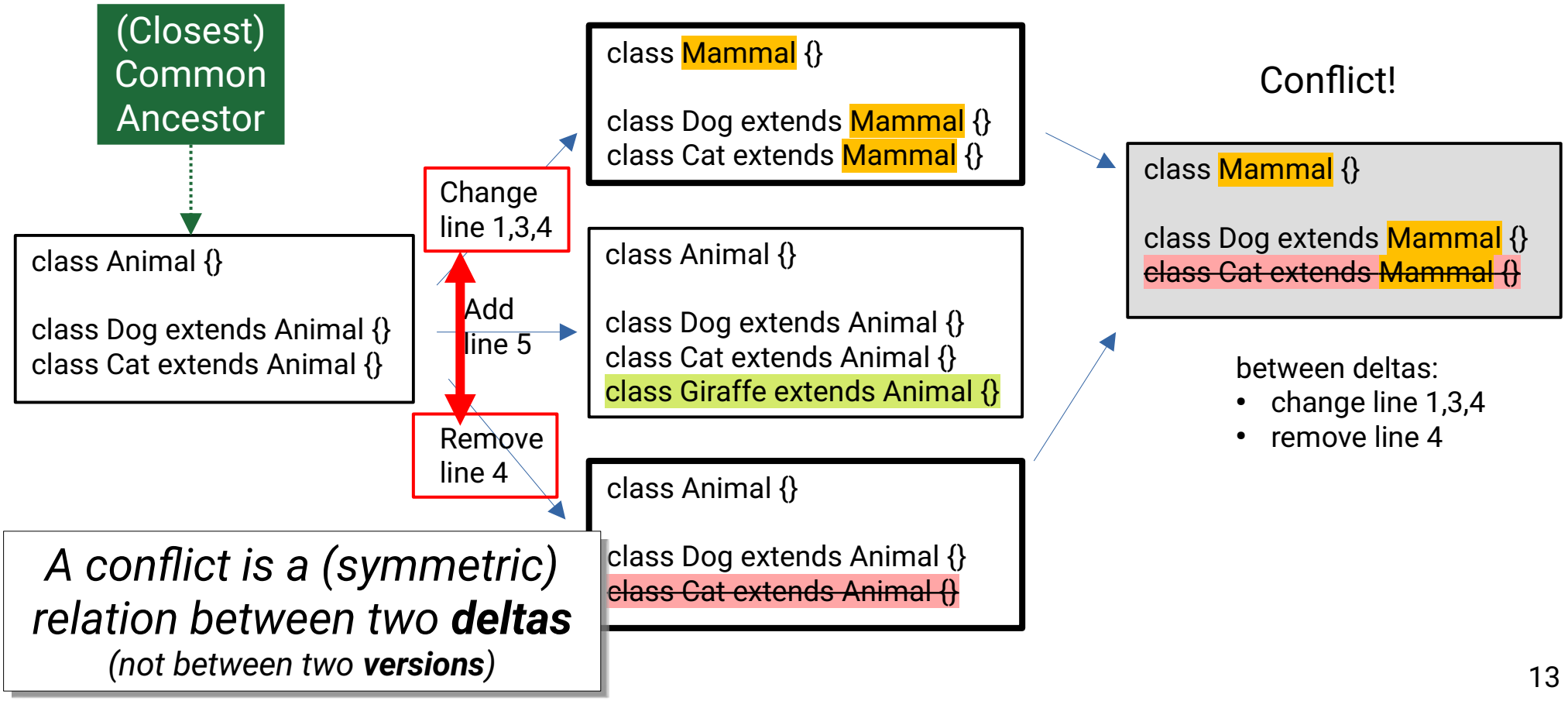

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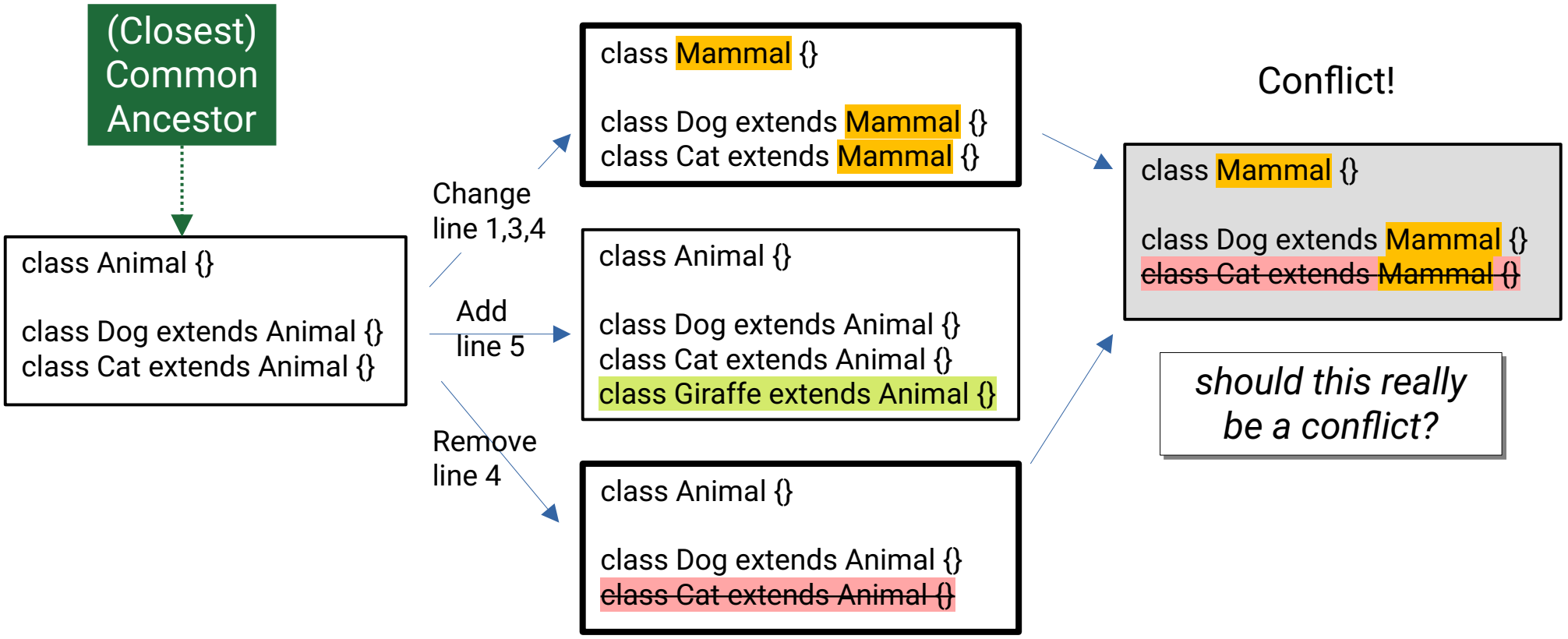

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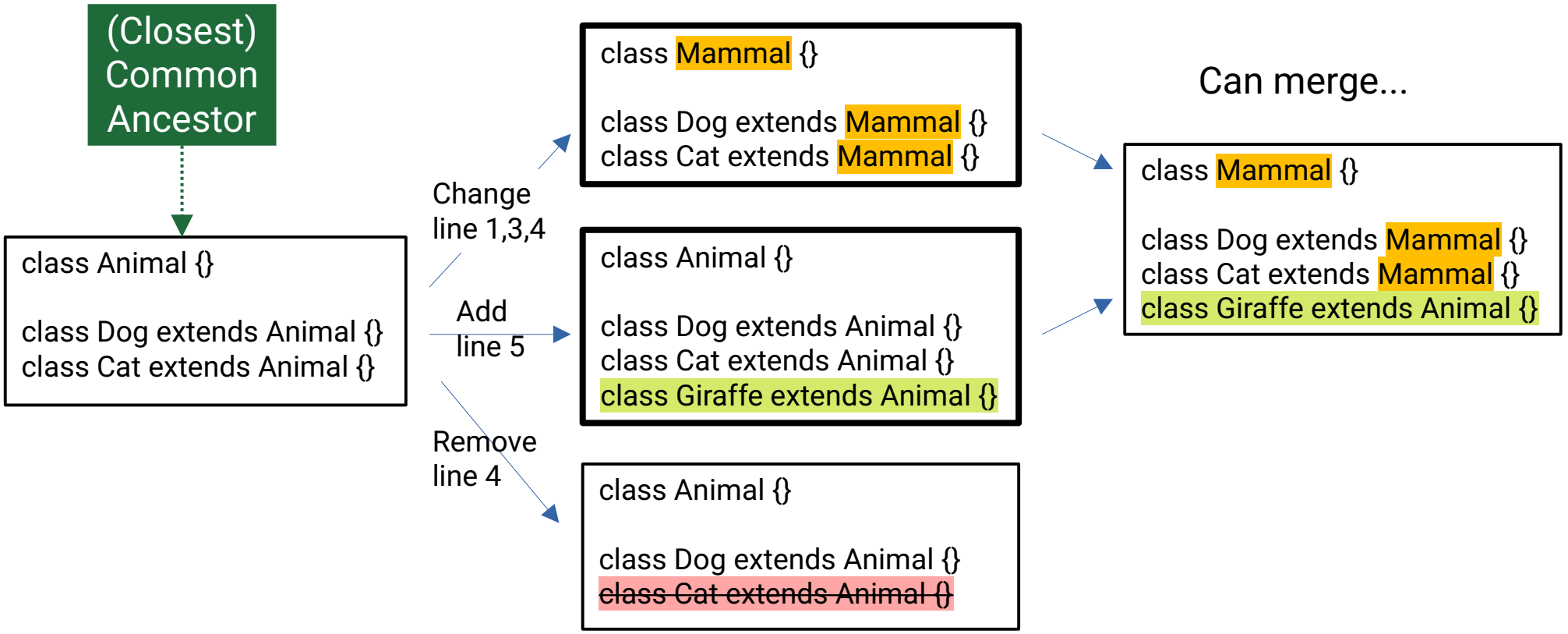

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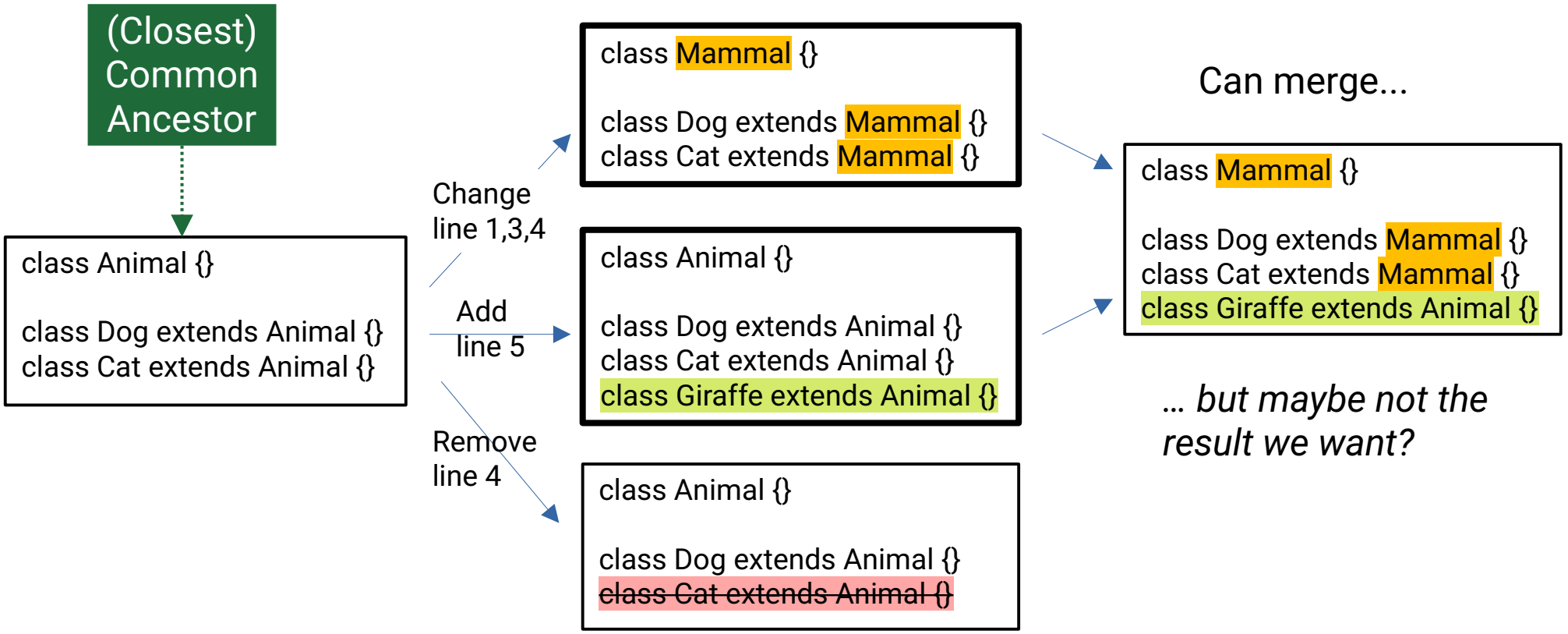
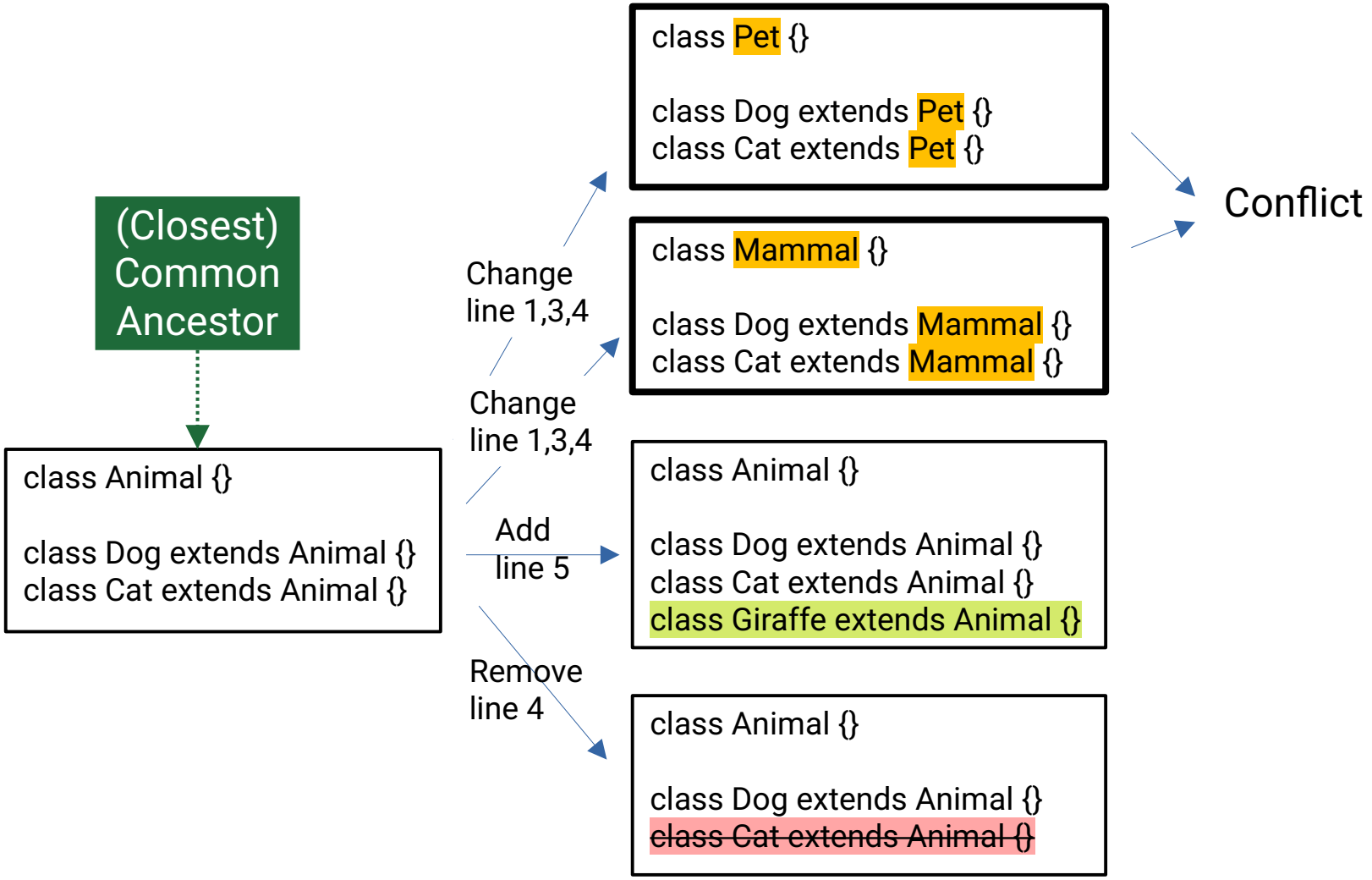


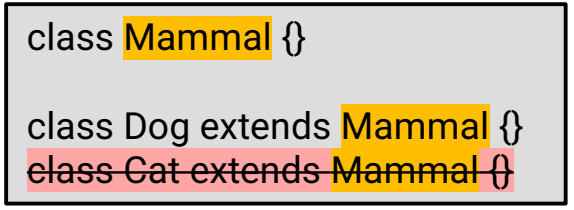

(Closest) Common Ancestor
class Animal {}
class Dog extends Animal {}
class Cat extends Animal {}
Change line 1,3,4
Change line 1,3,4
Add line 5
Remove line 4
class Pet {}
class Dog extends Pet {}
class Cat extends Pet {}
class Mammal {}
class Dog extends Mammal {}
class Cat extends Mammal {}
class Animal {}
class Dog extends Animal {}
class Cat extends Animal {}
class Giraffe extends Animal {}
class Animal {}
class Dog extends Animal {}
class Cat extends Animal {}
Conflict

Conflict terminology

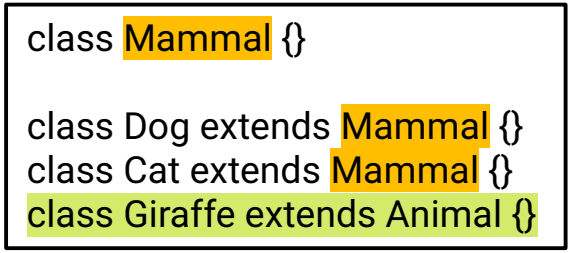
	class Animal {} class Dog extends Animal {} ~~class Cat extends Animal {}~~ class Giraffe extends Animal {}	class Pet {} class Dog extends Pet {} class Cat extends Pet {}	class Mammal {} class Dog extends Mammal {} ~~class Cat extends Mammal {}~~	? example will be given later...
conflict detected?	negative	positive	positive	negative
detection correct?	true	true	false	false
so let's call it a ...	***true negative***	***true positive***	***false positive***	***false negative***

Limitations of text-based versioning

- Problems encountered:



(a)



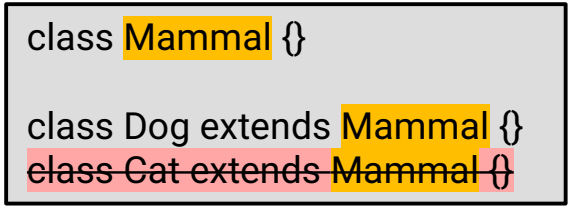
(b)

(a) “false positive” conflicts (common in git)

(b) undesired merge outcome

Limitations of text-based versioning

- Problems encountered:



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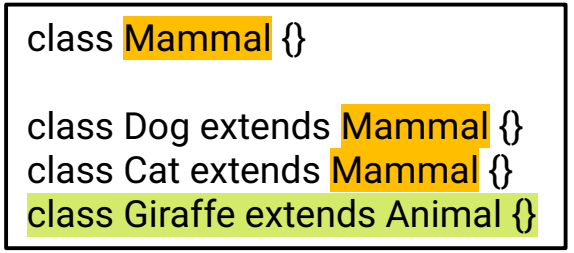


(b)

(a) “false positive” conflicts (common in git)

(b) undesired merge outcome

- Going beyond git
  1) Versioning the abstract syntax (instead of concrete syntax)
  2) Operation-based versioning (instead of snapshot-based)

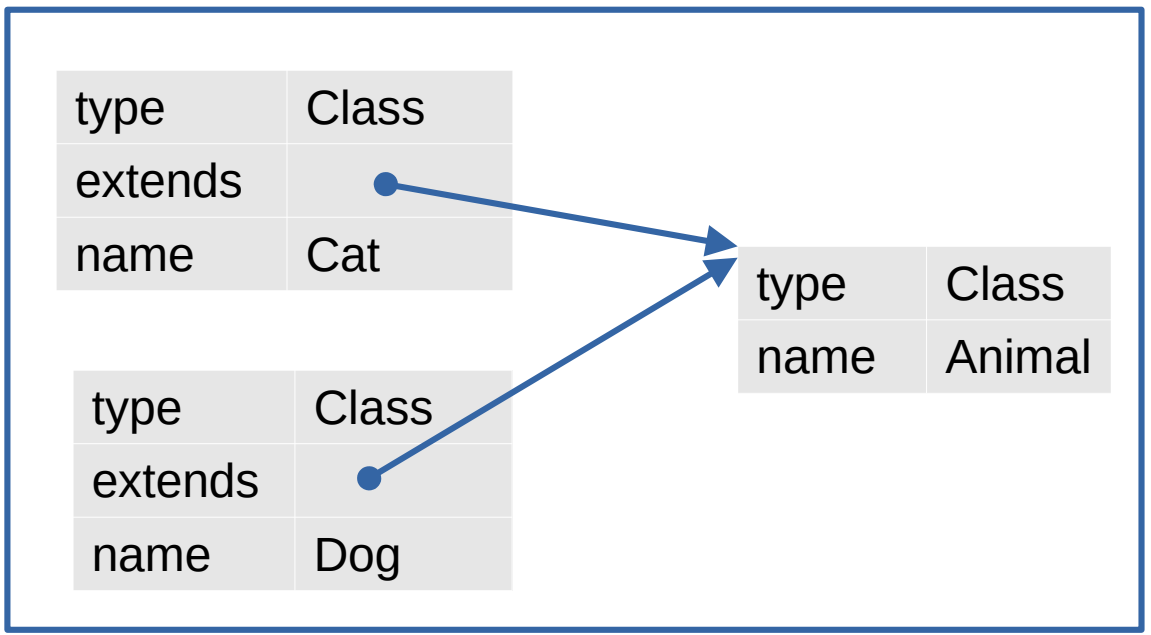
Beyond git: 1) Versioning the abstract syntax

concrete syntax

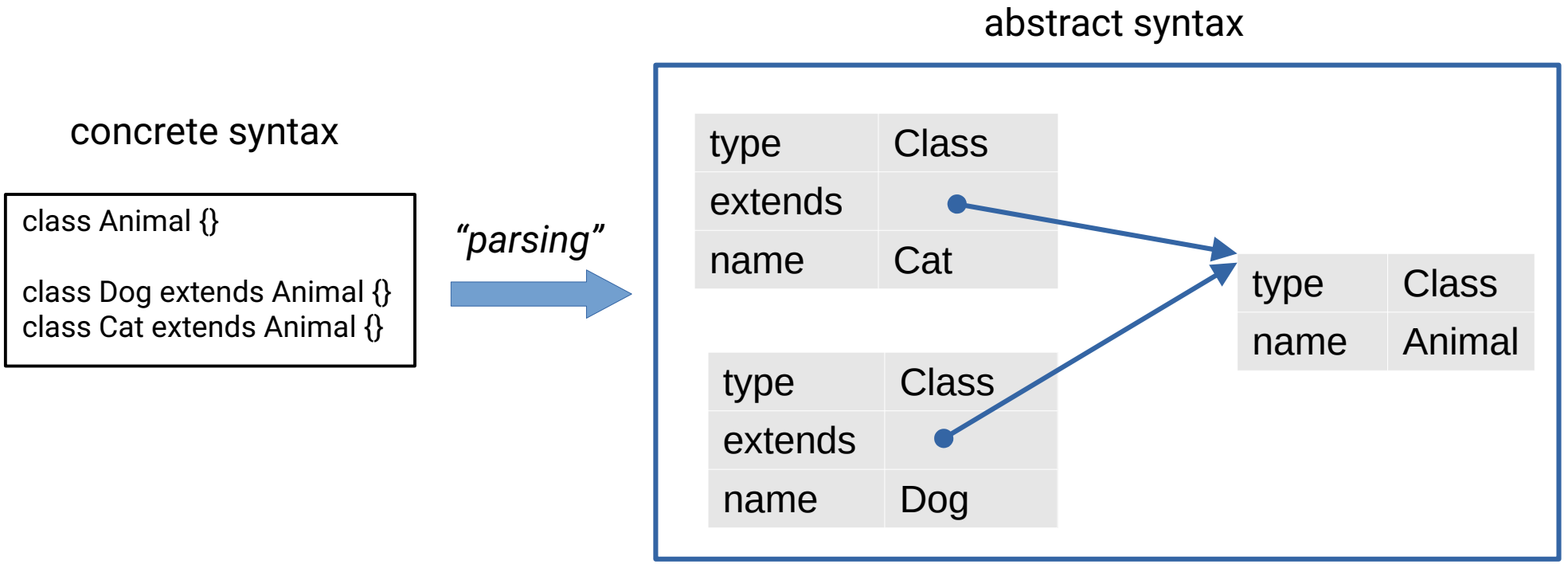
```
class Animal {}

class Dog extends Animal {}
class Cat extends Animal {}
```

abstract syntax



Beyond git: 1) Versioning the abstract syntax



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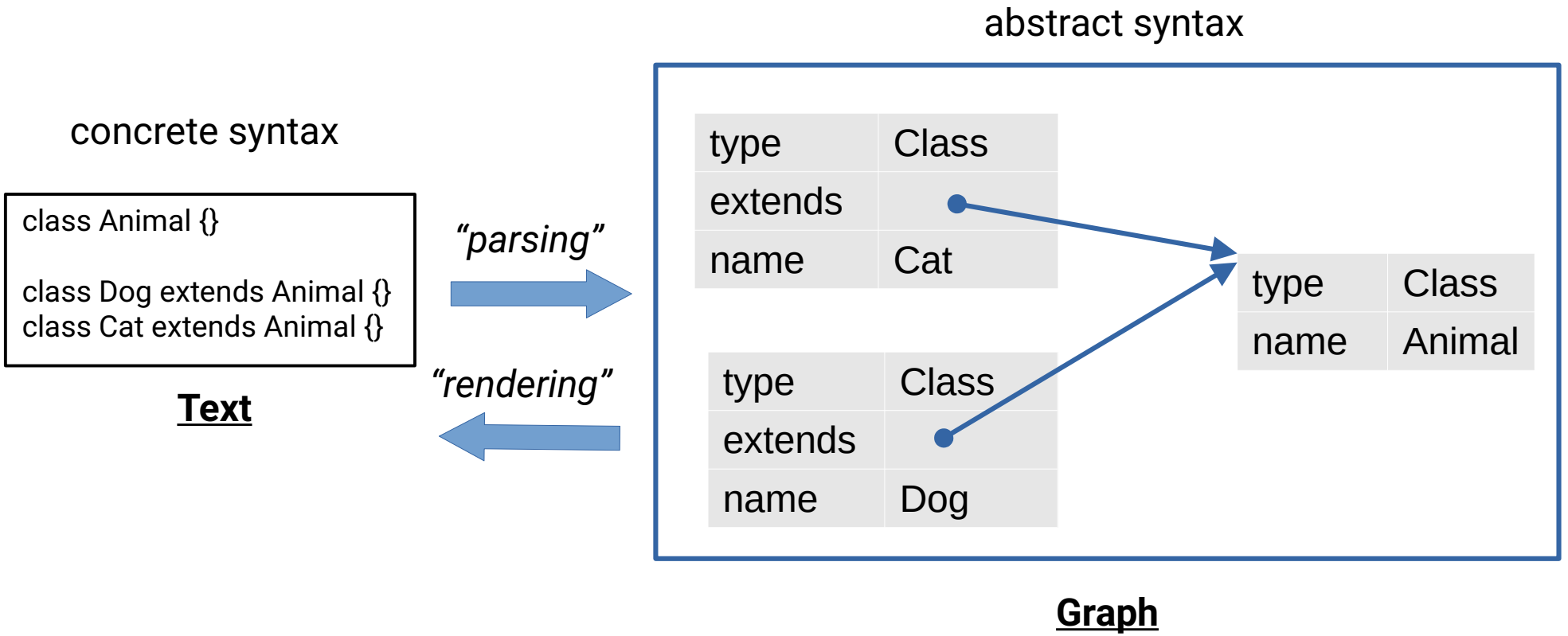
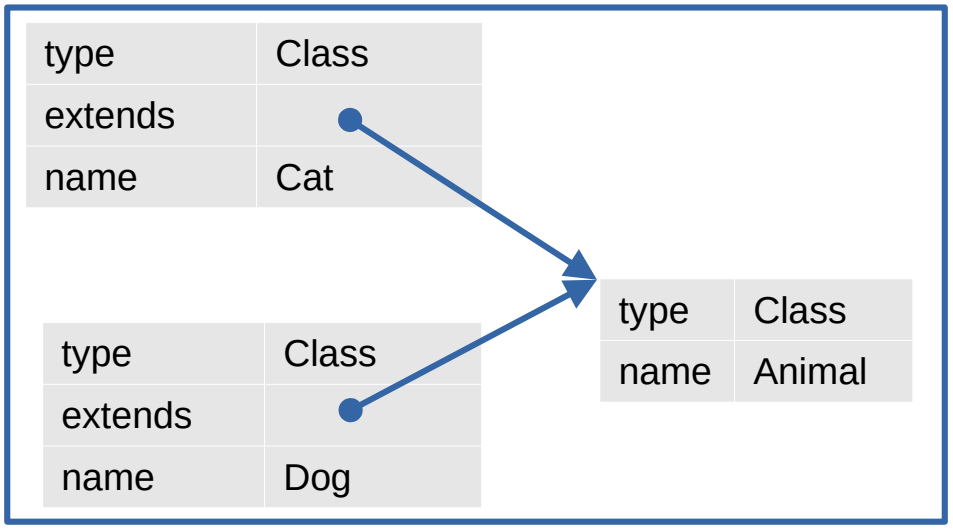
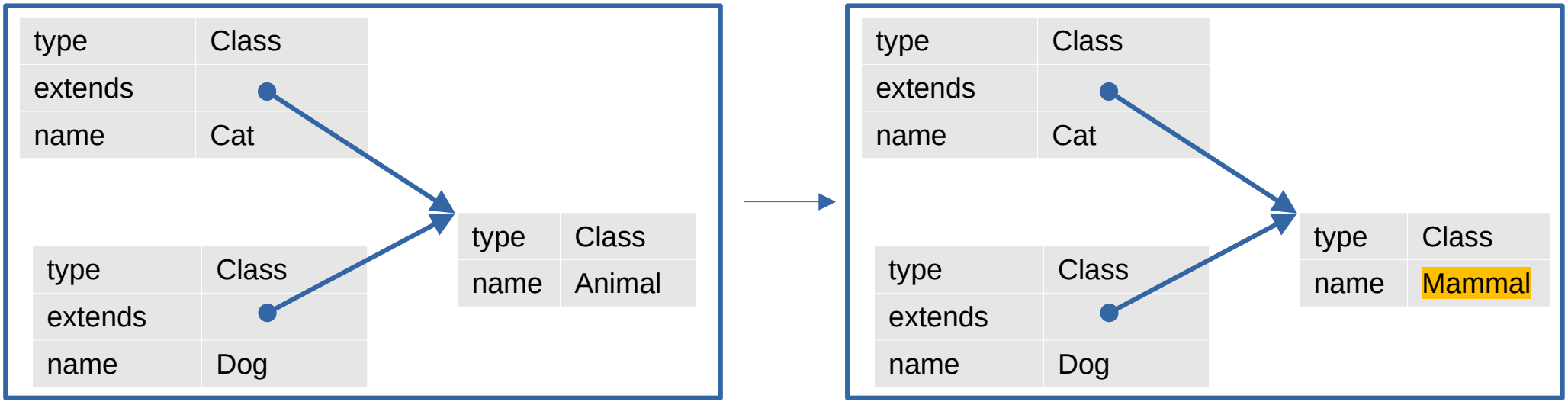



type
Class
extends
name
Cat
type
Class
name
Animal
type
Class
extends
name
Dog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name
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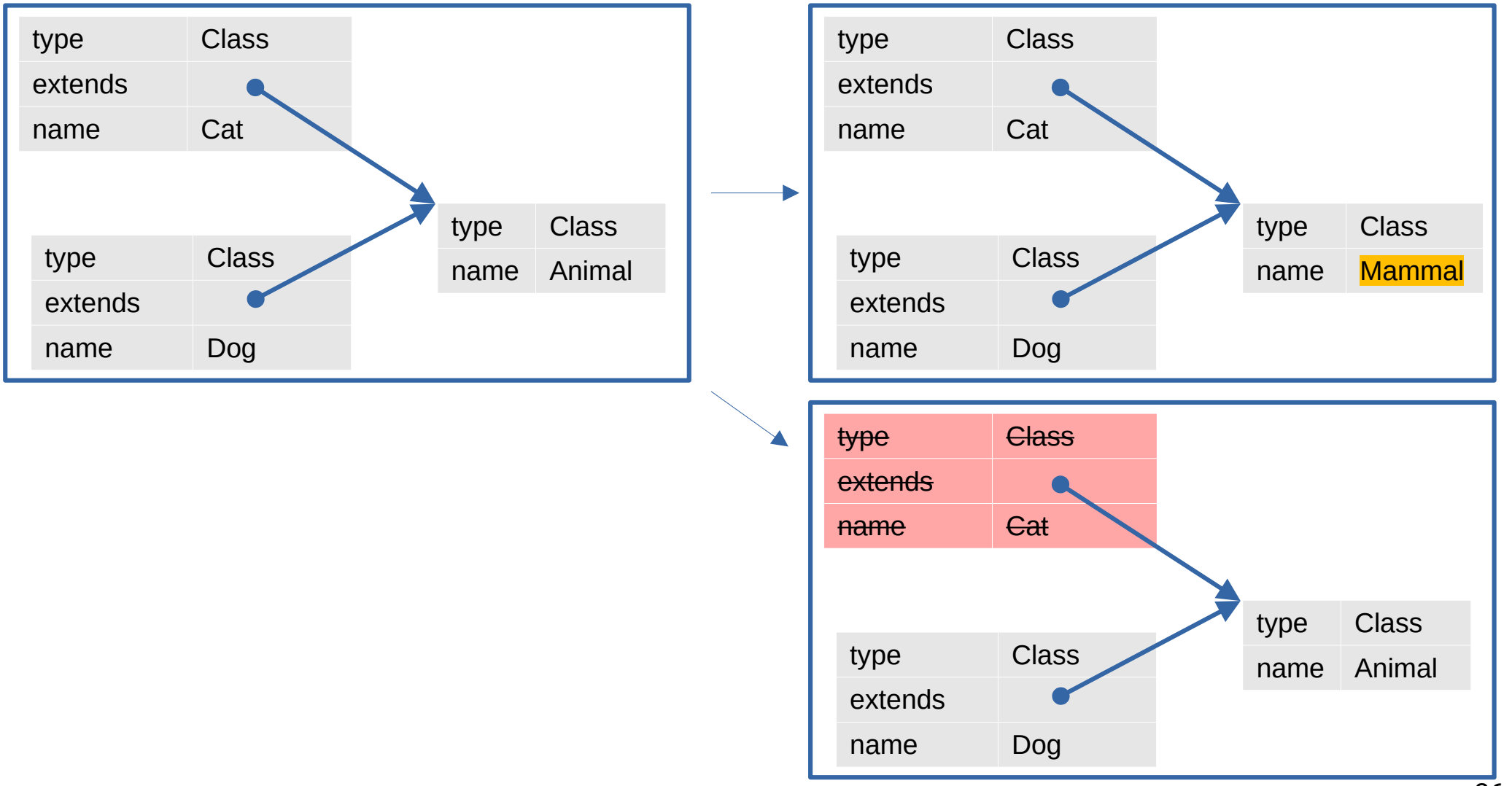
type
Class
extends
name
Dog
type
Class
name
Mammal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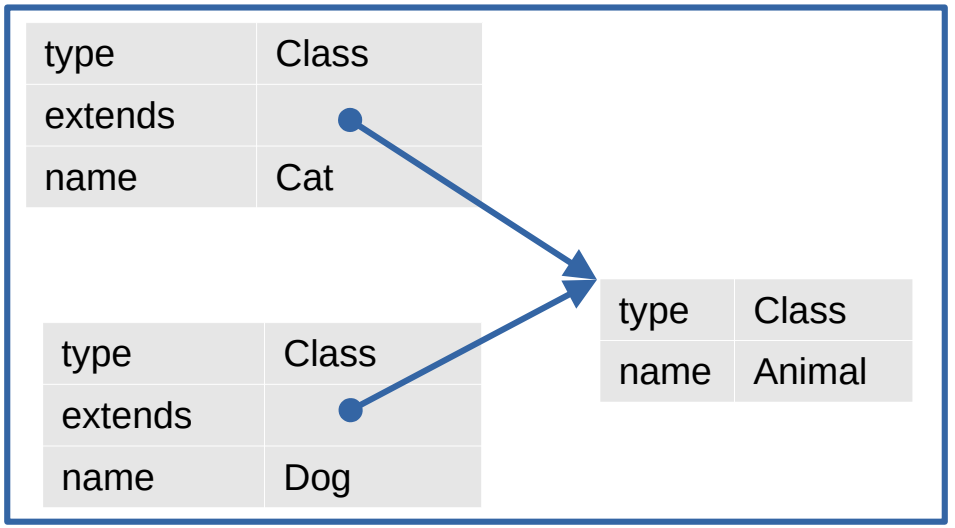
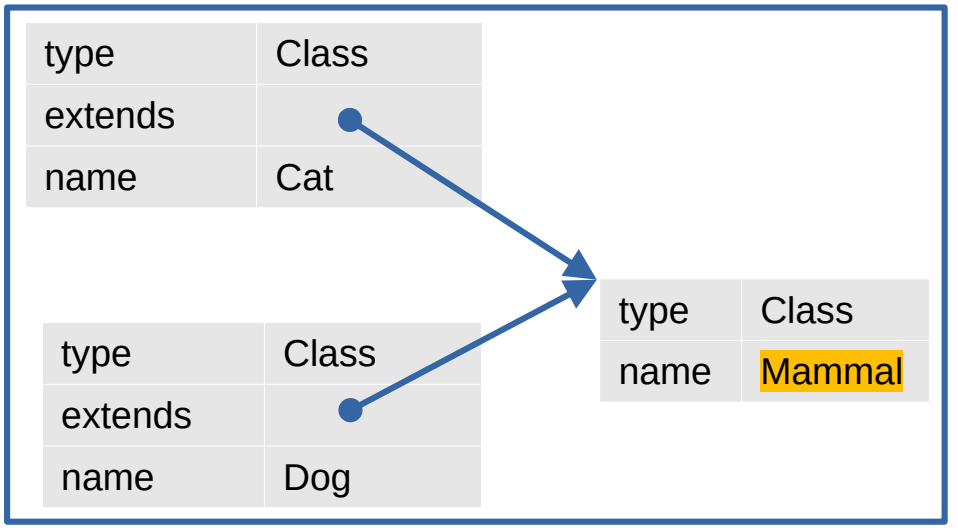
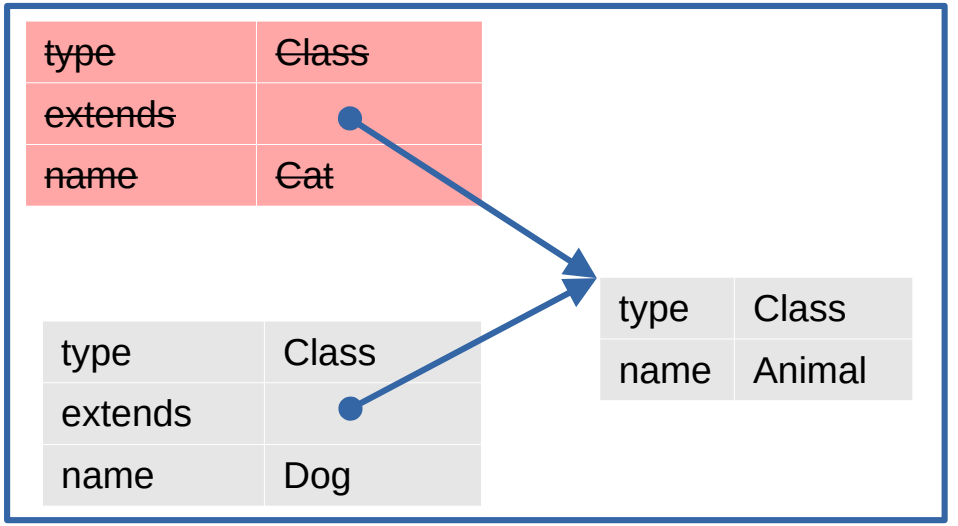




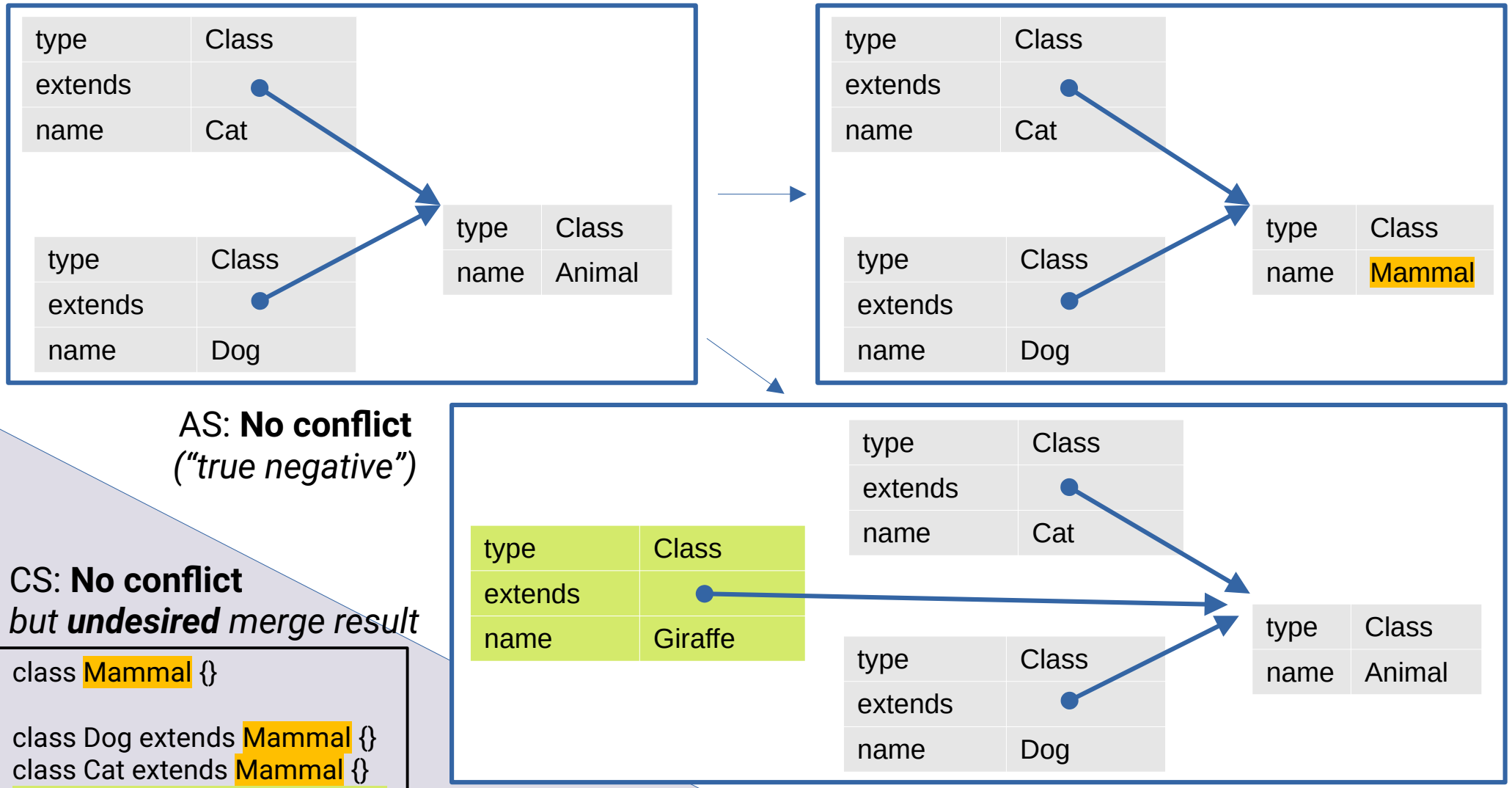
AS: **No conflict**
("true negative")



CS: **Conflict**
("false positive")

class Mammal {}

class Dog extends Mammal {}
~~class Cat extends Mammal {}~~


type Class
extends
name Cat
type Class
extends
name Dog
type Class
name Animal
type Class
extends
name Cat
type Class
extends
name Dog
type Class
name Mammal
AS: No conflict
("true negative")
type Class
extends
name Giraffe
type Class
extends
name Cat
type Class
extends
name Dog
type Class
name Animal
CS: No conflict
but undesired merge result
class Mammal {}
class Dog extends Mammal {}
class Cat extends Mammal {}
class Giraffe extends Animal {}

Beyond git: 1) Versioning the abstract syntax

- Benefits
  - Fewer “false positive” conflicts
  - Abstract syntax closer to semantics of language
    => captures better the intention
    => better merge results

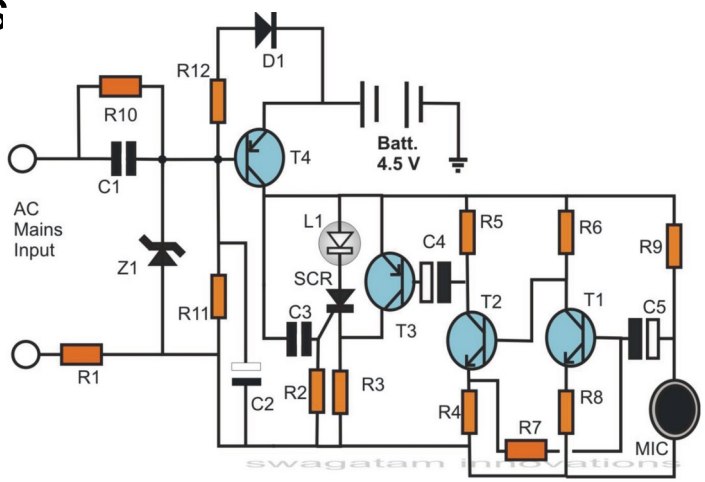
- However… (next slide)

Beware: only versioning the abstract syntax is undesirable

- Concrete syntax contains **more** information than abstract syntax
  - e.g., textual syntax: order of declarations
  - e.g., visual syntax: layout of elements

```
class Animal {}

class Dog extends Animal {}
class Cat extends Animal {}
```

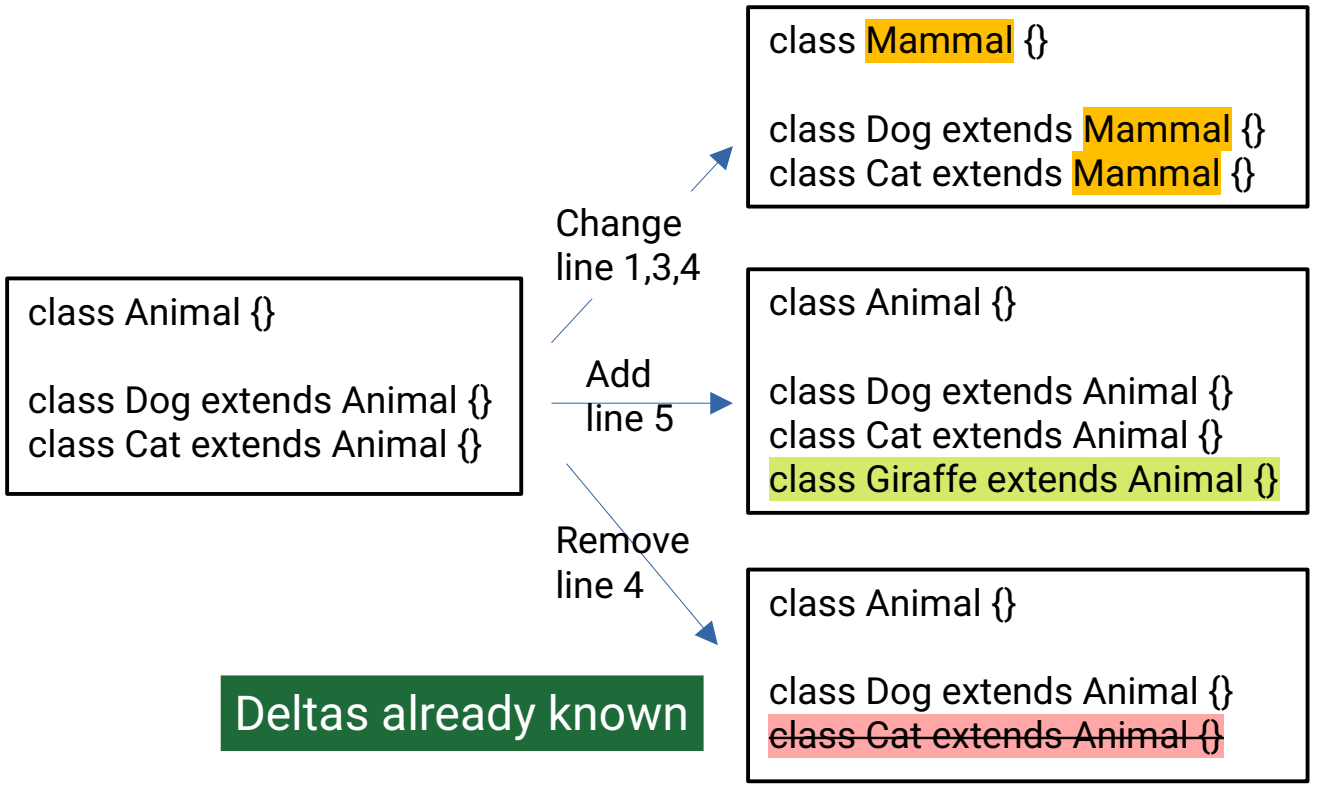


- This information is **useful** for **humans**
- Losing this information leads to ***layout discontinuity***

Beyond git: 2) Operation-based versioning

- Persist deltas immediately after they happen
  - no diffing
  - no need to record snapshots (can be restored from the deltas)
  - Version == sequence of deltas
- Can compute conflicts between deltas in advance (before merging)
  - can persist conflict relations

Beyond git: 2) Operation-based versioning



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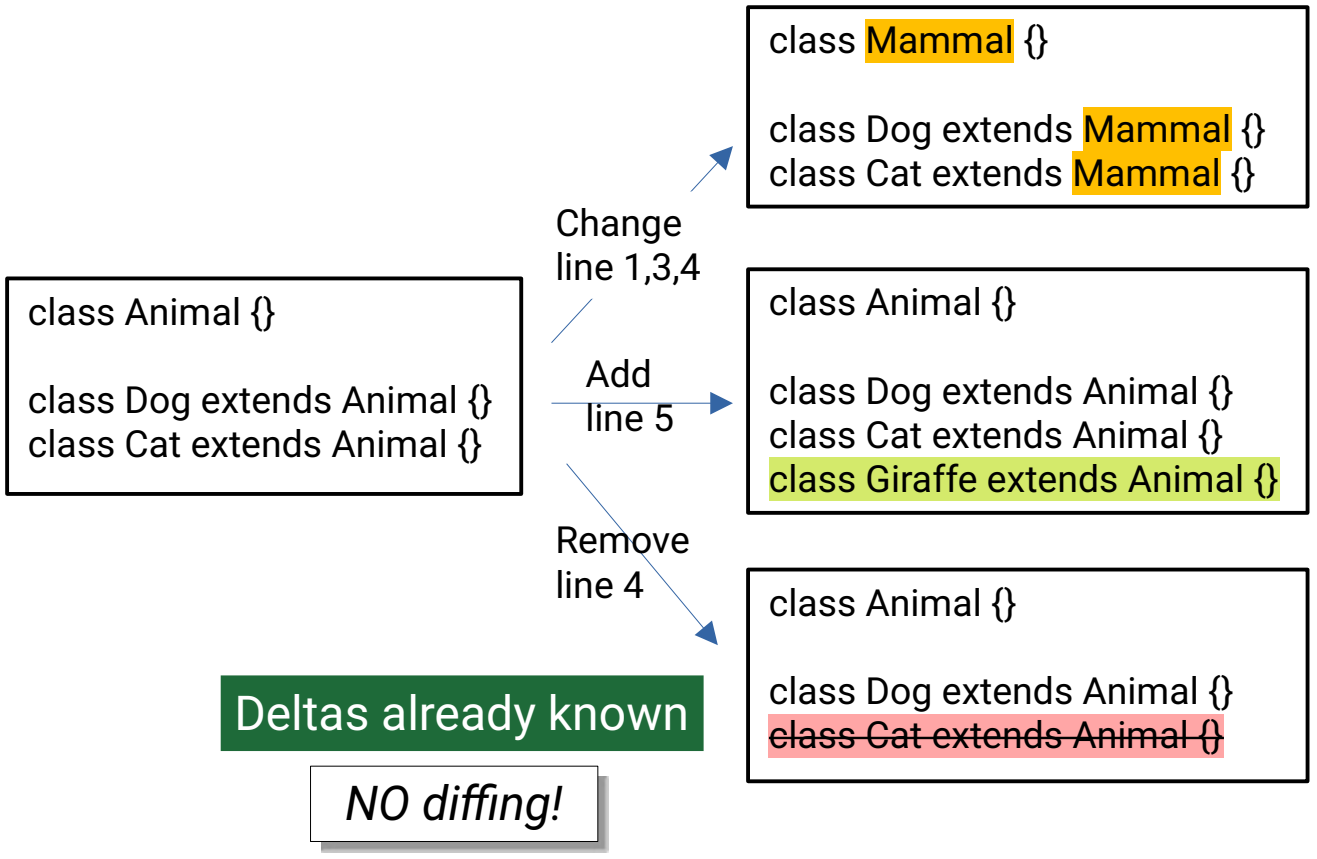

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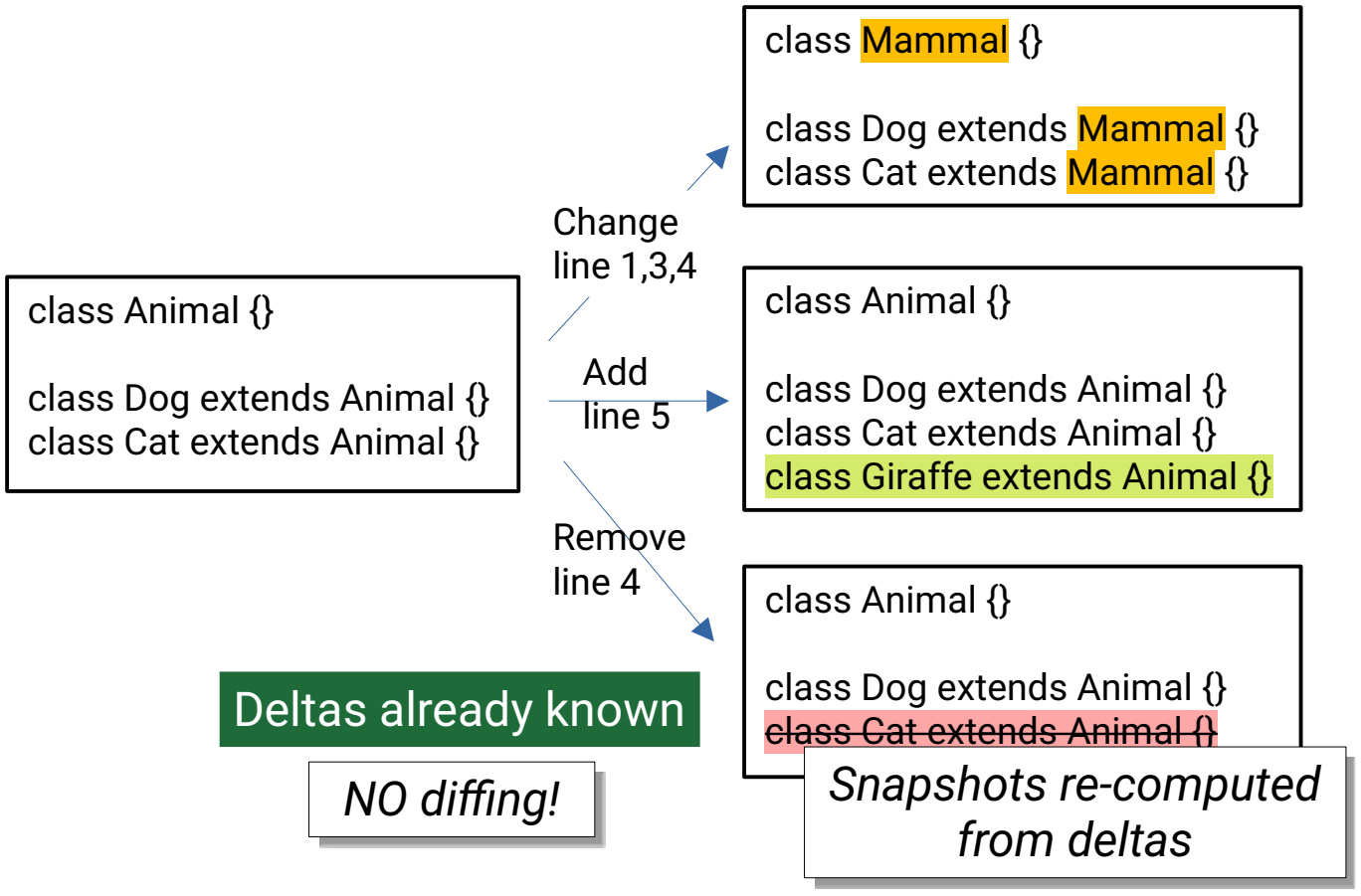

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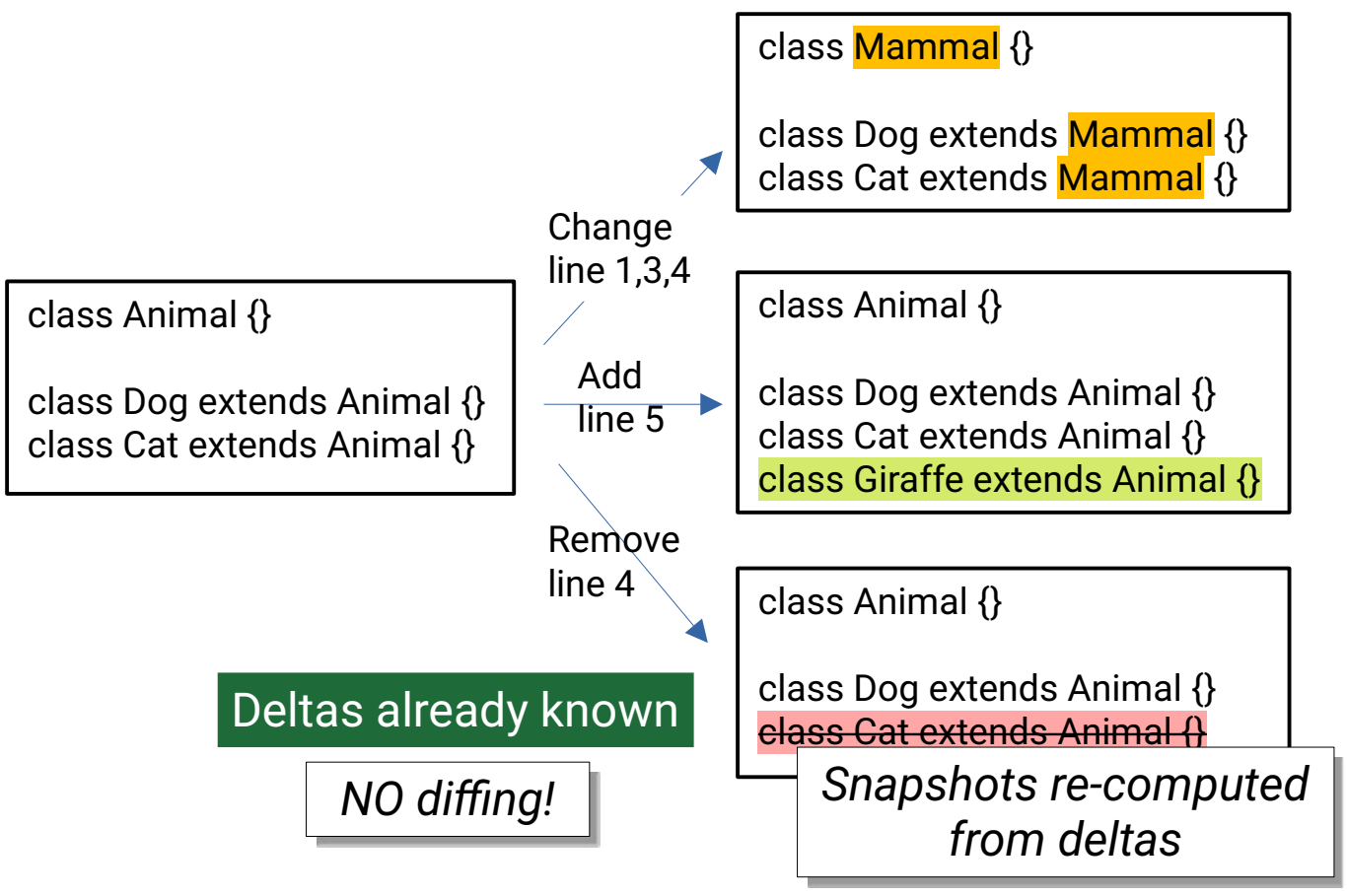

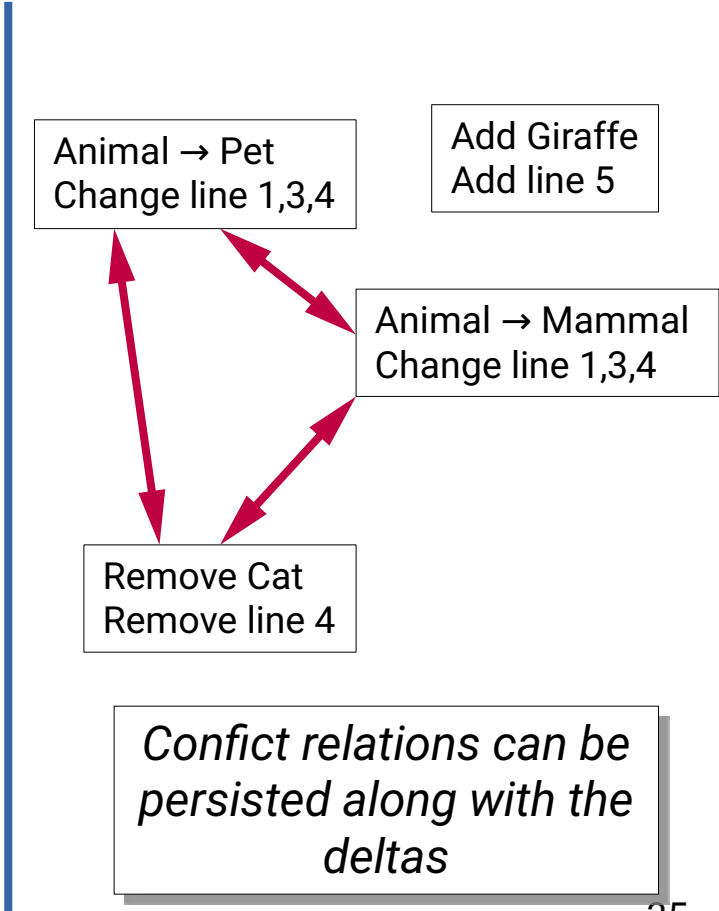

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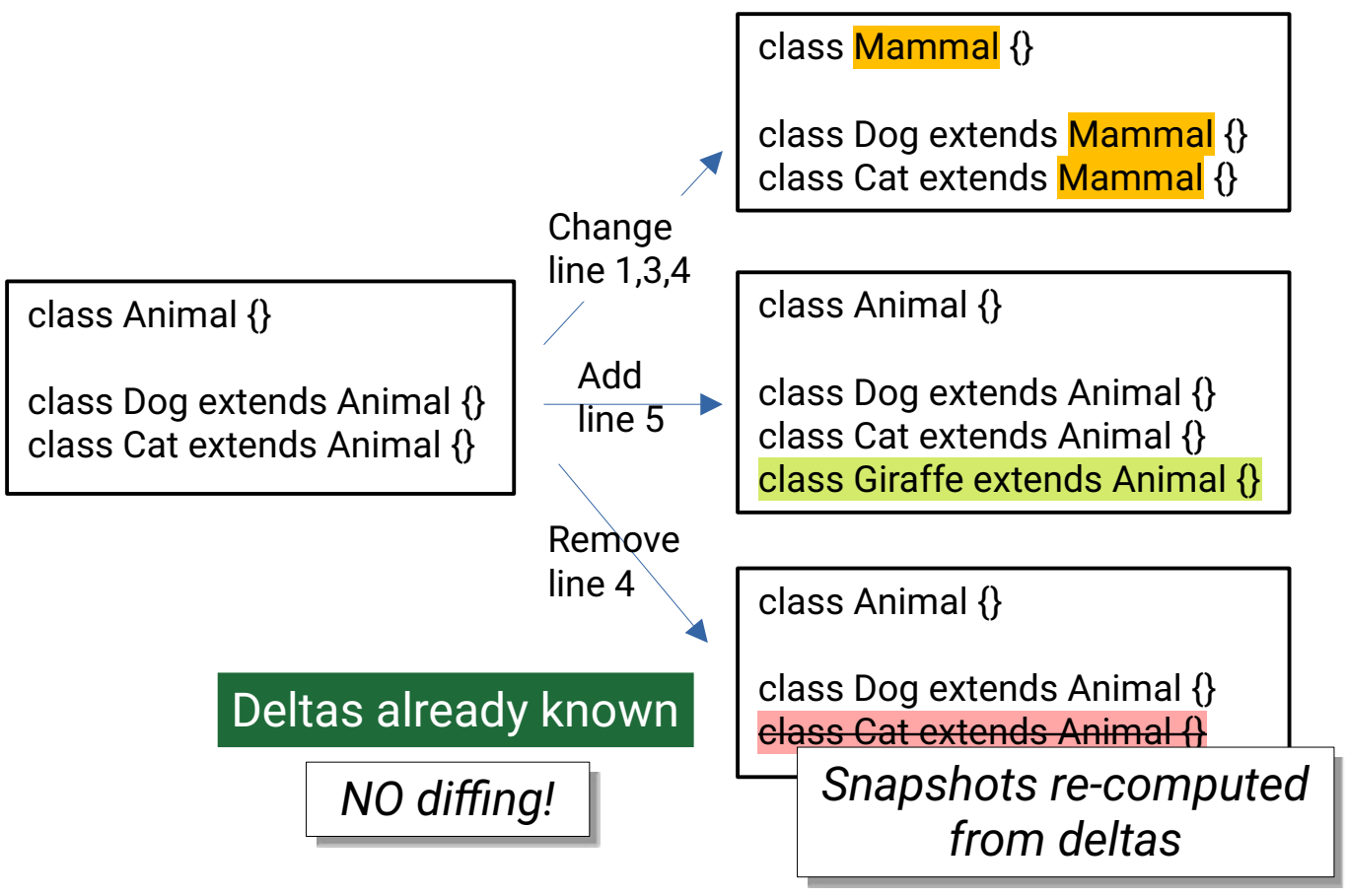

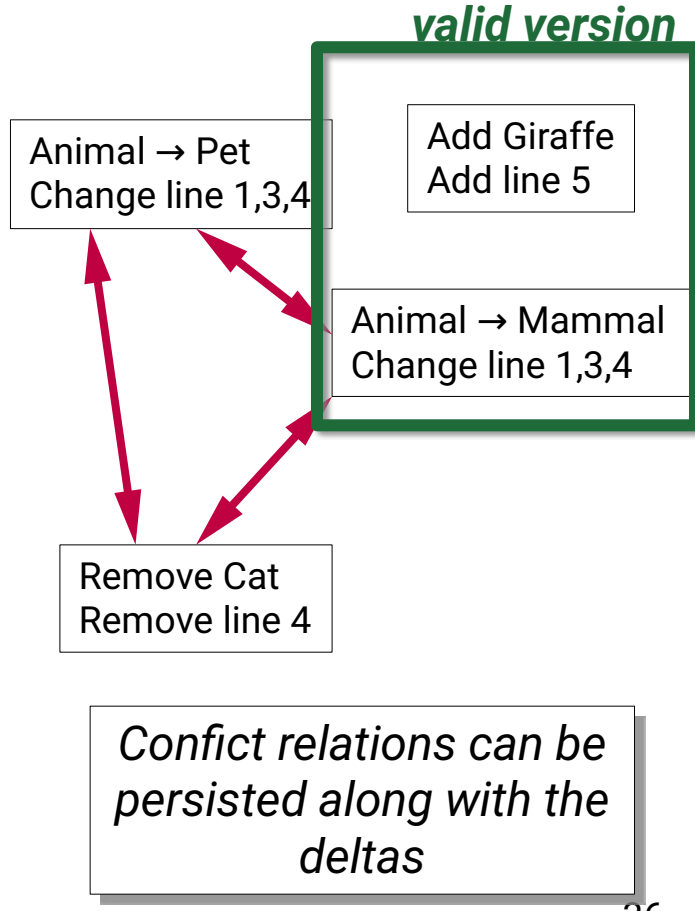

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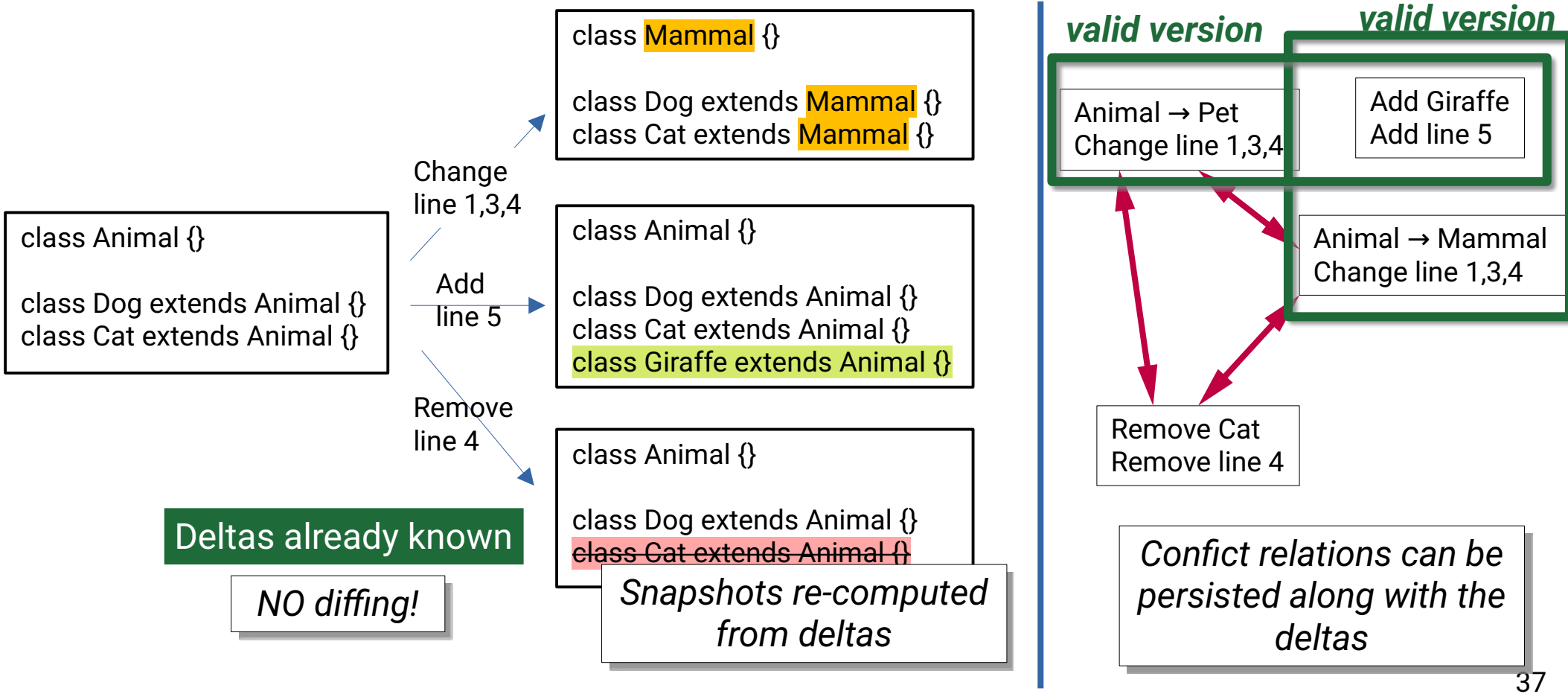

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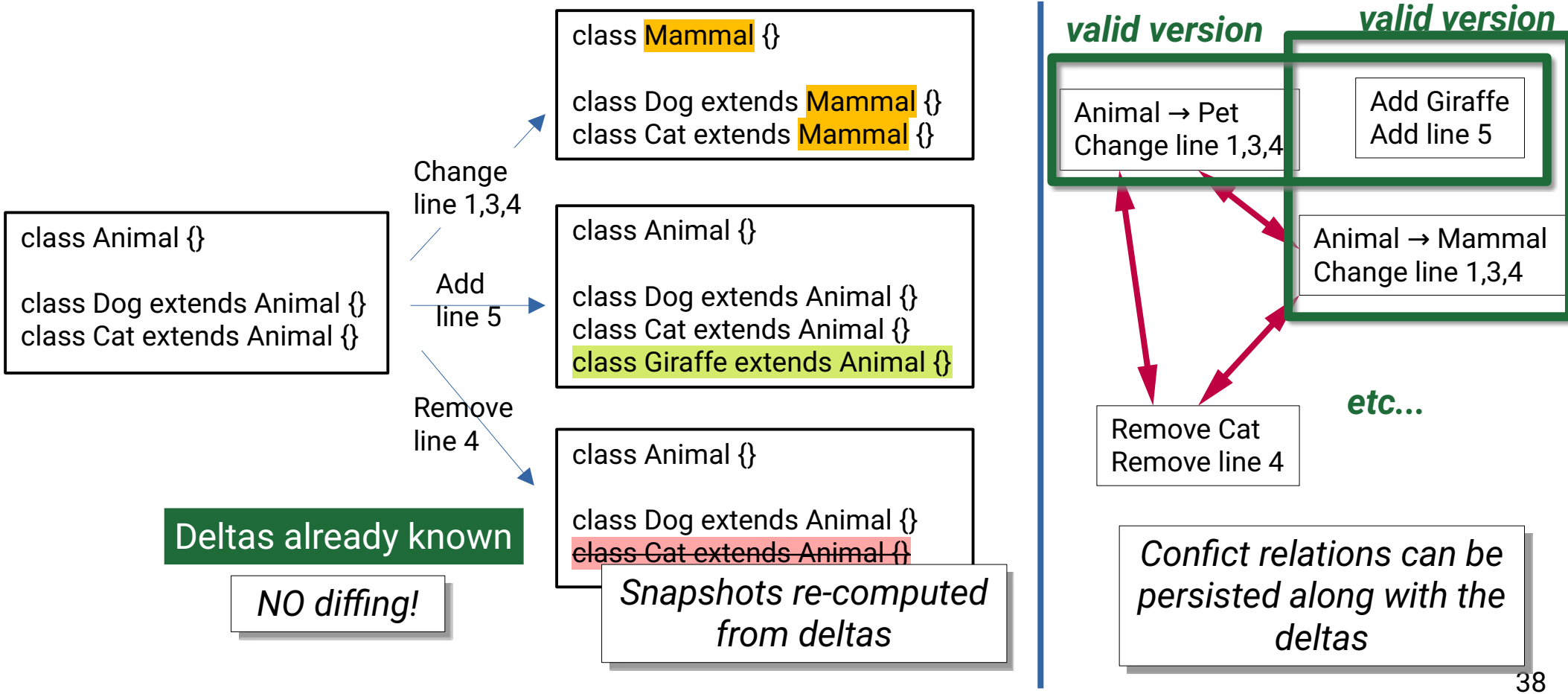


Beyond git: 2) Operation-based versioning

- Benefits
  - **More efficient** (does the work up front)
    - no diffing
    - no need to store snapshots (containing duplicate information)
  - Can persist **additional information** about deltas
    - conflicts
    - dependencies (explained later...)
  - Fine-grained edit history (every edit operation is recorded)
    - can also become a downside: drowning in information…
  - Need deltas **not only for merging**, but also:
    - “live” collaboration (e.g., Google Docs)
      - send deltas over network, rather than state snapshots
    - incremental transformations (e.g., parsing, code generation, ...)

Beyond git: Related work

- Darcs (https://darcs.net/)
  - alternative to git (textual versioning)
  - persists deltas and their *dependencies* (explained later…)
    (performs eager diffing)
  - written in Haskell

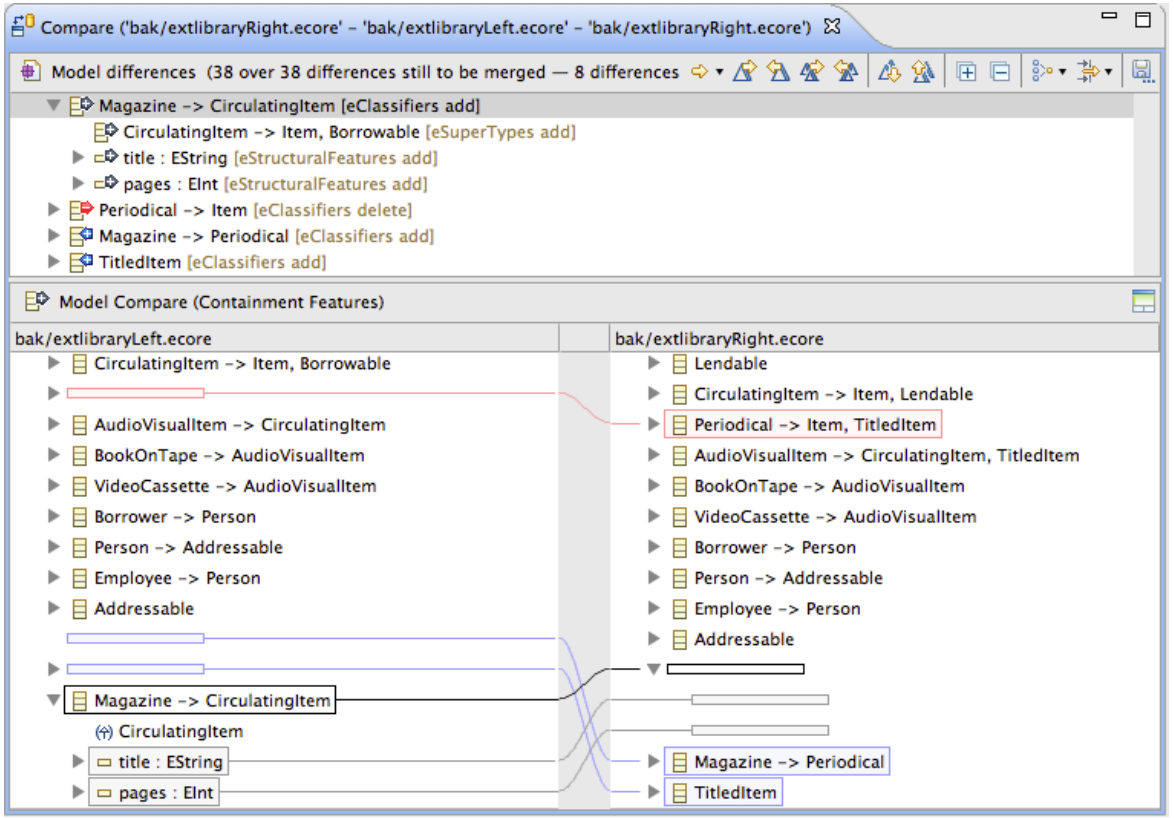
- Pijul (https://pijul.org/)
  - inspired by and similar to Darcs, but claims better performance
  - “theoretically sound”
  - written in Rust

Background: Versioning in model-driven engineering

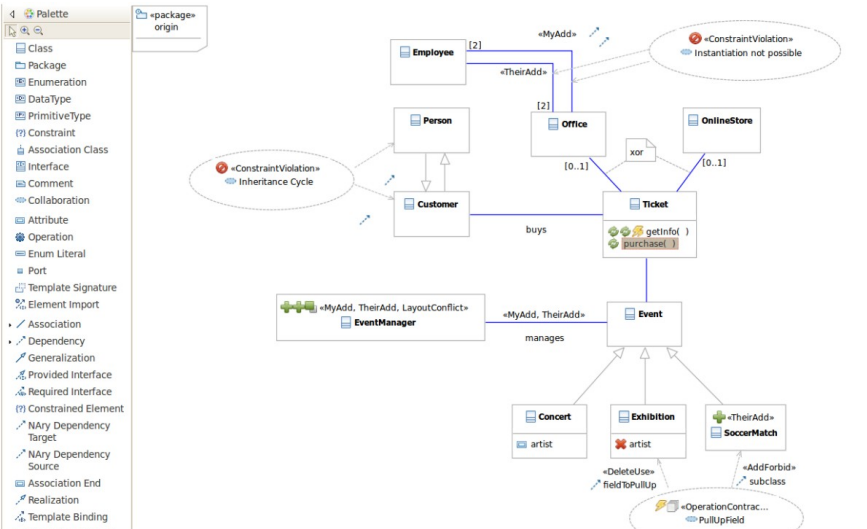
- **Text-based** versioning (e.g., git, SVN) is a poor fit for MDE
  - for models, can only take snapshots of *serializations* (e.g., XML)
  - often have “false positive” conflicts

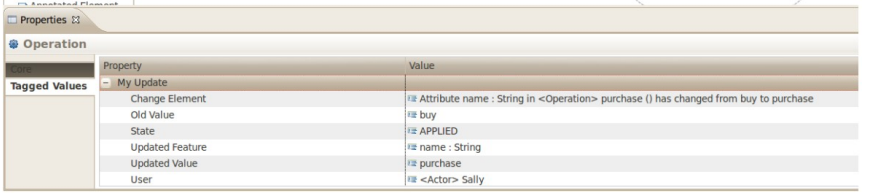
- **Model-specific** versioning solutions work primarily at the level of **abstract syntax**
  - a 1:1 mapping between concrete and abstract syntax elements is assumed (concrete syntax == abstract syntax + icons)

    => very little “concrete syntax freedom”



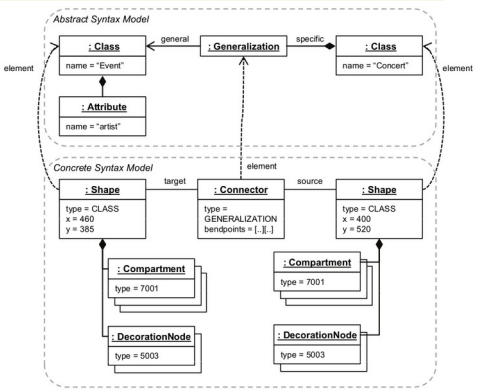
EMF Compare[1]





AMOR
Adaptable Model Versioning

2



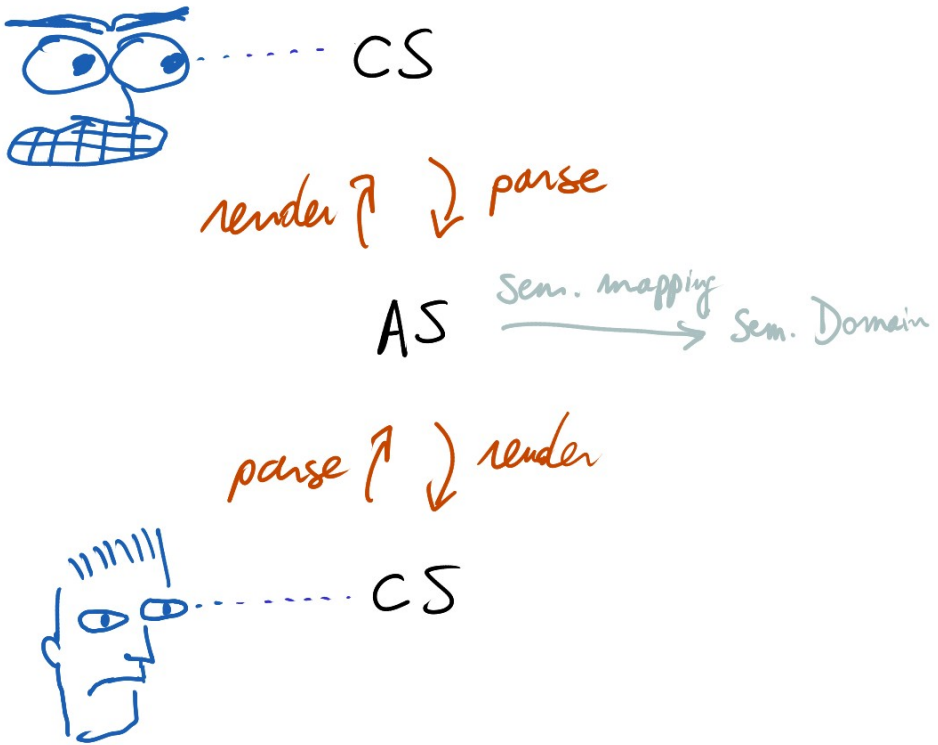
[1] https://www.eclipse.org/emf/compare/

[2] Petra Brosch, Martina Seidl, Manuel Wimmer, Gerti Kappel: **Conflict Visualization for Evolving UML Models**. J. Object Technol. 11(3): 2: 1-30 (2012)

Background: Blended modeling[1]

= Ability to *edit* a model (= abstract syntax)
through *multiple* concrete syntaxes

- Usability++: User can choose the **representation** that is **most efficient** for the current task
  - e.g., understanding connections between elements
    -> observe visual layout
  - e.g., renaming a variable
    -> find all/replace in textual CS
- Technical challenge: **<u>incremental</u> bi-directional synchronization** between CSs and AS



[1] Federico Ciccozzi, Matthias Tichy, Hans Vangheluwe, Danny Weyns: **Blended Modelling - What, Why and How**. MoDELS (Companion) 2019: 425-430

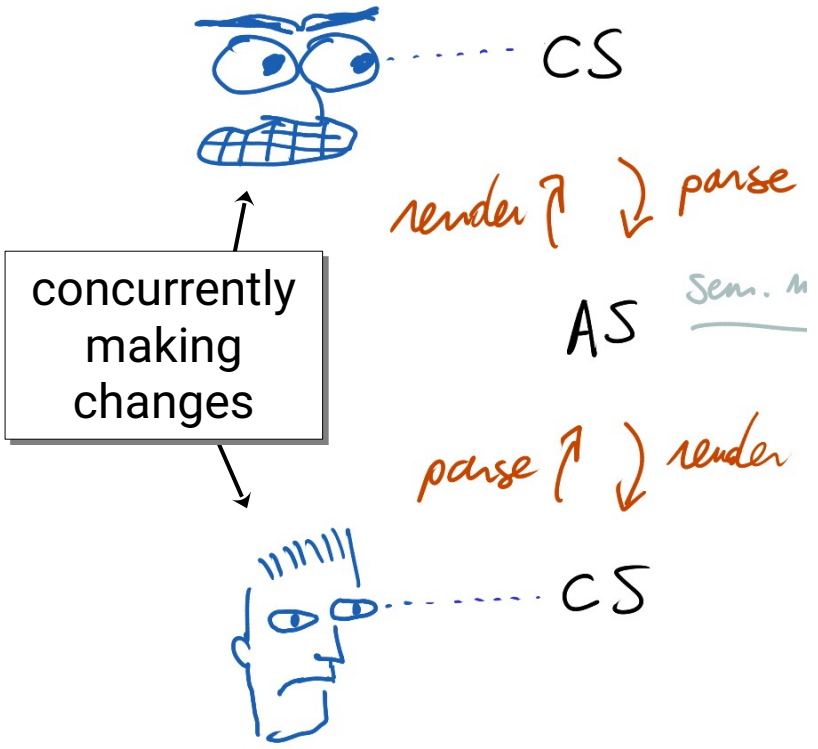
Research question

"What is needed to support collaborative blended modeling?"

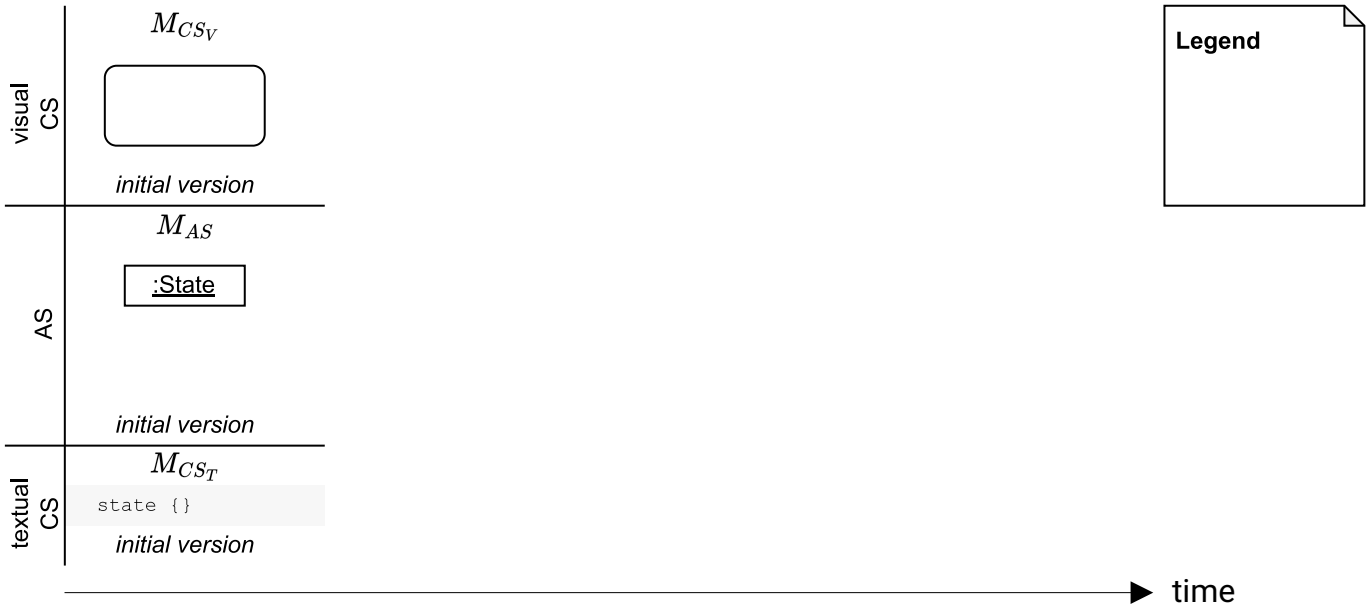
- branching
- detecting conflicts
- merging non-conflicting changes

At the level of:

- abstract syntax
- concrete syntaxes

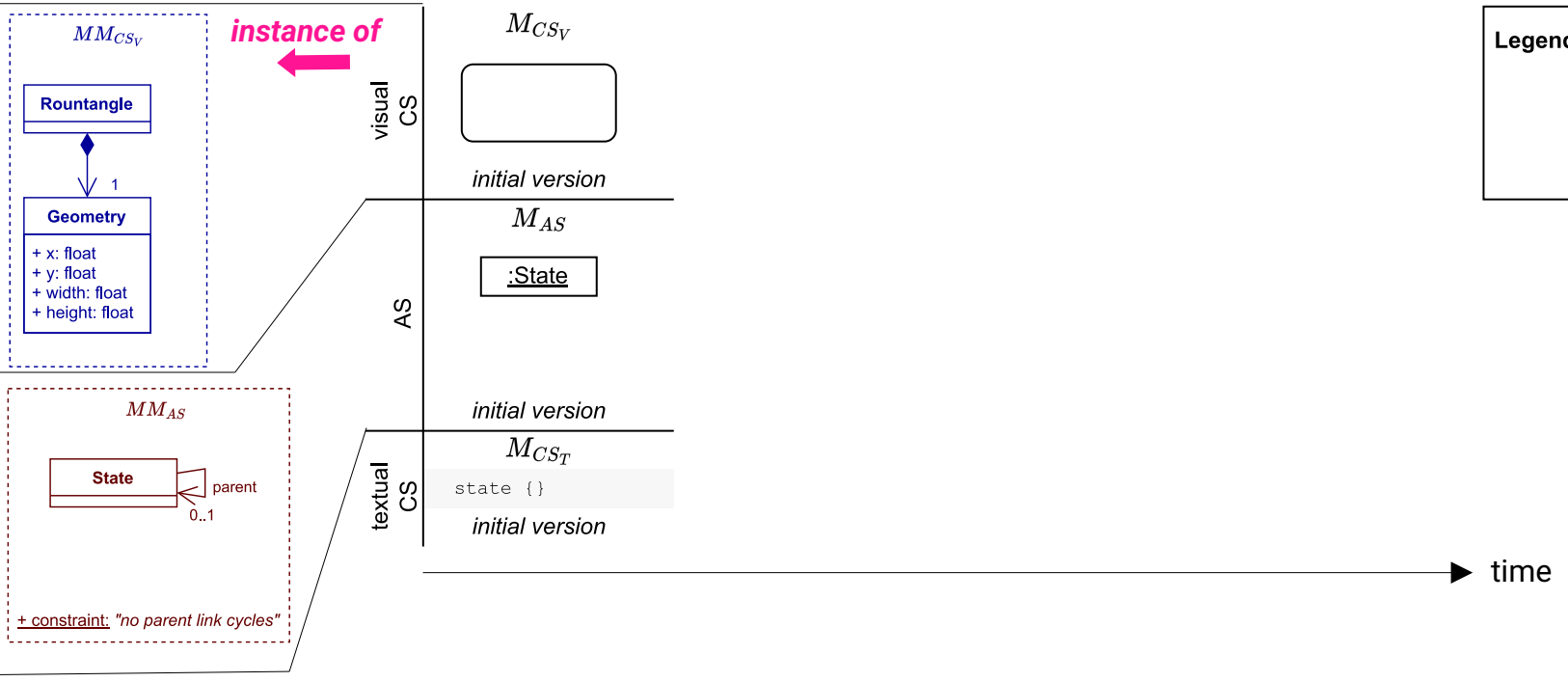


Running example: Concurrent edits × Blended modeling



Term "rountangle" was introduced by: David Harel: **On Visual Formalisms**. Commun. ACM 31(5): 514-530 (1988)

Running example: Concurrent edits × Blended modeling



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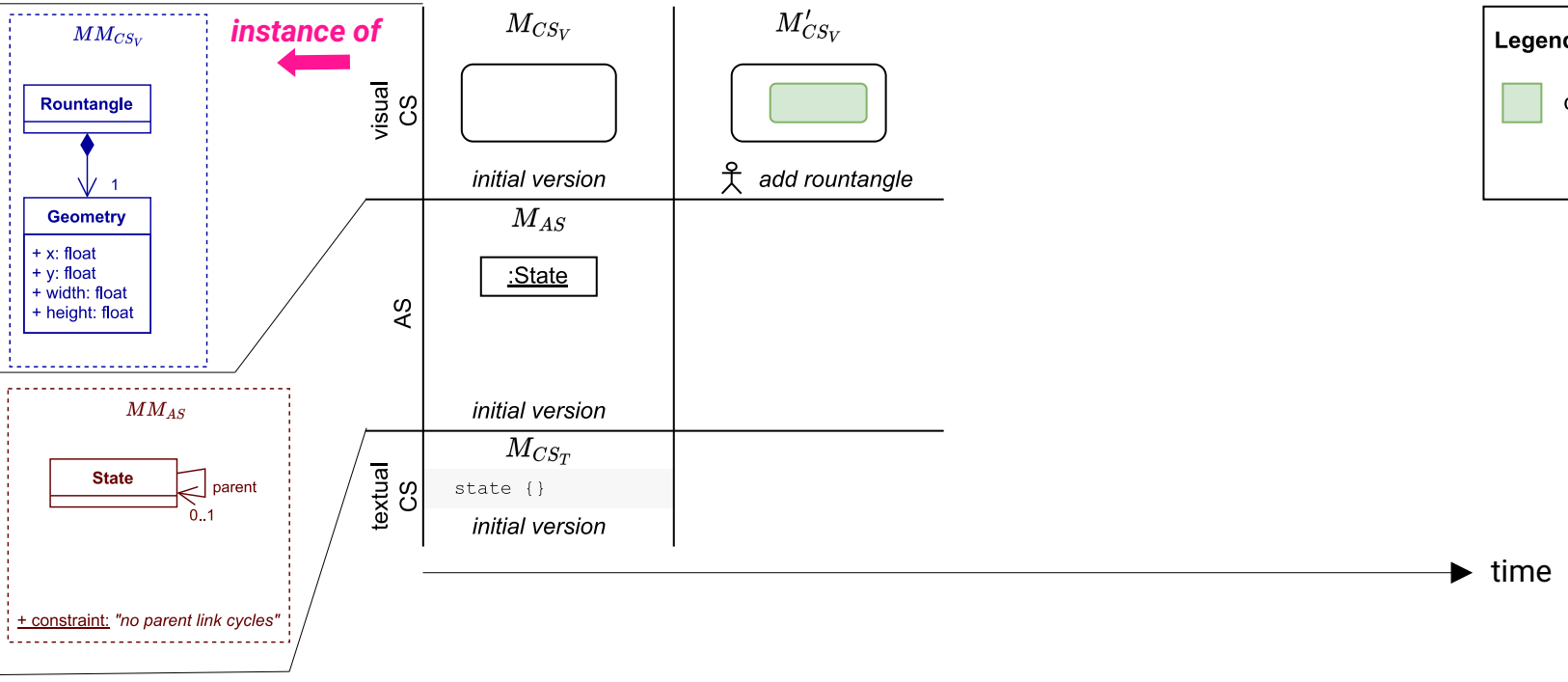
Running example: Concurrent edits × Blended modeling



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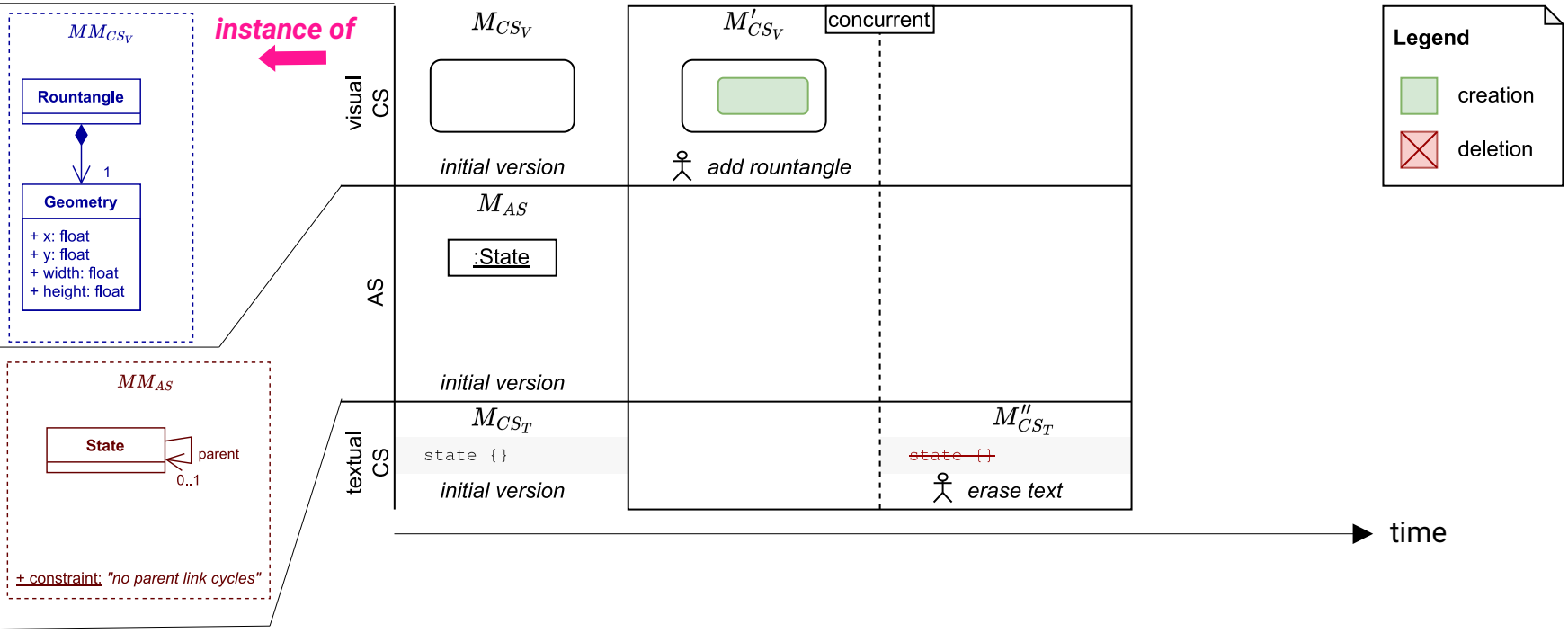
Running example: Concurrent edits × Blended modeling



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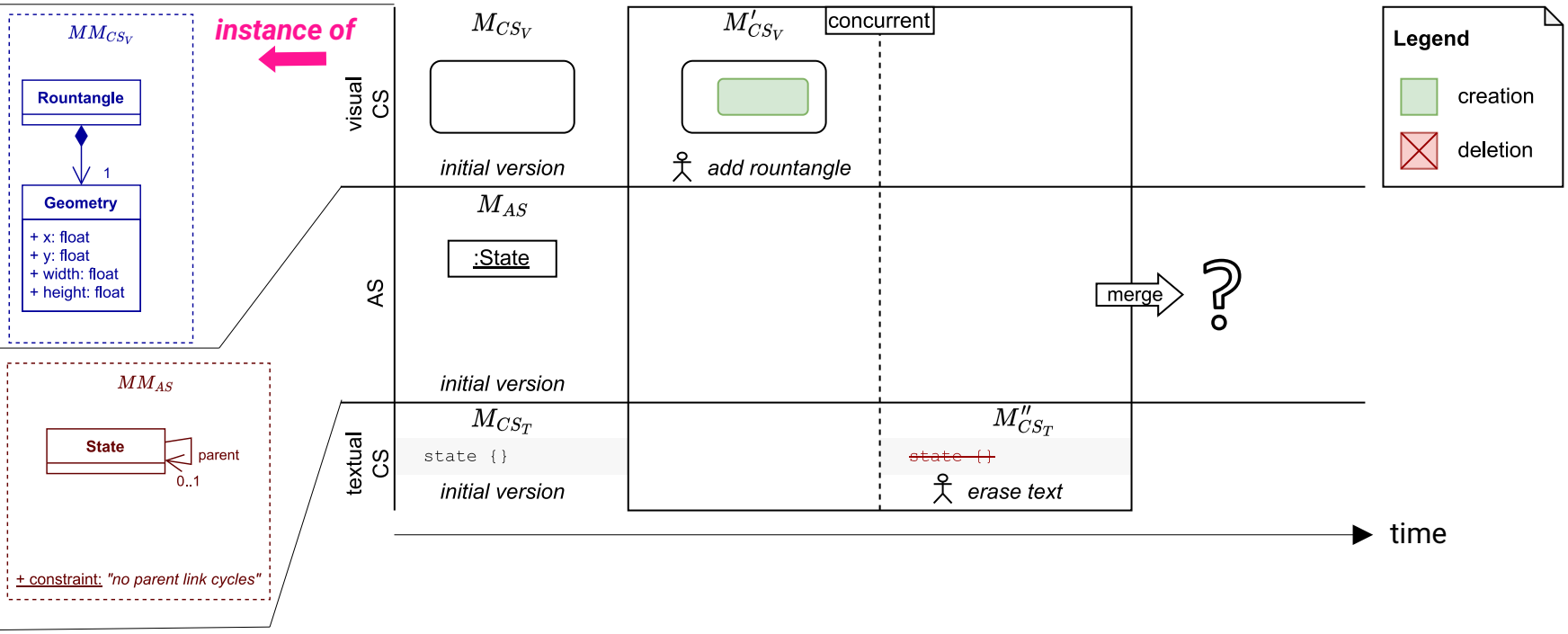

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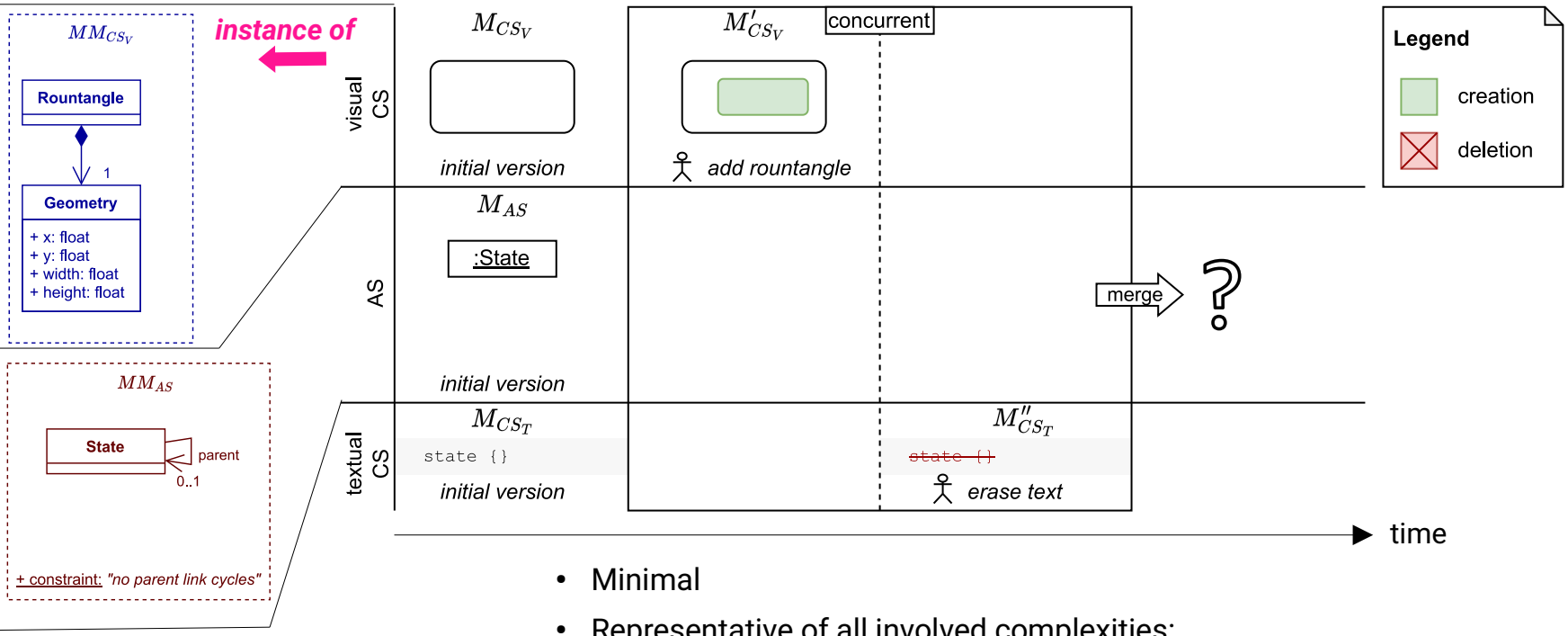
Running example: Concurrent edits × Blended modeling



- Minimal
- Representative of all involved complexities:
  - Concurrent edit operations
  - Bi-directional change propagation (CS <-> AS <-> CS)
  - Non-trivial CS <-> AS mappings

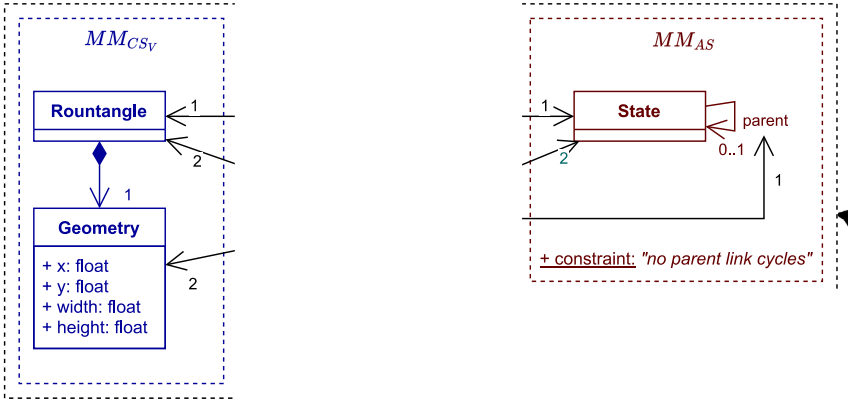
Term "rountangle" was introduced by: David Harel: **On Visual Formalisms**. Commun. ACM 31(5): 514-530 (1988)

Big picture of solution

- CS and AS are **both versioned**, and each conform to their **own metamodel** (inspired by [1])

  Running example:

  - visual CS metamodel: (vector) drawings (**reusable**!)
  - AS metamodel: Statecharts (simplified)

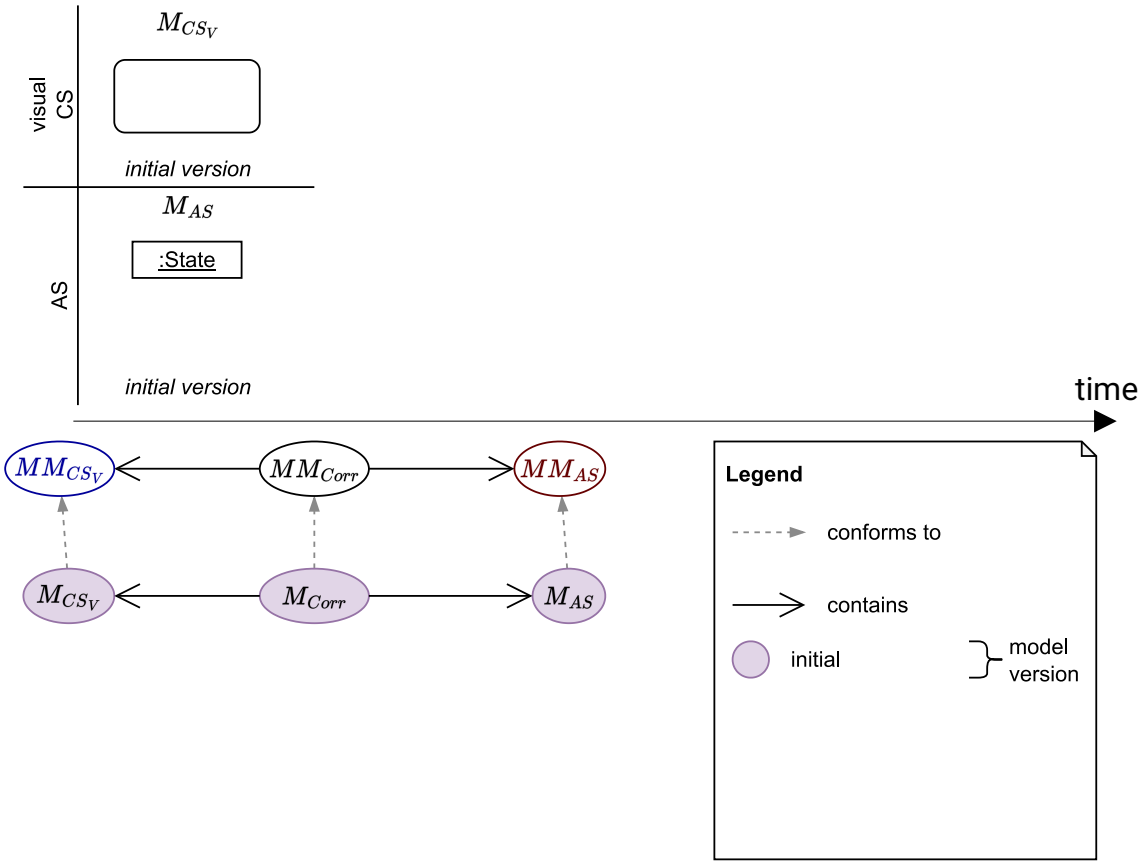


- Record correspondence links between CS and AS elements in **versioned correspondence model**
  - Idea taken from Triple Graph Grammars [2]
  - Correspondence model is **also versioned**, and also has its **own metamodel** (so-called “meta-triple”)

[1] Yentl Van Tendeloo, Hans Vangheluwe: **Unifying Model- and Screen Sharing**. WETICE 2018: 127-132
[2] Andy Schürr: **Specification of Graph Translators with Triple Graph Grammars**. WG 1994: 151-163

Running example: Co-evolving CS, Corr, AS

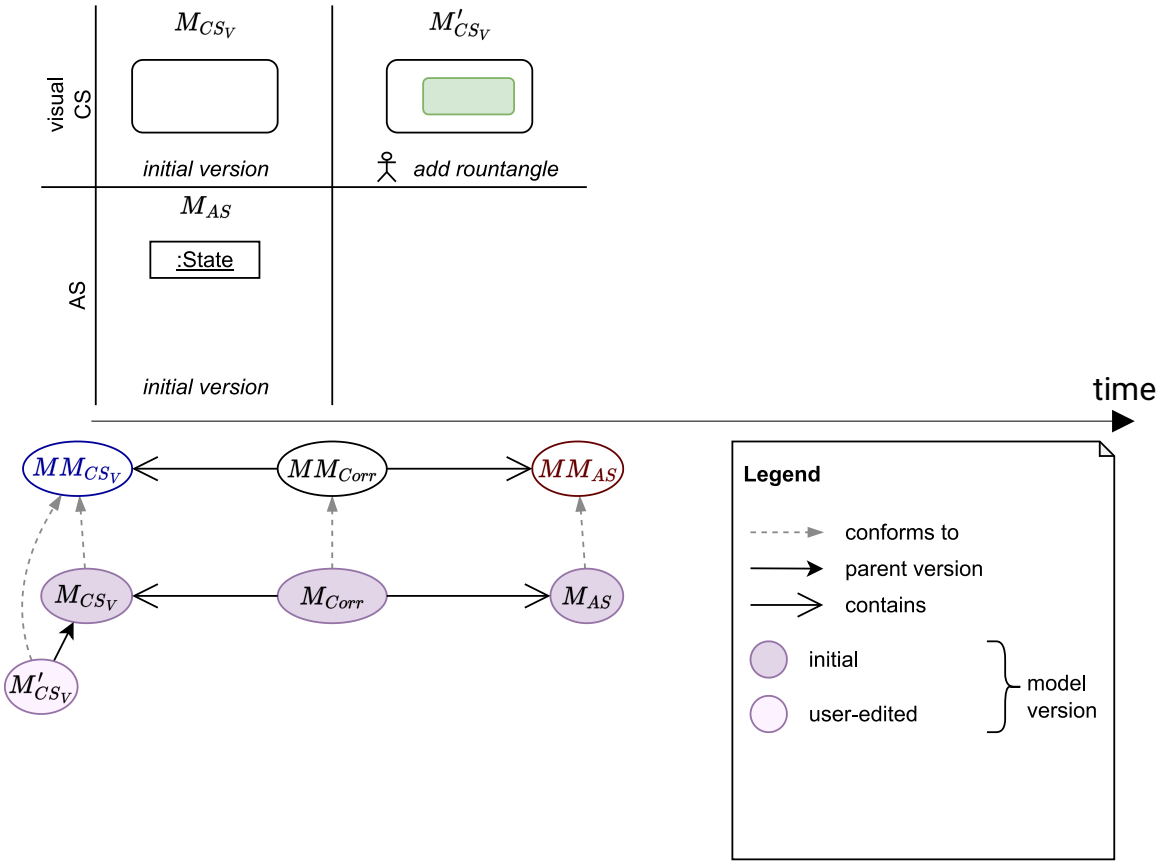
1. Initial versions of CS and AS



Running example: Co-evolving CS, Corr, AS

1. Initial versions of CS and AS

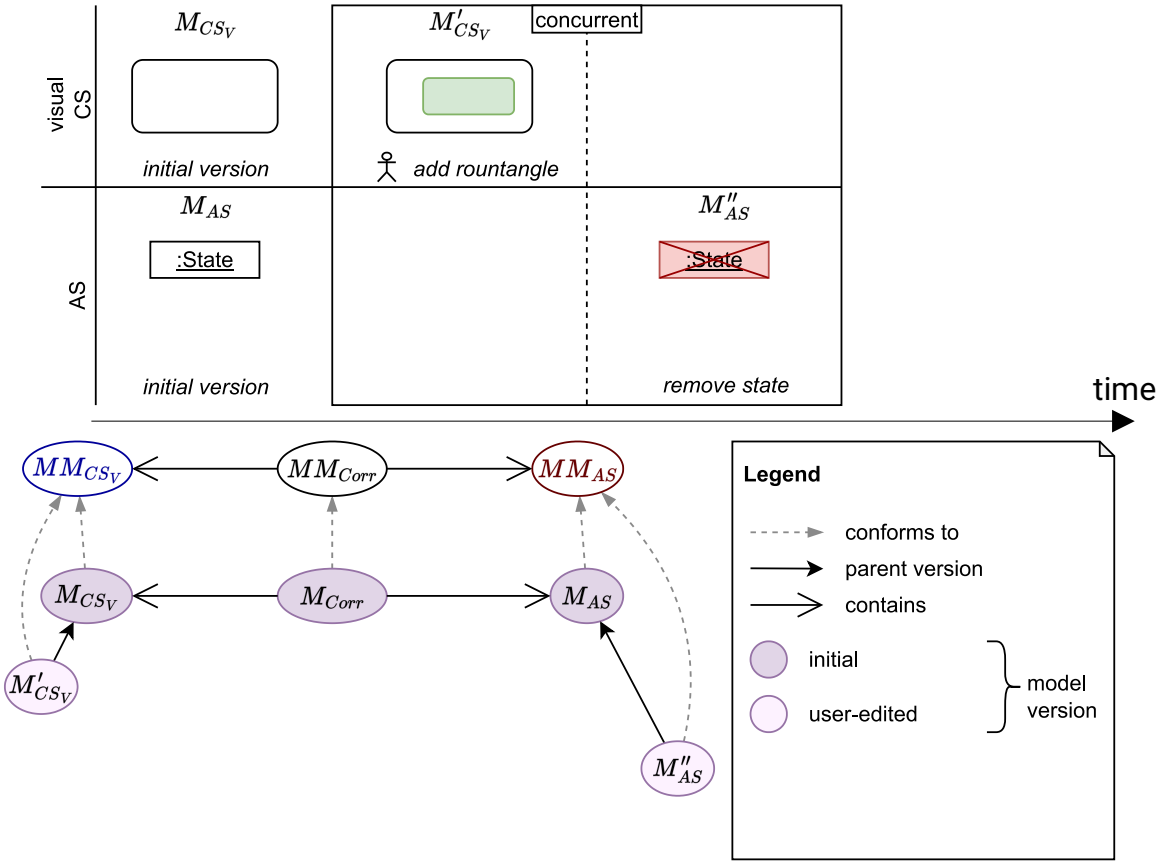
2.
   i. User change in CS creates a new CS model version



Running example: Co-evolving CS, Corr, AS

1. Initial versions of CS and AS

2. Concurrently:
   i. User change in CS creates a new CS model version
   ii. User change in AS creates a new AS model version

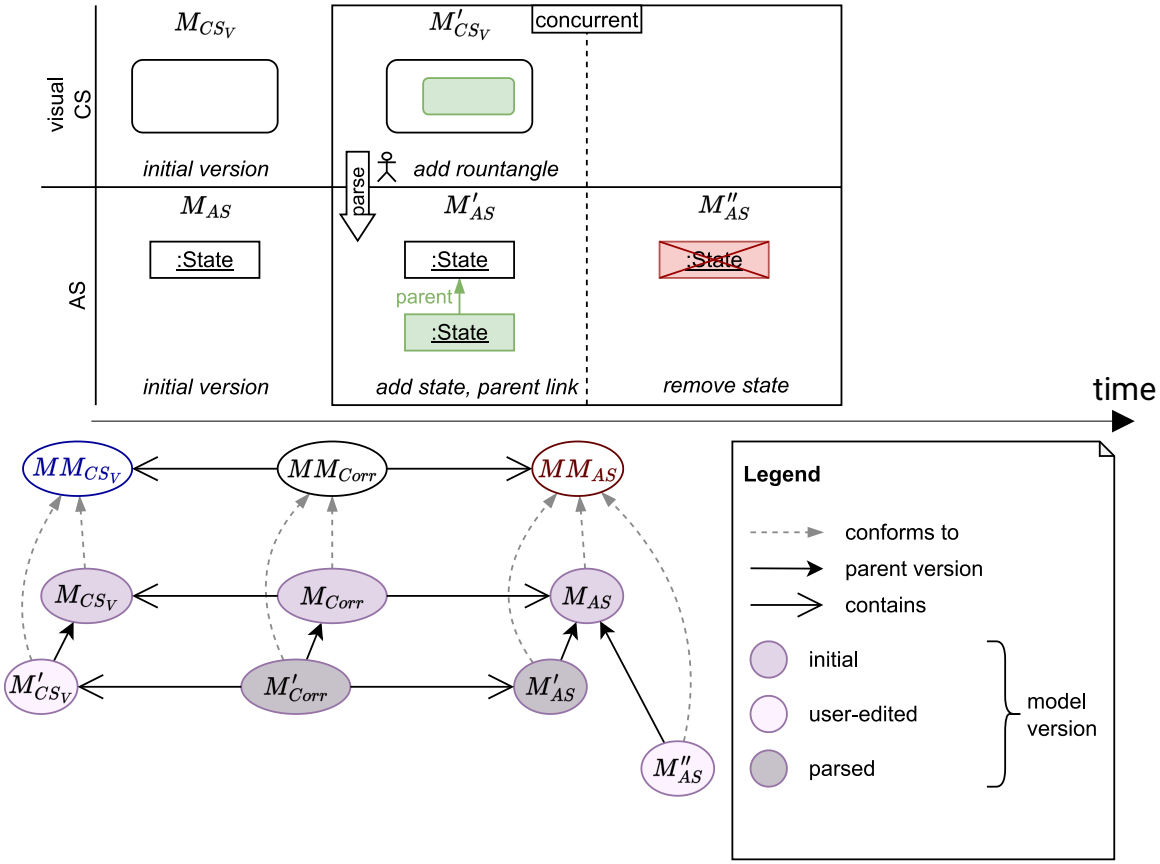


Running example: Co-evolving CS, Corr, AS

1. Initial versions of CS and AS

2. Concurrently:
   i. User change in CS creates a new CS model version
   ii. User change in AS creates a new AS model version

3.
   i. Parse changes to CS, resulting in new AS (+Corr) model version

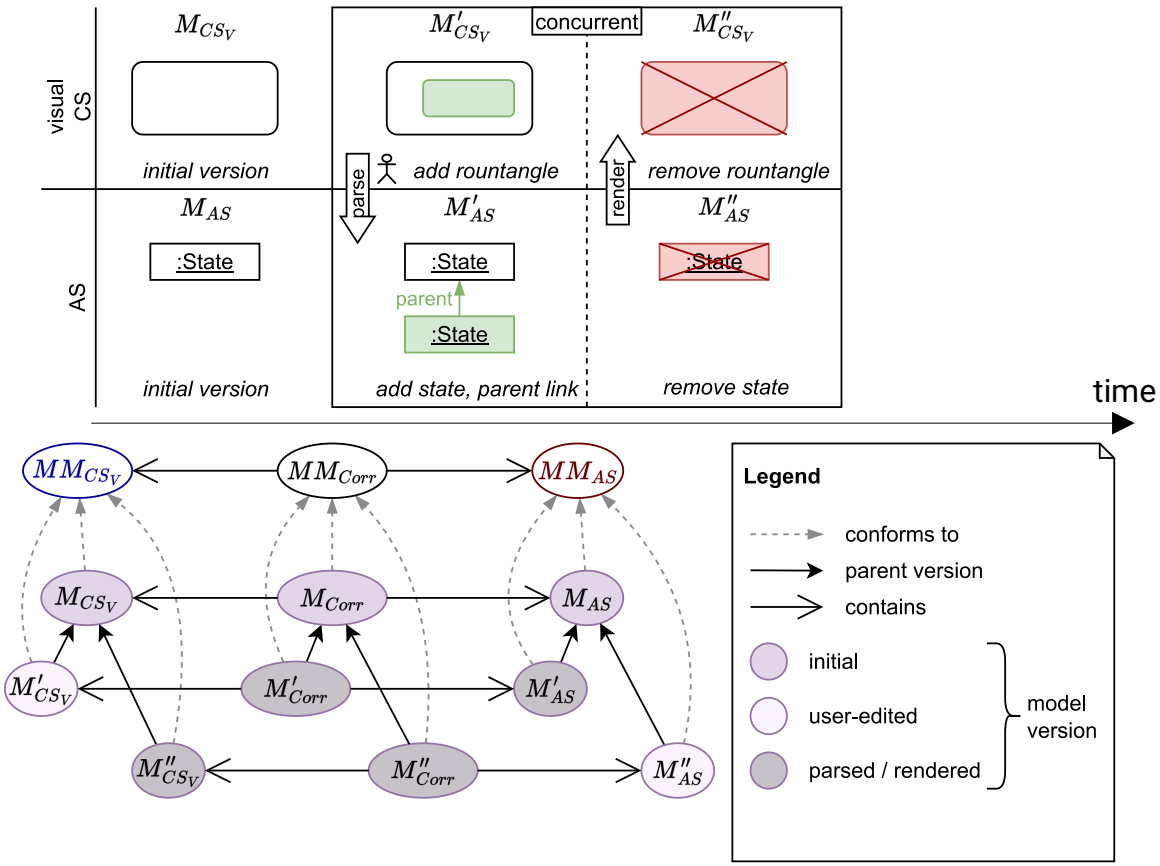


Running example: Co-evolving CS, Corr, AS

1. Initial versions of CS and AS

2. Concurrently:
   i. User change in CS creates a new CS model version
   ii. User change in AS creates a new AS model version

3.
   i. Parse changes to CS, resulting in new AS (+Corr) model version
   ii. Render changes to AS, resulting in new CS (+Corr) model version

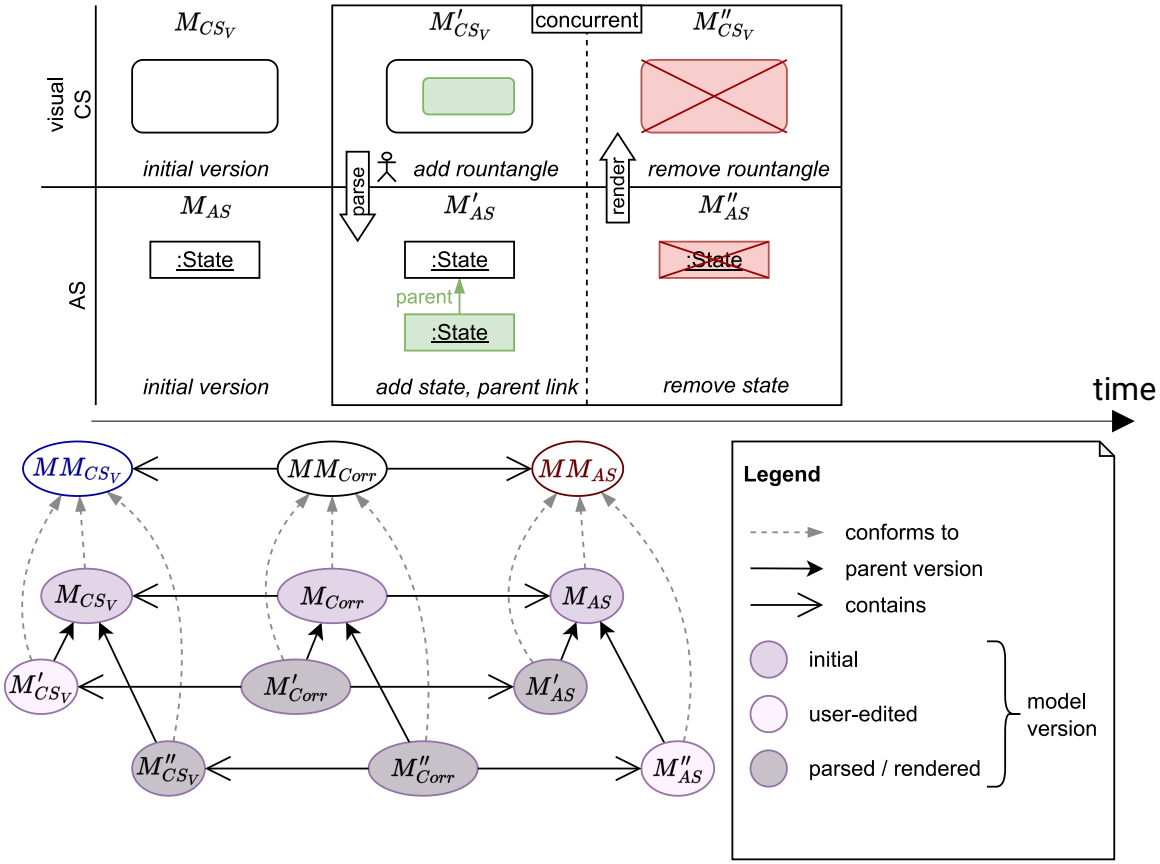


Running example: Co-evolving CS, Corr, AS

1. Initial versions of CS and AS

2. Concurrently:
   i. User change in CS creates a new CS model version
   ii. User change in AS creates a new AS model version

3. (in *any* order, at *any* time)
   i. Parse changes to CS, resulting in new AS (+Corr) model version
   ii. Render changes to AS, resulting in new CS (+Corr) model version



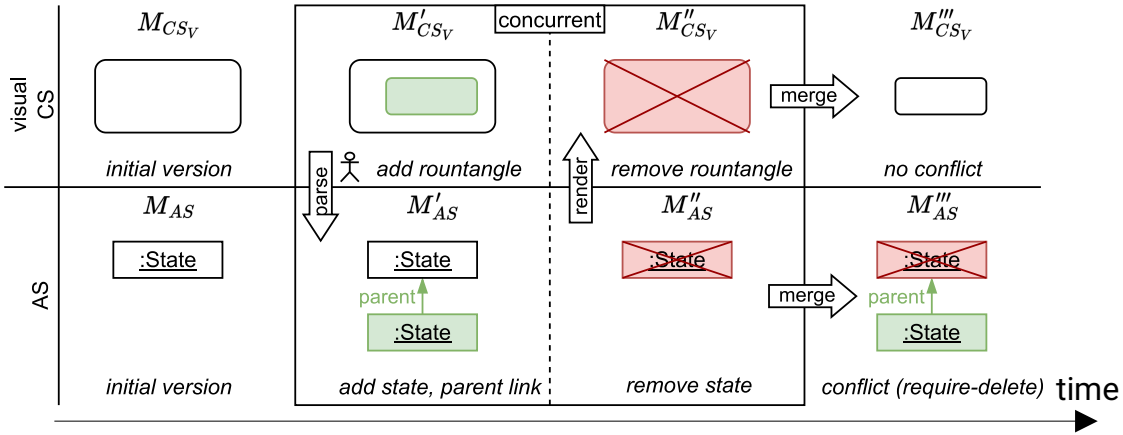
Running example: Co-evolving CS, Corr, AS

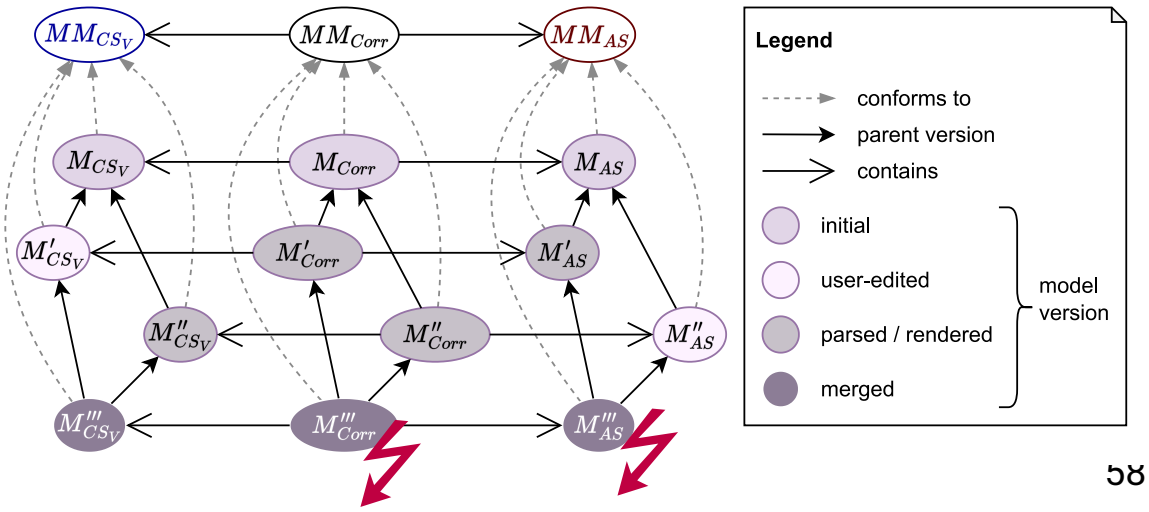
1. Initial versions of CS and AS

2. Concurrently:
   i. User change in CS creates a new CS model version
   ii. User change in AS creates a new AS model version

3. (in *any* order, at *any* time)
   i. Parse changes to CS, resulting in new AS (+Corr) model version
   ii. Render changes to AS, resulting in new CS (+Corr) model version

4. (Attempt to) merge concurrent versions at level of CS, AS, Corr





To be addressed

- **What** exactly is **recorded** in history?
- **How** do we **merge** concurrent versions and **detect conflicts?**
- **How** and **when** do we **parse** and **render**?

Parsing and rendering must happen **incrementally**

*Meaning: a change to CS must **only cause a corresponding change** to AS (instead of generating a new AS model), and vice versa.*

- Reasons:
  - for layout continuity
  - to deal with concurrency
  - for performance
- Fits nicely with **operation-based versioning**

How do we apply operation-based versioning?

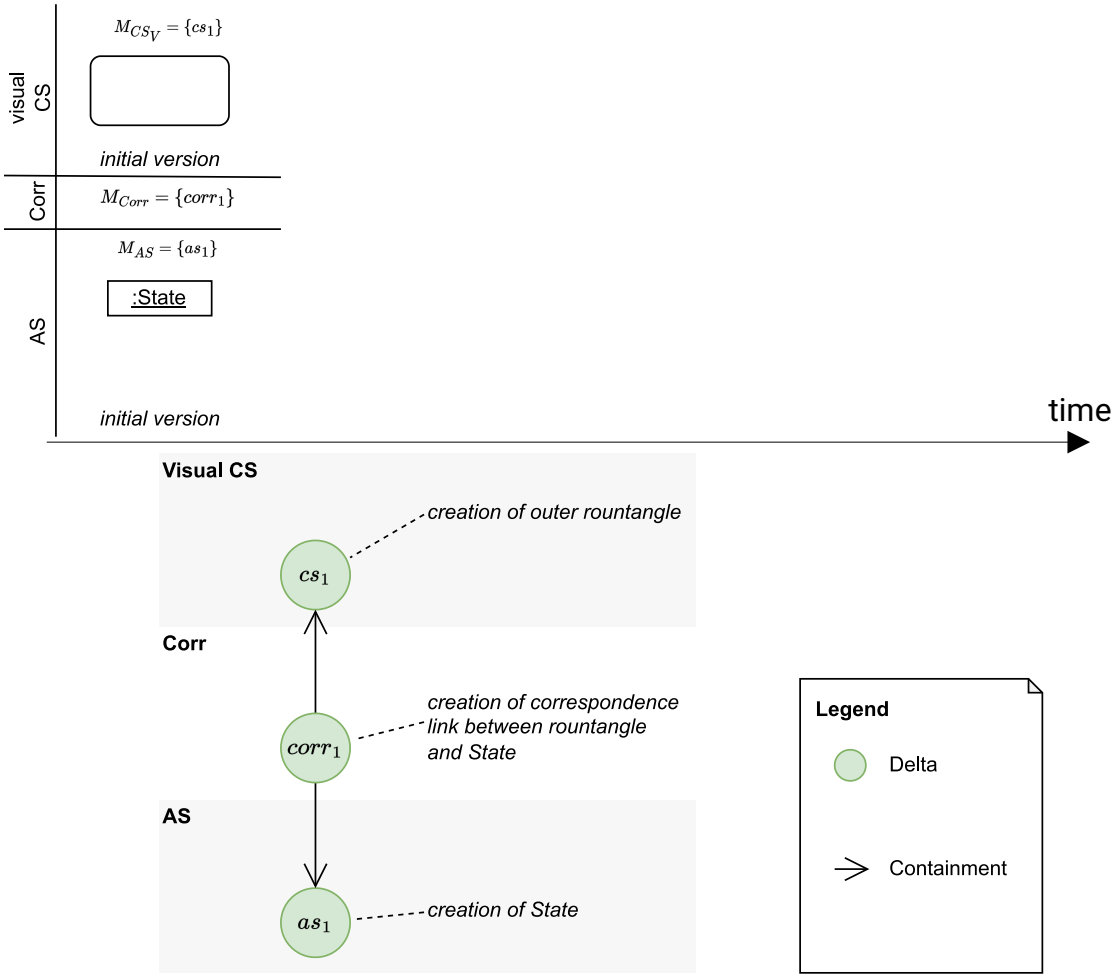
- A **delta** = a **set** of changes on a graph, caused by
  - an **edit operation** (by user)
  - a **propagated change** (by parser/renderer)
- A model **version** is just a set of deltas
  - empty version => empty graph
- A delta may **depend on** other (earlier) deltas
  - dependency types: require, update, delete
  - dependencies form a partial ordering relation on deltas
- Deltas can only be **conflicting** if they have **overlapping dependencies**
  - conflict types: update/update, update/delete, delete/require, delete/delete
  - for every new delta, can **compute** its dependencies and conflicts in (near-)**constant time**

Demo...

- https://mstro.duckdns.org/public/onion/

Running example: Persisting deltas and dependencies

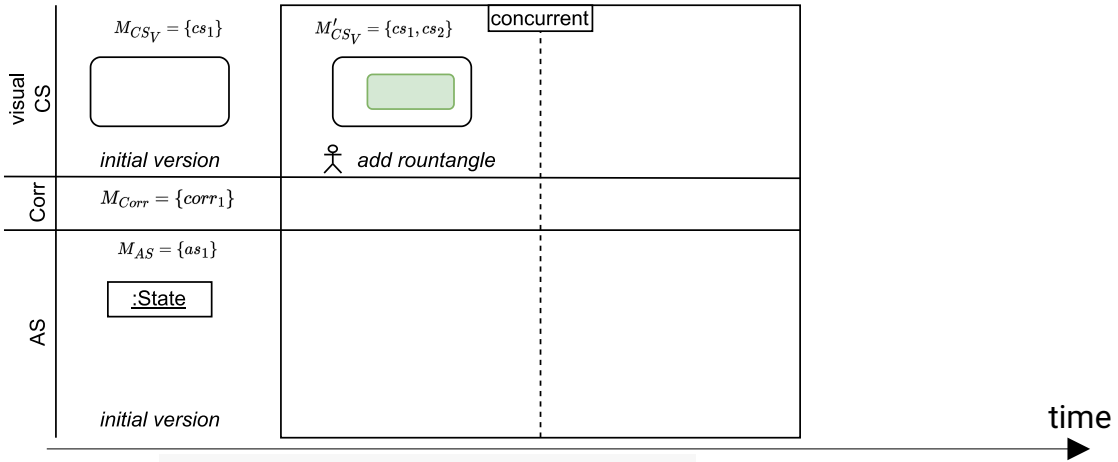
1. Initial versions assumed to each consist of a single delta

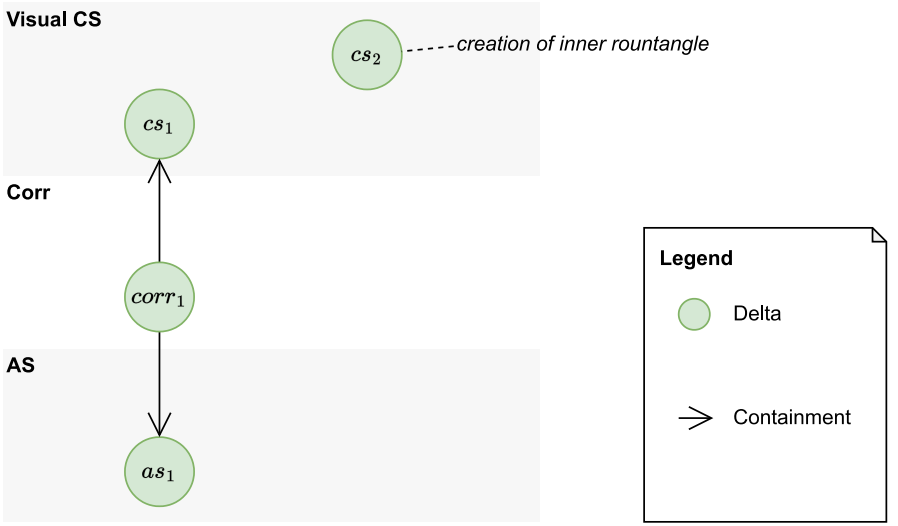


Running example: Persisting deltas and dependencies

1. Initial versions assumed to each consist of a single delta

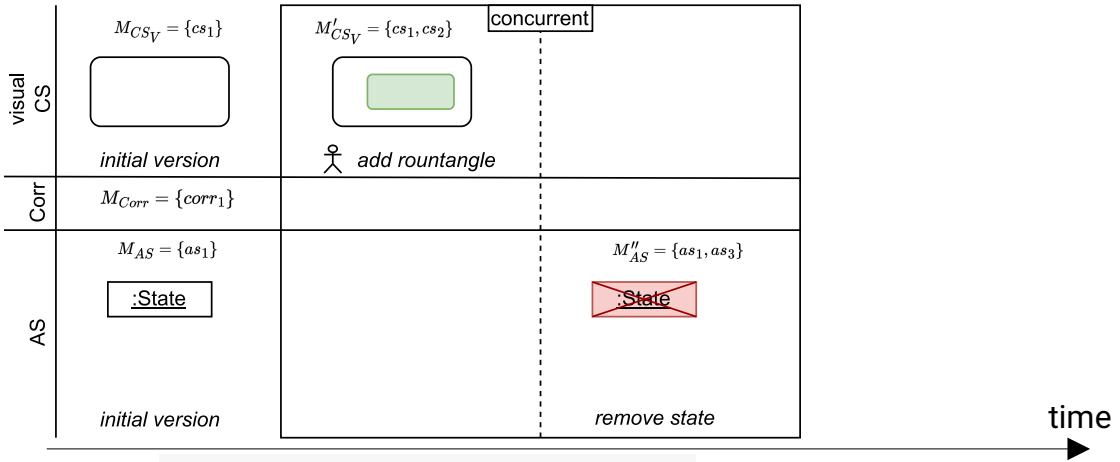
2. CS: Creation of inner rountangle does not depend on any other delta

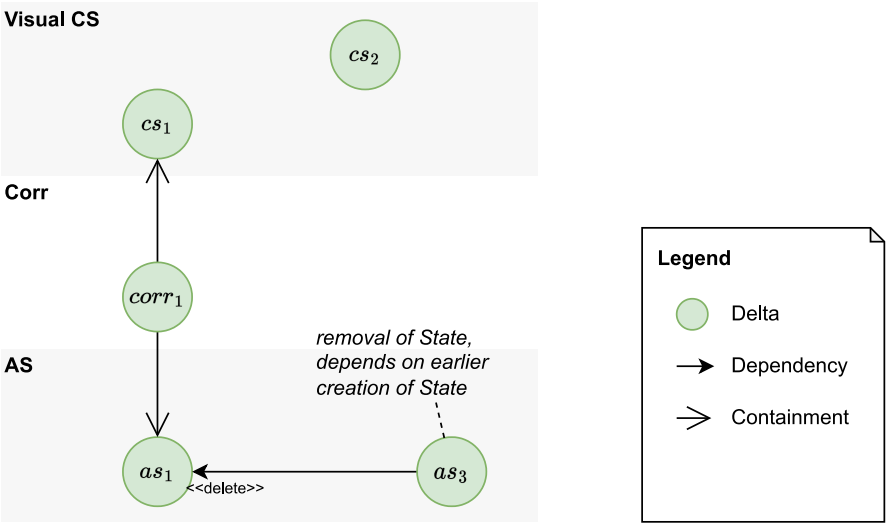




Running example: Persisting deltas and dependencies

1. Initial versions assumed to each consist of a single delta
2. CS: Creation of inner rountangle does not depend on any other delta
3. AS: Removal of State depends on earlier creation of State





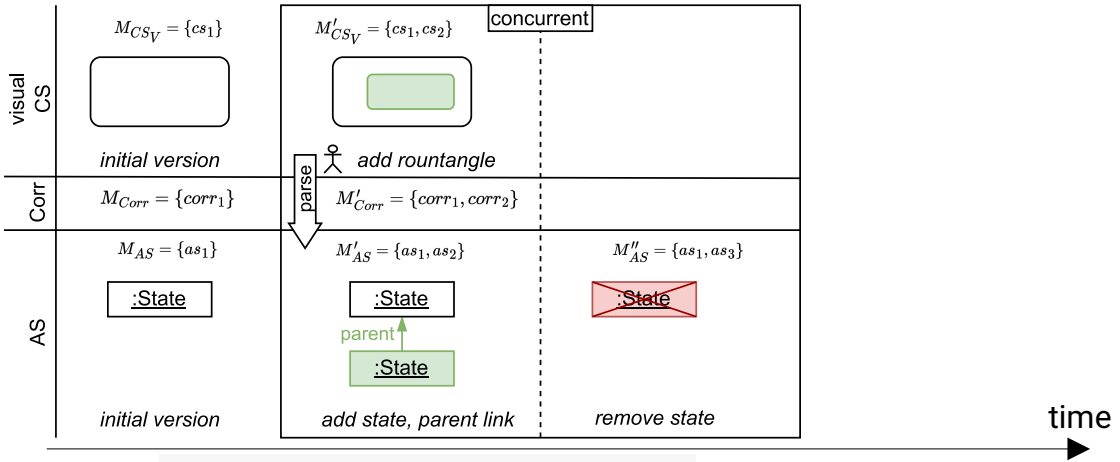
Running example: Persisting deltas and dependencies

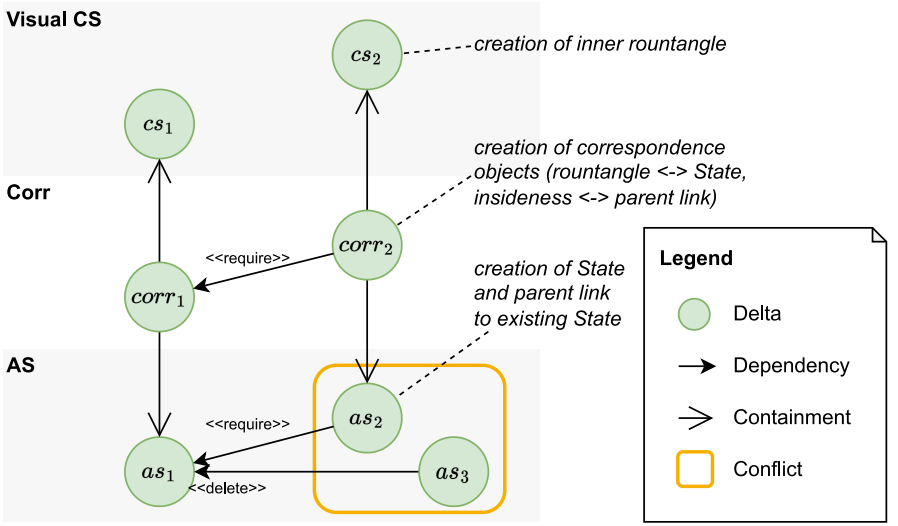
1. Initial versions assumed to each consist of a single delta

2. CS: Creation of inner rountangle does not depend on any other delta

3. AS: Removal of State depends on earlier creation of State

4. Parsing of inner rountangle creation results in 1 new delta in AS and 1 new delta in Corr





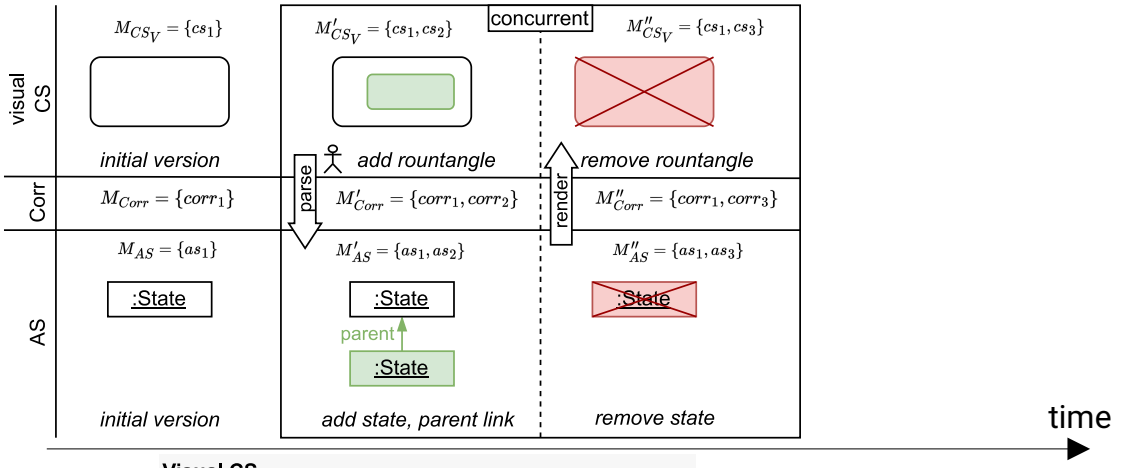
Running example: Persisting deltas and dependencies

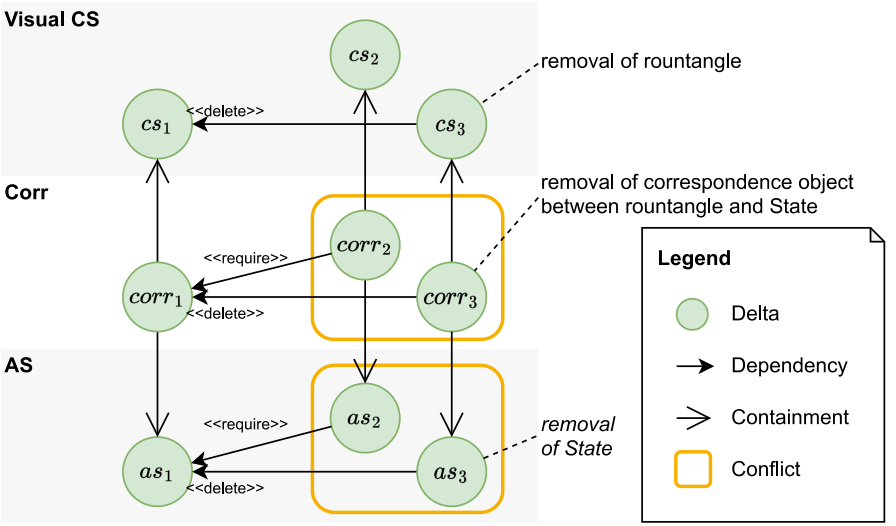
2. CS: Creation of inner rountangle does not depend on any other delta

3. AS: Removal of State depends on earlier creation of State

4. Parsing of inner rountangle creation results in 1 new delta in AS and 1 new delta in Corr

5. Rendering of State removal results in 1 new delta in CS and 1 new delta in Corr





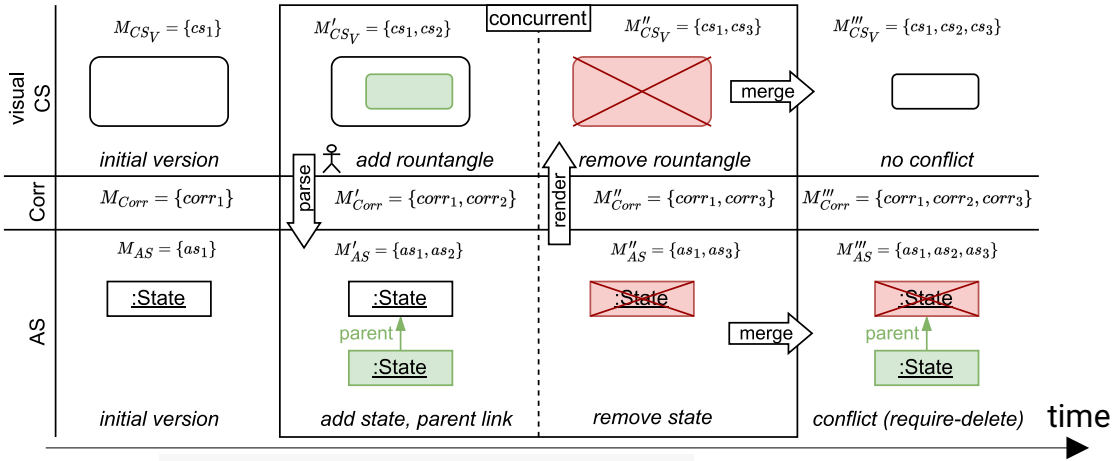
Running example: Persisting deltas and dependencies

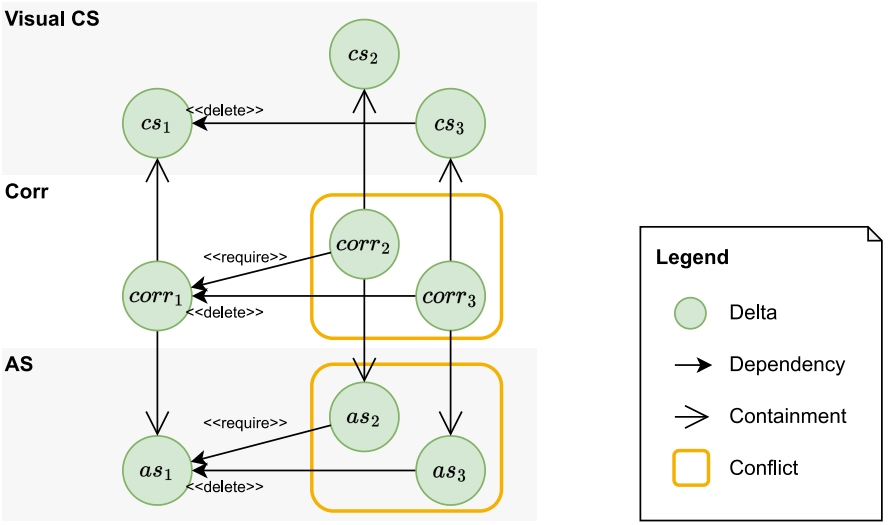
3. AS: Removal of State depends on earlier creation of State

4. Parsing of inner rountangle creation results in 1 new delta in AS and 1 new delta in Corr

5. Rendering of State removal results in 1 new delta in CS and 1 new delta in Corr

6. Merging at all levels does not result in new deltas: the merged versions simply consist of the unions of the existing deltas





Links

- Online demo
  - https://mstro.duckdns.org/public/onion/
- Source code
  - https://msdl.uantwerpen.be/git/jexelmans/onioncollab
- Publications
  - Joeri Exelmans, Jakob Pietron, Alexander Raschke, Hans Vangheluwe, Matthias Tichy:
    Optimistic Versioning for Conflict-tolerant Collaborative Blended Modeling.
    STAF Workshops 2022
    - Workshop article, original vision (still pretty consistent with implementation)
    - Was written before we started our implementation

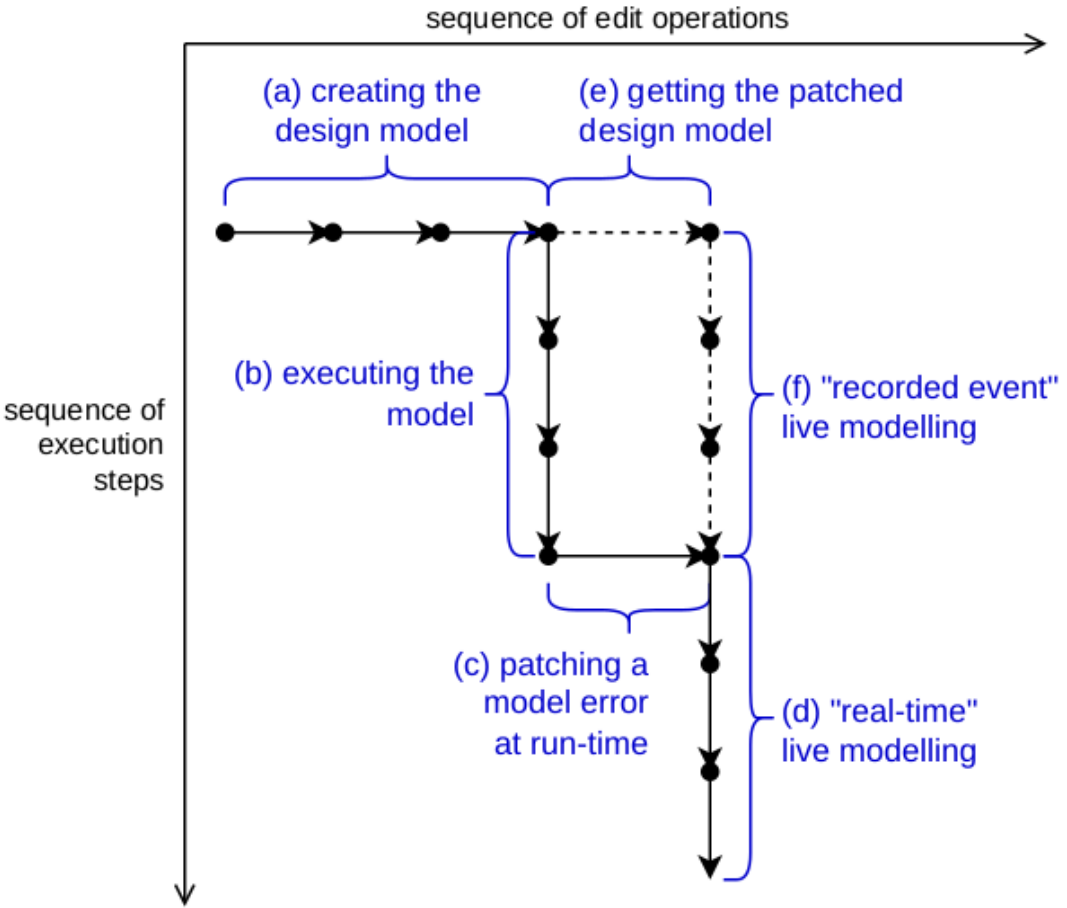
  - Joeri Exelmans, Jakob Pietron, Alexander Raschke, Hans Vangheluwe, Matthias Tichy:
    A New Versioning Approach for Collaboration in Blended Modeling.
    Journal of Computer Languages (June 2023)
    - Journal article, much more detailed, explains implementation

Part 2: Collaborative Live Modeling

Background: Live Modeling

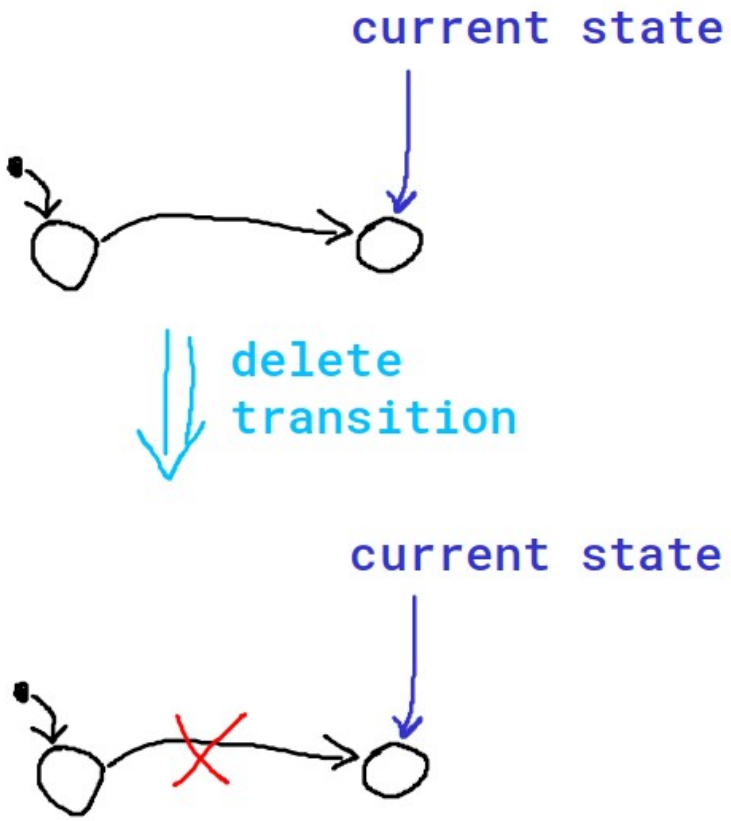
- Live Modeling = Editing a model while executing it
- Why?
  1) build model while executing it to reduce **cognitive gap**
  2) during model execution, realize your model contains a mistake and you **don’t want to restart** execution from scratch

Background: Real-time vs. recorded event live modeling[1]



[1] Yentl Van Tendeloo, Simon Van Mierlo, Hans Vangheluwe:
A Multi-Paradigm Modelling approach to live modelling. Softw. Syst. Model. 18(5): 2821-2842 (2019)

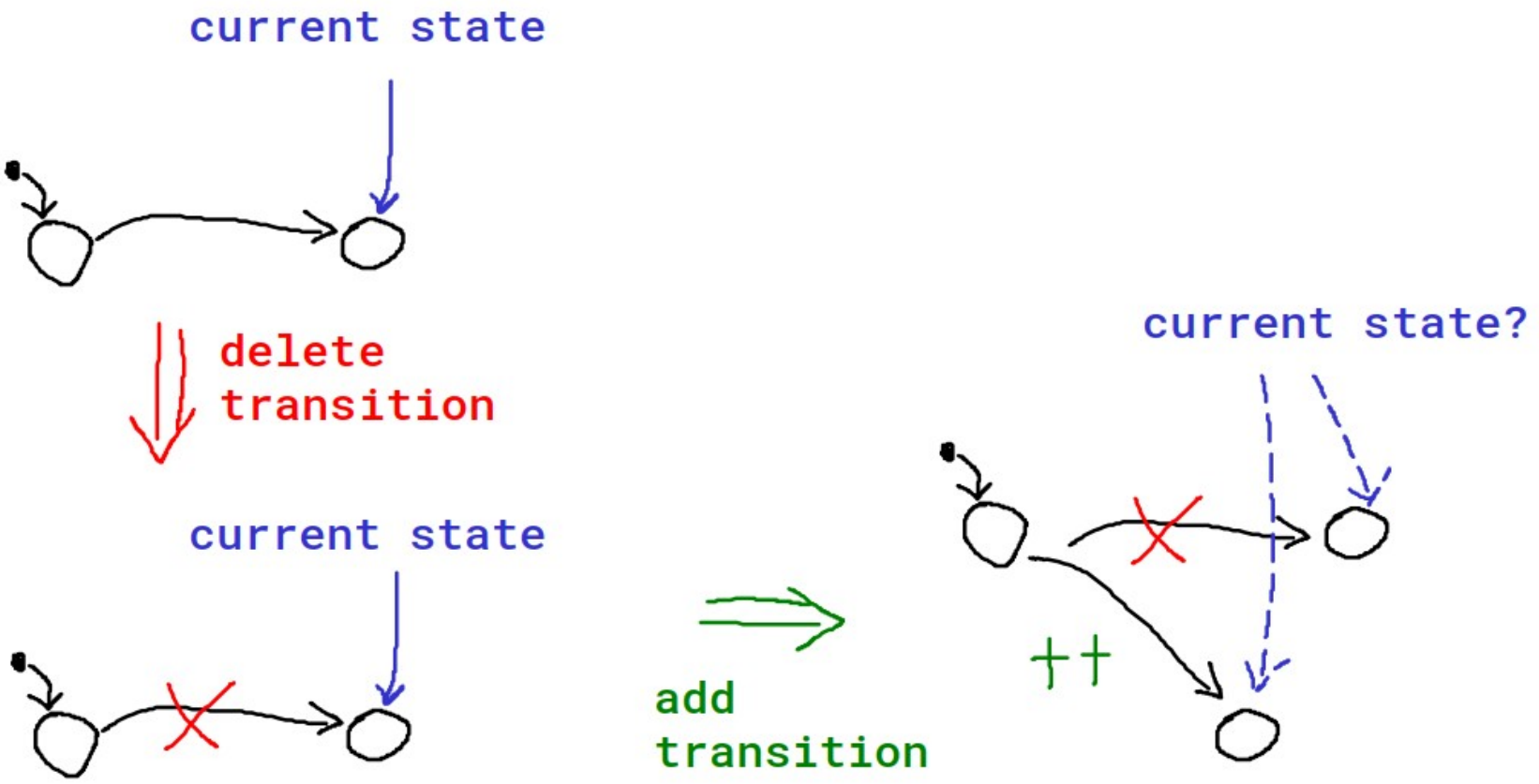
Background: Real-time vs. recorded event live modeling



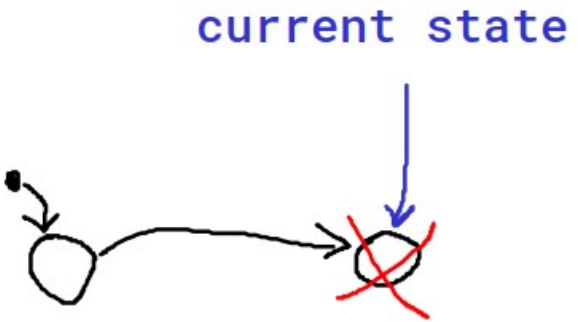
recorded event LM:
cannot replay execution

real-time LM:
no problem, just continue execution

Background: Real-time vs. recorded event live modeling



Background: Real-time live modeling



- State automata example: What if **current state** is **deleted**?
  - **forbid** deletion?
  - **ask user** for new current state?
  - set current state back to **initial state**?

Background: Real-time vs. recorded event live modeling

- Recorded event
  - **restarts** execution and automatically **replays** all execution steps (if possible)
  - cannot end up in unreachable run-time configuration
- Real-time
  - “patch”/consolidate ongoing execution with updated design model
  - **most intuitive** to user
  - could end up in unreachable run-time configuration

Real-time + notification when in unreachable configuration == best of both worlds?

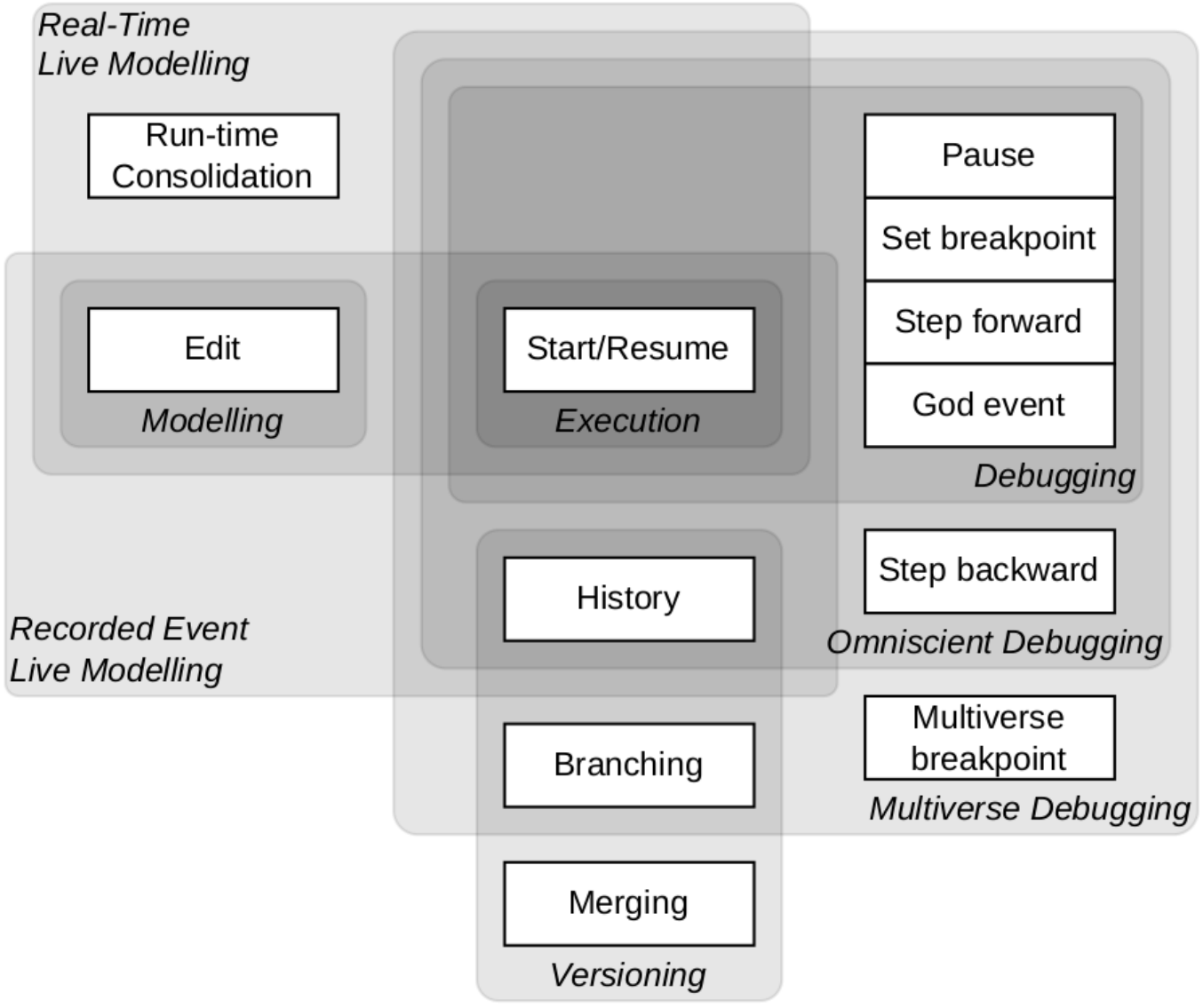
Background: Omniscient and multi-verse debugging

- Omniscient debugging[1]:
  - ability to **step back** in time
  - history remains linear (like undo)
- Multiverse debugging[2]:
  - additional ability to **jump** accross different branches of execution
  - history is branching
  - useful for **non-deterministic** languages
  - “multiverse” breakpoint (run until condition satisfied in *some branch)*

[1] Guillaume Pothier, Éric Tanter: **Back to the Future: Omniscient Debugging**. IEEE Softw. 26(6): 78-85 (2009)

[2] Matthias Pasquier, Ciprian Teodorov, Frédéric Jouault, Matthias Brun, Luka Le Roux, Loïc Lagadec:
Practical multiverse debugging through user-defined reductions: application to UML models. MoDELS 2022: 87-97

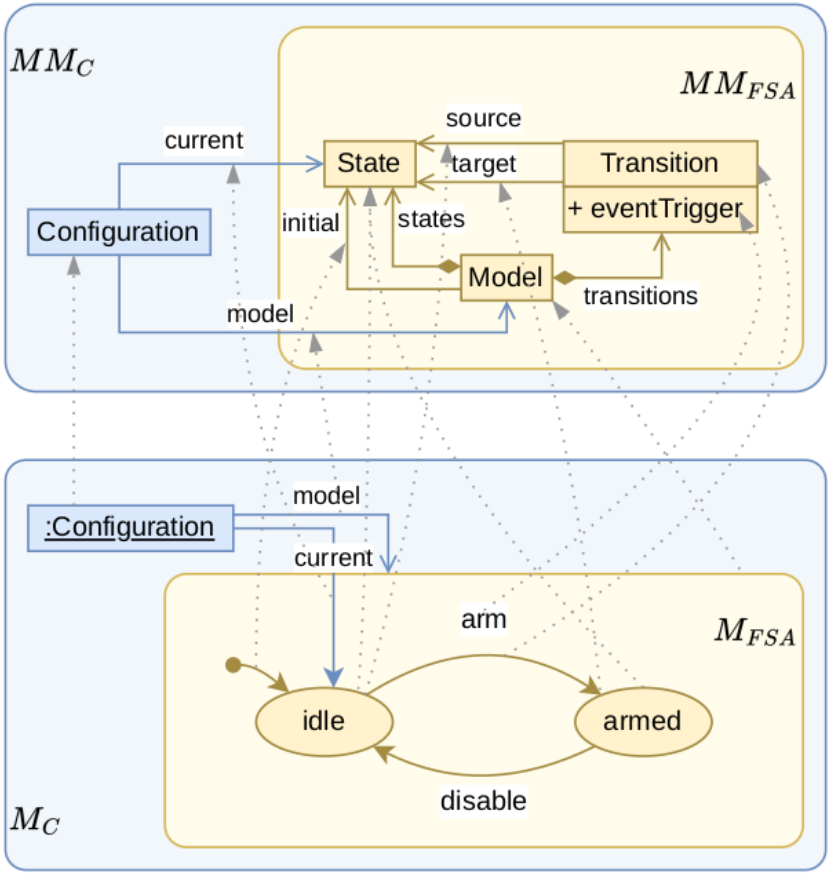
Big Picture


Real-Time
Live Modelling
Run-time
Consolidation
Edit
Modelling
Start/Resume
Execution
Pause
Set breakpoint
Step forward
God event
Debugging
Recorded Event
Live Modelling
History
Step backward
Omniscient Debugging
Branching
Multiverse
breakpoint
Multiverse Debugging
Merging
Versioning

Solution

Design model
= what you edit

Run-time model
= current (stable*) execution state
(of interpreter)
reads and points at elements
of design model



* stable meaning: in between
macro-steps (**not** micro-steps)

Solution

- We use **operation-based versioning** to record changes on design model and run-time model
  - e.g., edit operation → new version of design model
  - e.g., execution step → new version of run-time model
  - e.g., “god events” → new version of run-time model
- We record **dependencies** between deltas
- Run-time model **embeds** design model

  (just like correspondence model embeds CS and AS models)
  - run-time deltas can depend on design deltas (but not the other way around)
  - conflict between design delta and run-time delta

    = cannot combine some execution step / god event with some edit operation

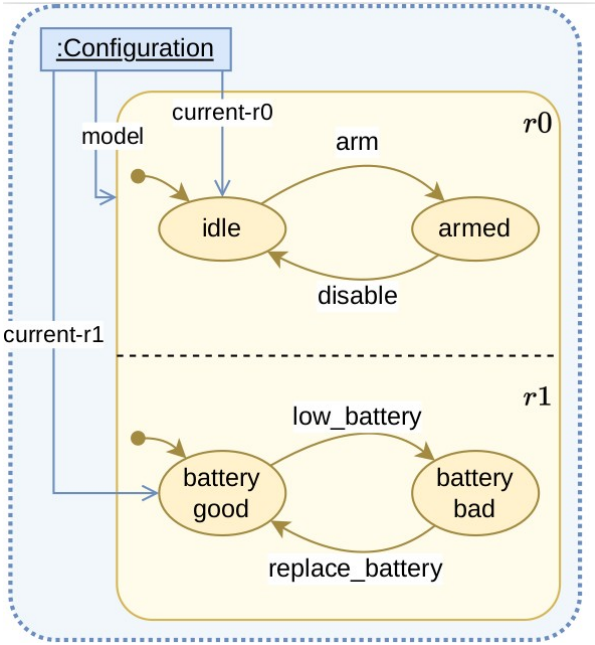
    => impossible configuration

Demo...

- https://mstro.duckdns.org/public/onion/

Additional benefits

- “Who set this variable (and when)?”
  - for every element in any model version, we already know the delta that most recently touched it
- Discovering parallel convergence
  - at run-time, independent deltas represent execution steps that can be (safely) taken in any order



Future work (ongoing here in Brest)

- Current implementation only records write-dependencies
  - Should also record the *read*-dependencies to find R/W conflicts

    => currently we fail to detect certain conflicts (*false negatives*)
- Current implementation has some ad-hoc components
  - e.g., history structure, graph encoding can made **more generic**, to ease integration with existing language implementations, model-checkers, ...
  - **De- and re-construct** as composable parts
  - Convinced that **dependencies** between deltas are **fundamental** to merging
- Creating a Statecharts + action language demo
- Also recording the interpreter's state in between micro-steps

Links

- Online demo
  - https://mstro.duckdns.org/public/onion/
- Source code
  - https://msdl.uantwerpen.be/git/jexelmans/onioncollab
- Publication
  - Joeri Exelmans, Ciprian Teodorov, Robert Heinrich, Alexander Egyed, Hans Vangheluwe:
    Collaborative Live Modelling by Language-Agnostic Versioning.
    MoDELS (Companion) 2023