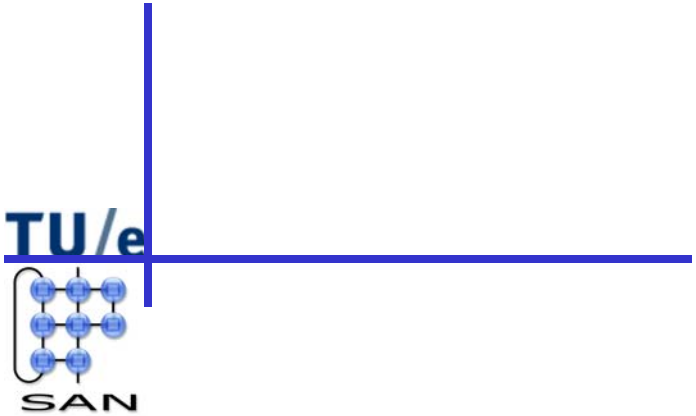

Module Architecture Control
using Relation Algebra

Reinder J. Bril
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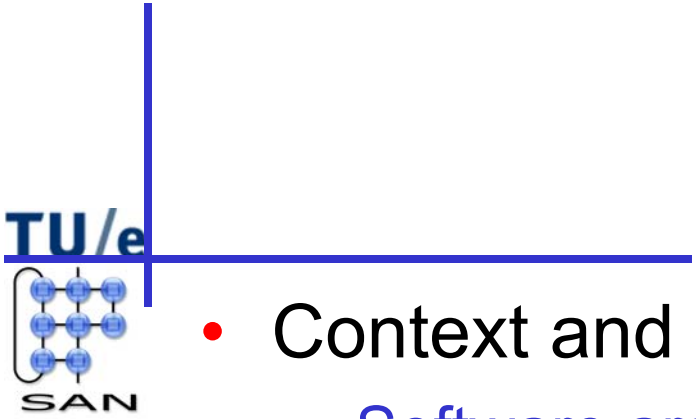
Questions

- Development artefacts of a system?
- How to maintain consistency:
  - between these artefacts (inter)?
  - between elements of an artefact (intra)?
- This lecture:
  - consistency between architecture and implementation
- SAN:
  - consistency of designs [Lange et al 05]
  - generalization [Muskens et al 05].

Goals

- Student understands:
  - the need for module architecture control;
  - how module architecture control can be performed;
  - the basics of relation algebra.
- Student can apply relation algebra on a simple example.



Overview

- Context and motivation
  - Software architecture – recap
  - Application domain
- Module architecture notions
- Relation algebra
- Verification
- Conclusion
- References

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Software architecture – recap

Stakeholders

- **End-User**:
  - behavior, performance, security, reliability
- **Customers**:
  - low cost, timely delivery
- **Product-Management**:
  - features, short time to market, low cost, parity with products
- **Development**:
  - low cost, employability
- **Maintenance**:
  - modifiability

Software architecture – recap

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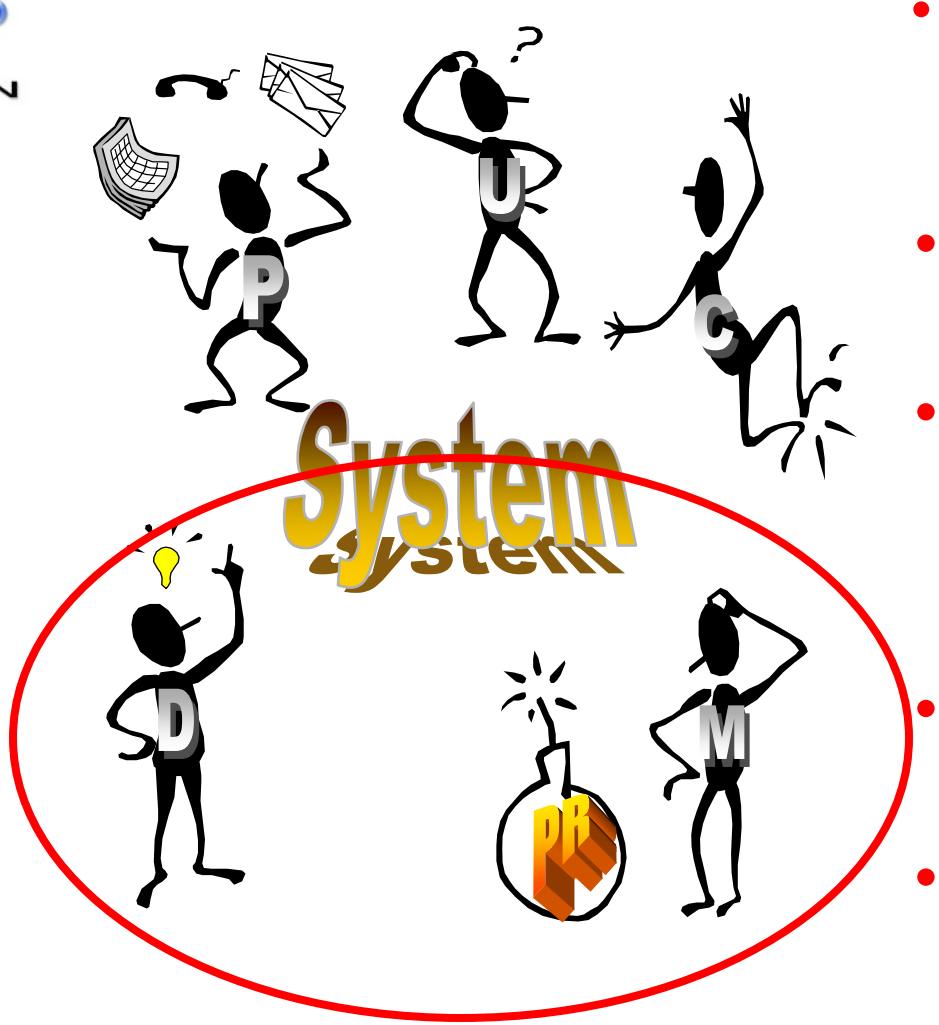
  - modifiability

Product view

Software architecture – recap



Stakeholders

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  - low cost, employability
- **Maintenance**:
  - modifiability

Development view

Software architecture – recap

- **Software architecture**:
  - earliest artifact
  - means for mutual communication
  - enables analysis of concerns
  - manifests concerns as system qualities
- **Software architecture is vital !**

[Bass et al 1995]

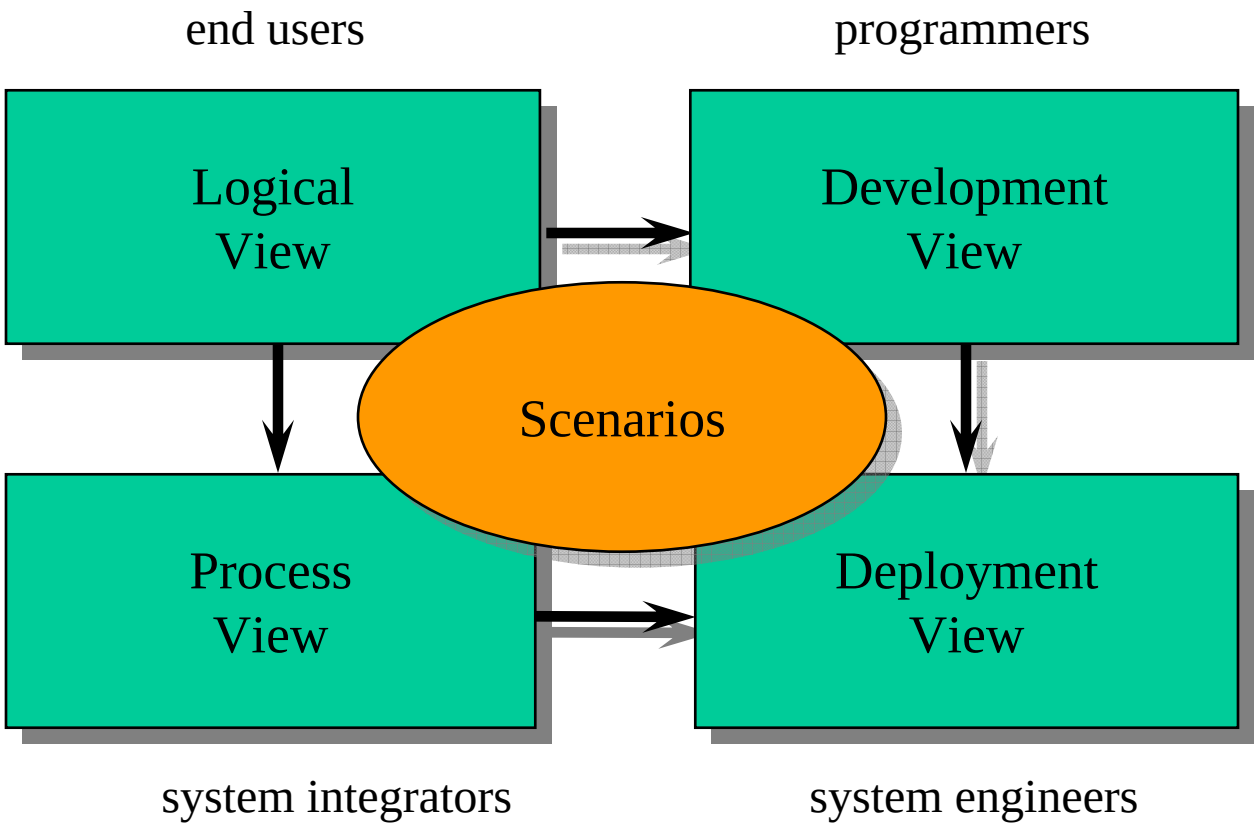
Software architecture – recap

Need for (system) architecture

- *If a project has not achieved a system architecture, including its rationale, the project should not proceed to full-scale system development. Specifying the architecture as a deliverable enables its use throughout the development and maintenance process.*

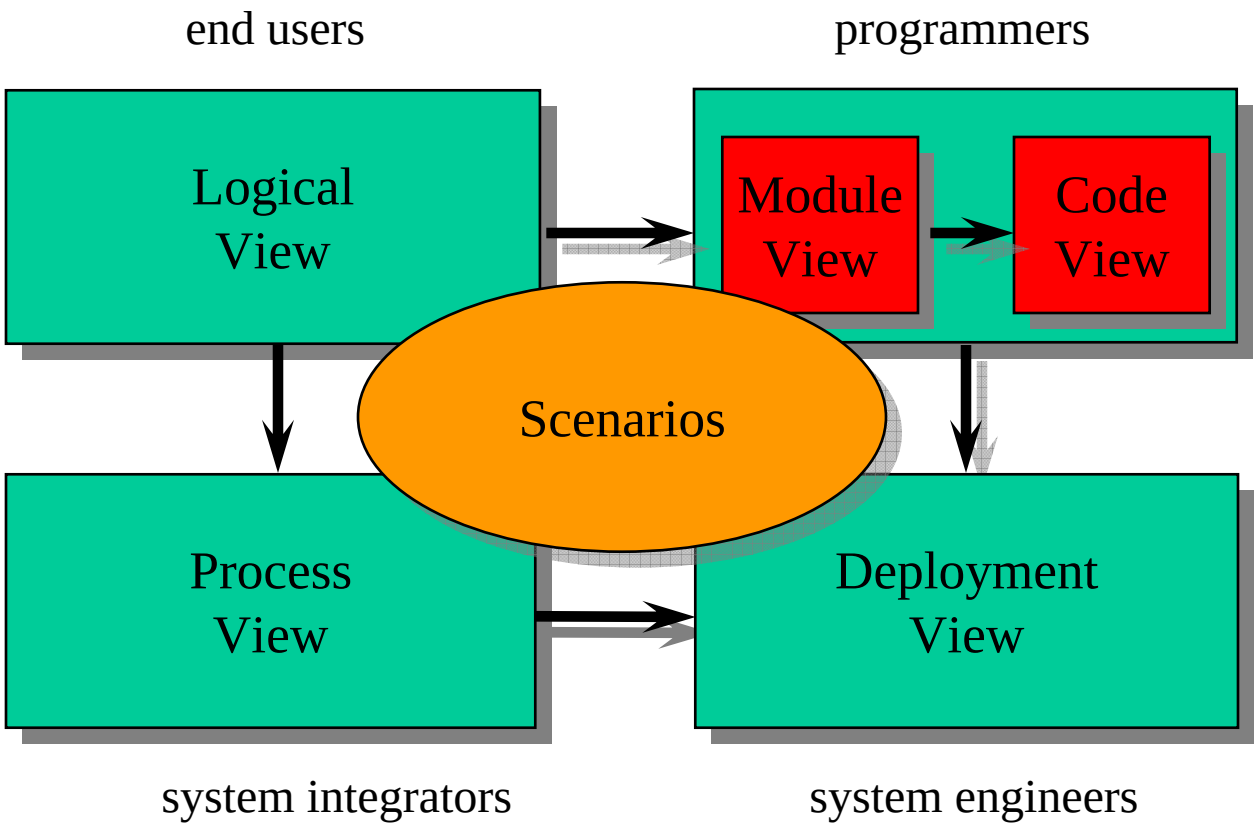
[Boehm 1995]

Software architecture – recap



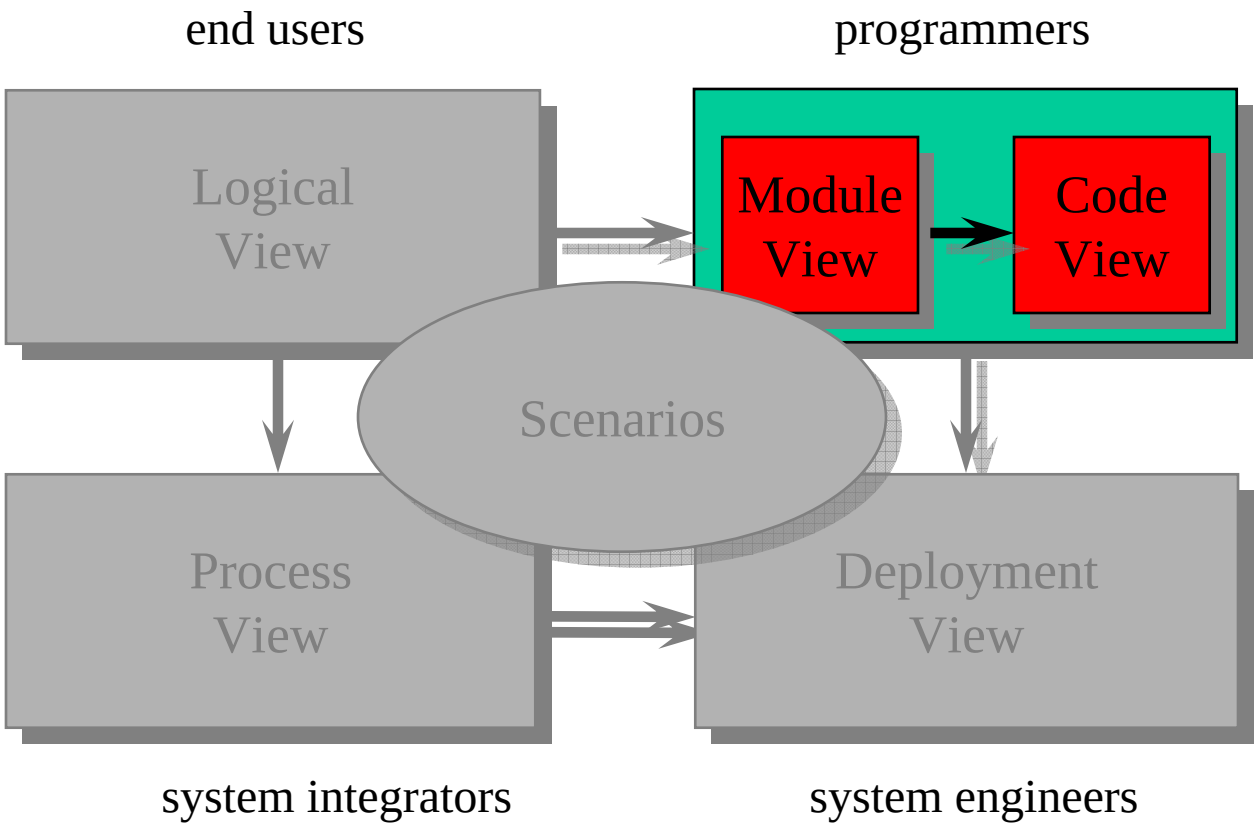
4+1 View Model [Kruchten 95]

Software architecture – recap



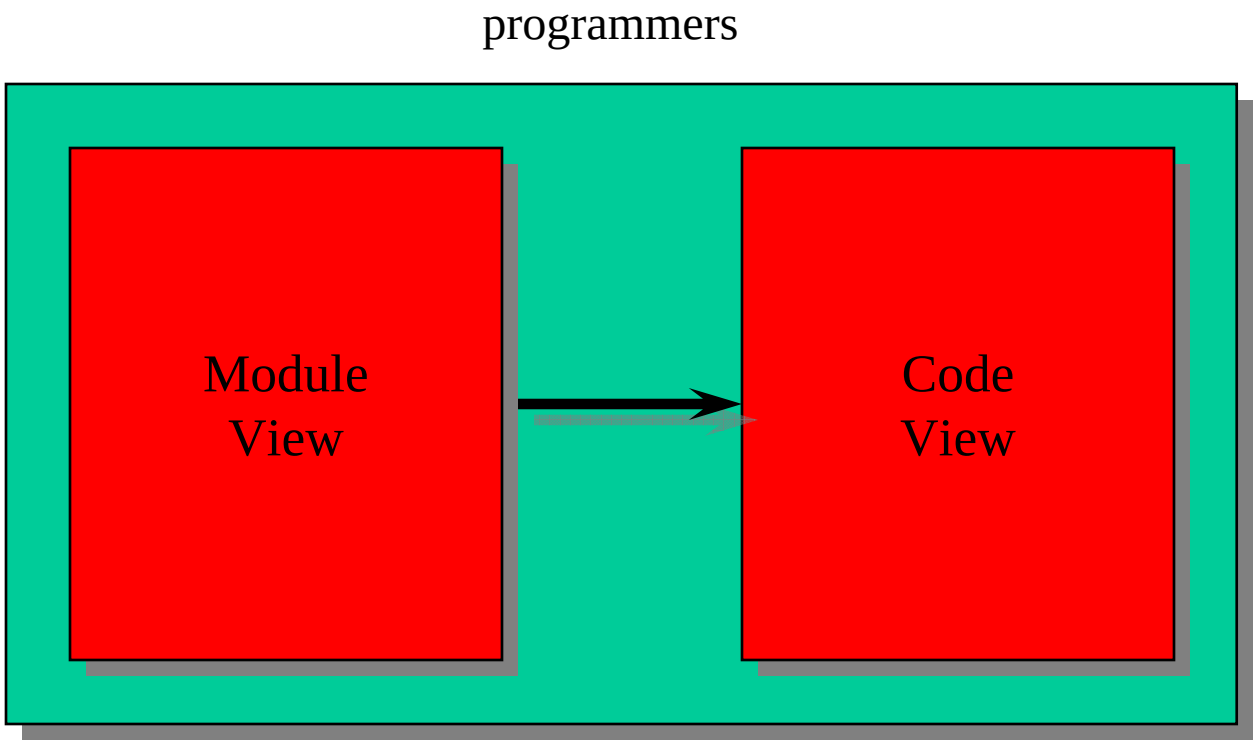
4+1 View Model Revisited

Software architecture – recap



4+1 View Model Revisited

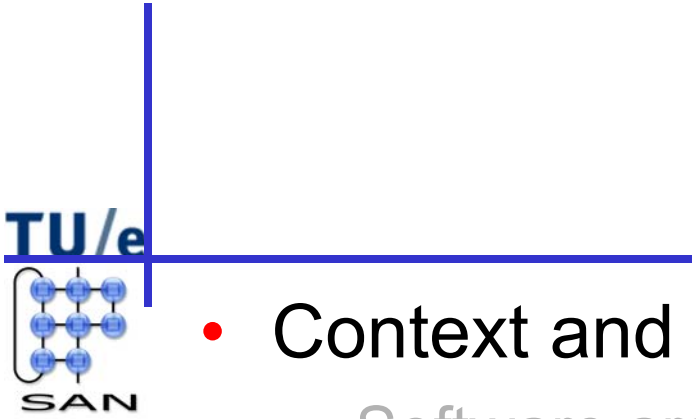
Software architecture – recap



Development View

Software architecture – recap

- A software architecture characterization:
  - Components (or [architectural] entities);
  - Connections;
  - Constraints.
- Module view:
  - System, Subsystems, Components;
  - Part-of relation and uses relation;
  - Layering, orthogonally.
- Code view:
  - Directories, Files;
  - Directory structure, location of files, and include relation;
  - File name conventions and file length constraints.



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Application domain

- Telecommunications domain
- SOPHO: Philips' family of PBXs
  - 100 - 1M telephony lines
  - origin dating back to early 1980's
  - economic lifetime ~ 15 years
  - maintenance obligations ≥ 10 years
  - 5 K files, 2.5 MLOC in C++
  - successful ⇒ asset
    ⇒ careful to maintain this legacy

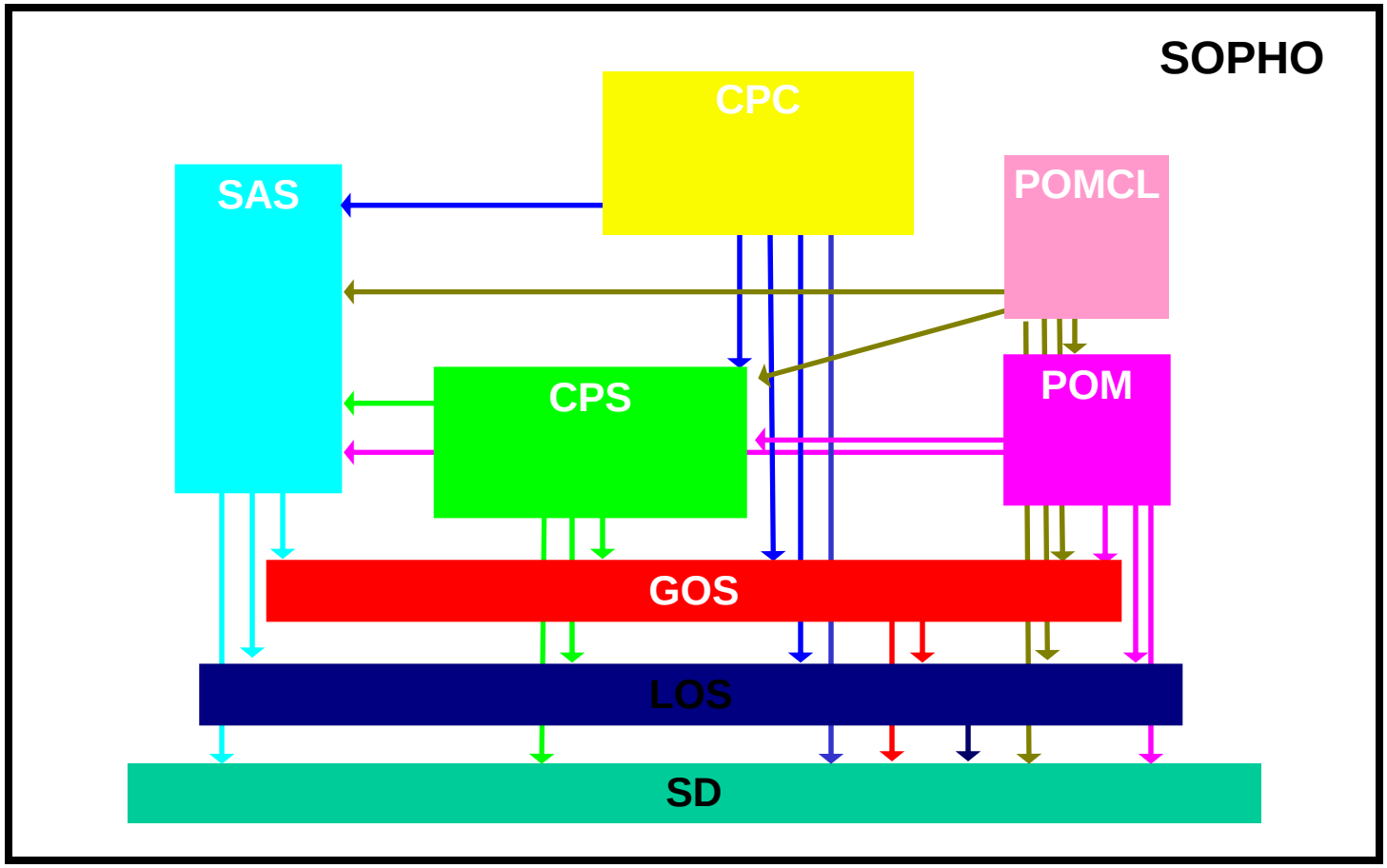
Application domain

- Complexity of legacy systems
  - hard to understand (e.g. size);
  - documentation out-of-date;
  - gap between intrinsic and experienced complexity.
- Architecture vital, but not maintained …:
  - recovery;
  - analysis;
  - verification and control;
  - (improvements).
- Need for architectural support !

Application domain

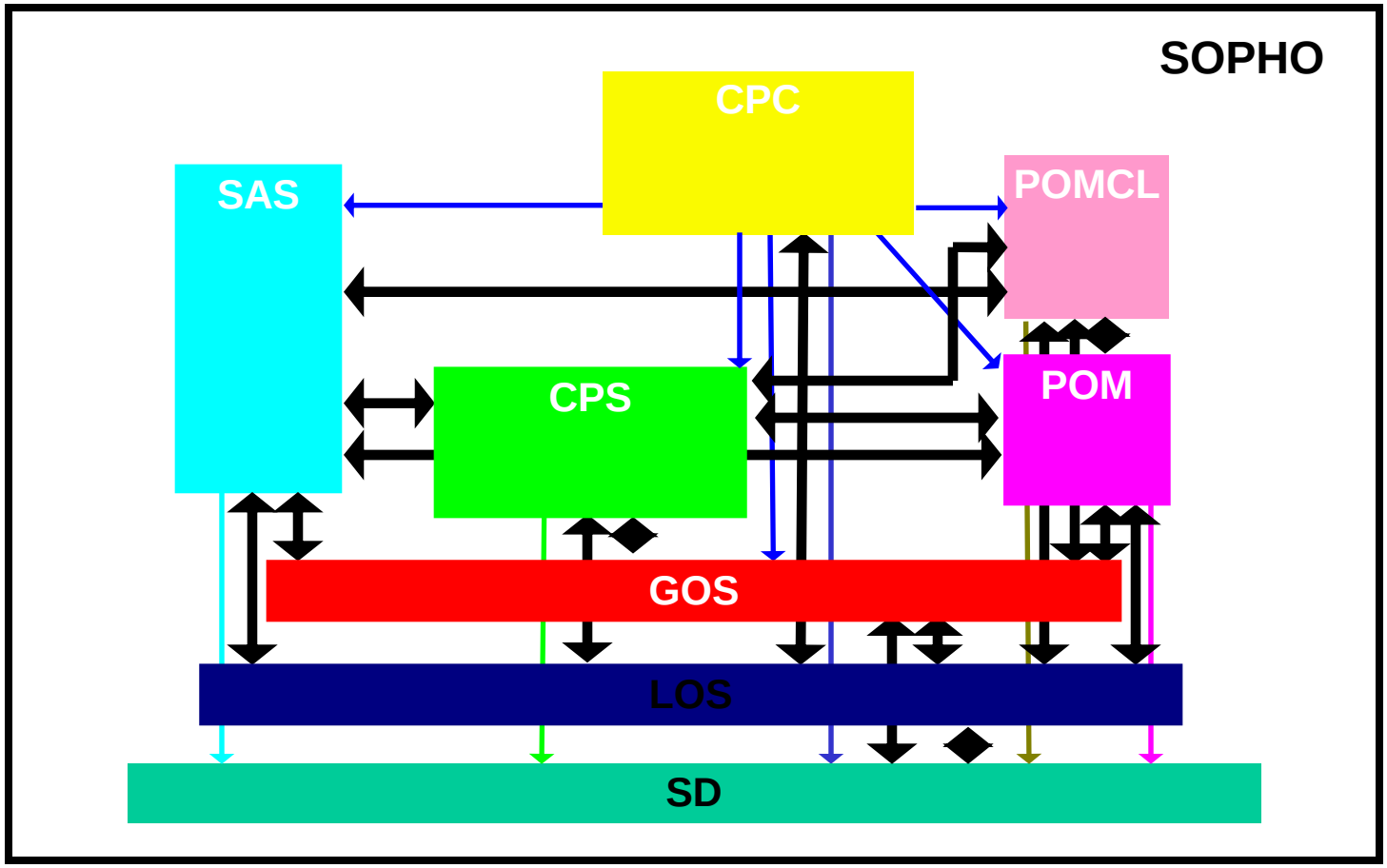
- Characteristics (development view):
  - module view
    - 8 K architectural entities;
    - organised in an unbalanced tree, depth 5 – 12;
    - layered system, consisting of 8 subsystems.
  - code view
    - 1 directory with 5 K files, and 2.5 MLOC in C++;
    - 35 K include statements;
    - File names based on “12 NCs”,
      file length varies from 100 to 20 K lines.

Application domain



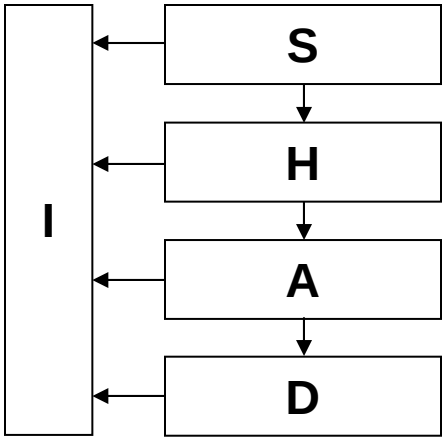
“Intended” module architecture (documentation + software architects)

Application domain

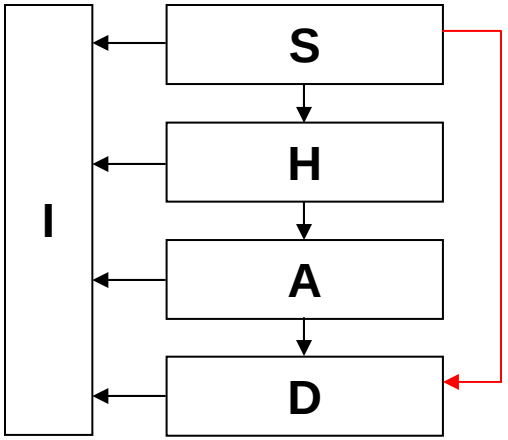


“Derived” module architecture (extracted from the implementation)

Conformance



Intended



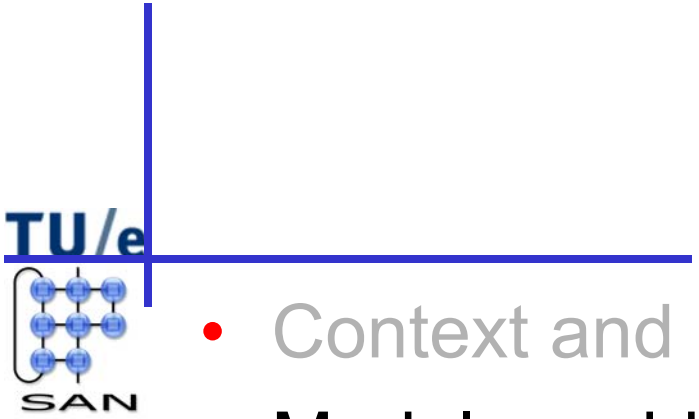
Extracted

Causes when “intended” and “extracted” differ:

1. “intended” is wrong (e.g. out-of-date): improve;
2. “extracted” is wrong: improve;
3. implementation is optimized for, e.g., speed $\Rightarrow$ refinement.

Application domain

- Ensure conformance to an architecture !
  - Keep the architecture up-to-date
- Approach using relation algebra (RPA):
  - Represent the “intended” architecture in RPA.
  - Extract the “derived” architecture from the implementation, and represent in RPA.
  - Express “conformance” in RPA.
  - Ensure conformance by means of verification (using RPA) and improvements (i.e. control).



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  - Module diagram
  - Decomposition tree
  - Lifting
  - Hiding
  - Lowering
  - Weights
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Module architecture notions

- Module diagram
- Decomposition tree
- Lifting
- Hiding
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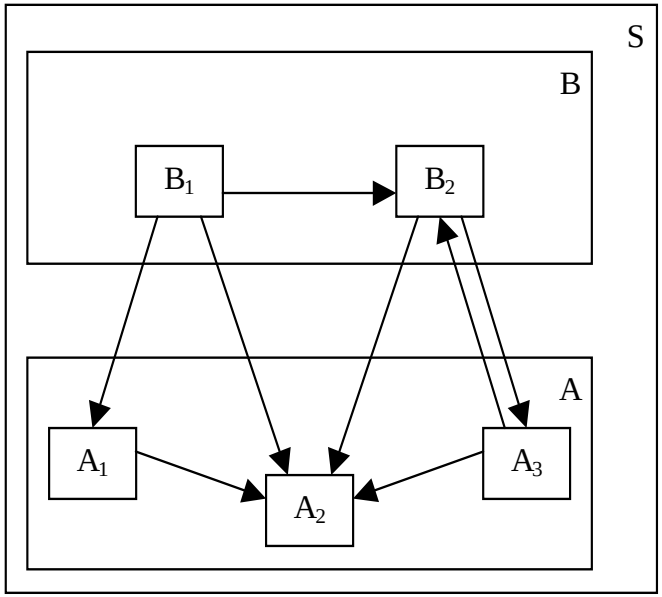
- Weights

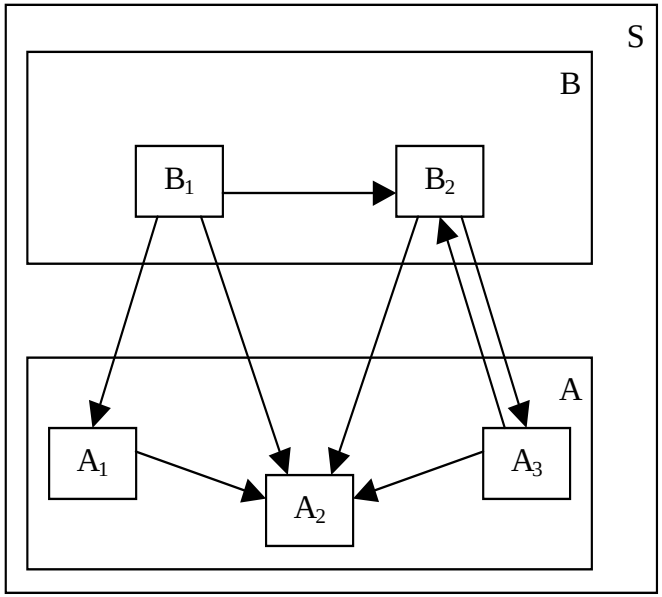
Module diagram

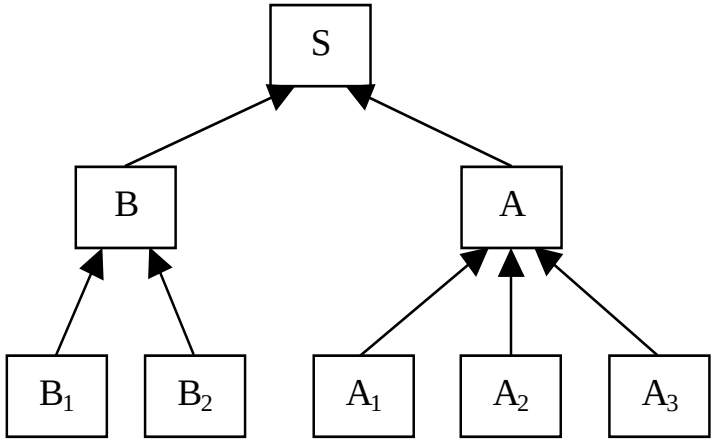


- Visualises a system's architecture
- "Boxes-in-boxes" representation
- Boxes represent entities
- Arrows represent dependencies

System S is *not* layered

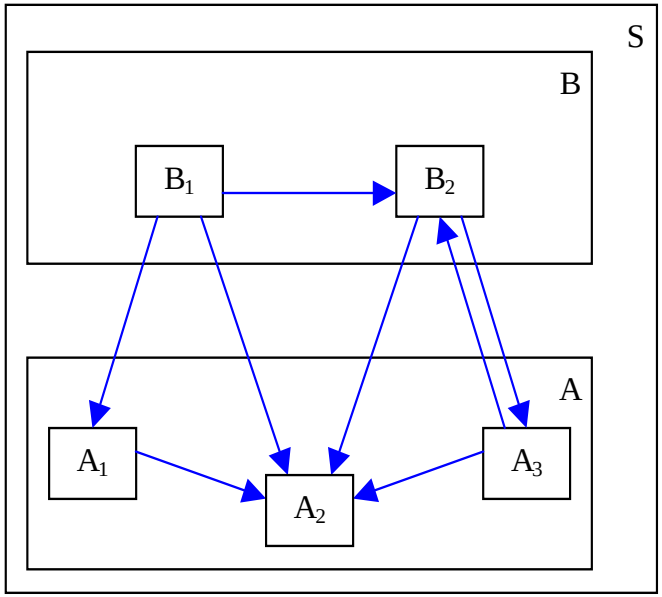
Decomposition tree

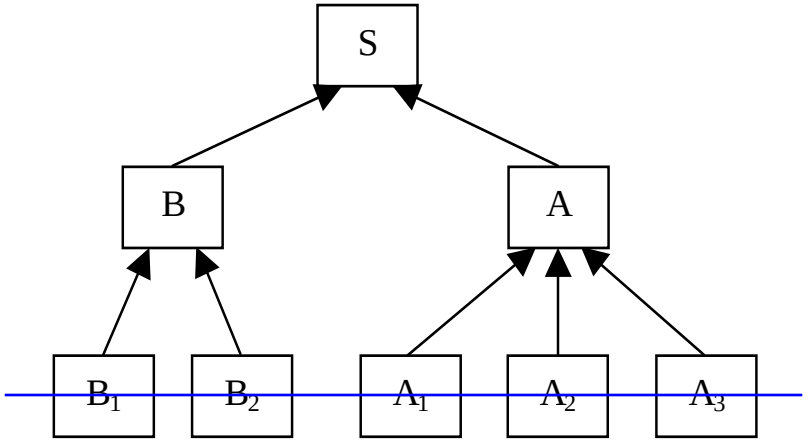




System S is *balanced, and*
the decomposition tree has *3 levels*

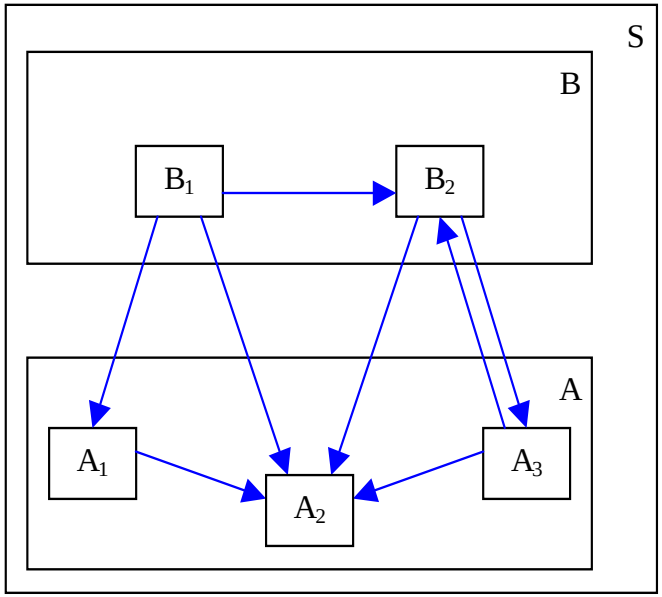
Lifting (1)

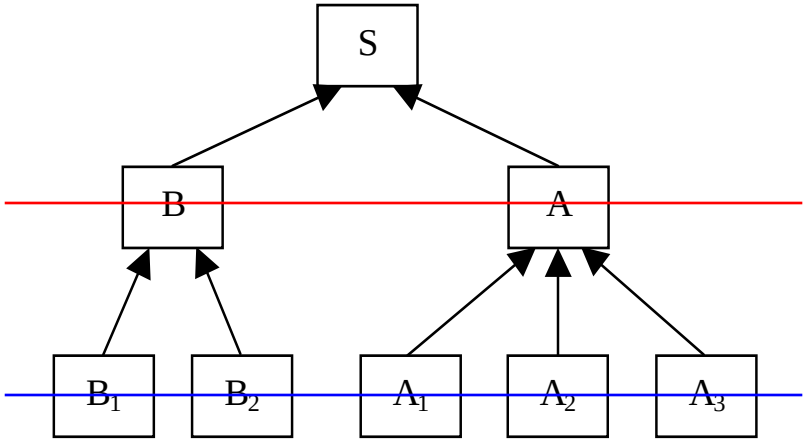




Uses relation corresponds with a level (*tree-cut)*

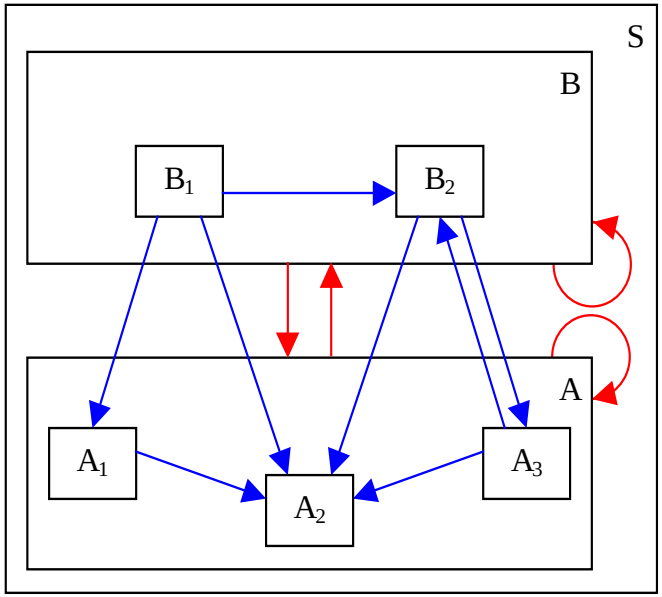
Lifting (1)

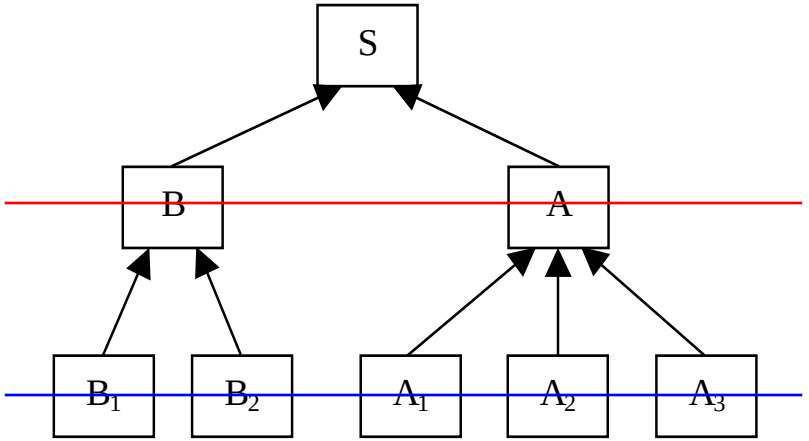




Transform a relation to a higher level.

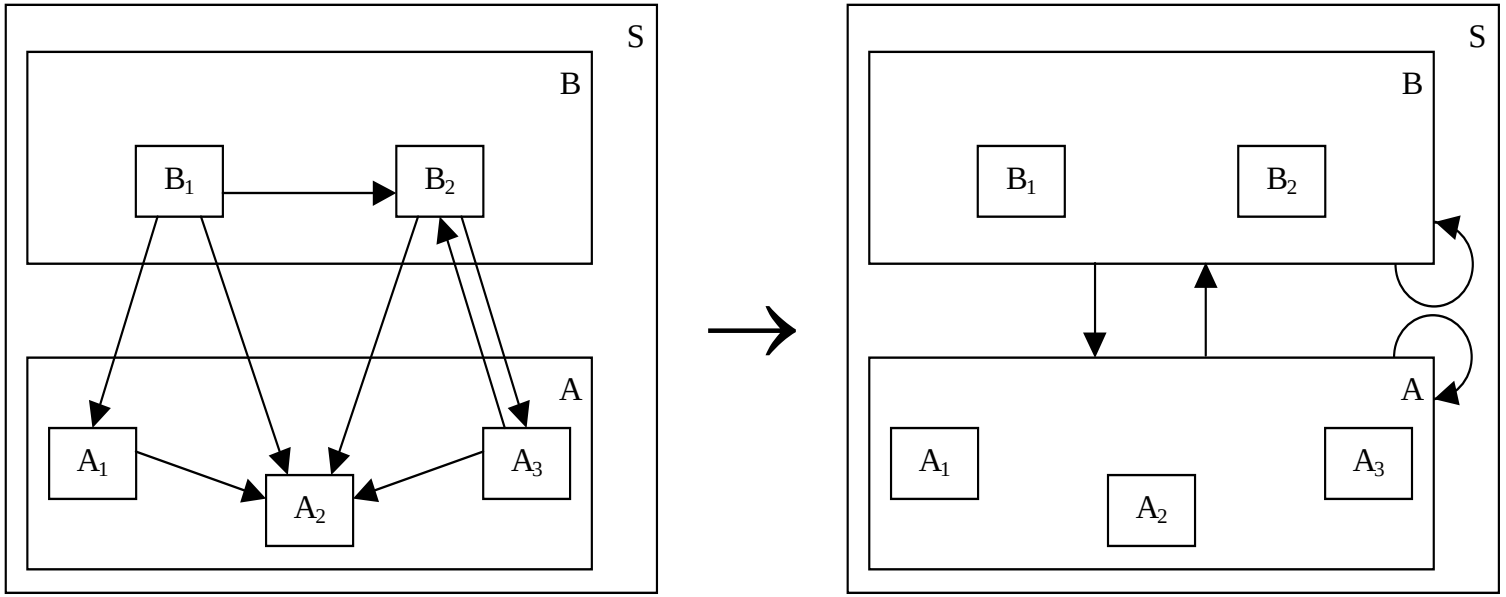
Lifting (1)





Transform a relation to a higher level, i.e. *replace both the source and the destination of each arrow by its enclosing entity*.

Lifting (2)



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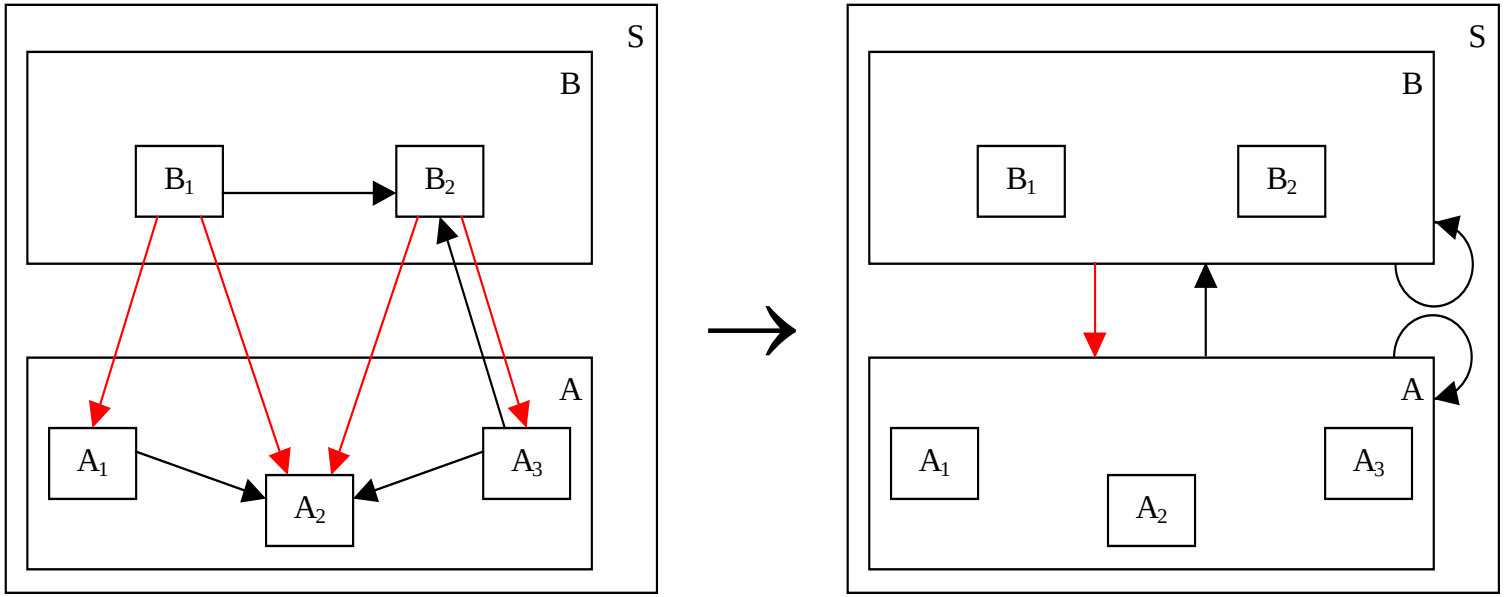
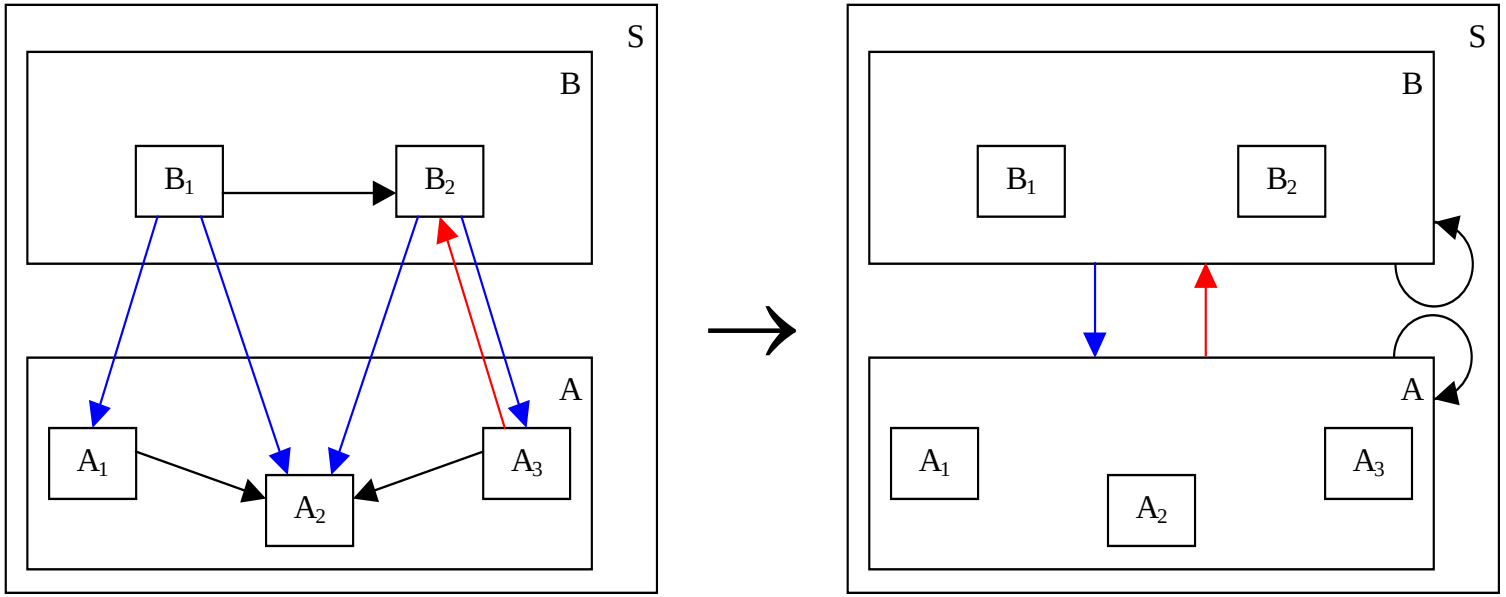
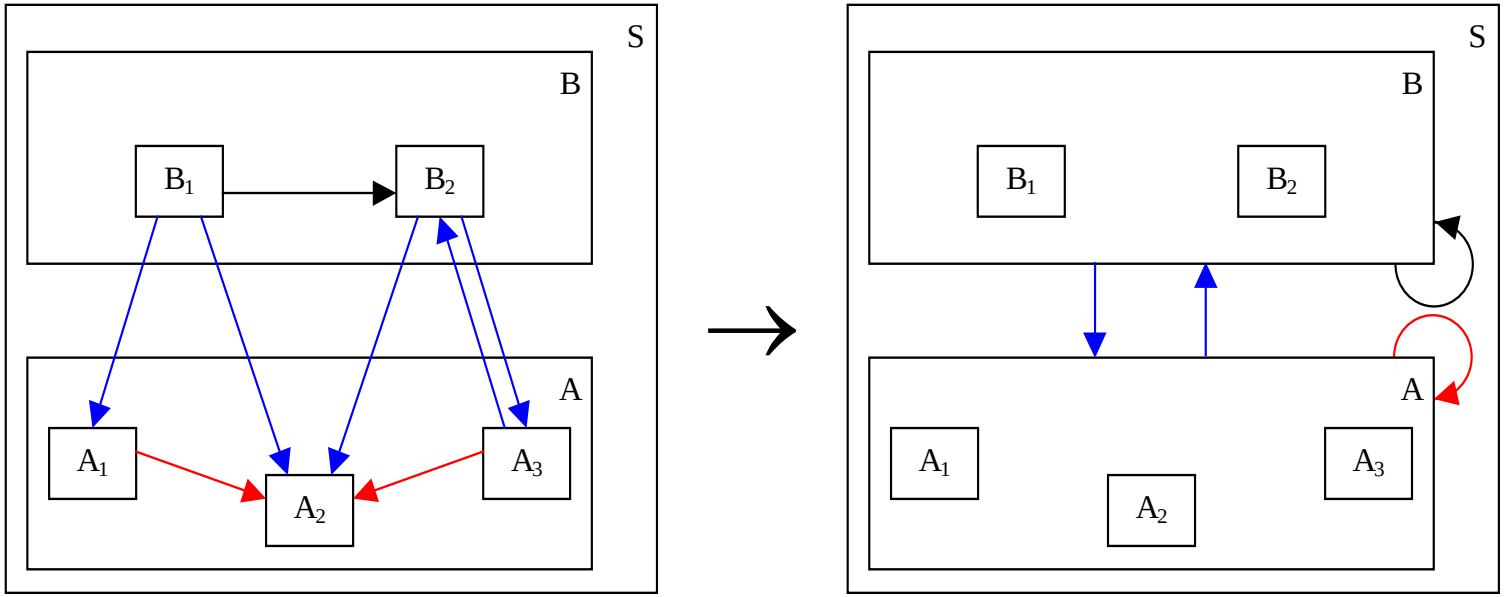
Lifting (2)



Lifting (2)



Lifting (2)



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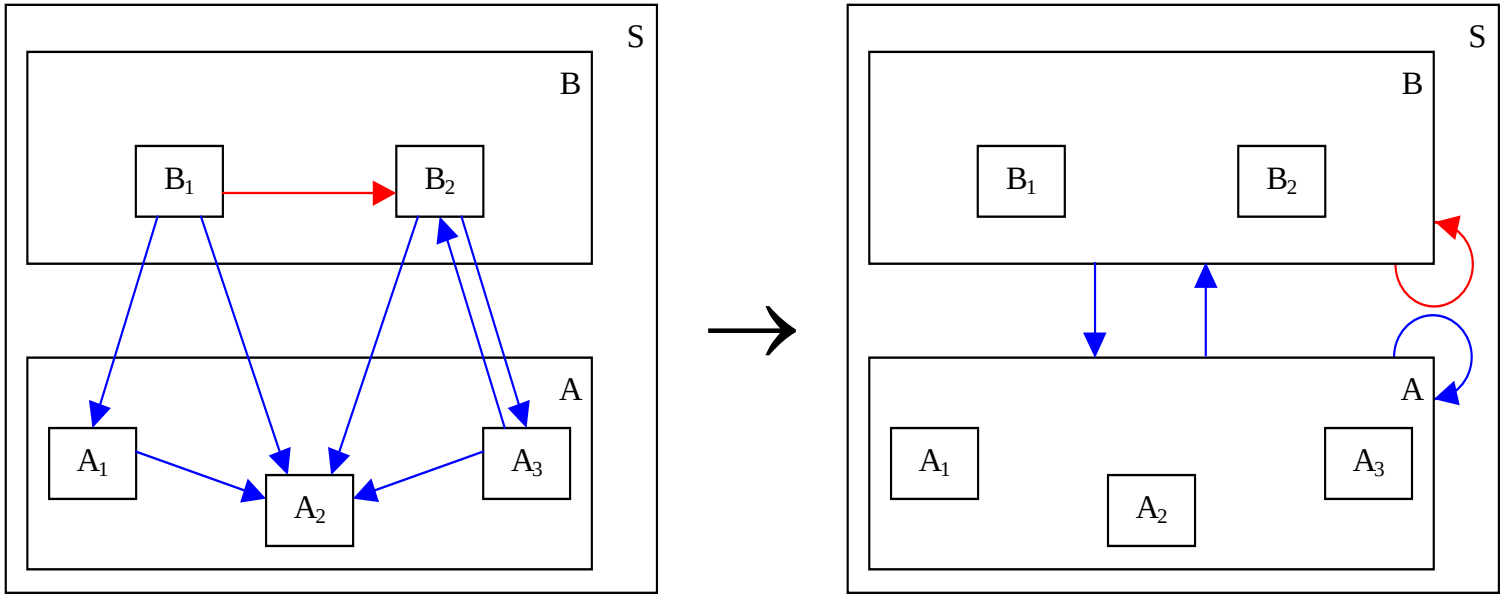

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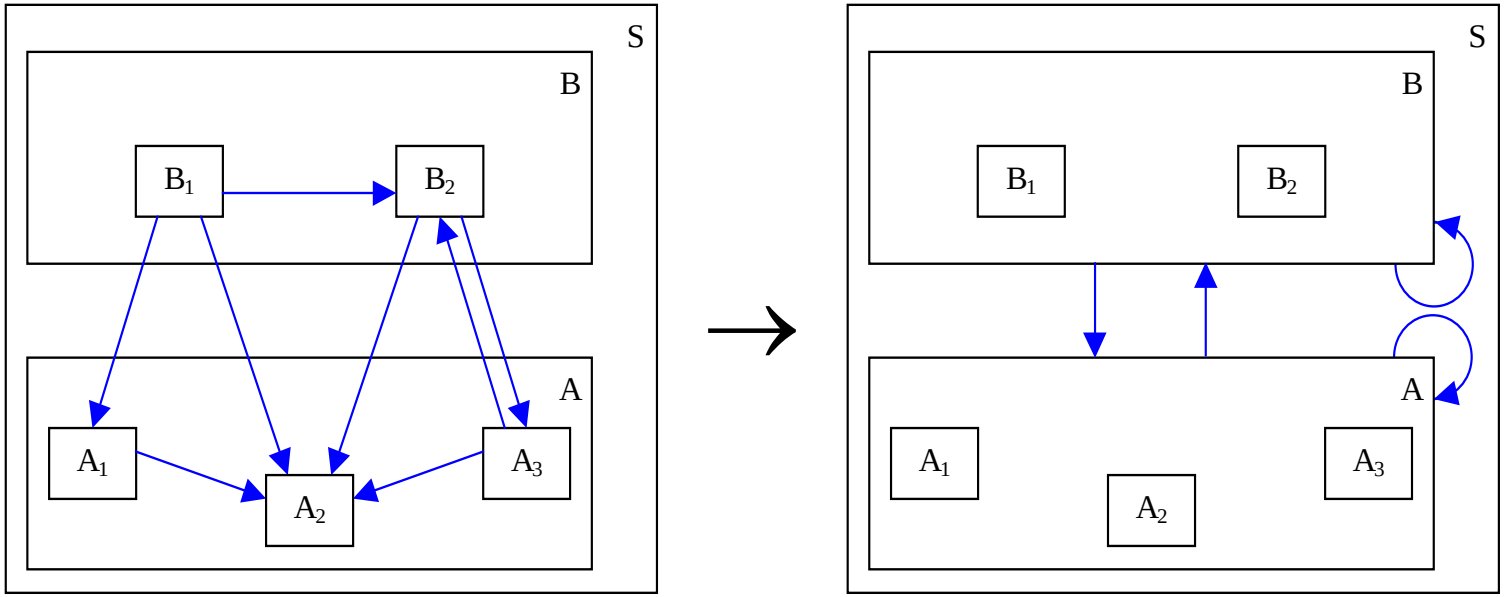
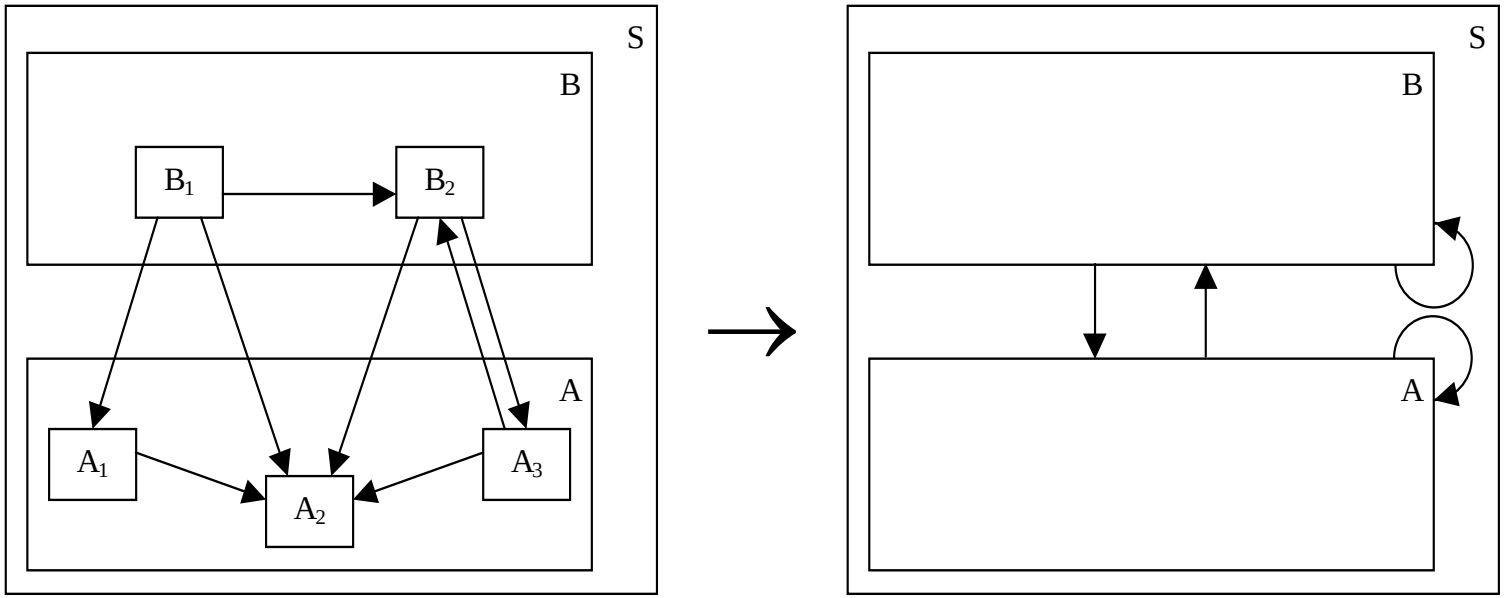
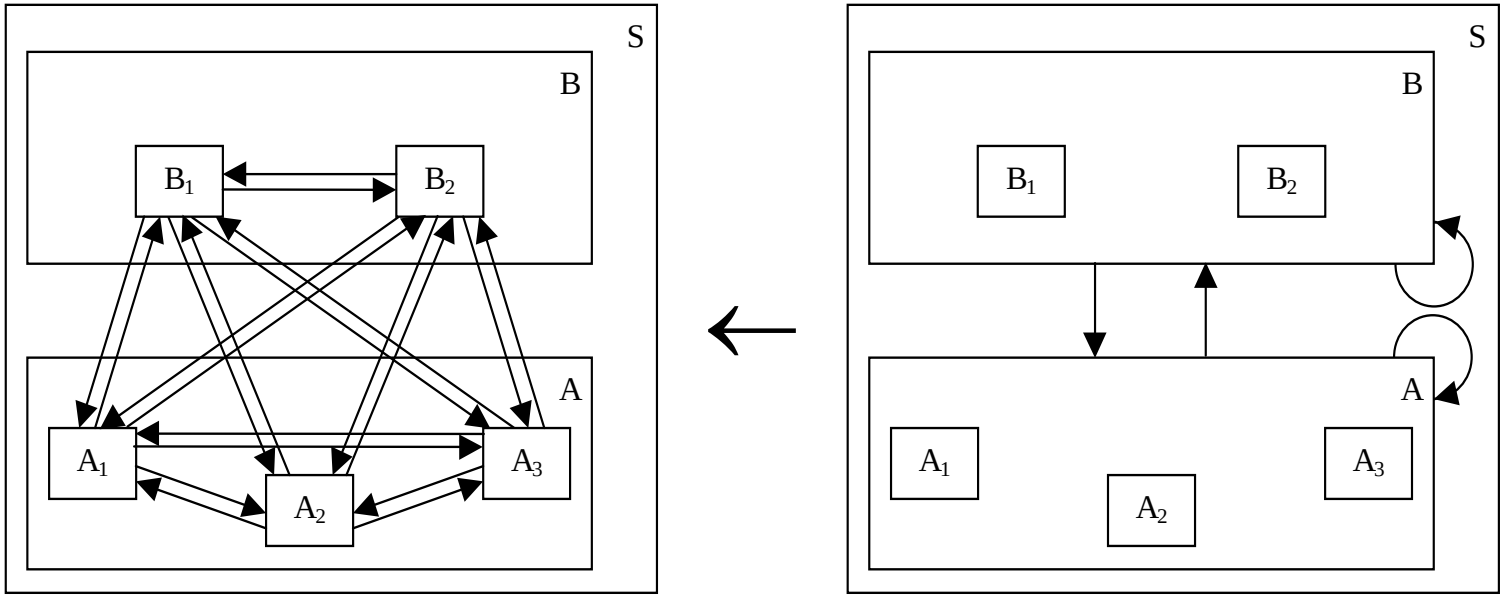


Hiding



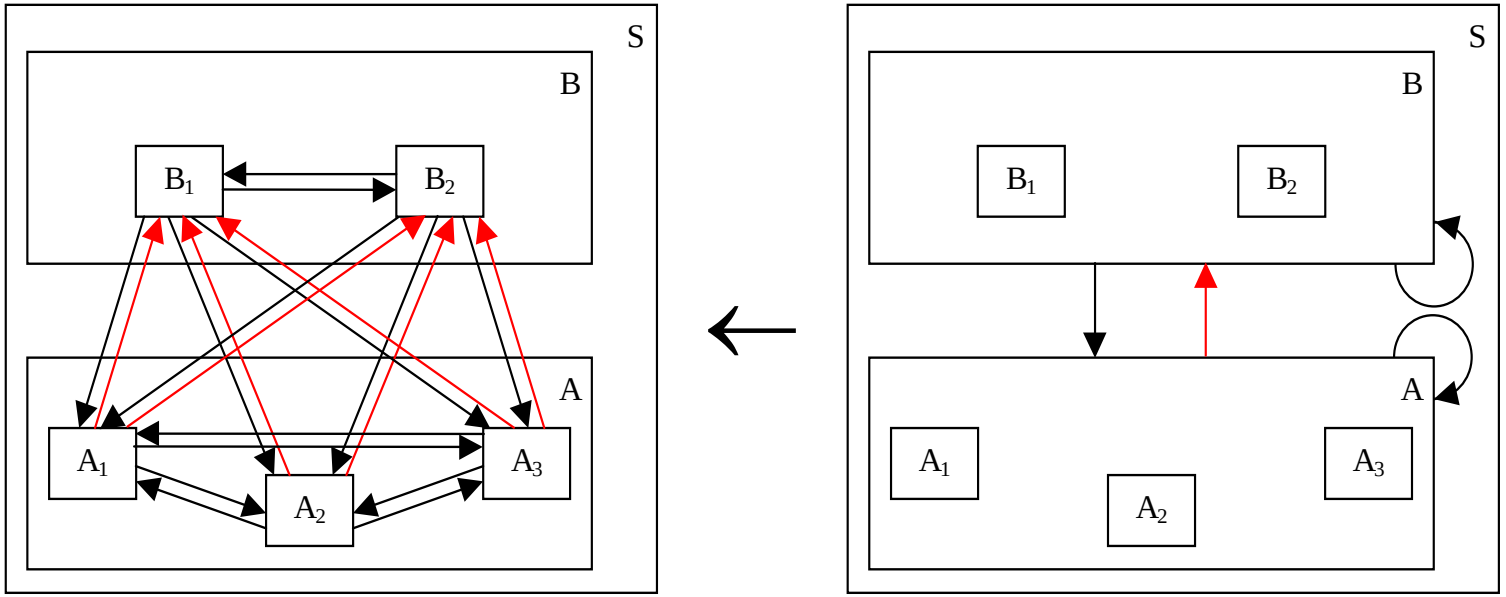
Hiding the decomposition structure of both A and B

Lowering



both cases a complete graph.

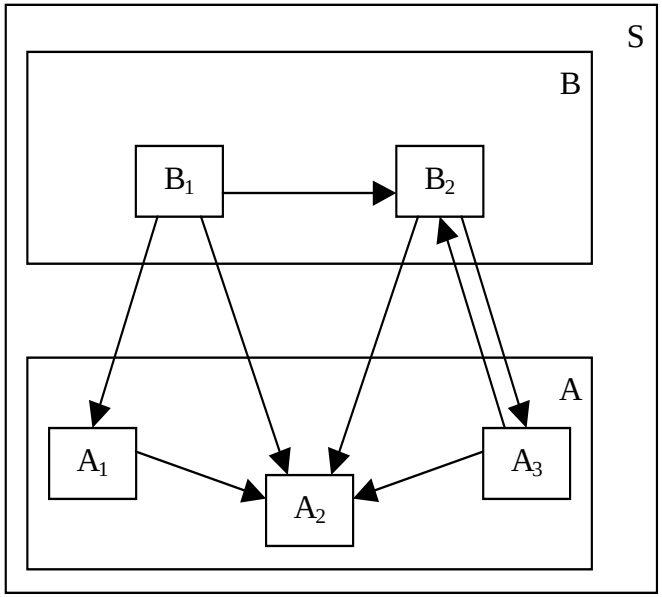
Lowering

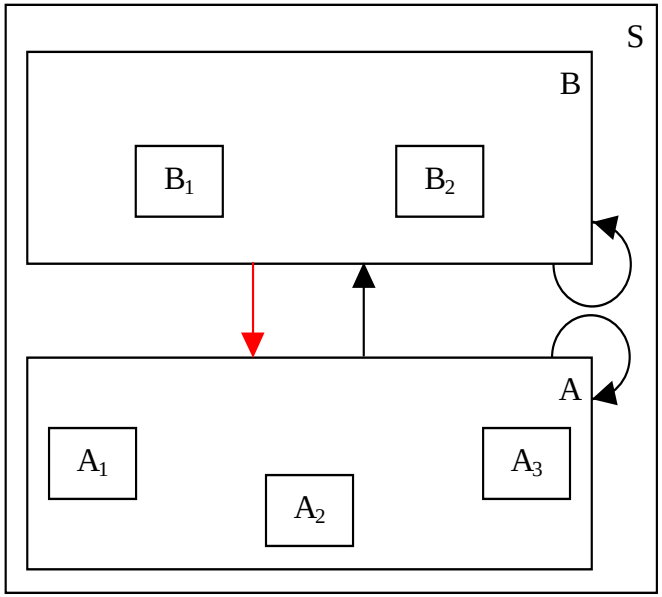


Application: architectural *verification*,

e.g. layering

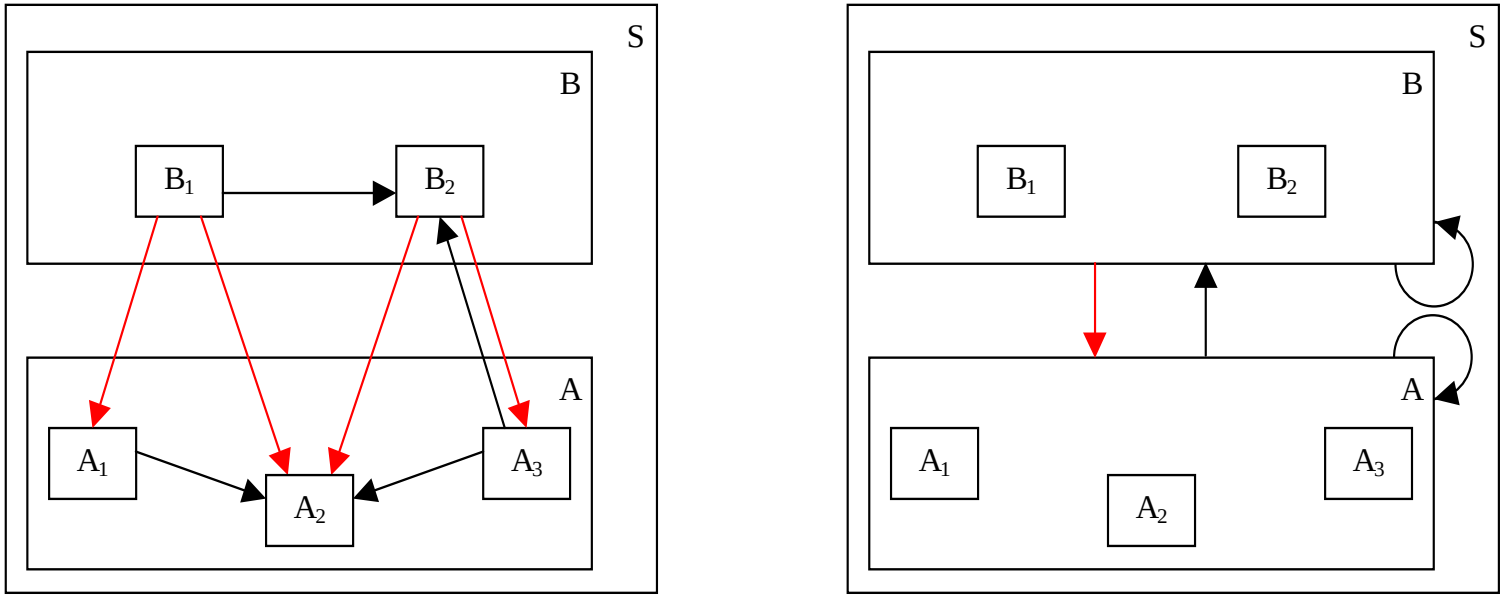
Weights





Which value to be associated ?

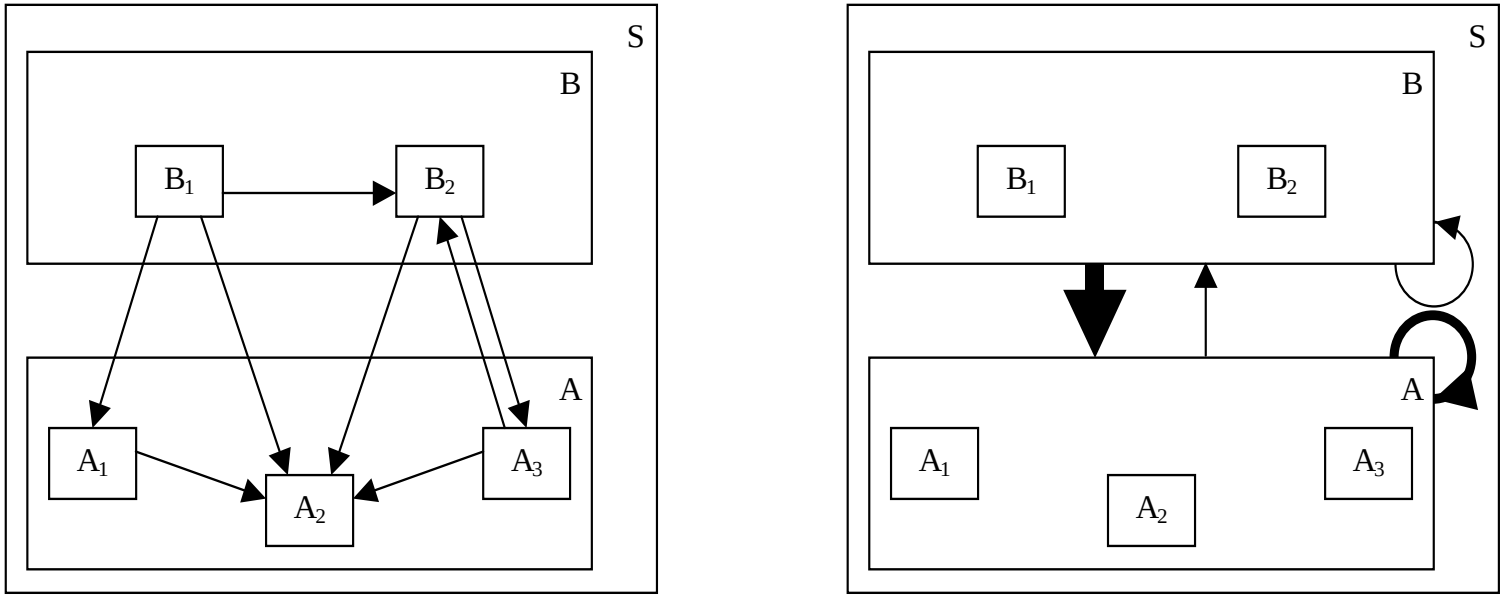
Weights



4: number of *uses* relations

size-oriented weight

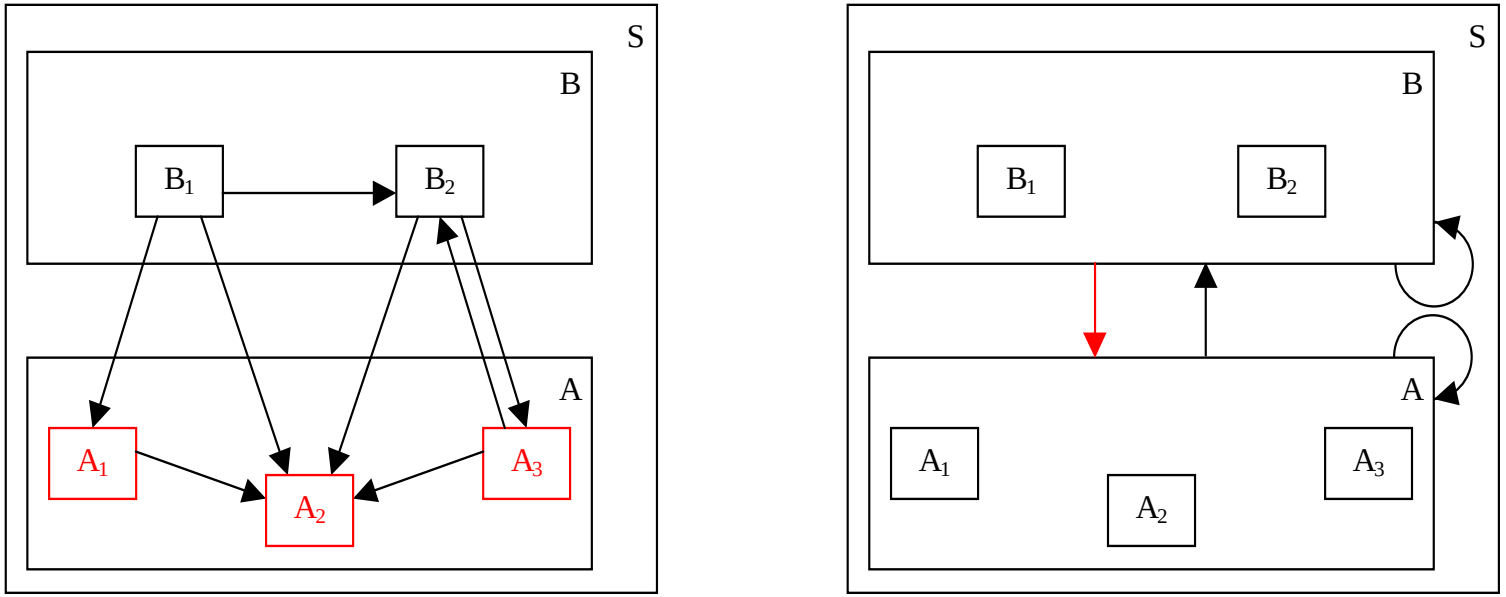
Weights



Fisheye view of the

size-oriented weight

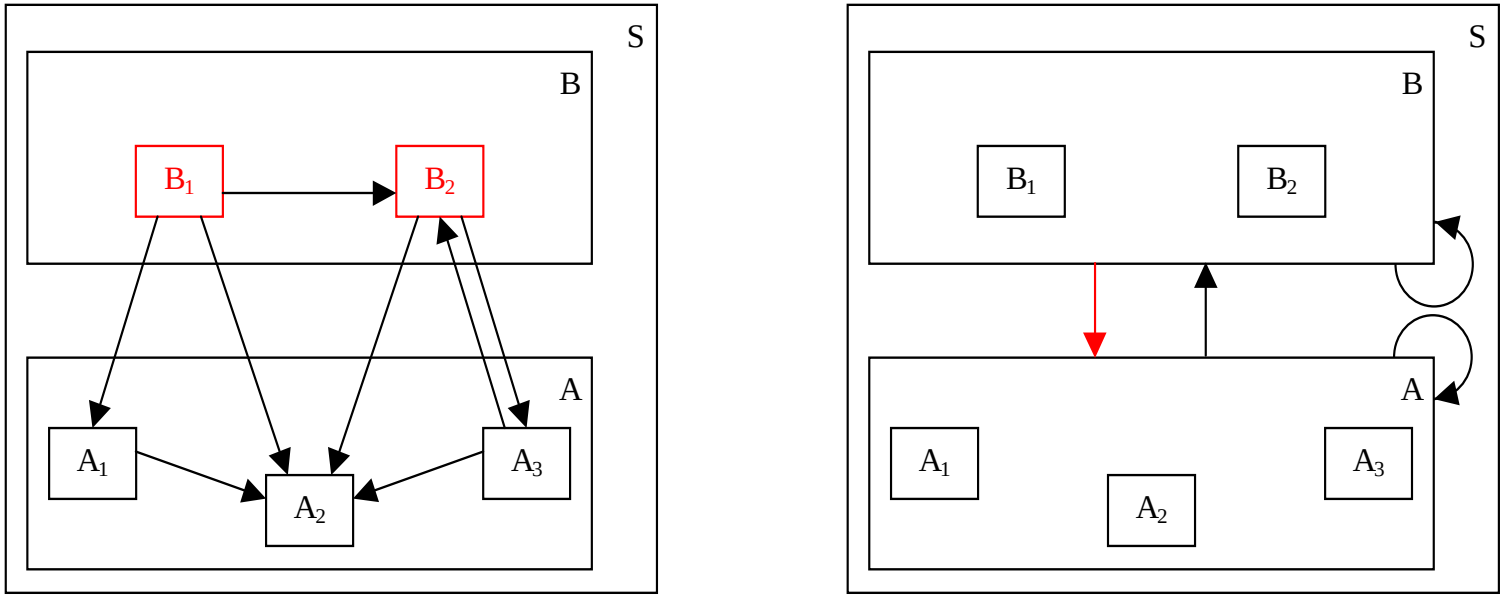
Weights



3: number of *used entities* (A_1, A_2 and A_3)

fan-in-oriented weight

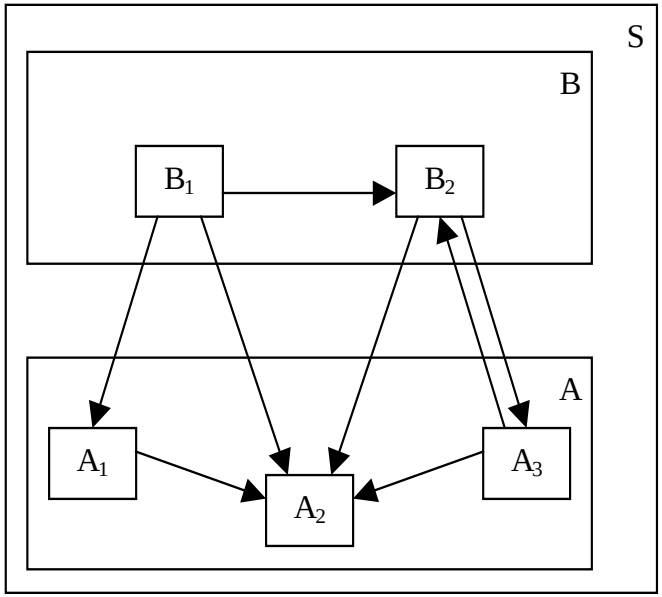
Weights

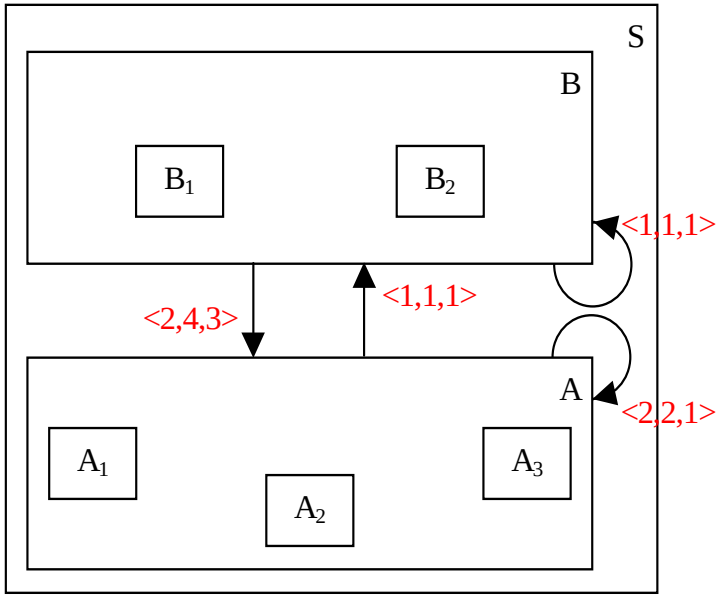


2: number of *using entities* (B_1 and B_2)

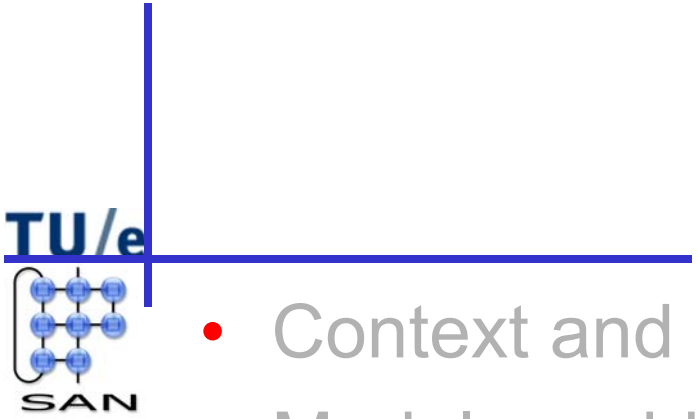
fan-out-oriented weight

Weights





Each weight has its merits during architectural analysis



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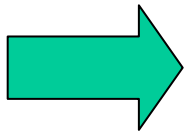
Relation Algebra: Usage

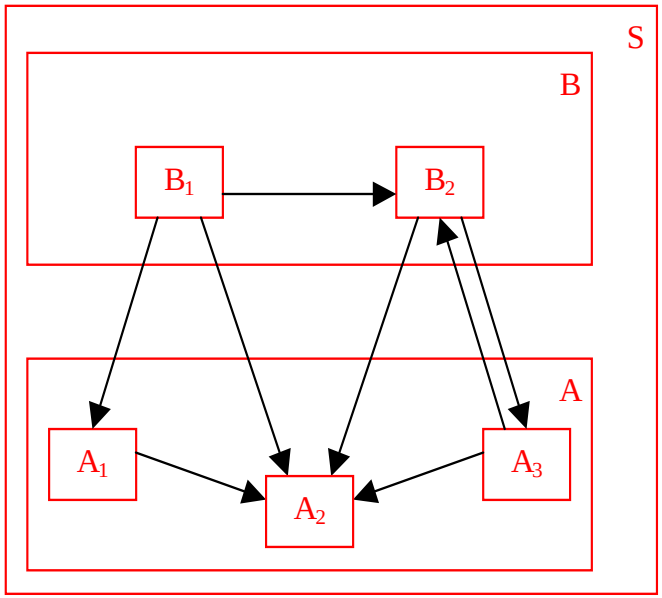
- Visualisation and view calculations
  - reverse architecting purposes
- Relational calculus
  - software architecture analysis
- Architectural rules
  - software architecture verification
- Architectural metrics
  - software architectural quality assurance
- (formal basis of tools)



Relation Algebra: Overview

- Sets
  - ø, ∪, ∩, −, ...
- Relations: sets of pairs
  - ; (composition), $^{-1}$, $^{+}$, *, |,↑ (lifting), ↓ (lowering)
- Multi-sets: bags
  - ⨅, ⨆
- Multi-relations: bags of pairs

Relation Algebra: Example



Set of *Entities* E:

E = { S, A, A_1, A_2, A_3, B, B_1, B_2}

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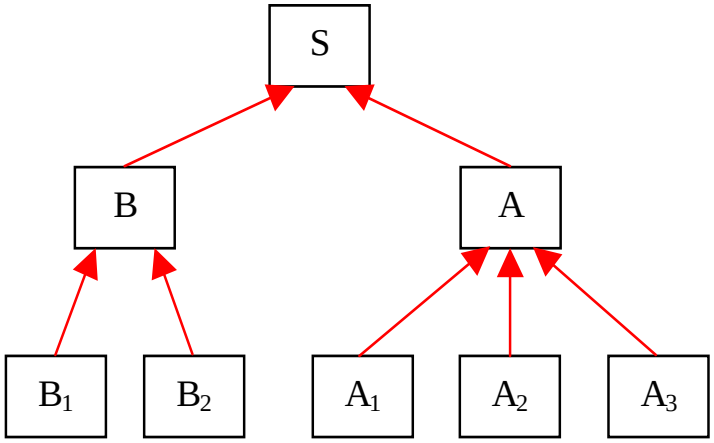
Relation Algebra: Example



Part-of relation P:

P = { <B, S>, <A, S>,

, <B_1, B>, <B_2, B>

, <A_1, A>, <A_2, A>, <A_3, A>

}

A part-of relation:

- describes the decomposition tree;
- is both: *functional* and *a-cyclic*.

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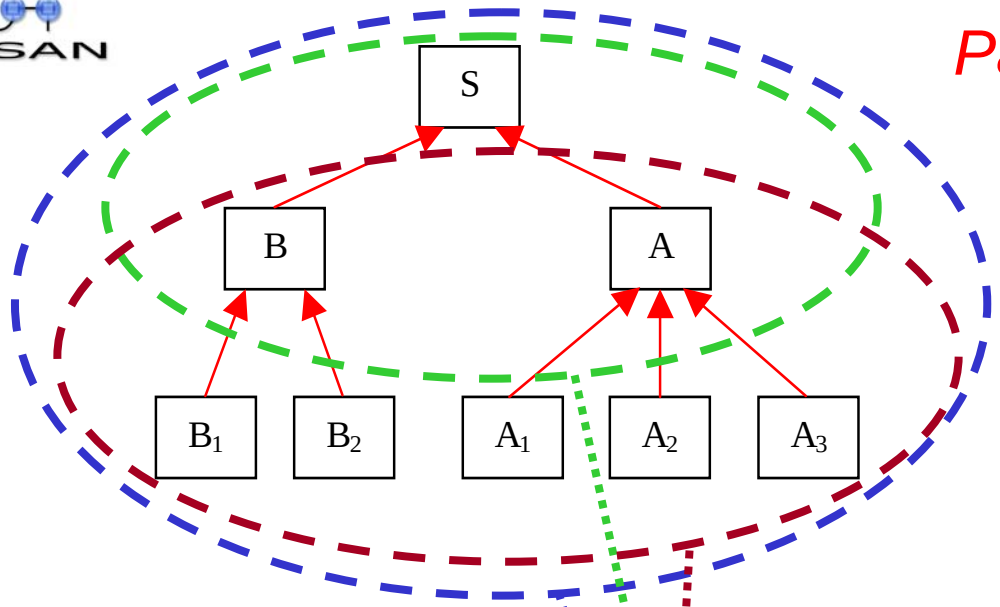
Relation Algebra: Example



Part-of relation P:

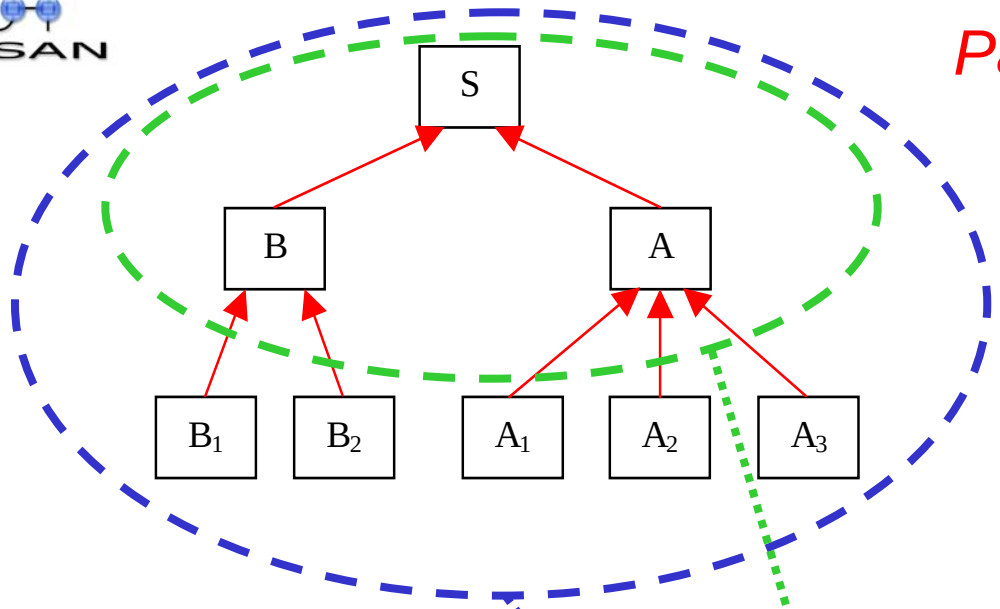
P = { <B, S>, <A, S>,
, <B_1, B>, <B_2, B>
, <A_1, A>, <A_2, A>, <A_3, A>
}

Domain of P: dom(P) = { B_1, B_2, B, A_1, A_2, A_3, A }.

Range of P: ran(P) = { B, A, S }.

Carrier of P: car(P) = { B_1, B_2, B, A_1, A_2, A_3, B, A, S } = E.

Relation Algebra: Example



Part-of relation P:

P = { <B, S>, <A, S>,

, <B_1, B>, <B_2, B>

, <A_1, A>, <A_2, A>, <A_3, A>

}

Question: How to express the leafs of the decomposition tree in relation algebra using P?

Answer: leafs(E) = car(P) – ran(P) = { B_1, B_2, A_1, A_2, A_3 }.

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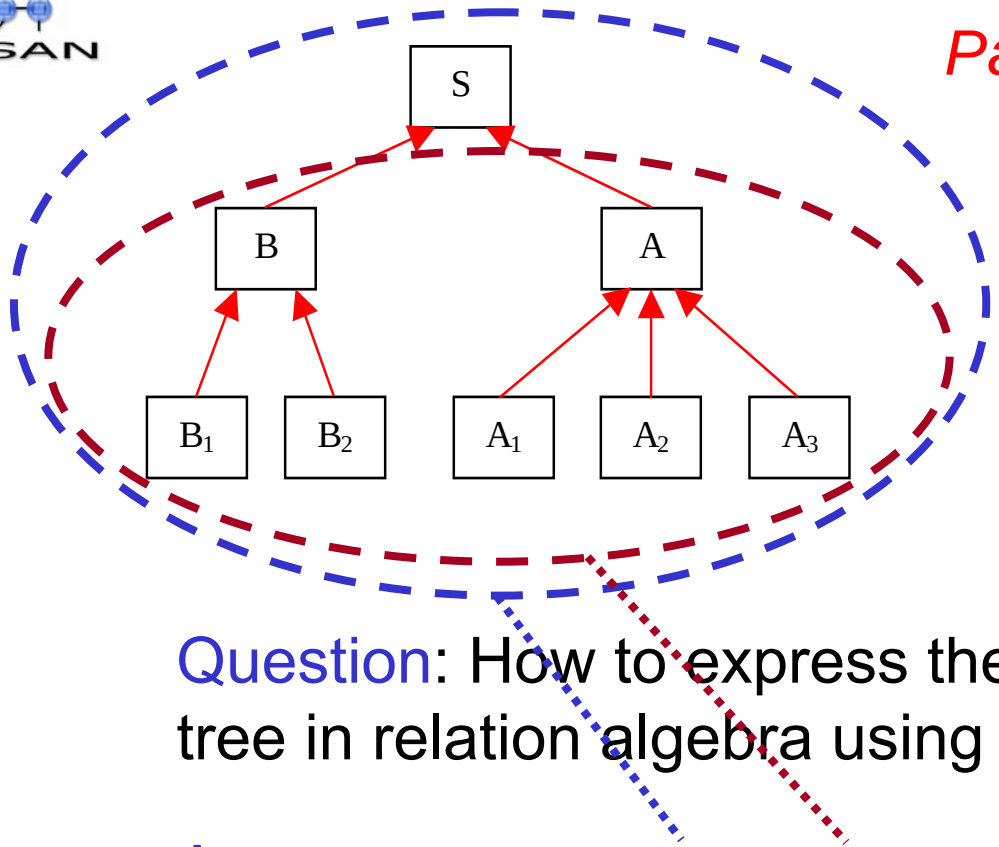
Relation Algebra: Example



Part-of relation P:

P = { <B, S>, <A, S>,

, <B_1, B>, <B_2, B>

, <A_1, A>, <A_2, A>, <A_3, A>

}

Question: How to express the root of the decomposition tree in relation algebra using P?

Answer: root(E) = car(P) – dom(P) = { S }.

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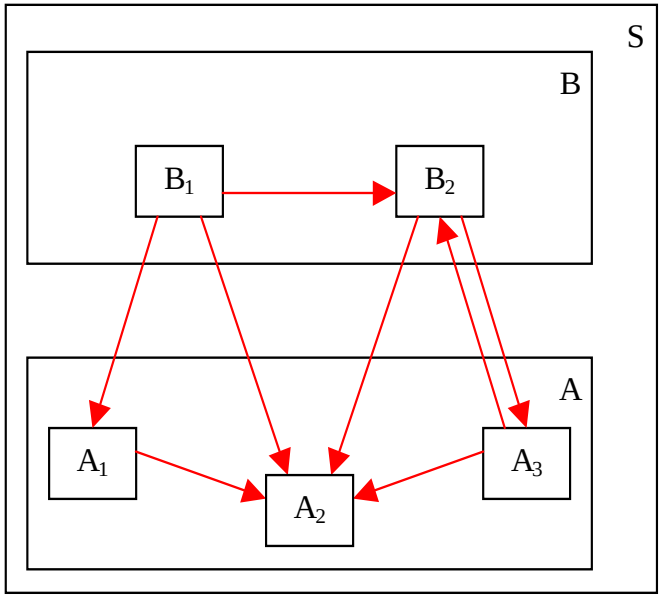
Relation Algebra: Example



Uses relation U:

U = { $\langle A_1, A_2 \rangle$, $\langle A_3, A_2 \rangle$,
, $\langle B_1, A_1 \rangle$, $\langle B_1, A_2 \rangle$, $\langle B_1, B_2 \rangle$
, $\langle B_2, A_2 \rangle$, $\langle B_2, A_3 \rangle$
, $\langle A_3, B_2 \rangle$
}

Question: How to express the entities that use, but are not used by, entities in relation algebra ?

Answer: use_only = car(U) – ran(U) = { B_1 }.

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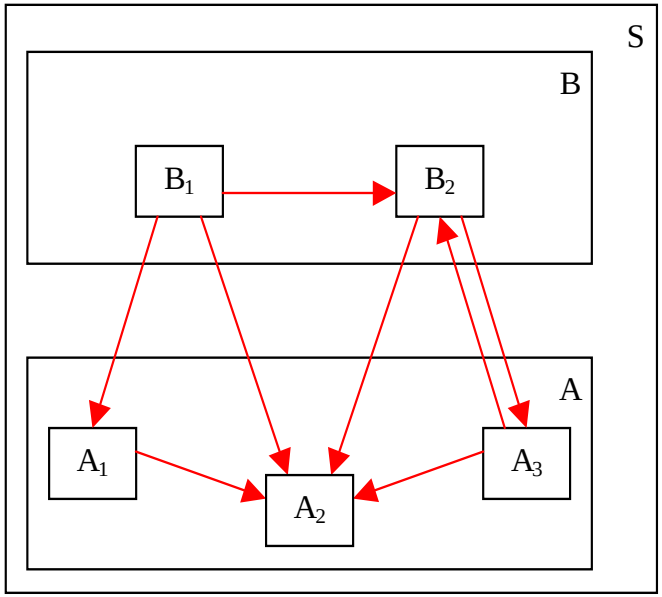
Relation Algebra: Example



Uses relation U:

U = { <A_1, A_2>, <A_3, A_2>,
, <B_1, A_1>, <B_1, A_2>, <B_1, B_2>
, <B_2, A_2>, <B_2, A_3>
, <A_3, B_2>
}

Question: How to express the leaf entities that neither use nor are used by entities in relation algebra ?

Answer: isolated = leafs(E) – car(U) = ø.

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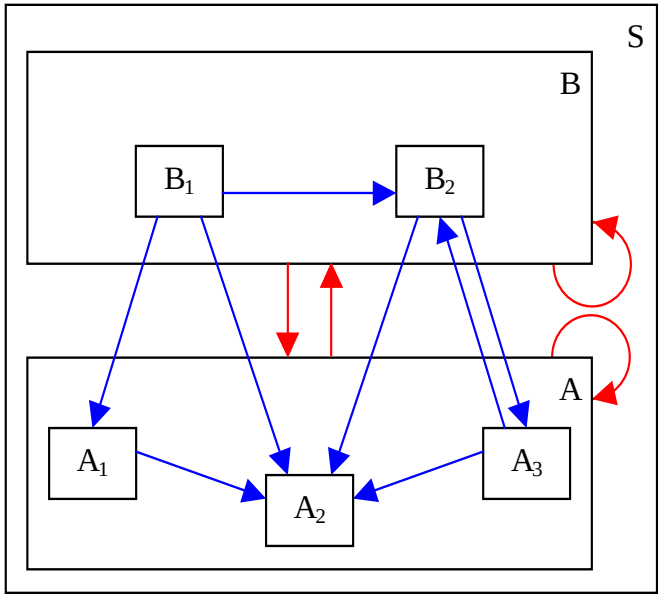
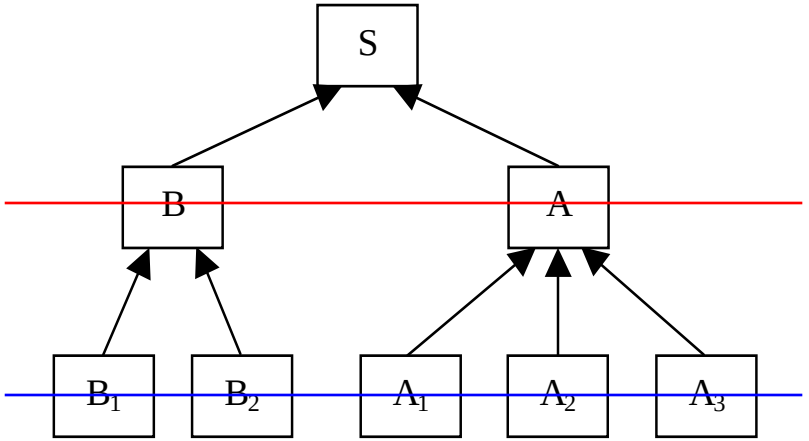
Relation Algebra: Example





Transform a relation to a higher level, i.e. *replace both the source and the destination of each arrow by its enclosing entity*.

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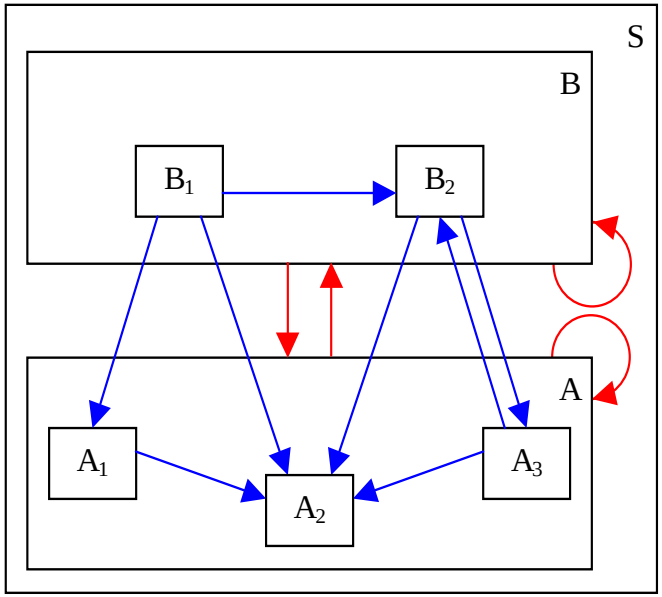
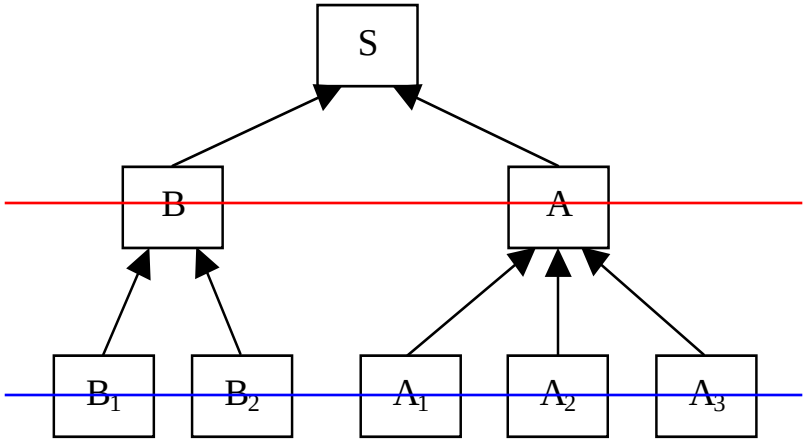
Relation Algebra: Example





Example: <B_1, A_1>

- *replace source:* B_1 by B;
- *replace destination:* A_1 by A.

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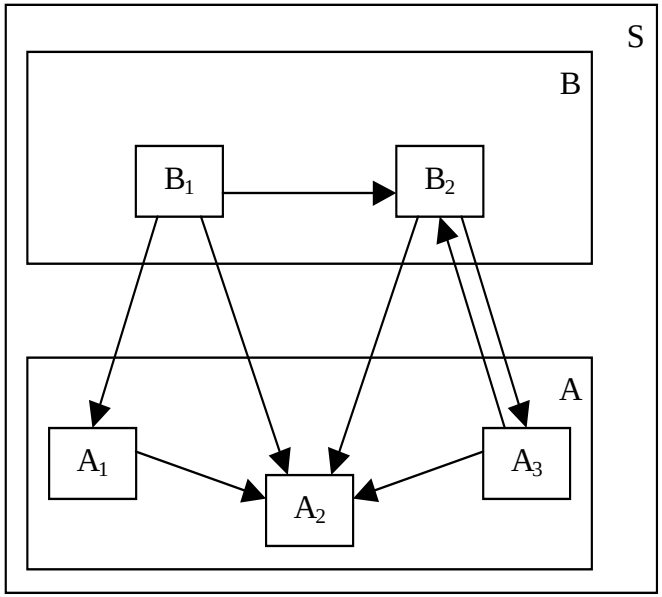
Relation Algebra: Example



Lifting:

def.: $U \uparrow P \equiv P^{-1} ; U ; P$

ex.: $\langle B_1, B \rangle \in P \Leftrightarrow \langle B, B_1 \rangle \in P^{-1}$;

$\langle B_1, A_1 \rangle \in U$;

$\langle A_1, A \rangle \in P$;

For $U \uparrow P$, P must be a part-of relation

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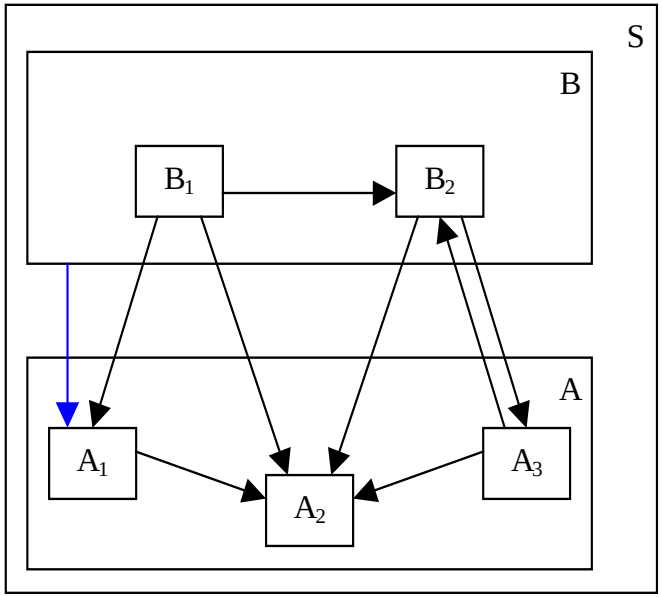
Relation Algebra: Example



Lifting:

def.: $U \uparrow P \equiv P^{-1} ; U ; P$

ex.: $\langle B_1, B \rangle \in P \Leftrightarrow \langle B, B_1 \rangle \in P^{-1}$;

$\langle B_1, A_1 \rangle \in U$;

$\langle A_1, A \rangle \in P$;

$\langle B, A_1 \rangle \in P^{-1} ; U$

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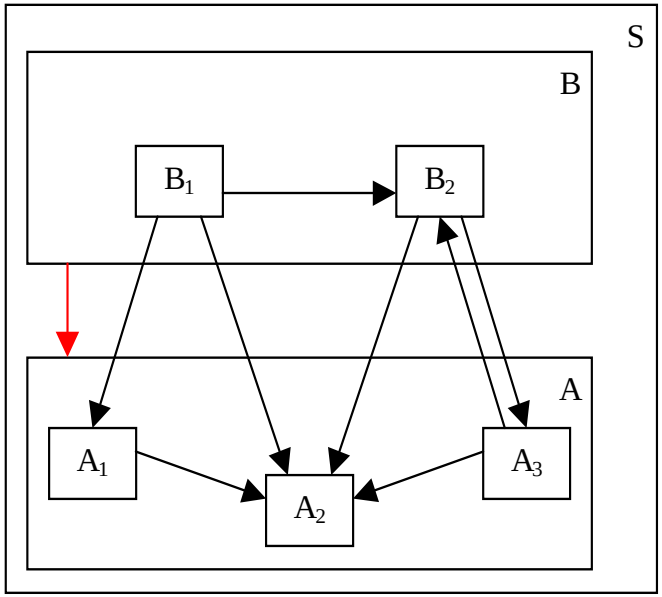
Relation Algebra: Example



Lifting:

def.: $U \uparrow P \equiv P^{-1} ; U ; P$

ex.: $\langle B_1, B \rangle \in P \Leftrightarrow \langle B, B_1 \rangle \in P^{-1}$;

$\langle B_1, A_1 \rangle \in U$;

$\langle A_1, A \rangle \in P$;

$\langle B, A \rangle \in P^{-1} ; U ; P$

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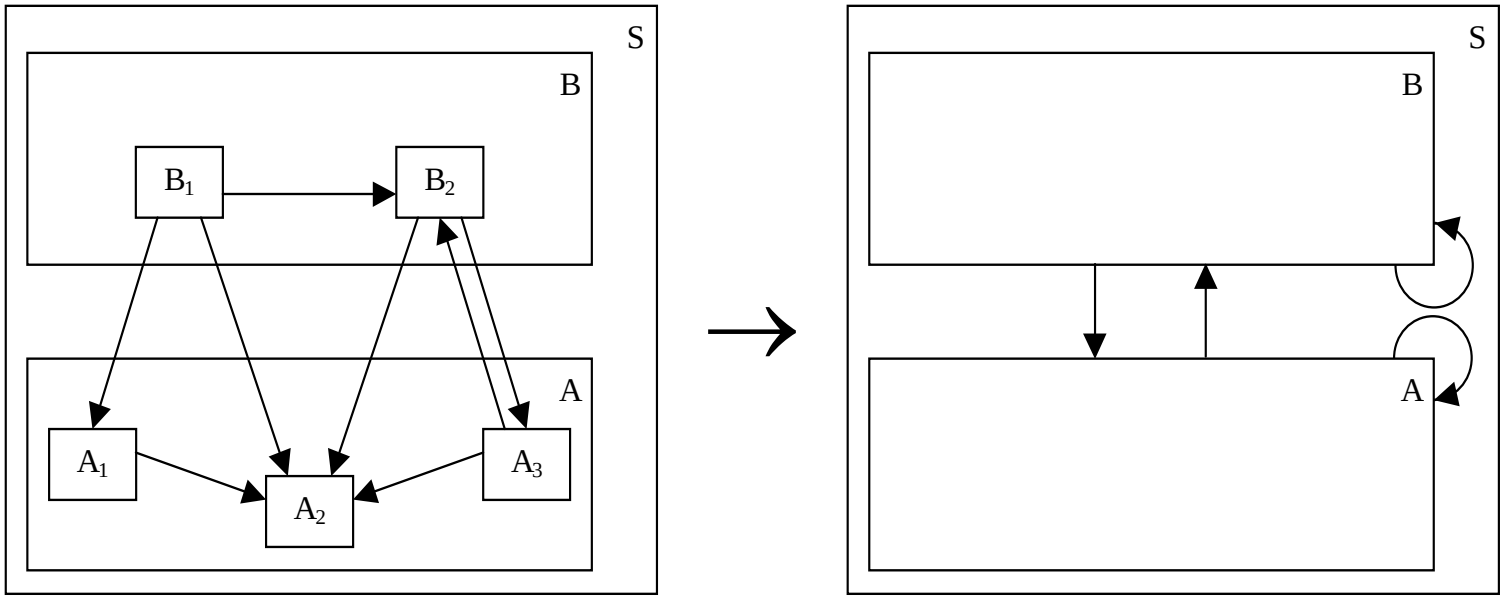
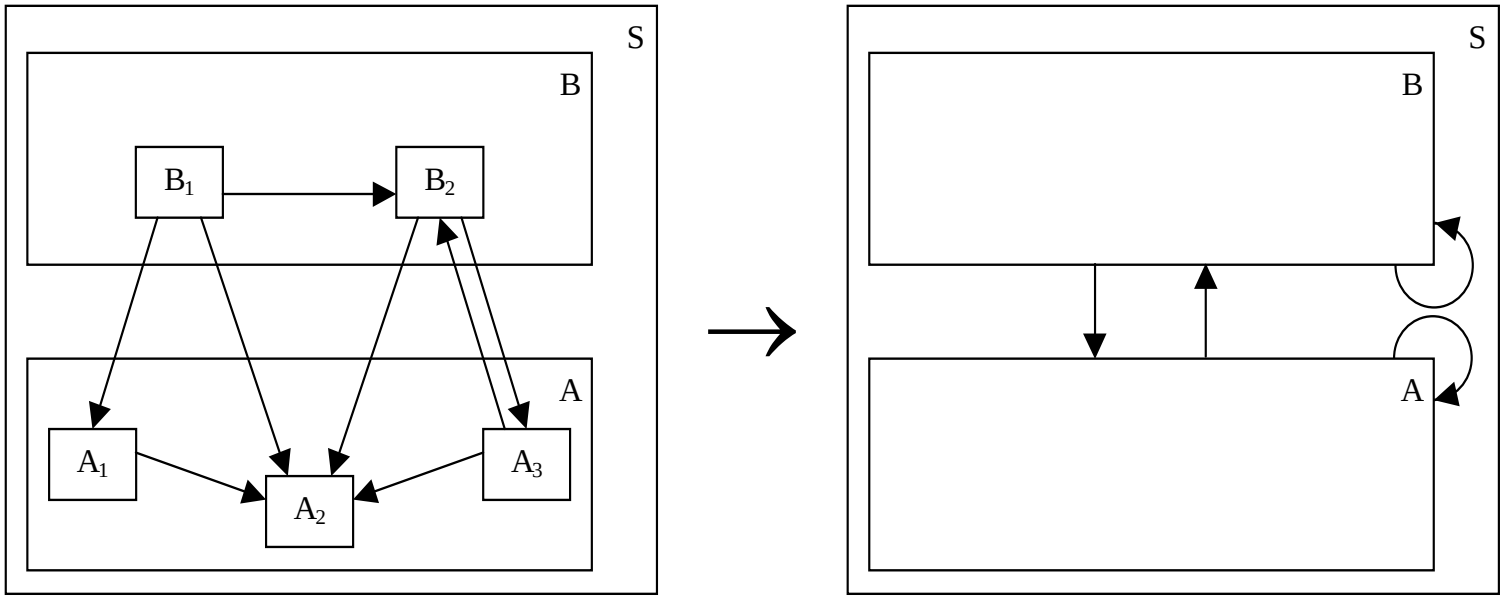
Relation Algebra: Example



Hiding the decomposition structure of both A and B

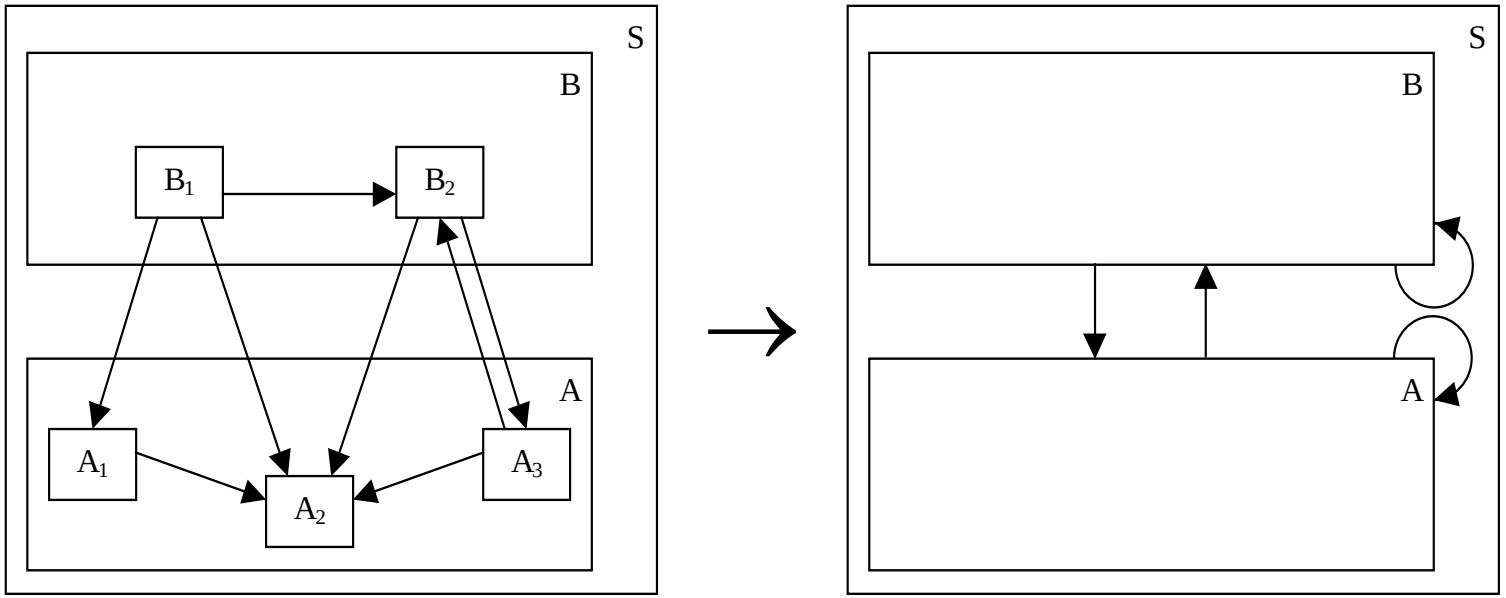
Relation Algebra: Example



Question: How to express the set of entities E' after hiding in relation algebra using P?

Answer: E' = ran(P) = { S, A, B }.

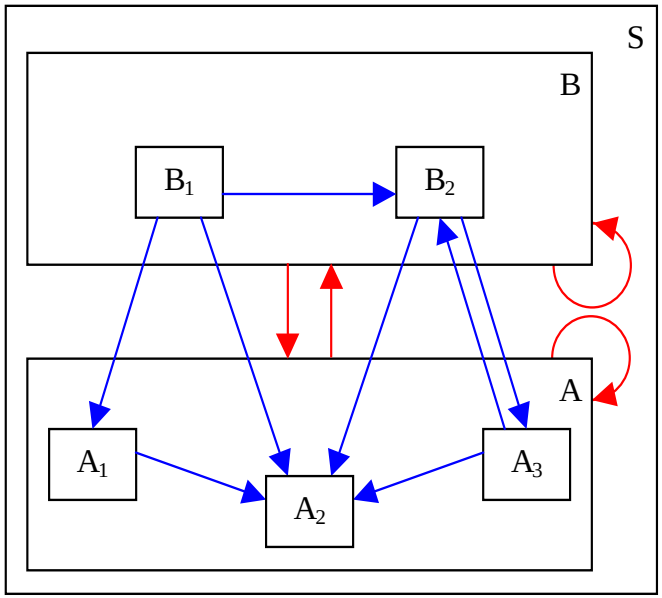
Relation Algebra: Example



Question: How to express the part-of relation P' after hiding in relation algebra ?

Answer: P' = P $|_{car}$ E' = { S, A, B }.

Relation Algebra: Example



Lowering:

def.: $U \downarrow P \equiv P ; U ; P^{-1}$

For $U \downarrow P$, P must be a part-of relation

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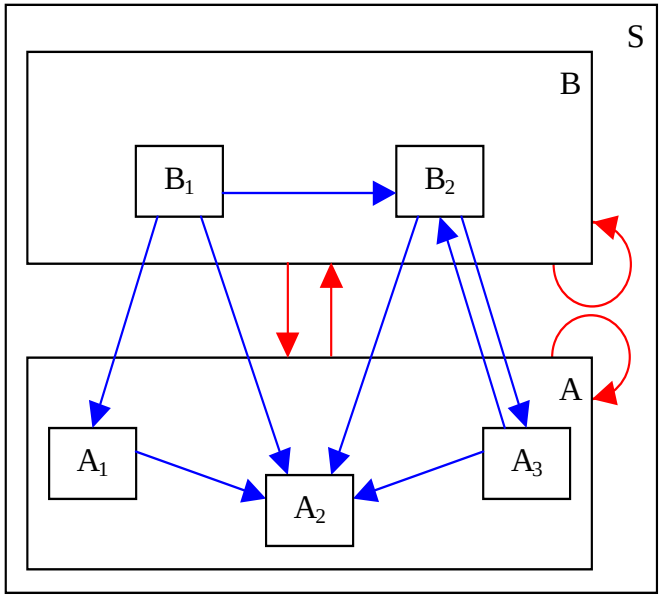
Relation Algebra: Example



Lowering:

def.: $U \downarrow P \equiv P ; U ; P^{-1}$

ex.: $\{<A, B>\} \downarrow P = \{<A_1, B_1>, <A_1, B_2>$
$,<A_2, B_1>, <A_2, B_2>$
$,<A_3, B_1>, <A_3, B_2>$
$\}$

$\{<A, B>\} \downarrow P \cap U = \{<A_3, B_2>\}$

Layering rule:

$$\{<A, B>\} \downarrow P \cap U = \emptyset$$

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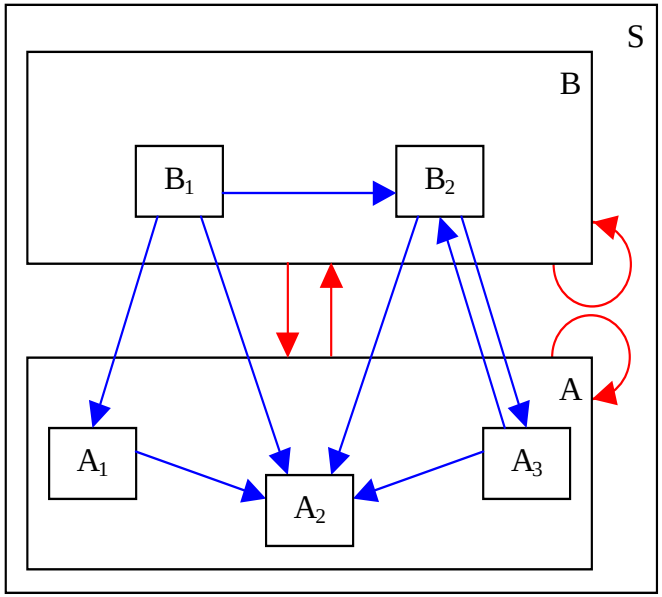
Relation Algebra: Example



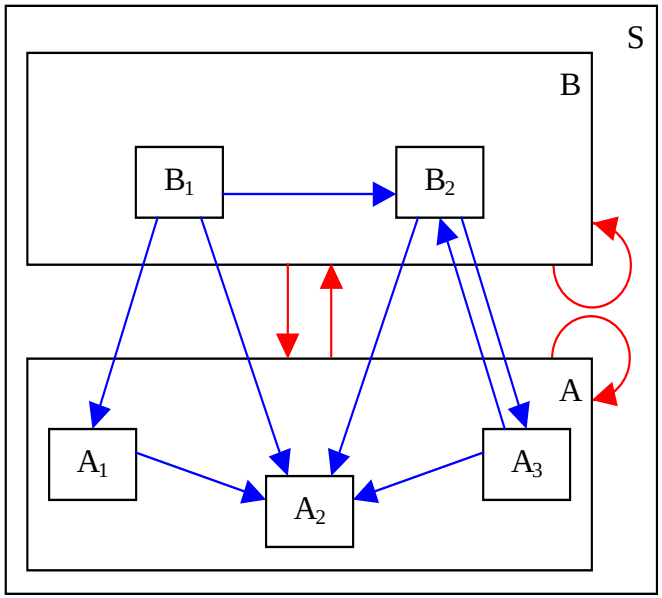
Size-oriented lifting:

def.: $U_M \uparrow P \equiv \lceil P^{-1} \rceil ; U_M ; \lceil P \rceil$

where $U_M = \lceil U \rceil$

ex.: <B, A> 4 times in $U_M \uparrow P$

Relation Algebra: Example



Fan-out-oriented lifting:

$U_M \uparrow_{\triangleright} P \equiv \lceil P^{-1} \rceil ; \lceil \lfloor U_M \rfloor ; P \rceil$

<B, A> 2 times in $U_M \uparrow_{\triangleright} P$

Fan-in-oriented lifting:

$U_M \uparrow_{\triangleleft} P \equiv \lceil P^{-1} ; \lfloor U_M \rfloor \rceil ; \lceil P \rceil$

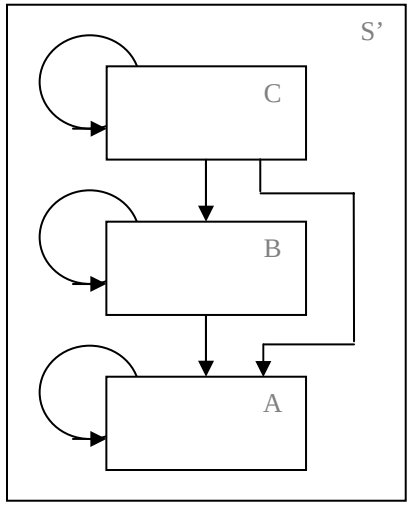
<B, A> 3 times in $U_M \uparrow_{\triangleleft} P$

Relation Algebra: Application

- Analytical techniques:
  - lifting,
  - checking of rules,
  - impact analysis,
  - finding unused and unavailable components,
  - identification of top and bottom layers,
  - study of alternative component groupings,
  - improvement of presentation by suppressing elements,
  - improvement of locality,
  - checking of linearity,
  - analysis of cycles,
  - improvement of presentation by transitive reduction.

[Feijs et al 98]

Verification



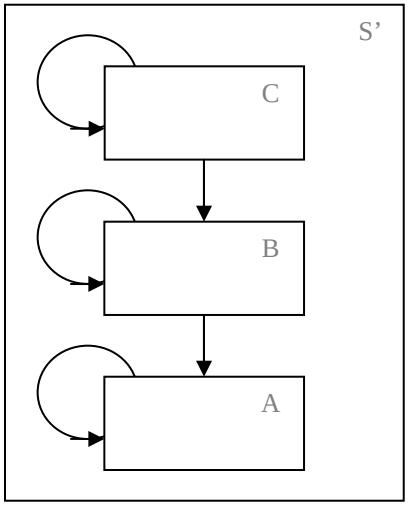
System S' consists of 3 levels, and is *layered*.

Question: How to express layering rule LR for S' in relation algebra?

Answer: Layering rule LR for S':

LR(S'): {<A, B>, <A, C>, <B, C>}$\downarrow$ P $\cap$ U = ø

Verification



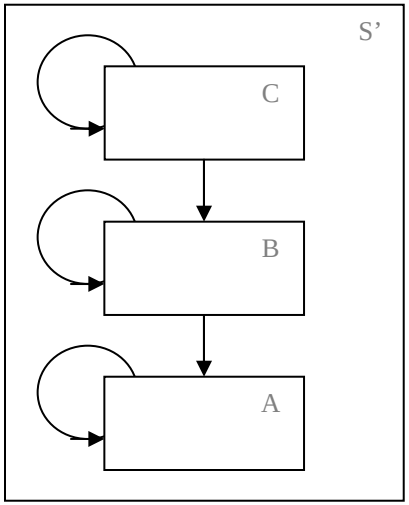
System S' consists of 3 levels, and is *strictly* layered.

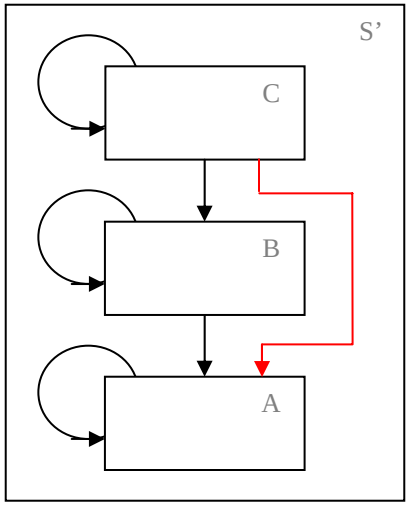
Question: How to express strictly layering rule SLR for S' in relation algebra?

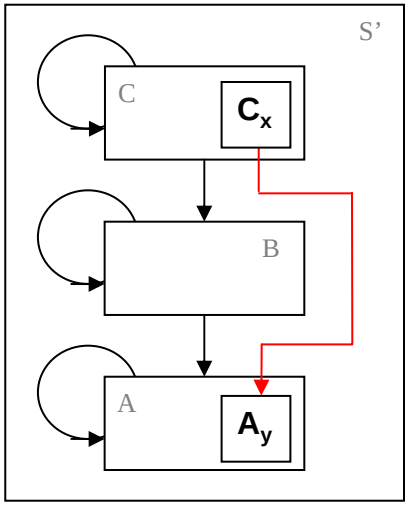
Answer: Strictly layering rule SLR for S':

SLR(S'): {<A, B>, <A, C>, <B, C>, <C, A>}$^{\downarrow}$ P $\cap$ U = ø

Verification







Intended **Derived**

Question: How to express the exception to the strictly layering rule SLR(S') for S' in relation algebra?

Answer: Delete specific uses relation between modules !

$$\{<A, B>, <A, C>, <B, C>, <C, A>\}\downarrow P \cap U - \{<C_x, A_y>\} = \emptyset$$

Conclusion

Goals revisited

- Student understands:
  - the need for module architecture control;
    - diversion of intended and derived architecture over time
  - how module architecture control can be performed;
    - describe the architecture in terms of rules, check compliance of the derived architecture, and adapt
  - the basics of relation algebra.
- Student can apply relation algebra on a simple example.

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- [Boehm 1995] *Engineering context (for software architecture), invited talk, 1st Int. Workshop on Architecture for Software Systems, Seattle, Washington, April 1995.*
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