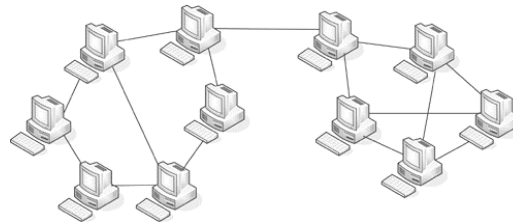# DL-Lite$_R$ in the light of propositional logic for decentralized data management

Nada Abdallah   **François Goasdoué**

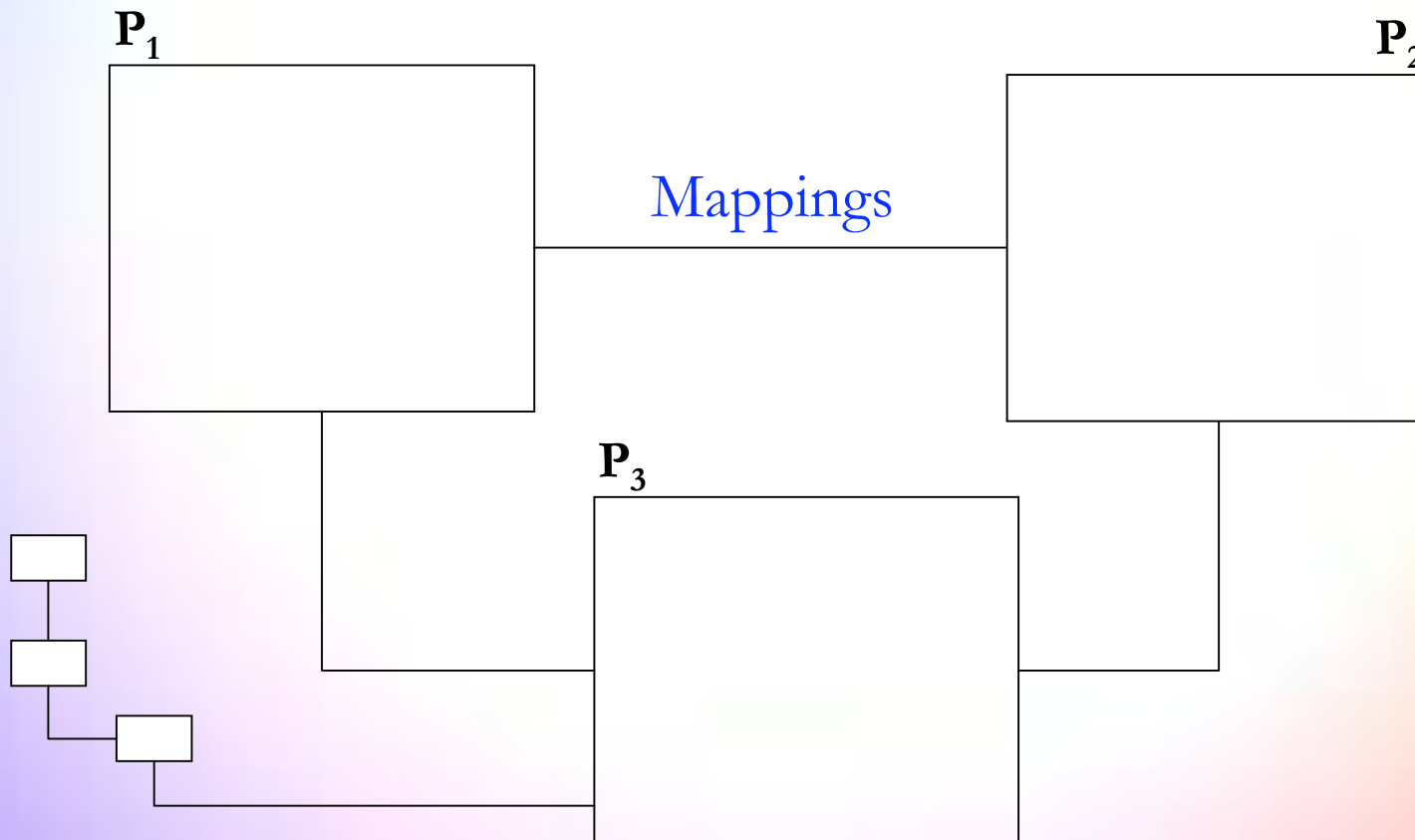Université Paris-Sud & CNRS(LRI/IASI) – INRIA (Saclay/GEMO)

Marie-Christine Rousset

Université Grenoble & CNRS(LIG) – INRIA

Context   Decentralized Data management system for the Semantic Web

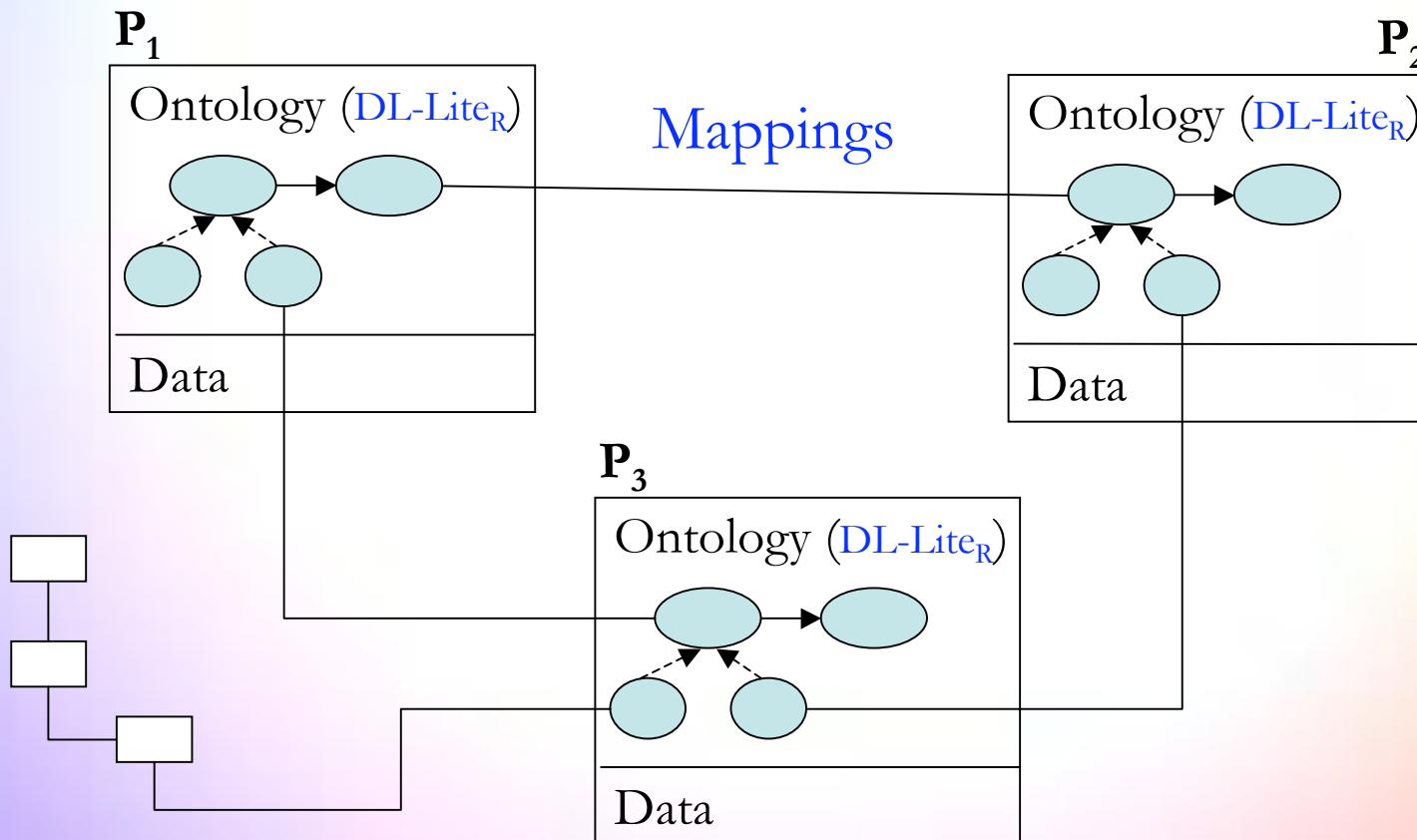**Context** Decentralized Data management system for the Semantic Web

Decentralized: Dynamic Network of collaborative peers

P$_1$

P$_2$

Mappings

P$_3$

Context   Decentralized Data management system for the Semantic Web

Decentralized: Dynamic Network of collaborative peers

Semantic Web: Data are described with ontologies (OWL2)

Context   Decentralized Data management system for the Semantic Web

Decentralized: Dynamic Network of collaborative peers
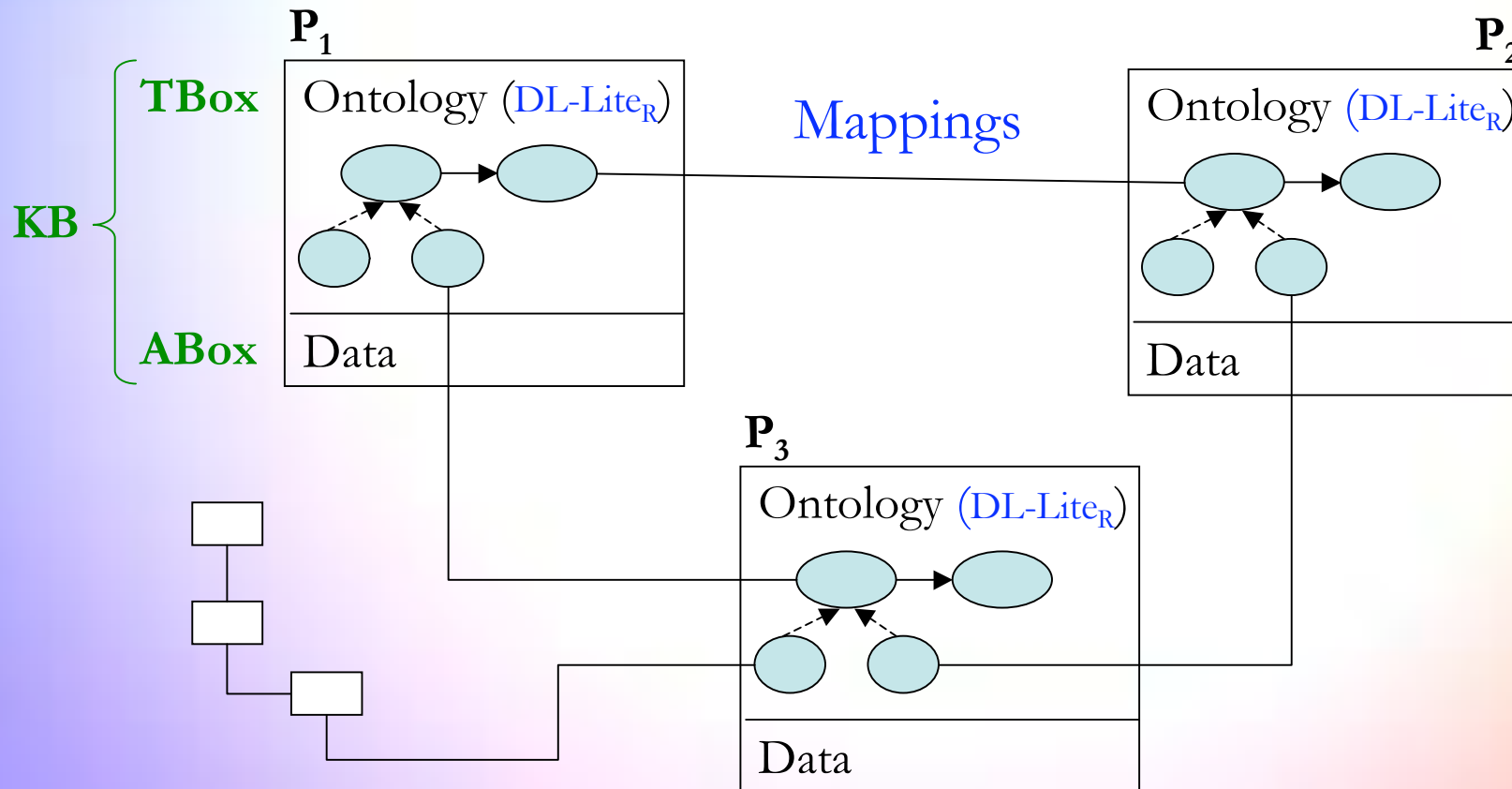
Semantic Web: Data are described with ontologies (OWL2)

Context   Decentralized Data management system for the Semantic Web

Decentralized: Dynamic Network of collaborative peers

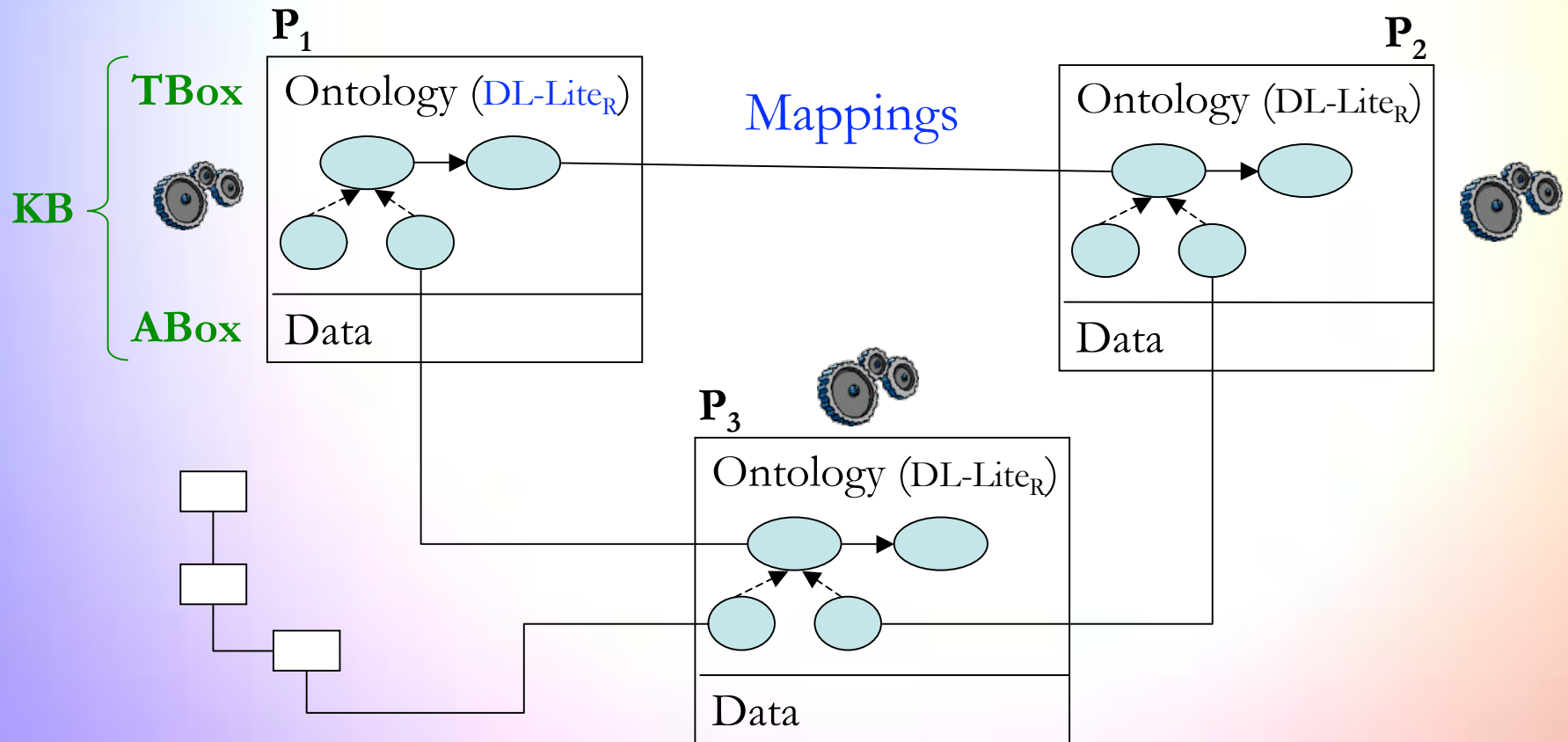Semantic Web: Data are described with ontologies (OWL2)

Global knowledge unknown

P_1

TBox

KB

ABox

Ontology (DL-Lite$_R$)

Mappings

P_2

Ontology (DL-Lite$_R$)

Data

Data

P_3

Ontology (DL-Lite$_R$)

Data

Context   Decentralized Data management system for the Semantic Web

EXISTING: SomeOWL - SomeRDFS

Global knowledge unknown
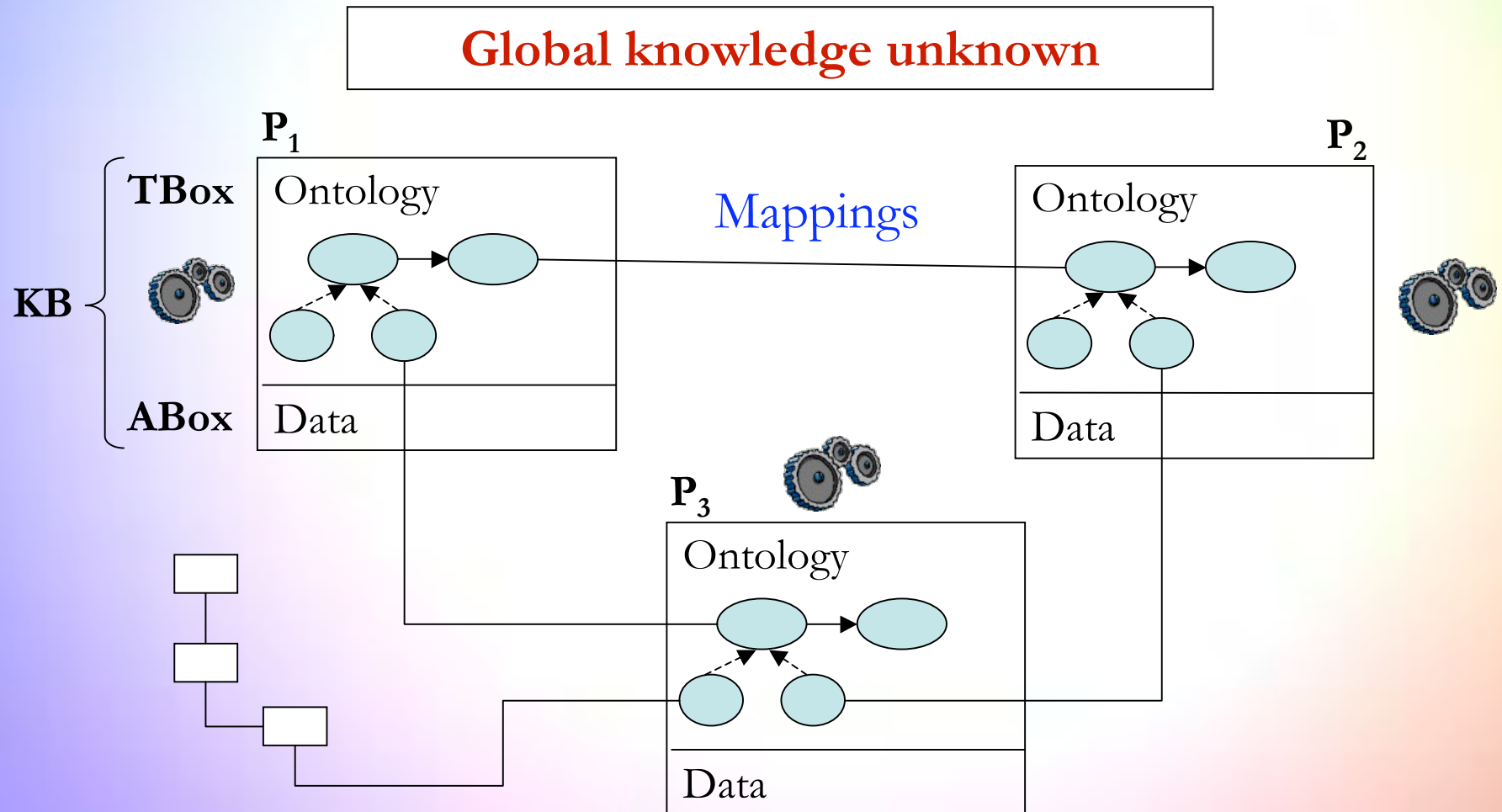
Contributions

1. **DL-Lite$_R$ decentralized data model**

2. **Decentralized Algorithms for:**
   - ✓ **Data consistency checking**
   - ✓ **Query Answering**

Contributions

State of the art

1. **DL-Lite$_R$ decentralized data model**

2. **Decentralized Algorithms for:**

   ✓ **Data consistency checking**

   ✓ **Query Answering**

- D.Calvenese and al. (JAR 07) "Tractable reasoning and efficient query answering in description logics"

Centralized DL-Lite$_R$ KB

Centralized Algorithms for:

   ✓ **Data consistency checking**

   ✓ **Query Answering**

Contributions

State of the art

1. **DL-Lite$_R$ decentralized data model**

2. **Decentralized** **Algorithms for:**

    ✓ **Data consistency checking**

    ✓ **Query Answering**

- D.Calvenese and al. (JAR 07) "Tractable reasoning and efficient query answering in description logics"

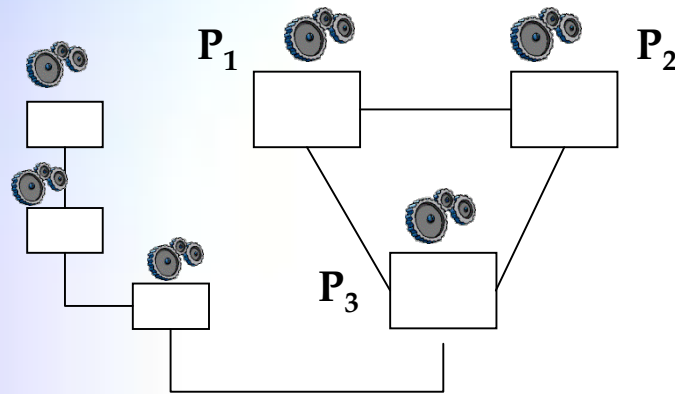| Centralized DL-Lite$_R$ KB |

Centralized **Algorithms for:**

✓ **Data consistency checking**

✓ **Query Answering**

3. **Decentralized & Centralized Algorithms for:**

    ✓ **View consistency checking**

    ✓ **Query Answering using views**

Outline

❑ **DL-Lite$_R$ decentralized data management system**

    ❑ **Data consistency checking**

    ❑ **Query Answering**

    ❑ **Conclusion & Future Work**

DL-Lite$_R$ decentralized data management system

P$_1$

Course$_1$

$\subseteq$ $\subseteq$

Lang$_1$ Math$_1$

P$_2$

Student$_2$

$\subseteq$

ES$_2$

P$_3$

Teacher$_3$

$\subseteq$

Mathematician$_3$

P$_4$

Diploma$_4$

DL-Lite$_R$ decentralized data management system

DL-Lite$_R$ decentralized data management system

DL-Lite$_R$ decentralized data management system

DL-Lite$_R$ decentralized data management system

DL-Lite$_R$ decentralized data management system

P$_1$

$Lang_1 \subseteq Course_1$ $\exists TaughtTo_1 \subseteq Course_1$

$Math_1 \subseteq Course_1$ $\exists LangTaughtTo_1 \subseteq Lang_1$

$Lang_1 \subseteq \neg Math_1$ $\exists MathTaughtTo_1 \subseteq Math_1$

$LangTaughtTo_1 \subseteq TaughtTo_1$

$MathTaughtTo_1 \subseteq TaughtTo_1$

$TaughtTo_1(Algebra, John)$

$\exists TaughtTo_1^- \subseteq Student_2$
$\exists LangTaughtTo_1^- \subseteq \neg ES_2$
$\exists MathTaughtTo_1^- \subseteq Student_2$

P$_2$

$ES_2 \subseteq Student_2$
$\exists TaughtBy_2 \subseteq Student_2$

$ES_2 (Mike)$
$TaughtBy_2 (Mike, Nada)$

$\exists TaughtBy_2^- \subseteq Teacher_3$
$Student_2 \subseteq \neg Teacher_3$

P$_3$

$Mathematician_3 \subseteq Teacher_3$
$\exists Teach_3 \subseteq Mathematician_3$

$Teach_3 (John, Analysis)$
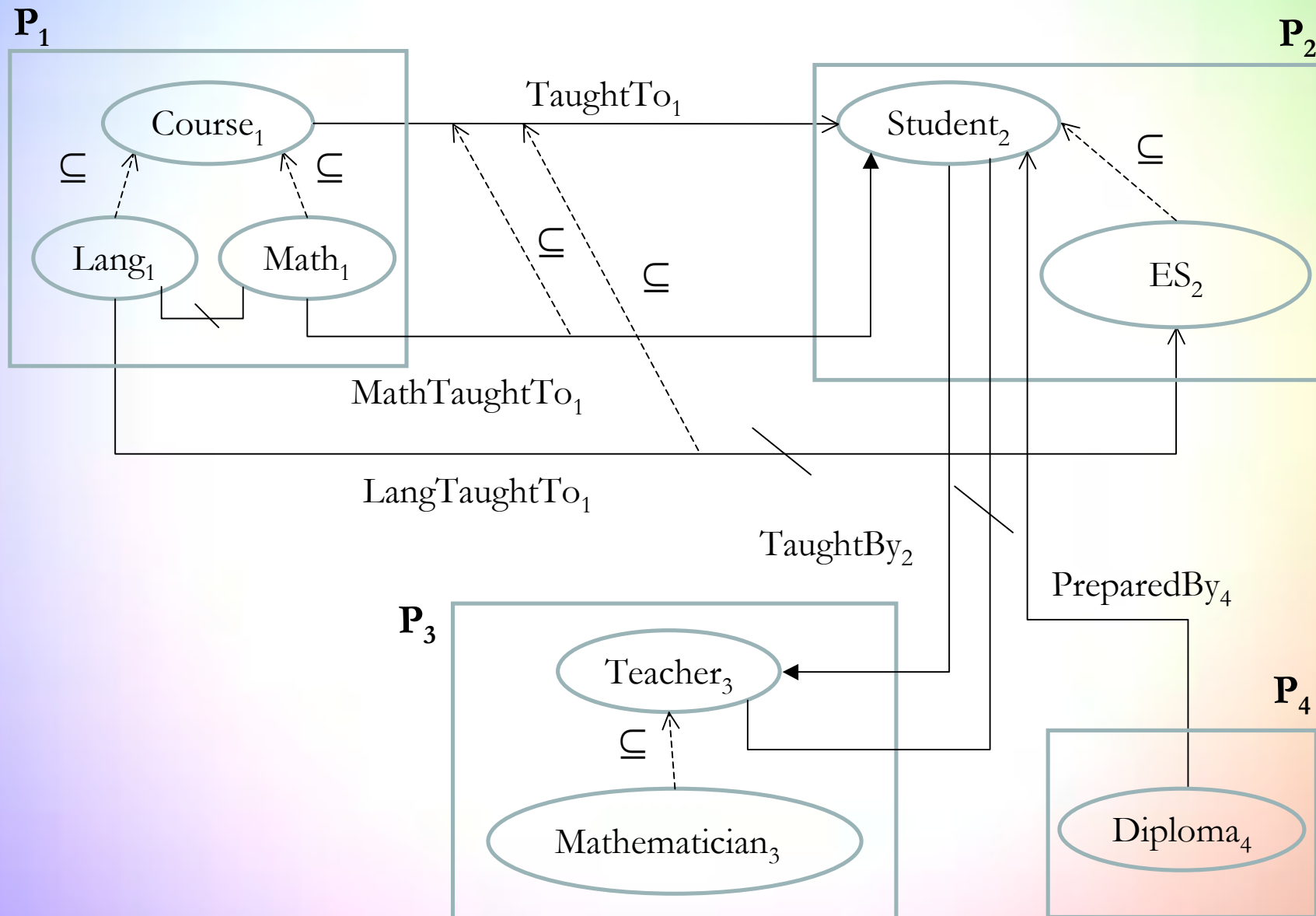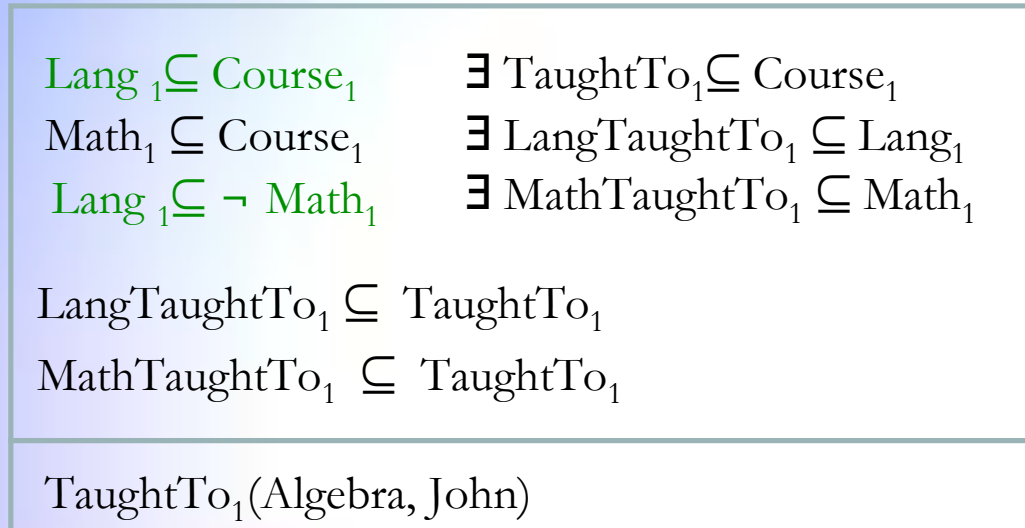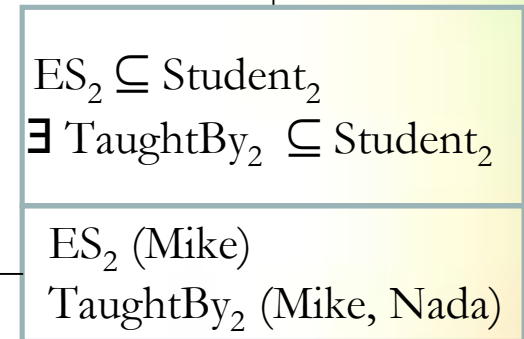
$\exists Teach_3^- \subseteq Course_1$

$\exists PreparedBy_4^- \subseteq Student_2$

P$_4$
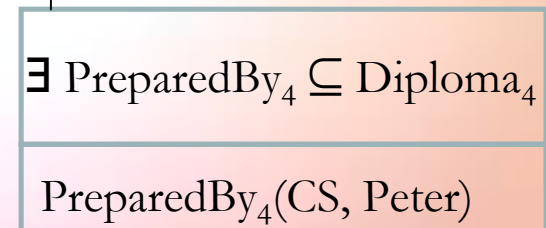
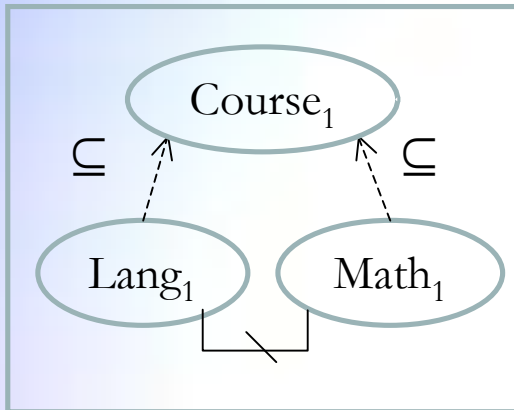$\exists PreparedBy_4 \subseteq Diploma_4$
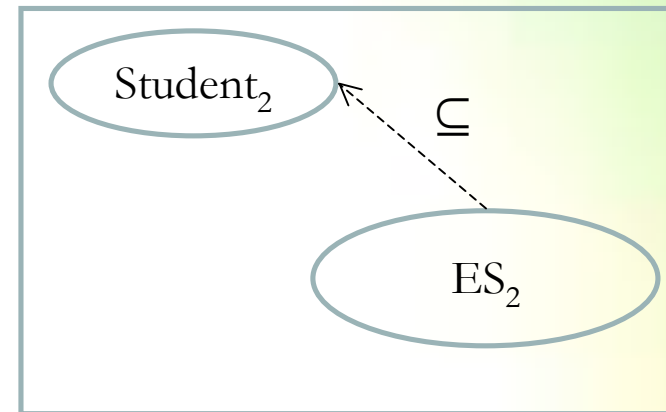
$PreparedBy_4(CS, Peter)$

Outline

❑ **DL-Lite$_R$ decentralized data management system**

❑ **Data consistency checking**

❑ **Query Answering**

❑ **Conclusion & Future Work**

Data consistency Checking

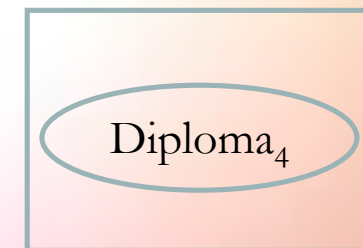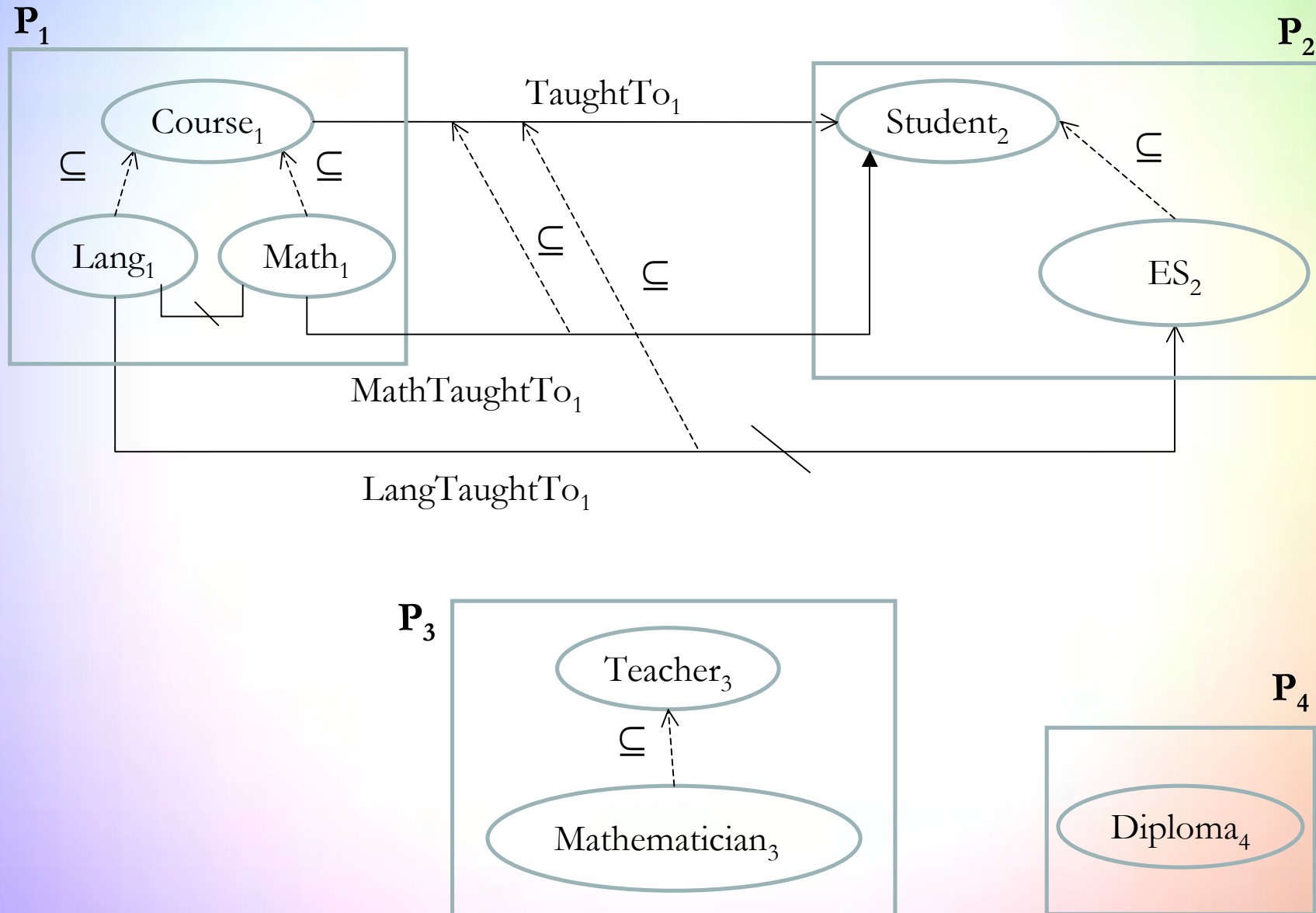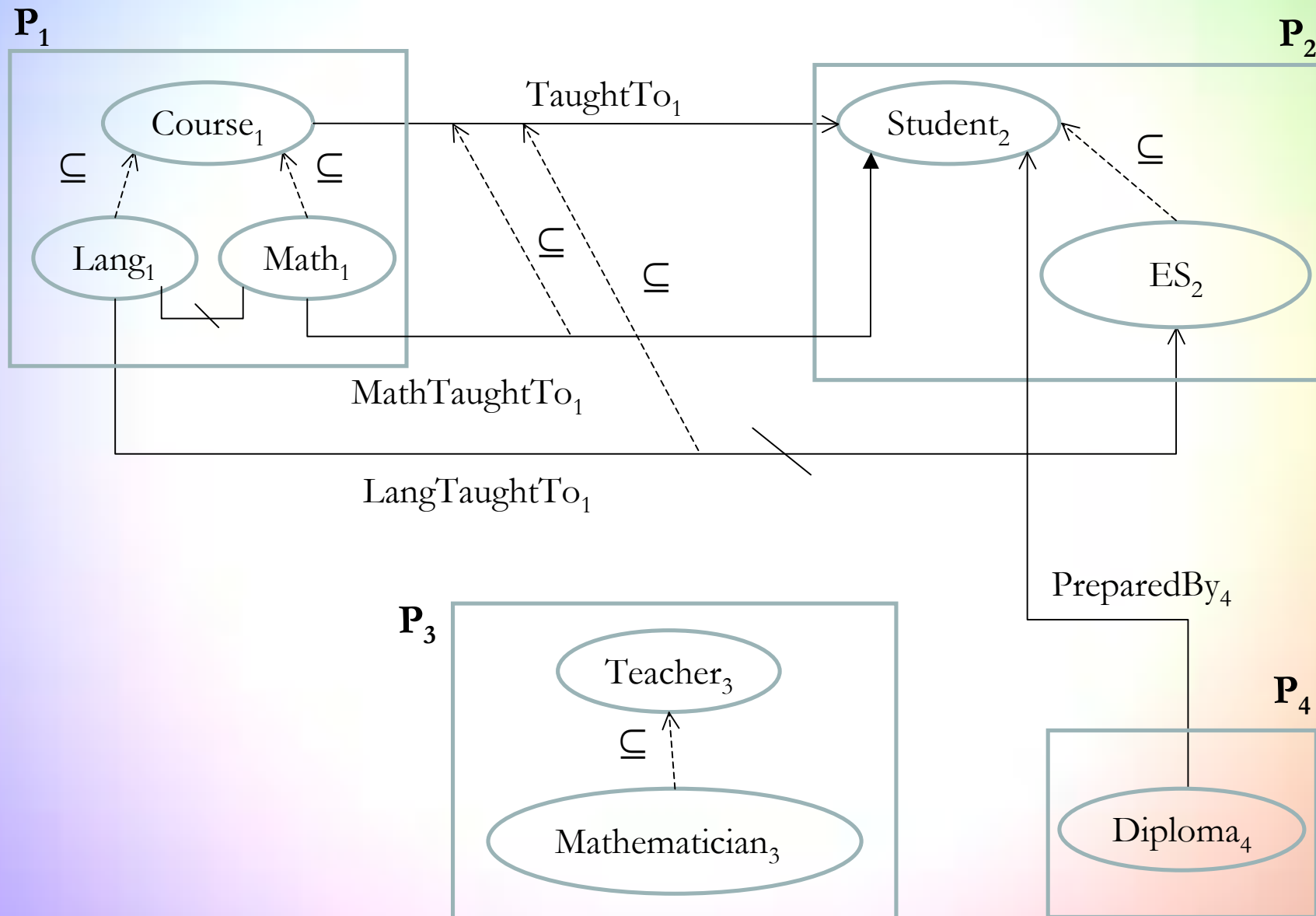- Consistency problem:

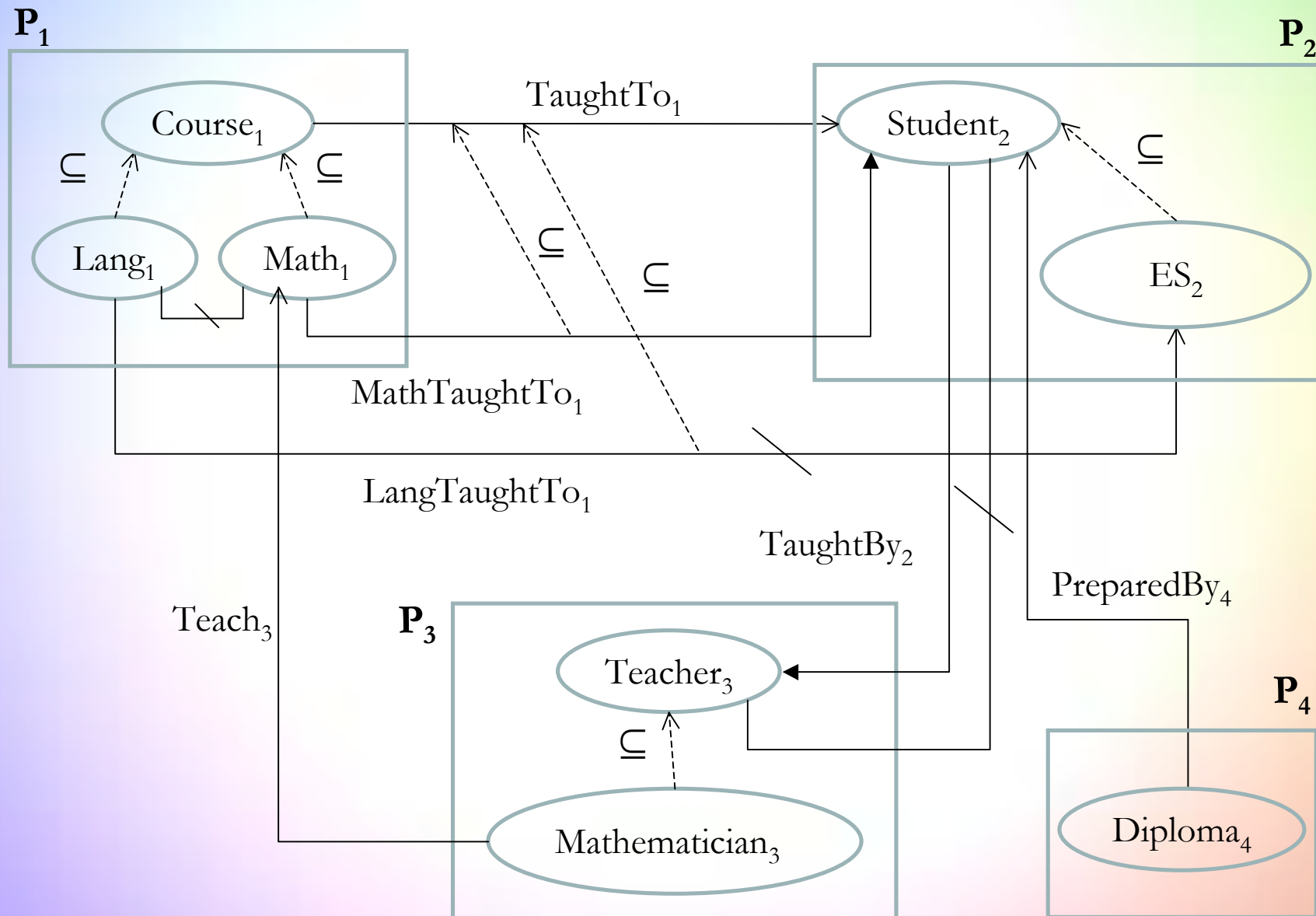 A data management system is consistent iff its KB (Tbox + Abox) is satisfiable.

Data consistency Checking

- Consistency problem:

    A data management system is consistent iff its KB (Tbox + Abox) is satisfiable.

- In DL-Lite$_R$:
    - ✓ Tbox is always satisfiable
    - ✓ Tbox + Abox may be insatisfiable

Data consistency Checking

- Consistency problem:

  A data management system is consistent iff its KB (Tbox + Abox) is satisfiable.

- In DL-Lite$_R$:
  - ✓ Tbox is always satisfiable
  - ✓ Tbox + Abox may be insatisfiable

- Example :

  TBox

  $\exists\, \text{TaughtTo}_1^- \subseteq \text{Student}_2$

  $\text{Student}_2 \subseteq \neg\, \text{Teacher}_3$

  $\text{Mathematician}_3 \subseteq \text{Teacher}_3$

  $\exists\, \text{Teach}_3 \subseteq \text{Mathematician}_3$

  Implicit Negative Inclusion

  $\text{TBox} \models \exists\, \text{TaughtTo}_1^- \subseteq \neg\, \exists\, \text{Teach}_3$

  ABox

  $\text{TaughtTo}_1\, (\text{Algebra}, \text{John})$

  $\text{Teach}_3\, (\text{John}, \text{Analysis})$

  $\text{KB} \models \exists\, y\, \text{TaughtTo}_1\, (\, y\, ,\ \text{John})$

  $\text{KB} \models \exists\, y\, \text{Teach}_3(\, \text{John}\, ,\ y\,)$

  $\perp$

Data consistency Checking

- Centralized case

Existing Algorithm Consistent :
D.Calvenese and al. (JAR 07) :"Tractable reasoning and efficient query
  answering in description logics"

➢ Computes all the Negative Inclusions entailed by the Tbox.
➢ Checks if the computed negative inclusions are violated by the Abox.

Checking if the DL-Lite$_R$ formulae that must be disjoint according to
the TBox, indeed have disjoint instances in the Abox

Data consistency Checking

- Decentralized case

  ➢ Decentralized Data consistency Checking w.r.t a peer

    ✓ Each peer propagates over the network each of its positive or negative inclusions and collects in return all the negative inclusions of the network the entailment of which uses the Tbox of the peer.

      o All Negative Inclusions entailed by the network are not necessarily computed.

    ✓ Each peer checks if the negative inclusions that he has collected are violated by the Data by sending queries to the corresponding peers.

P1

$Lang_1 \subseteq Course_1$
$Math_1 \subseteq Course_1$
$Lang_1 \subseteq \neg Math_1$
$\exists TaughtTo_1 \subseteq Course_1$
$\exists LangTaughtTo_1 \subseteq Lang_1$
$\exists MathTaughtTo_1 \subseteq Math_1$
$LangTaughtTo_1 \subseteq TaughtTo_1$
$MathTaughtTo_1 \subseteq TaughtTo_1$

$\exists TaughtTo_1^- \subseteq Student_2$
$\exists LangTaughtTo_1^- \subseteq \neg ES_2$
$\exists MathTaughtTo_1^- \subseteq Student_2$
$\exists Teach_3^- \subseteq Course_1$

$TaughtTo_1(Algebra, John)$

P2

$ES_2 \subseteq Student_2$
$\exists TaughtBy_2 \subseteq Student_2$

$\exists TaughtTo_1^- \subseteq Student_2$
$\exists LangTaughtTo_1^- \subseteq \neg ES_2$
$\exists MathTaughtTo_1^- \subseteq Student_2$
$\exists TaughtBy_2^- \subseteq Teacher_3$
$Student_2 \subseteq \neg Teacher_3$
$\exists PreparedBy_4^- \subseteq Student_2$

$ES_2 (Mike)$

P3

$Mathematician_3 \subseteq Teacher_3$
$\exists Teach_3 \subseteq Mathematician_3$

$\exists Teach_3^- \subseteq Course_1$
$\exists TaughtBy_2^- \subseteq Teacher_3$
$Student_2 \subseteq \neg Teacher_3$

$Teach_3 (John, Analysis)$

P4

$\exists PreparedBy_4 \subseteq Diploma_4$

$\exists PreparedBy_4^- \subseteq Student_2$

$PreparedBy_4(CS, Peter)$

P₁

$Lang_1 \subseteq Course_1$
$Math_1 \subseteq Course_1$
$Lang_1 \subseteq \neg Math_1$
$\exists TaughtTo_1 \subseteq Course_1$
$\exists LangTaughtTo_1 \subseteq Lang_1$
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$LangTaughtTo_1 \subseteq TaughtTo_1$
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P₂

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$ES_2 (Mike)$

$\exists TaughtTo_1^- \subseteq Student_2$

P₃
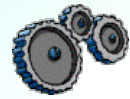
$Mathematician_3 \subseteq Teacher_3$
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$Student_2 \subseteq \neg Teacher_3$

$Teach_3 (John, Analysis)$

P₄

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$PreparedBy_4(CS, Peter)$

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$TaughtTo_1(Algebra, John)$

P₂

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$\exists MathTaughtTo_1^- \subseteq Student_2$
$\exists TaughtBy_2^- \subseteq Teacher_3$
$Student_2 \subseteq \neg Teacher_3$
$\exists PreparedBy_4^- \subseteq Student_2$

$ES_2 (Mike)$

$\exists TaughtTo_1^- \subseteq Student_2$

$\exists TaughtTo_1^- \subseteq \neg Teacher_3$

$Student_2 \subseteq \neg Teacher_3$

P₃

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$\exists\, TaughtTo_1^- \subseteq Student_2$
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$\exists\, MathTaughtTo_1^- \subseteq Student_2$
$\exists\, Teach_3^- \subseteq Course_1$

$TaughtTo_1(Algebra, John)$

P2

$ES_2 \subseteq Student_2$
$\exists\, TaughtBy_2 \subseteq Student_2$

$\exists\, TaughtTo_1^- \subseteq Student_2$
$\exists\, LangTaughtTo_1^- \subseteq \neg\, ES_2$
$\exists\, MathTaughtTo_1^- \subseteq Student_2$
$\exists\, TaughtBy_2^- \subseteq Teacher_3$
$Student_2 \subseteq \neg\, Teacher_3$
$\text{...paredBy}_4^- \subseteq Student_2$

$\exists\, TaughtTo_1^- \subseteq Student_2$

$\exists TaughtTo_1^- \subseteq \neg Teacher_3$
$\exists\, TaughtTo_1^- \subseteq \neg\, Mathematician_3$

$Student_2 \subseteq \neg\, Teacher_3$
$\exists\, TaughtTo_1^- \subseteq \neg\, Mathematician_3$

P3

$Mathematician_3 \subseteq Teacher_3$
$\exists\, Teach_3 \subseteq Mathematician_3$

$\exists\, Teach_3^- \subseteq Course_1$
$\exists\, TaughtBy_2^- \subseteq Teacher_3$
$Student_2 \subseteq \neg\, Teacher_3$
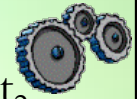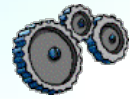
$Teach_3\,(John, Analysis)$

P4

$\exists\, PreparedBy_4 \subseteq Diploma_4$
$\exists PreparedBy_4^- \subseteq Student_2$
$PreparedBy_4(CS, Peter)$

P₁

$\text{Lang}_1 \subseteq \text{Course}_1$

$\text{Math}_1 \subseteq \text{Course}_1$

$\text{Lang}_1 \subseteq \neg\, \text{Math}_1$

$\exists\, \text{TaughtTo}_1 \subseteq \text{Course}_1$

$\exists\, \text{LangTaughtTo}_1 \subseteq \text{Lang}_1$

$\exists\, \text{MathTaughtTo}_1 \subseteq \text{Math}_1$

$\text{LangTaughtTo}_1 \subseteq \text{TaughtTo}_1$

$\text{MathTaughtTo}_1 \subseteq \text{TaughtTo}_1$

$\exists\, \text{TaughtTo}_1^- \subseteq \text{Student}_2$

$\exists\, \text{LangTaughtTo}_1^- \subseteq \neg\, \text{ES}_2$

$\exists\, \text{MathTaughtTo}_1^- \subseteq \text{Student}_2$

$\exists\, \text{Teach}_3^- \subseteq \text{Course}_1$

$\text{TaughtTo}_1(\text{Algebra}, \text{John})$

P₂

$\text{ES}_2 \subseteq \text{Student}_2$

$\exists\, \text{TaughtBy}_2 \subseteq \text{Student}_2$

$\exists\, \text{TaughtTo}_1^- \subseteq \text{Student}_2$

$\exists\, \text{LangTaughtTo}_1^- \subseteq \neg\, \text{ES}_2$

$\exists\, \text{MathTaughtTo}_1^- \subseteq \text{Student}_2$

$\exists\, \text{TaughtBy}_2^- \subseteq \text{Teacher}_3$

$\text{Student}_2 \subseteq \neg\, \text{Teacher}_3$

$\exists\, \text{PreparedBy}_4^- \subseteq \text{Student}_2$

$\exists\, \text{TaughtTo}_1^- \subseteq \text{Student}_2$

$\exists\, \text{TaughtTo}_1^- \subseteq \neg\, \text{Teacher}_3$

$\exists\, \text{TaughtTo}_1^- \subseteq \neg\, \text{Mathematician}_3$

$\exists\, \text{TaughtTo}_1^- \subseteq \neg\, \exists\, \text{Teach}_3$

$\text{Student}_2 \subseteq \neg\, \text{Teacher}_3$

$\exists\, \text{TaughtTo}_1^- \subseteq \neg\, \text{Mathematician}_3$

$\exists\, \text{TaughtTo}_1^- \subseteq \neg\, \exists\, \text{Teach}_3$

P₃

$\text{Mathematician}_3 \subseteq \text{Teacher}_3$

$\exists\, \text{Teach}_3 \subseteq \text{Mathematician}_3$

$\exists\, \text{Teach}_3^- \subseteq \text{Course}_1$

$\exists\, \text{TaughtBy}_2^- \subseteq \text{Teacher}_3$

$\text{Student}_2 \subseteq \neg\, \text{Teacher}_3$

$\text{Teach}_3\,(\text{John}, \text{Analysis})$

P₄

$\exists\, \text{PreparedBy}_4 \subseteq \text{Diploma}_4$

$\exists\, \text{PreparedBy}_4^- \subseteq \text{Student}_2$

$\text{PreparedBy}_4(\text{CS}, \text{Peter})$

P1

$\text{Lang}_1 \subseteq \text{Course}_1$
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$\exists \text{TaughtTo}_1 \subseteq \text{Course}_1$
$\exists \text{LangTaughtTo}_1 \subseteq \text{Lang}_1$
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$\text{MathTaughtTo}_1 \subseteq \text{TaughtTo}_1$

$\exists \text{TaughtTo}_1^- \subseteq \text{Student}_2$
$\exists \text{LangTaughtTo}_1^- \subseteq \neg \text{ES}_2$
$\exists \text{MathTaughtTo}_1^- \subseteq \text{Student}_2$
$\exists \text{Teach}_3^- \subseteq \text{Course}_1$

$\text{TaughtTo}_1(\text{Algebra, John})$

P2

$\text{ES}_2 \subseteq \text{Student}_2$
$\exists \text{TaughtBy}_2 \subseteq \text{Student}_2$

$\exists \text{TaughtTo}_1^- \subseteq \text{Student}_2$
$\exists \text{LangTaughtTo}_1^- \subseteq \neg \text{ES}_2$
$\exists \text{MathTaughtTo}_1^- \subseteq \text{Student}_2$
$\exists \text{TaughtBy}_2^- \subseteq \text{Teacher}_3$
$\text{Student}_2 \subseteq \neg \text{Teacher}_3$
$\exists \text{PreparedBy}_4^- \subseteq \text{Student}_2$

$\exists \text{TaughtTo}_1^- \subseteq \text{Student}_2$

$\exists \text{TaughtTo}_1^- \subseteq \neg \text{Teacher}_3$
$\exists \text{TaughtTo}_1^- \subseteq \neg \text{Mathematician}_3$
$\exists \text{TaughtTo}_1^- \subseteq \neg \exists \text{Teach}_3$

$\text{Student}_2 \subseteq \neg \text{Teacher}_3$
$\exists \text{TaughtTo}_1^- \subseteq \neg \text{Mathematician}_3$
$\exists \text{TaughtTo}_1^- \subseteq \neg \exists \text{Teach}_3$

$\bot$

P3

$\text{Mathematician}_3 \subseteq \text{Teacher}_3$
$\exists \text{Teach}_3 \subseteq \text{Mathematician}_3$

$\exists \text{Teach}_3^- \subseteq \text{Course}_1$
$\exists \text{TaughtBy}_2^- \subseteq \text{Teacher}_3$
$\text{Student}_2 \subseteq \neg \text{Teacher}_3$

$\text{Teach}_3 (\text{John, Analysis})$

P4

$\exists \text{PreparedBy}_4 \subseteq \text{Diploma}_4$
$\exists \text{PreparedBy}_4^- \subseteq \text{Student}_2$

$\text{PreparedBy}_4(\text{CS, Peter})$

P₁

$Lang_1 \subseteq Course_1$
$Math_1 \subseteq Course_1$
$Lang_1 \subseteq \neg\, Math_1$
$\exists\, TaughtTo_1 \subseteq Course_1$
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$\exists\, MathTaughtTo_1 \subseteq Math_1$
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$\exists\, TaughtTo_1^- \subseteq Student_2$
$\exists\, LangTaughtTo_1^- \subseteq \neg\, ES_2$
$\exists\, MathTaughtTo_1^- \subseteq Student_2$
$\exists\, Teach_3^- \subseteq Course_1$
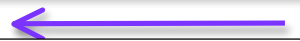
$TaughtTo_1(Algebra, John)$

P₂

$ES_2 \subseteq Student_2$
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$\exists\, TaughtTo_1^- \subseteq Student_2$
$\exists\, LangTaughtTo_1^- \subseteq \neg\, ES_2$
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$\exists\, TaughtBy_2^- \subseteq Teacher_3$
$Student_2 \subseteq \neg\, Teacher_3$
$\exists\, PreparedBy_4^- \subseteq Student_2$

$\perp$

$\exists\, TaughtTo_1^- \subseteq Student_2$

$\exists\, TaughtTo_1^- \subseteq \neg Teacher_3$

$\exists\, TaughtTo_1^- \subseteq \neg\, Mathematician_3$

$\exists\, TaughtTo_1^- \subseteq \neg\, \exists\, Teach_3$

$Student_2 \subseteq \neg\, Teacher_3$
$\exists\, TaughtTo_1^- \subseteq \neg\, Mathematician_3$
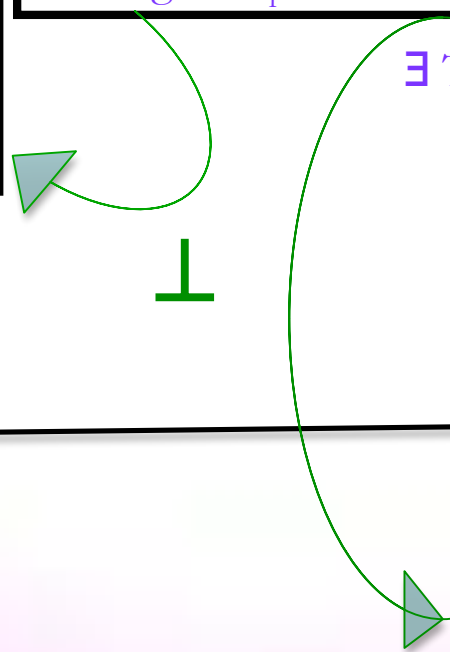$\exists\, TaughtTo_1^- \subseteq \neg\, \exists\, Teach_3$

P₃

$Mathematician_3 \subseteq Teacher_3$
$\exists\, Teach_3 \subseteq Mathematician_3$

$\exists\, Teach_3^- \subseteq Course_1$
$\exists\, TaughtBy_2^- \subseteq Teacher_3$
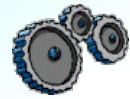$Student_2 \subseteq \neg\, Teacher_3$

$Teach_3\,(John, Analysis)$

P₄

$\exists\, PreparedBy_4 \subseteq Diploma_4$

$\exists\, PreparedBy_4^- \subseteq Student_2$

$PreparedBy_4(CS, Peter)$

P₁

$Lang_1 \subseteq Course_1$
$Math_1 \subseteq Course_1$
$Lang_1 \subseteq \neg\, Math_1$
$\exists\, TaughtTo_1 \subseteq Course_1$
$\exists\, LangTaughtTo_1 \subseteq Lang_1$
$\exists\, MathTaughtTo_1 \subseteq Math_1$
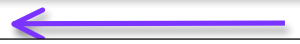$LangTaughtTo_1 \subseteq TaughtTo_1$
$MathTaughtTo_1 \subseteq TaughtTo_1$

$\exists\, TaughtTo_1^- \subseteq Student_2$
$\exists\, LangTaughtTo_1^- \subseteq \neg\, ES_2$
$\exists\, MathTaughtTo_1^- \subseteq Student_2$
$\exists\, Teach_3^- \subseteq Course_1$

$TaughtTo_1(Algebra, John)$

$\perp$ **OK**

P₂

$ES_2 \subseteq Student_2$
$\exists\, TaughtBy_2 \subseteq Student_2$

$\exists\, TaughtTo_1^- \subseteq Student_2$
$\exists\, LangTaughtTo_1^- \subseteq \neg\, ES_2$
$\exists\, MathTaughtTo_1^- \subseteq Student_2$
$\exists\, TaughtBy_2^- \subseteq Teacher_3$
$Student_2 \subseteq \neg\, Teacher_3$
$\exists PreparedBy_4^- \subseteq Student_2$

$ES_2\ (Mike)$

P₃

$Mathematician_3 \subseteq Teacher_3$
$\exists\, Teach_3 \subseteq Mathematician_3$

$\exists\, Teach_3^- \subseteq Course_1$
$\exists\, TaughtBy_2^- \subseteq Teacher_3$
$Student_2 \subseteq \neg\, Teacher_3$

$Teach_3\ (John, Analysis)$

P₄

$\exists\, PreparedBy_4 \subseteq Diploma_4$
$\exists PreparedBy_4^- \subseteq Student_2$

$PreparedBy_4(CS, Peter)$

$\perp$ **OK**

Decentralized Negative Inclusion computation by using SomeWhere

✓ An existing Decentralized Infrastructure "SomeWhere" for reasoning in propositional logic and for which the experiments have demonstrated the scalability.

   P. Adjiman and al. (IJCAI 05) : Scalability study of peer-to-peer consequence finding"

✓ An existing Decentralized Consequence finding Algorithm in propositional logic (DECA)

✓ A propositional encoding of the DL-Lite$_R$ TBox.

Implementation using SomeWhere
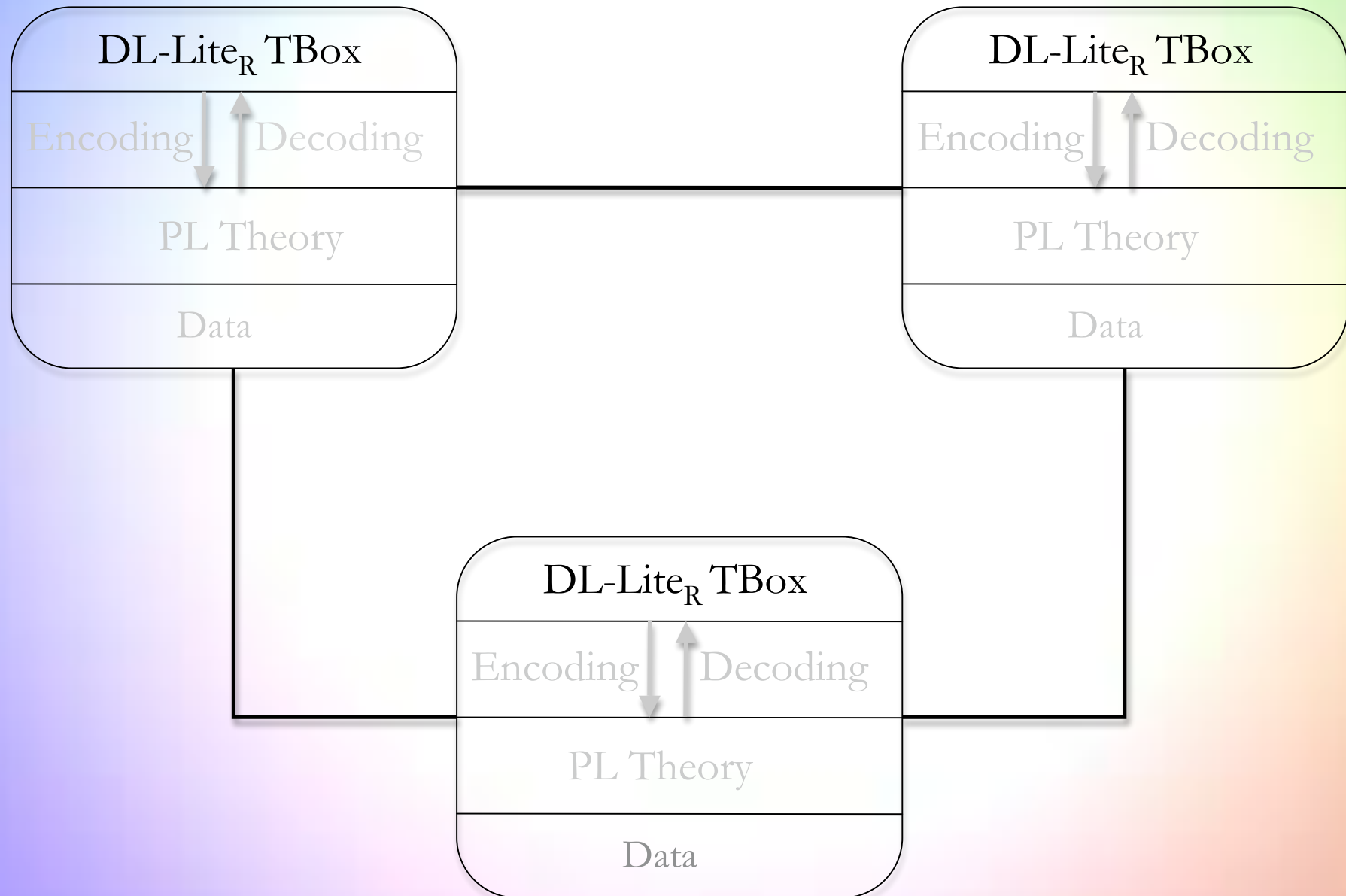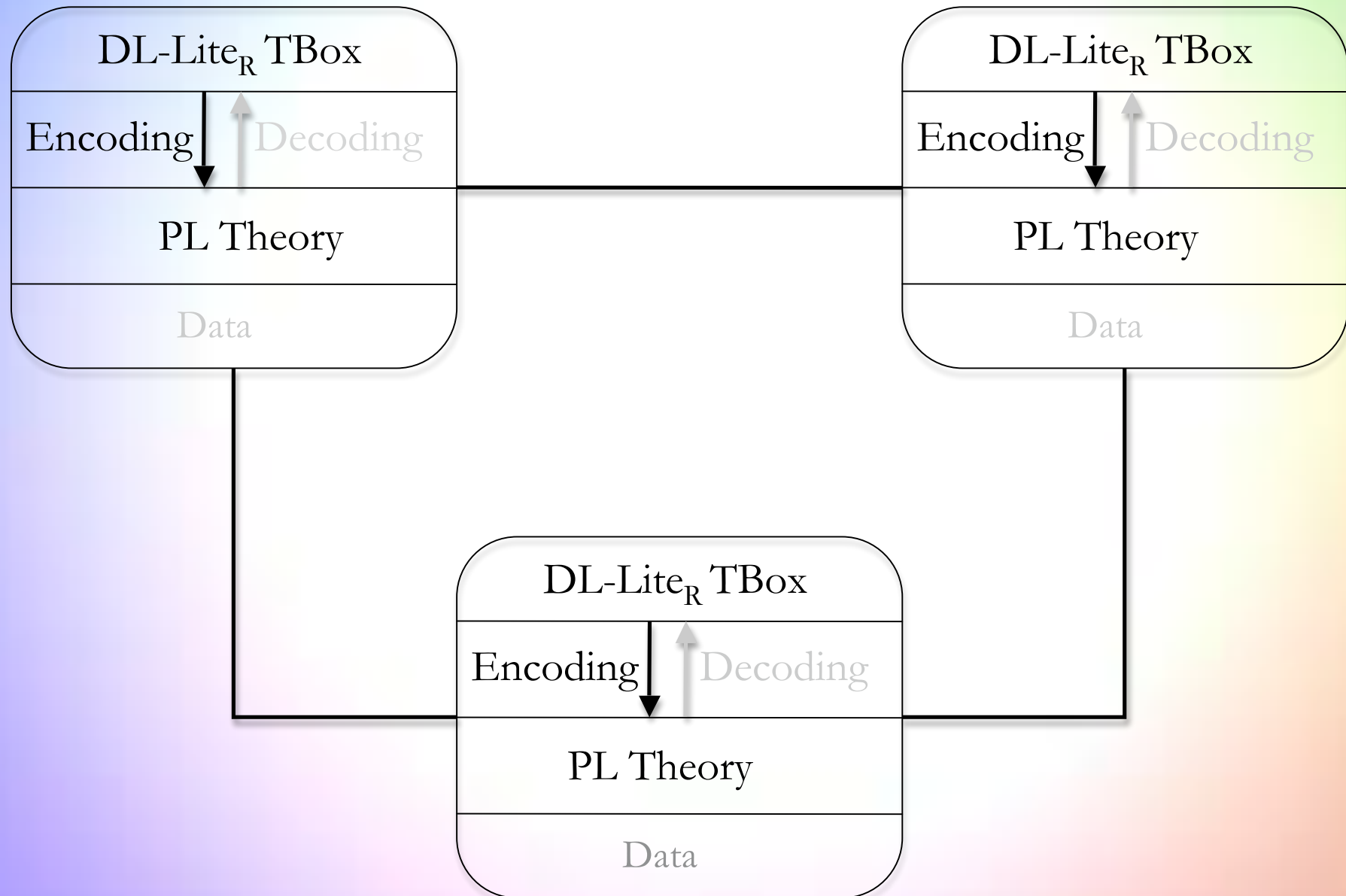
Implementation using SomeWhere

Implementation using SomeWhere

Implementation using SomeWhere
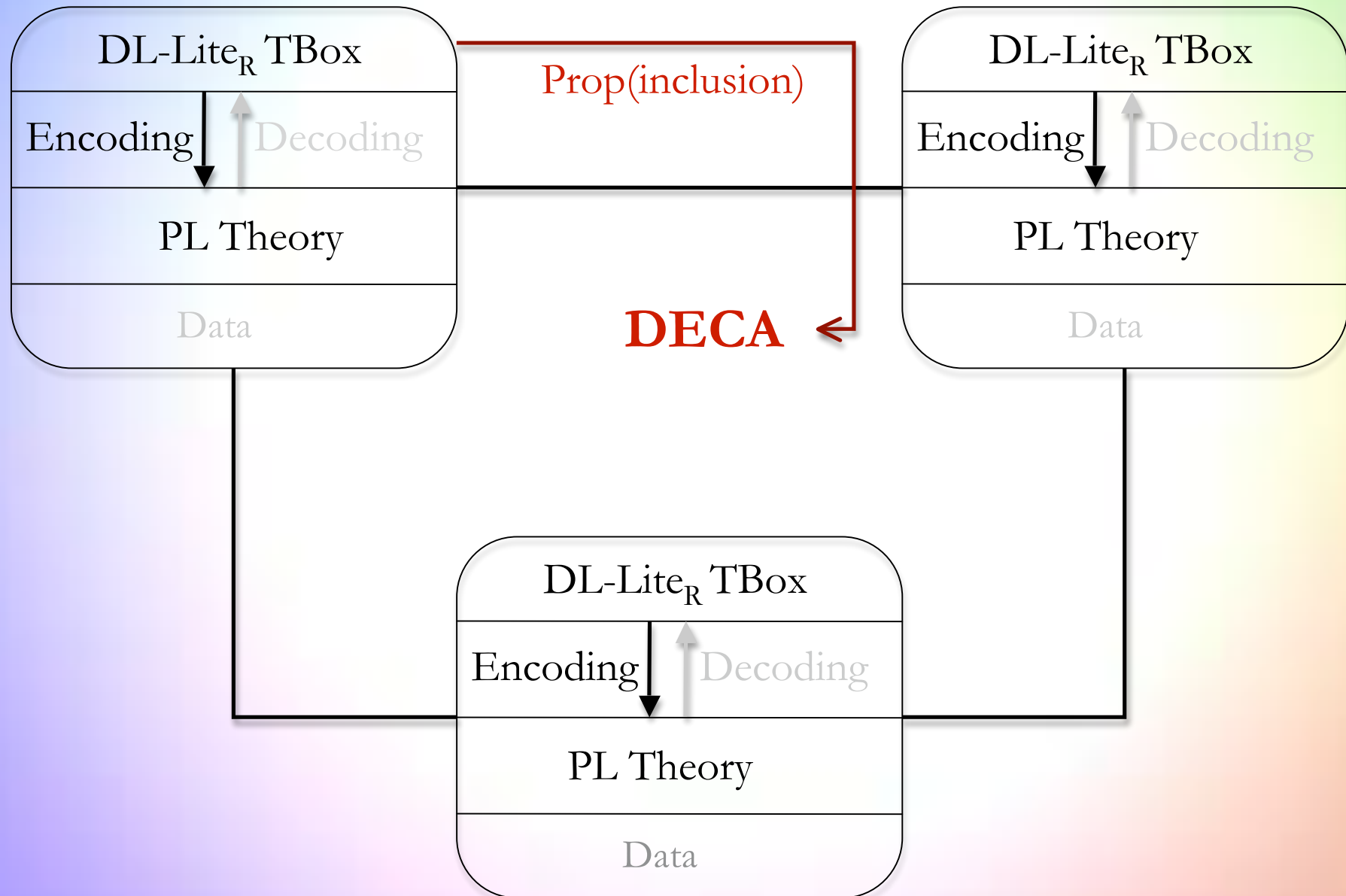
Implementation using SomeWhere
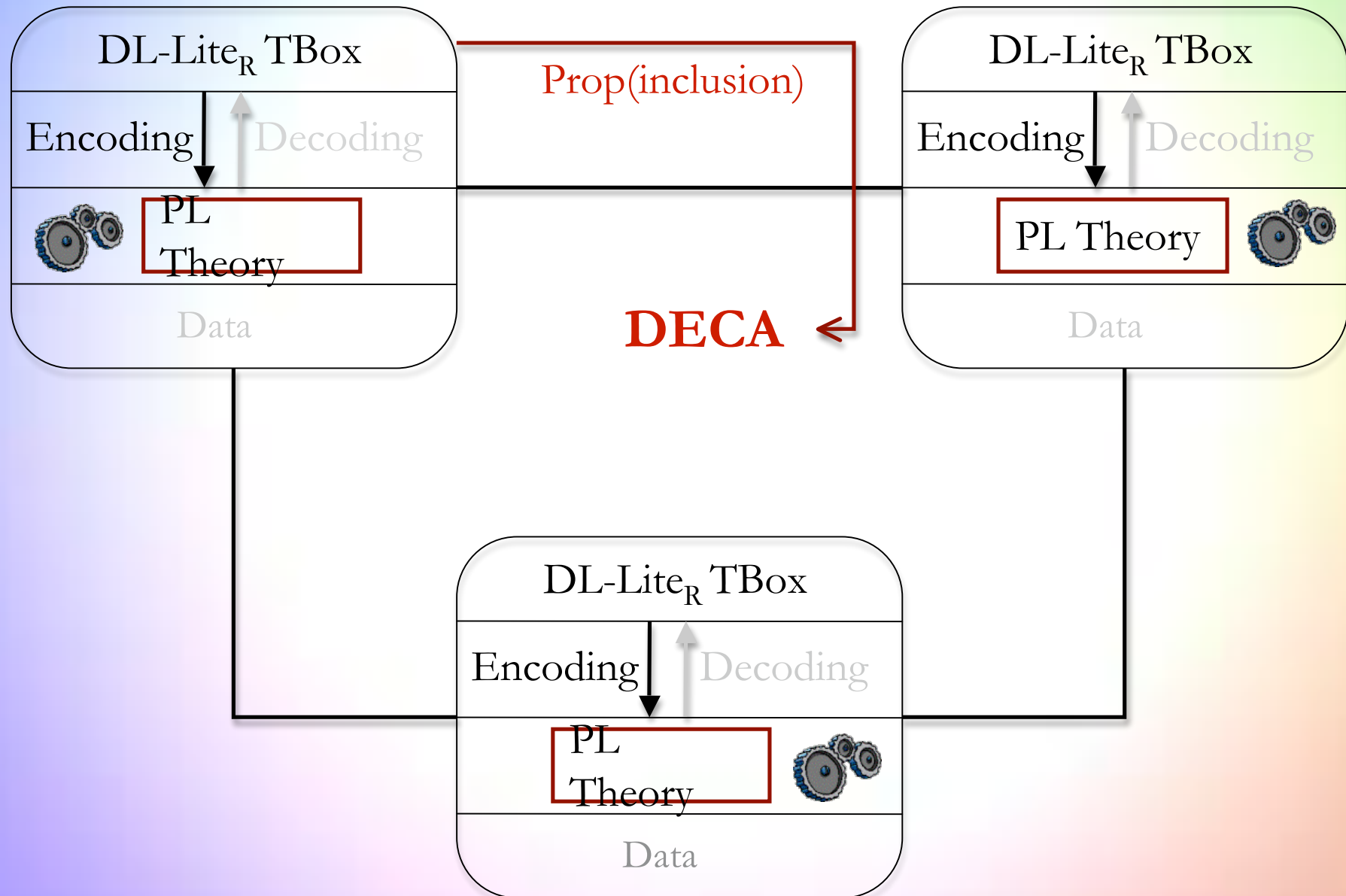
Implementation using SomeWhere
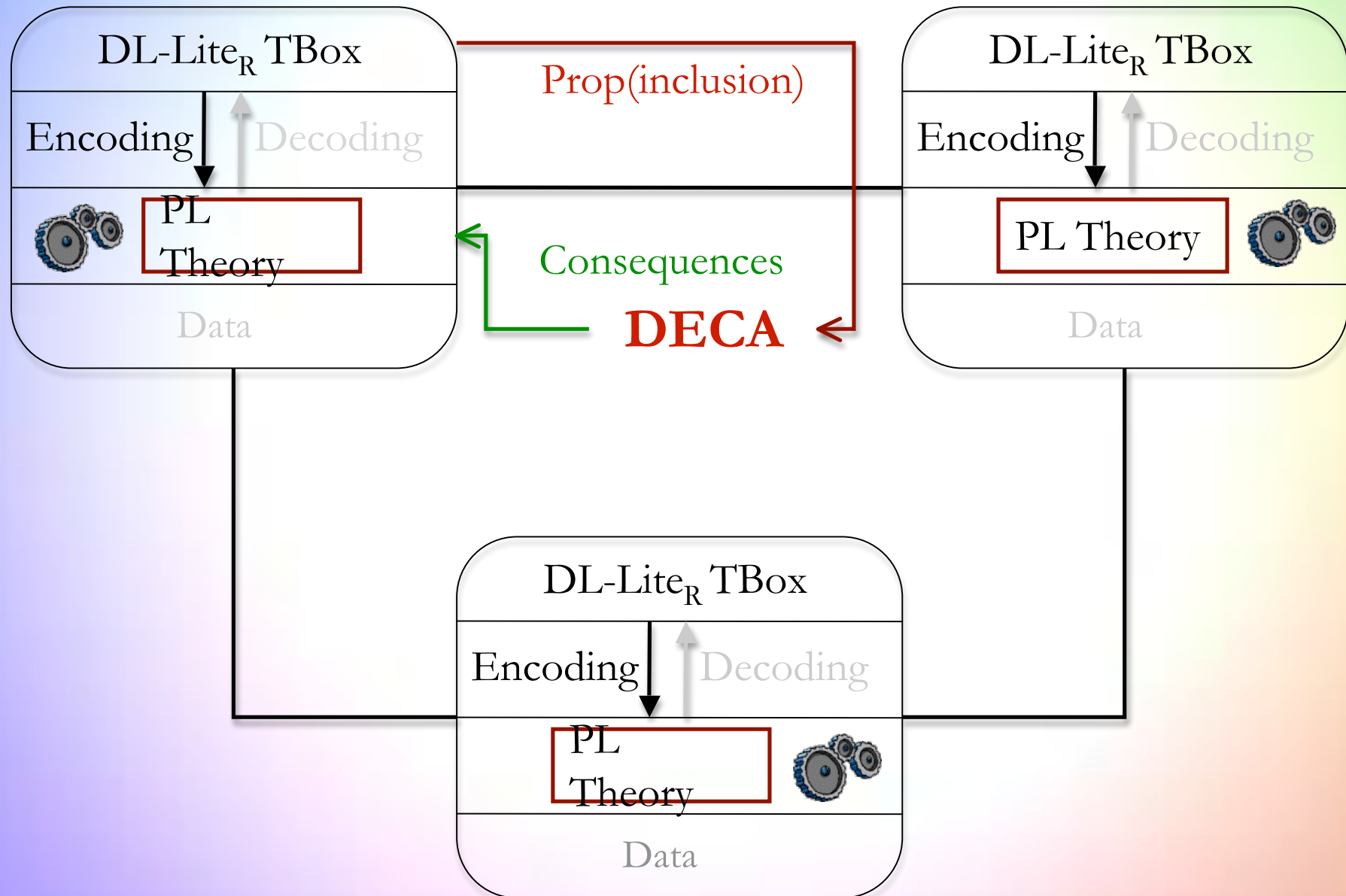
Implementation using SomeWhere

Negative Inclusions
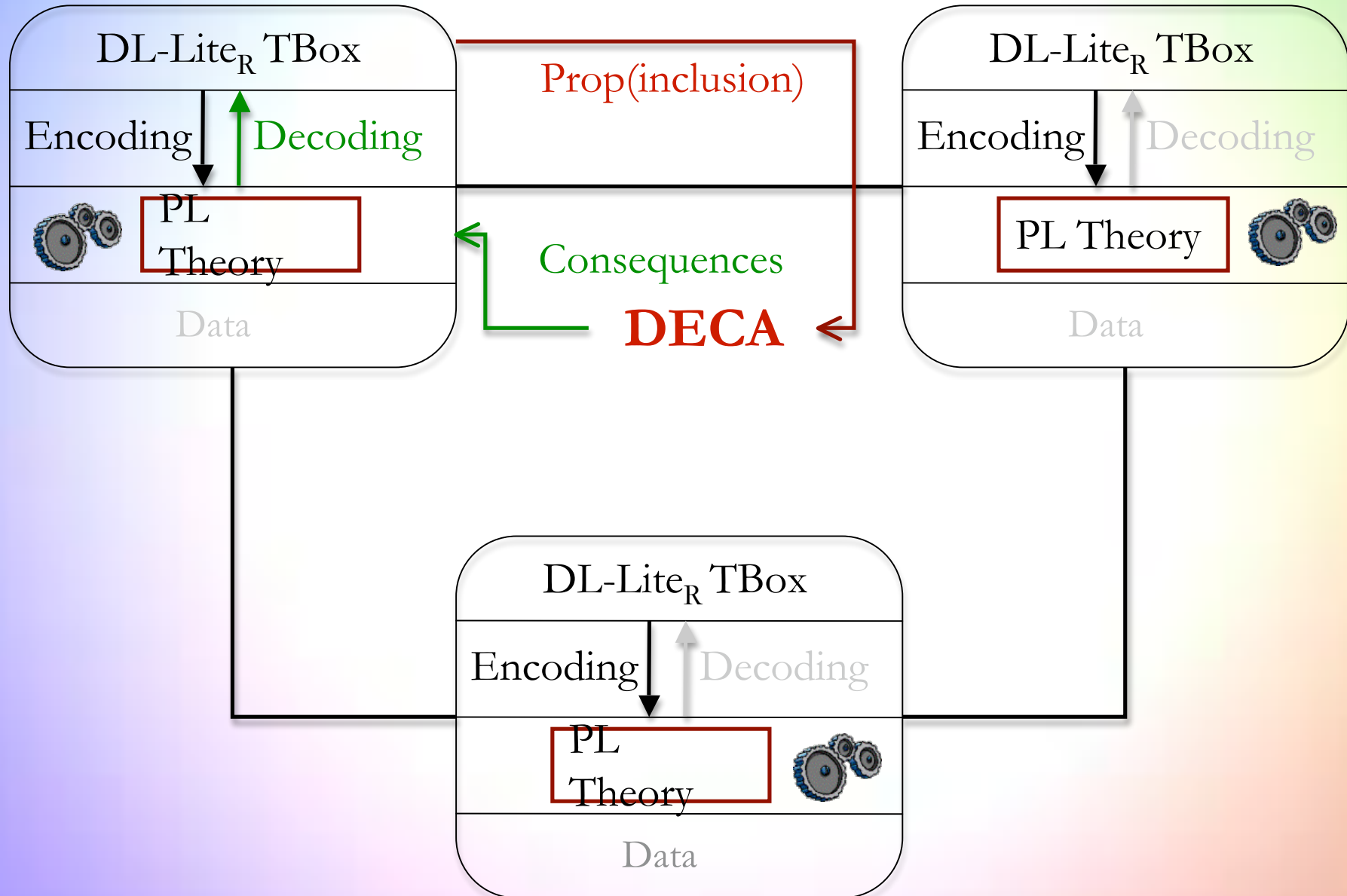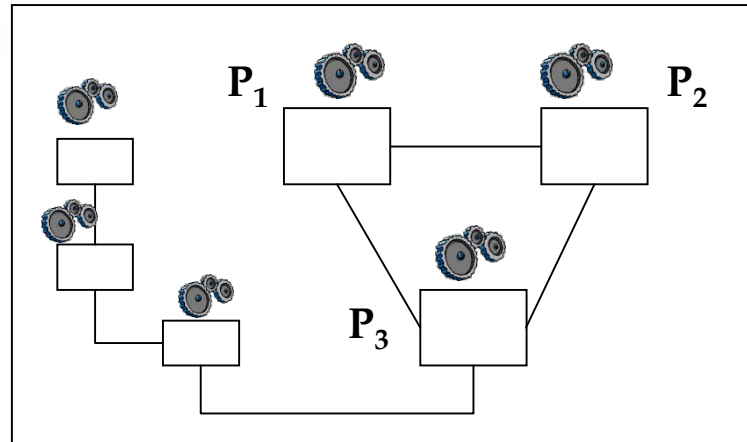
DL-Lite$_R$ TBox

Encoding | Decoding

PL Theory

Data

Prop(inclusion)

Consequences

DECA

DL-Lite$_R$ TBox

Encoding | Decoding

PL Theory

Data

DL-Lite$_R$ TBox

Encoding | Decoding

PL Theory

Data

Encoding: Binary Clauses

Easy case in SomeWhere

Exp. AVG: < 1 sec

Network: 1000 peers

Outline

❑ **DL-Lite$_R$ decentralized data management system**

❑ **Data consistency checking**

❑ **Query Answering**

❑ **Conclusion & Future Work**

Query Answering

• Query Answering problem:

Given a conjunctive query q, compute the answers of q over the system.

Query Answering

- Query Answering problem:

Given a conjunctive query q, compute the answers of q over the system.

- Answer :

  A tuple t of the constants appearing in KB such that:

KB $\models$ q(t)

Query Answering

- Query Answering problem:

Given a conjunctive query q, compute the answers of q over the system.

- Answer :

A tuple t of the constants appearing in KB such that:

KB $\models$ q(t)

- In centralized case:

Algorithm PerfectRef: D.Calvenese and al. (JAR 07)
"Tractable reasoning and efficient query answering in description logics"

Data consistency checking
Query Answering
- Query Reformulation
- Reformulation Evaluation

Decentralized Query Answering

P₁   ⊥

$\exists \text{TaughtTo}_1^- \subseteq \text{Student}_2$
$\exists \text{LangTaughtTo}_1^- \subseteq \neg \text{ES}_2$
$\exists \text{MathTaughtTo}_1^- \subseteq \text{Student}_2$

$\text{Lang}_1 \subseteq \text{Course}_1$ $\exists \text{TaughtTo}_1 \subseteq \text{Course}_1$
$\text{Math}_1 \subseteq \text{Course}_1$ $\exists \text{LangTaughtTo}_1 \subseteq \text{Lang}_1$
$\text{Lang}_1 \subseteq \neg \text{Math}_1$ $\exists \text{MathTaughtTo}_1 \subseteq \text{Math}_1$

$\text{LangTaughtTo}_1 \subseteq \text{TaughtTo}_1$

$\text{MathTaughtTo}_1 \subseteq \text{TaughtTo}_1$

$\text{TaughtTo}_1(\text{Algebra, John})$

OK   **P₂**

$\text{ES}_2 \subseteq \text{Student}_2$
$\exists \text{TaughtBy}_2 \subseteq \text{Student}_2$

$\text{ES}_2 (\text{Mike})$
$\text{TaughtBy}_2 (\text{Mike, Nada})$

$\exists \text{Teach}_3^- \subseteq \text{Course}_1$

$q(x) = \text{Student}_2(x)$

P₃

$\exists \text{PreparedBy}_4^- \subseteq \text{Student}_2$

$\text{Mathematician}_3 \subseteq \text{Teacher}_3$
$\exists \text{Teach}_3 \subseteq \text{Mathematician}_3$

⊥

$\text{Student}_2 \subseteq \neg \text{Teacher}_3$
$\exists \text{TaughtBy}_2^- \subseteq \text{Teacher}_3$

OK   **P₄**

$\text{Teach}_3 (\text{John, Analysis})$

$\exists \text{PreparedBy}_4 \subseteq \text{Diploma}_4$

$\text{PreparedBy}_4(\text{CS, Peter})$

Decentralized Query Answering

- Contribution:

  - Decentralized algorithm for query answering.
    - Well Founded Answers even in globally inconsistent Networks

      1. Decentralized Query Reformulation

      2. Checking data consistency w.r.t the peers involved in each reformulation
         o We keep only sound reformulations

      3. Evaluation of the sound reformulations
         - Well founded answers

Decentralized Query Answering

- Contribution:

  - Decentralized algorithm for query answering.

    ➢ Query reformulation

      q (x) = Student$_2$(x)

Decentralized Query Answering

P$_1$ ⊥

$$\text{Lang}_1 \subseteq \text{Course}_1 \qquad \exists\, \text{TaughtTo}_1 \subseteq \text{Course}_1$$
$$\text{Math}_1 \subseteq \text{Course}_1 \qquad \exists\, \text{LangTaughtTo}_1 \subseteq \text{Lang}_1$$
$$\text{Lang}_1 \subseteq \neg\, \text{Math}_1 \qquad \exists\, \text{MathTaughtTo}_1 \subseteq \text{Math}_1$$

$$\text{LangTaughtTo}_1 \subseteq \text{TaughtTo}_1$$
$$\text{MathTaughtTo}_1 \subseteq \text{TaughtTo}_1$$

$$\text{TaughtTo}_1(\text{Algebra}, \text{John})$$

$$\exists\, \text{TaughtTo}_1^- \subseteq \text{Student}_2$$
$$\exists\, \text{LangTaughtTo}_1^- \subseteq \neg\ \text{ES}_2$$
$$\exists\, \text{MathTaughtTo}_1^- \subseteq \text{Student}_2$$

OK **P$_2$**

$$\text{ES}_2 \subseteq \text{Student}_2$$
$$\exists\, \text{TaughtBy}_2 \subseteq \text{Student}_2$$

$$\text{ES}_2\,(\text{Mike})$$
$$\text{TaughtBy}_2\,(\text{Mike}, \text{Nada})$$

$$\exists\, \text{Teach}_3^- \subseteq \text{Course}_1$$

$$q\,(x) = \text{Student}_2(x)$$

P$_3$

$$\text{Mathematician}_3 \subseteq \text{Teacher}_3$$
$$\exists\, \text{Teach}_3 \subseteq \text{Mathematician}_3$$

⊥

$$\text{Student}_2 \subseteq \neg\ \text{Teacher}_3$$
$$\exists\, \text{TaughtBy}_2^- \subseteq \text{Teacher}_3$$

$$\text{Teach}_3\,(\text{John}, \text{Analysis})$$

$$\exists\text{PreparedBy}_4^- \subseteq \text{Student}_2$$

OK **P$_4$**

$$\exists\, \text{PreparedBy}_4 \subseteq \text{Diploma}_4$$

$$\text{PreparedBy}_4(\text{CS}, \text{Peter})$$

Decentralized Query Answering

- Contribution:

  Decentralized algorithm for query answering.

  ➢ Query reformulation

  q (x) = Student$_2$ (x)

  q$_1$ (x) = ES$_2$ (x)

Decentralized Query Answering

P₁ $\quad \perp$

$\exists \, TaughtTo_1^- \subseteq Student_2$
$\exists \, LangTaughtTo_1^- \subseteq \neg \, ES_2$
$\exists \, MathTaughtTo_1^- \subseteq Student_2$

$Lang_1 \subseteq Course_1 \qquad \exists \, TaughtTo_1 \subseteq Course_1$
$Math_1 \subseteq Course_1 \qquad \exists \, LangTaughtTo_1 \subseteq Lang_1$
$Lang_1 \subseteq \neg \, Math_1 \qquad \exists \, MathTaughtTo_1 \subseteq Math_1$

$LangTaughtTo_1 \subseteq TaughtTo_1$

$MathTaughtTo_1 \subseteq TaughtTo_1$

$TaughtTo_1(Algebra, John)$

OK $\qquad$ **P₂**

$ES_2 \subseteq Student_2$
$\exists \, TaughtBy_2 \subseteq Student_2$

$ES_2 \, (Mike)$
$TaughtBy_2 \, (Mike, Nada)$

$\exists \, Teach_3^- \subseteq Course_1$

$q\,(x) = Student_2(x)$

P₃

$Mathematician_3 \subseteq Teacher_3$
$\exists \, Teach_3 \subseteq Mathematician_3$

$\perp$

$Teach_3 \, (John, Analysis)$

$Student_2 \subseteq \neg \, Teacher_3$
$\exists \, TaughtBy_2^- \subseteq Teacher_3$

$\exists PreparedBy_4^- \subseteq Student_2$

OK $\qquad$ **P₄**

$\exists \, PreparedBy_4 \subseteq Diploma_4$

$PreparedBy_4(CS, Peter)$

Decentralized Query Answering

- Contribution:

  Decentralized algorithm for query answering.

  ➢ Query reformulation

  $q(x) = Student_2(x)$

  $q_1(x) = ES_2(x)$

  $q_2(x) = \exists z\ TaughtTo_1(z, x)$

Decentralized Query Answering

P₁ ⊥

$Lang_1 \subseteq Course_1$ $\exists TaughtTo_1 \subseteq Course_1$
$Math_1 \subseteq Course_1$ $\exists LangTaughtTo_1 \subseteq Lang_1$
$Lang_1 \subseteq \neg Math_1$ $\exists MathTaughtTo_1 \subseteq Math_1$

$LangTaughtTo_1 \subseteq TaughtTo_1$

$MathTaughtTo_1 \subseteq TaughtTo_1$

$TaughtTo_1(Algebra, John)$

$\exists Teach_3^- \subseteq Course_1$

P₃

$Mathematician_3 \subseteq Teacher_3$

$\exists Teach_3 \subseteq Mathematician_3$

⊥

$Teach_3 (John, Analysis)$

$\exists TaughtTo_1^- \subseteq Student_2$
$\exists LangTaughtTo_1^- \subseteq \neg ES_2$
$\exists MathTaughtTo_1^- \subseteq Student_2$

OK   **P₂**

$ES_2 \subseteq Student_2$
$\exists TaughtBy_2 \subseteq Student_2$

$ES_2 (Mike)$
$TaughtBy_2 (Mike, Nada)$

$q (x) = Student_2(x)$

$\exists PreparedBy_4^- \subseteq Student_2$

$Student_2 \subseteq \neg Teacher_3$
$\exists TaughtBy_2^- \subseteq Teacher_3$

OK   **P₄**

$\exists PreparedBy_4 \subseteq Diploma_4$

$PreparedBy_4(CS, Peter)$

Decentralized Query Answering

- Contribution:

    Decentralized algorithm for query answering.

    ➢ Query reformulation

    $q(x) = \text{Student}_2(x)$

    $q_1(x) = \text{ES}_2(x)$

    $q_2(x) = \exists z\ \text{TaughtTo}_1(z, x)$

    $q_3(x) = \exists y\ \text{PreparedBy}_4(y, x)$

Decentralized Query Answering

- Contribution:

  Decentralized algorithm for query answering.

  ➤ Query reformulation

  $q(x) = \text{Student}_2(x)$

  $q_1(x) = \text{ES}_2(x)$

  $q_2(x) = \exists z\ \text{TaughtTo}_1(z, x)$

  $q_3(x) = \exists y\ \text{PreparedBy}_4(y, x)$

  ➤ Data consistency checking

Decentralized Query Answering

- Contribution:

  Decentralized algorithm for query answering.

  ➢ Query reformulation

  $q(x) = Student_2(x)$

  $q_1(x) = ES_2(x)$

  $q_2(x) = \exists z\ TaughtTo_1(z, x)$

  $q_3(x) = \exists y\ PreparedBy_4(y, x)$

  ➢ Data consistency checking

  Consistent algorithm on P_1, P_2 and P_4

  On P_1 : $\perp$

  On P_2 : OK

  On P_4 : OK

Decentralized Query Answering

- Contribution:

  Decentralized algorithm for query answering.

  ➢ Query reformulation   Query Evaluation

  $q(x) = \text{Student}_2(x)$

  $q_1(x) = \text{ES}_2(x)$

  $q_2(x) = \exists z\ \text{TaughtTo}_1(z, x)$

  $q_3(x) = \exists y\ \text{PreparedBy}_4(y, x)$

  ➢ Data consistency checking

  Consistent algorithm on P_1, P_2 and P_4

  On P_1 : $\perp$

  On P_2 : OK

  On P_4 : OK

Decentralized Query Answering

P₁   ⊥

$\exists\, TaughtTo_1^- \subseteq Student_2$
$\exists\, LangTaughtTo_1^- \subseteq \neg\ ES_2$
$\exists\, MathTaughtTo_1^- \subseteq Student_2$

$Lang_1 \subseteq Course_1$ $\exists\, TaughtTo_1 \subseteq Course_1$
$Math_1 \subseteq Course_1$ $\exists\, LangTaughtTo_1 \subseteq Lang_1$
$Lang_1 \subseteq \neg\ Math_1$ $\exists\, MathTaughtTo_1 \subseteq Math_1$

$LangTaughtTo_1 \subseteq TaughtTo_1$

$MathTaughtTo_1 \subseteq TaughtTo_1$

$TaughtTo_1(Algebra, John)$

OK   **P₂**

$ES_2 \subseteq Student_2$
$\exists\, TaughtBy_2 \subseteq Student_2$

$ES_2\ (Mike)$
$TaughtBy_2\ (Mike, Nada)$

$\exists\, Teach_3^- \subseteq Course_1$

$q\ (x) = Student_2(x)$

P₃

⊥

$Mathematician_3 \subseteq Teacher_3$

$\exists\, Teach_3 \subseteq Mathematician_3$

$Teach_3\ (John, Analysis)$

$Student_2 \subseteq \neg\ Teacher_3$
$\exists\, TaughtBy_2^- \subseteq Teacher_3$

$\exists PreparedBy_4^- \subseteq Student_2$

OK   **P₄**

$\exists\, PreparedBy_4 \subseteq Diploma_4$

$PreparedBy_4(CS, Peter)$

Decentralized Query Answering

- Contribution:

  Decentralized algorithm for query answering.

  ➢ Query reformulation   Query Evaluation

  $q(x) = Student_2(x)$ ⟶   No answers

  $q_1(x) = ES_2(x)$

  $q_2(x) = \exists z\ TaughtTo_1(z, x)$

  $q_3(x) = \exists y\ PreparedBy_4(y, x)$

  ➢ Data consistency checking

  Consistent algorithm on P_1, P_2 and P_4

  On P_1: $\bot$

  On P_2:   OK

  On P_4:   OK

Decentralized Query Answering

P$_1$ $\perp$

$\exists$ TaughtTo$_1^-$ $\subseteq$ Student$_2$
$\exists$ LangTaughtTo$_1^-$ $\subseteq$ ¬ ES$_2$
$\exists$ MathTaughtTo$_1^-$ $\subseteq$ Student$_2$

Lang$_1$ $\subseteq$ Course$_1$ $\exists$ TaughtTo$_1$ $\subseteq$ Course$_1$
Math$_1$ $\subseteq$ Course$_1$ $\exists$ LangTaughtTo$_1$ $\subseteq$ Lang$_1$
Lang$_1$ $\subseteq$ ¬ Math$_1$ $\exists$ MathTaughtTo$_1$ $\subseteq$ Math$_1$

LangTaughtTo$_1$ $\subseteq$ TaughtTo$_1$

MathTaughtTo$_1$ $\subseteq$ TaughtTo$_1$

TaughtTo$_1$(Algebra, John)

OK   **P$_2$**

ES$_2$ $\subseteq$ Student$_2$
$\exists$ TaughtBy$_2$ $\subseteq$ Student$_2$

ES$_2$ (Mike)
TaughtBy$_2$ (Mike, Nada)

$\exists$ Teach$_3^-$ $\subseteq$ Course$_1$

$q_1(x) = ES_2(x)$

P$_3$ $\perp$

Mathematician$_3$ $\subseteq$ Teacher$_3$
$\exists$ Teach$_3$ $\subseteq$ Mathematician$_3$

Student$_2$ $\subseteq$ ¬ Teacher$_3$
$\exists$ TaughtBy$_2^-$ $\subseteq$ Teacher$_3$

Teach$_3$ (John, Analysis)

$\exists$PreparedBy$_4^-$ $\subseteq$ Student$_2$

OK   **P$_4$**

$\exists$ PreparedBy$_4$ $\subseteq$ Diploma$_4$

PreparedBy$_4$(CS, Peter)

Decentralized Query Answering

- Contribution:

  Decentralized algorithm for query answering.

Query reformulation	Query Evaluation

  ➢ Query reformulation $\qquad\qquad\qquad\qquad$ Query Evaluation

  $q(x) = Student_2(x) \qquad\longrightarrow$ No answers

  $q_1(x) = ES_2(x) \qquad\longrightarrow$ Well founded Answer = {Mike}

  $q_2(x) = \exists z\ TaughtTo_1(z, x)$

  $q_3(x) = \exists y\ PreparedBy_4(y, x)$

  ➢ Data consistency checking

  Consistent algorithm on P_1, P_2 and P_4

  On P_1 : $\perp$

  On P_2 : OK

  On P_4 : OK

Decentralized Query Answering

- Contribution:

  Decentralized algorithm for query answering.

  ➤ Query reformulation   Query Evaluation

  $q(x) = Student_2(x)$ ⟶   No answers

  $q_1(x) = ES_2(x)$ ⟶   Well founded Answer= {Mike}

  ~~$q_2(x) = \exists z\ TaughtTo_1(z, x)$~~

  $q_3(x) = \exists y\ PreparedBy_4(y, x)$

  ➤ Data consistency checking

  Consistent algorithm on P_1, P_2 and P_4

  On P_1 : ⊥

  On P_2 : OK

  On P_4 : OK

Decentralized Query Answering

P₁ ⊥

$Lang_1 \subseteq Course_1$ $\exists\, TaughtTo_1 \subseteq Course_1$
$Math_1 \subseteq Course_1$ $\exists\, LangTaughtTo_1 \subseteq Lang_1$
$Lang_1 \subseteq \neg\, Math_1$ $\exists\, MathTaughtTo_1 \subseteq Math_1$

$LangTaughtTo_1 \subseteq TaughtTo_1$

$MathTaughtTo_1 \subseteq TaughtTo_1$

$TaughtTo_1(Algebra, John)$

$\exists\, TaughtTo_1^- \subseteq Student_2$
$\exists\, LangTaughtTo_1^- \subseteq \neg\, ES_2$
$\exists\, MathTaughtTo_1^- \subseteq Student_2$

OK **P₂**

$ES_2 \subseteq Student_2$
$\exists\, TaughtBy_2 \subseteq Student_2$

$ES_2\,(Mike)$
$TaughtBy_2\,(Mike, Nada)$

$\exists\, Teach_3^- \subseteq Course_1$ $q_3\,(x) = \exists y\ PreparedBy_4\,(y, x)$

P₃

$Mathematician_3 \subseteq Teacher_3$

$\exists\, Teach_3 \subseteq Mathematician_3$ $Student_2 \subseteq \neg\, Teacher_3$

⊥ $\exists\, TaughtBy_2^- \subseteq Teacher_3$

$Teach_3\,(John, Analysis)$

$\exists PreparedBy_4^- \subseteq Student_2$

OK **P₄**

$\exists\, PreparedBy_4 \subseteq Diploma_4$

$PreparedBy_4(CS, Peter)$

Decentralized Query Answering

- Contribution:

  Decentralized algorithm for query answering.

  ➤ Query reformulation $\qquad$ | $\qquad$ Query Evaluation

  $q(x) = \text{Student}_2(x)$ $\longrightarrow$ | No answers

  $q_1(x) = \text{ES}_2(x)$ $\longrightarrow$ | Well founded Answer= {Mike}

  ~~$q_2(x) = \exists z\ \text{TaughtTo}_1(z, x)$~~

  $q_3(x) = \exists y\ \text{PreparedBy}_4(y, x)$ $\longrightarrow$ | Well founded Answer= {Peter}

  ➤ Data consistency checking

  Consistent algorithm on P_1, P_2 and P_4

  On P_1 : ⊥

  On P_2 : OK

  On P_4 : OK
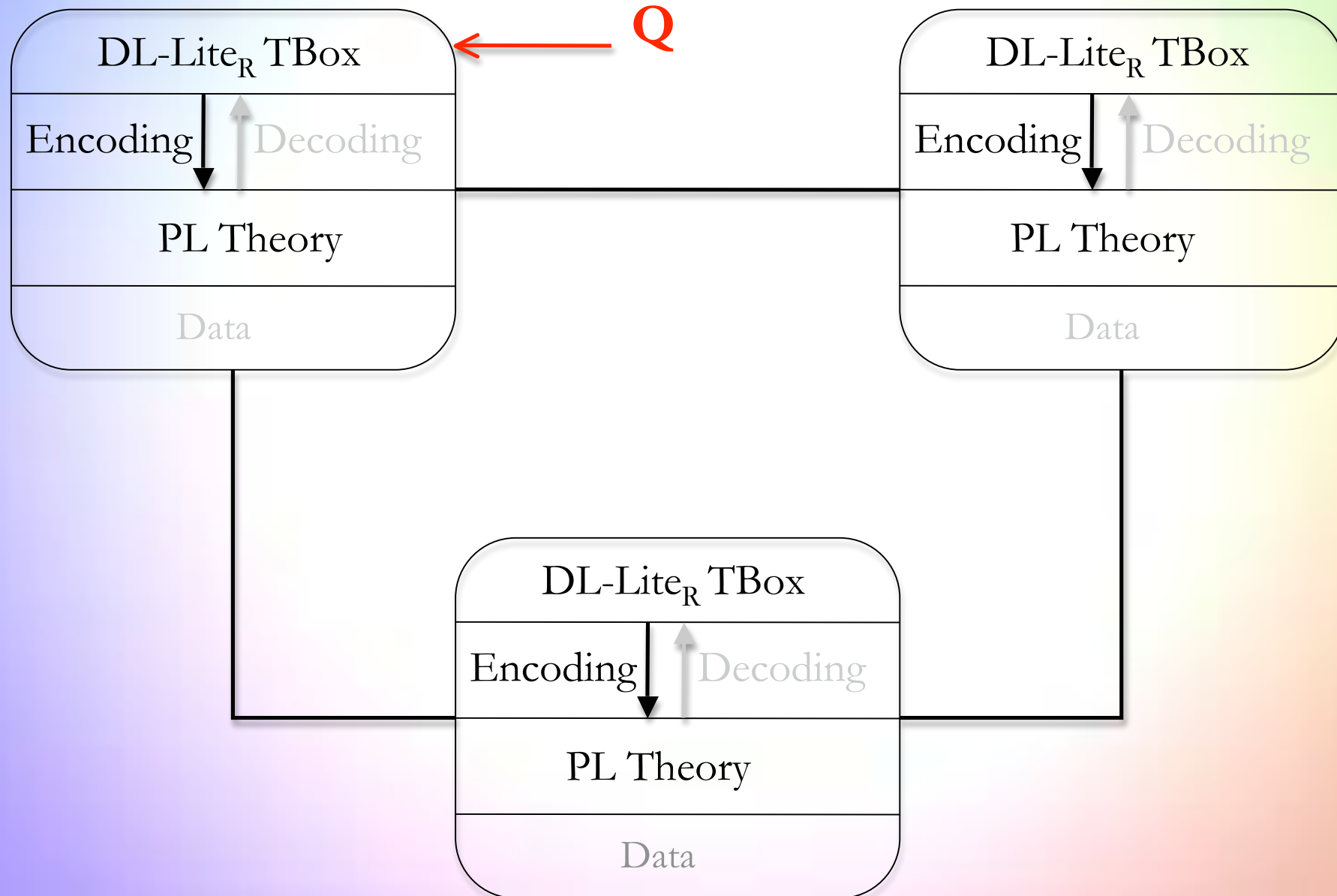
Decentralized Query Reformulation by using SomeWhere

Decentralized Query Reformulation by using SomeWhere
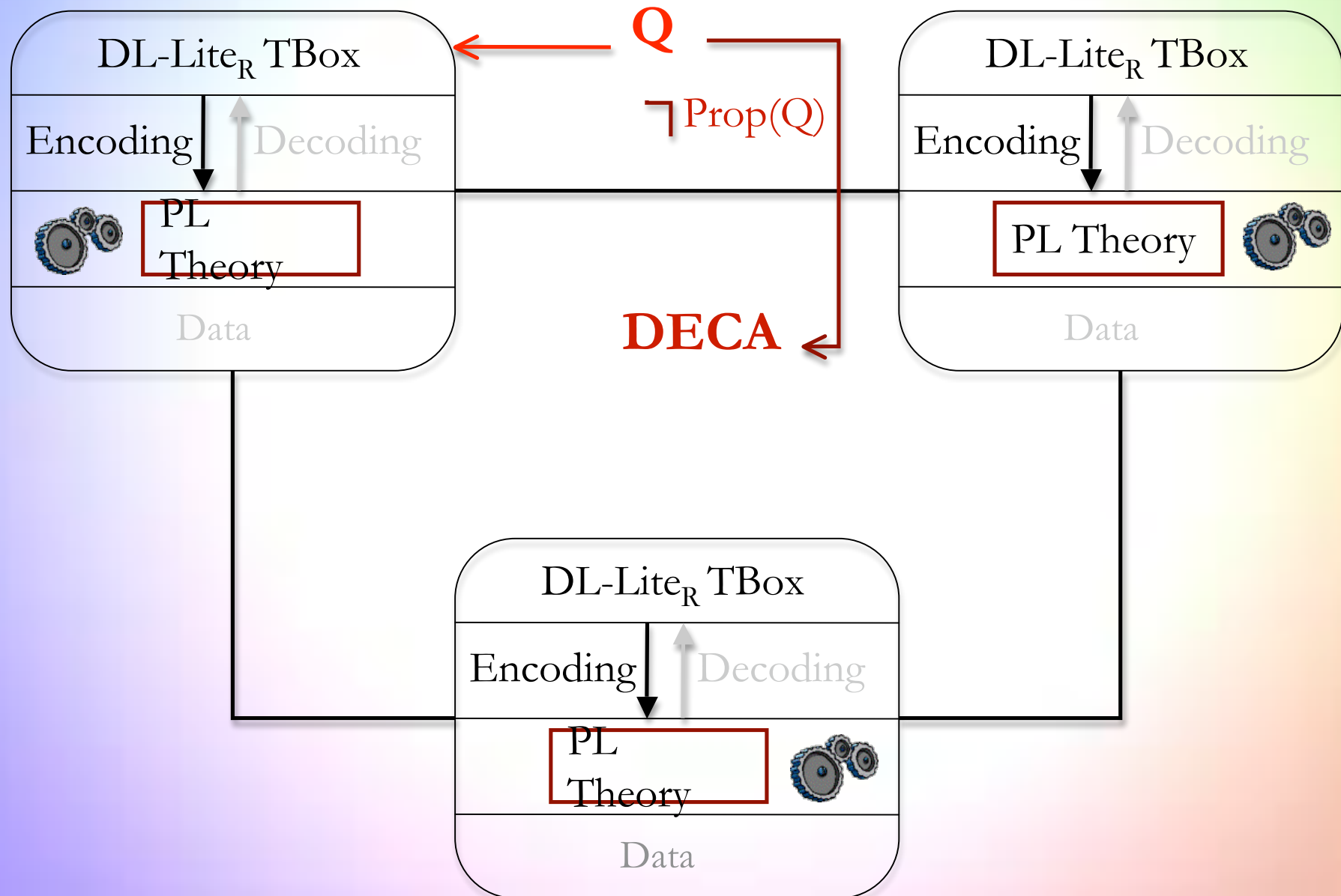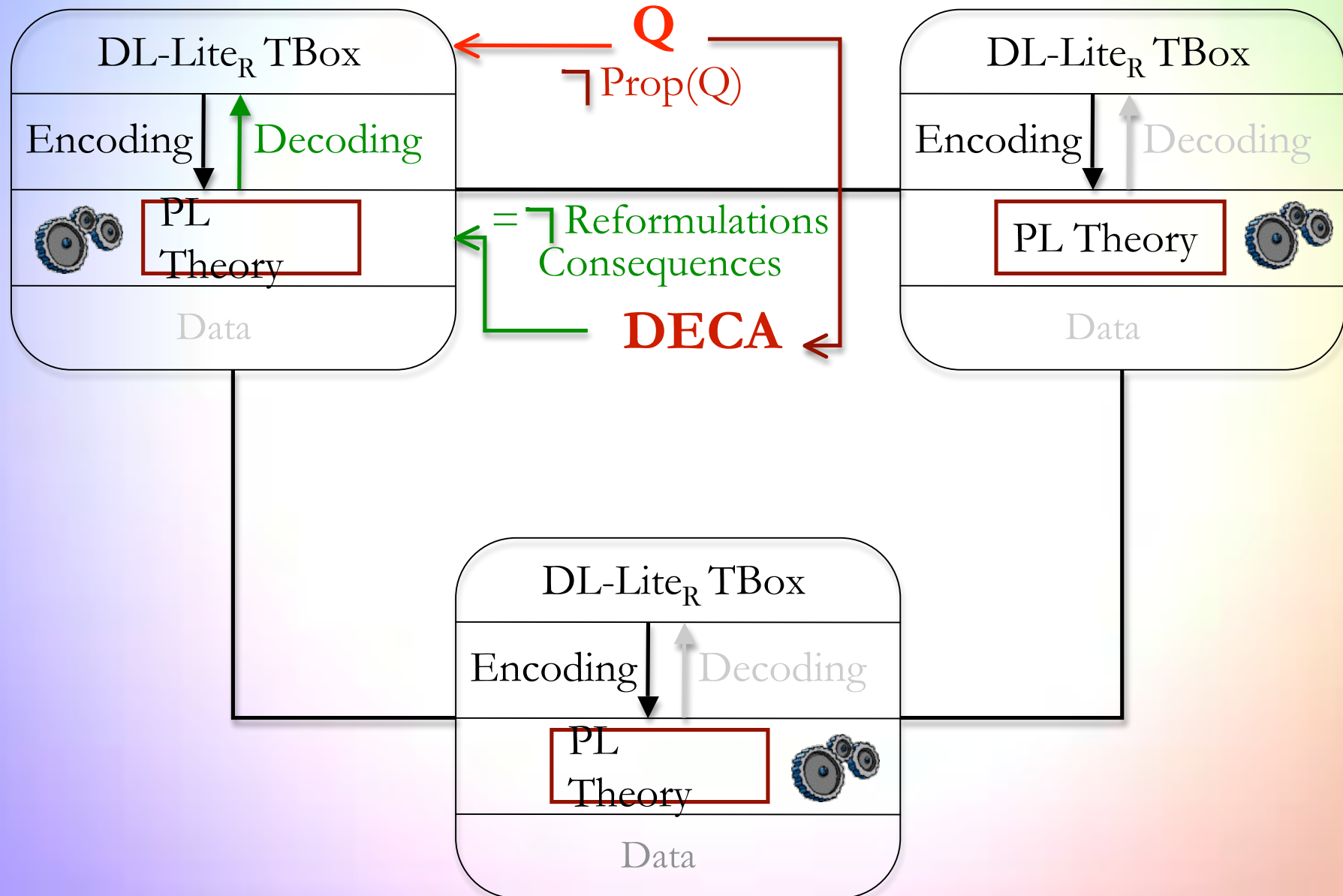
Q

DL-Lite$_R$ TBox

Encoding | Decoding

PL Theory

Data

$\neg$Prop(Q)

DECA

DL-Lite$_R$ TBox

Encoding | Decoding

PL Theory

Data

DL-Lite$_R$ TBox

Encoding | Decoding

PL Theory

Data

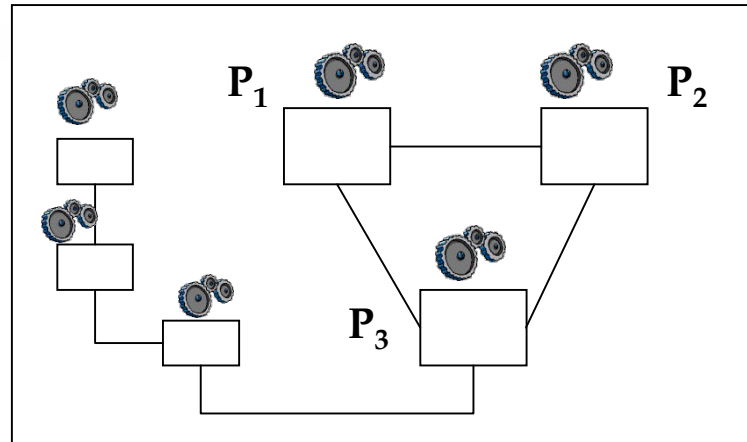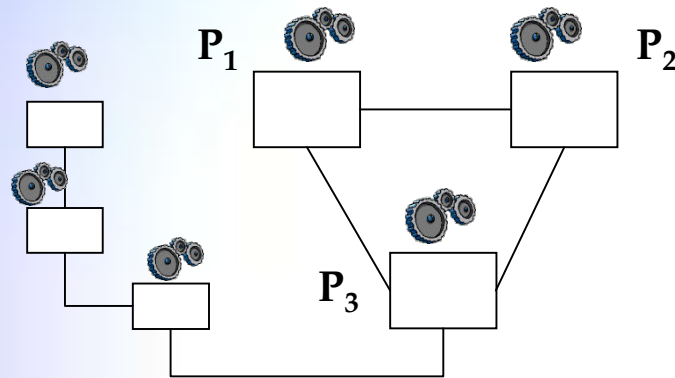# Decentralized Query Reformulation by using SomeWhere

Outline

❏ **DL-Lite$_R$ decentralized data management system**

   ❏ **Data consistency checking**

   ❏ **Query Answering**

   ❏ **Conclusion & Future Work**

Conclusion & future work

1. **DL-Lite$_R$ decentralized data model**

2. **Decentralized Algorithms for:**

   ✓ **Data consistency checking**

   ✓ **Query Answering**

3. **Decentralized & Centralized Algorithms for:**

   ✓ **View consistency checking**

   ✓ **Query Answering using views**
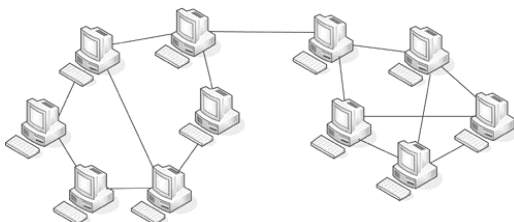
Other Applications

- **Mapping discovery**
- **Data reconciliation**
- **Explanation of answers to queries**

Feasibility of the approach with other dialects of DL-Lite

Thank You

Questions?

SomeWhere and the Semantic Web

After SomeOWL and SomeRDFS

SomeDL-Lite$_R$

Nada Abdallah