An Approach to Information Integration Based on the AMN Formalism

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Goals

- To use two or more databases (data sources) in the frame of a large database, possibly virtual, containing information from all sources, so the data can be queried as a unit.

Agenda

- Problems of Information Integration
- State of the Art
- Canonical Model and Principle of its Extension
- AMN Formalization of Data Model
- Mapping from RDM into Canonical Model
- Summary & Future Work

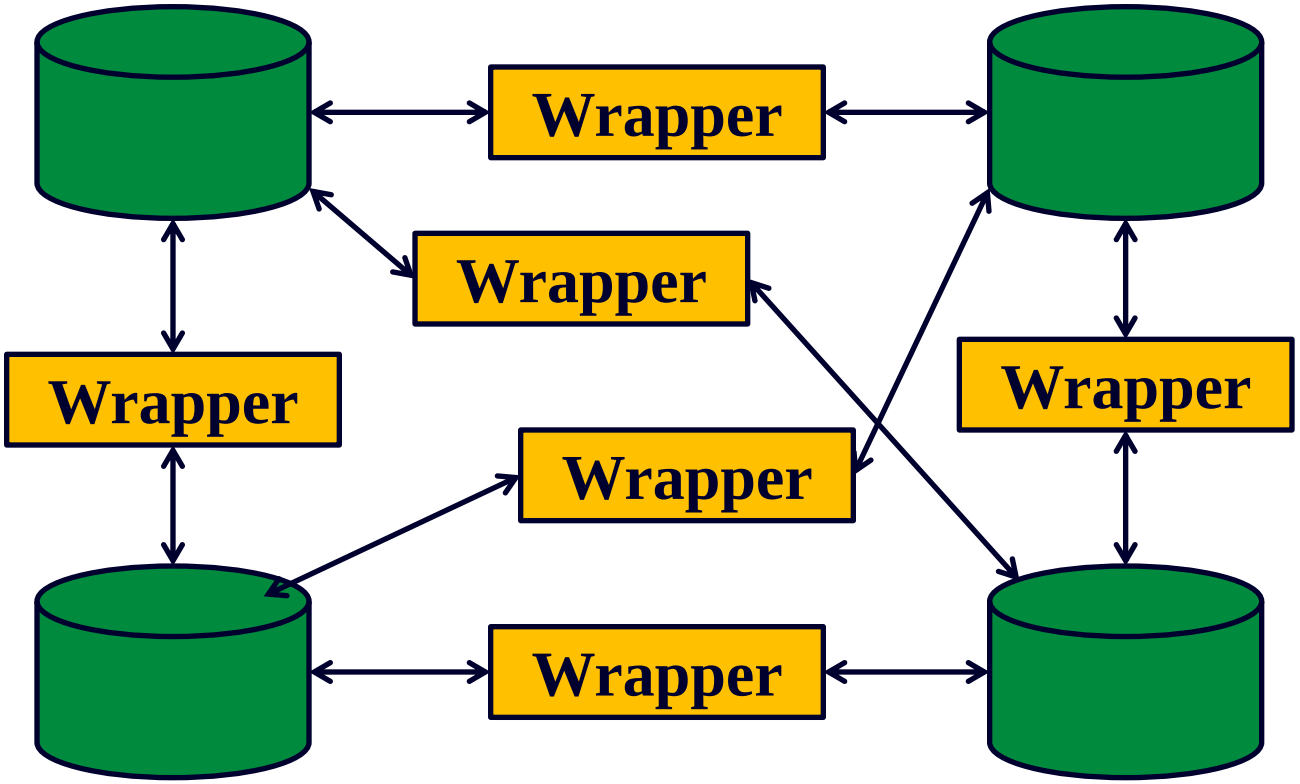
Problems of Information Integration

- **Data Type Differences** The same property is presented by different types;
- **Value Differences** The value of the same property have different encodings;
- **Semantic Differences** Terms may be given different interpretations;
- **Missing Values** A source might not record information of a type that all or most of the other sources provide.

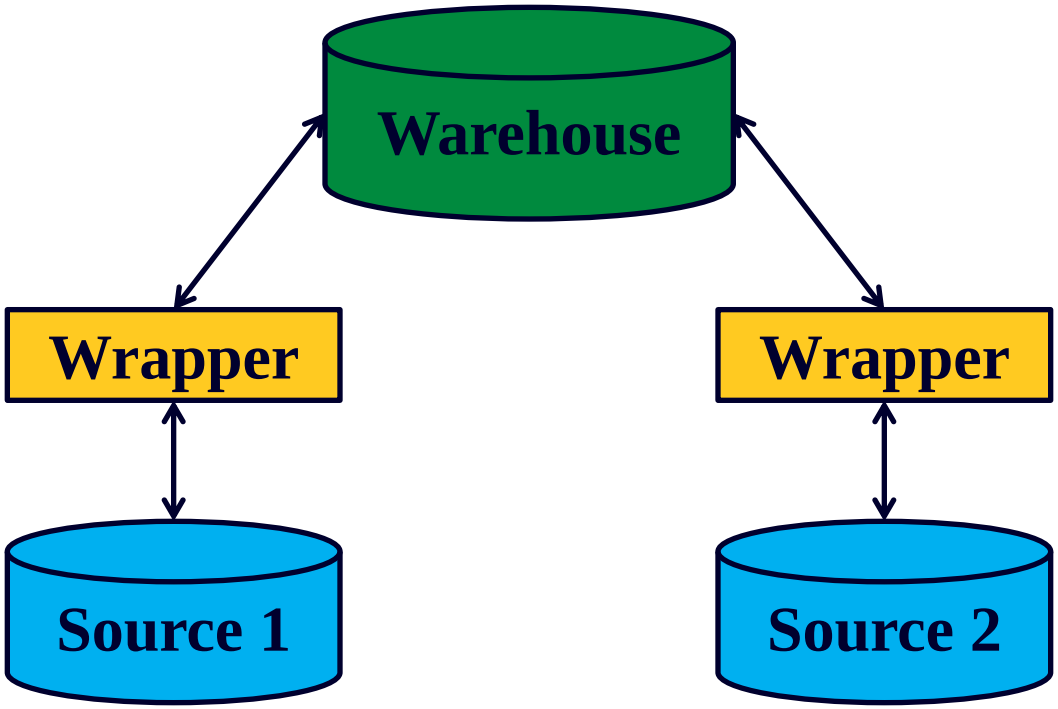
Common Approaches

- **Federated Databases** Everybody talks directly to everyone else;
- **Warehousing** Sources are translated from their local schema to a global schema and copied to a central DB;
- **Mediation** Transforms a user query into a sequence of source queries.

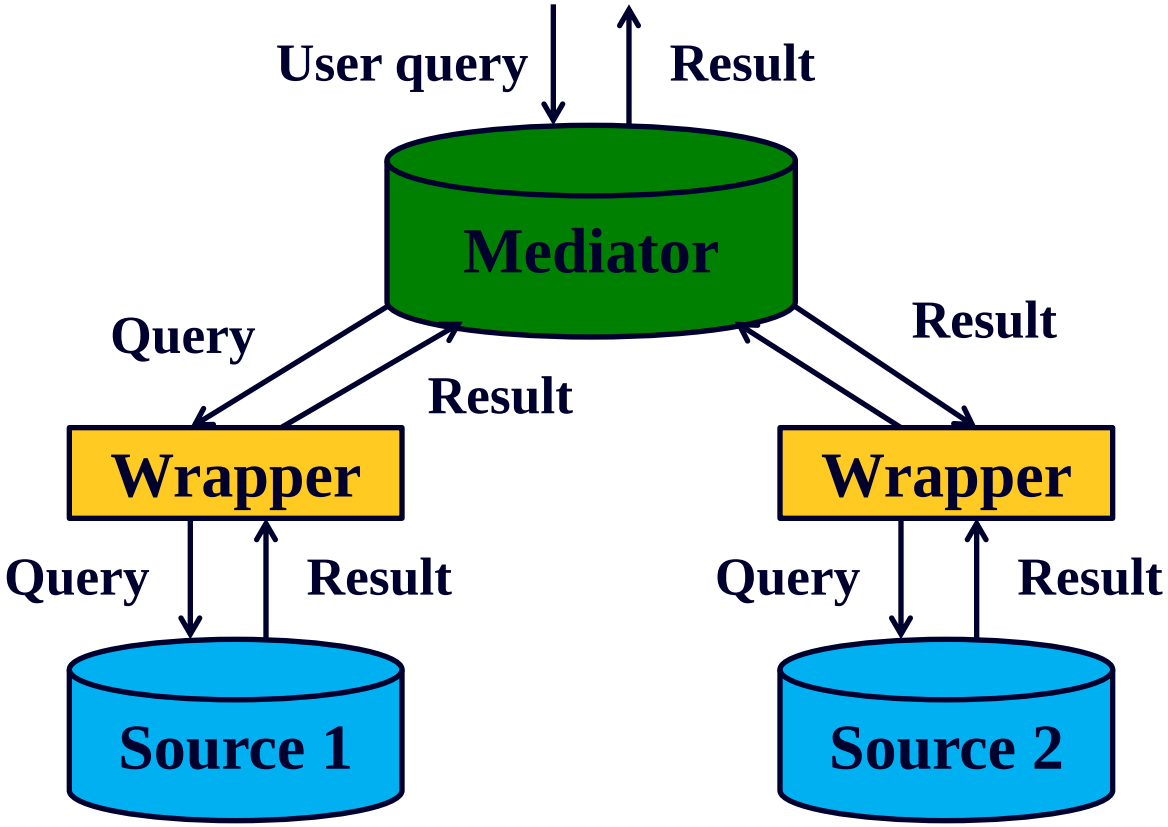
Federated Database Systems



Data Warehouses



Mediators


User query
Result
Mediator
Query
Result
Result
Wrapper
Wrapper
Query
Result
Query
Result
Source 1
Source 2

Two Mediation Approaches

- **Global as View** Global schema is defined as a view over the data sources;
- **Local as View** Sources are defined in terms of global schema; mediator finds all ways to build query from views.

Example: Local View (1)

The mediator supports a **par(c,p)** relation:

- Source 1 provides some parent facts:

  V1(c,p) ← par(c,p)

- Source 2 supports only grandparent facts:

  V2(c,g) ← par(c,p) AND par(p,g)

Example: Local View (2)

- **Query** (great-grandparents):

ggp(c,x) ← par(c,u) AND par(u,v) AND par(v,x)

Sol1(c,x) ← V1(c,u) AND V1(u,v) AND V1(v,x)

Sol2(c,x) ← V1(c,u) AND V2(u,x)

Sol3(c,x) ← V2(c,u) AND V1(u,x)

LAV and GAV Comparison

- **GAV** approach has better query processing capabilities (simpler to implement);
- **LAV** is more extensible (new data sources easier integrated).

GLAV

GLAV approach combines the **GAV** and **LAV** approaches:

- Provides direct access to data sources;
- Provides capability to define global schema as a view over the data sources.

Theoretical Basis (1)

Works of SYNTHESIS Group (http://synthesis.ipi.ac.ru):

- **AMN** is used to formalize data models;
- The canonical model should be extensible;
- A kernel of the canonical model is fixed. For each specific data model **M** of the environment an appropriate kernel extension is defined axiomatically;
- The canonical model is synthesized as a union of extensions, constructed for models **M** of the environment.

Theoretical Basis (2)

In the frame of the considered formalism is offered to construct:

- A mapping from $\mathbf{M_s}$ into an extension $\mathbf{M_t}$;
- **AMN** semantics of $\mathbf{M_s}$;
- **AMN** semantics of the extended $\mathbf{M_t}$.

After that the **B** - technology is applied to proof that $\mathbf{M_s}$ is a refinement of the extension of $\mathbf{M_t}$. We say that specification $\mathbf{S_1}$ refines specification $\mathbf{S_2}$, if it is possible to use $\mathbf{S_1}$ instead of $\mathbf{S_2}$ so that the user of $\mathbf{S_2}$ does not notice this substitution.

XDM as Kernel of Canonical Model

The following kinds of **XDM** objects are considered:

- **Basic Objects** constants of atomic types, variables of different sorts, etc.
- **Compound Objects** are defined in terms of *application* and *binding* in λ - calculus.

Type System of XDM (1)

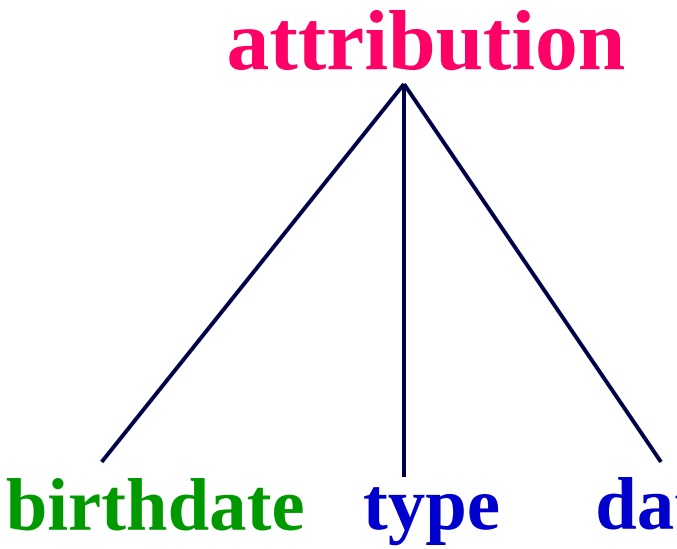
- To define metadata;
- To formalize the signature of **XDM** symbols;
- Formalism:
  - term calculus;
  - inference rules of judgments.

Type System of XDM (2)

- **Basis** consists of conventional atomic types, for example, **int**, **string**, **boolean**, etc.
- *Attribution*. If **v** is a basic object variable and **t** is a typed object, then **attribution**(**v**, **type t**) is a typed object.

Type System of XDM (3)

(Example)



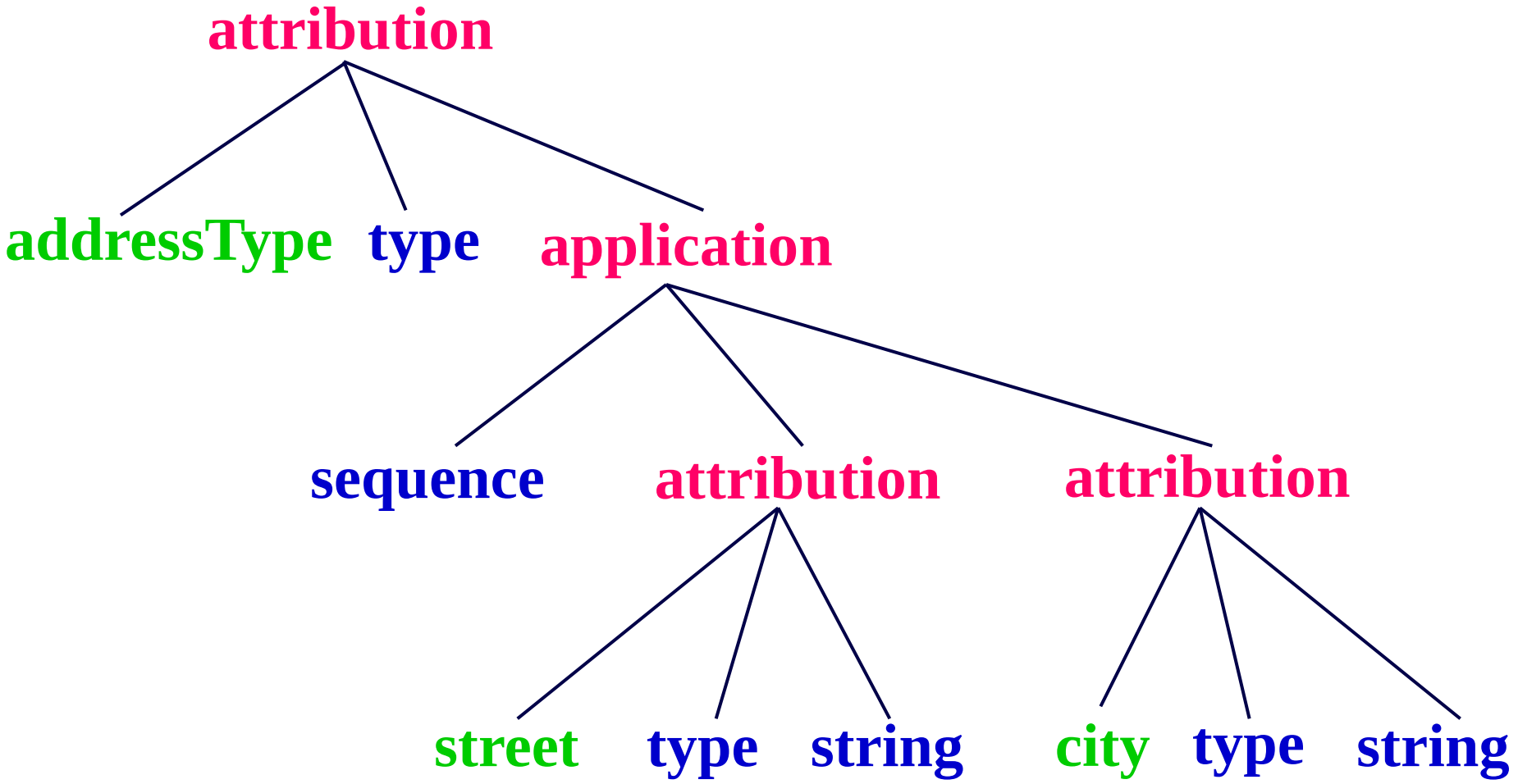

```
<xdmattr>
  <xdmatp>
    <xdms  name="type"  cd="ecc"/>
    <xdms  name="date"  cd="ecc"/>
  </xdmatp>
   <xdmelm name="birthdate"/>
</xdmattr>
```

Type System of XDM (4)

- *Abstraction*. If **v** is a basic object variable and **t, A** are typed objects, then **binding(lambda, attribution(v, type t), A)** is typed object;
- *Application*. If **F** and **A** are typed objects, then **application(F, A)** is typed object;
- *Function Space*. If **t** and **u** are typed objects, and **v** is a basic variable object, then **binding(PiType, attribution(v, type t), u)** is typed object.

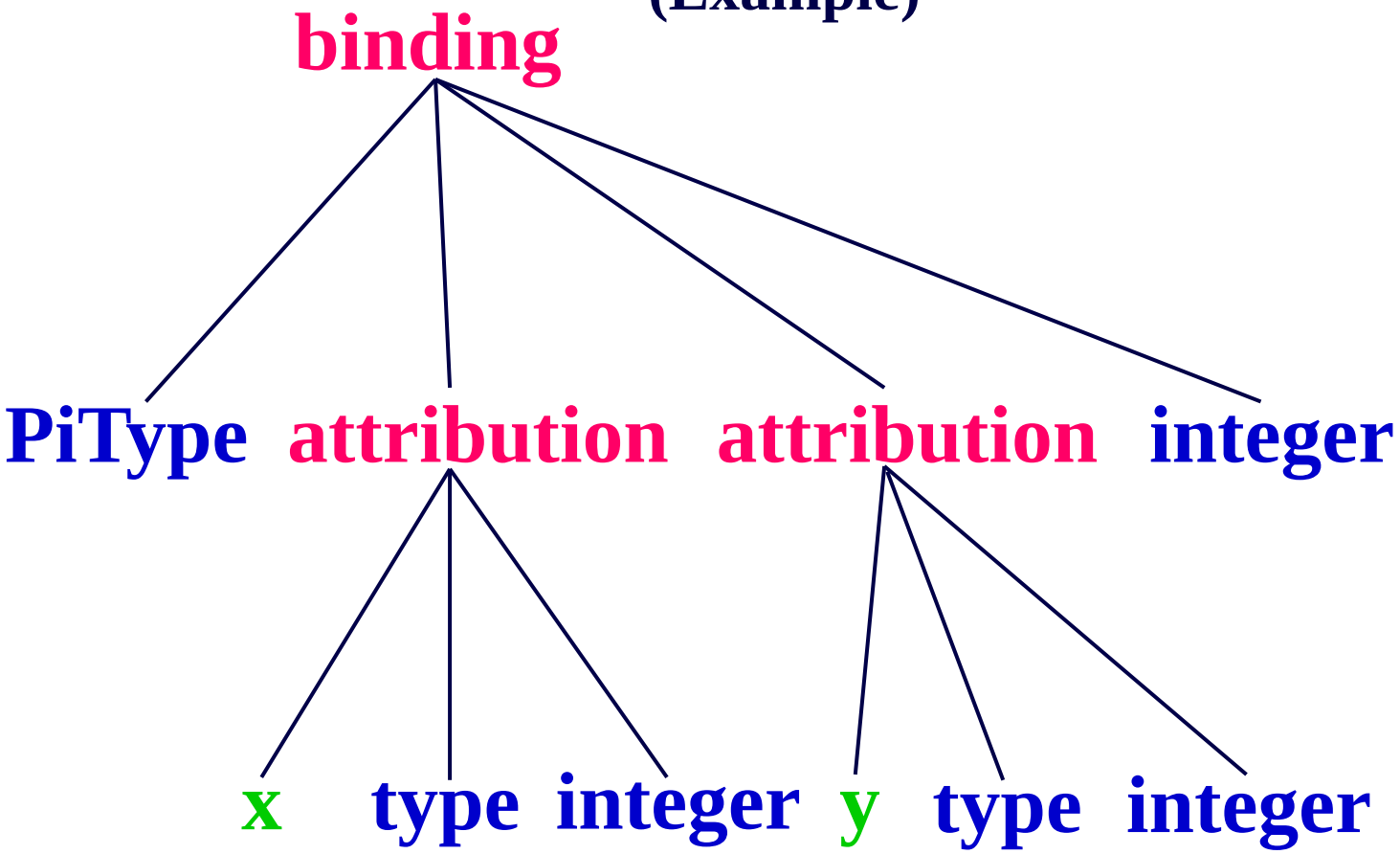
Type System of XDM (5)

(Example)



Type System of XDM (6)

(Example)



integer × integer → integer

Kernel Extension Principle (1)

- The extension of canonical model is formed by consideration of each new data model by adding new symbols to its DDL (symbols are used for data models conceps representation);
- For applying a concept on the canonical model level the following rule is proposed:

Concept ← Symbol Context Definition

Kernel Extension Principle (2)

(Example)

- To support the concepts of **referential integrity** and **key's** of relational data model, we have expanded the kernel with the following symbols: **key**, **unique**, **foreign key**, **constraint**, **on update**, **on delete**, **cascade**, and **set null**.
- **S = {Snum, Sname, Status, City}**

  P = {Pnum, Pname, Color, Weight, City}

  SP = {Snum, Pnum, Qty}

Kernel Extension Principle (3)

(Example)

S ← **attribution(S, type** TypeContext**,**
constraint ConstContext**)**

TypeContext ← **application(sequence,** AppContext**)**

AppContext ← **attribution(Snum, type int),**
attribution(Sname, type string),
attribution(Status, type int),
attribution(City, type string)

ConstContext ← **attribution(ConstName, key Snum)**

Kernel Extension Principle (4)

(Example)

SP ← **attribution(SP, type** TypeContext**,**
constraint KConstContext**,**
constraint FKConstContext1**,**
constraint FKConstContext2**)**

...

KConstContext ← **attribution(**ConstName, **key**
application(list, Snum, Pnum))

FKConstContext1← **attribution(ConstName,**
foreign key application(ref, ConstNameOFS),
on update cascade, on delete cascade)

AMN as Formal Language of Specification

AMN is a state-oriented formalism for software development and consists the following notations:

- the logical notation;
- the basic set notation;
- the relational notation;
- the mathematical object notation;
- the generalized substitution notation.

Basic Constructions of AMN

- Abstract Machine;
- Refinement;
- Implementation.

Abstract Machine Notation

MACHINE *MachineDeclaration*

USES *MachineList*

SEES *MachineList*

INCLUDES *InstantiatedMachineList*

EXTENDS *InstantiatedMachineList*

SETS *SetList*

CONSTANTS *ConstantList*

PROPERTIES *Predicate*

VARIABLES *VariableList*

INVARIANTS *Predicate*

INITIALISATION *Substitution*

OPERATIONS *OperationList*

END

Refinement

REFINEMENT r

REFINES m

SEES sm

INCLUDES im

SETS s

CONSTANTS c

PROPERTIES P(s,c)

VARIABLES x

INVARIANTS I(x)

INITIALISATION S

OPERATIONS O_1; O_2;... ; O_n

END

Formalization of the Concept Refinement in AMN (1)

REFINEMENT M
REFINES K
CONSTANTS c_M
PROPERTIES P_M
VARIABLES v
INVARIANTS I_M
INITIALISATION $Init_M$
OPERATIONS
  $y \leftarrow$ op(x) =
    PRE $Pre_{op,M}$
    THEN $Def_{op,M}$
    END
  ...
END

REFINEMENT N
REFINES M
CONSTANTS c_N
PROPERTIES P_N
VARIABLES w
INVARIANTS I_N
INITIALISATION $Init_N$
OPERATIONS
  $y \leftarrow$ op(x) =
    PRE $Pre_{op,M}$
    THEN $Def_{op,M}$
    END
  ...
END

Formalization of the Concept Refinement in AMN (2)

Definition We say that **M** refines **N** if holds the following *proof obligations*:

- $P_M \wedge P_N \Rightarrow \exists(v,w) \bullet (I_M \wedge I_N)$
- $P_M \wedge P_N \Rightarrow [Init_N] \neg ([Init_M] \neg I_N)$
- $P_M \wedge P_N \wedge I_M \wedge I_N \wedge Pre_{op,M} \Rightarrow$
  $Pre_{op,N} \wedge [Def_{op,N}\{y \rightarrow y'\}] \neg$
  $([Def_{op,M}] \neg (I_N \wedge y' = y))$

AMN Formalization of Data Model (1)

Our approach to information integration assumes to create:

- **AMN** semantics for **XDM** (mapping form **XDM** to **AMN**);
- **AMN** semantics for each source data model (mapping form source data model to **AMN**);
- The canonical model extension by concepts of the source data model which are not yet present in target model.

After that the **B** - technology is applied to proof that source data model is a refinement of the extension of target model.

AMN Formalization of Data Model (2)

First of all we introduce an abstract machine in which some common concepts of data models are included.

MACHINE
  DatamodelContext
SETS
  OBJ, Types
ABSTRACT_CONSTANTS
  atomicTypes, extent, typeOf
PROPERTIES
  atomicTypes ∈ P(OBJ) ∧ extent ∈ Types → P(OBJ) ∧
  typeOf ∈ OBJ → Types
END

AMN Formalization of Data Model (3)
(AMN semantics for XDM)

For each data model an abstract machines hierarchy is created which represents **AMN** semantics for that model. We use the following definition of **XDM** schema to create the **AMN** semantics for **XDM**:

Definition We say that **S** is a schema, if

S = ⟨name, atomictype, f⟩ or

S = ⟨name, typeOp(S_1, S_2, … , S_n), f⟩, and S_i is a schema, where **typeOp∈{sequence, choice, all}, f∈{?, *, +, ⊥}, $1 \leq i \leq n$.**

AMN Formalization of Data Model (4)
(AMN semantics for XDM)

MACHINE XDM_Schema
(p_name, p_operationType, p_argOfOperation, p_frequency)
CONSTANTS Frequency, OperationTypes, FunctionSpace
PROPERTIES
Frequency = {?, *, +, ⊥} ∧
OperationTypes = {sequence, choice, all, empty} ∧
FunctionSpace = *seq*(Types) x Types
VARIABLES name, operationType, argOfOperation, frequency
INVARIANT
name ∈ STRING ∧ operationType ∈ OperationTypes ∧
argOfOperation ∈ P(*extent*(XDM_Schema)) ∧
frequency ∈ Frequency
CONSTRAINTS p_name ∈ STRING ∧ p_operationType ∈ operationTypes ∧ …
INITIALISATION name := p_name ∧ operationType := p_operationType ∧ …
END

Extension of the Canonical Model

MACHINE Mch_T
SETS S_T
CONSTANTS C_T
PROPERTIES P_T
VARIABLES V_T
INVARIANTS I_T
INITIALISATION S
END

MACHINE $Concepts_{ST}$
SETS S_{ST}
CONSTANTS C_{ST}
PROPERTIES P_{ST}
END

MACHINE Mch_{ST}
EXTENDS Mch_T
SEES $Concepts_{ST}$
END

REFINEMENT Mch_S
REFINES Mch_{ST}
SEES $Concepts_{ST}$
SETS S_s
CONSTANTS C_s
PROPERTIES P_s
VARIABLES V_s
INVARIANTS $I_S \wedge Cond_S$
INITIALISATION S
END

AMN Semantics of Relational Data Model (1)

MACHINE
  REL_Schema
VARIABLES
  schemaName, state
INVARIANT
  schemaName ∈ STRING ∧
  state ∈ P(STRING × atomicTypes)
END

AMN Semantics of Relational Data Model (2)

MACHINE
  REL_DB_Schema
VARIABLES
  dbSchemaName, schemas
INVARIANT
  dbSchemaName ∈ STRING ∧
  schemas ∈ P(*extent*(REL_Shema))
END

Mapping from Relational Data Model into Canonical Model (1)

MACHINE
REL_Canonical_Mapping
USES
REL_Schema, REL_DB_Schema, XDM_Schema
OPERATIONS
xdm_Schema ← REL_attr_to_XDM(attr) =
PRE
attr ∈ string × atomicTypes ∧ xdmSchema ∈ *extent*(XDM_Schema)
THEN
xdmSchema = XDM_Schema(*dom*(attr), *ran*(attr), ∅, ⊥)
END

Mapping from Relational Data Model into Canonical Model (2)

xdm_Schema ← REL_Schema_to_XDM(relSchema) =
PRE
relSchema ∈ *extent*(REL_Schema) ∧
xdmSchema ∈ *extent*(XDM_Schema)
THEN
xdmSchema = XDM_Schema(*name*, *sequence*, *recSequence*, ⊥)
END
xdm_Schema ← REL_DB_Schema_to_XDM(relDbSchema) =
PRE
relDbSchema ∈ *extent*(REL_DB_Schema) ∧
xdmSchema ∈ *extent*(XDM_Schema)
THEN
xdmSchema = XDM_Schema(*name*, *sequence*, *recSequence*, ⊥)
END
END

DML Formalization Principles in AMN

MACHINE

RelationalAlgebra

USES

Relation

OPERATIONS

s ← union(r, q) =

PRE

r ∈ *extent*(Relation) ∧ q ∈ *extent*(Relation) ∧

s ∈ *extent*(Relation) ∧ *isUnionCompatibility*(r, q)

THEN

s.schema : = r.schema || s.tuples := r.tuples ∪ q.tuples

END

Summary & Future Work

- **Canonical Model**
  - **The XDM has been formalized in the frame of the AMN,**
  - **Principle of extension of canonical model has been proposed and formalized in the frame of AMN.**
- **Example of Mappings**
  - **The RDM has been formalized in the frame of AMN,**
  - **Mapping from AMN representation of RDM to canonical model has been proposed.**
- **In the future we plan to develop**
  - **Algorithms for generation of mappings from the source models into canonical model,**
  - **Temporal extension of canonical model.**

THANK YOU FOR YOUR ATTENTION!