Logical Approach to Physical Data Independence and Query Compilation

Introduction, Background, and Goals

David Toman

D.R. Cheriton School of Computer Science
University of
Waterloo

Organization

Lectures/Exercises

- web page:

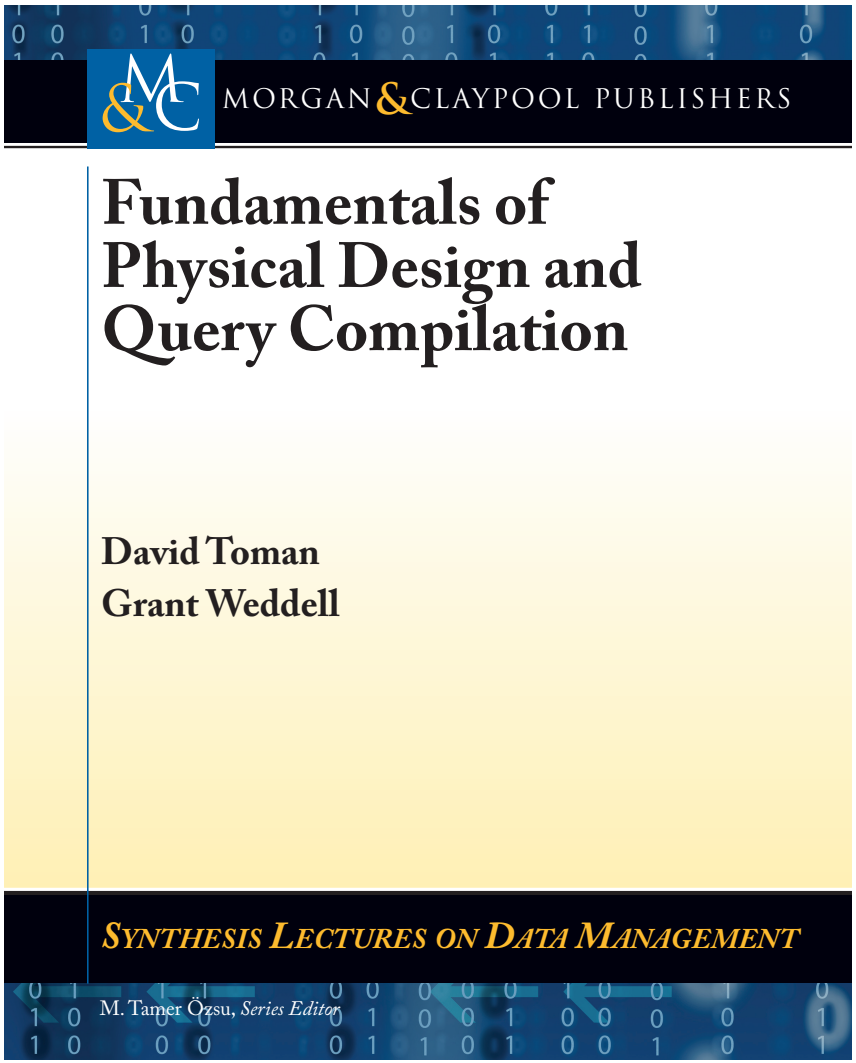
  `http://lat.inf.tu-dresden.de/teaching/ss2014/Toman-VL/`

  `http://cs.uwaterloo.ca/~david/tud/tud.html`

- schedule:

	Monday 14:50-18:10 E 005	Tuesday 14:50-16:20 E 005	Wednesday 16:40-18:10 3027	Thursday 14:50-16:20 E 005
7–11 April	-	-	Lecture	Lecture
14–18 April	Ex&Lect	-	Lecture	Exercise
21–25 April	-	Lecture	Lecture	Exercise

Textbook (aka Shameless plug)



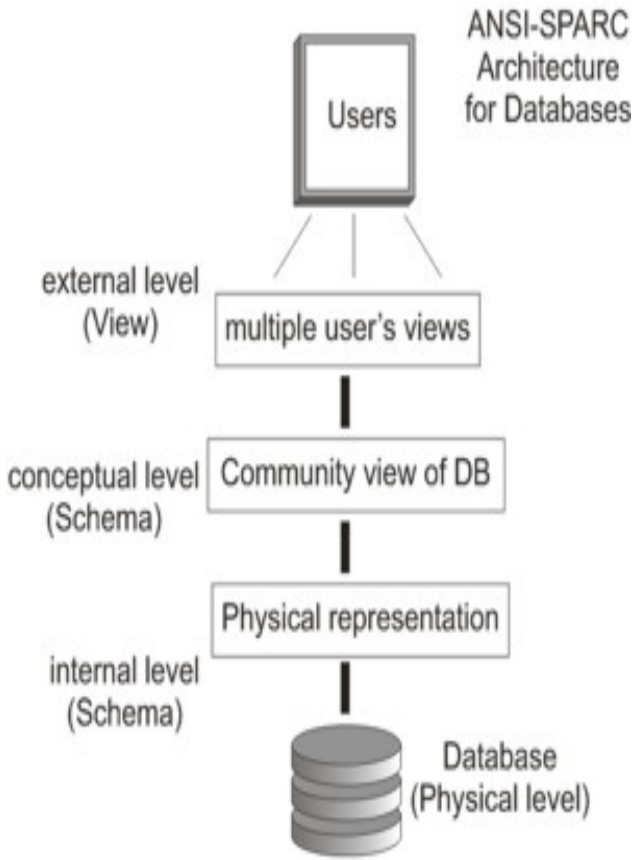
D. Toman and G. Weddell. *Fundamentals of Physical Design and Query Compilation*. Morgan and Claypool Data Management Series, 2011.

USE SCENARIOS AND GOALS

Phyical Data Independence

IDEA:

Separate the users' view(s) of the data from the way it is physically represented.



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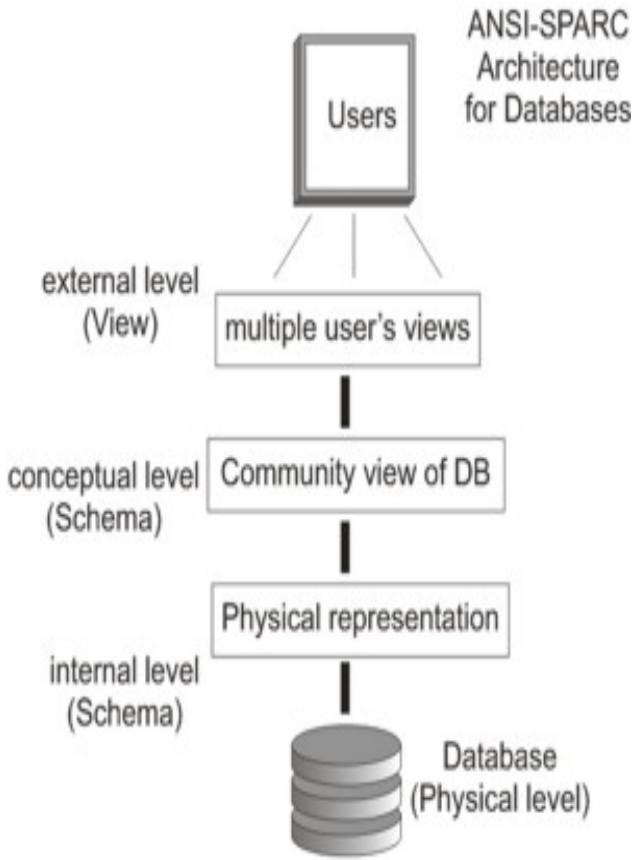

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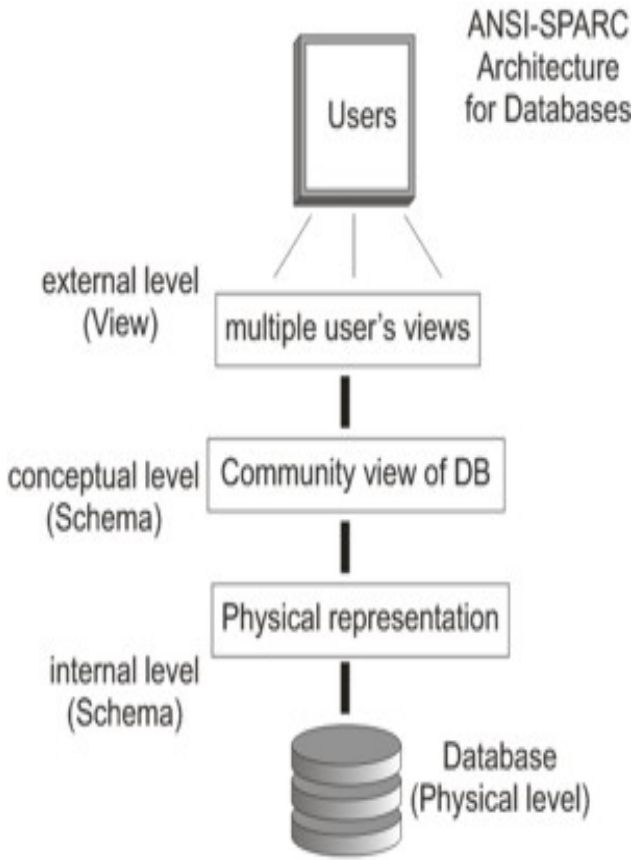

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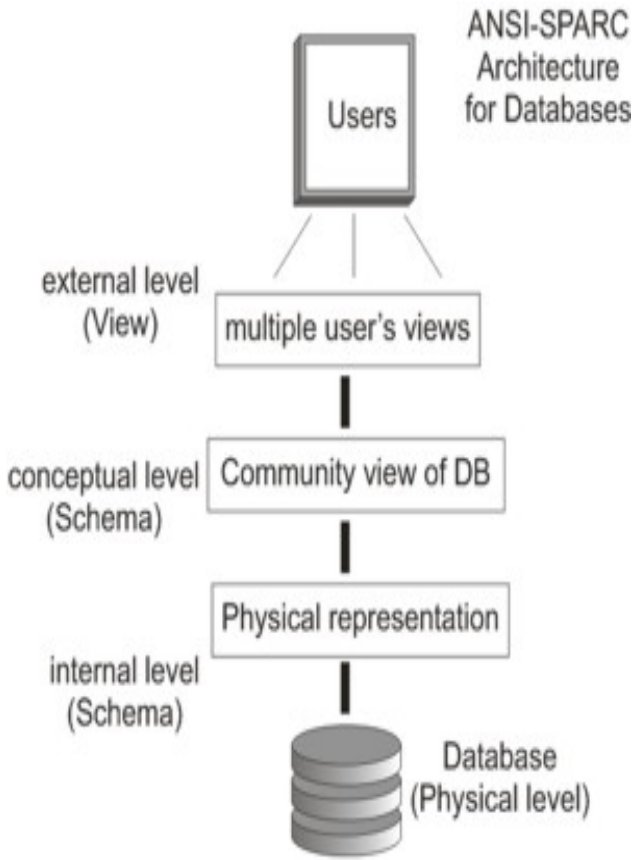

- physical storage details hidden from users,
- changes to physical storage without affecting conceptual view,

Originally just two levels: physical and conceptual/logical [Codd1970].

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Example: PAYROLL

A *Conceptual (user) view* of PAYROLL data:

Example of PAYROLL data:

1. Mary is an employee.
2. Mary's employee number is 3412.
3. Mary's salary is 72000.

Example of PAYROLL:

4. There is a kind of entity called an `employee`.
5. There are attributes called `enumber`, `name` and `salary`.
6. Each employee entity has attributes `enumber`, `name` and `salary`.
7. Employees are identified by their `enumber`.

Example: PAYROLL

A *physical design* for PAYROLL:

8. There is a file of records called `emp-file`.
9. There are record fields `emp-num`, `emp-name` and `emp-salary`.
10. Each `emp-file` record has the fields `emp-num`, `emp-name` and `emp-salary`.
11. File `emp-file` is organized as a B-tree data structure that supports an `emp-lookup` operation, given a value for attribute `enumber`.

12. Records in file `emp-file` correspond one-to-one to `employee` entities.
13. Record fields in file `emp-file` encode the corresponding attribute values for `employee` entities, for example, `emp-num` encodes an `enumber`.

Ontology-based Data Access

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Queries are answered not only w.r.t. *explicit data*
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- Every MAN is MORTAL (background)

List all MORTALs $\Rightarrow \{\text{Socrates}\}$ (query)

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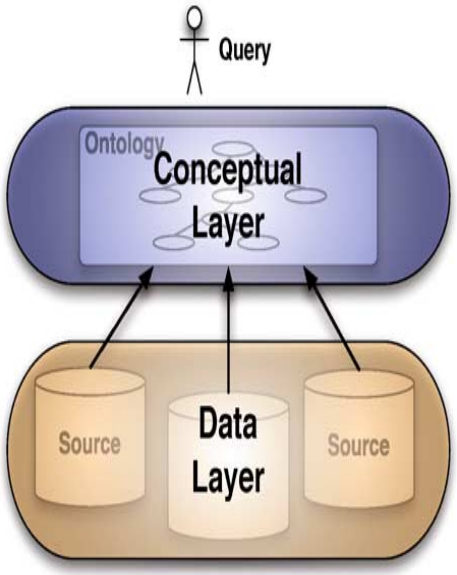

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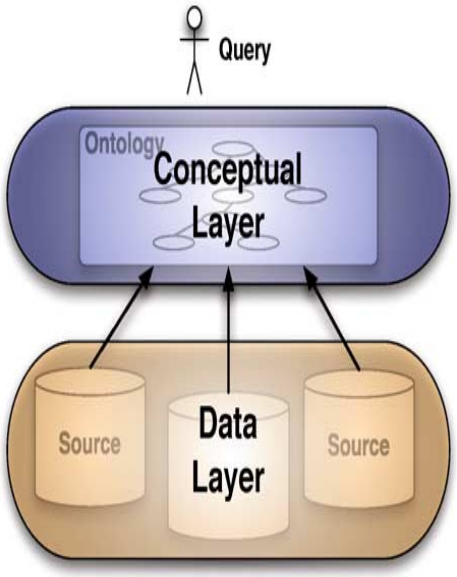

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Question:

Is Aristoteles a MORTAL?

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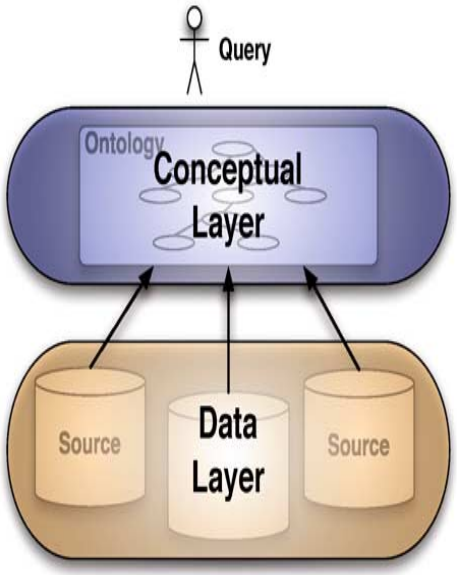

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Question:

Is Aristoteles a MORTAL? ... can we *really* say "NO"?

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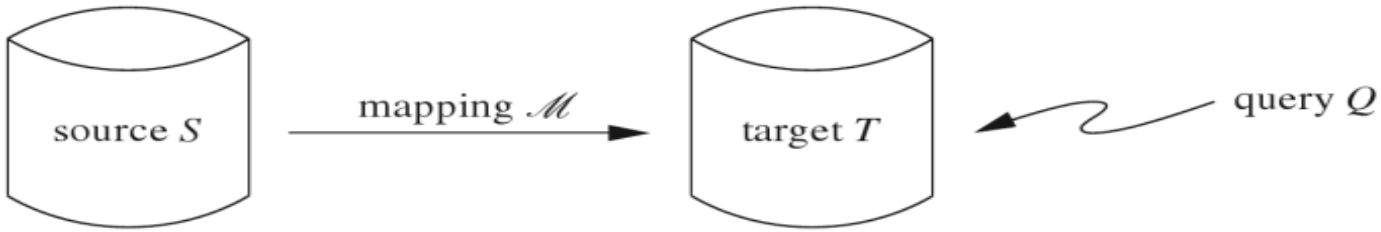
The general setting of data exchange is this:



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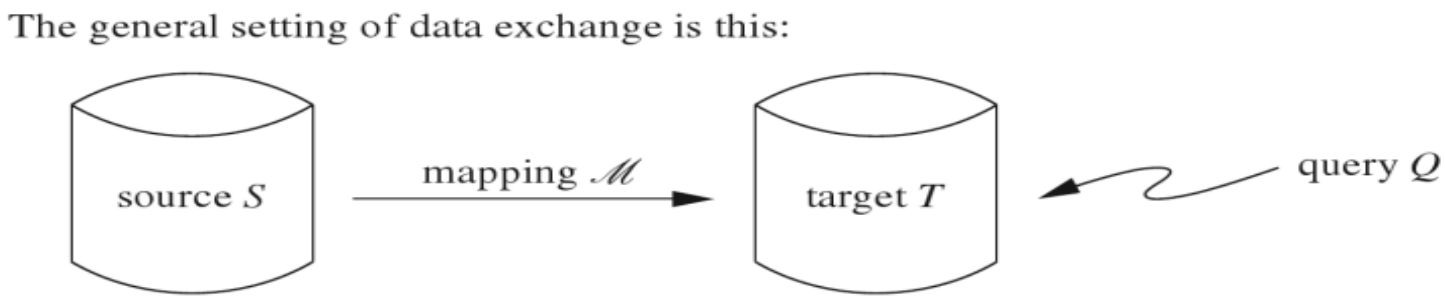

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Issues:

- what should happen when the *target* is more complex than the *source*?
- how do we answer queries over the target?

Information Integration

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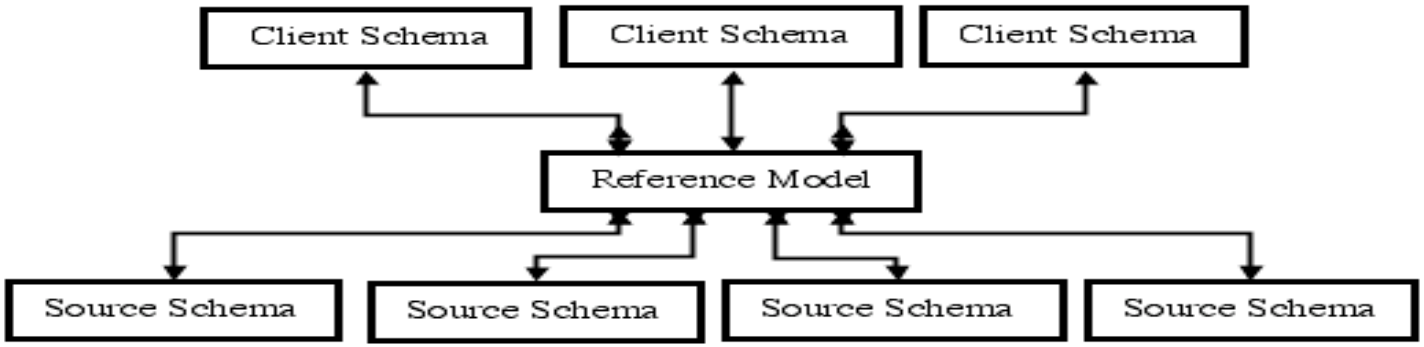
Data integration provides a uniform access to a set of data sources, through a unified representation called global schema. A mapping specifies the relationship between the global schema and the sources.



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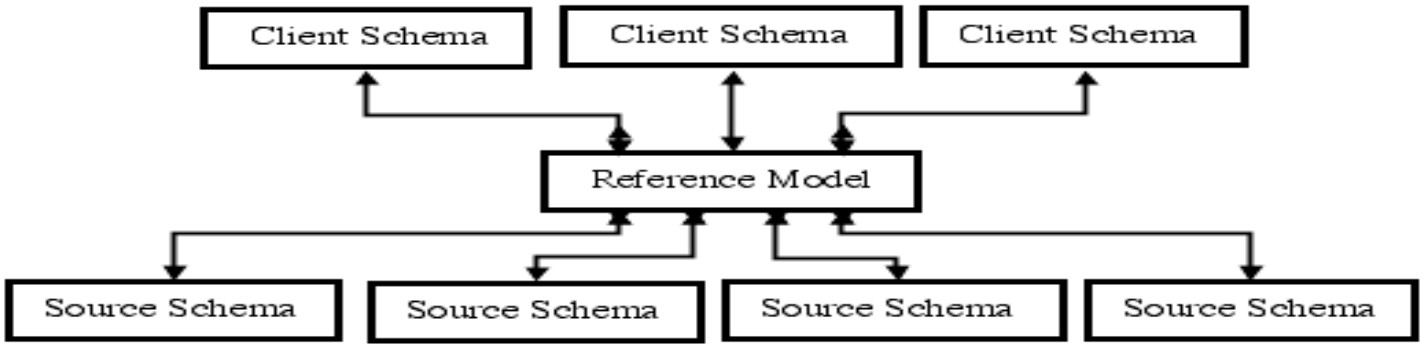

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Variants “which way do the arrows point” [Lenzerini]

GAV (global as a view), LAV (local as a view), and GLAV (“both ways”).

Common Threads and Issues

- In general two *schemas*: Conceptual/Logical and Physical
  - $\Rightarrow$ both endowed with *metadata* (vocabulary, . . .)
  - $\Rightarrow$ mappings connect the schemas
  - $\Rightarrow$ (source) data only “in” the *physical* schema
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- Issues to be formalized/fixed:
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  2. Language(s) for metadata and mappings
  3. (user level) Data representation
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  5. Algorithms/Execution model for queries: e.g., does *materialization* matter?

Phyical Data Independence: My Motivation

Goal: Application of the Ideas to Embedded Systems

1. High-level conceptual view of the system
2. High level query (and, eventually, update) language
3. Fine-grained physical schema description
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Challenge

The code generated from queries *must be competitive* with hand-written code.

LINUX-INFO System: Conceptual View

Example of LINUX-INFO data:

1. process (called) `gcc` is running;
2. `gcc`'s process number is 1234;
3. the user (id) running `gcc` is 145;
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Example of LINUX-INFO metadata:

5. There entities called `process` and `file`.
6. There are attributes called `pno`, `pname`, `uname`, and `fname`.
7. Each process entity has attributes `pno`, `pname` and `uname`.
8. Each file entity has attribute `fname`.
9. Processes are identified by their `pno`.
10. Files are identified by their `fname`.
11. There is a relationship `uses` between processes and files.

The LINUX-INFO System: Physical Design

A *physical design* for LINUX (selected by Linus Torvalds).

12. There are process records called `task-struct`.
13. Each `task-struct` record has record fields `pid`, `uid`, `comm`, and `fds`.
14. All `task-struct`s is organized as a tree data structure.
15. The `task-struct` records correspond one-to-one to `process` entities.
16. Record fields in `task-struct` encode the corresponding attribute values for `process` entities, for example, `pid` encodes an `pno`, etc.
17. Similarly, `fs`s correspond appropriately to (open) `file` entities.
18. `fds` field of `task-struct` is an array of `fd`s; a non-null entry in this array indicates that the `process` corresponding to this `task-struct` is using the `file` identified by the `name` field of the `fd` record in the array.

LINUX-INFO System: Queries and Query Plans

Back to Desiderata

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Is the plan correct?

. . . and how do/can we answer this question?

UNIFYING LOGIC-BASED APPROACH

Metadata and Signatures

Vocabularies: Relational Model for both Conceptual and Physical Schemata.

Conceptual/Logical (S_L):

predicate symbols $R_1/a_1, \ldots, R_k/a_k$ (a_i is the *arity* of R_i)

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a distinguished subset $S_A \subseteq S_P$ of *access paths*

- $\Rightarrow$ denote *capabilities to retrieve tuples* (i.e., data structures)
- $\Rightarrow$ (optionally) binding patterns (restrictions on tuple retrieval)
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... a standard way of defining interpretations

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Metadata: First-order sentences Σ over $S_L \cup S_P$.

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... we resort to fragments of FOL to gain better computational properties

Example: LINUX-INFO

Conceptual/Logical:

$$S_L = \{\, \texttt{process}/3, \texttt{file}/1, \texttt{uses}/2 \,\}$$

$$\Sigma_L = \{\, \texttt{process}(x, y_1, z_1) \wedge \texttt{process}(x, y_2, z_2) \rightarrow y_1 = y_2 \wedge z_1 = z_2,$$
$$\texttt{uses}(x, y) \rightarrow \exists z, w.\texttt{process}(x, z, w) \wedge \texttt{file}(y), \quad \ldots \quad \}$$

Physical:

$$S_A = \{\texttt{task\_struct}/1/0, \texttt{pid}/2/1, \texttt{uid}/2/1, \texttt{fds}/2/1, \texttt{fname}/2/1\}$$

$$\Sigma_P = \{\, \texttt{task\_struct}(x) \rightarrow \exists y, z, w.\texttt{pid}(x, y) \wedge \texttt{uid}(z) \wedge \texttt{fds}(x, w)$$
$$\texttt{pid}(x_1, y) \wedge \texttt{pid}(x_2, y) \rightarrow x_1 = x_1$$
$$\texttt{process}(x, y, z) \rightarrow \exists t.\texttt{task\_struct}(t) \wedge \texttt{pid}(t, x), \quad \ldots \quad \}$$

Queries and Answers

Queries: First-order formulae (φ) over S_L.

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Definition (Certain Answers)

$$\begin{aligned} \text{cert}_{\Sigma,D}(\varphi) &= \{\vec{a} \mid \Sigma \cup D \models \varphi(\vec{a})\} && \text{logical implication} \\ &= \bigcap_{I \models \Sigma \cup D} \{\vec{a} \mid I \models \varphi(\vec{a})\} && \text{answer in every model} \end{aligned}$$

The BAD News (and what can be done)

Theorem

"$\vec{a} \in \text{cert}_{\Sigma,D}(\varphi)$?" is undecidable.

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	S_L, Σ_L	S_P, Σ_P	queries
OBDA	(lite) TBox	ABox	CQ/UCQ
Data Exchange	target, target deps	source, st-tgds	CQ/UCQ
Information Integration	global view	local view, {G|L}AV	CQ/UCQ

What do Relational Systems do??

IDEA: "make it look like a single model"

(severely) restrict what logical schema may look like:

every logical predicate $P(\vec{x})$ must correspond 1-1 to *some* access path.

. . . conceptual/logical symbols in queries *are* (mere aliases of) access paths.

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IDEA-2: "only queries that think there is a single model"

A formula φ is *domain independent* if for all pairs of models I_1, I_2 of D and valuation θ we have

$$I_1, \theta \models \varphi \text{ if and only if } I_2, \theta \models \varphi.$$

. . . I_1 and I_2 can only differ in their *domains* (hence the name).

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Domain independent formulae can be evaluated in a model based on the *active domain of D* (set of individuals that appear in the access paths).

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A Turing machine T_φ

- read only input tape storing (an encoding of) $\vec{a}$ and D;
- read/write work tape storing a *counter* for each variable in φ ($\log |D|$ bits) and fixed number of auxiliary counters;
- a finite control that *implements* top-down satisfaction check w.r.t. a valuation defined by the current state of the counters
  $\Rightarrow$ used as pointers to individuals on the work tape.

A LOGSPACE Algorithm

IDEA

Domain independent formulae can be evaluated in a model based on the *active domain of D* (set of individuals that appear in the access paths).

. . . active domain of D is a *finite set*.

A Turing machine T_φ

- read only input tape storing (an encoding of) $\vec{a}$ and D;
- read/write work tape storing a *counter* for each variable in φ ($\log |D|$ bits) and fixed number of auxiliary counters;
- a finite control that *implements* top-down satisfaction check w.r.t. a valuation defined by the current state of the counters

  $\Rightarrow$ used as pointers to individuals on the work tape.

Theorem

$$\mathrm{cert}_{\Sigma,D}(\varphi) = \{\vec{a} \mid \langle \vec{a}, D \rangle \in \mathcal{L}(T_\varphi)\}.$$

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Bottom-up "Algebraic" Query Evaluation:

every production above maps (at least naively) to a algebraic operation on finite relations:

- scan (with renaming),
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Datalog (limited iteration)

additional predicates defined as a fixpoint positive query allows PTIME-complete problems.

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- practical (relational) systems: (almost) trivial instance of the framework.

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Plan of Lectures:

1. Classical OBDA: another way of gaining tractability (and its limits)
2. Database Approach Extension and Interpolation
3. Modeling Complex Physical Designs
4. Updates of Data and Future Directions