Uncertain Data Management
Boolean c-tables

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c-tables

Remember c-tables:

Member ⋈ Booking

id	date	teacher	class	room	
2	2016-11-28	$\texttt{NULL}_1$	UDM	$\texttt{NULL}_2$	
3	2016-12-05	$\texttt{NULL}_1$	UDM	$\texttt{NULL}_2$	
4	2016-12-12	$\texttt{NULL}_1$	UDM	$\texttt{NULL}_2$	*if $\texttt{NULL}_0$ is "UDM"*

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$\rightarrow$ Variant: Only allow NULLs in the conditions

NULLs in conditions

- The possible tuples are exactly the rows
- Each row may either be kept or deleted
  - $\rightarrow$ Depends on the condition

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- Each row may either be kept or deleted
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$\rightarrow$ Finite number of possible worlds
  - $\rightarrow$ at most 2^N if we have N rows

Example

Member ⋈ Booking

id	date	teacher	class	room	
2	2016-11-28	Antoine	UDM	C42	*if* $NULL_1$ *is "Antoine"*
3	2016-12-05	Antoine	UDM	C42	*if* $NULL_1$ *is "Antoine"*
4	2016-12-12	Antoine	UDM	C42	*if* $NULL_1$ *is "Antoine"*
2	2016-11-28	Silviu	UDM	C42	*if* $NULL_1$ *is "Silviu"*
3	2016-12-05	Silviu	UDM	C42	*if* $NULL_1$ *is "Silviu"*
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→ We can rewrite:

  - $x_i = x_j$ to $(x_i \wedge x_j) \vee (\neg x_i \wedge \neg x_j)$
  - $x_i \neq x_j$ to $(x_i \wedge \neg x_j) \vee (\neg x_i \wedge x_j)$

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→ We can rewrite:

  - $x_i = x_j$ to $(x_i \land x_j) \lor (\neg x_i \land \neg x_j)$
  - $x_i \neq x_j$ to $(x_i \land \neg x_j) \lor (\neg x_i \land x_j)$

→ The conditions become Boolean expressions

Expressiveness

Theorem

We can always rewrite a c-table having `NULL`s only in conditions to a Boolean c-table.

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Theorem

We can always rewrite a c-table having `NULL`s only in conditions to a Boolean c-table.

Proof: Two steps:

1. We can pick the `NULL`s in a finite domain
2. We can rewrite any finite domain to `True` and `False`

Step 1: Reducing to a finite domain

- We can choose among infinitely many values for the `NULL`s
- However, the values only appear in the conditions:
  - $\texttt{NULL}_i = \texttt{NULL}_j$
  - $\texttt{NULL}_i$ = “c”
  - Boolean combinations

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  - Boolean combinations
- We call two assignments of values to NULLs equivalent if all conditions evaluate to the same

Step 1: Reducing to a finite domain (example)

→ Call two assignments of values to `NULL`s equivalent if all conditions evaluate to the same.

Consider the following:

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- (x, c) with $x \neq c$
  → false, true
- (x, x) with $x \neq c$
  → true, false
- (y, x) with $x \neq c$ and $y \neq x$
  → false, false

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Lemma

For any c-table with `NULL`s only in conditions, its set of possible worlds is the same:

- *under the standard semantics*
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$\rightarrow$ For simplicity, let's pad $\mathcal{D}$ to have exactly 2^k values for some k

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- $\texttt{NULL}_7 = \texttt{NULL}_8$
  - $\rightarrow$ $x_7^1 = x_8^1$ and $x_7^2 = x_8^2$ and $x_7^3 = x_8^3$

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- $\texttt{NULL}_7 = \texttt{NULL}_8$
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$\rightarrow$ It suffices to study Boolean c-tables

Table of contents

Strong representation system

- Are Boolean c-tables a strong representation system for relational algebra? …

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  - $\rightarrow$ Yes!

Strong representation system

- Are Boolean c-tables a strong representation system for relational algebra? …

  $\rightarrow$ Yes!

  - $\rightarrow$ c-tables are a strong representation system
  - $\rightarrow$ `NULL`s will never appear by themselves outside of conditions

Capturing all uncertain relations

- Fix a finite set of possible tuples
- A possible world: a subset of the possible tuples
- An finite uncertain relation: (finite) set of possible worlds

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21	Antoine	Saphir
21	Silviu	Saphir
21	Silviu	C47
28	Antoine	Saphir
28	Antoine	C47
28	Silviu	Saphir

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→ Can we capture all finite uncertain relations?

Capturing finite uncertain relations

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01	
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v	**w**
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11

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Numbering tuples

For each tuple, write the possible worlds where it appears

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v	**w**	**v**	**w**	**v**	**w**	**v**	**w**
a	d	a	d	a	d	a	d
b	e	b	e	b	e	b	e
c	f	c	f	c	f	c	f

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00		01		10		11	
v	**w**	**v**	**w**	**v**	**w**	**v**	**w**
a	d	a	d	a	d	a	d
b	e	b	e	b	e	b	e
c	f	c	f	c	f	c	f

v	**w**				
a	d	00	01	10	11
b	e		01		
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- Create one non-Boolean variable
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- Obtain a non-Boolean c-table

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a	d	$\neg x_1 \wedge \neg x_2 \vee \neg x_1 \wedge x_2 \vee x_1 \wedge \neg x_2 \vee x_1 \wedge x_2$
b	e	$\neg x_1 \wedge x_2$
c	f	$\neg x_1 \wedge x_2 \vee x_1 \wedge \neg x_2 \vee x_1 \wedge x_2$

Conclusion

We have studied:

- First:
  - Codd tables with `NULL`s
  - v-tables with named `NULL`s
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  - Boolean c-tables: Boolean variables

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We have studied:

- First:
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  - v-tables with named `NULL`s
  - c-tables with named `NULL`s and conditions
- Then:
  - c-tables with `NULL`s only in conditions
  - Boolean c-tables: Boolean variables

We have shown:

→ Any c-table with `NULL`s only in conditions rewrites to a Boolean c-table

→ Boolean c-tables capture all finite uncertain relations

→ Boolean c-tables are a strong representation system

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References I

Abiteboul, S., Hull, R., and Vianu, V. (1995).
Foundations of Databases.
Addison-Wesley.
`http://webdam.inria.fr/Alice/pdfs/all.pdf`.

Suciu, D., Olteanu, D., Ré, C., and Koch, C. (2011).
Probabilistic Databases.
Morgan & Claypool.
Unavailable online.