Temporal Alignment

University of Zurich[UZH]

Anton Dignös, Michael H. Böhlen, and Johann Gamper

{adignoes, boehlen}@ifi.uzh.ch, gamper@inf.unibz.it

Freie Universität Bozen
Libera Università di Bolzano
Free University of Bozen · Bolzano

Goal and Approach

Goal: Reduction of temporal operators to nontemporal operators using adjustment of timestamps.

Problem Definition: Given a temporal operator ψ^T, and input relations $\mathbf{r}_1, \dots \mathbf{r}_n$, our goal is to express $\psi^T(\mathbf{r}_1, \dots \mathbf{r}_n)$ as follows:

$$\psi^T\left(\mathbf{r}_1, \dots \mathbf{r}_n\right) = \psi\left(\mathcal{P}^\mathcal{T}(\mathbf{r}_1, \dots \mathbf{r}_n), \dots \mathcal{P}^\mathcal{T}(\mathbf{r}_n, \dots \mathbf{r}_1)\right) \qquad \textbf{(reduction)}$$

where ψ is the nontemporal operator corresponding to ψ^T, and $\mathcal{P}^\mathcal{T}$ is a temporal primitive.

Solution:

- Two new algebra operators (primitives) for the adjustment of timestamps:
  - Temporal Splitter $\mathcal{N}$
  - Temporal Aligner ϕ
- Reduction rules for usage within nontemporal RA.
- Timestamp propagation for accessing original timestamps.

Key Points

Reduction rules that satisfy three key properties:

- Reducible to nontemporal queries on each snapshot.
  - $\forall t : \tau_t(\psi^T(\mathbf{D^T})) \equiv \psi(\tau_t(\mathbf{D^T}))$
- Original Timestamps are accessible.
  - $\forall t : \tau_t(\psi^T(\mathbf{D^T})) \equiv \psi(\tau_t(\epsilon(\mathbf{D^T})))$
- Interval boundaries of input are preserved.
  1. $\forall t \in z.T : \mathsf{L}[\psi^T(\mathbf{D^T})](z, t)$ is equal
  2. $z.T$ is maximal with respect to 1

where τ_t is the timeslice operator, ϵ propagates original timestamps, and $\mathsf{L}[\psi^T(\mathbf{D^T})](z, t)$ is the lineage set of result tuple z for $\psi^T(\mathbf{D^T})$ at time point t.

Example

Input: Manager M manages, employee N employed at department D during time T.

M

	M	I	T
m_1	Tom	DB	[Feb, Dec)

R

	N	D	T
r_1	Joe	DB	[Feb, Jul)
r_2	Ann	DB	[Feb, Sep)
r_3	Sam	AI	[May, Oct)

Query: Which employees has a manager been managing who have a shorter contract period than the manager?

Result: Temporal Left Outer Join $\mathbf{M} ⟕^T_{I=D \wedge DUR(\mathbf{M}.T)>DUR(\mathbf{R}.T)} \mathbf{R}$

M	I	N	T
Tom	DB	Joe	[Feb, Jul)
Tom	DB	Ann	[Feb, Sep)
Tom	DB	ω	[Sep, Dec)

Processing steps:

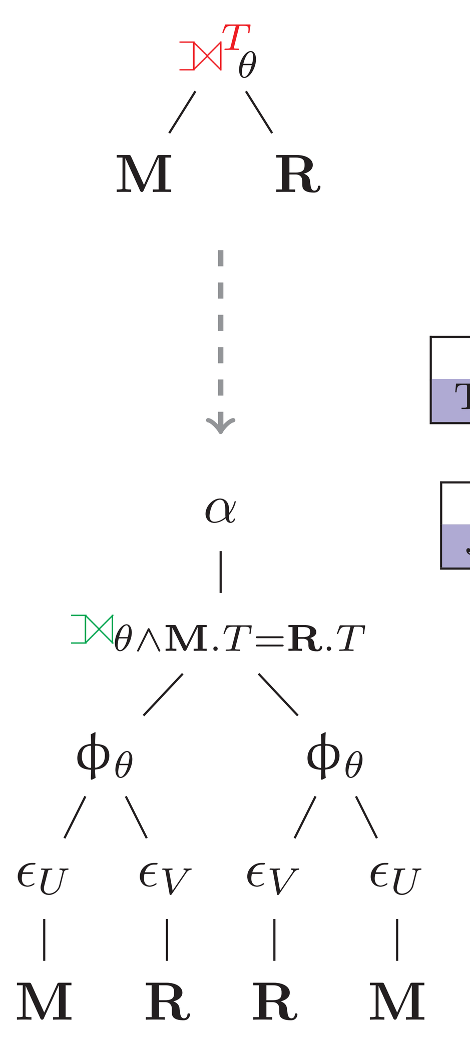
Query:
$\mathbf{M} ⟕^T_{I=D \wedge DUR(\mathbf{M}.T)>DUR(\mathbf{R}.T)} \mathbf{R}$

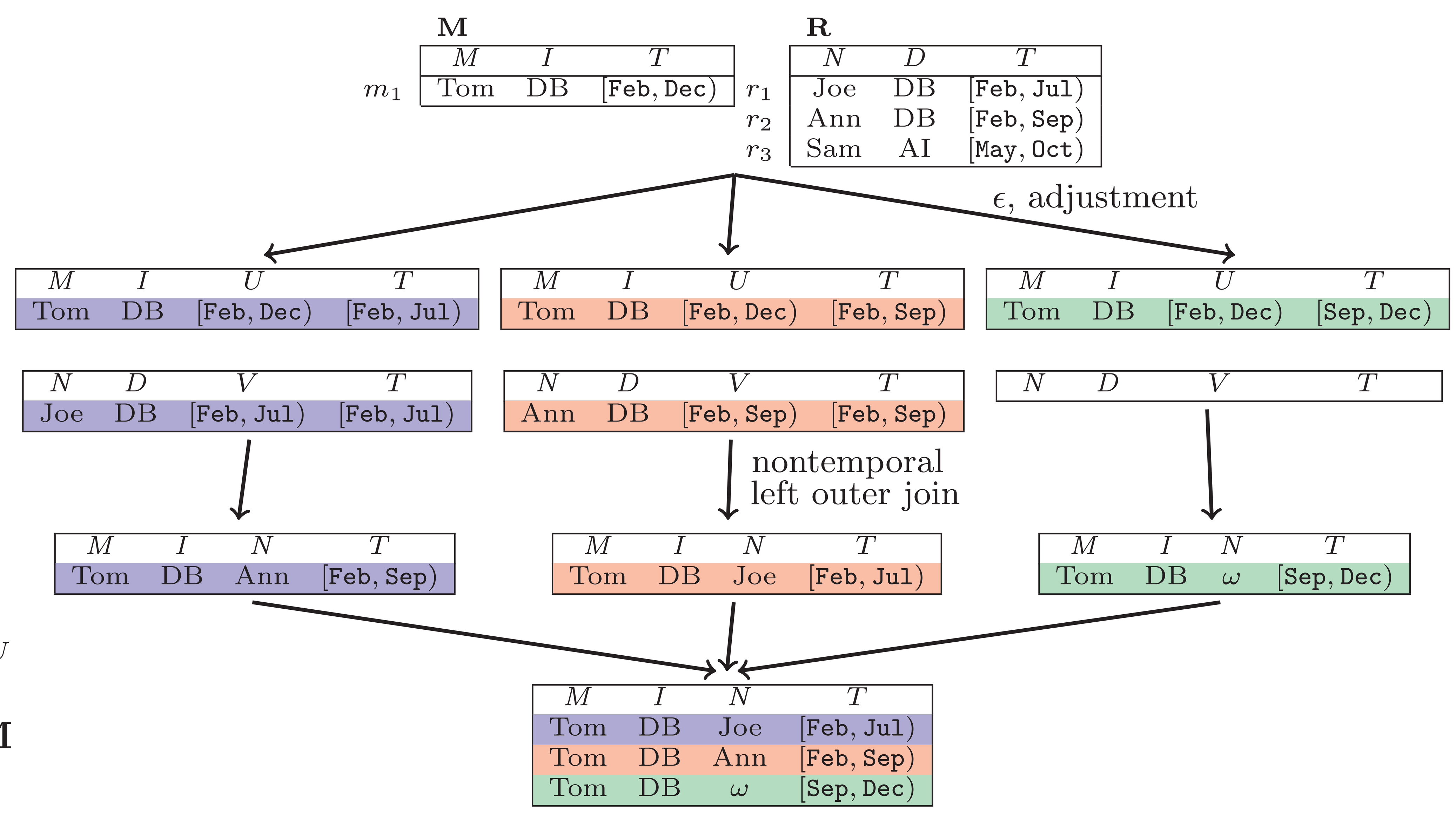
1. Timestamp propagation:
$\epsilon_U(\mathbf{M}) ⟕^T_{I=D \wedge DUR(\mathbf{M}.T)>DUR(\mathbf{R}.T)} \epsilon_V(\mathbf{R})$

2. Timestamp substitution:
$\epsilon_U(\mathbf{M}) ⟕^T_{I=D \wedge DUR(U)>DUR(V)} \epsilon_V(\mathbf{R})$

3. Temporal adjustment:
$\mathbf{M}' \leftarrow \phi_\theta(\epsilon_U(\mathbf{M}), \epsilon_V(\mathbf{R}))$
$\mathbf{R}' \leftarrow \phi_\theta(\epsilon_V(\mathbf{R}), \epsilon_U(\mathbf{M}))$

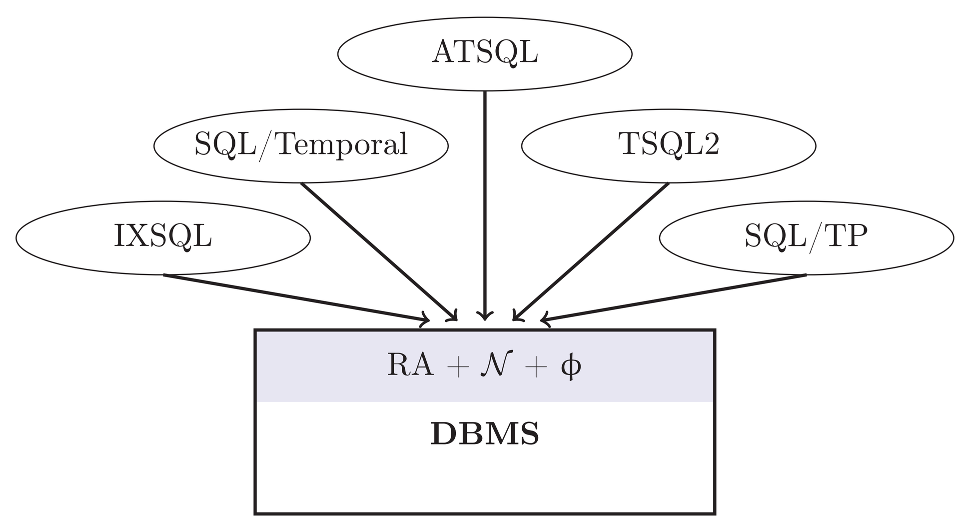
4. Reduction:
$\alpha(\mathbf{M}' ⟕_{\theta \wedge \mathbf{M}.T=\mathbf{R}.T} \mathbf{R}')$





Implementation

Operator		Reduction
$\sigma^T_\theta(\mathbf{r})$	$=$	$\sigma_\theta(\mathbf{r})$
$\pi^T_\mathbf{B}(\mathbf{r})$	$=$	$\pi_{\mathbf{B},T}(\mathcal{N}_\mathbf{B}(\mathbf{r}, \mathbf{r}))$
$_\mathbf{B}\vartheta^T_F(\mathbf{r})$	$=$	$_{\mathbf{B},T}\vartheta_F(\mathcal{N}_\mathbf{B}(\mathbf{r}, \mathbf{r}))$
$\mathbf{r} -^T \mathbf{s}$	$=$	$\mathcal{N}_\mathbf{A}(\mathbf{r}, \mathbf{s}) - \mathcal{N}_\mathbf{A}(\mathbf{s}, \mathbf{r})$
$\mathbf{r} \cup^T \mathbf{s}$	$=$	$\mathcal{N}_\mathbf{A}(\mathbf{r}, \mathbf{s}) \cup \mathcal{N}_\mathbf{A}(\mathbf{s}, \mathbf{r})$
$\mathbf{r} \cap^T \mathbf{s}$	$=$	$\mathcal{N}_\mathbf{A}(\mathbf{r}, \mathbf{s}) \cap \mathcal{N}_\mathbf{A}(\mathbf{s}, \mathbf{r})$
$\mathbf{r} \times^T \mathbf{s}$	$=$	$\alpha(\phi_\top(\mathbf{r}, \mathbf{s}) \bowtie_{\mathbf{r}.T=\mathbf{s}.T} \phi_\top(\mathbf{s}, \mathbf{r}))$
$\mathbf{r} \bowtie^T_\theta \mathbf{s}$	$=$	$\alpha(\phi_\theta(\mathbf{r}, \mathbf{s}) \bowtie_{\theta \wedge \mathbf{r}.T=\mathbf{s}.T} \phi_\theta(\mathbf{s}, \mathbf{r}))$
$\mathbf{r} ⟕^T_\theta \mathbf{s}$	$=$	$\alpha(\phi_\theta(\mathbf{r}, \mathbf{s}) ⟕_{\theta \wedge \mathbf{r}.T=\mathbf{s}.T} \phi_\theta(\mathbf{s}, \mathbf{r}))$
$\mathbf{r} ⟖^T_\theta \mathbf{s}$	$=$	$\alpha(\phi_\theta(\mathbf{r}, \mathbf{s}) ⟖_{\theta \wedge \mathbf{r}.T=\mathbf{s}.T} \phi_\theta(\mathbf{s}, \mathbf{r}))$
$\mathbf{r} ⟗^T_\theta \mathbf{s}$	$=$	$\alpha(\phi_\theta(\mathbf{r}, \mathbf{s}) ⟗_{\theta \wedge \mathbf{r}.T=\mathbf{s}.T} \phi_\theta(\mathbf{s}, \mathbf{r}))$
$\mathbf{r} \triangleright^T_\theta \mathbf{s}$	$=$	$\phi_\theta(\mathbf{r}, \mathbf{s}) \triangleright_{\theta \wedge \mathbf{r}.T=\mathbf{s}.T} \phi_\theta(\mathbf{s}, \mathbf{r})$



$\epsilon_U(\mathbf{r})$: `SELECT Ts Us, Te Ue, * FROM r`

$\mathcal{N}_\mathbf{B}(\mathbf{r}, \mathbf{s})$: `FROM (r NORMALIZE s USING(B)) r`

$\phi_\theta(\mathbf{r}, \mathbf{s})$: `FROM (r ALIGN s ON` θ`) r`

$\alpha(\mathbf{r})$: `SELECT ABSORB * FROM r`

http://www.ifi.uzh.ch/dbtg/research/align.html

Summary

- Algebraic basis for temporal operators.
- Reduction of temporal operators to nontemporal operators.
- Deep integration into PostgreSQL kernel.

Future Work

- Optimization/equivalence rules for temporal primitives.
- Extensions towards time depended (malleable) quantities.
- Extension to bag algebra.

Published in: *Proceedings of the 38th ACM SIGMOD International Conference on Management of Data*, Scottsdale, Arizona, USA, May 2012.