Efficient Analysis and Execution of Correct and Complete Model Transformations **Based on Triple Graph Grammars**

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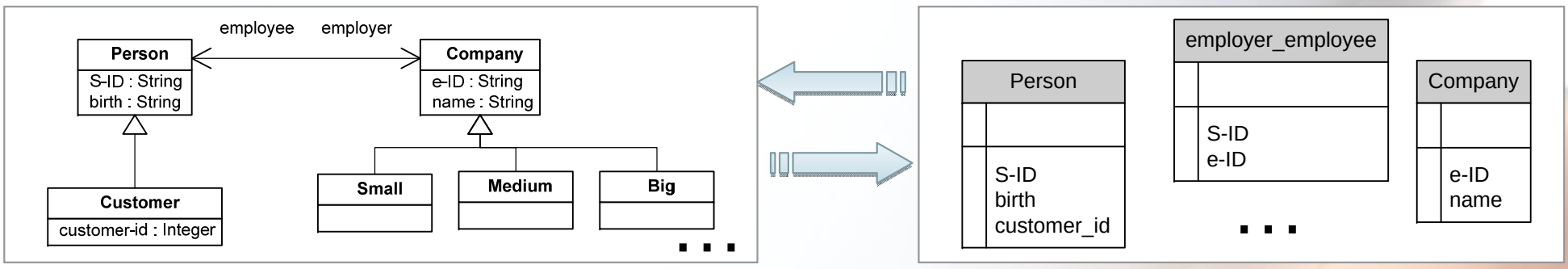
Outline

1. Motivation
2. Triple Graph Grammars with NACs
3. Main Results:
   - Correctness, Completeness, Termination
   - Verification of Functional Behaviour
   - Reduction / Elimination of Backtracking
   - Automated Tool Support
4. Conclusion and Future Work

Motivation

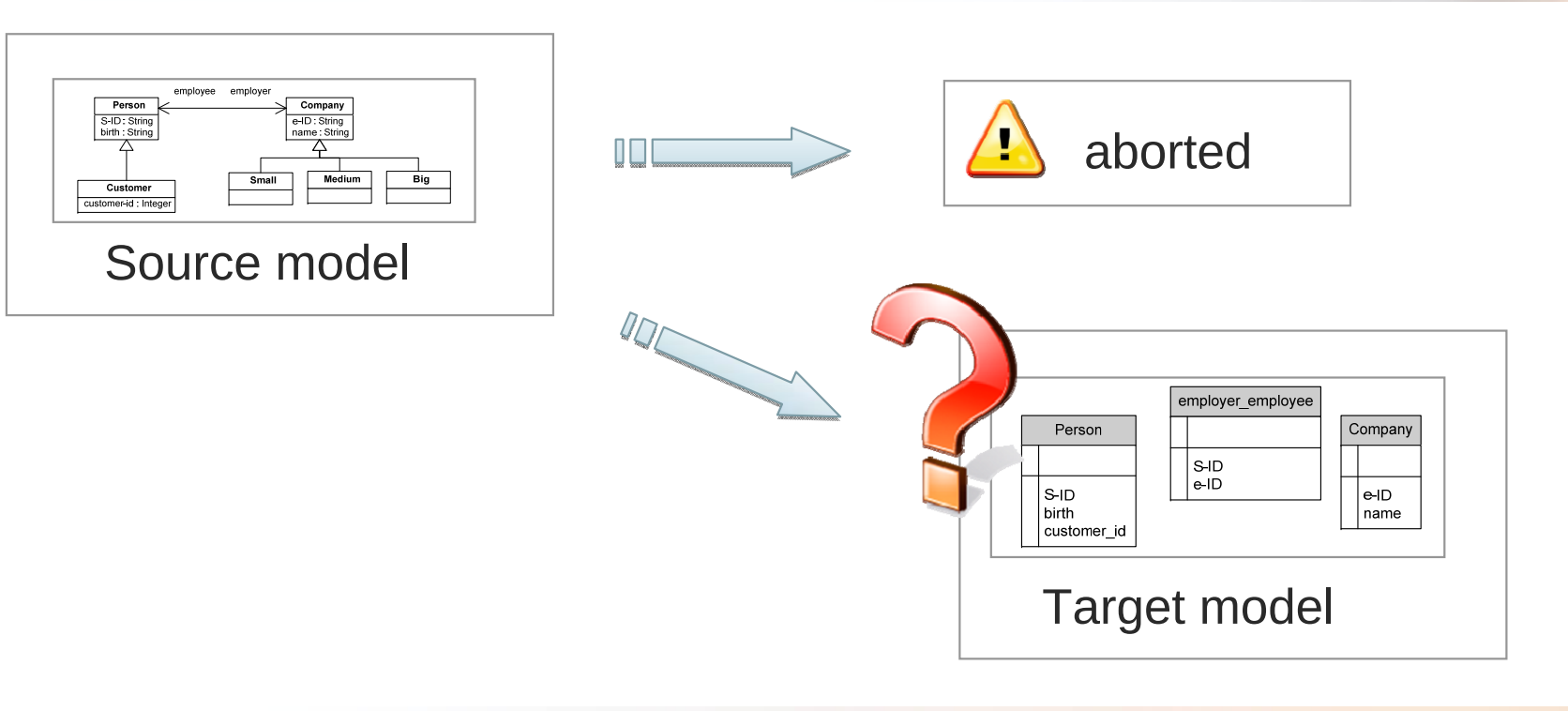
- Correct, Complete and Efficient Model Transformations



- Triple Graph Grammars:
  - Bidirectional Model Transformations [Schürr94, SK08]
  - Derived Forward & Backward Transformation Rules [Schürr94]
  - Formal results: Correctness, Completeness, Termination [EEHP09]
  - Powerful Control Mechanisms [EEE+07], [EEHP09], [GEH10]
  - Basis for Incremental Model Synchronization [GW09]

Efficiency

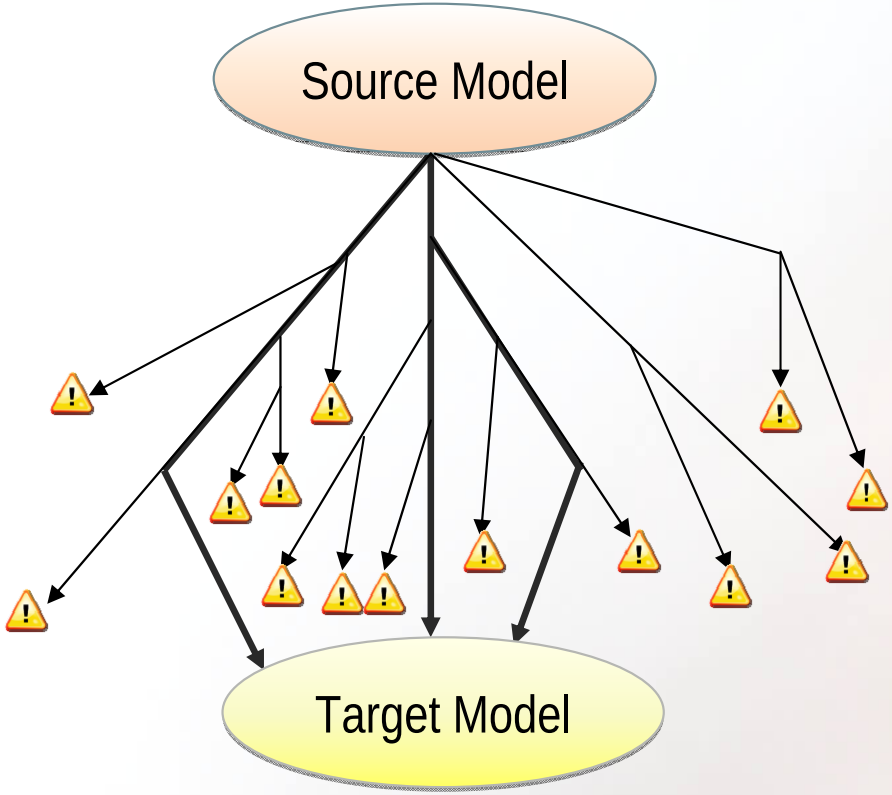
- **Question:** How to improve efficiency of correct and **complete** model transformations?



- In general, **backtracking** is necessary for ensuring completeness! This means exponential complexity!

Efficiency (2)

- **Aim:** Avoid Backtracking, if possible.
- **Requirement:** Tool support for a **static analysis** and **optimization** of the model tranformation rules to **reduce or avoid backtracking**



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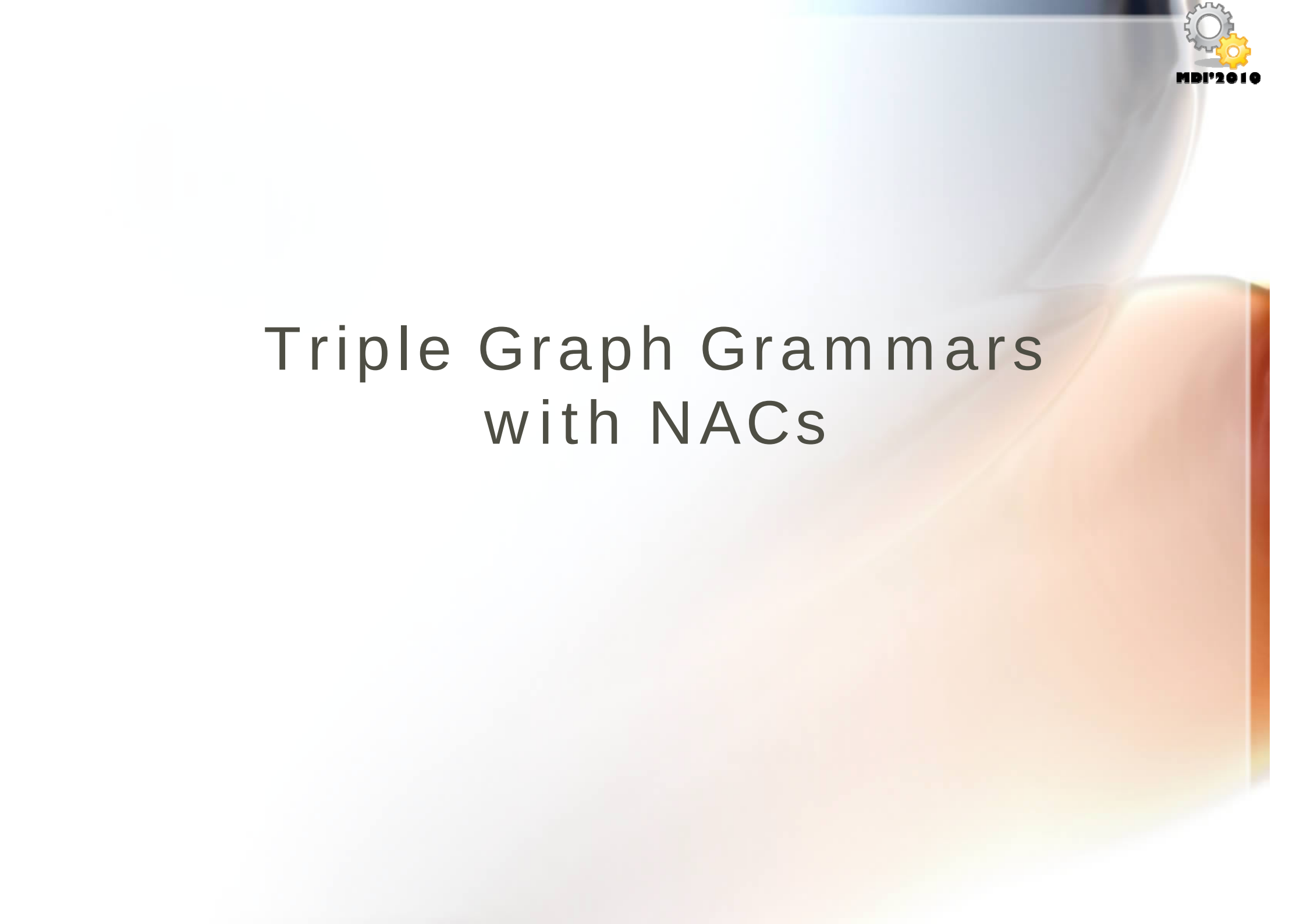
Theoretical Foundation:

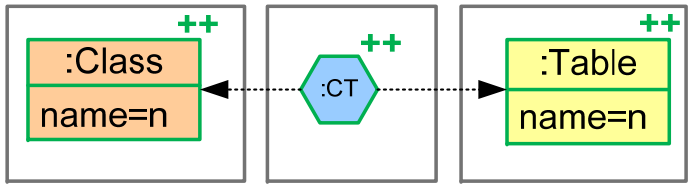
Analysis of
Functional Behaviour
=
unique results



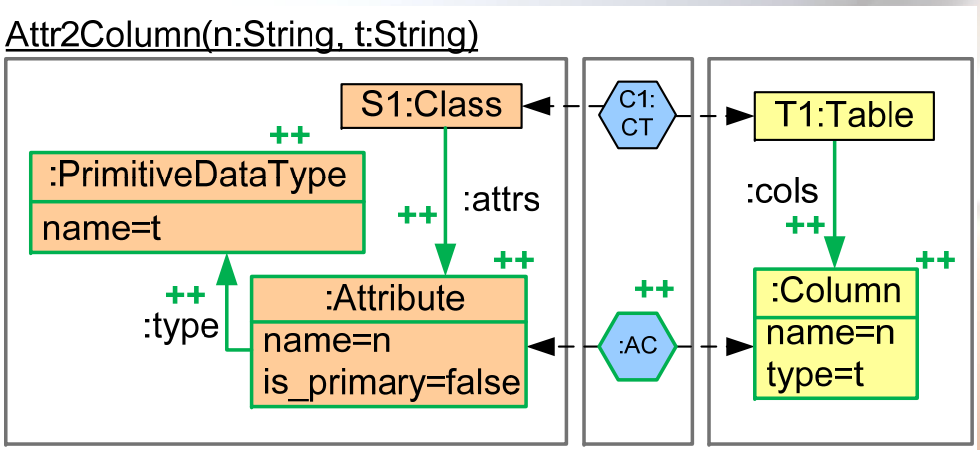
Triple Graph Grammars with NACs

4 Triple Rules of *CD2RDBM*

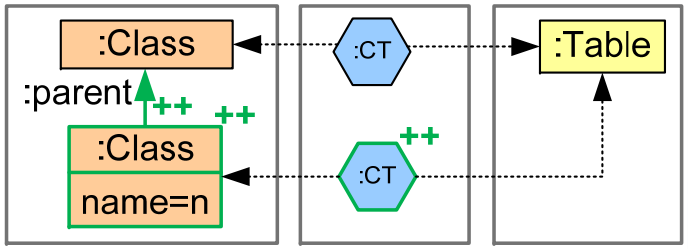
Class2Table(n:String)



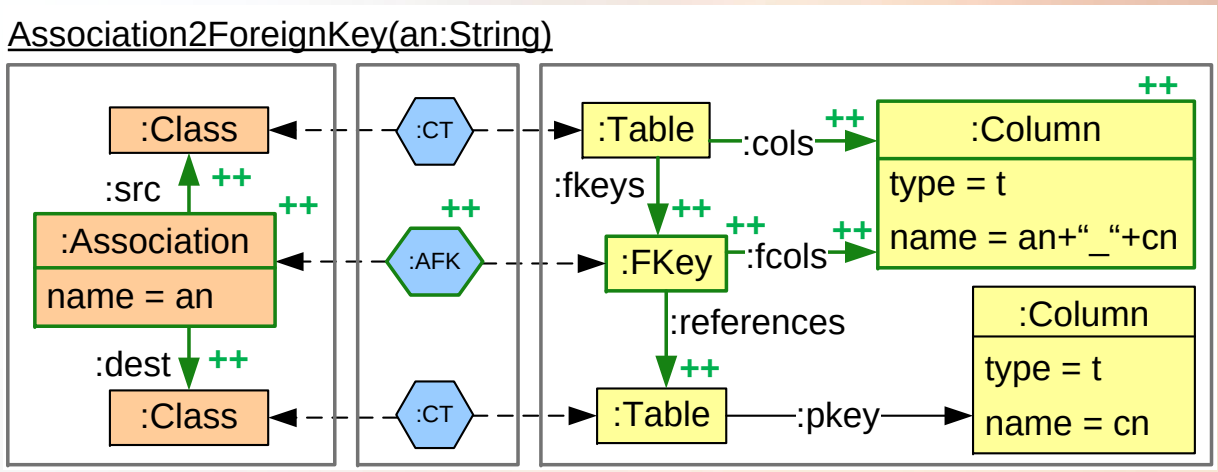
Attr2Column(n:String, t:String)



Subclass2Table(n:String)

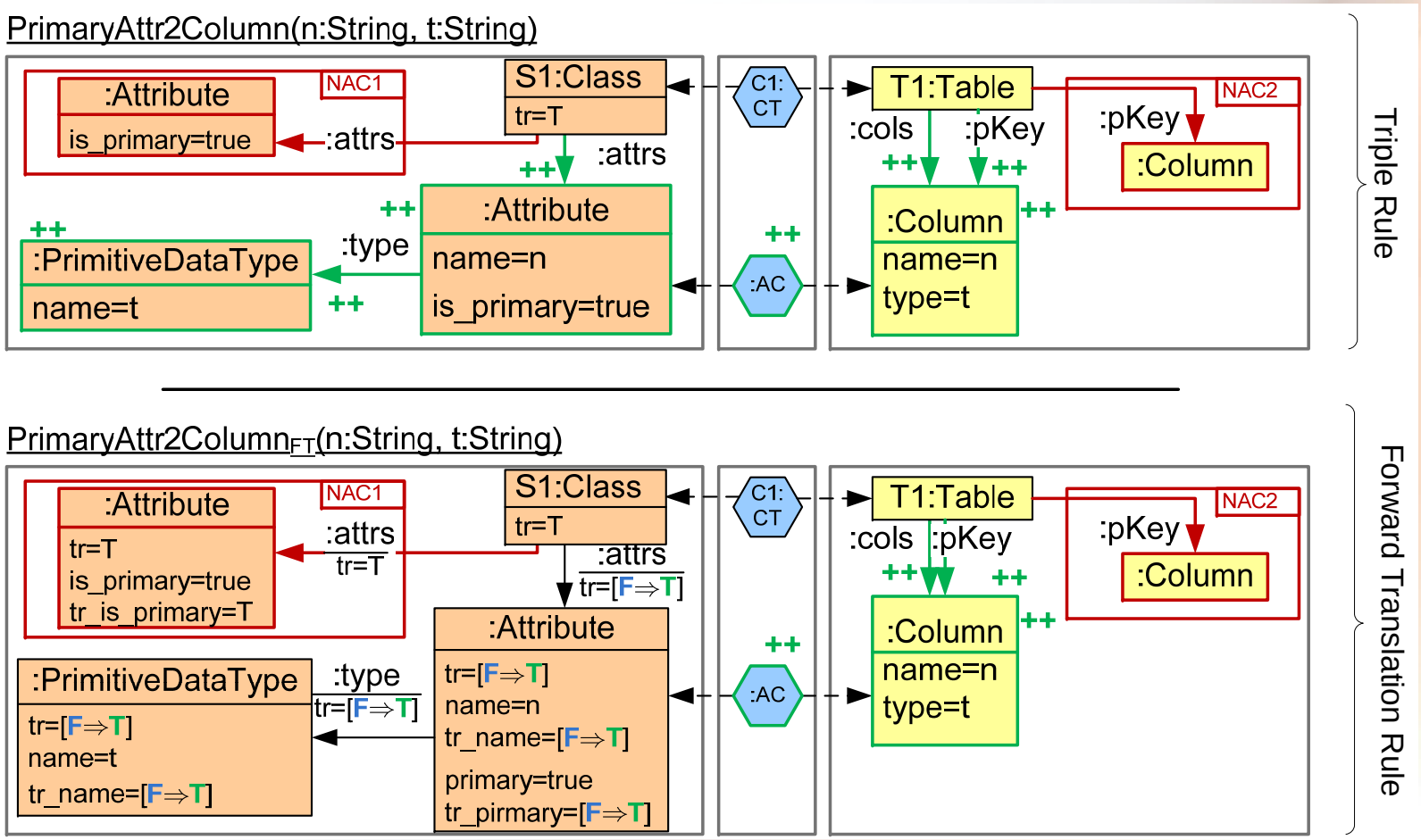


Association2ForeignKey(an:String)



Derived Forward Translation Rule

- modified source component:
  - identic on structure
  - translation attributes tr=[F ⇒ T] for parsing



Model transformation based on FT-rules

- $MT : VL_S \Rrightarrow VL_T$
  defined by complete forward translation sequences
  via FT-Rules:

$$(G_S,\ G'_0 \overset{tr^*_{FT}}{\Longrightarrow} G'_n, G_T)$$

$$G'_0 = (Att^{\mathbf{F}}(G_S) \leftarrow \varnothing \rightarrow \varnothing)$$
$$G'_n = (Att^{\mathbf{T}}(G_S) \leftarrow G_C \rightarrow G_T)$$

- Termination: No further FT-rule is applicable

Main Results

Main Results (1)

Theorem (Termination)

MT terminating, if each FT-rule changes at least one tr-attribute: tr=[**F** $\Rightarrow$ **T**]

Theorem (Correctness)

$\forall$ MT-sequences: $(G_S,\ G'_0 \overset{tr^*_{FT}}{\Longrightarrow} G'_n, G_T)$

$\exists\, G \in VL$, s.t. G=$(G_S \leftarrow G_C \rightarrow G_T)$

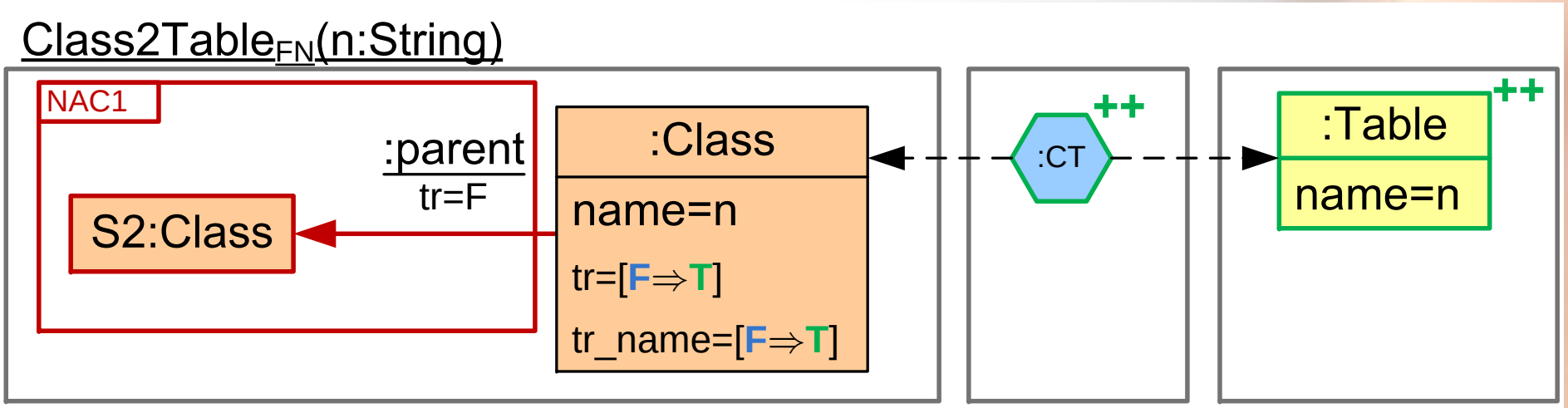
Theorem (Completeness)

$\forall\, G_S \in VL_S\ \exists$ MT-seuqence $(G_S,\ G'_0 \overset{tr^*_{FT}}{\Longrightarrow} G'_n, G_T)$

$\forall\, G_T \in VL_T\ \exists$ MT-seuqence $(G_S,\ G'_0 \overset{tr^*_{FT}}{\Longrightarrow} G'_n, G_T)$

Reduction of Backtracking

- **Misleading Graph:** cannot be completely translated in any context
- **Filter NAC:** extends LHS by a graph that would be transformed by the rule to a misleading graph



- **Generation of Filter NACs:**
  - Atomated static generation
  - Dynamic generation based on CPA engine in AGG

Main Results (2): Functional Behaviour

Theorem (Functional Behaviour)

Given MT based on FT-rules that are extended by Filter NACs, s.t. **all critical pairs are strictly confluent** and MT is terminating. Then:

- MT based on $\mathbf{TR_{FT}}$ (or $\mathbf{TR_{FN}}$) has **functional behaviour,** ie. unique result for each given source model
- MT based on $\mathbf{TR_{FN}}$ **does not require backtracking**

Analysis

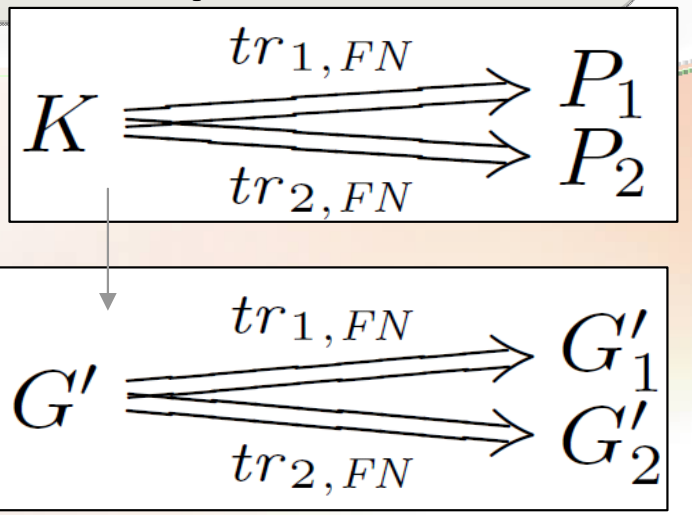
1. Flattening of FT-Rules TR_{FN} to Flat(TR_{FN}) [EEH08]
2. Critical Pair Analysis of Flat(TR_{FN}) using the tool support by AGG

Main Results (3): Functional Behaviour

Theorem (Strong Functional Behaviour)

Given MT based on FT-rules with Filter NACs TR_{FN}, s.t. MT is terminating. Then:

MT has strong **functional behaviour**
(unique trafo sequences up to sw-equivalence) and
does not require backtracking
iff
TR_{FN} has no **significant critical pair**



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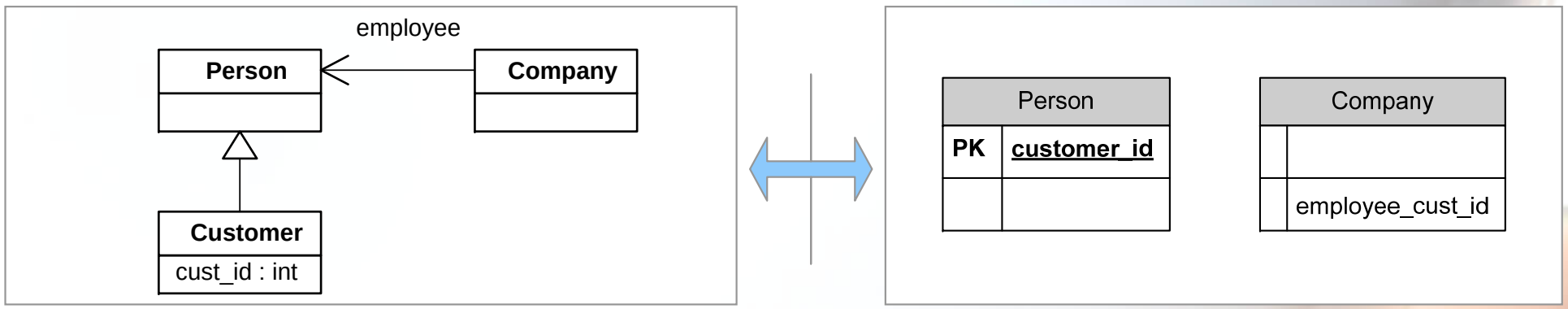
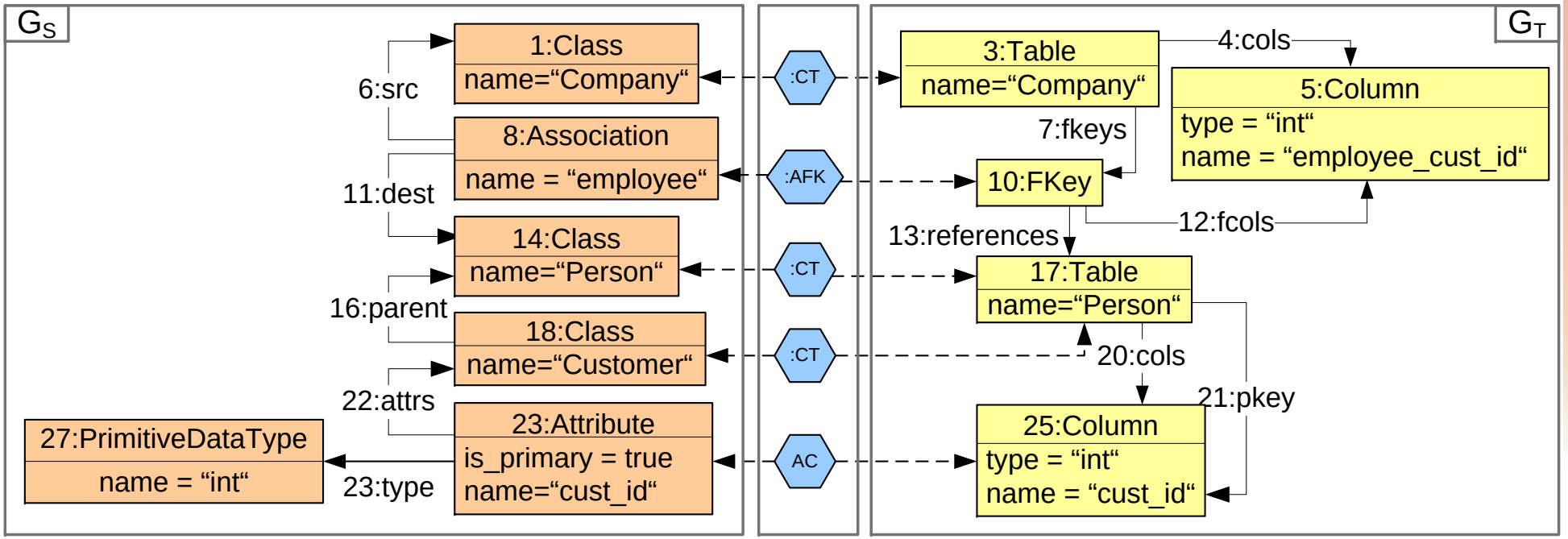
Analysis: as before with AGG

Example: Model Trafo



concrete syntax

abstract syntax



Benchmark

Model Size	Model Transformation Sequences of CD2RDBM				
	without Filter NACs		with Filter NACs		
	Time[1)]	Success Rate	Time[1)]	Overhead	Success Rate
[Elements[2)]]	[ms]	[%]	[ms]	[%]	[%]
11	143.75	42.86	158.33	10.14	100.00
25	302.75	16.84	335.45	10.80	100.00
53	672.68	3.94	742.62	10.40	100.00
109	1,481.43	0.17	1,584.86	6.98	100.00

1) Average time of 100 successful model transformation sequences

2) Nodes and Edges

- **Overhead of Filter NACs: fairly small**
- **Without Filter NACs: backtracking** is necessary and will cause a **huge overhead** even when using highly optimized partial order reduction techniques

Conclusion

Important new results for Bidirectional Model Transformations based on TGGs:

- Analysis of
  - **Functional Behaviour:** unique Target Models
  - **Strong Functional Behaviour:** Unique Trafo Sequences
- Reduction / Elimination of **Backtracking** by **Filter NACs**
- All results (correctness, completeness, termination) are preserved for execution in **standard GraTra tools**

Future work:

- Functional Behaviour up to Semantic Equivalence
- Further automated techniques for the Generation of Filter NACs
- Checking of Significance of Critical Pairs
- Combination with Partial Order Reduction Techniques

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