On-the-Fly Construction, Correctness and Completeness of Model Transformations based on Triple Graph Grammars

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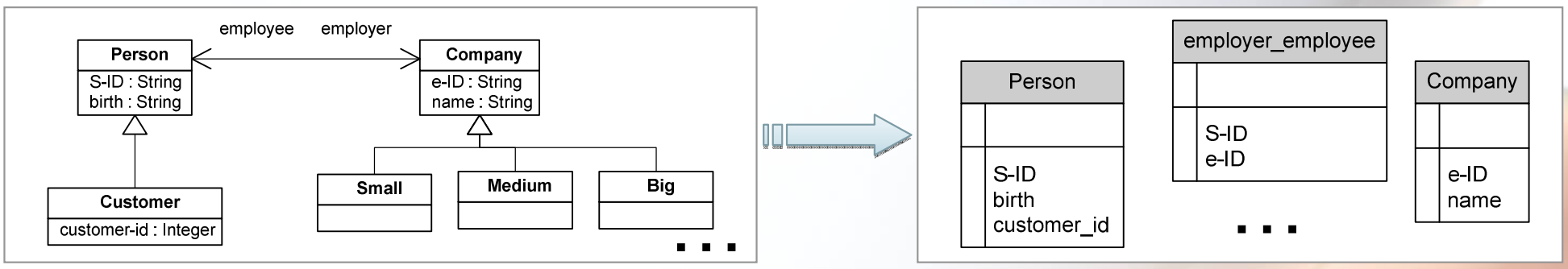
Outline

1. Motivation
2. Triple Graph Grammars with NACs
3. Main Results:
   - On-the-fly construction
   - Termination
   - Correctness and Completeness
   - Partial Order Reduction
4. Conclusion and Future Work

Motivation

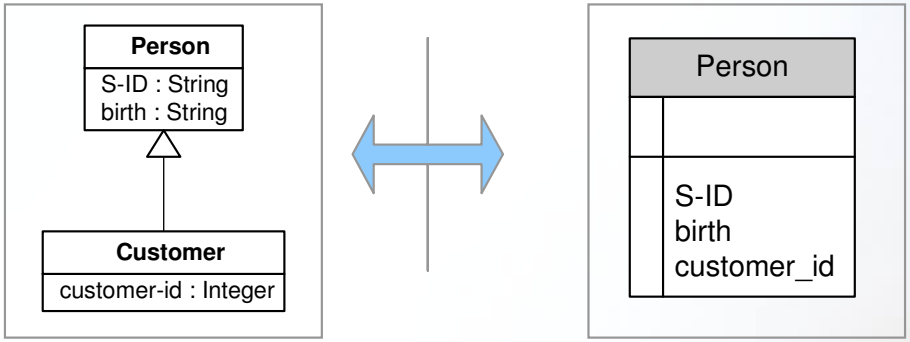
- Correct and Efficient Model Transformations



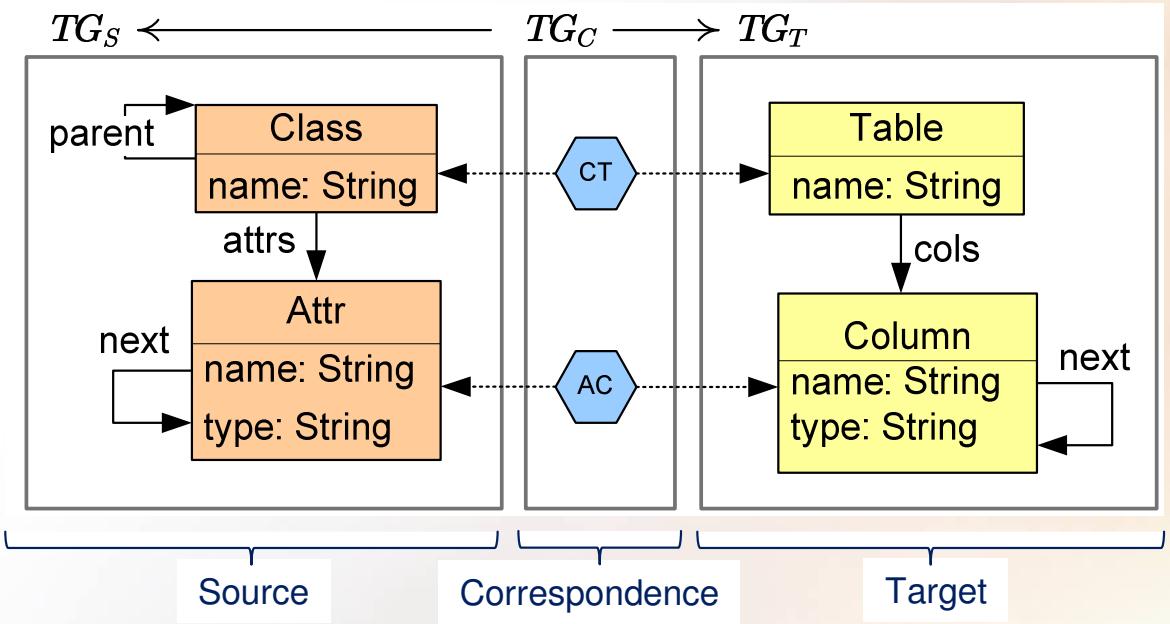
- **Triple Graph Grammars:**
  - Bidirectional Model transformations [Schürr94, SK08]
  - Derived Forward & Backward Transformation Rules [Schürr94]
  - Formal results for Correctness and Completeness [EEH08,EHS09]
  - Control Mechanisms:
    - Negative Application Conditions (NACs) [EHS09]
    - Source Consistency [EEE+07]

Example: CD2RDBM

- Relationship of instances in concrete syntax:



- Type graph in abstract syntax:



Triple Graph Grammars with NACs

Triple graphs and triple rules

- Graph $G = (V, E, s, t)$
- Category **TripleGraphs**
  - triple graph: $G = (G^S \xleftarrow{s_G} G^C \xrightarrow{t_G} G^T)$
  - triple graph morphism:

$$tr = (tr^S, tr^C, tr^T): L \to R$$

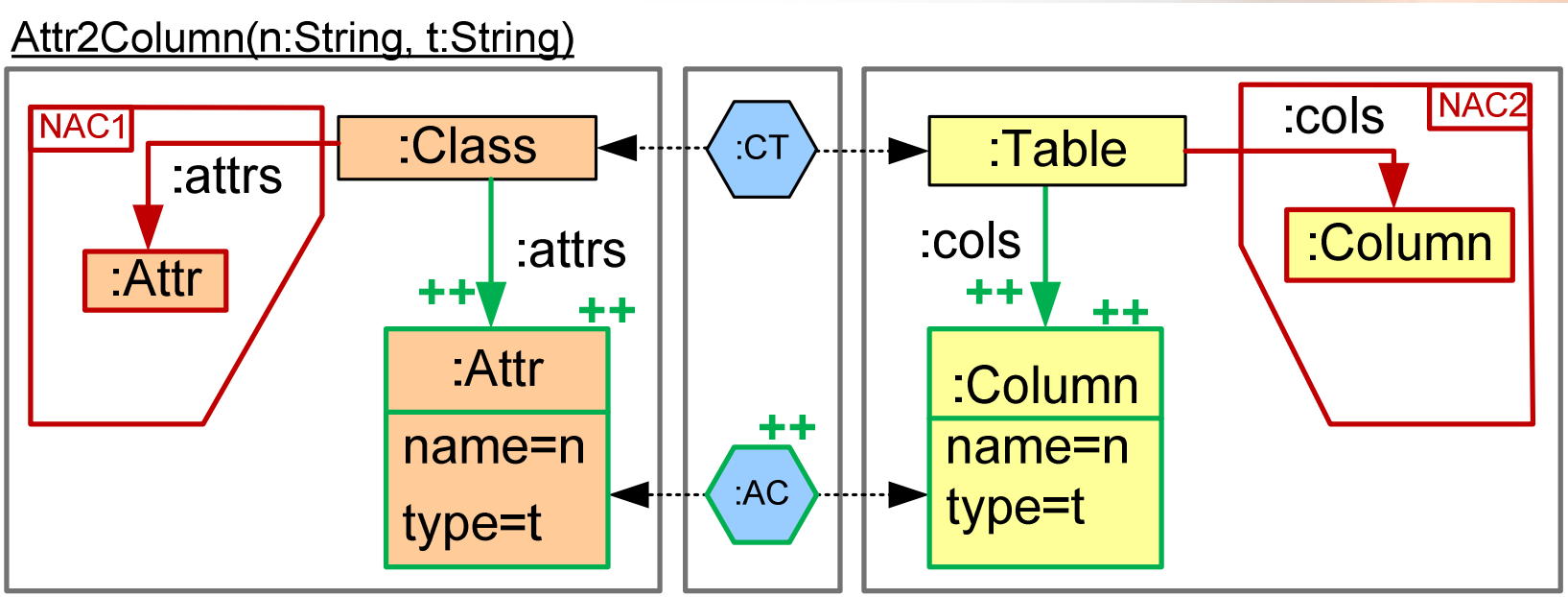
$$\begin{array}{ccccc} L = (L^S & \xleftarrow{s_L} & L^C & \xrightarrow{t_L} & L^T) \\ tr\downarrow \quad tr^S\downarrow & & tr^C\downarrow & & tr^T\downarrow \\ R = (R^S & \xleftarrow[s_R]{} & R^C & \xrightarrow[t_R]{} & R^T) \end{array}$$

- Triple rule is injective triple graph morphism: $tr: L \to R$

  $\Rightarrow$ Rules are nondeleting

  specified for synchronous creation of model elements in source and target language

Triple Rules of *CD2RDBM*

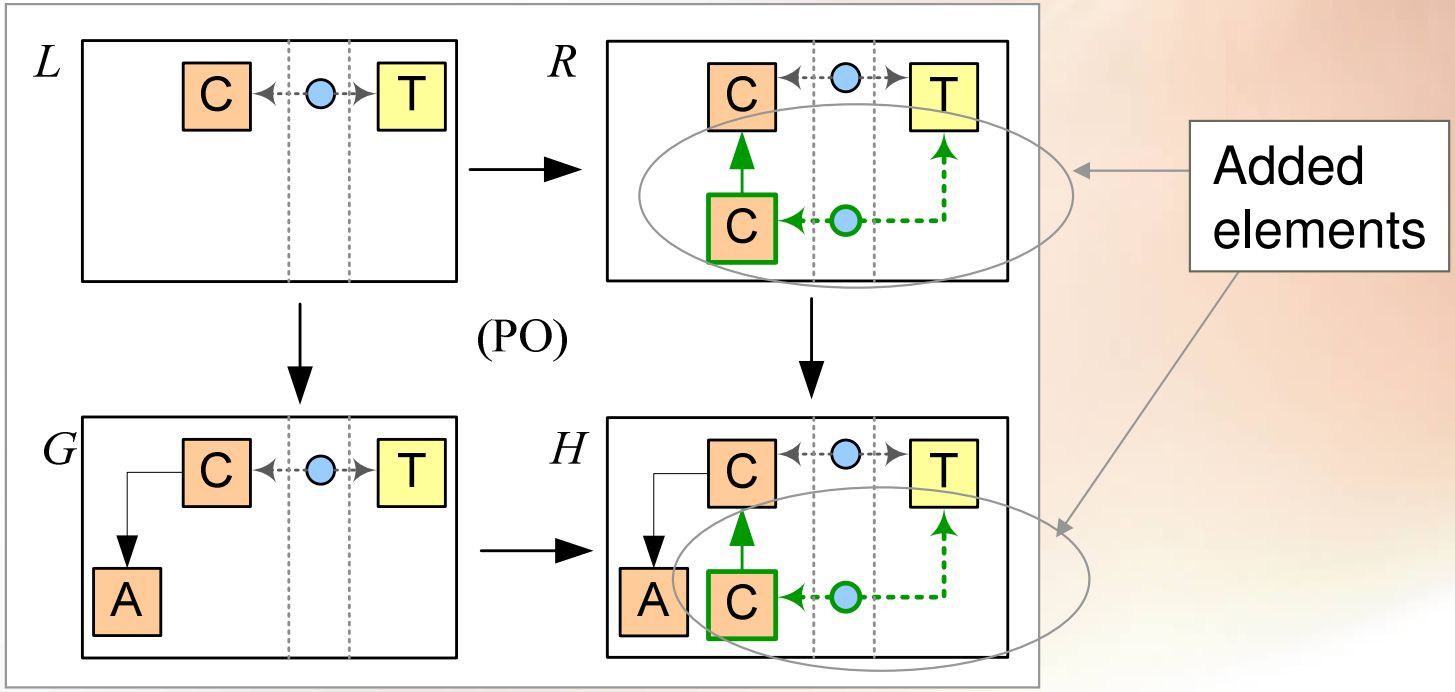


Triple Graph Transformation

- Transformation: $G \overset{tr,m,n}{\Longrightarrow} H$
  - injective match m
  - PO in **TripleGraphs**
  - H is gluing of R and G along L

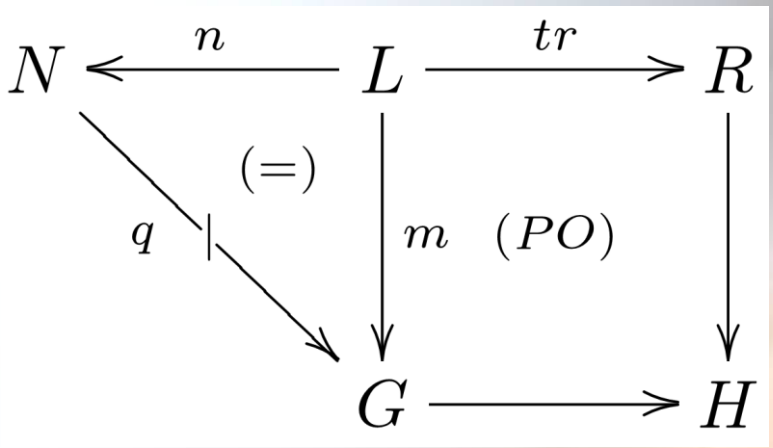
$$\begin{array}{ccc} L & \xrightarrow{tr} & R \\ {\scriptstyle m}\downarrow & (PO) & \downarrow{\scriptstyle n} \\ G & \xrightarrow[t]{} & H \end{array}$$

- Example:



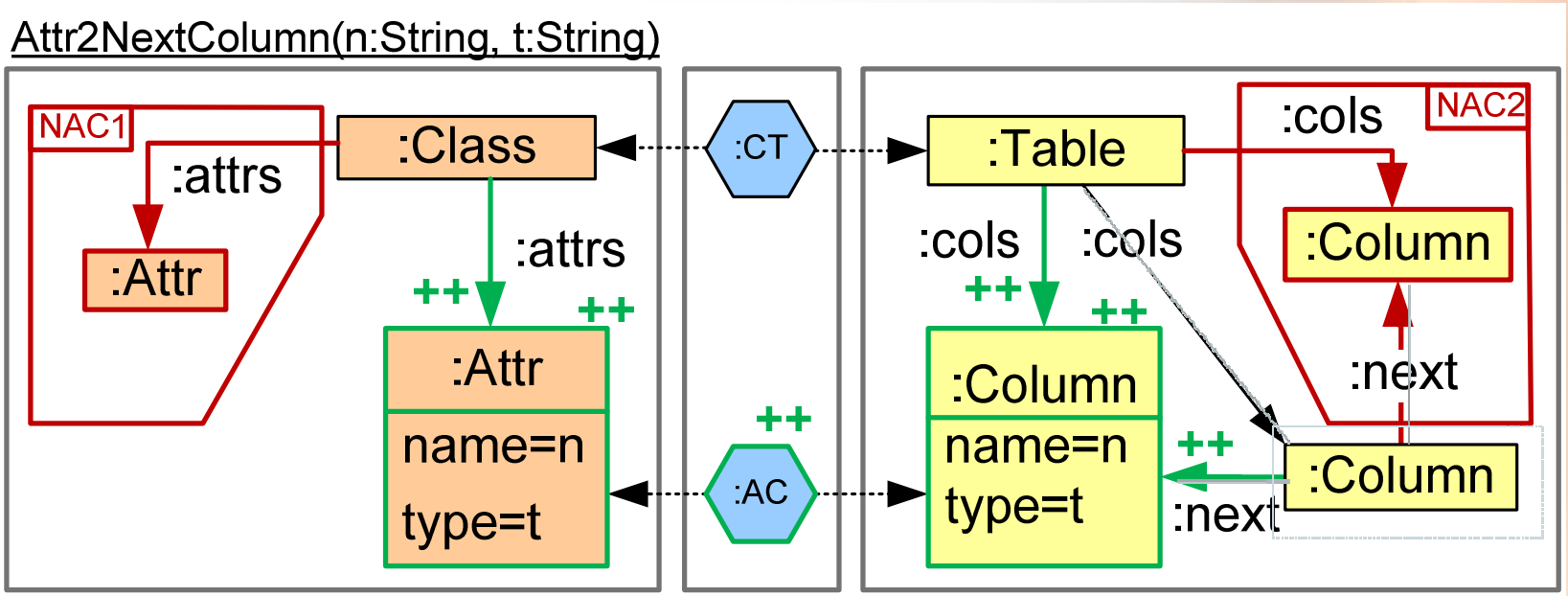
Negative Application Conditions

- **General NAC** (n,N):
  n: $L \to N$ is injective
  triple graph morphism

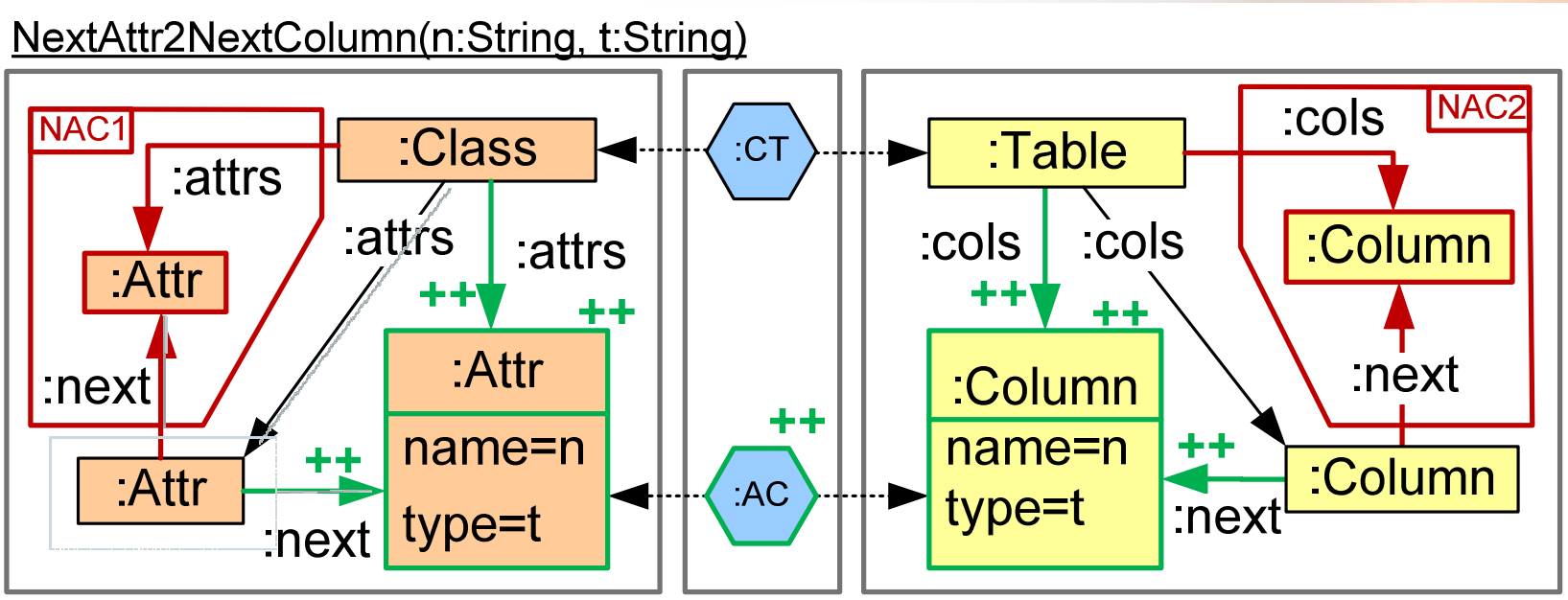


- Match m: $L \to G$ is **NAC consistent:** $\nexists$ injective q: $N \to G$ s. t. $q \circ n = m$ for all NACs of tr
- **Source NAC** (n,N): $n=(n^S, id_{L^C}, id_{L^T})$, i.e. NAC on source component only
- **Target NAC** (n,N): $n=(id_{L^S}, id_{L^C}, n^T)$, i.e. NAC on target component only
- In most cases: Source-Target NACs sufficient

Triple Rules of *CD2RDBM*



Triple Rules of *CD2RDBM*



Derived Source Rule

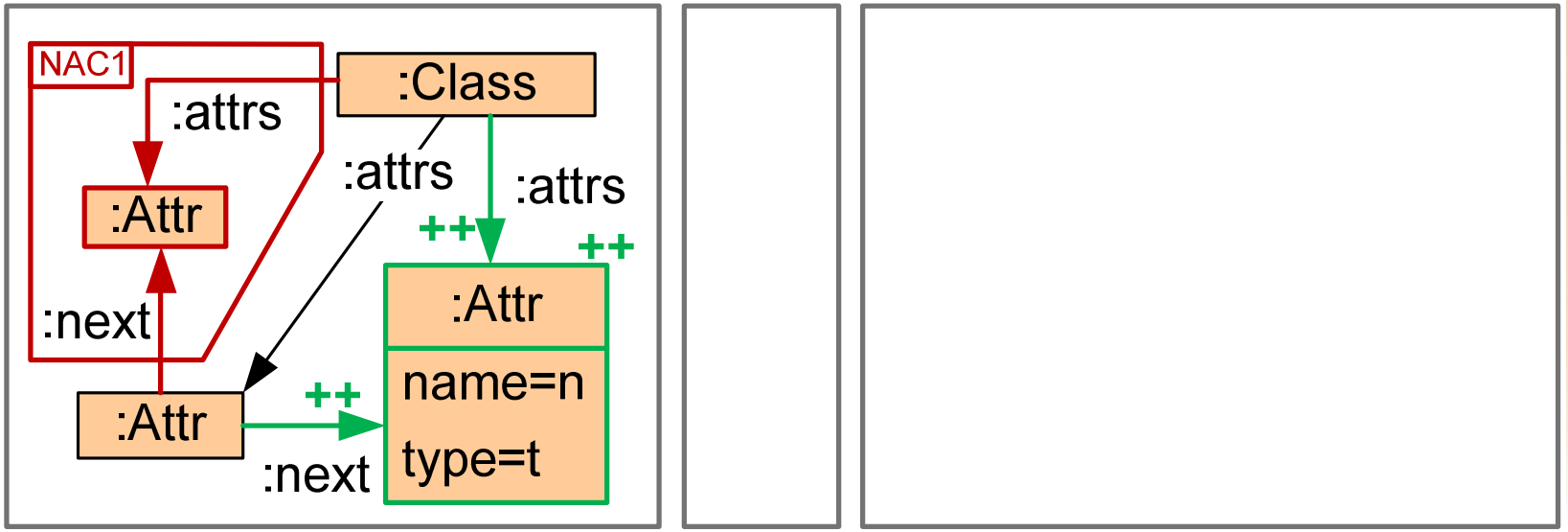
$$\begin{array}{ccccc} L & = & (L^S & \xleftarrow{s_L} & L^C \xrightarrow{t_L} L^T) \\ {\scriptstyle tr}\downarrow & & {\scriptstyle tr^S}\downarrow & & {\scriptstyle tr^C}\downarrow \quad {\scriptstyle tr^T}\downarrow \\ R & = & (R^S & \xleftarrow[s_R]{} & R^C \xrightarrow[t_R]{} R^T) \end{array}$$

triple rule tr
with source and target NACs

$$\begin{array}{ccccc} L_S & = & (L^S & \longleftarrow & \varnothing \longrightarrow \varnothing) \\ & & {\scriptstyle tr^S}\downarrow & & \downarrow \quad \downarrow \\ R_S & = & (R^S & \longleftarrow & \varnothing \longrightarrow \varnothing) \end{array}$$

source rule tr_S
with source NACs

NextAttr2NextColumn$_S$(n:String, t:String)



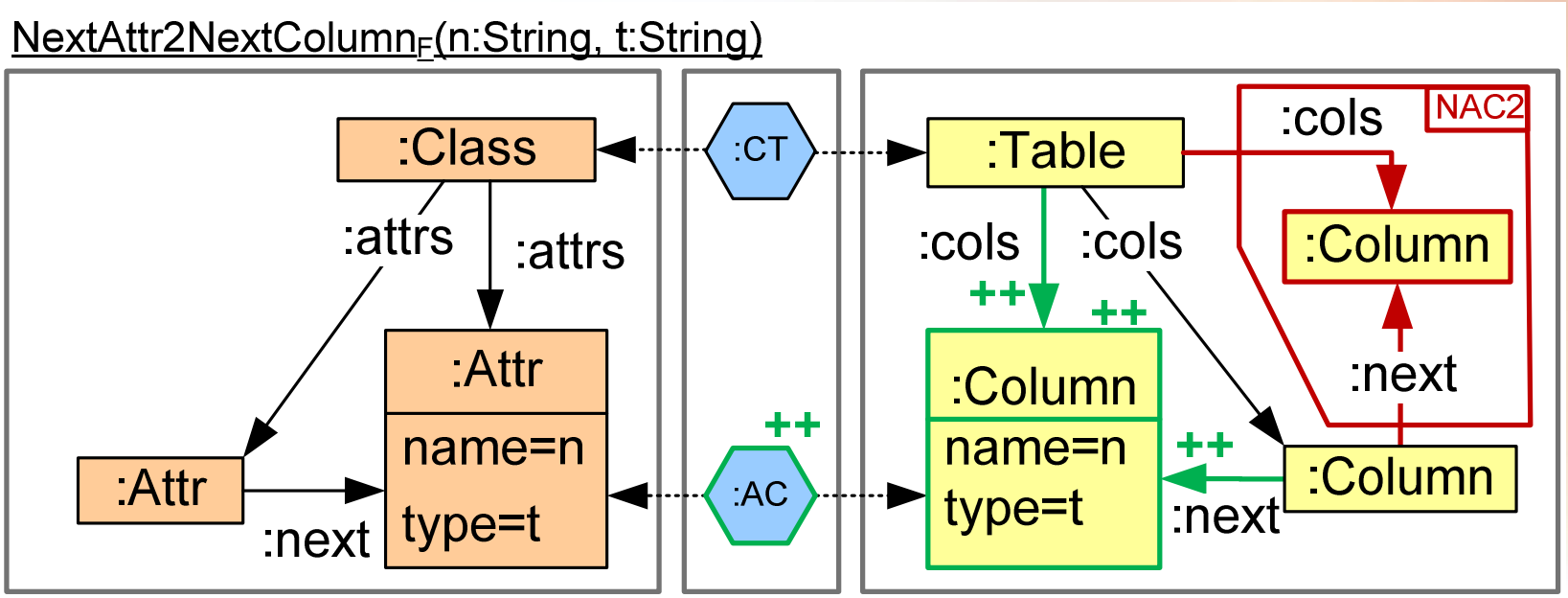
Derived Forward Rule

$$\begin{array}{ccccc} L & = & (L^S & \xleftarrow{s_L} & L^C & \xrightarrow{t_L} & L^T) \\ {\scriptstyle tr}\downarrow & & {\scriptstyle tr^S}\downarrow & & {\scriptstyle tr^C}\downarrow & & {\scriptstyle tr^T}\downarrow \\ R & = & (R^S & \xleftarrow[s_R]{} & R^C & \xrightarrow[t_R]{} & R^T) \end{array}$$

triple rule tr
with source and target NACs

$$\begin{array}{ccccc} L_F & = & (R^S & \xleftarrow{tr^S \circ s_L} & L^C & \xrightarrow{t_L} & L^T) \\ & & {\scriptstyle id}\downarrow & & {\scriptstyle tr^C}\downarrow & & \downarrow{\scriptstyle tr^T} \\ R_F & = & (R^S & \xleftarrow{s_R} & R^C & \xrightarrow{t_R} & R^T) \end{array}$$

forward rule tr_F
with target NACs



Model transformation based on Fw-rules

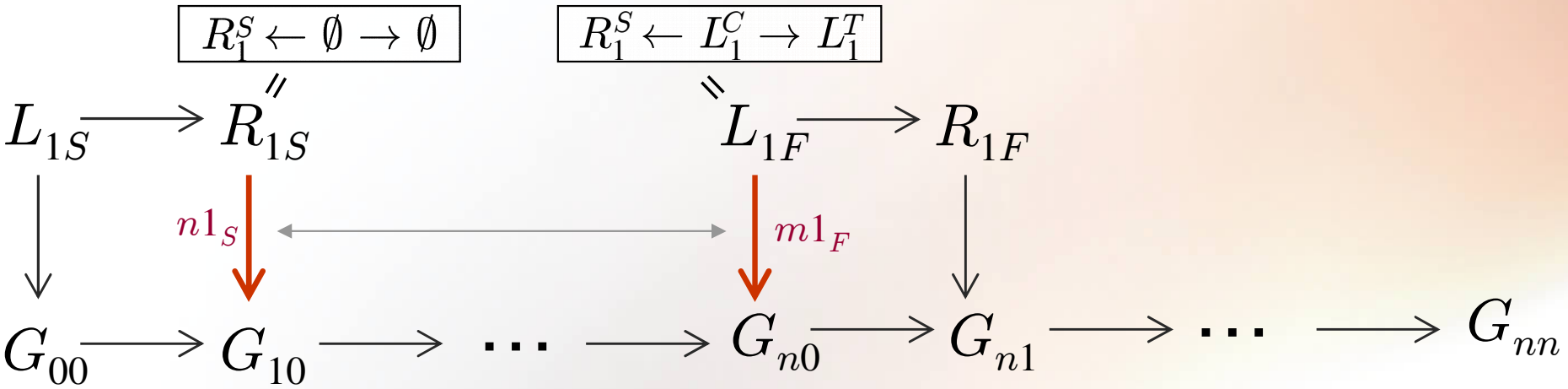
- $MT : VL_S \Rrightarrow VL_T$

  defined by forward rules: $(G_S, G_0 \overset{tr_F^*}{\Longrightarrow} G_n, G_T)$
  NAC and source consistent

- Source consistency ensures:
  - Source model can be parsed according to source rules
  - All elements of source model are translated exactly once, thus model transformation stops when everything is translated

Model Transformation Sequence

- Model transformation sequence $(G_S, G_0 \overset{tr_F^*}{\Longrightarrow} G_n, G_T)$:
  - $G_S = proj_S(G_0)$, $G_T = proj_T(G_n)$ and $G_0 \overset{tr_F^*}{\Longrightarrow} G_n$ is NAC and source consistent
- **Source consistency**: There is a NAC consistent sequence $\emptyset \overset{tr_S^*}{\Longrightarrow} G_0$, s.t. $\emptyset \overset{tr_S^*}{\Longrightarrow} G_0 \overset{tr_F^*}{\Longrightarrow} G_n$ is match consistent
- Match consistency: each comatch ni_S in source sequence determines S-component of match mi_F in forward sequence



Main Results

On-The-Fly Construction

- **Start:** $G_0 = (G_S \leftarrow \varnothing \rightarrow \varnothing)$
- **Running:**

$$\varnothing = G_{00} \overset{tr_S^*}{\Longrightarrow} G_{n-1,0} \overset{g_n}{\hookrightarrow} G_0 \overset{tr_F^*}{\Longrightarrow} G_{n-1}$$

Source sequence

Forward sequence

Match consistency holds for i=0 .. n-1

1. Find : new forward match $m_{n,F}$ for $tr_{n,F}$
2. Derive : source match $m_{n,S}$ for $tr_{n,S}$
3. Check : - NACs of $tr_{n,F}$ and $tr_{n,S}$
   - Effective elements $R_{i,S} \setminus L_{i,S}$ are matched for the first time: (1) is PB
4. Extend : source and forward sequences (breath first search or depth first search)

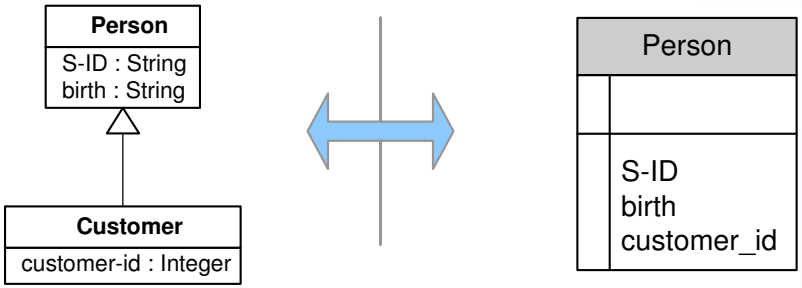
$$\begin{array}{ccccc} L_{n,S} & \hookrightarrow & R_{n,S} & \hookrightarrow & L_{n,F} \\ {\scriptstyle m_{n,S}}\downarrow & & (1) & & \downarrow{\scriptstyle m_{n,F}} \\ G_{n-1,0} & \underset{g_{n-1}}{\hookrightarrow} & G_0 & \hookrightarrow & G_{n-1} \end{array}$$

- **Finish:** if $g_n = id$, i.e. G_0 is constructed by the source sequence, result: G_n

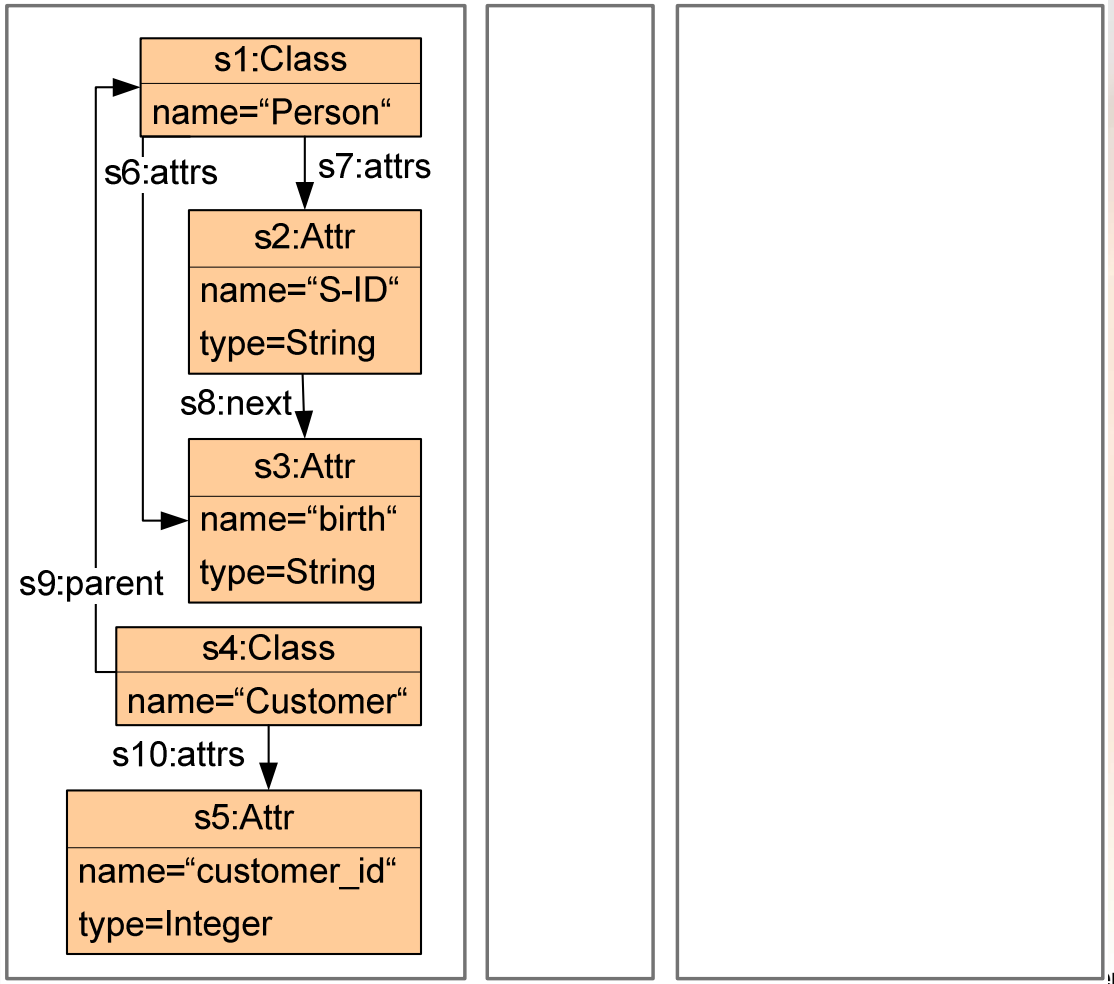
Main Results: On-The-Fly Construction

- Triple language $VL = \{G \mid \emptyset \Rightarrow^* G \; via \; TR\}$
- **Termination:** guaranteed, if all derived source rules are creating: $R_{i,S} \setminus L_{i,S} \neq \emptyset$
- **Correctness:** For each constructed MT-sequence: $(G_S, G_0 \overset{tr_F^*}{\Longrightarrow} G_n, G_T)$ there is a $G \in VL$, s.t. $G = (G_S \leftarrow G_C \rightarrow G_T)$
- **Completeness:** For each $G_S \in VL^S$ there is an MT-seuqence: $(G_S, G_0 \overset{tr_F^*}{\Longrightarrow} G_n, G_T)$

Example: Model Trafo

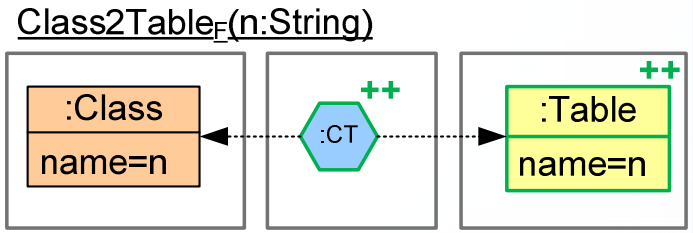


Instance in concrete syntax

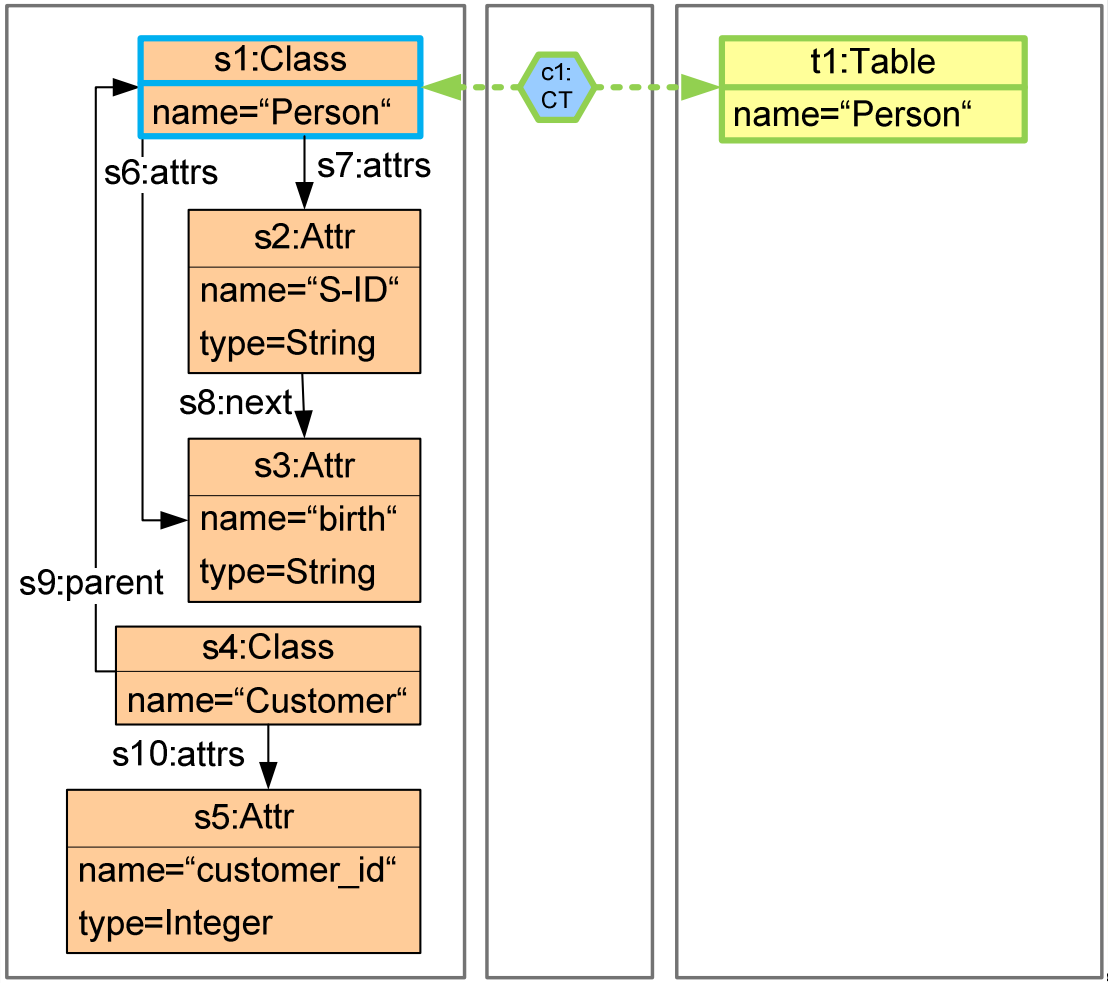


Triple Graph (abstract syntax)

Example: Model Trafo

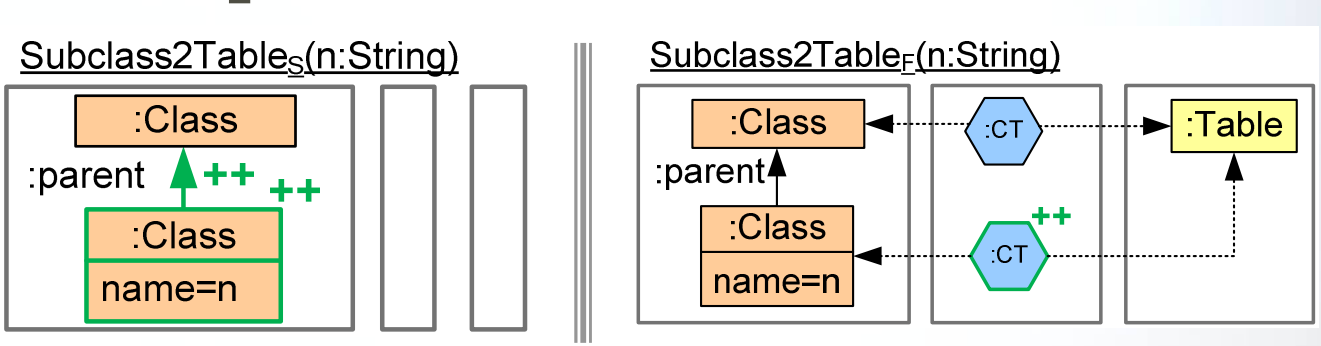


FW-Rule
(abstract syntax)



Triple Graph
(abstract syntax)

Example: Model Trafo



Source rule and FW-Rule (abstract syntax)

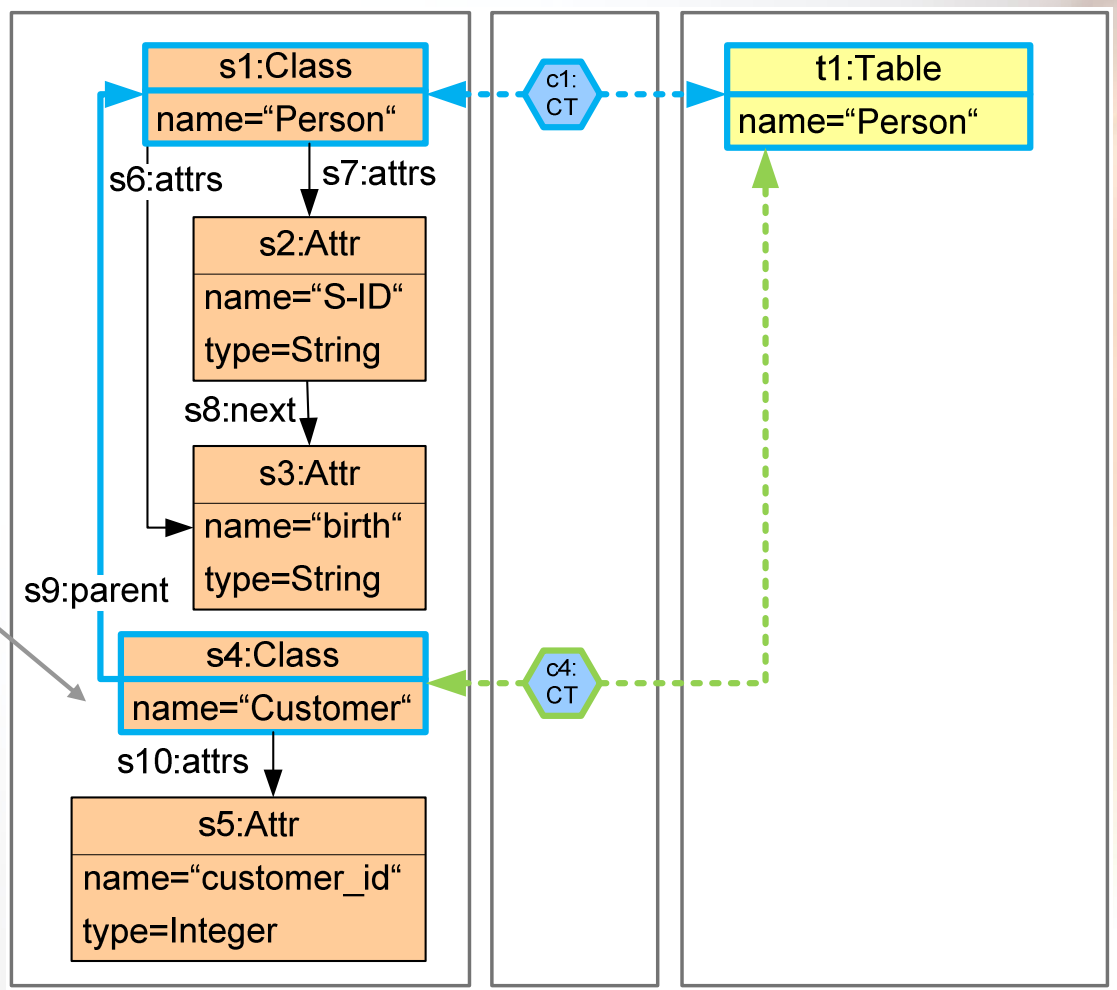
On-the-fly Construction

1. Forward match
2. Source match
3. Check:

a) NACs

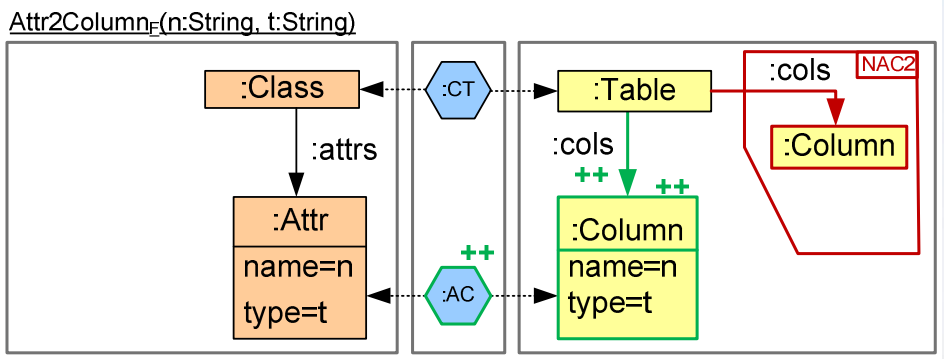
b) Effective Elements not matched before

4. Extend



Triple Graph (abstract syntax)

Example: Model Trafo



FW-Rule
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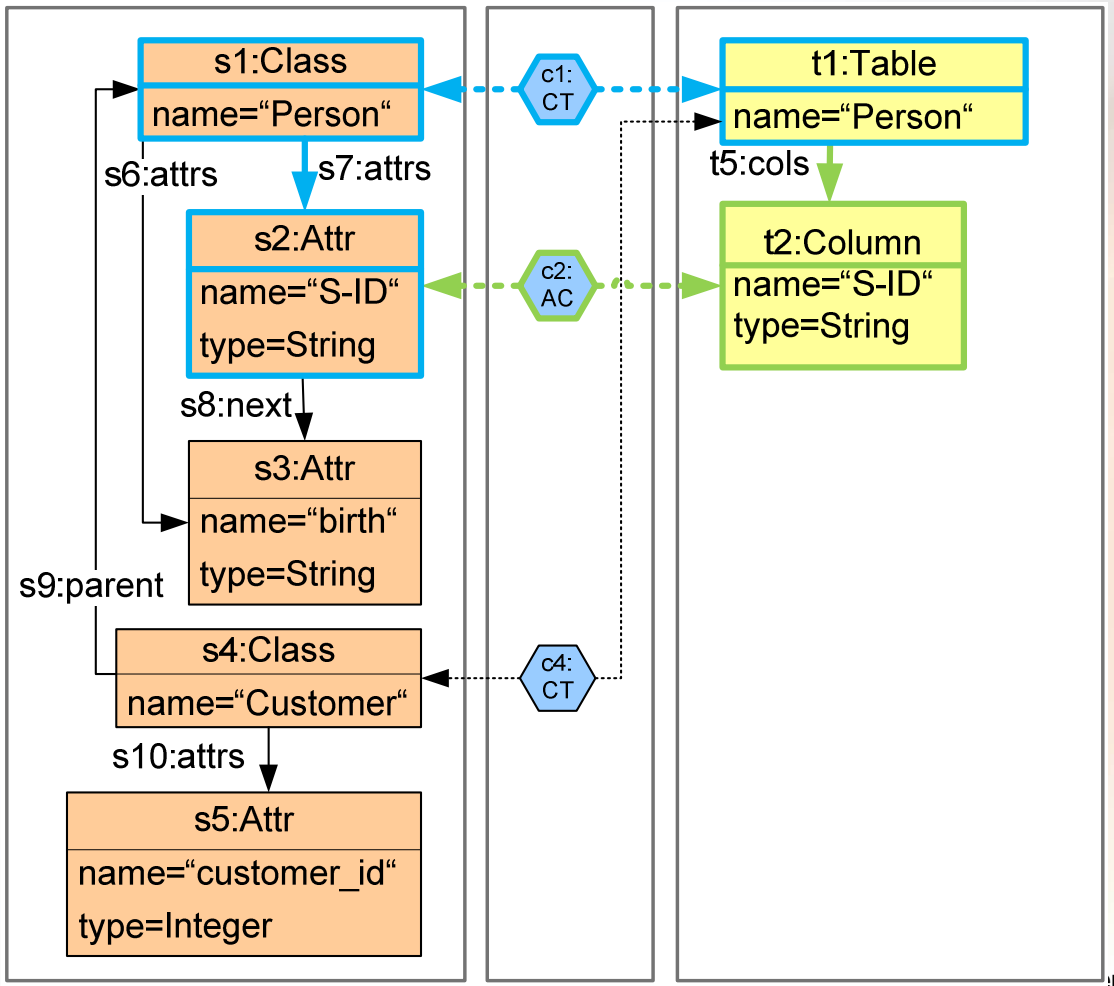

Triple Graph
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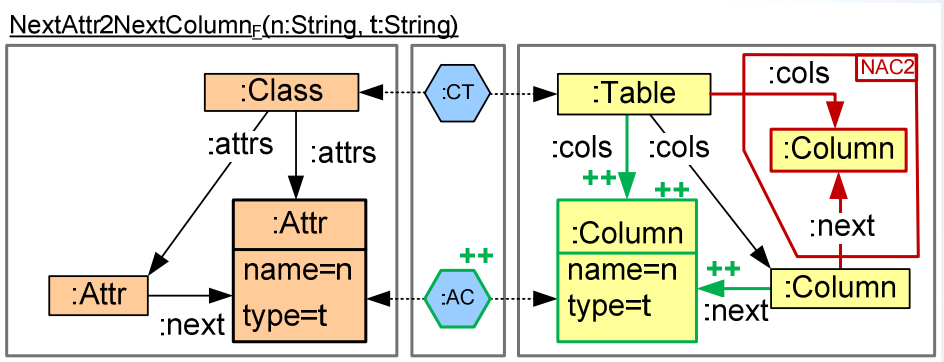
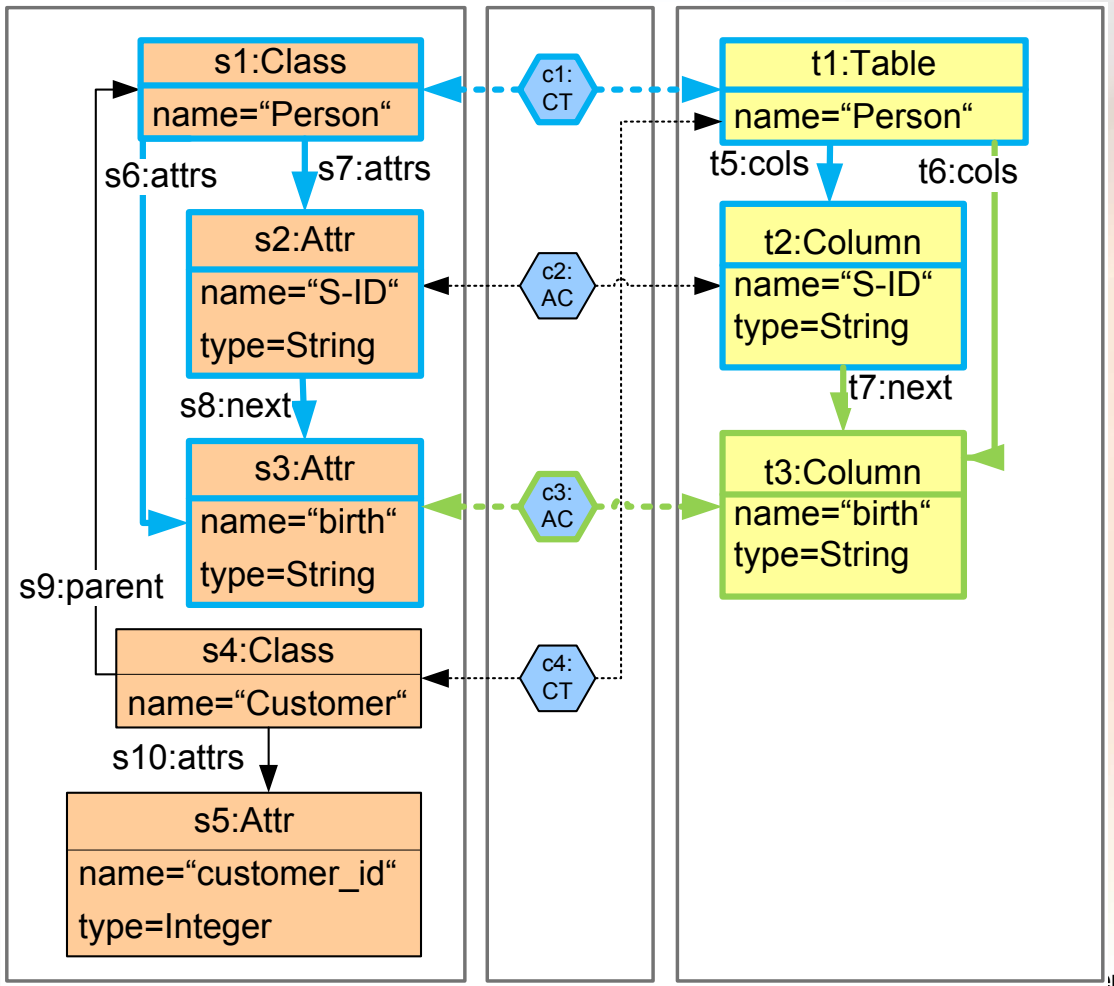
Example: Model Trafo



FW-Rule
(abstract syntax)



Triple Graph
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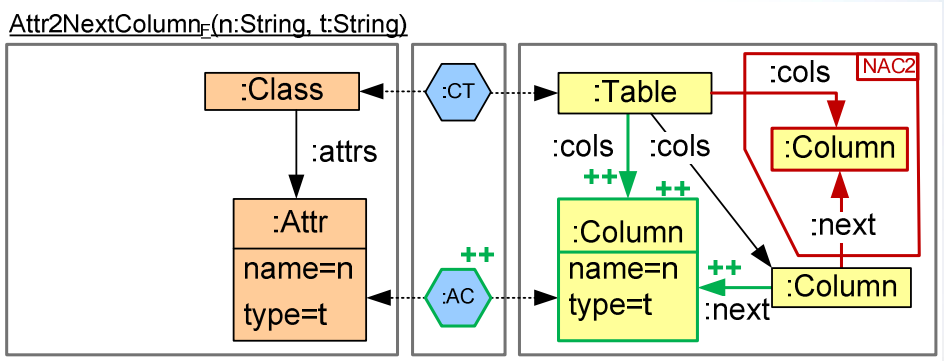

FW-Rule
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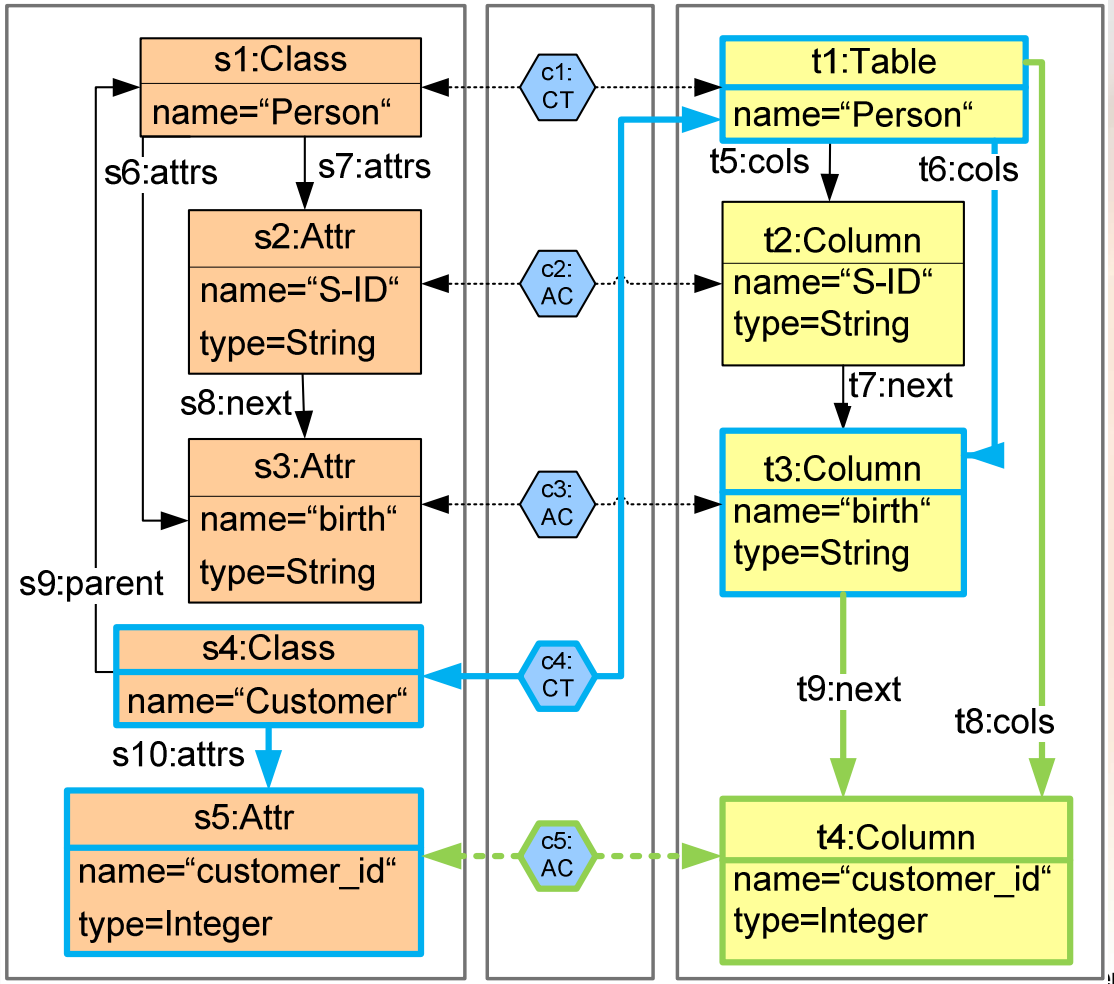

Triple Graph
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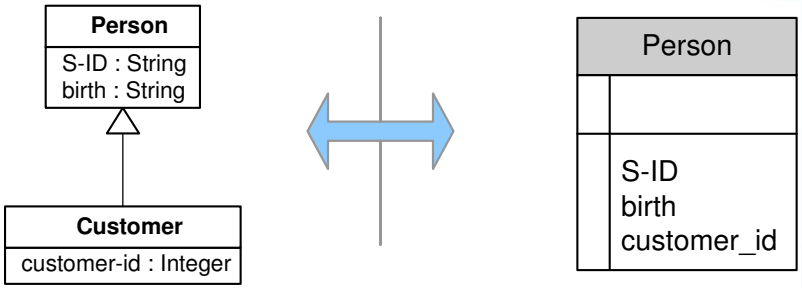

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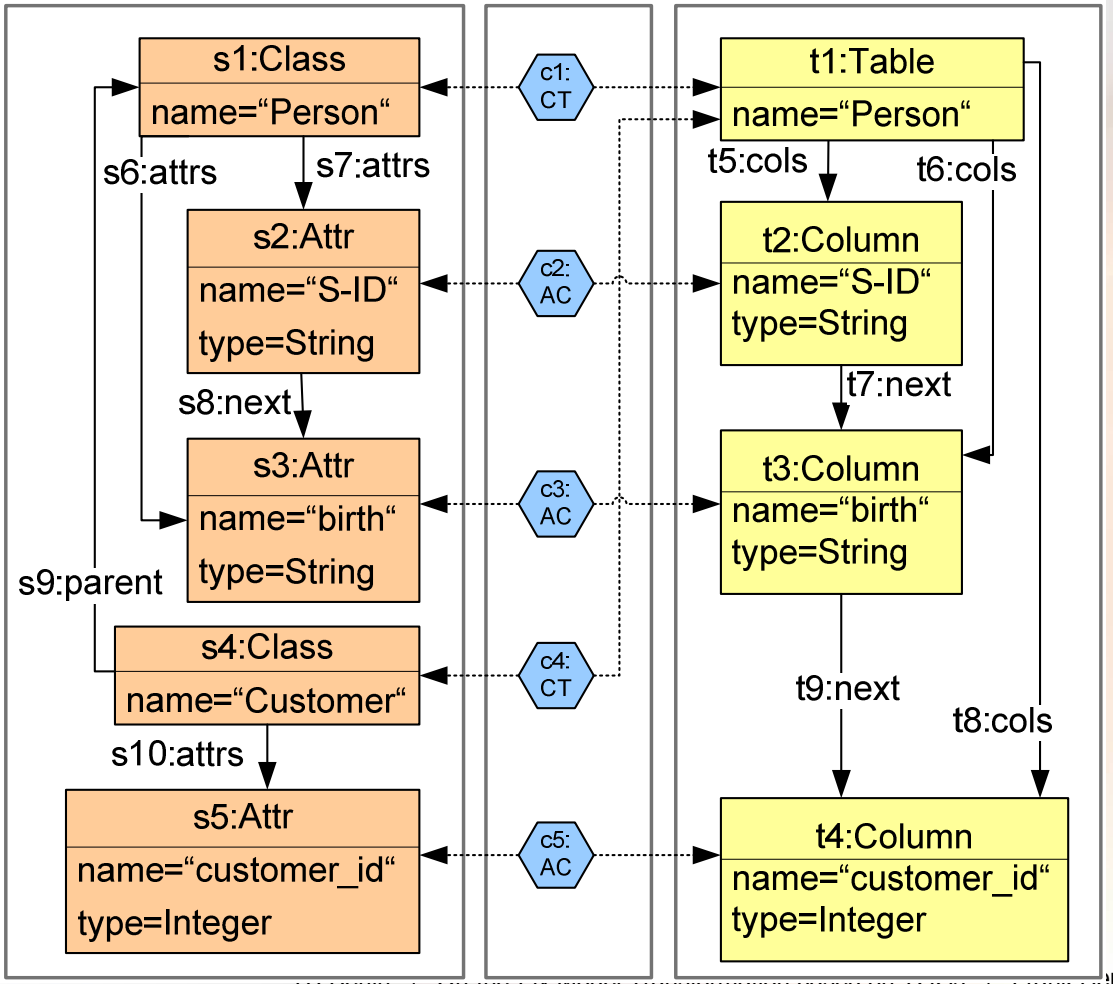
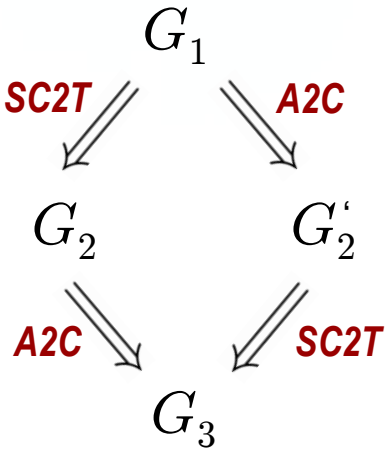
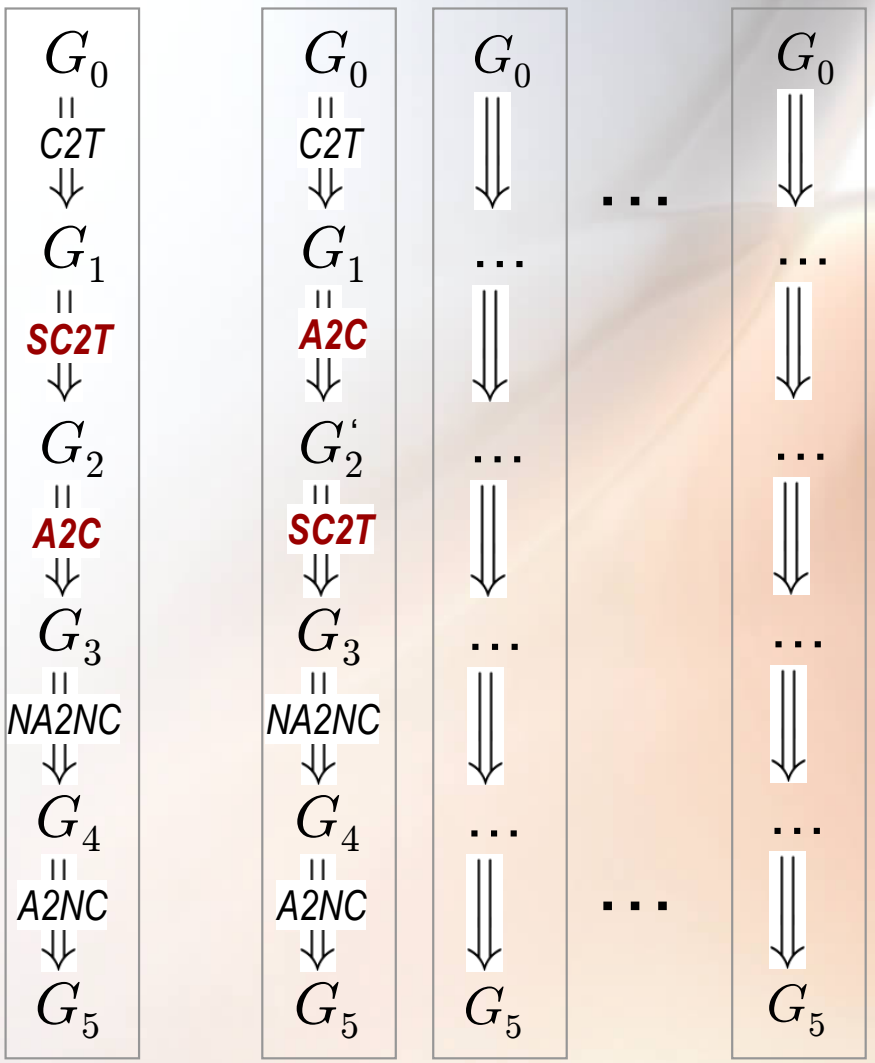


Triple Graph (abstract syntax)

Partial Order Reduction

- Based on parallel independence and switch equivalence





- One sequence is sufficient
- Double Diamond Condition

Main Results

- **Termination:** guaranteed, if all derived source rules are creating: $R_{i,S} \setminus L_{i,S} \neq \emptyset$
- **Correctness:** For each constructed MT-sequence: $(G_S, G_0 \overset{tr_F^*}{\Longrightarrow} G_n, G_T)$ there is a $G \in VL$, s.t. $G = (G_S \leftarrow G_C \rightarrow G_T)$
- **Completeness:** For each $G_S \in VL^S$ there is an MT-seuqence: $(G_S, G_0 \overset{tr_F^*}{\Longrightarrow} G_n, G_T)$
- **Parallel Independence and Partial Order Reduction**

Conclusion

- **Important** new results for TGGs with **NACs**
  - Termination, Correctness and Completeness of MTs
- Efficiency of standard construction improved by:
  - On-the-fly construction
  - Partial order reduction

Future work:

- Implementation: based on Mathematica and Eclipse
- Benchmarks: effect of partial order reduction and the on-the-fly construction

References

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