Universal Translation Algorithm for Formulation of Transport Network Problems

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Universal Translation Algorithm for Formulation of Transport Network Problems

MYNTS

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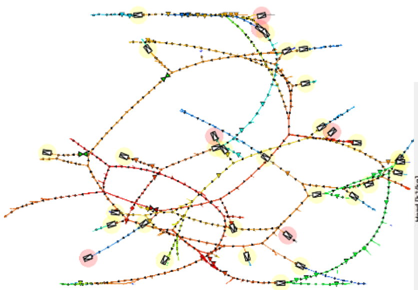

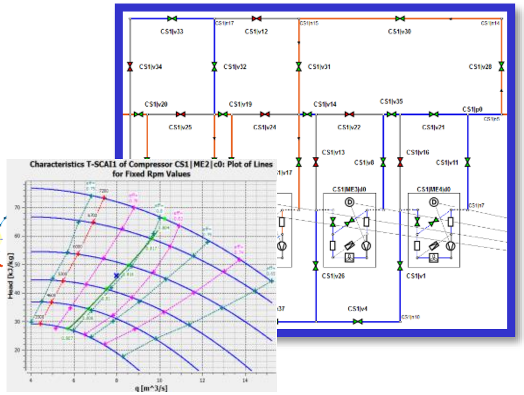

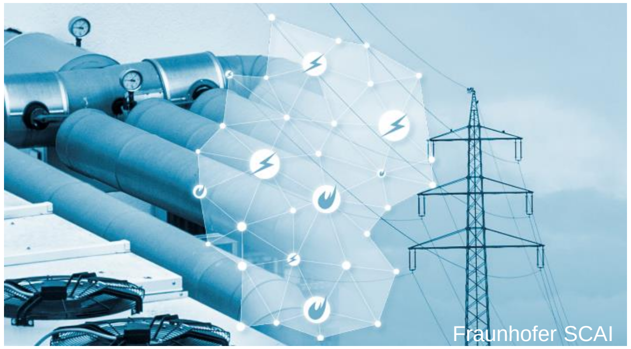

Math Energy

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Introduction

- MYNTS (MultiphYsal NeTwork Simulator), a system for physics-based simulation of energy transport networks, is enhanced by our UTrans method.
- UTrans implements a general concept of a “universal translation” (UT) – formulation of a network problem is considered as a translation between two domain specific languages (DSL)
- In our case, UTrans translates from a network description language (DSL1), used by the community, to the problem description language (DSL2), understood by generic non-linear solvers, such as IPOPT, Mathematica, Matlab.
- The translation is performed applying a set of user-configurable translation rules, as contained in the so-called translation matrix (TM).
- Generic syntax of TM allows to formulate network problems for different energy sectors (gas, water, power, etc.) and to model a coupling between them.
- Complexity analysis and benchmarks show efficiency of the overall method.

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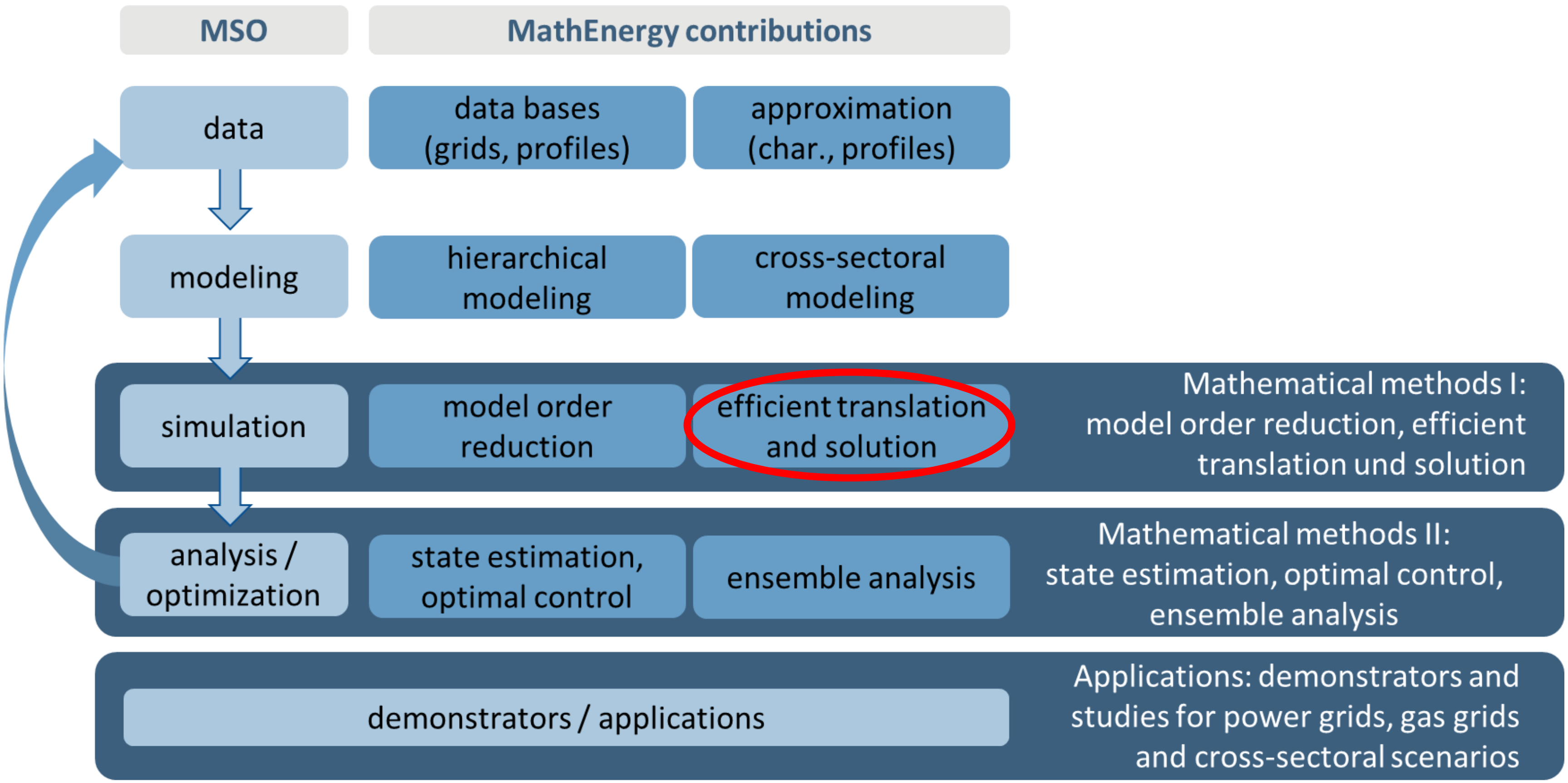
Key Aspects of this Contribution



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UTrans – Overview

- A novel algorithm UTrans for „universal translation“ was developed and implemented in MYNTS.
- The algorithm translates a network description (NET) in an appropriate (human-readable) format to a problem description (a list of equations for the solver) suitable for a solver. Currently, IPOPT, Mathematica, and Matlab are supported.
- The translation rules (translation matrix, TM) are contained in an ASCII file.
- TM encodes all physical laws (e.g., Kirchhoff, Papay, Hofer, etc.) and control equations (for regulators, compressors, etc.), is human-readable and can be changed freely.
- Coupling of different sectors becomes easy.

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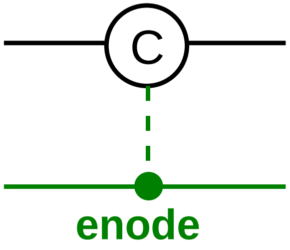
Example 1 – Excerpt of a Translation Matrix for Coupling of Multiple Sectors

- multiple sectors as simple concatenation of TM and NET structures with possible cross-references:




```
class=n, sector=gas, var=P;rho  # list of variables
class=e, sector=gas, var=Q;m
class=n, sector=water, var=P;T
class=e, sector=water, var=Q
class=n, sector=power, var=U
class=e, sector=power, var=I

class=e, sector=gas, eq=[m]-[rho_norm]*[Q]  # list of equations
class=e, sector=gas, type=p, eq=[P@n1]*abs([P@n1])-[P@n2]*abs([P@n2])
                        -[R]*[Q]*abs([Q])+...
class=e, sector=power, type=w, eq=[U@n1]-[U@n2]-[R]*[I]
class=e, sector=water, type=p, eq=...
class=e, sector=gas, type=c, drive=E, eq=[Q]-efun([P@n1],[P@n2],[U@enode])
...
```

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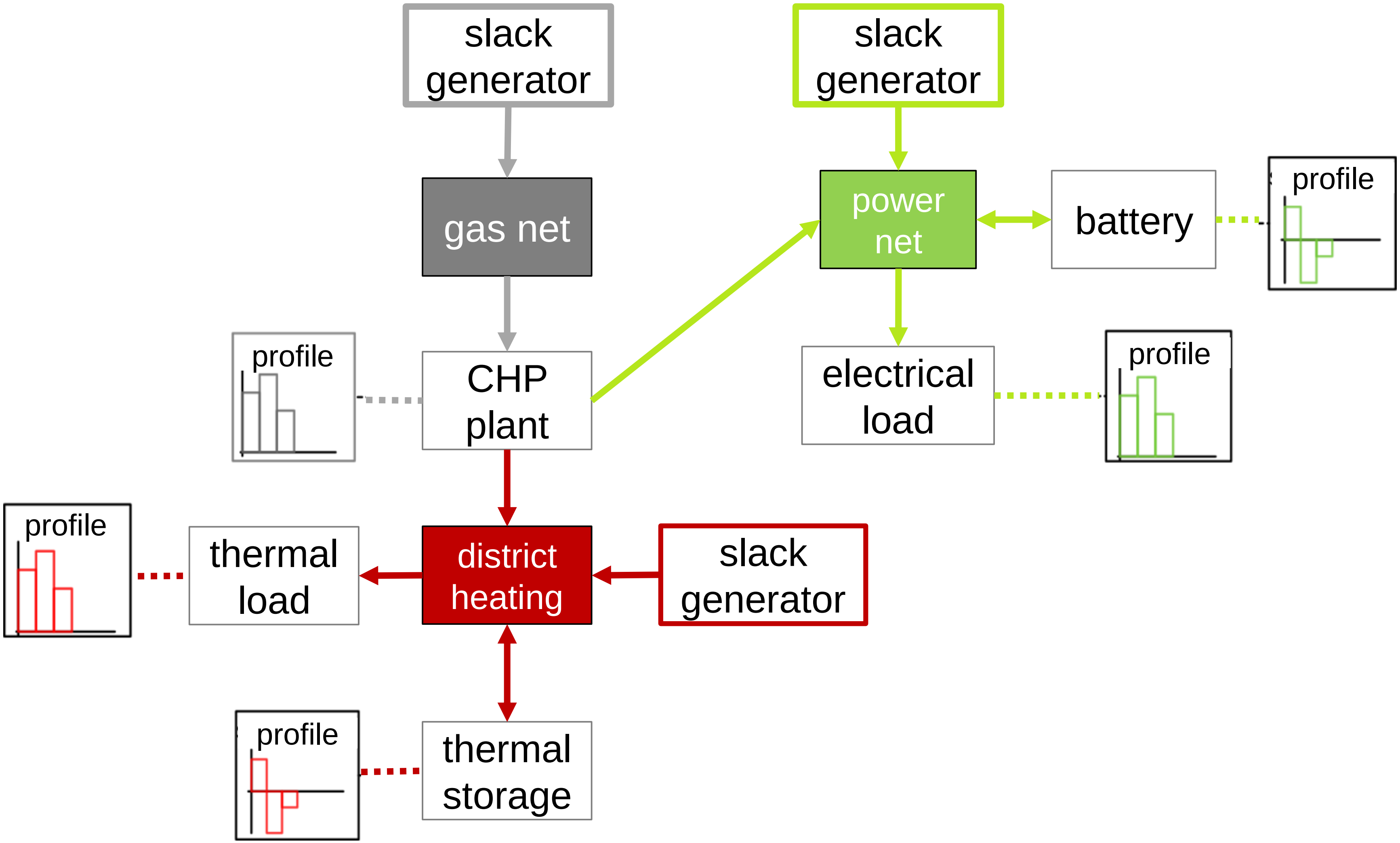
Example 2 – Sketch



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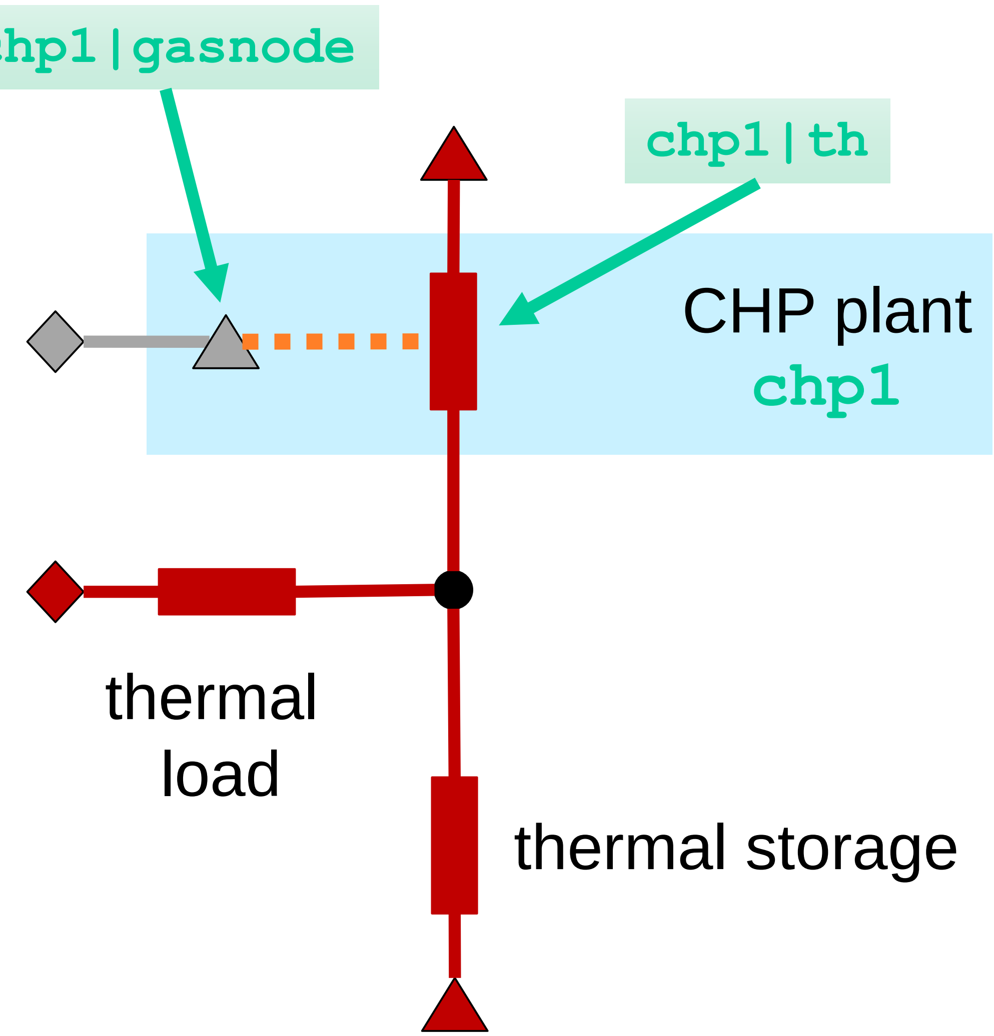
Example 2 – Basic MYNTS Network (for Demonstration)

- For demonstration purposes, we restrict ourselves to a simplified version here:
- The basic network for MYNTS contains two sectors,
  - gas (gray)
  - and water (district heating, red)
- and the following elements:
  - CHP plant (power delivery not shown here)
  - thermal load
  - thermal storage
- coupling: orange



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Example 2 – Excerpt from Translation Matrix

- Excerpt from the respective translation matrix,
  showing one exemplary coupling of the gas and water sectors:

- Properties **`eta_th_set`** and **`powset`**
  of the **`n_gas`** node from the gas sector
  are referenced by the **`kwk_th`** element from the water sector:

```
sector=water, class=e, type=kwk_th, mtype=1,
    eq="[c]*fabs([m])*([T]-[T@in])-
            [eta_th_set@n_gas]/100*[powset@n_gas]*1e6"
```

- In the net, an element of type **`kwk_th`** needs, in particular, a property **`n_gas`** containing the name of the respective gas node.

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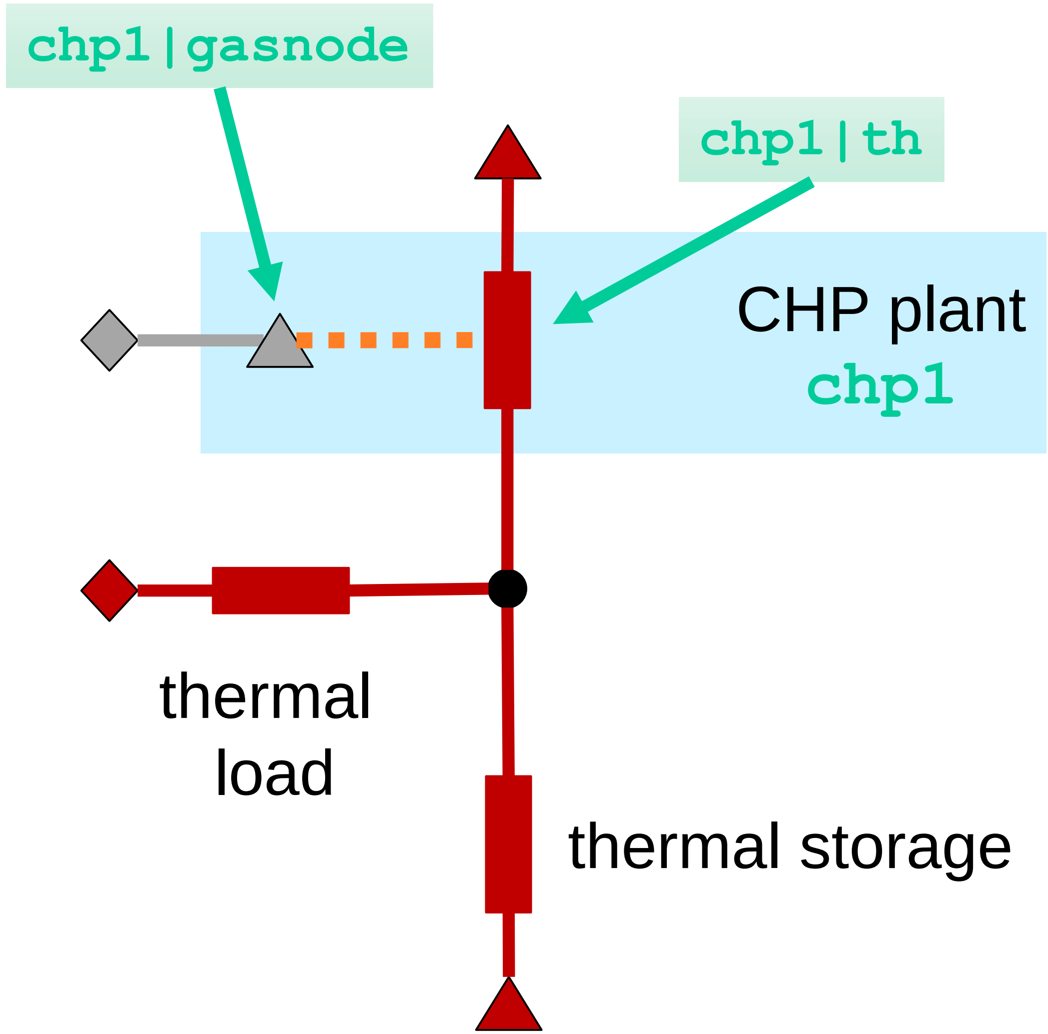
Example 2 – Relationship of Translation Matrix and Network

- In the basic MYNTS net:
  - `chp1|th` is an edge of type `kwk_th`
  - It needs, in particular, a property `n_gas` containing the name of the respective gas node, here: `chp1|gasnode`
- Via TM, the connection between the sectors is made.



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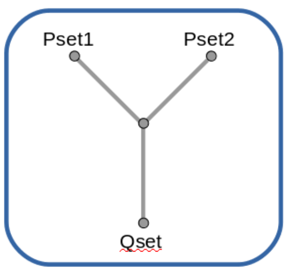
UTrans – Basic Workflow for NL-Format (IPOPT Solver)

- `net-w`: writes MYNTS network
- `preNL`: creates NL-ready format TM-NL of translation matrix TM
- `utrans`: creates core system to be solved based on net and (here) TM-NL
- `postNL`: writes system (incl. headers etc.) in suitable format, here: NL
- `solver`: here, IPOPT
- `x2net`: converts solver output back to MYNTS



x

Translation matrix for water networks with laminar flow (TM)

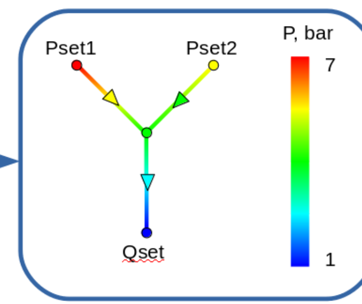
```
# variables with start values
class=n, var=P, var0=1
class=e, type=p, var=Q, var0=0

# equations of elements (linear resistors)
class=e, type=p,
      eq="[P@node1]-[P@node2]-[R]*[Q]"
```

=

NL: eqs encoded in Polish prefix notation (PPN)

```
7 7                        #nvars,neqs
o1 v0 n7                   #eq0
o1 v1 n5                   #...
o1 o1 v0 v2 o2 n0.3 v4
o1 o1 v1 v2 o2 n0.05 v5    #...
o1 o1 v2 v3 o2 n0.1 v6     #eq6
```

solver



net-w preNL utrans postNL x2net

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Complexity of the Algorithm

- Complexity estimation:

$$O(N_{elem}\, N_{prop}\, N_{eq})$$

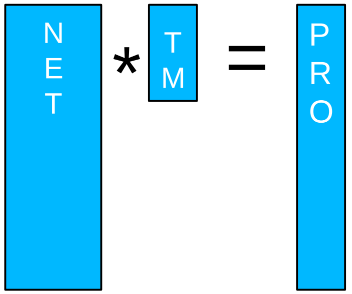
N_{elem} – number of elements,

N_{prop} – (average) number of properties per element,

N_{eq} – (average) number of equations per element.

- For linear problems with only one type of elements, complexity is identical to that of a matrix multiplication

$$NET * TM = PRO$$



where NET is an $N_{elem}\ x\ N_{prop}$, TM an $N_{prop}\ x\ N_{eq}$, and PRO an $N_{elem}\ x\ N_{eq}$ matrix.

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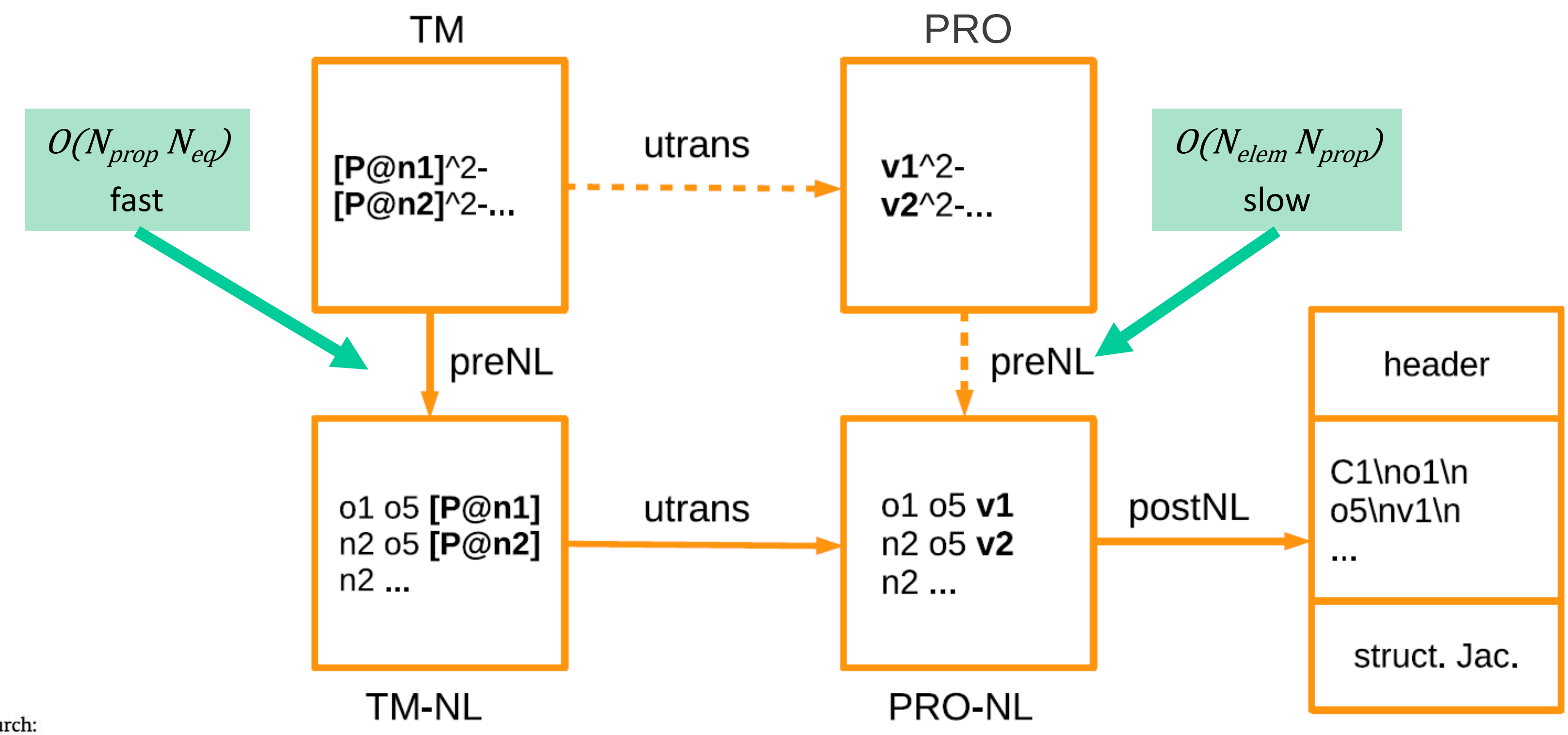
Behind the Scenes

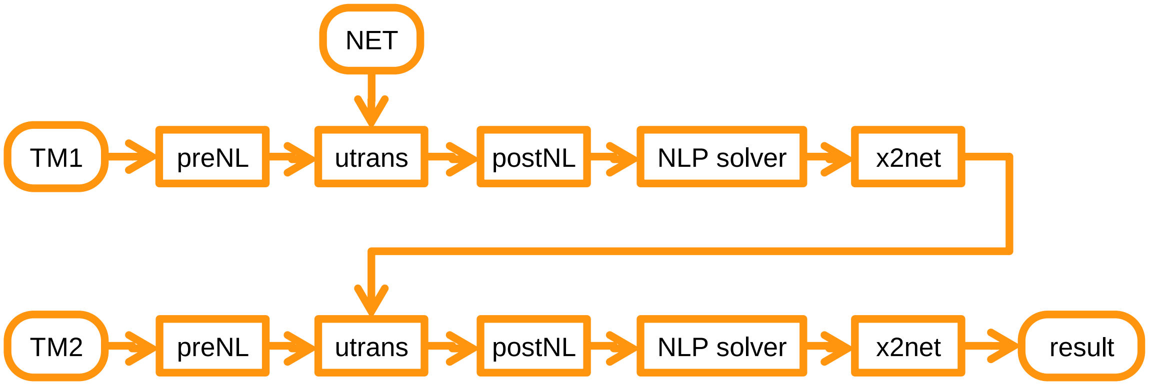
- Retranslation of the problem to NL form: The translation path, shown by solid lines, is much faster than the one shown by dashed lines.



Usage of UTrans – Exemplary Solver Workflow

- Call to the new kernel invokes a Python workflow
- It describes a multiphase solution procedure
  - e.g., start with forced goals of compressors and regulators
  - proceed with free compressors
  - then with advanced
  - iterate mixing of temperature and gas properties
  - …

Example:
2-phase solution process



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Exemplary Results

- Performance benchmarks for selected realistic gas transport networks:

network	nodes	edges	translation [sec]	solution* [sec]
N1	100	111	0.04	0.02
N2	931	1047	0.15	0.24
N3	4466	5362	0.39	0.42

- Timings on a workstation with 3 GHz Intel i7 CPUs and 8 GB RAM
- *) one-phase solution process

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More Remarks on Features and Performance

- UTrans comes with several filters, e.g. for topological reduction*.
- Particular representation of NET and TM structures plays no role – different implementations for the same abstract structure (sets of maps)
- Implementation based on set and map containers of C++ STL, allowing usage of efficient search and set-theoretical algorithms
- Syntax of TM flexible and completely in user's hand:

  One can define other names for the properties in NET and adopt TM accordingly. One can also change the syntax of equations in TM according to the solver language – main algorithm independent of format!
- Translation algorithm is highly parallelizable (future work):

  Processing loops can be separated element-wise and proportionally accelerated by using multiprocessor architectures.

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**) see separate set of slides*

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Thanks for Your Attention

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