Incremental pattern matching in the VIATRA model transformation system

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Introduction

Incremental model transformations

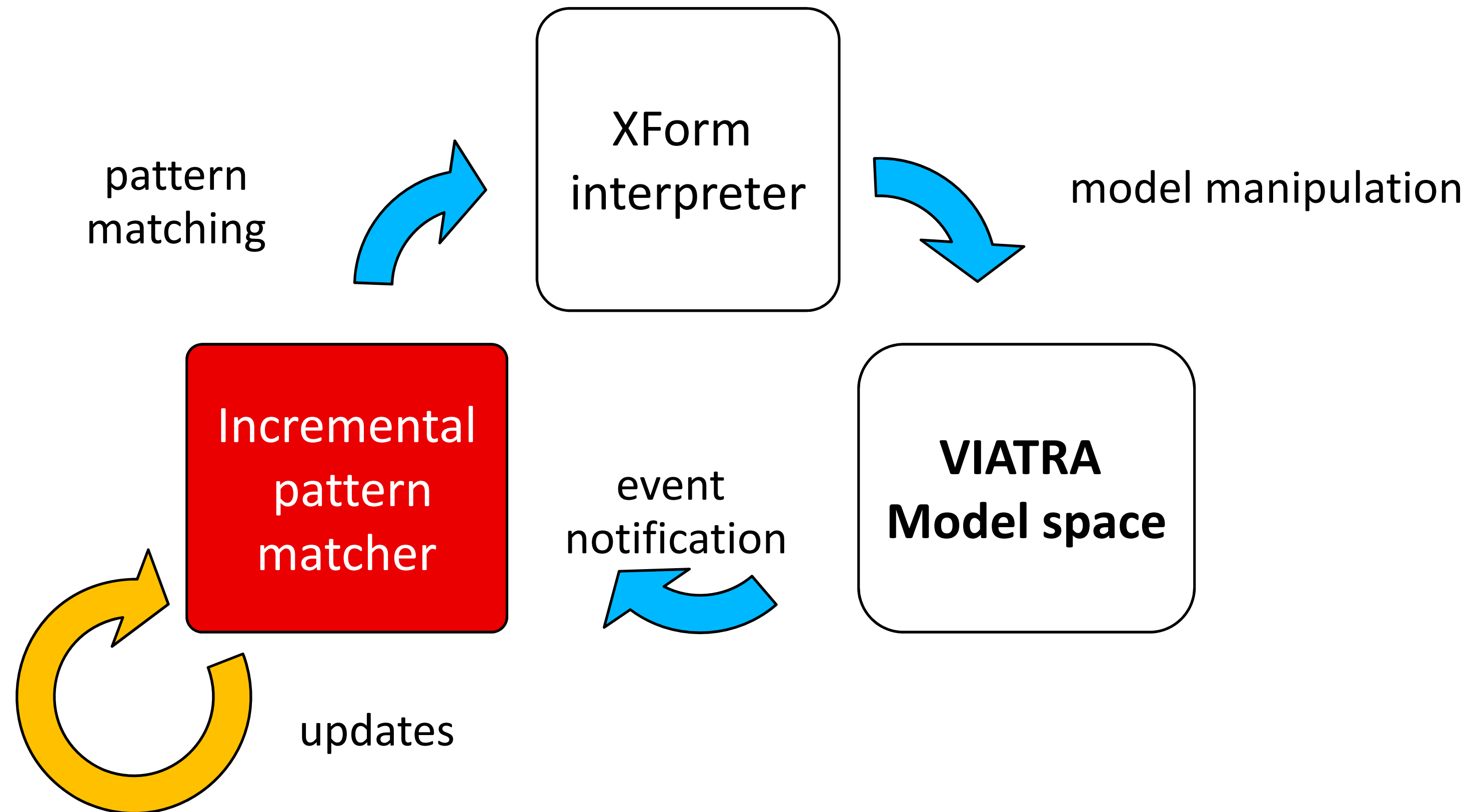
- Key usage scenarios for MT:
  - Mapping between languages
  - Intra-domain model manipulation
    - Model execution
    - Validity checking (constraint evaluation)
- They work with **evolving** models.
  - Users are constantly changing/modifying them.
  - Users usually work with **large** models.
- Problem: transformations are slow
  - To execute… (large models)
  - and to re-execute again and again (always starting from scratch).
- Solution: incrementality
  - Take the source model, and its mapped counterpart;
  - Use the information about how the source model was changed;
  - Map and apply the changes (but ONLY the changes) to the target model.

- How to achieve incrementality?
  - Incremental *updates:* avoid re-generation.
    - Don’t recreate what is already there.
    - → Use reference (correspondence) models.
  - Incremental *execution*: avoid re-computation.
    - Don’t recalculate what was already computed.
    - How?

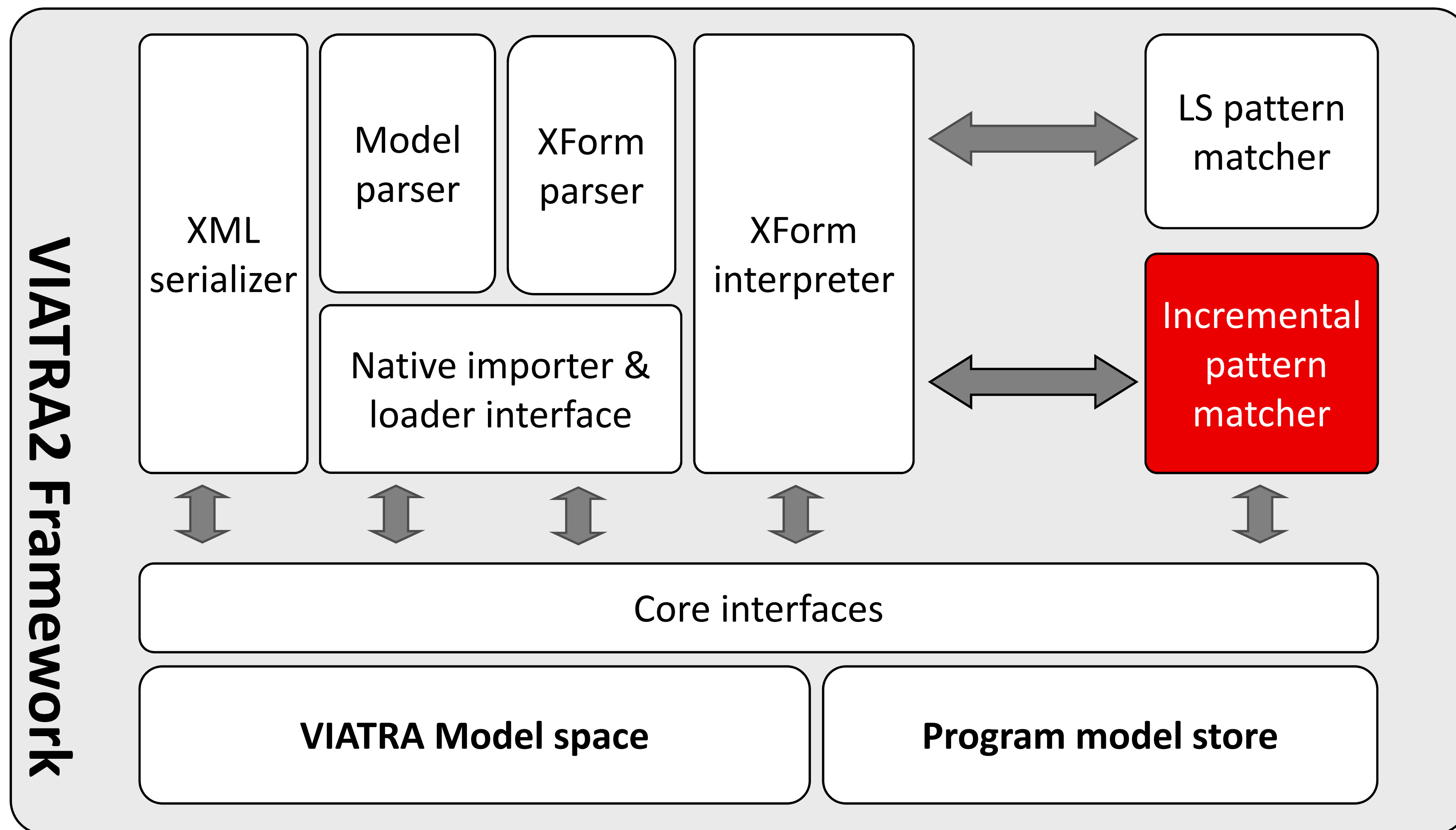
Incremental graph pattern matching

- Graph transformations require pattern matching
- Goal: retrieve the *matching set* quickly
- How?
  - Store (cache) matchings
  - Update them as the model changes
    - Update precisely (incrementality)
- *Expected* results: good, if…
  - There is enough memory (*)
  - Queries are dominant
  - Model changes are relatively sparse (**)
  - e.g. synchronization, constraint evaluation, …

Operational overview



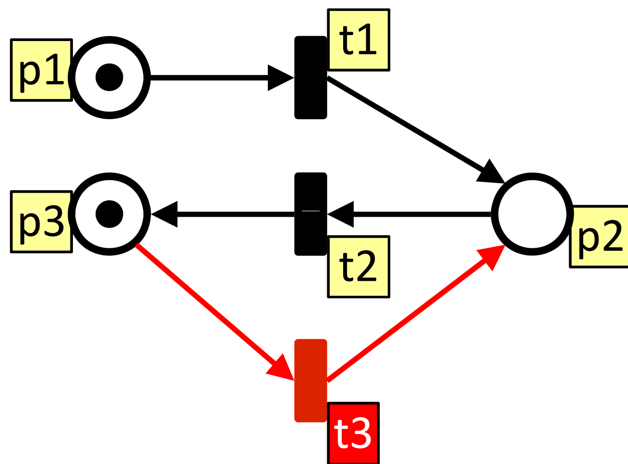
Architecture

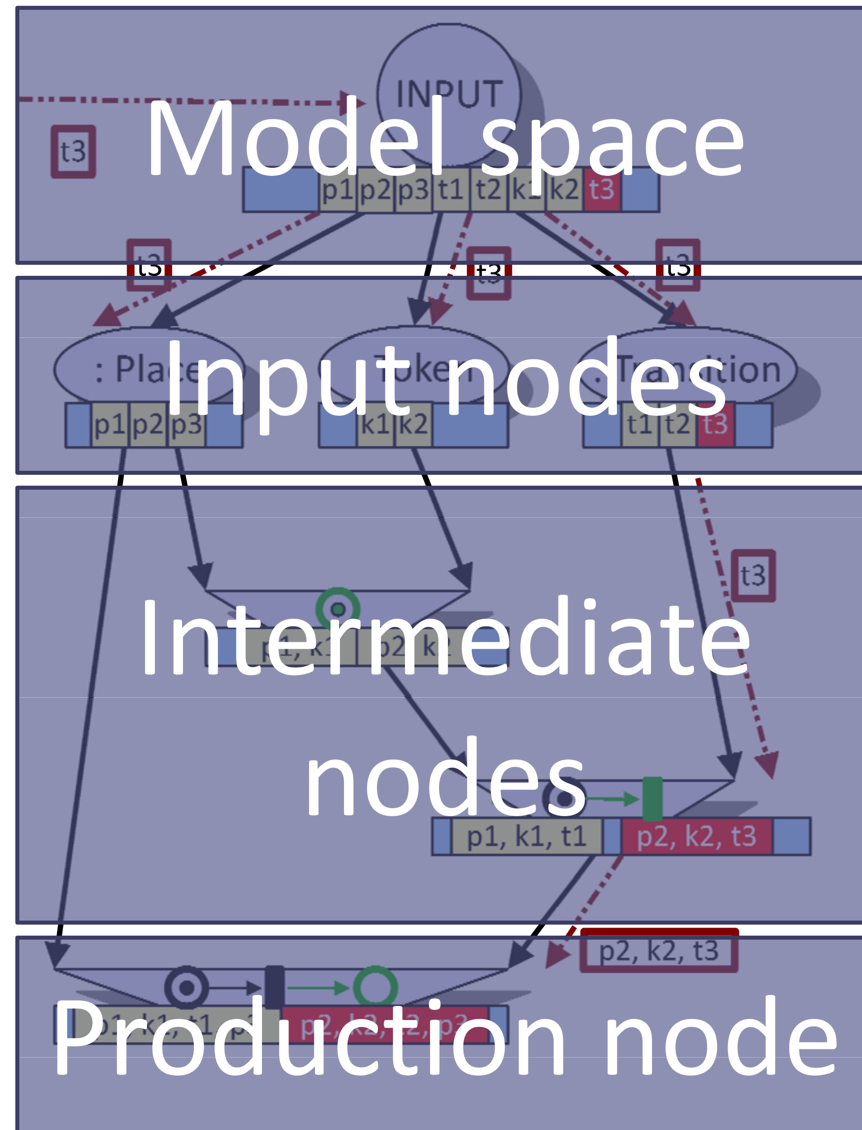


Concepts

Core idea: use RETE nets

- RETE network
  - node: (partial) matches of a (sub)pattern
  - edge: update propagation
- Demonstrating the principle
  - input: Petri net
  - pattern: fireable transition
  - Model change: new transition (t3)



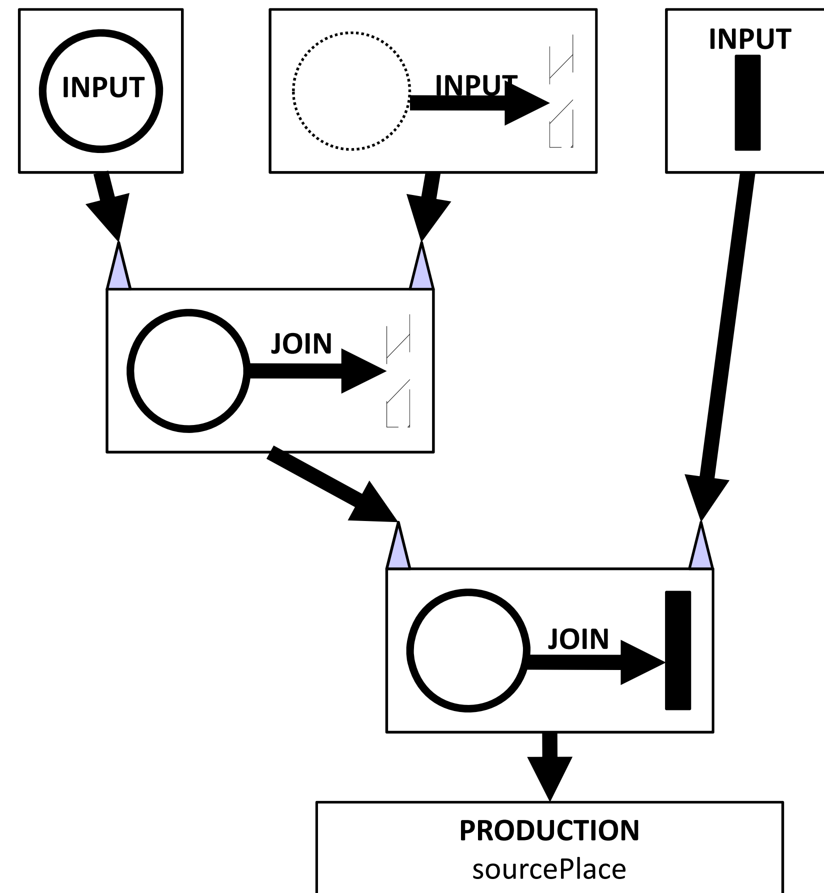


RETE network construction

- Key: pattern decomposition
  - Pattern = set of constraints (defined over pattern variables)
  - Types of constraints: type, topology (source/target), hierarchy (containment), attribute value, generics (instanceOf/supertypeOf), *injectivity*, [negative] pattern calls, …
- Construction algorithm (roughly)
  - 1. Decompose the pattern into elementary constraints (*)
  - 2. Process the elementary constraints and connect them with appropriate intermediate nodes (JOIN, MINUS-JOIN, UNION, …)
  - 3. Create terminator production node

Key RETE components

- JOIN node
  - ~relational algebra: natural join
- MINUS-JOIN
  - Negative existence



Other VIATRA features

- Pattern calls
  - Simply connect the production nodes
  - → Pattern recursion is fully supported
- OR-patterns
  - UNION intermediate nodes
- Check conditions
  - `check (value(X) % 5 == 3)`
  - `check (length(name(X)) < 4)`
  - `check (myFunction(name(X))!='myException')`
  - → Filter and term evaluator nodes
- Result: full VIATRA transformation language support; any pattern can be matched incrementally.

Updates

- Needed when the model space changes
- VIATRA notification mechanism (EMF is also possible)
  - Transparent: user modification, model imports, results of a transformation, external modification, … → RETE is always updated!
- Input nodes receive elementary modifications and release an update token
  - Represents a change in the partial matching (+/-)
- Nodes process updates and propagate them if needed
  - PRECISE update mechanism

Performance analysis

Performance

- In theory…
  - Building phase is slow ("warm-up")
    - How slow?
  - Once the network is built, pattern matching is an "instantaneous" operation.
    - Excluding the linear cost of reading the result set.
  - But… there is a performance penalty on model manipulation.
    - How much?
- Dependencies?
  - Pattern size
  - Matching set size
  - Model size
  - …?

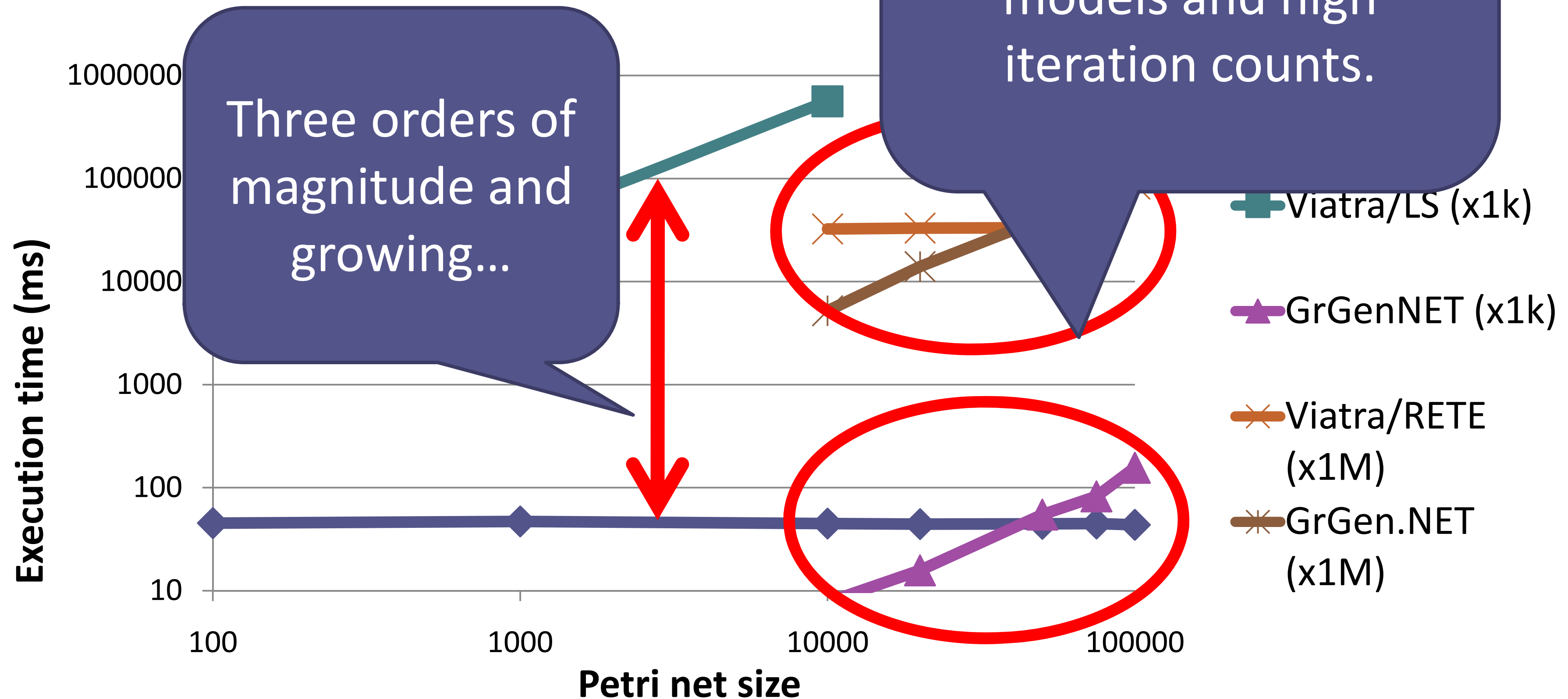
Benchmarking

- Example transformation: Petri net simulation
  - One complex pattern for the enabledness condition
  - Two graph transformation rules for firing
  - As-long-as-possible (ALAP) style execution (“fire at will”)
  - Model graphs:
    - A “large” Petri net actually used in a research project (~60 places, ~70 transitions, ~300 arcs)
    - Scaling up: automatic generation preserving liveness (up to 100000 places, 100000 transitions, 500000 arcs)
- Analysis
  - Measure execution time (average multiple runs)
  - Take “warm-up” runs into consideration
- Profiling
  - Measure overhead, network construction time
  - “Normalize” results

Profiling results

- Model manipulation overhead: ~15% (of overall CPU time)
  - Depends largely on the transformation!
- Memory overhead
  - Petri nets (with RETE networks) up to ~100000 fit into 1-1.5GB RAM (VIATRA model space limitations)
  - Grows linearly with model size (as expected)
  - Nature of growth is pattern-dependent
- Network construction overhead
  - Similar to memory; pattern-dependent.
  - PN: In the same order as VIATRA's LS heuristics initialization.

Execution times



Benchmarking summary

- Predictable near-linear growth
  - As long as there is enough memory
  - Certain problem classes: constant execution time ☺
  - A ga

- Strategies
  - Improve the construction algorithm
    - Memory efficiency (node sharing)
    - Heuristics-driven constraint enumeration (based on pattern [and model space] content)
  - Parallelism
    - Update the RETE network in parallel with the transformation
    - Parallel network construction
  - ?

Future work

- Ongoing research
  - Extending the Varro benchmark
    - Mutex STS/LTS
    - ORM
  - Extended benchmarking use cases
    - Simulation (model execution)
    - Synchronization
    - Constraint evaluation
  - Parallel transformations

- Problem: MT is mostly batch-like
  - But models are constantly evolving → Frequent re-transformations are needed for
    - mapping
    - synchronization
    - constraint checking
    - …
- An incremental PM can solve the performance problem, but a formalism is needed
  - to specify *when* to (re)act
  - and *how.*
- Ideally, the formalism should be MT-like.

Event-driven live transformations (cont'd)

- An idea: represent events as model elements.
- Our take: represent events as changes in the matching set of a pattern.
  - ~generalization
- Live transformations
  - maintain the context (variable values, global variables, …);
  - run as a "daemon", react whenever necessary;
  - as the models change, the system can react instantly, since everything needed is there in the RETE network: *no re-computation is necessary.*
- Paper accepted at ICMT2008.

- Incremental pattern matching support integrated into VIATRA2 R3
  - Based on the RETE algorithm
  - Provides full support for the pattern language
  - High performance in certain problem classes
- Future
  - Performance will be further improved
  - New applications in live transformations