Domain-Level Observation and Control for Compiled Executable DSLs

MODELS 2019 Foundations Track – Münich, Germany

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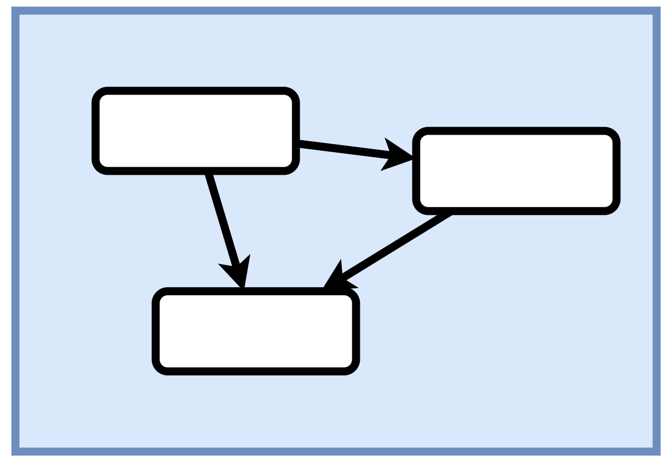
Dynamic Analysis of Behavioral Models

- Behavioral models (eg. state machines) can conveniently describe the behaviors of systems under design.
- Domain-specific languages (DSLs) can be engineered and used to build such models.
- Dynamic analyses of behavioral models are crucial in early design phases to see how a described behavior *unfolds over time*.

Require the possibility to *execute models* ⚙!



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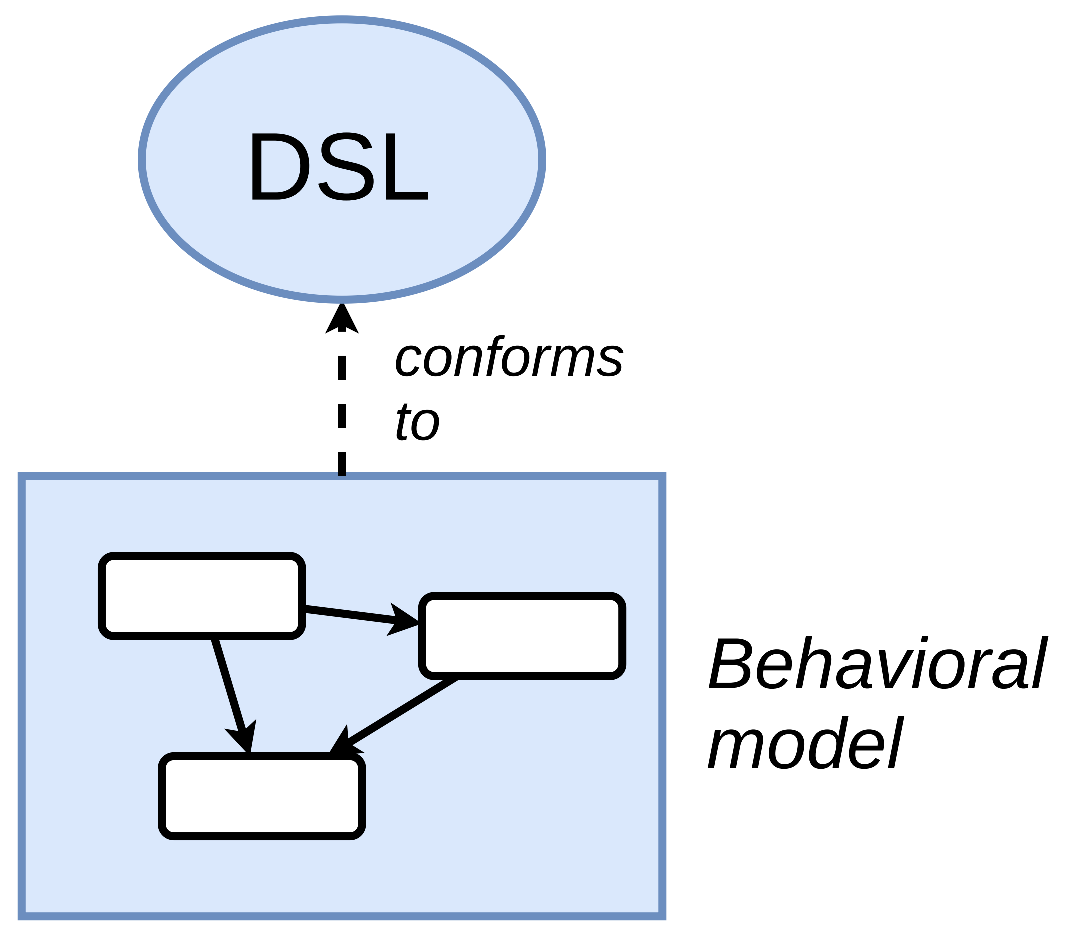

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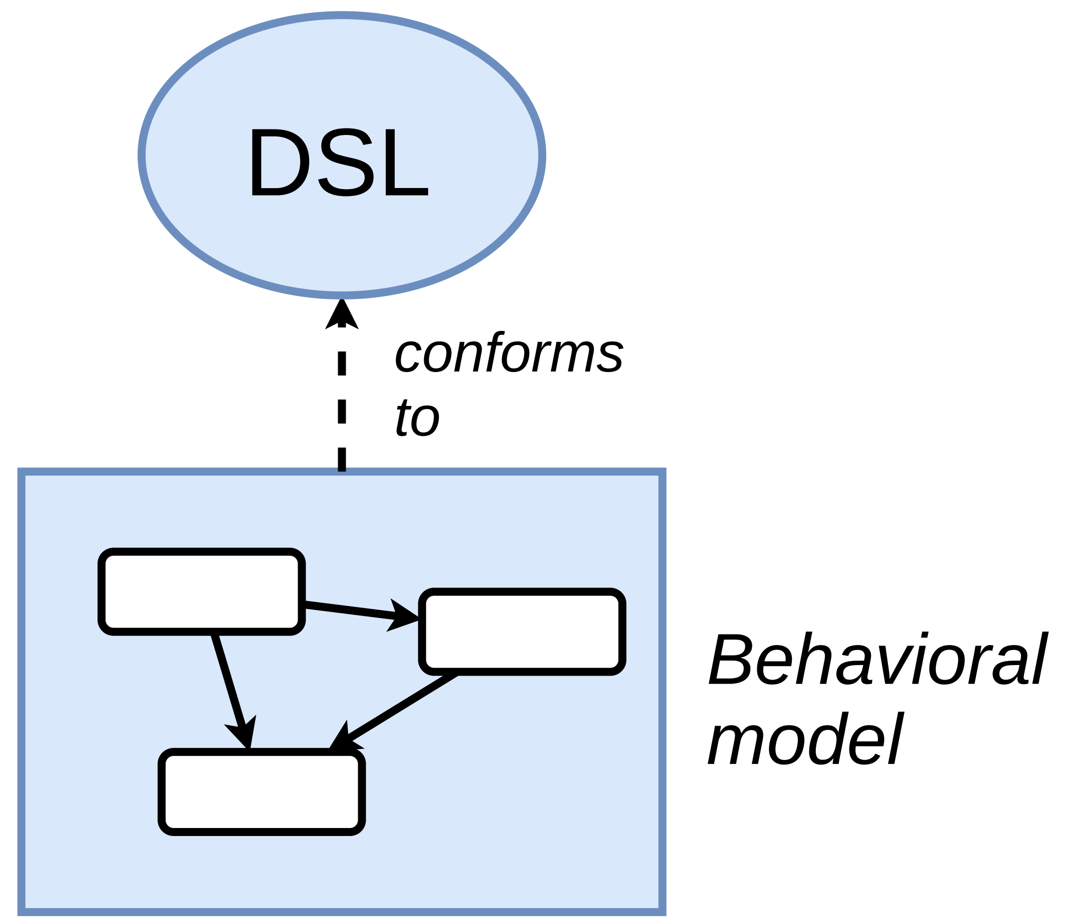

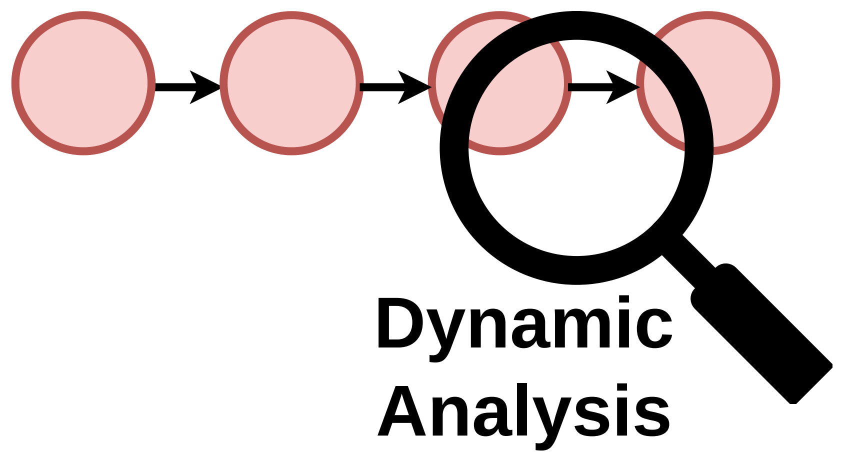

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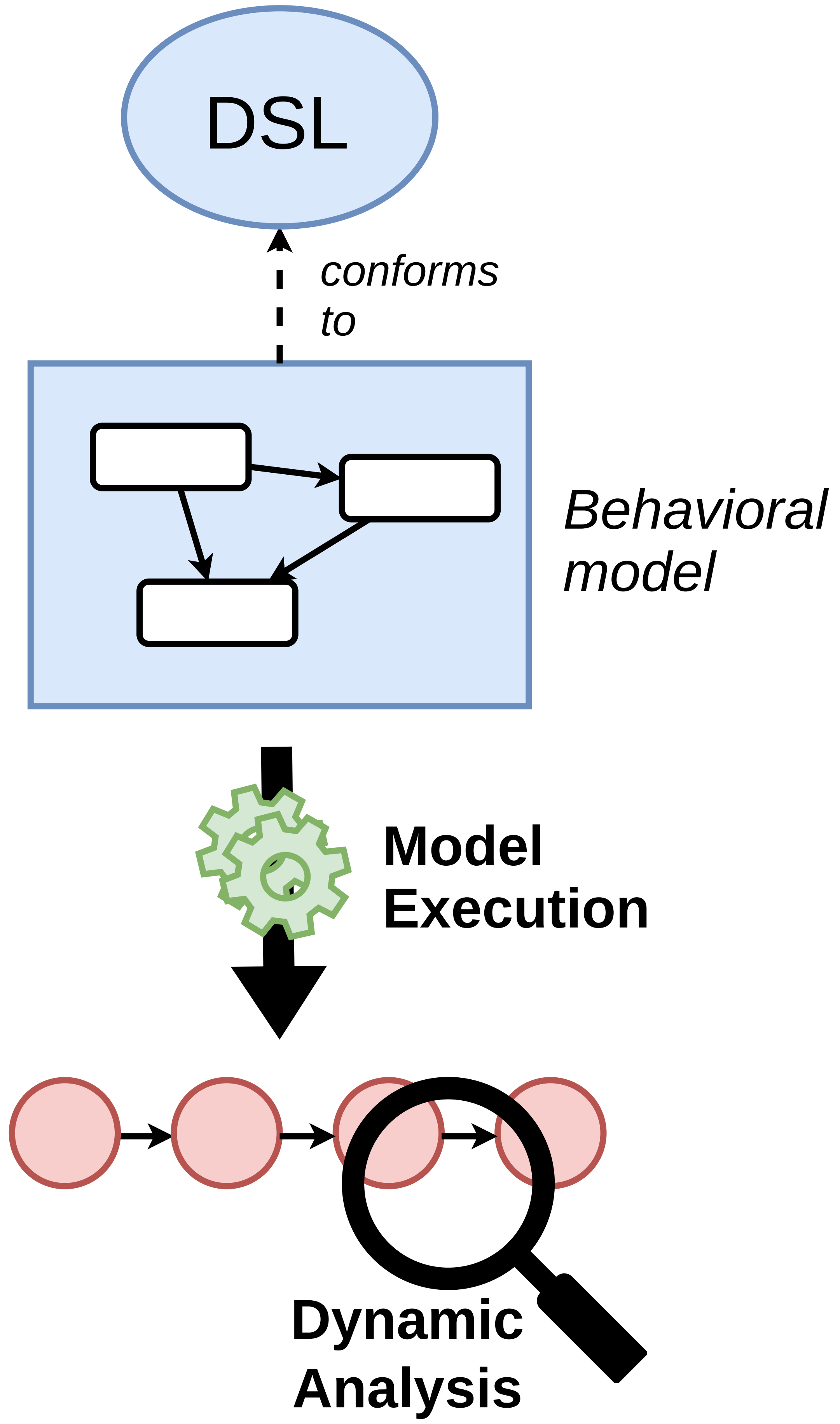
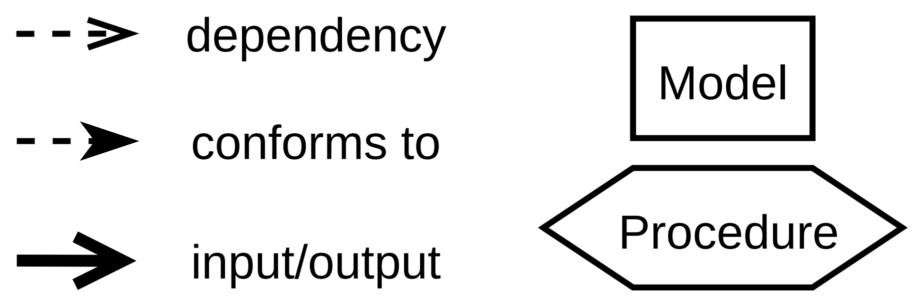


Model execution with an interpreted DSL



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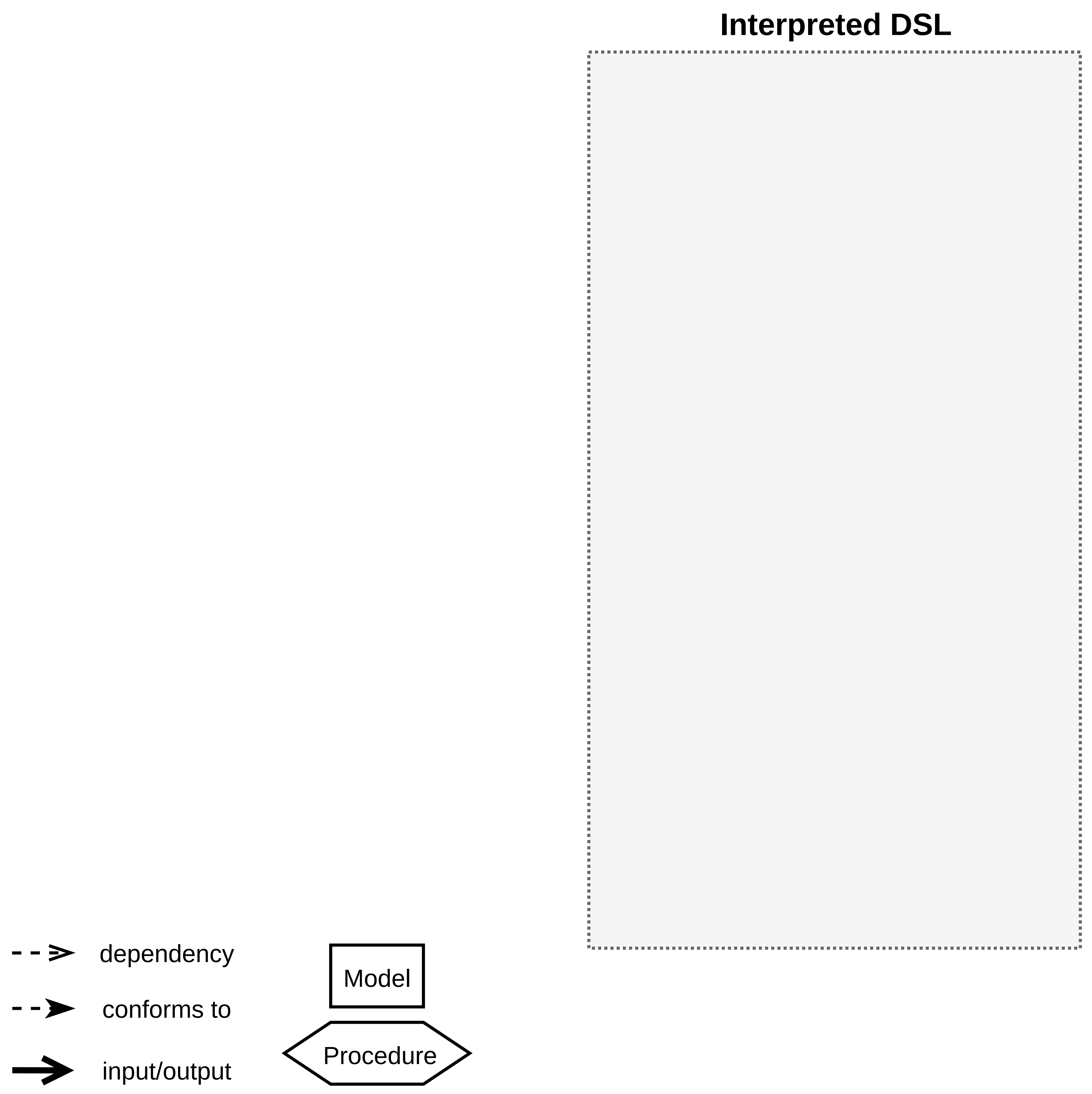

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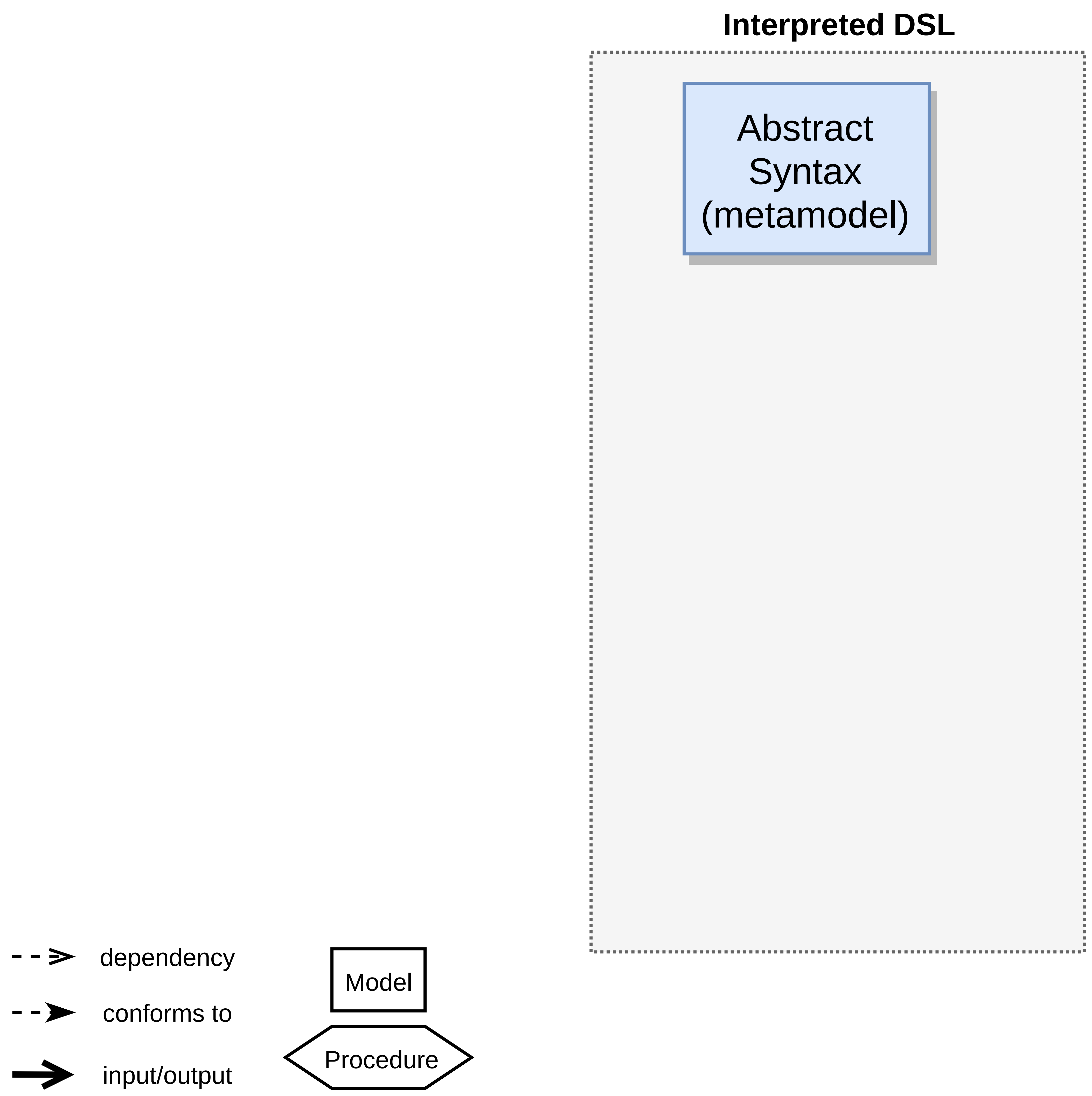

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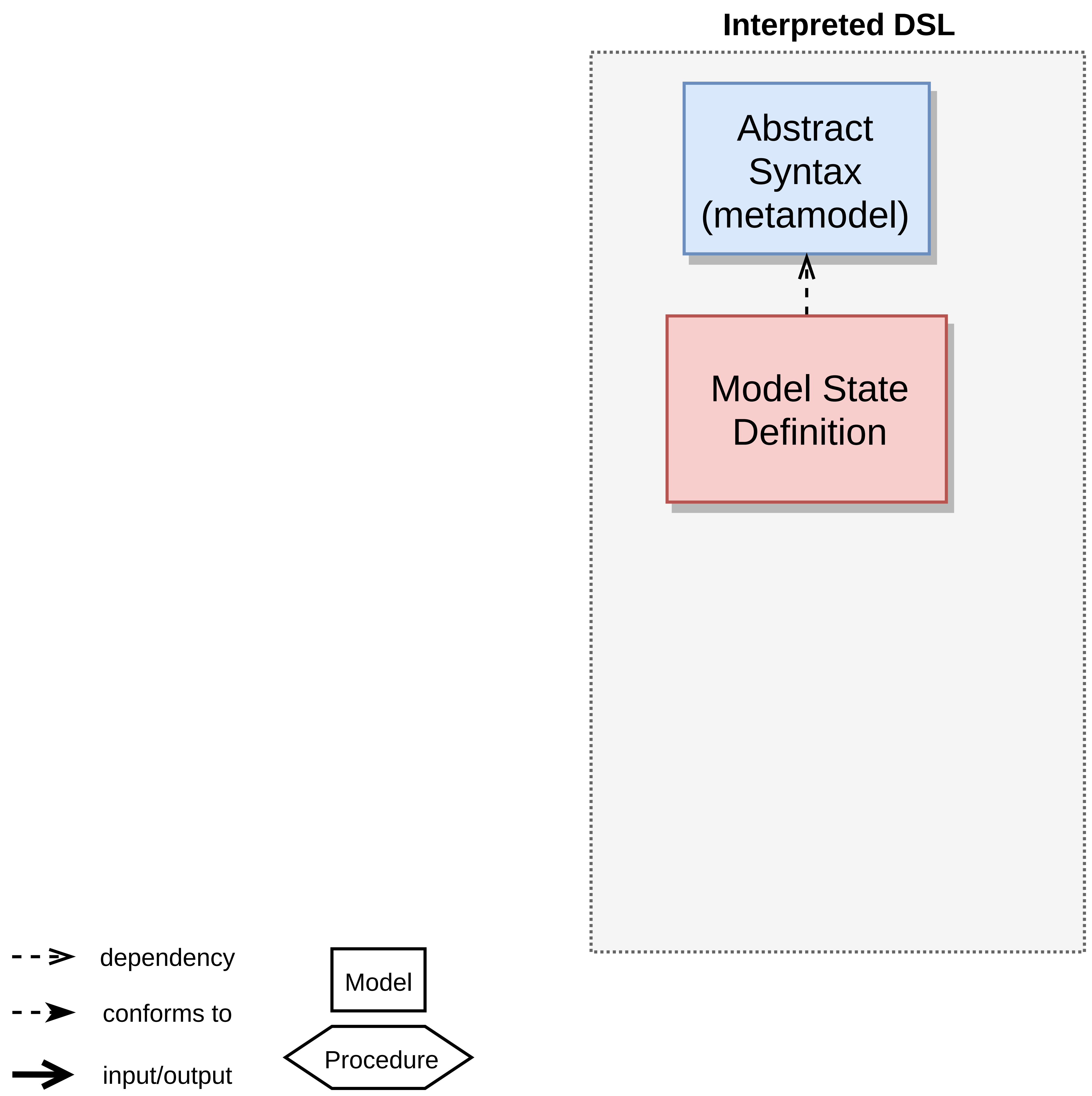

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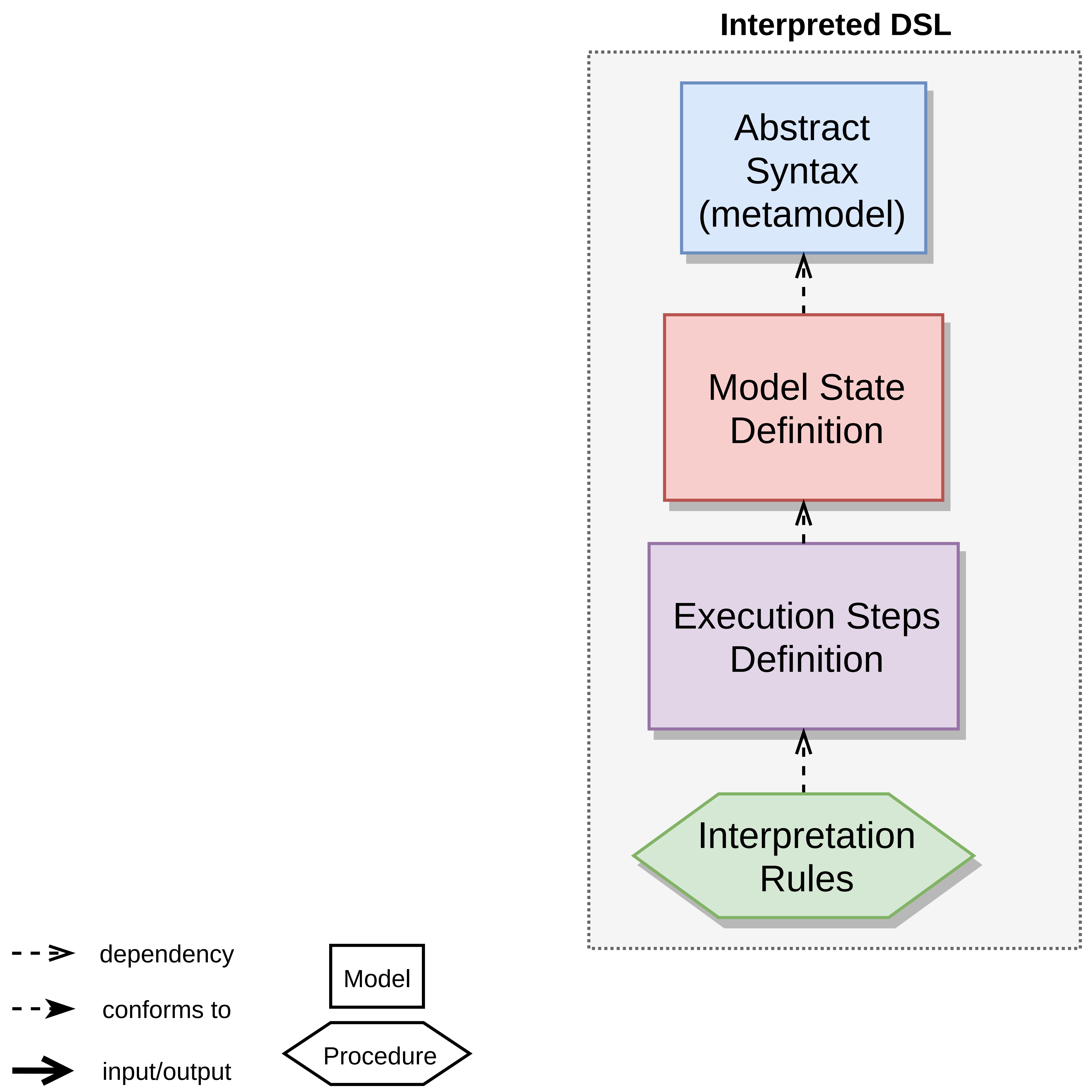

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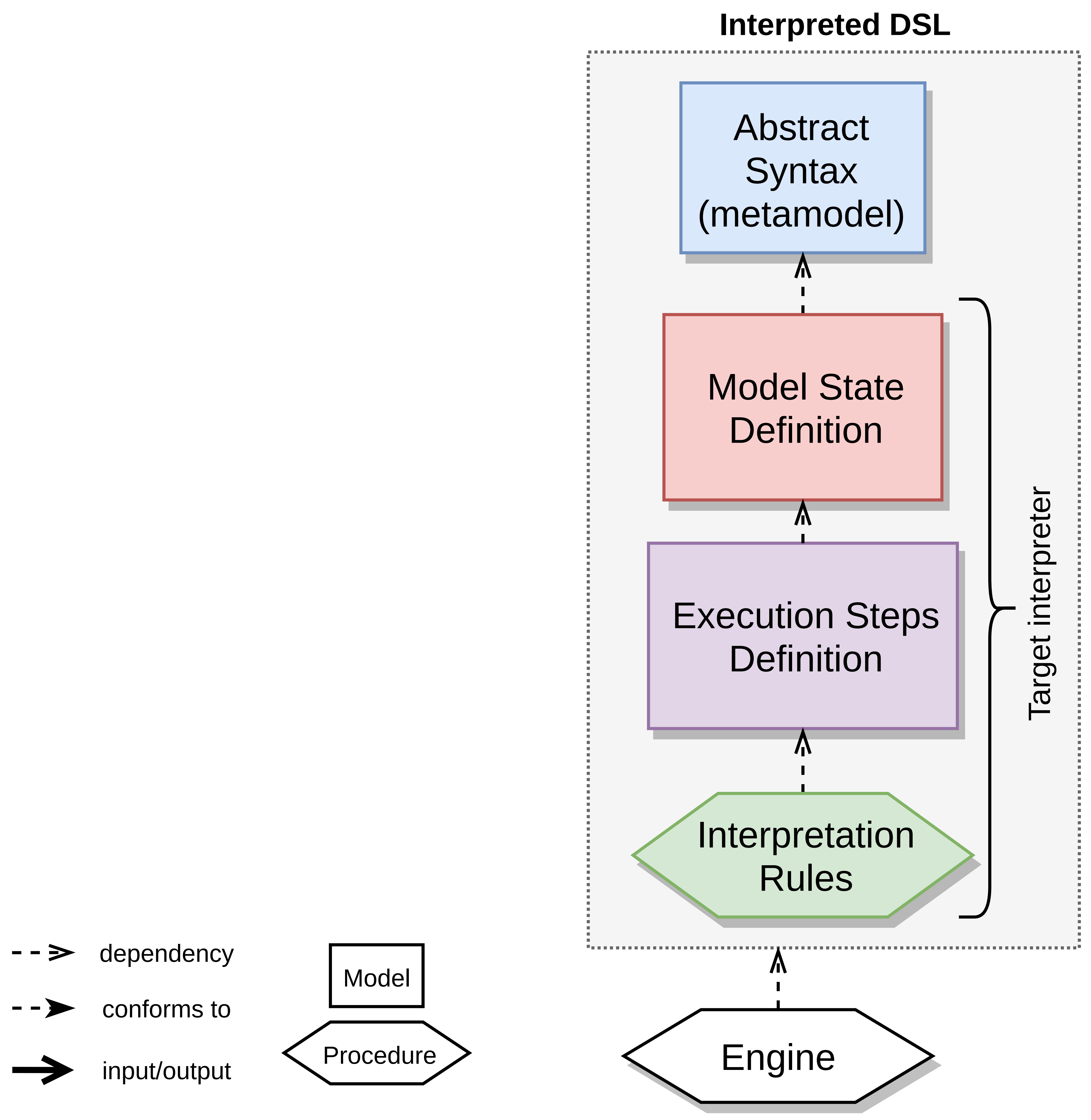

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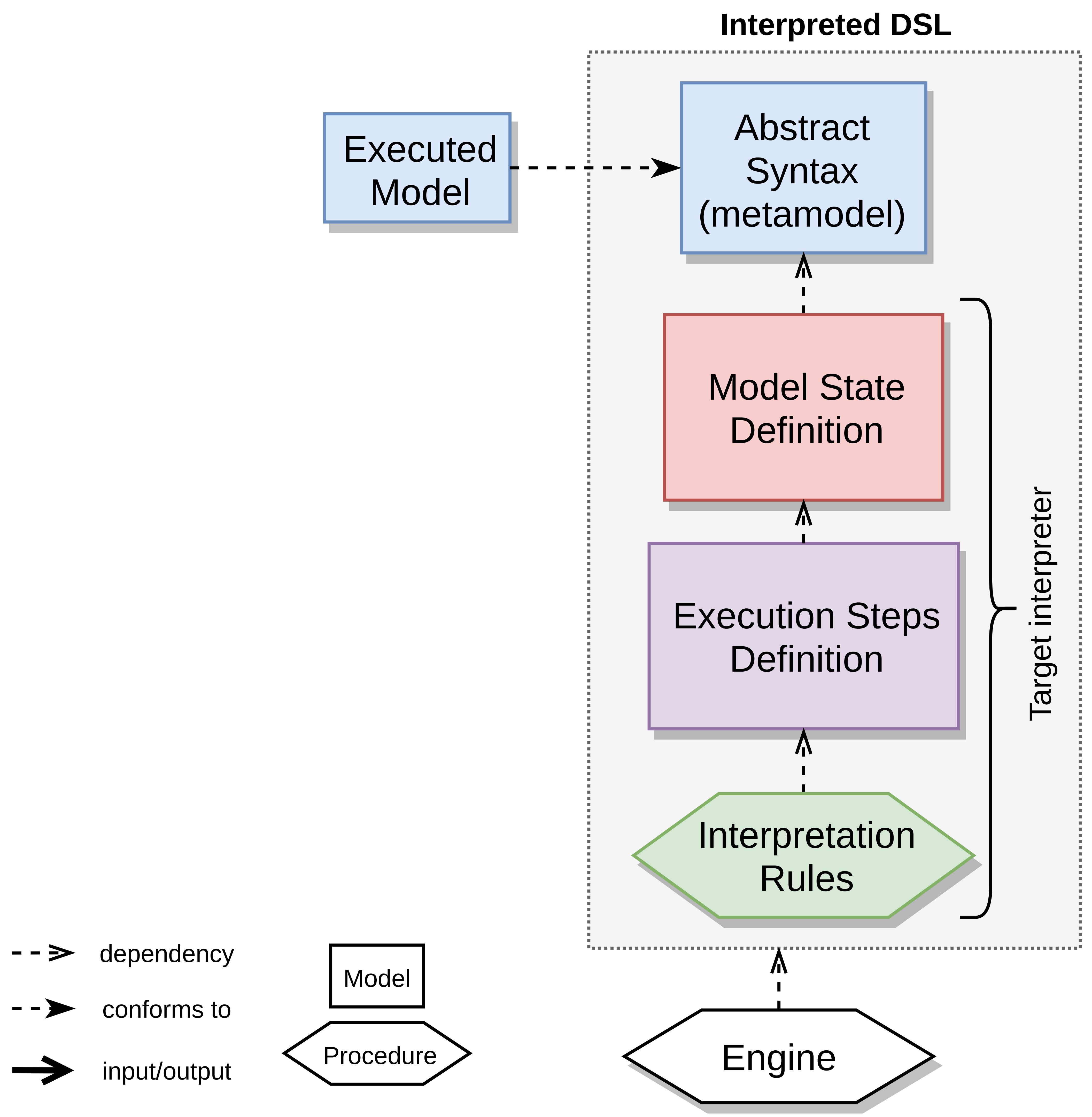

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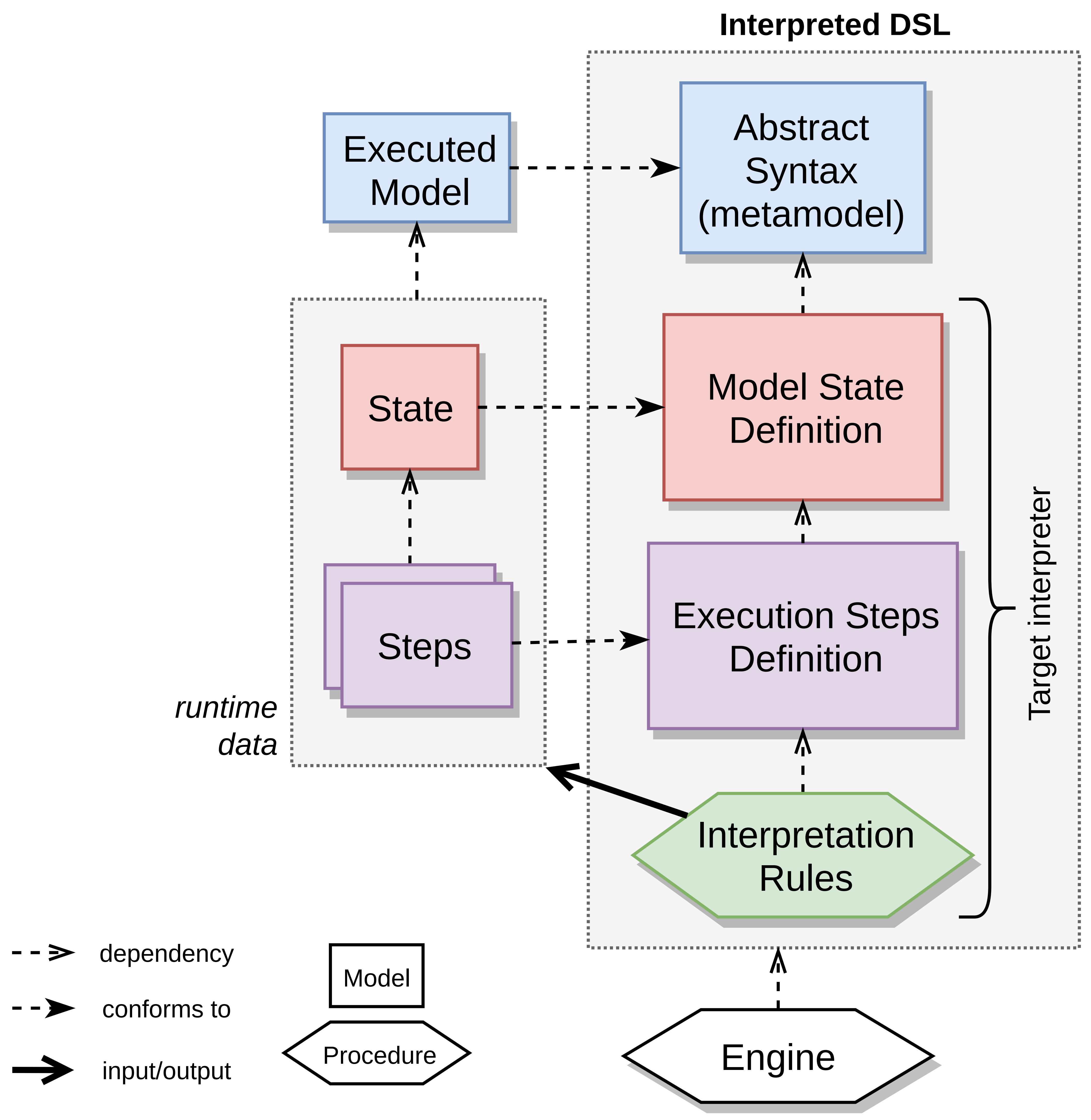

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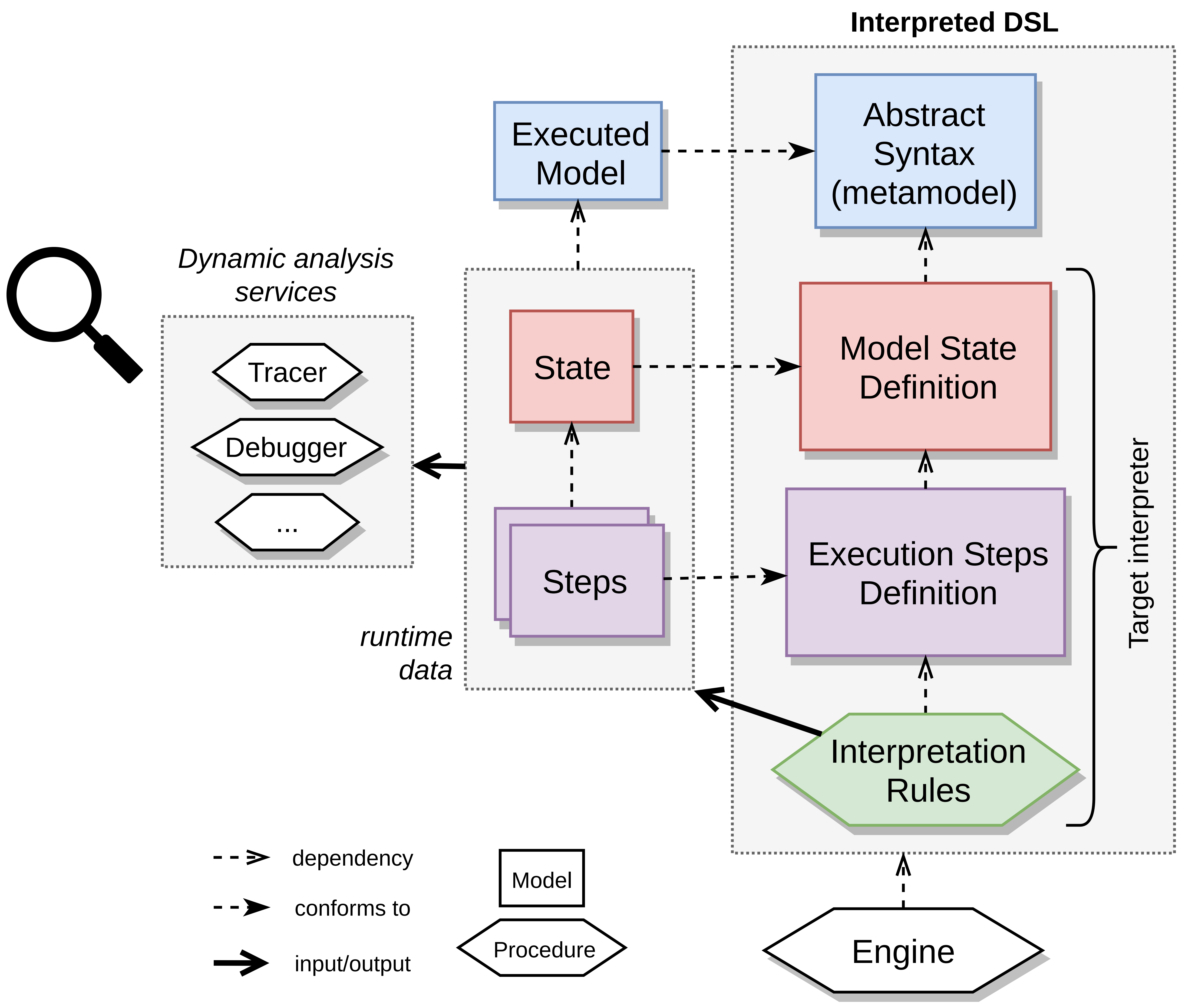

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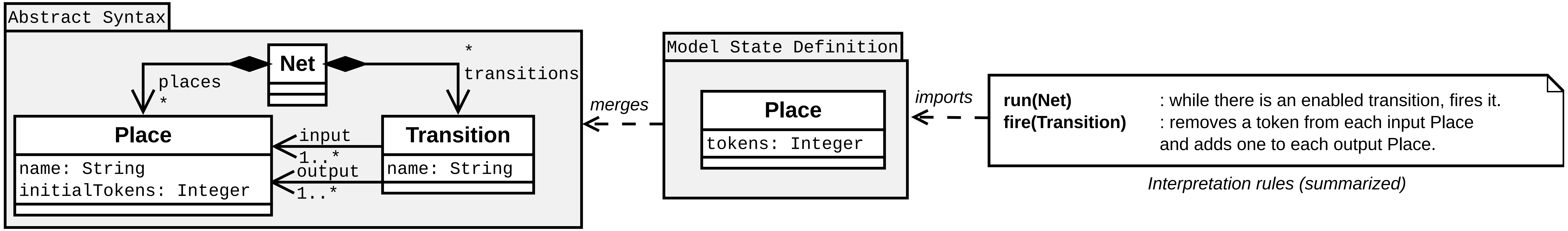

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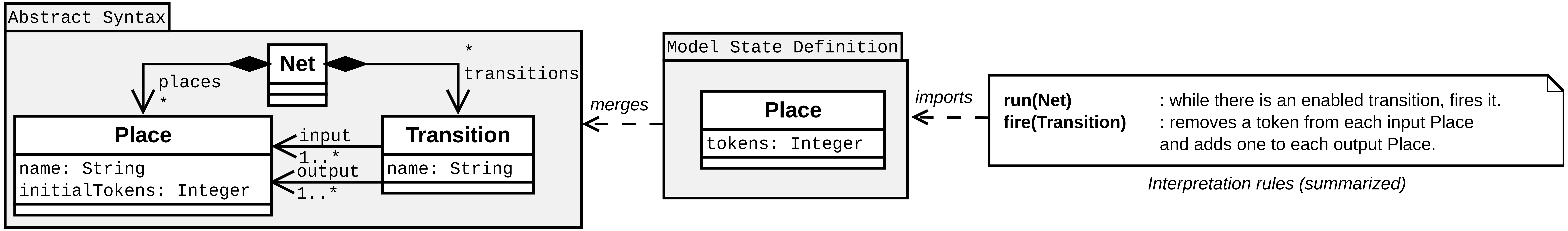

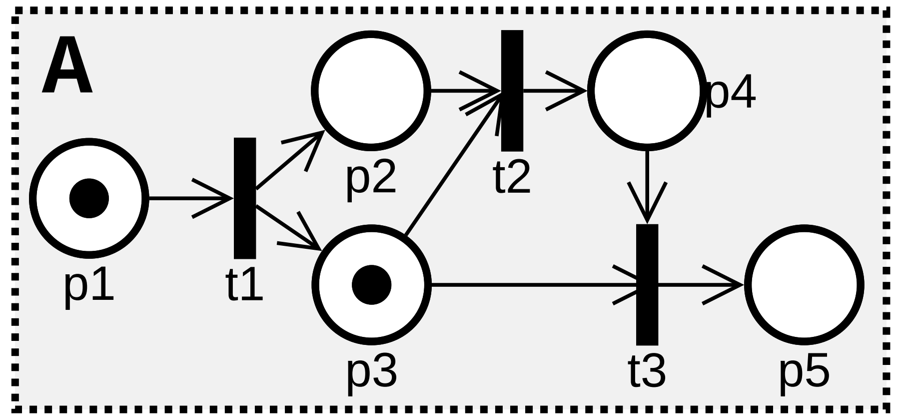

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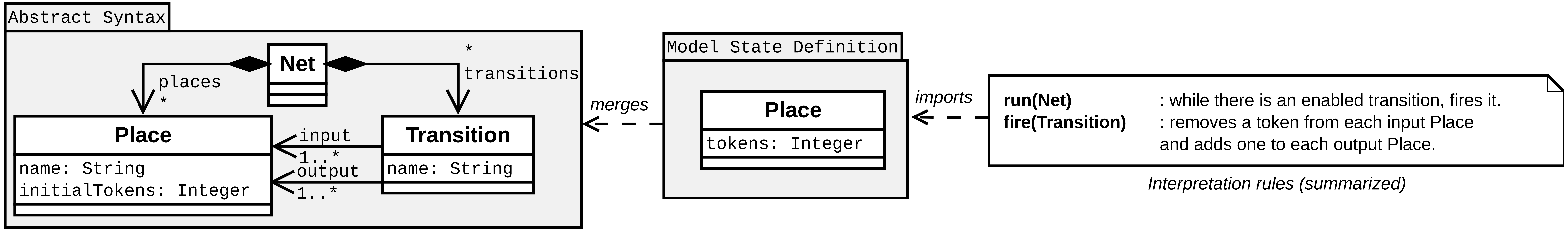

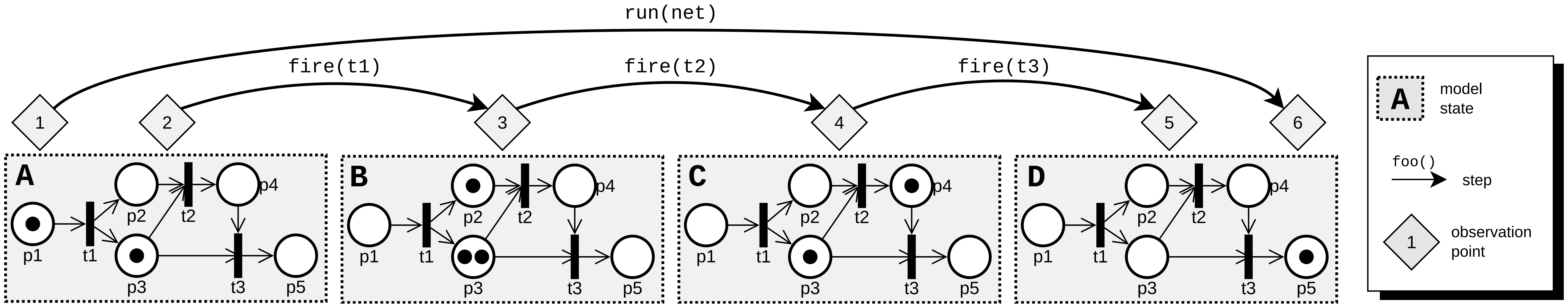

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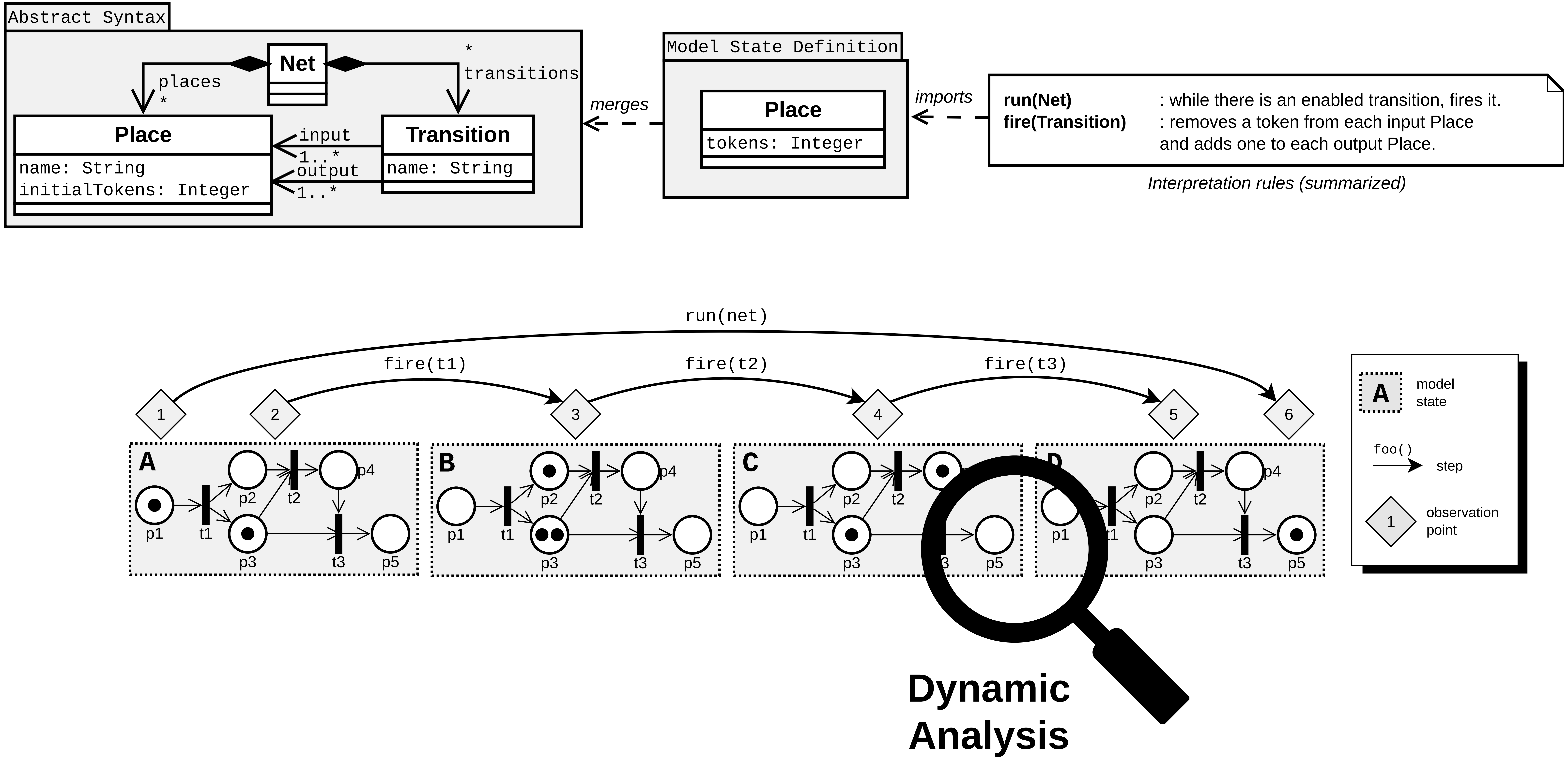
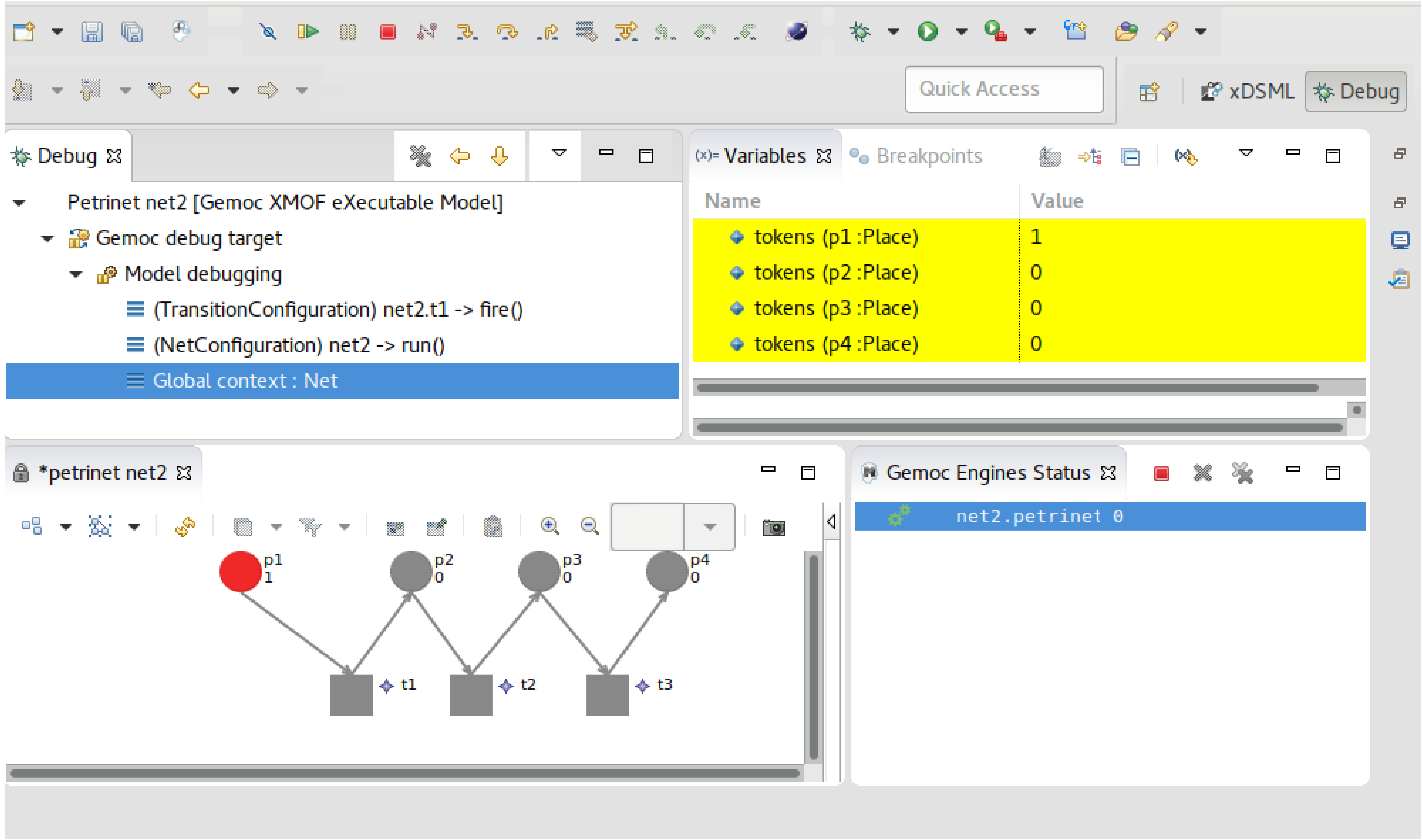


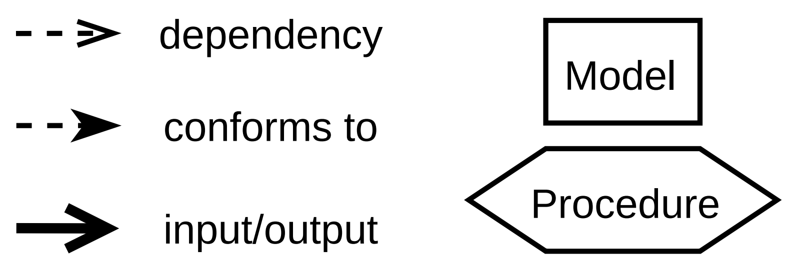
Debugging/Tracing an interpreted model in the GEMOC Studio



Question

What about DSLs built with a compiler (eg. a code generator) instead of an interpreter?

Model execution with a compiled DSL



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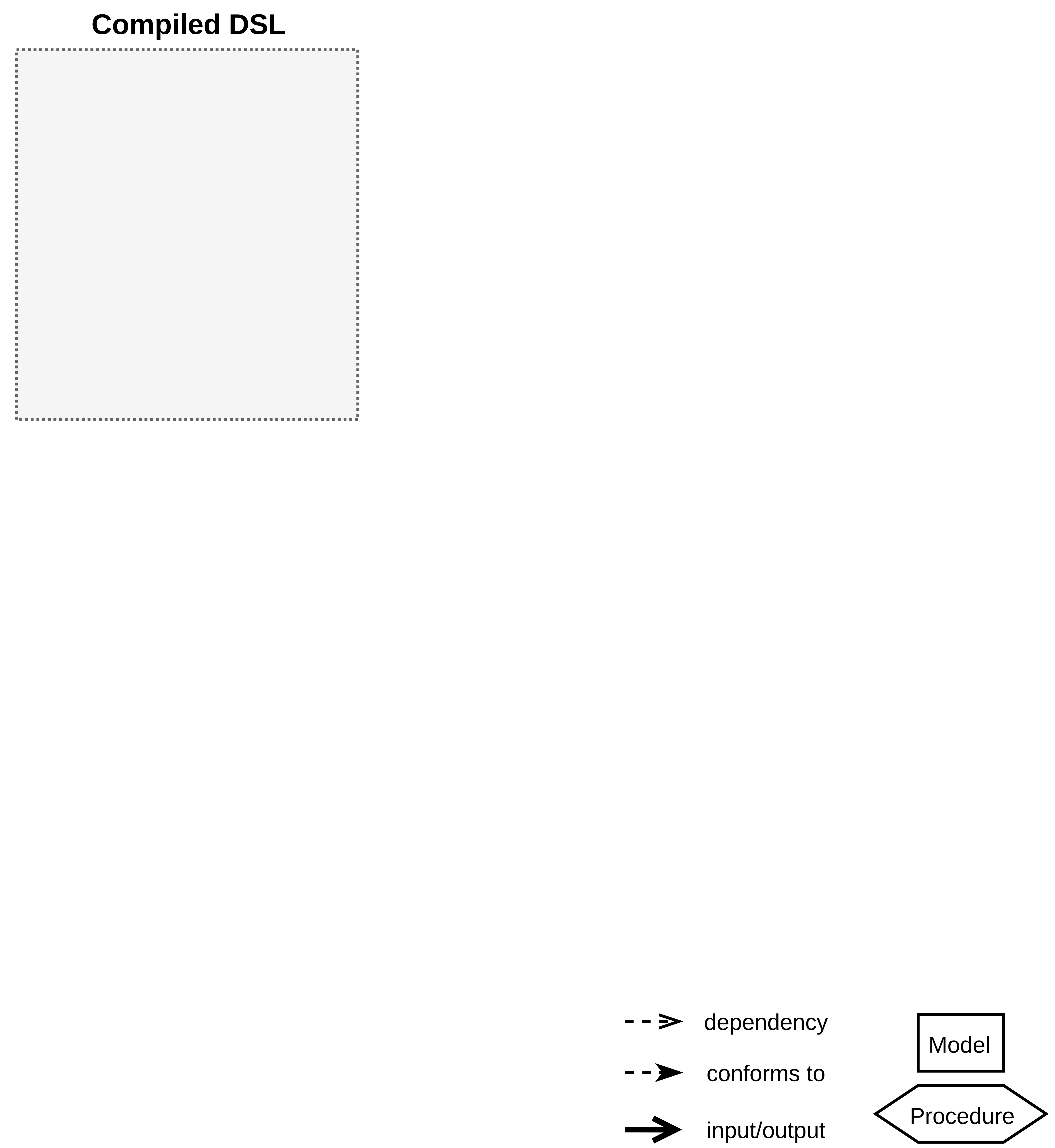

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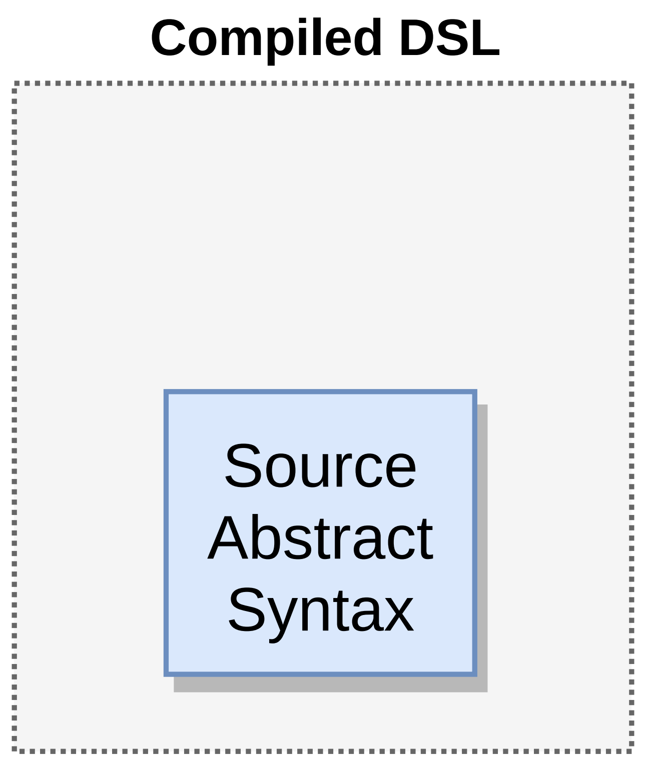

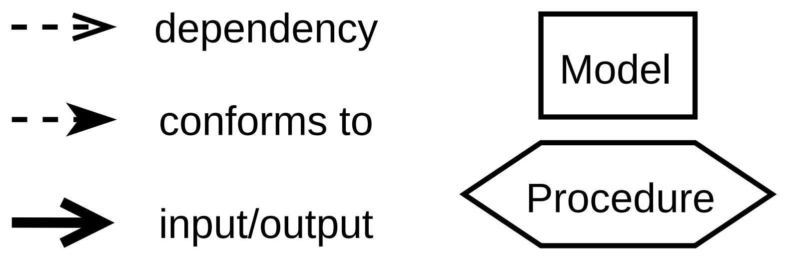

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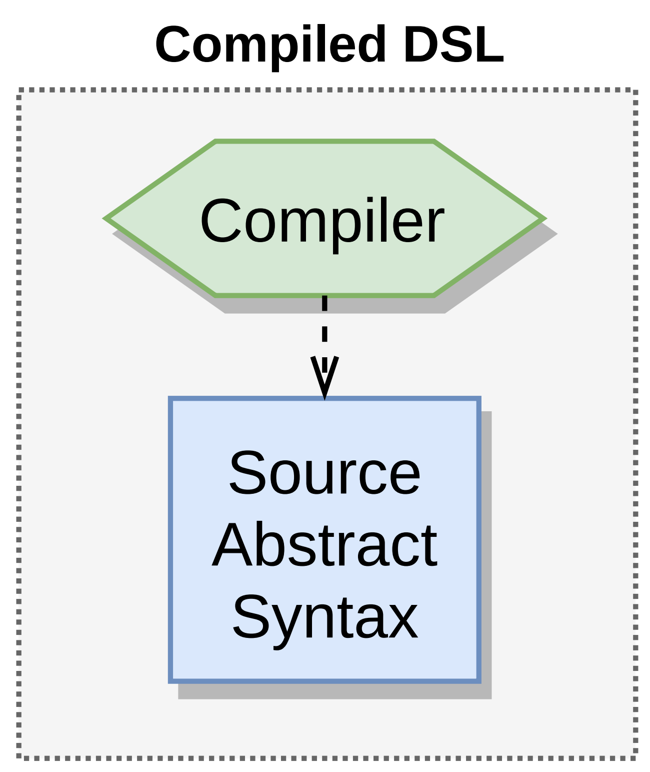

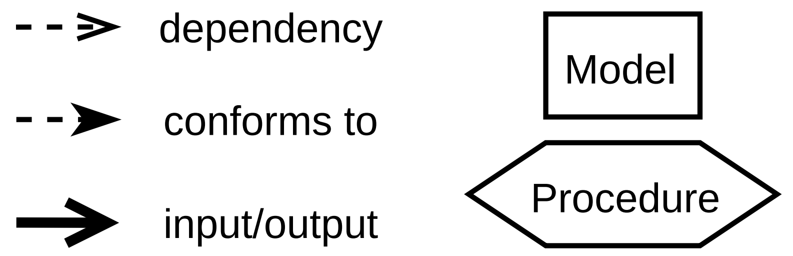

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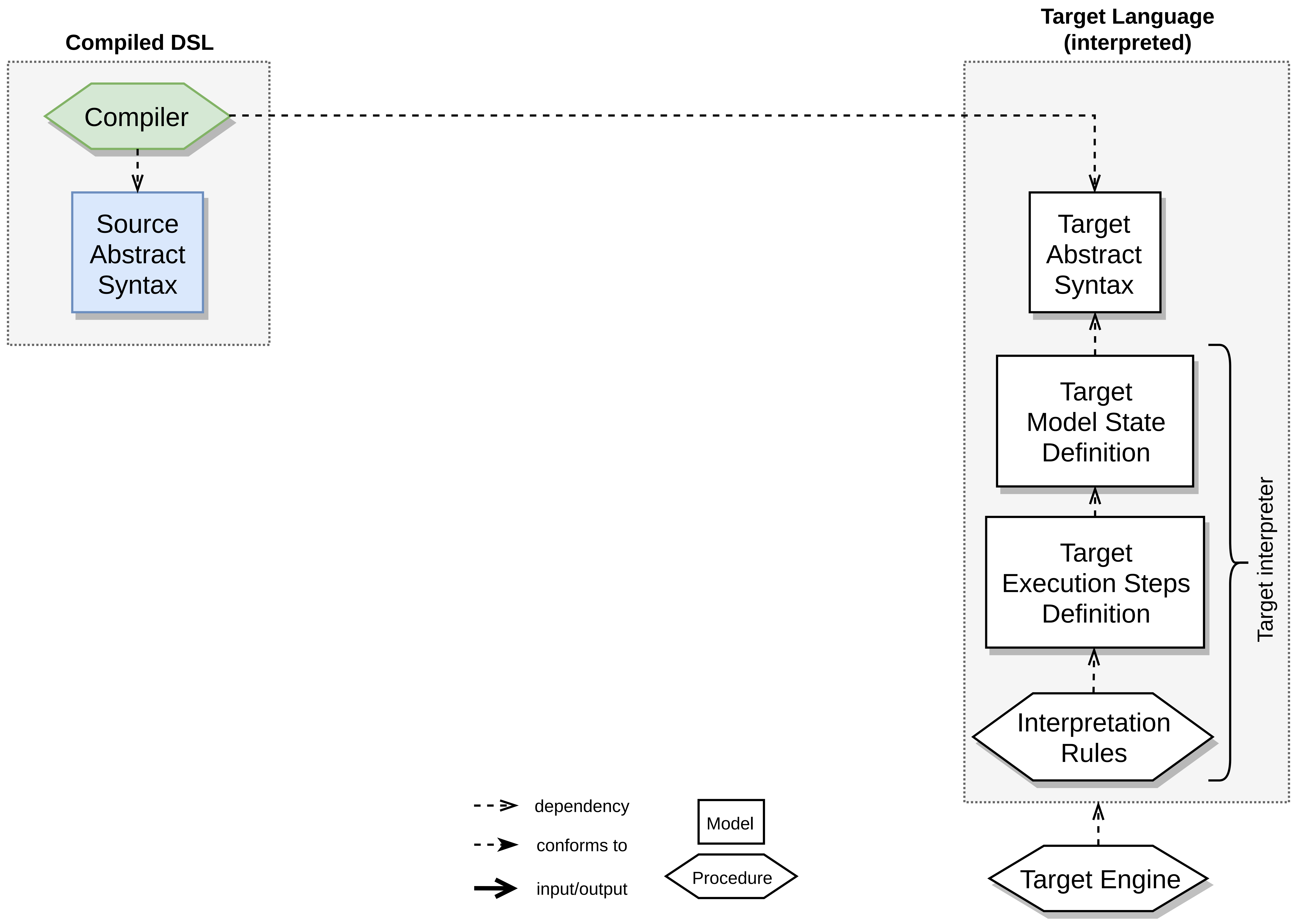

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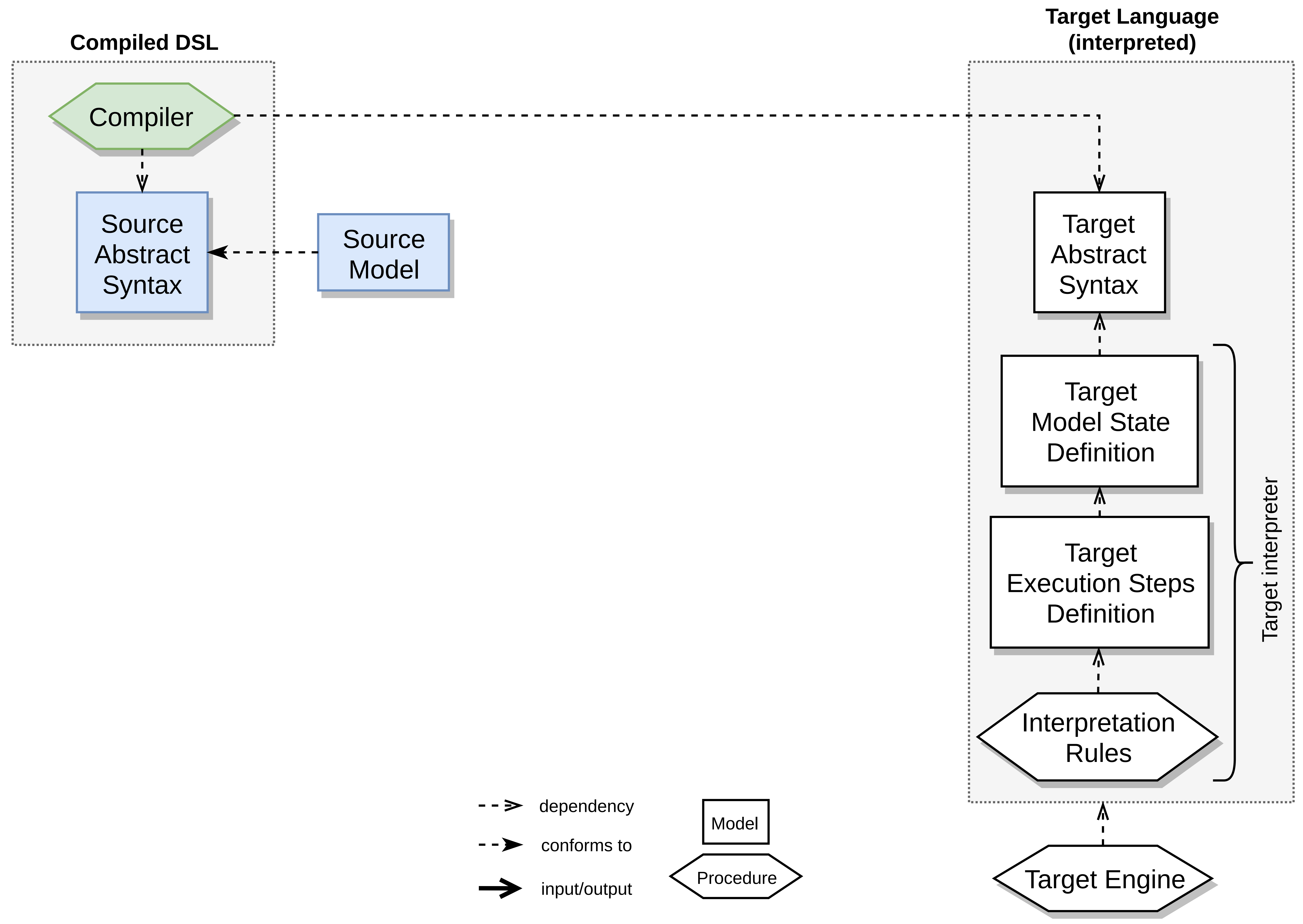

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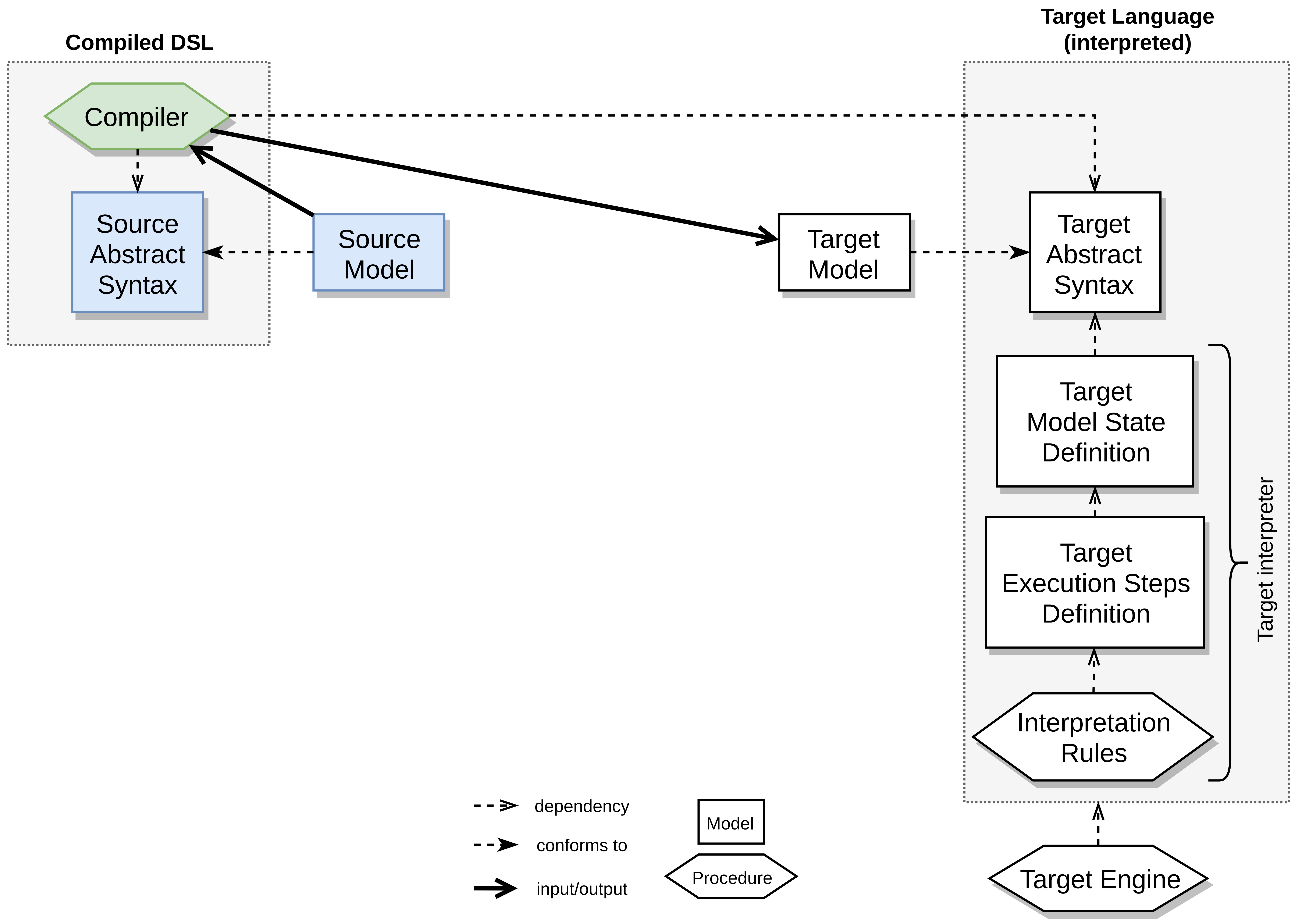

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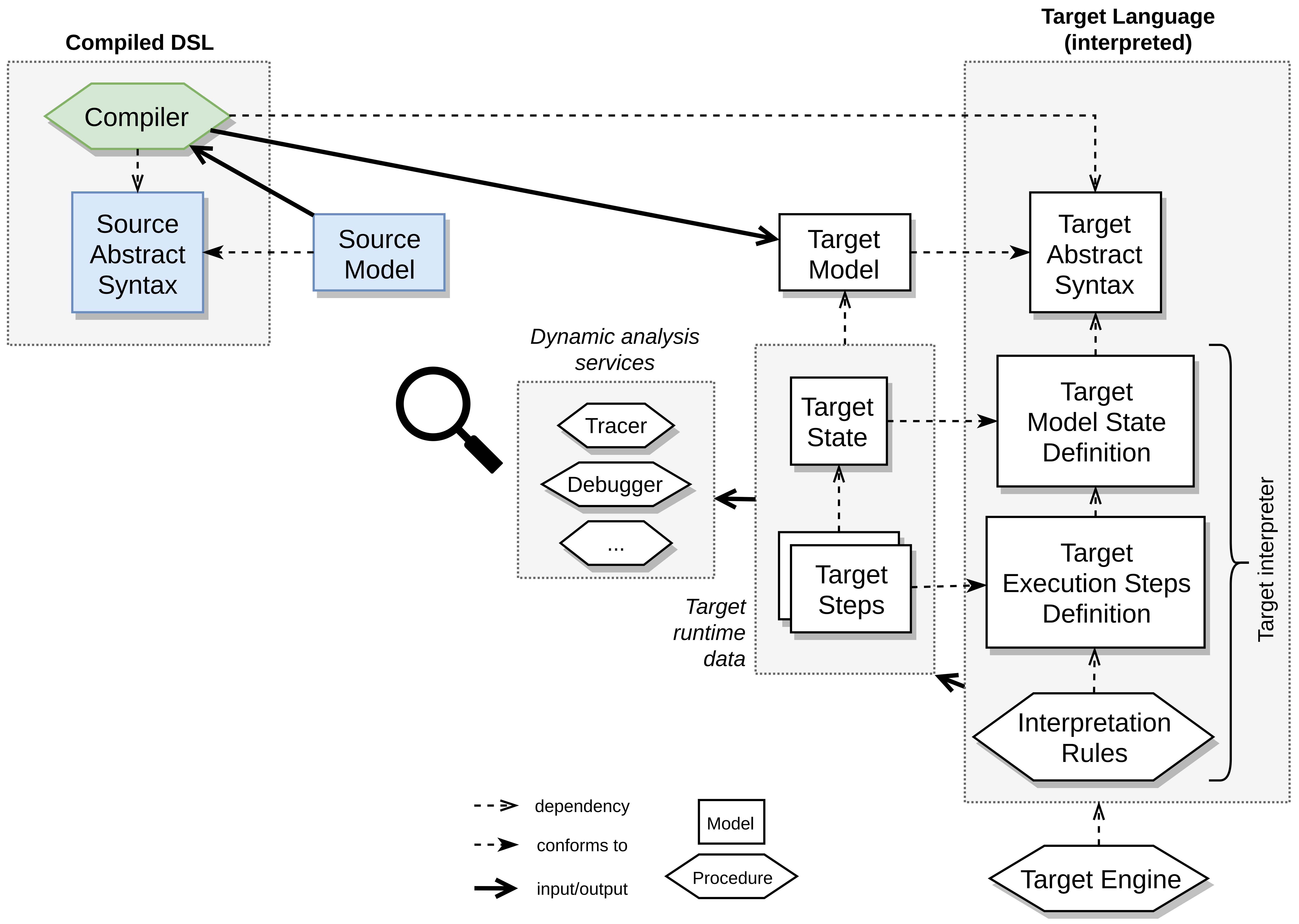

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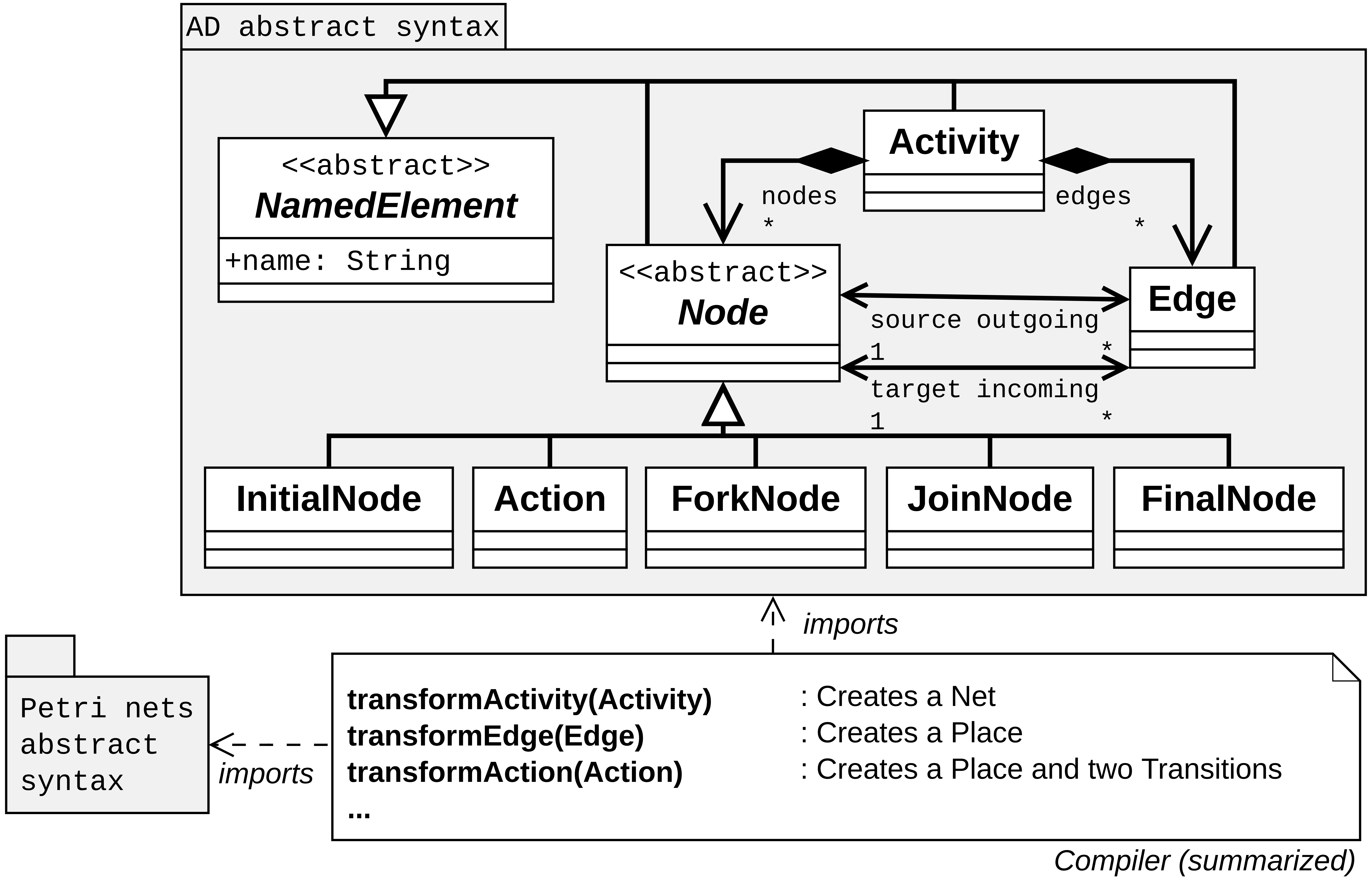
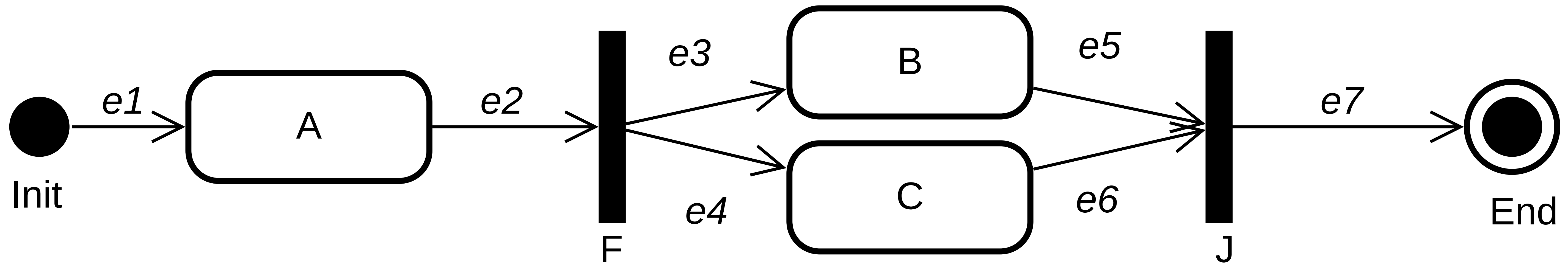


Example of a compiled DSL (2)



Source activity diagram

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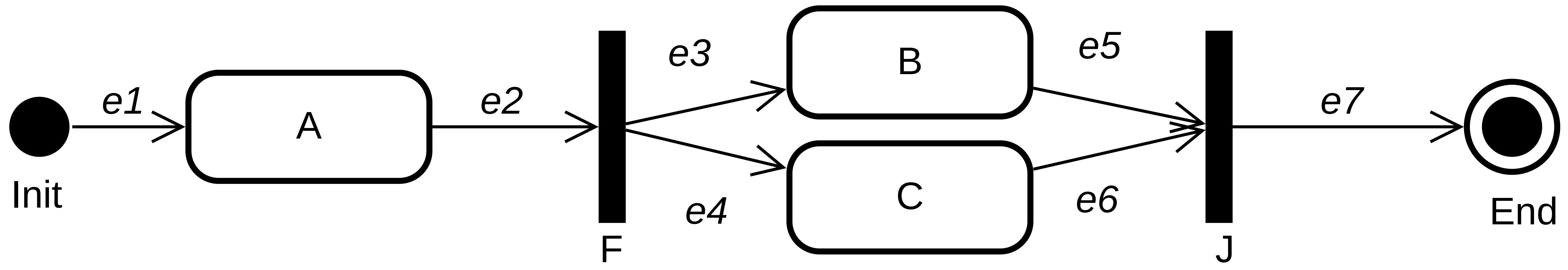

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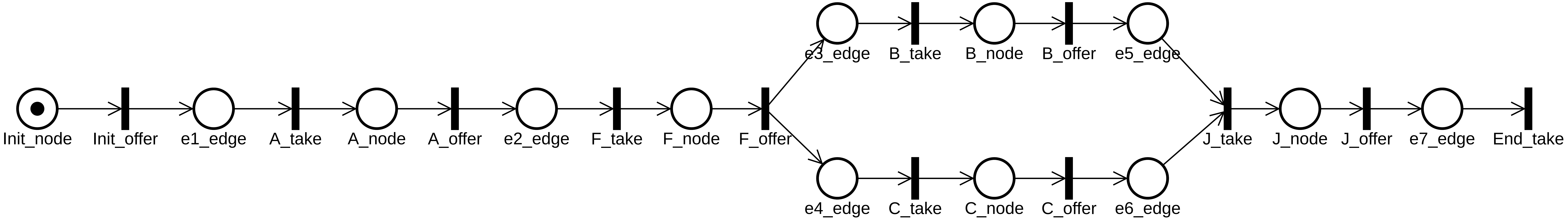
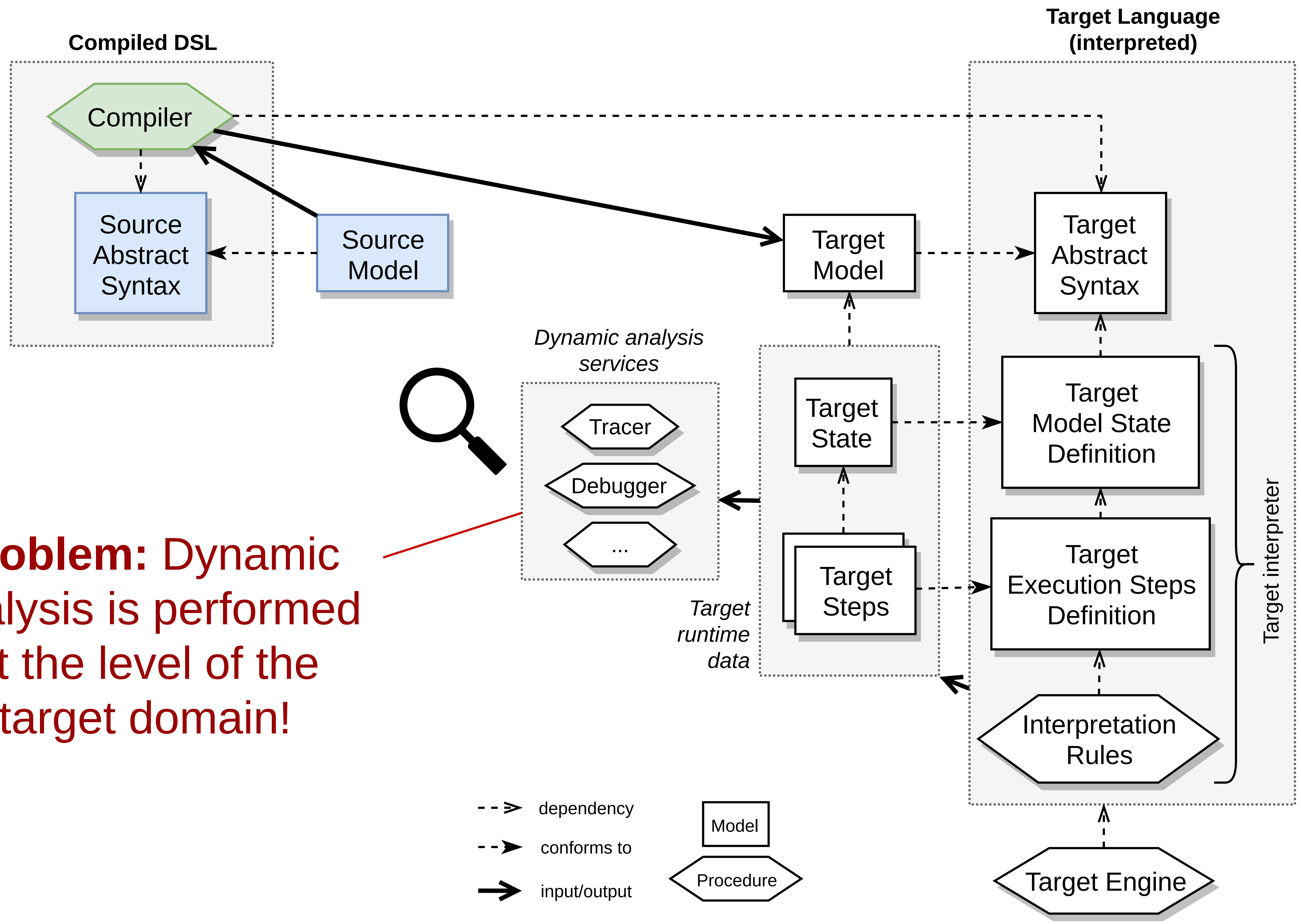


Target Petri net obtained after compilation

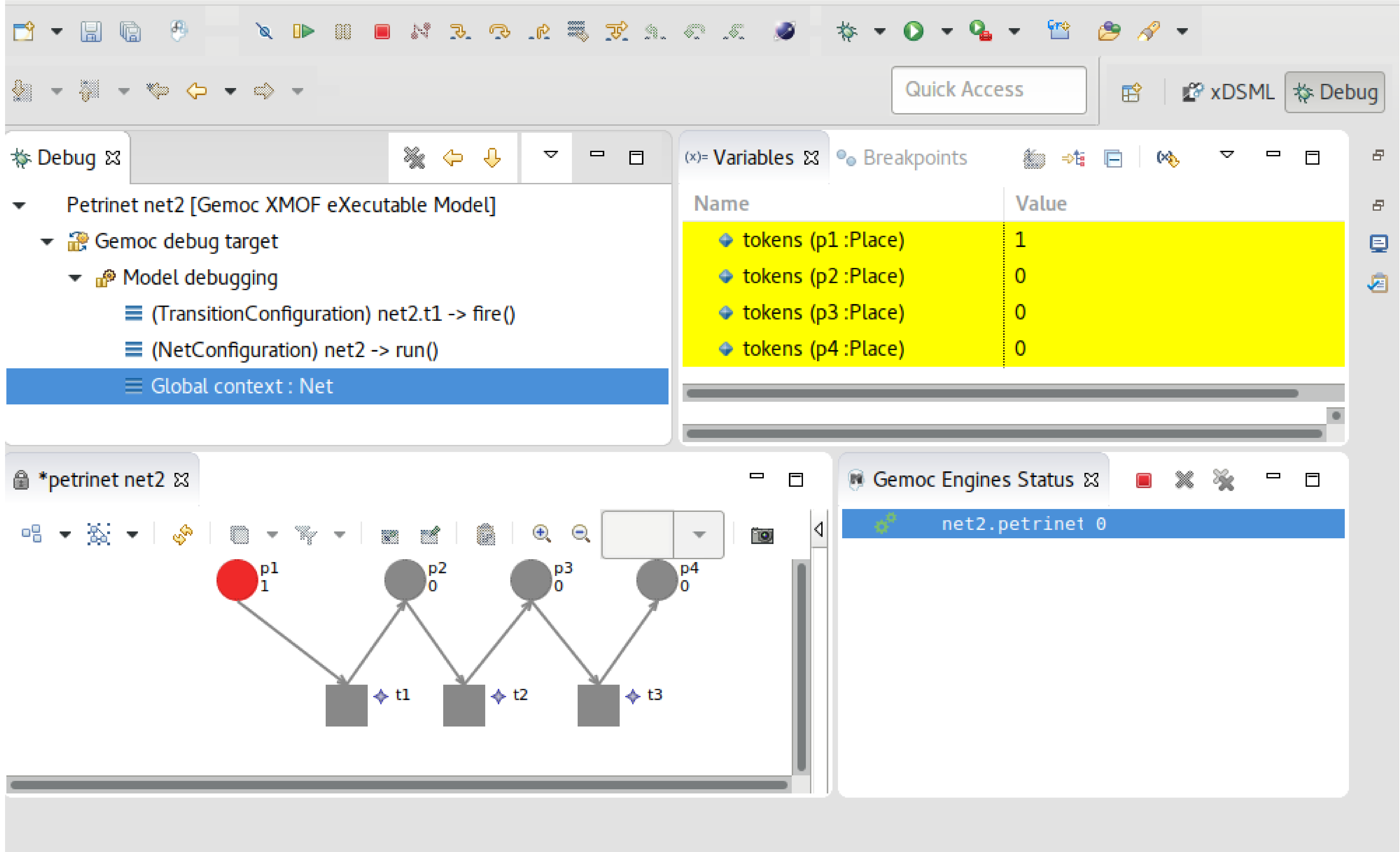
Problem (1)



Problem: Dynamic analysis is performed at the level of the target domain!

Problem (2)

ie. when debugging activity diagrams, we must use a petri nets debugger:



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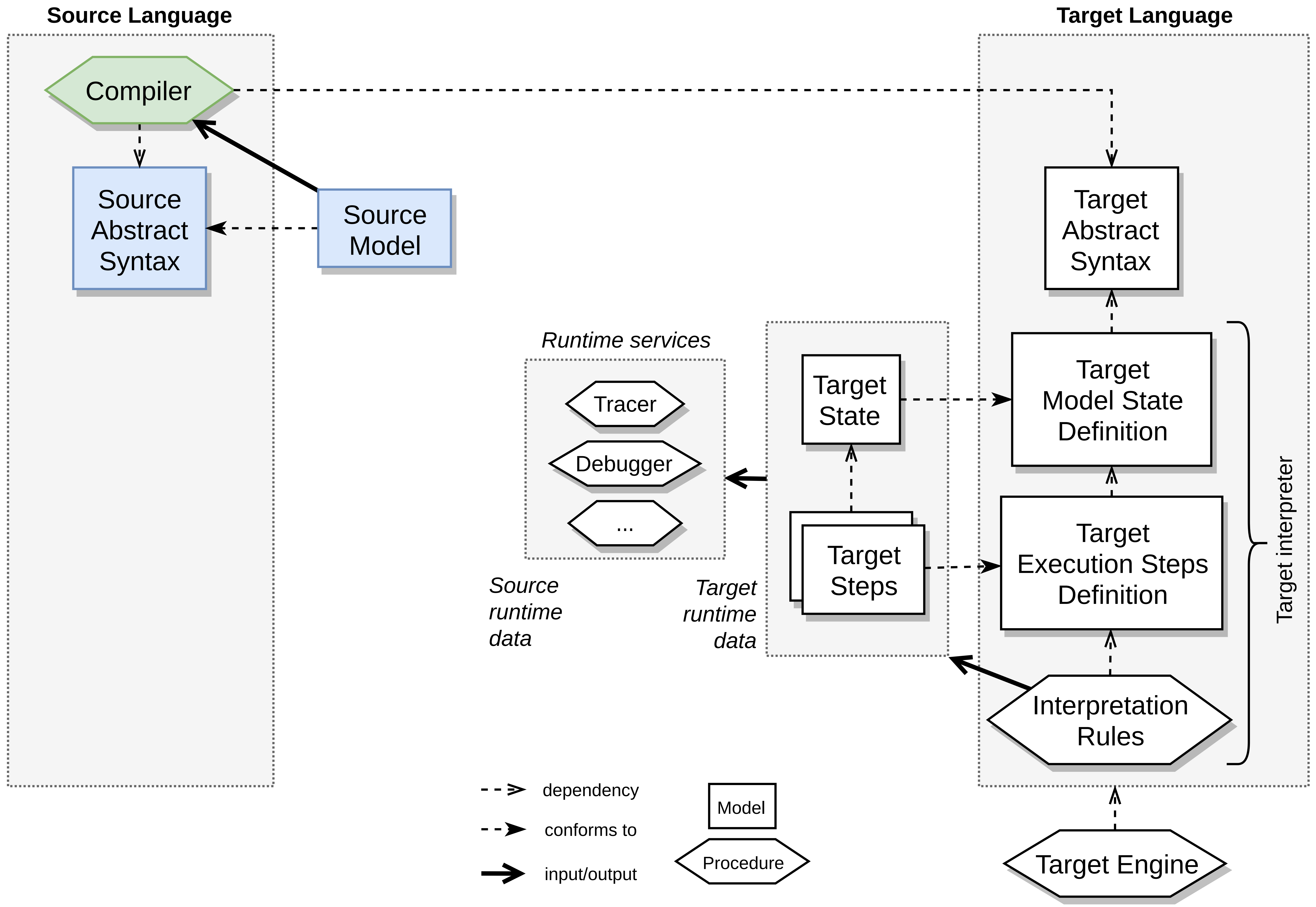
- But these debuggers result from ad-hoc language engineering work! This does not give us a systematic recipe for engineering new DSLs.

How can we engineer compiled DSLs compatible with *dynamic analyses at the source domain level*, just as common general-purpose programming languages?

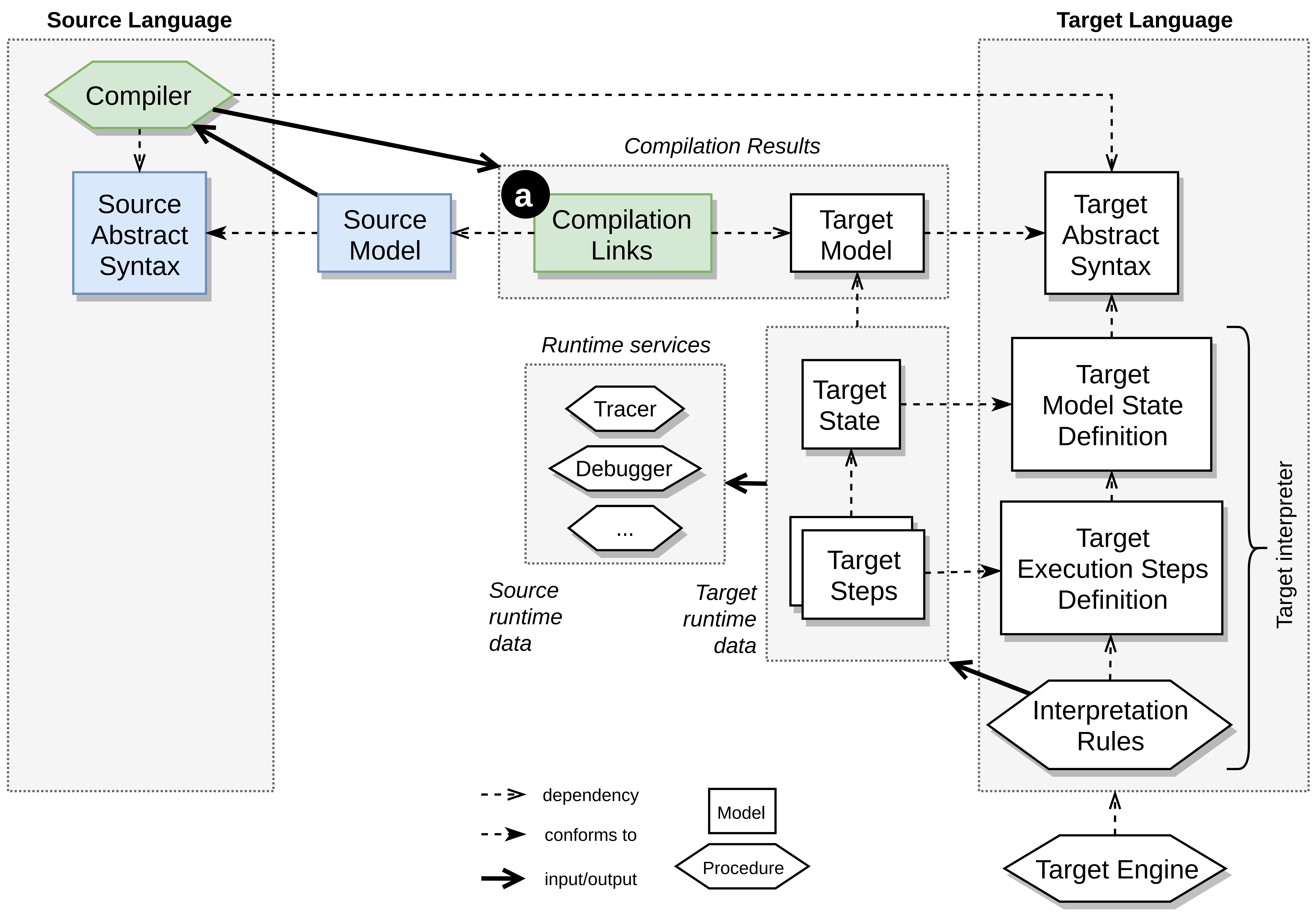
Contribution

An architecture to support observation and control for compiled DSLs.

Approach Overview



Approach Overview (1)



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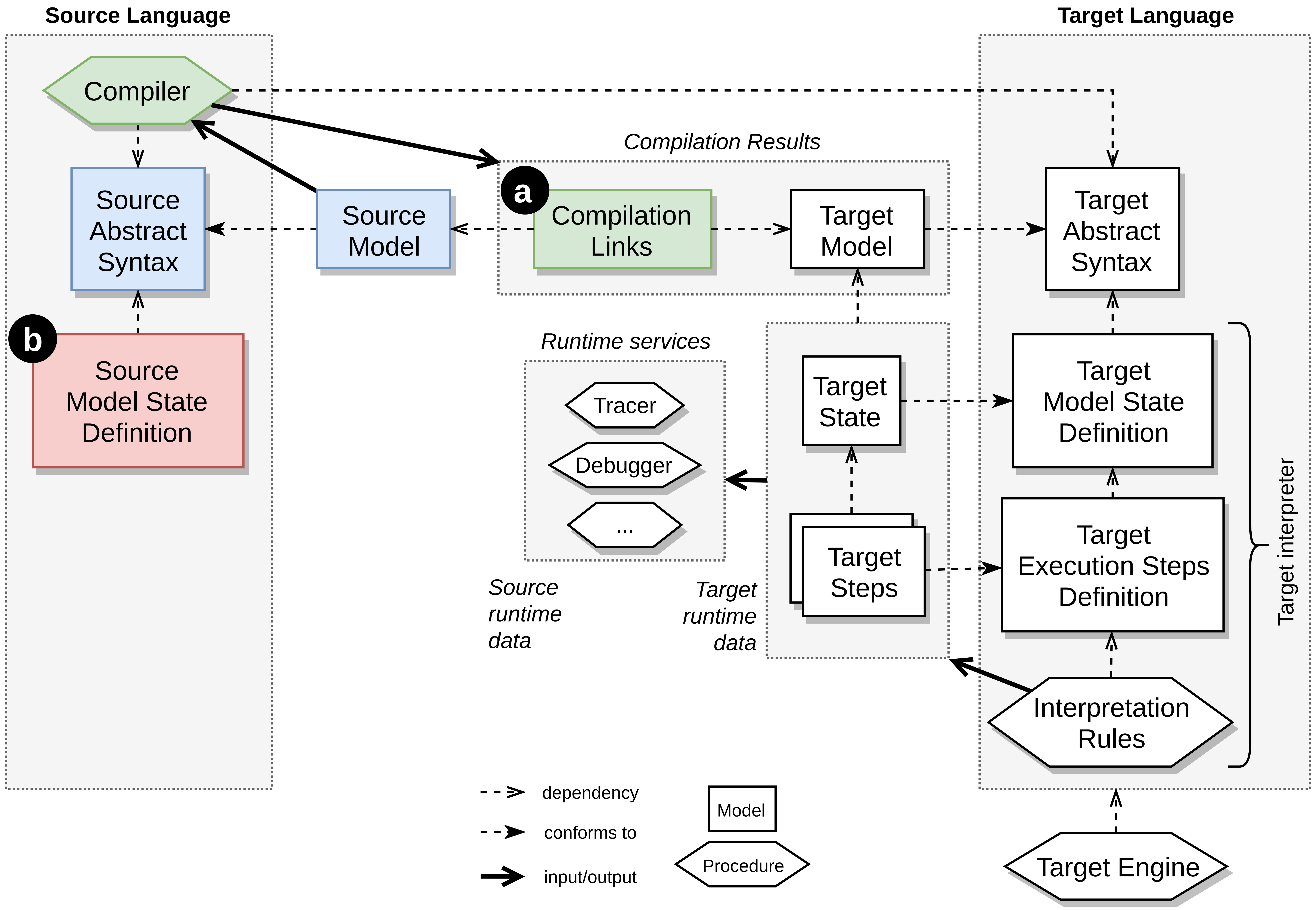

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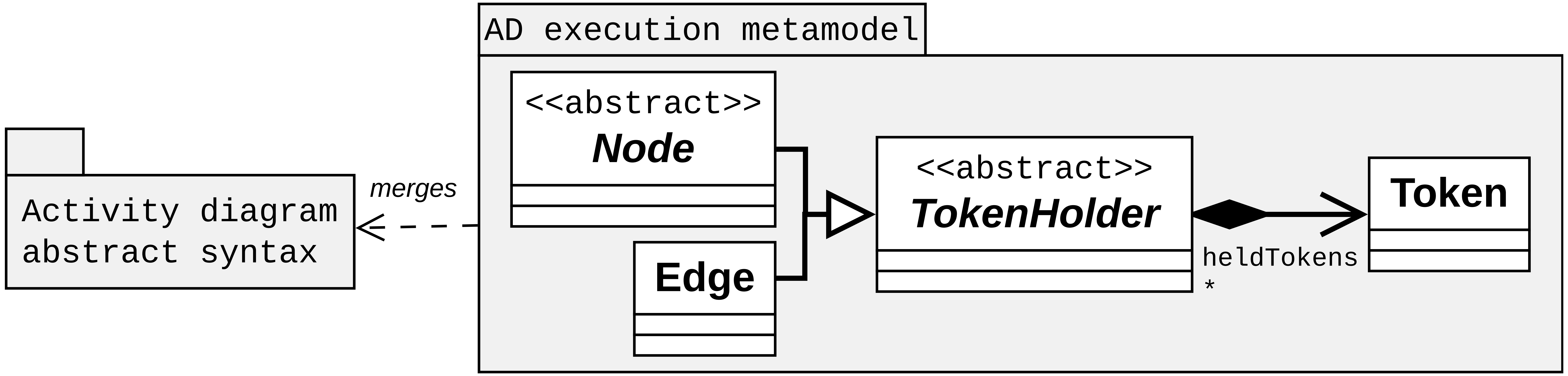
- But for compiled DSLs, everything related to execution is delegated to the target language, including the state definition.
- Hence, necessary to extend a compiled DSL with a model state definition, to define explicitly the possible states of conforming source models.

Example of model state definition for the AD DSL

- When executing a UML activity diagram, tokens flow through both *nodes* and *edges* of the model.
- We add a `TokensHolder` metaclass to reflect that:



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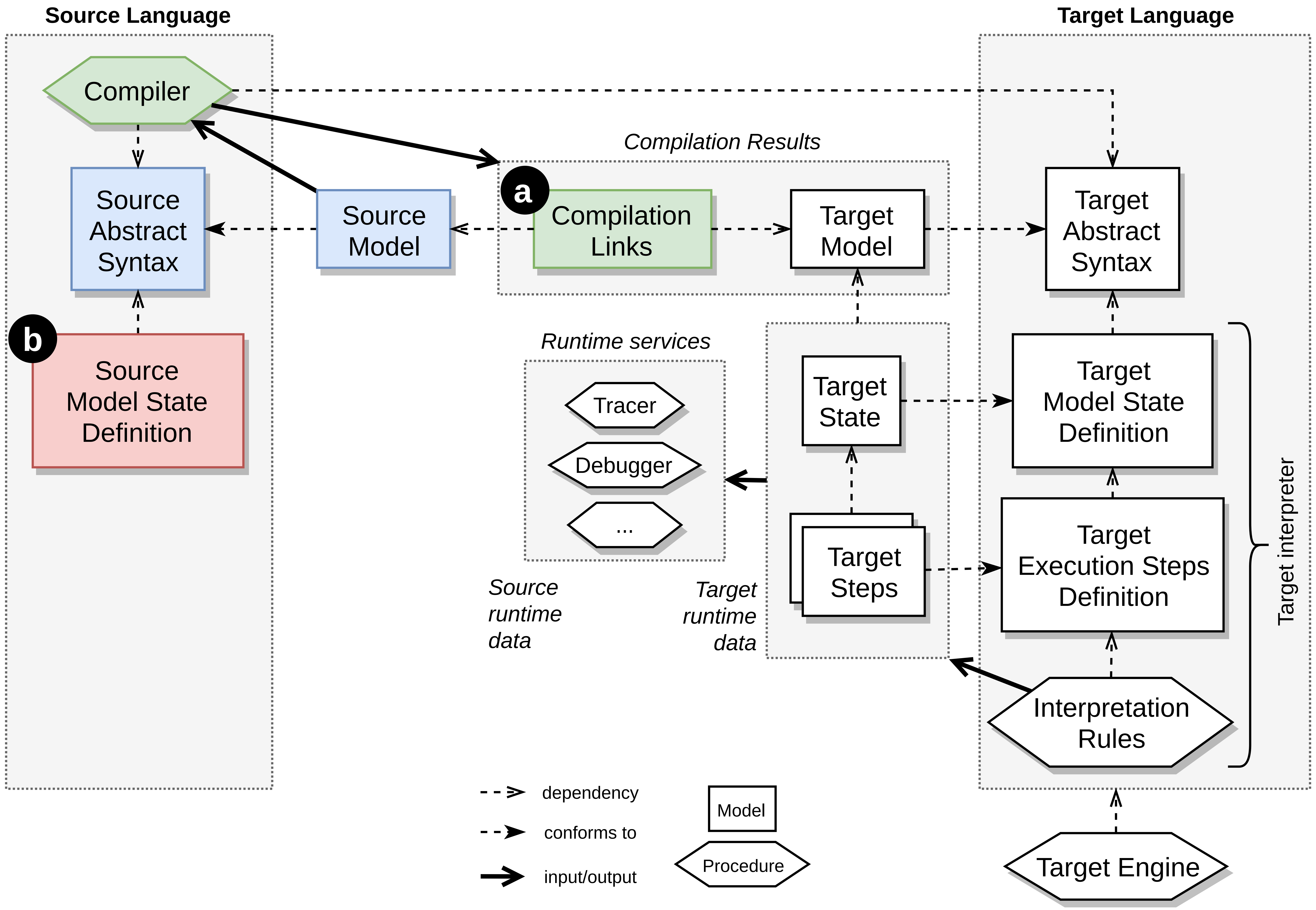

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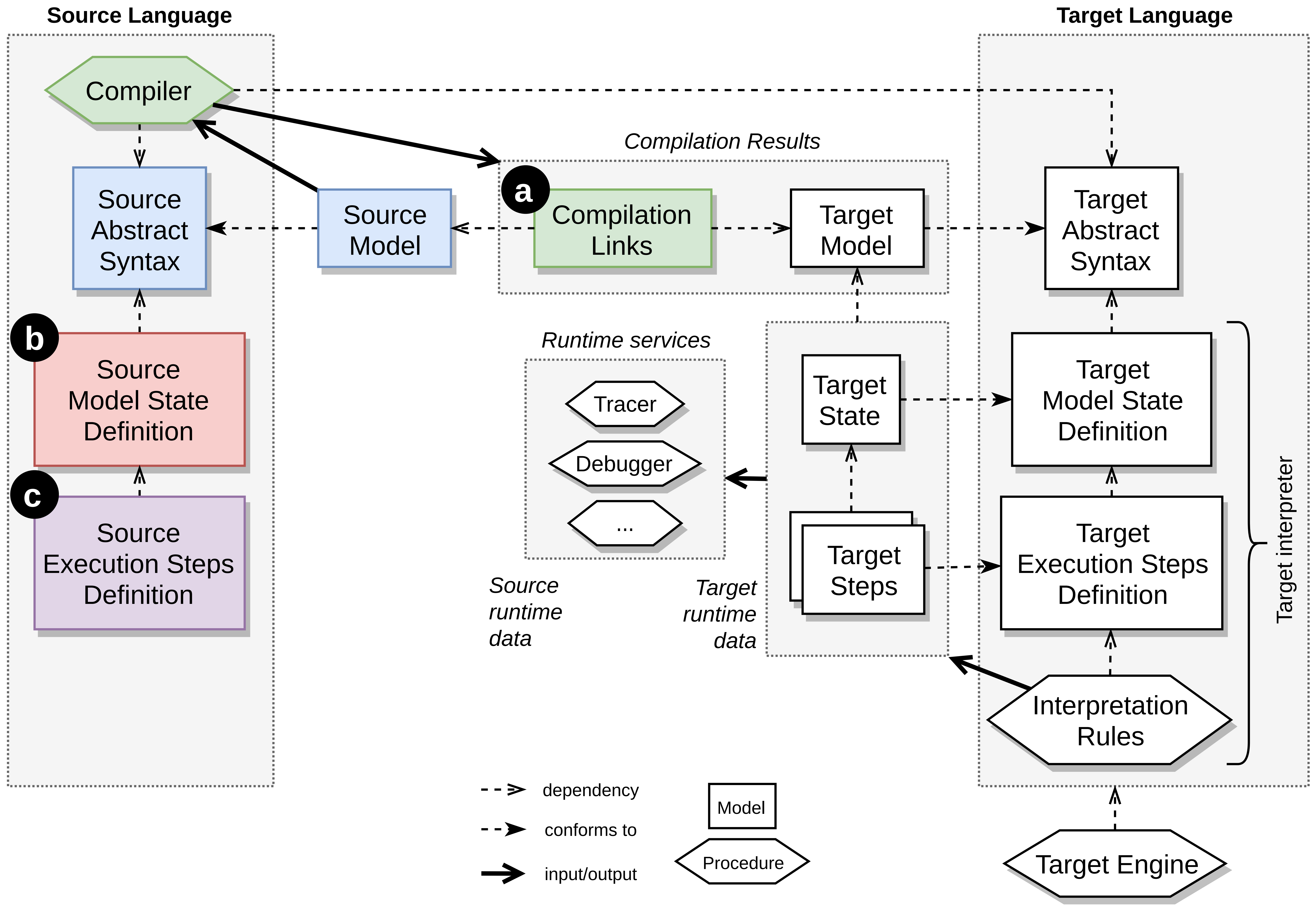

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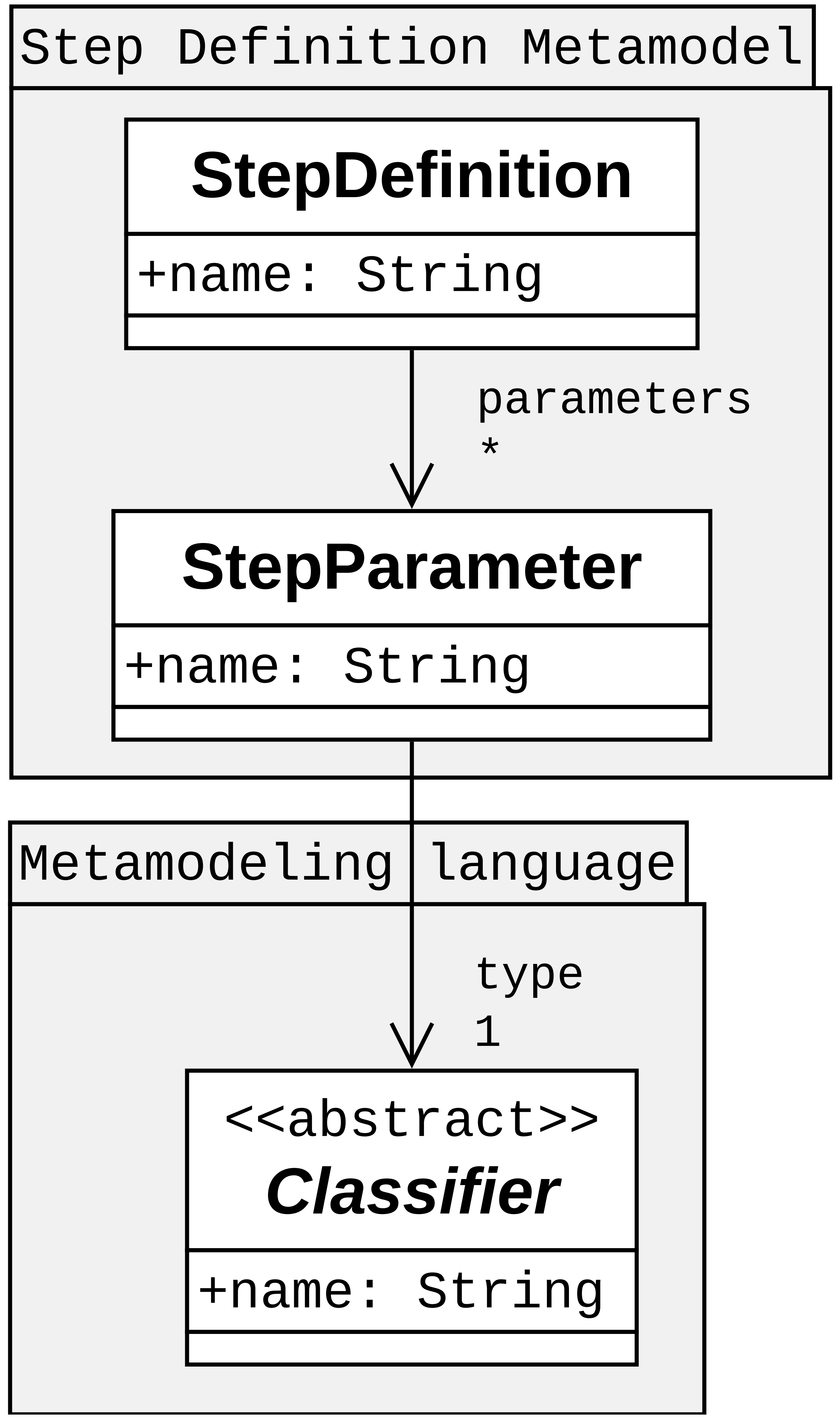

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- We define the following execution steps to reflect that:
  - `offer(Node)`: offering of tokens of a `Node` to the outgoing edges of the `Node` ;
  - `take(Node)`: taking of tokens by a `Node` from the incoming edges of the `Node` ;
  - `executeNode(Node)`: taking and offering of tokens by a `Node` , *i.e.*, a composite step containing both an `offer` step and a `take` step;
  - `executeActivity(Activity)`: execution of the `Activity` until no tokens can be offered or taken, *i.e.*, a composite step containing `executeNode` steps.

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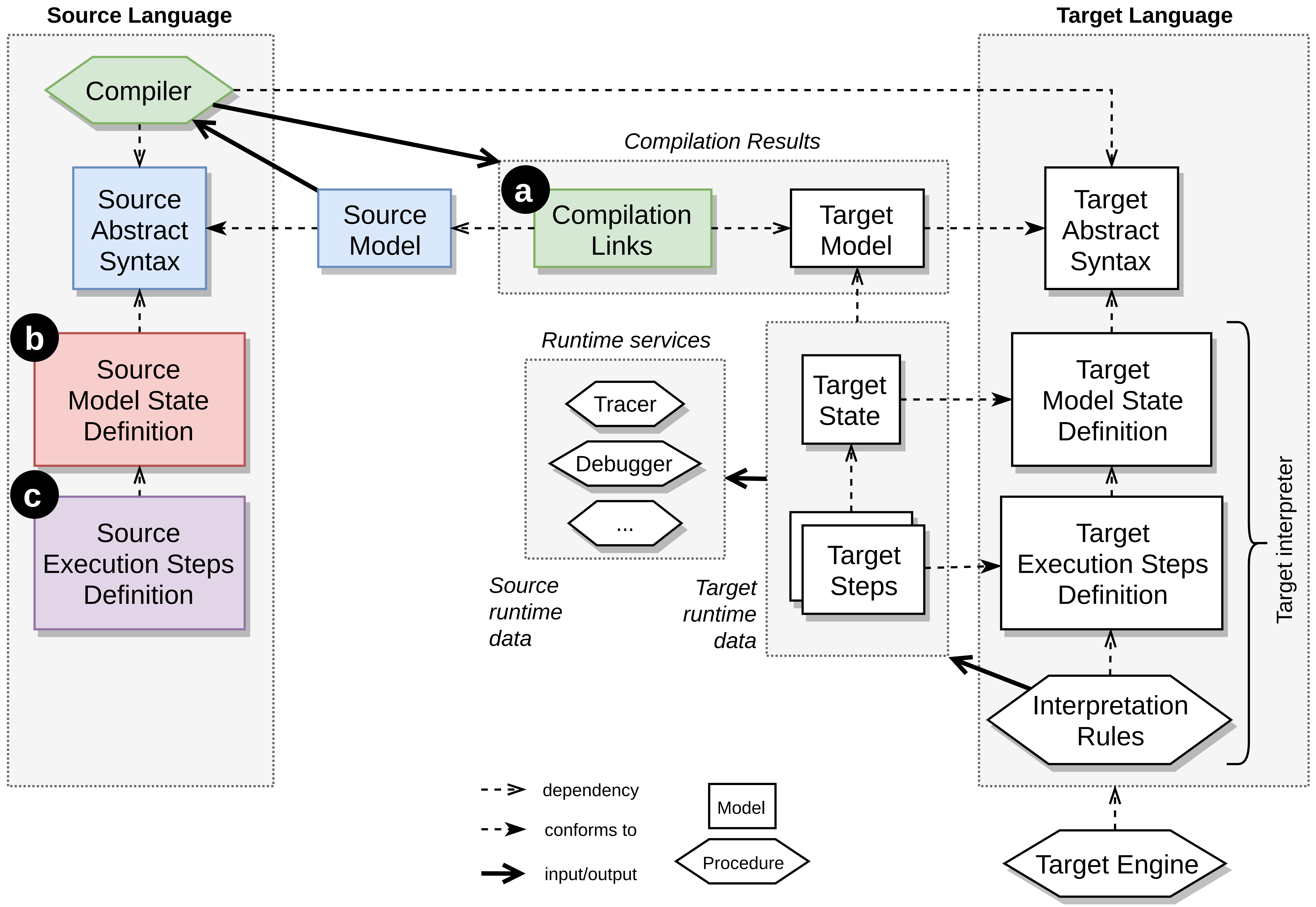
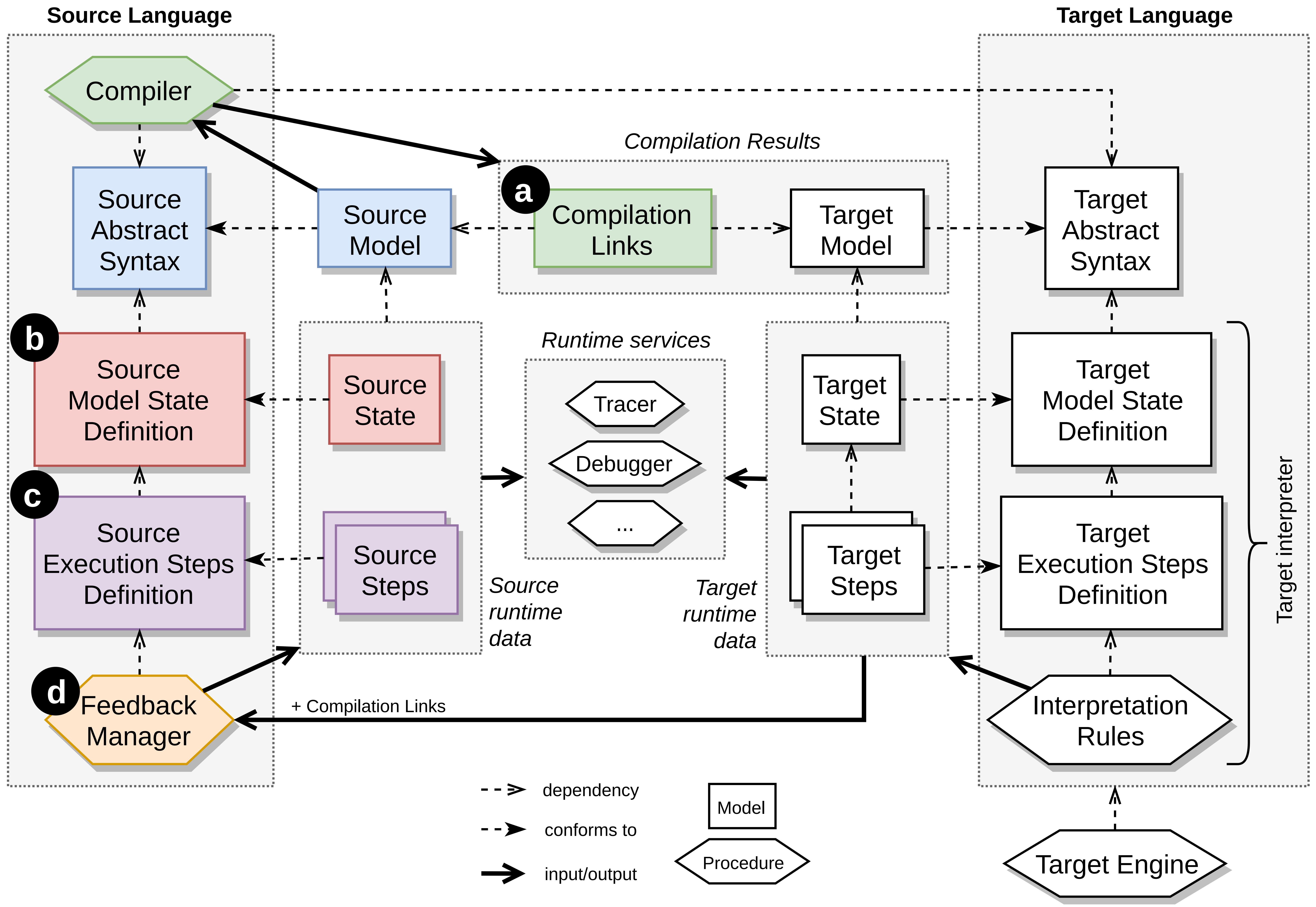


Approach Overview (4)



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- *Our approach*: definition of a feedback manager attached to the execution, which performs said translation on the fly during the model execution.
- Proposed interface for feedback managers:
    - `feedbackState`: Update the source model state based on the set of changes applied on the target model state in the last target execution step.
    - `processTargetStepStart`: Translate a target starting step into source steps.
    - `processTargetStepEnd`: Translate a target ending step into source steps.

Example of execution reconstructed by a feedback manager

Target Petri net execution trace (invisible to users and tools)

Source activity diagram execution trace (seen by users and tools)

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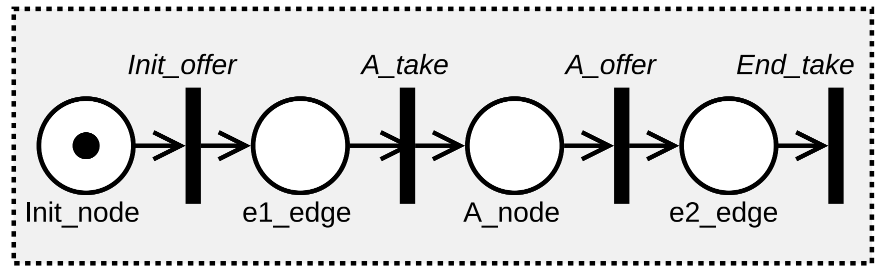

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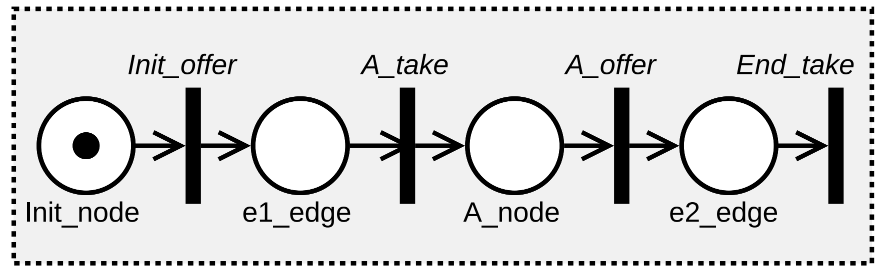

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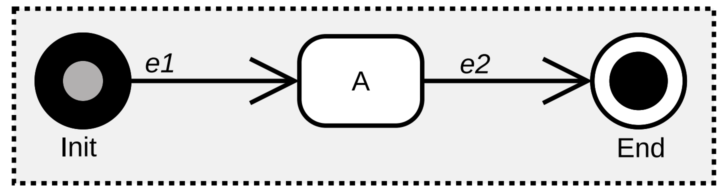

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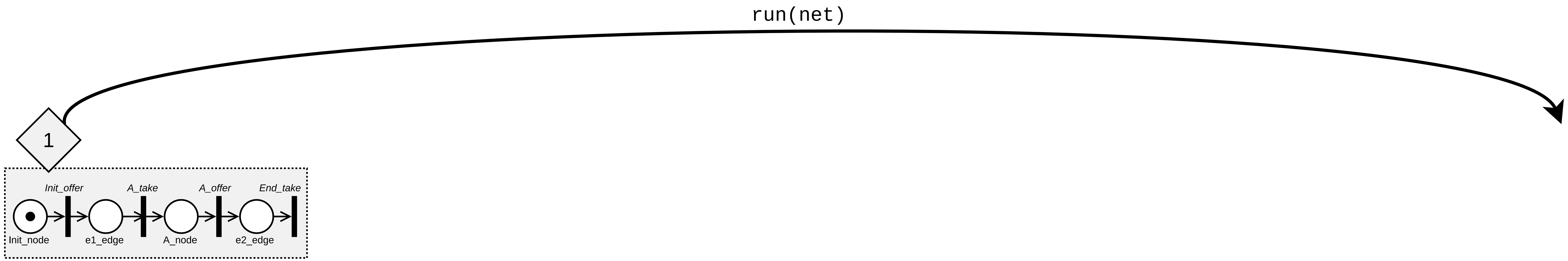

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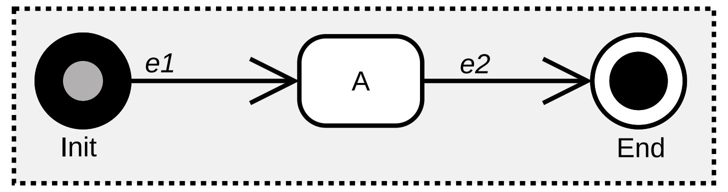

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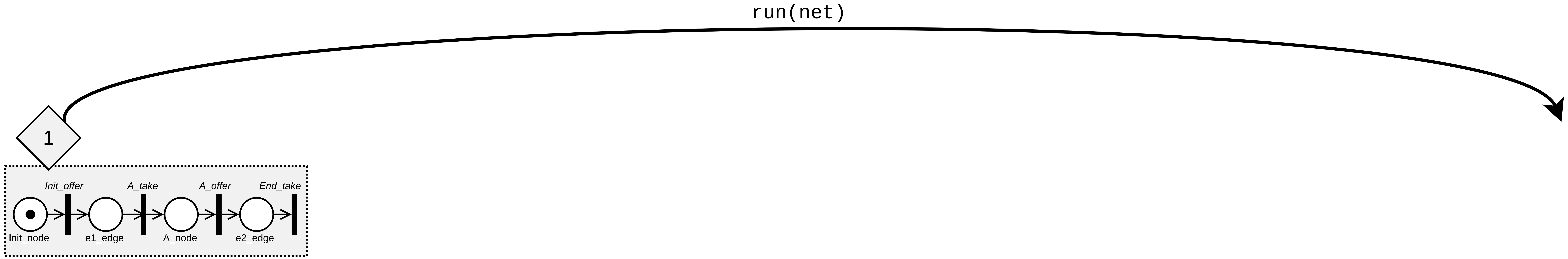
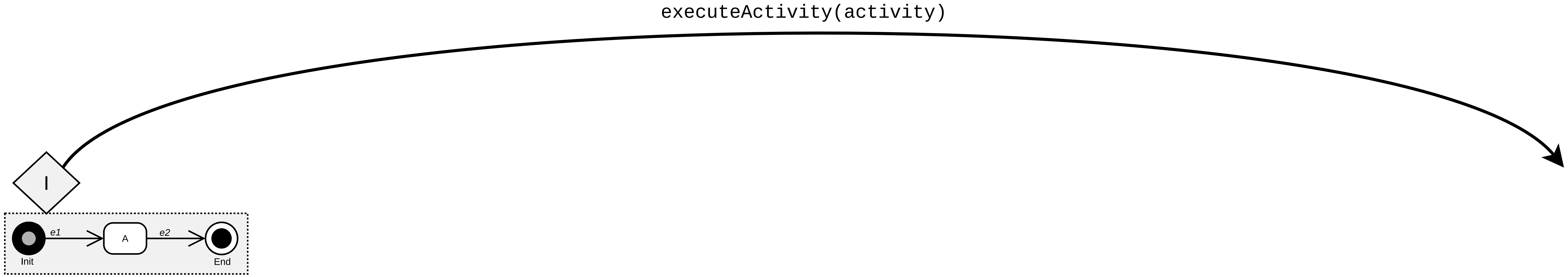
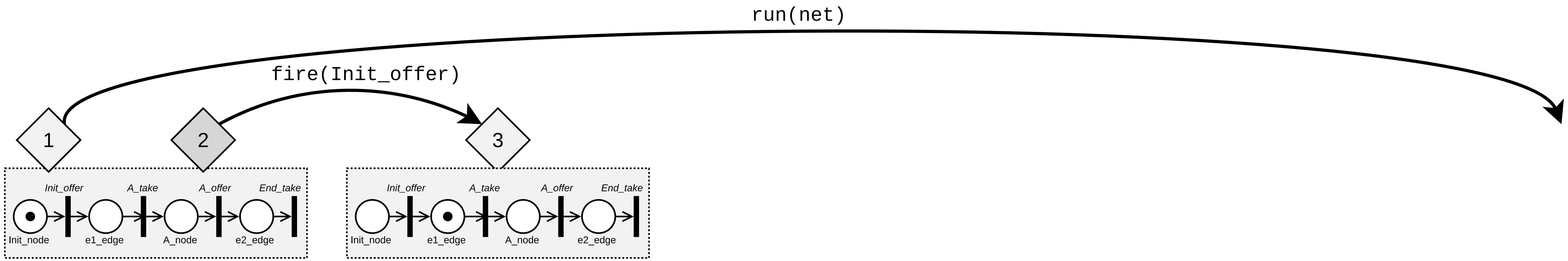


Target Petri net execution trace (invisible to users and tools)

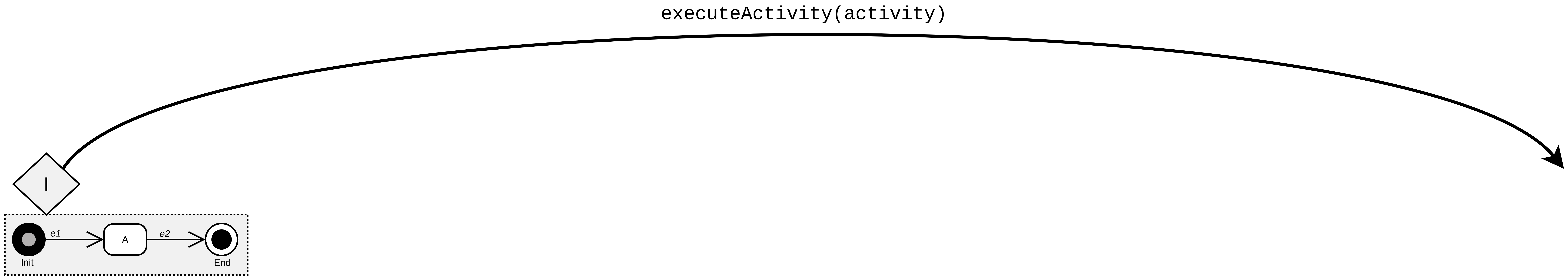


Source activity diagram execution trace (seen by users and tools)

Example of execution reconstructed by a feedback manager



Target Petri net execution trace (invisible to users and tools)



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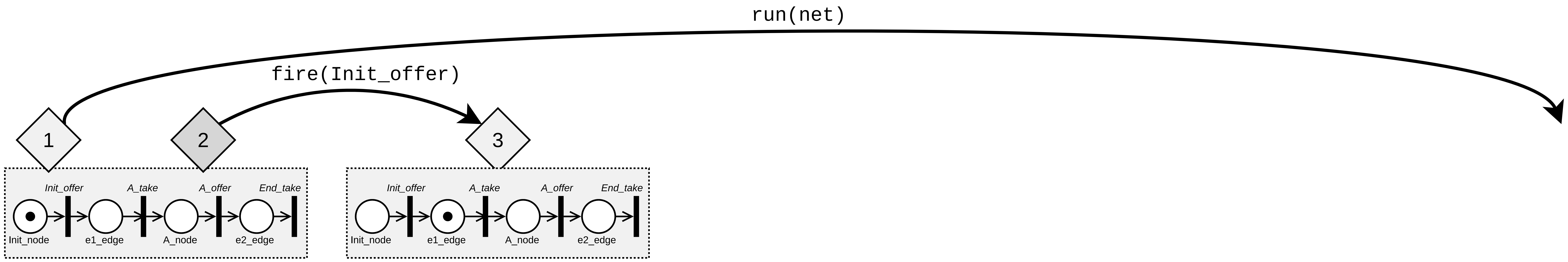

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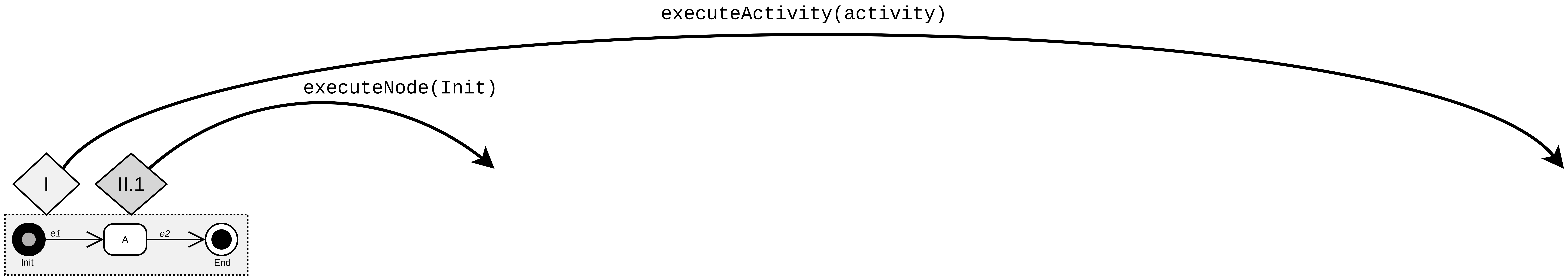

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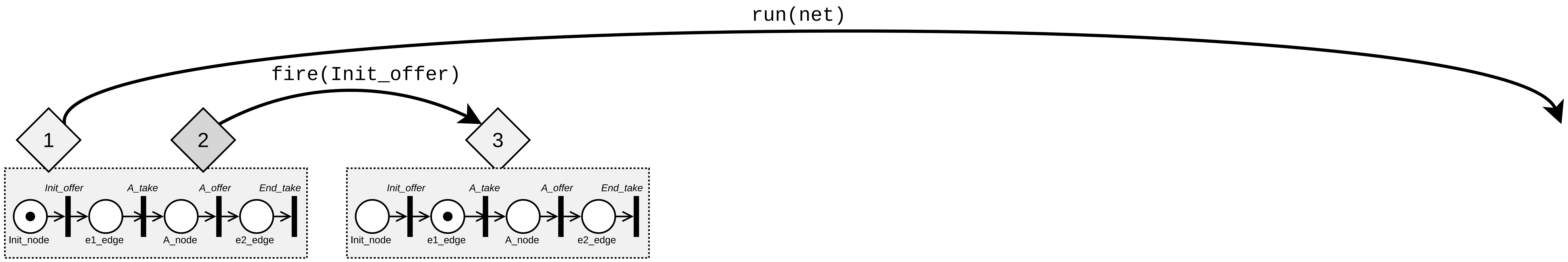

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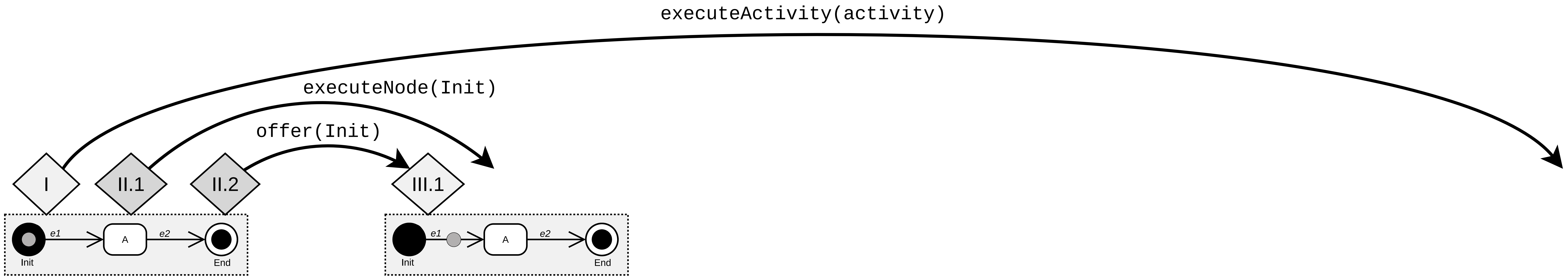

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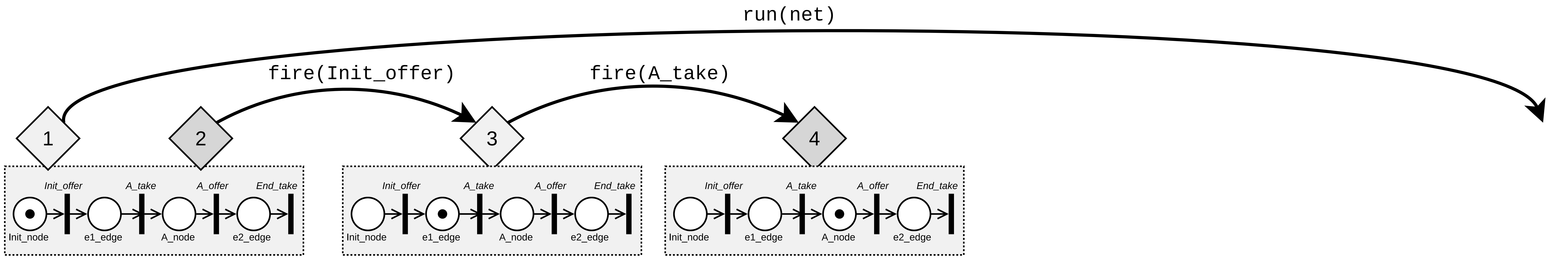

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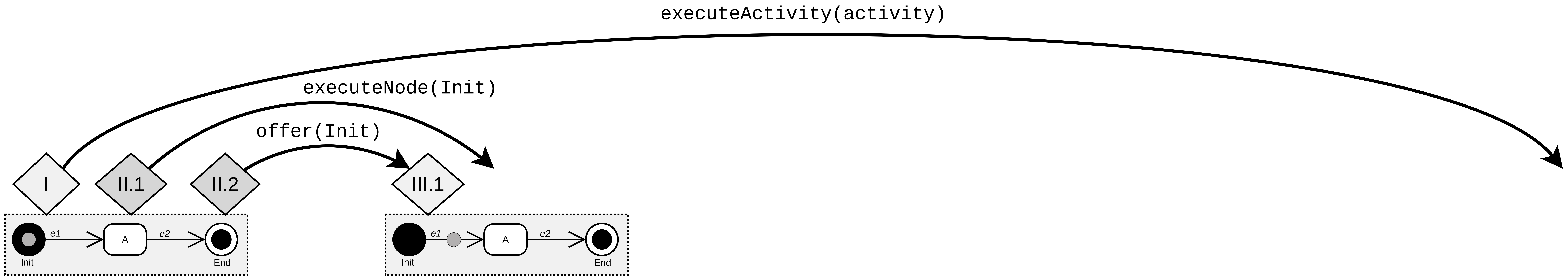

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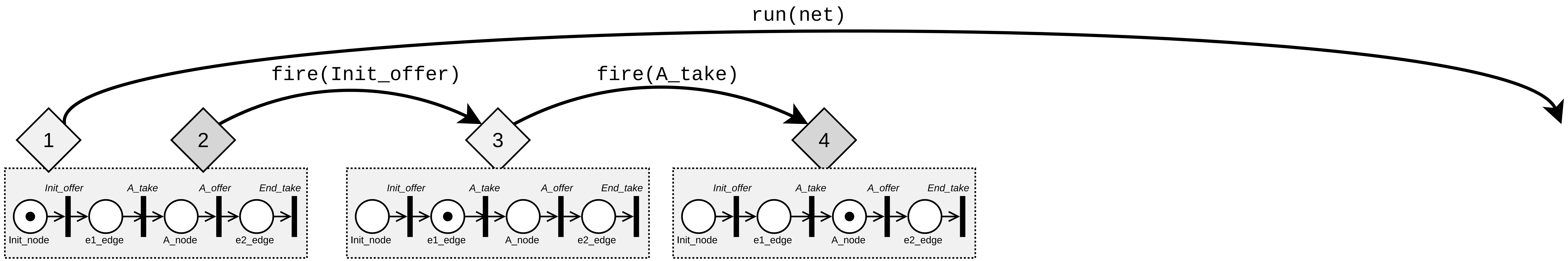
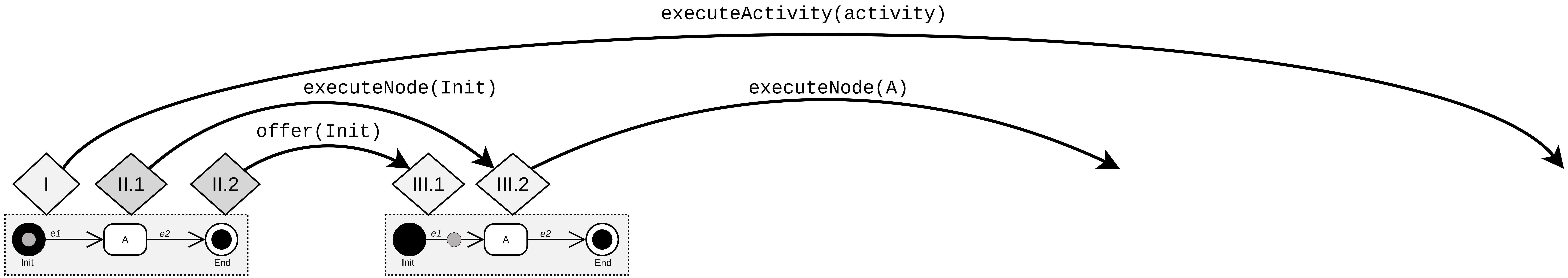


Target Petri net execution trace (invisible to users and tools)



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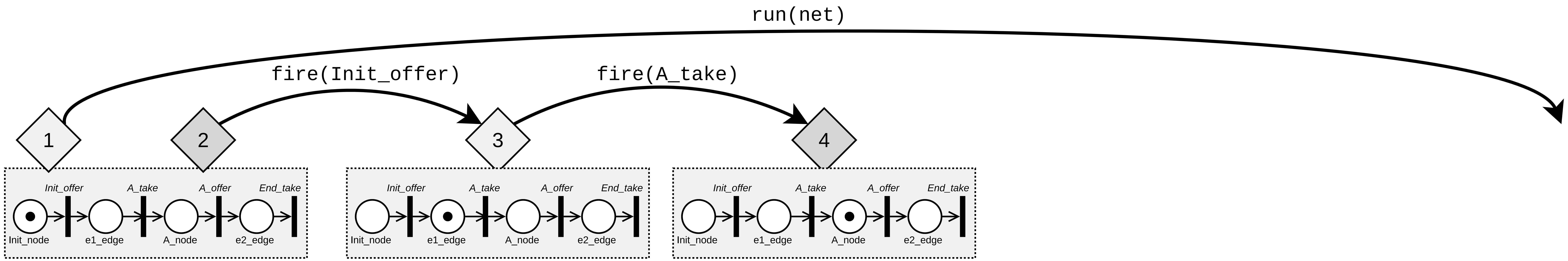
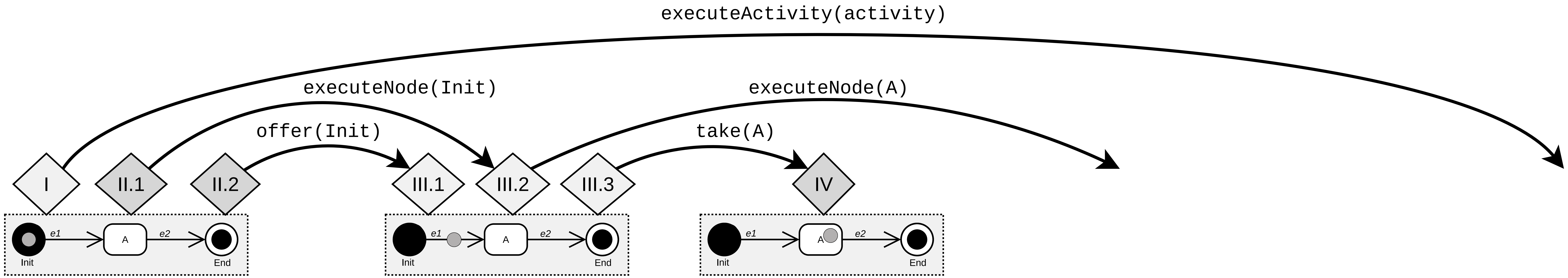


Target Petri net execution trace (invisible to users and tools)



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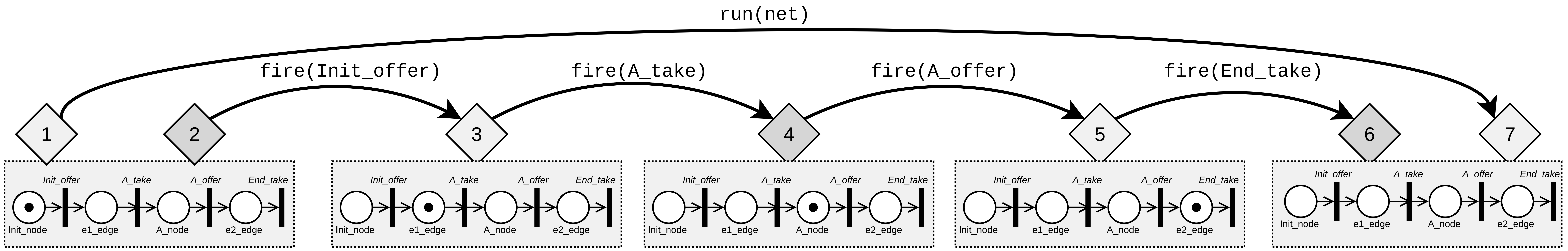

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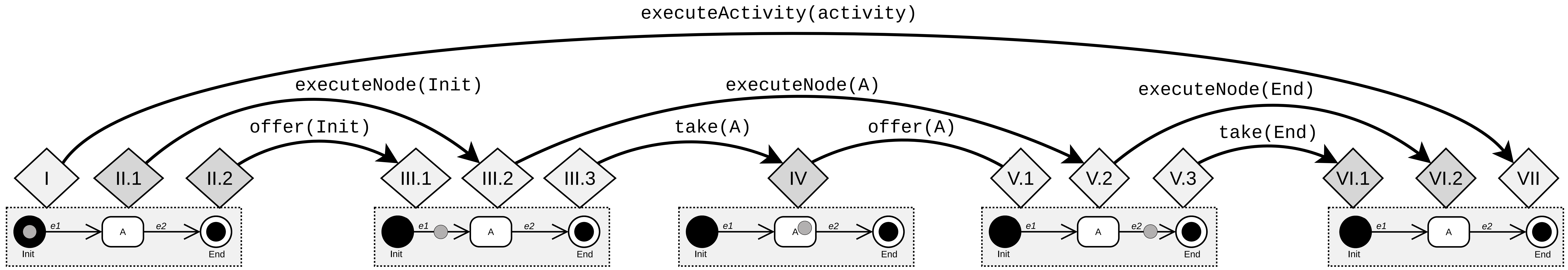

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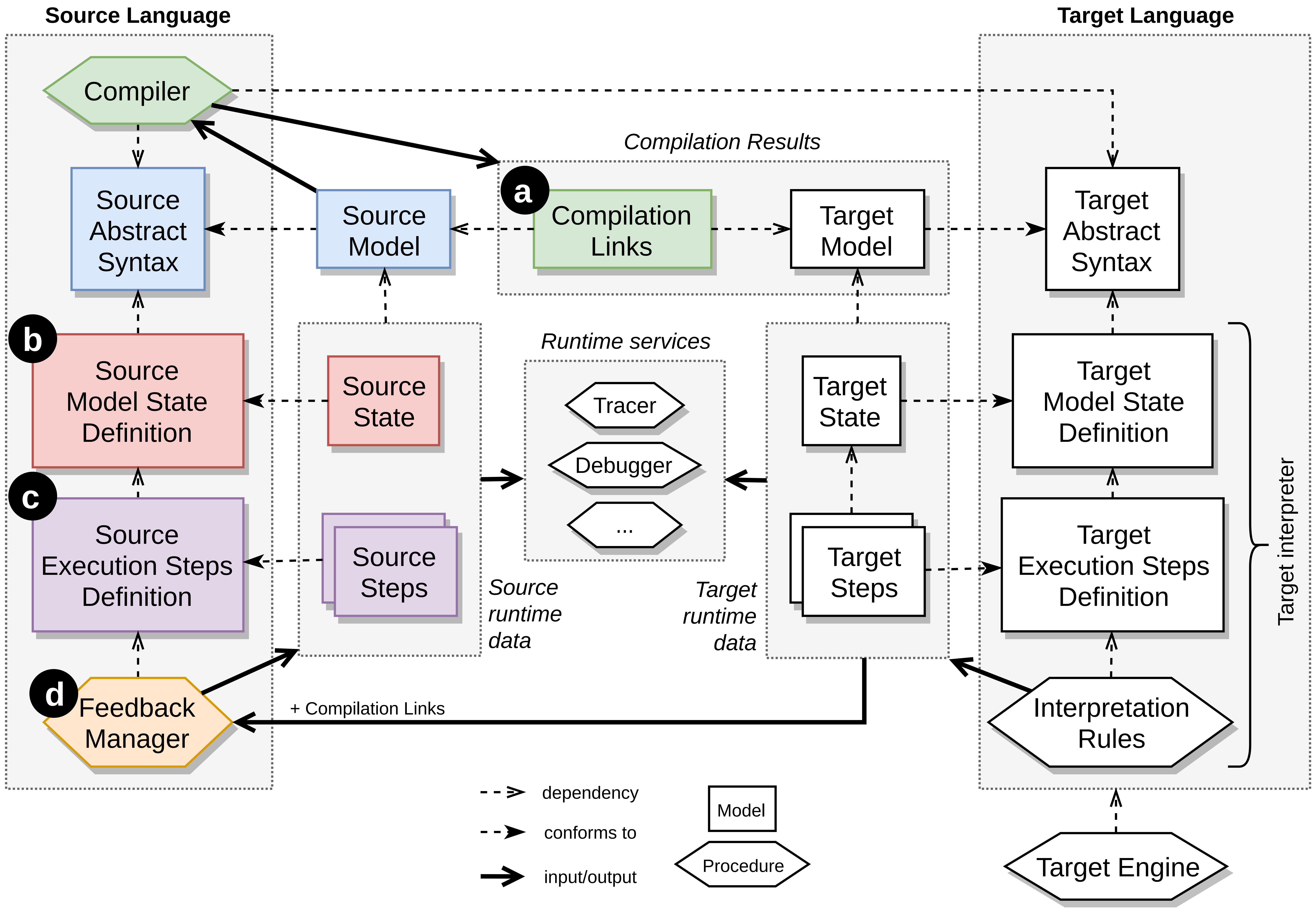
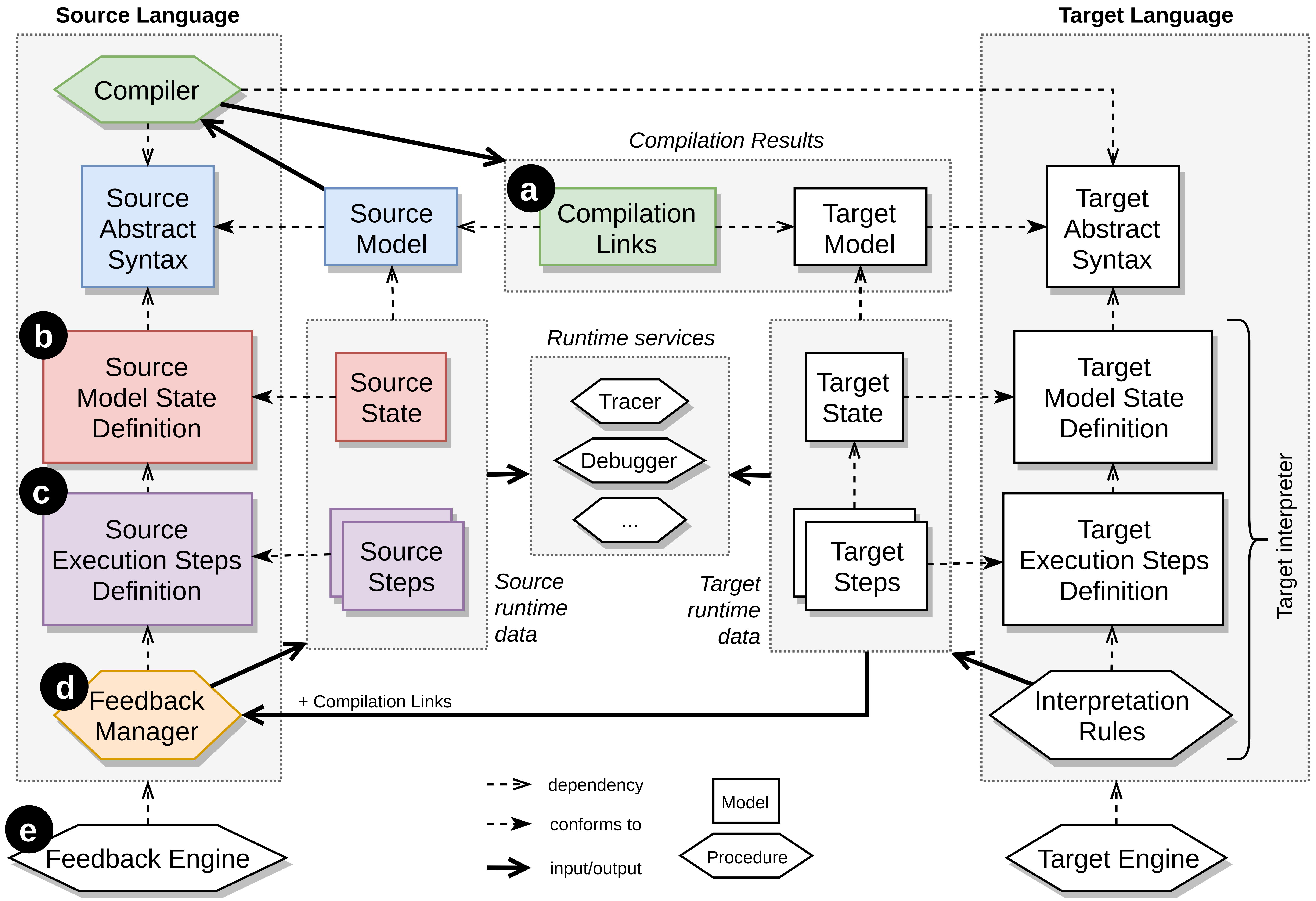
Approach Overview (4)



Approach Overview (5)



Evaluation

Can we observe and control compiled models?

In reasonable time?

Implementation

- Common parts (eg. glue code, APIs, integration layer) of the approach implemented for the GEMOC Studio, an Eclipse-based language workbench.
- The source code (Eclipse plugins written in Xtend and Java) is available on Github: https://github.com/tetrabox/gemoc-compilation-engine

Note

As he GEMOC Studio originally focused on interpreted DSLs, *this is the first attempt to support compiled DSLs in the GEMOC Studio*.

Evaluation: RQs

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RQ#1

Given an interpreted DSL and a compiled DSL with trace-equivalent semantics, does the approach make it possible to observe the same traces with both DSLs?

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Given an interpreted DSL and a compiled DSL with trace-equivalent semantics, does the approach make it possible to observe the same traces with both DSLs?

RQ#2

Does the approach enable the use of runtime services at the domain-level of compiled DSLs?

RQ#3

What is the time overhead when executing compiled models with feedback management?

Evaluation: Setup

Evaluation: Setup

Considered DSLs – 2 UML-based languages

- a subset of fUML activity diagrams, using *Petri nets* as a target language,
- a subset of UML state machines using a subset of *Java* as a target language.

Each DSL implemented twice: one interpreted variant and one compiled variant.

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Considered Runtime Services – 2 tools from our previous work

- a trace constructor (ECMFA 2015, SoSym 2017)
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Considered Models – random generation

- 100 fUML activity diagrams in 10 groups ranging from 10 to 100 nodes,
- 30 UML state machines from 10 to 100 states, and 3 scenarios per state machine.

Evaluation: Results

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RQ#1: same traces between interpreted and compiled variants?

- all 130 generated models executed with the interpreted and the compiled variants of both executable DSLs
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Evaluation: Results

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- all 130 generated models executed with the interpreted and the compiled variants of both executable DSLs
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RQ#2: working runtime services?

- both runtime services (trace constructor and omniscient debugger) work as expected at the domain-level

RQ#3: execution time overhead when using the feedback manager?

- fUML activity diagrams → Petri nets: 1,6 times slower on average
- UML State Machines → MiniJava: 1,01 times slower on average

Conclusion

Summary

- Observing and controlling the execution of compiled models is difficult, and there is a lack of systematic approach to design compiled DSLs with that goal in mind.
- Our proposal: a generic language engineering architecture to define explicit feedback management in compiled DSLs

Perspectives (excerpt)

- handling compilers defined as code generators;
- provide an easier way to define feedback managers;
- managing stimuli sent to the source model during the execution;
- measuring the amount of effort required to define a feedback manager as compared to defining an interpreter.

Thank you!

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