The PIPE Tool

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Motivation

- Modern Service Level Agreements (SLAs) include increasingly complex performance properties
- System designers need to know at design-time whether their systems are going to meet SLAs
- They are not only interested in verifying system properties, but also in obtaining key quantitative performance metrics

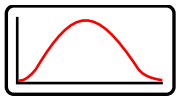
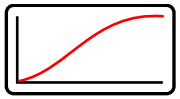
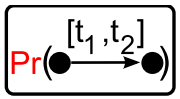
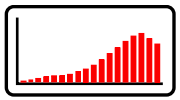
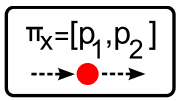
Motivation

- Property verification is supported by model-checkers using stochastic logics
- Measure extraction is supported by quantitative analysers using tool-specific query languages
- There is a need for the *accessible* specification and verification of performance properties
- We aim to provide a unified framework that caters for performance property verification and measure extraction

Performance Trees

- A new formalism for quantitative performance property and measure specification that
  - incorporates quantitative analysis-oriented features as well as traditional property verification capabilities
  - can represent high-level concepts such as distributions, densities, convolutions and moments
  - is extensible
  - supports accessible graphical query representation

Performance Tree Operators

Graphical	Textual	Description
	PTD	Passage time density
	Dist	Passage time distribution
	ProbInInterval	Probability with which a passage occurs in a given amount of time
	SS:P	Steady-state probability distribution of a state function over a set of states
	SS:S	Set of states satisfying certain steady-state probability constraints

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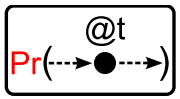
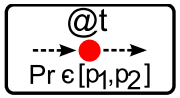
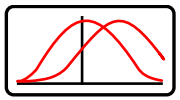
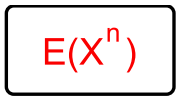
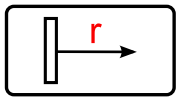
	ProbInStates	Transient probability of being in a set of states at a given time
	StatesAtTime	Set of states that the system occupies at a given time within a given probability bound
	Conv	Convolutions of densities
	Moment	Moments of densities and distributions
	FR	Average occurrence rates of actions

Performance Tree Operators

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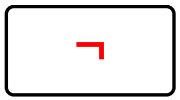
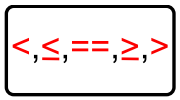
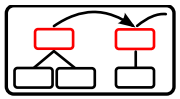
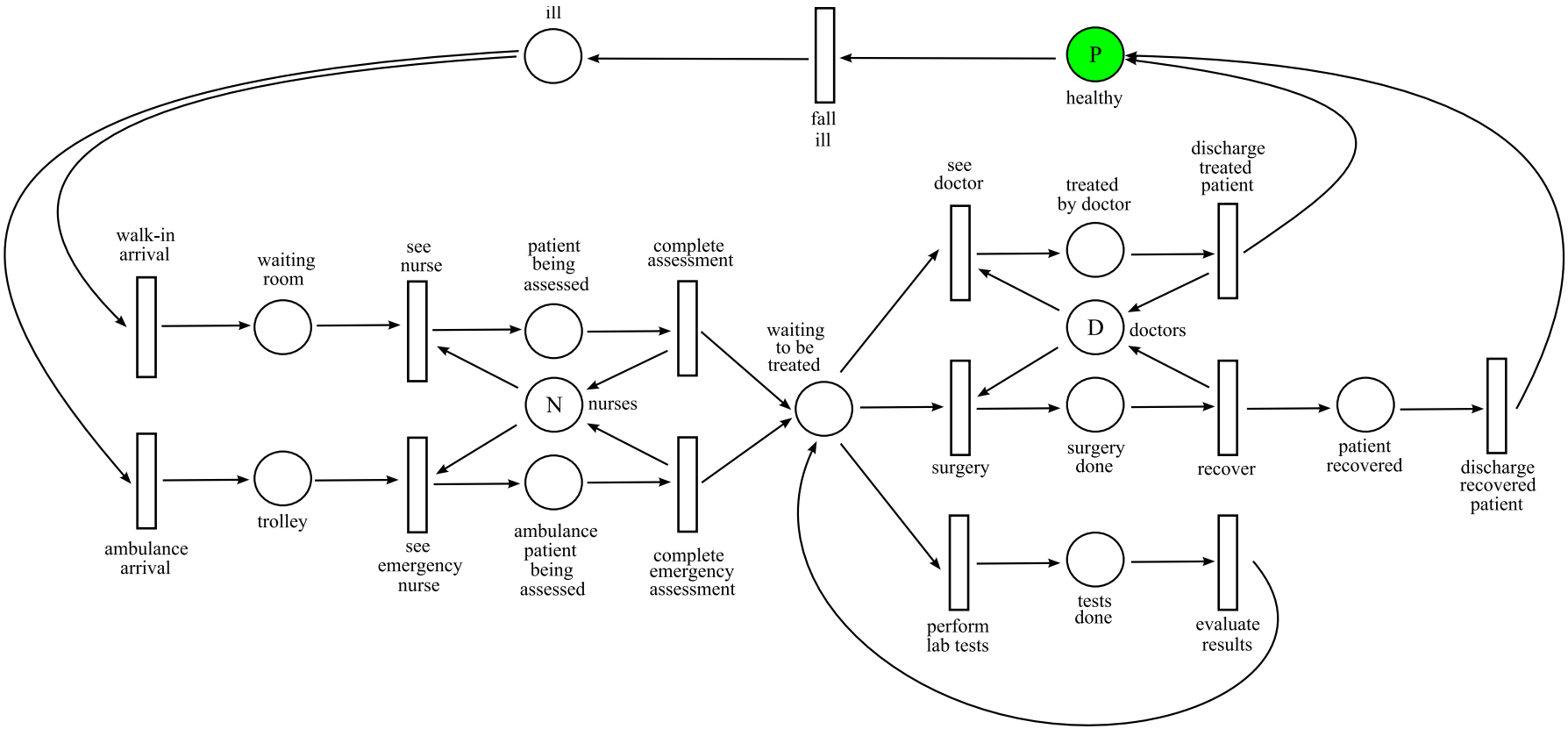
	$\vee, \wedge$	Boolean disjunction or conjunction
	$\neg$	Boolean negation
	$+, -, *, /, \hat{}$	Arithmetic operations
	$<, \leq, ==, \geq, >$	Arithmetic comparisons
	;	Sequential evaluation of independent queries

Case Study: A Hospital A&E Unit



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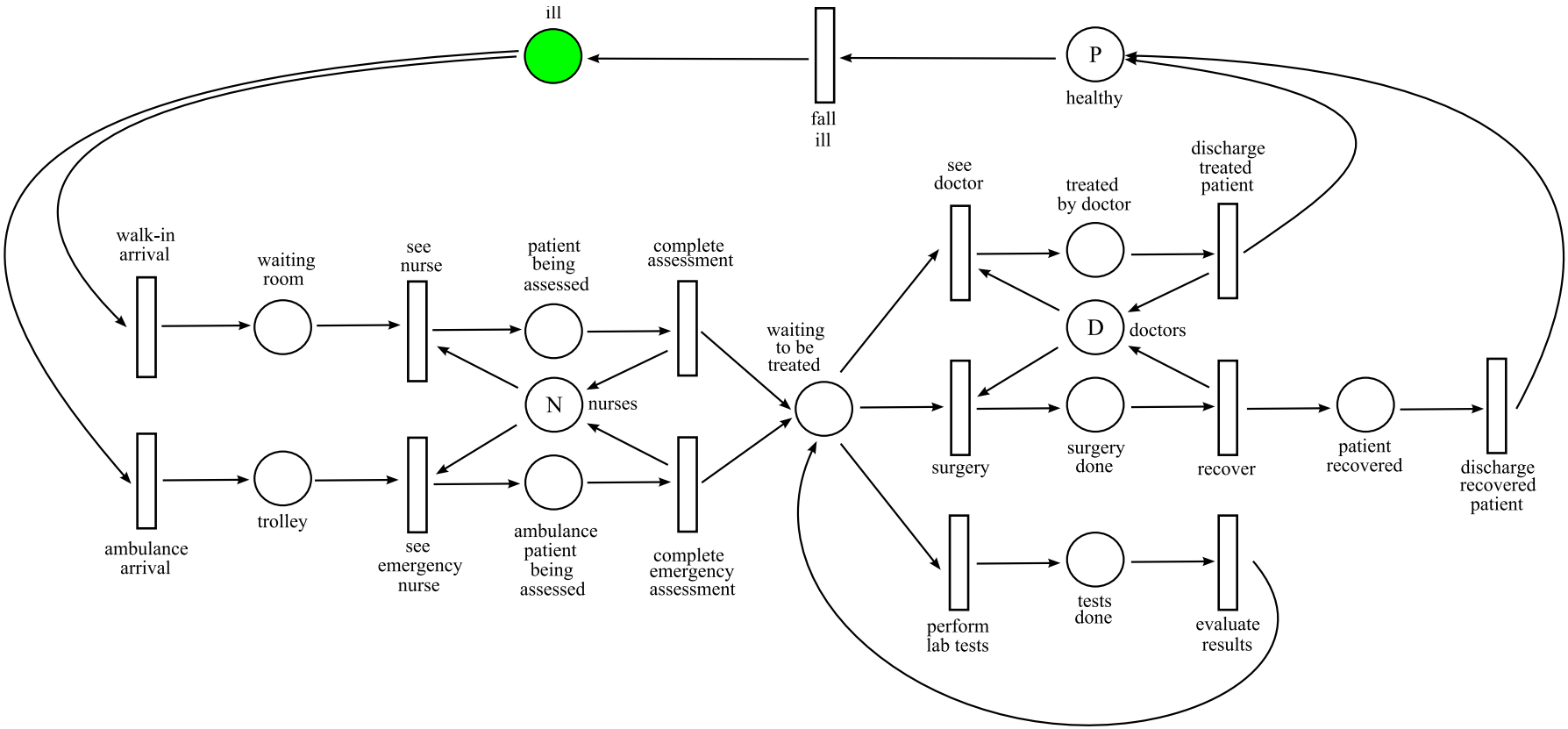

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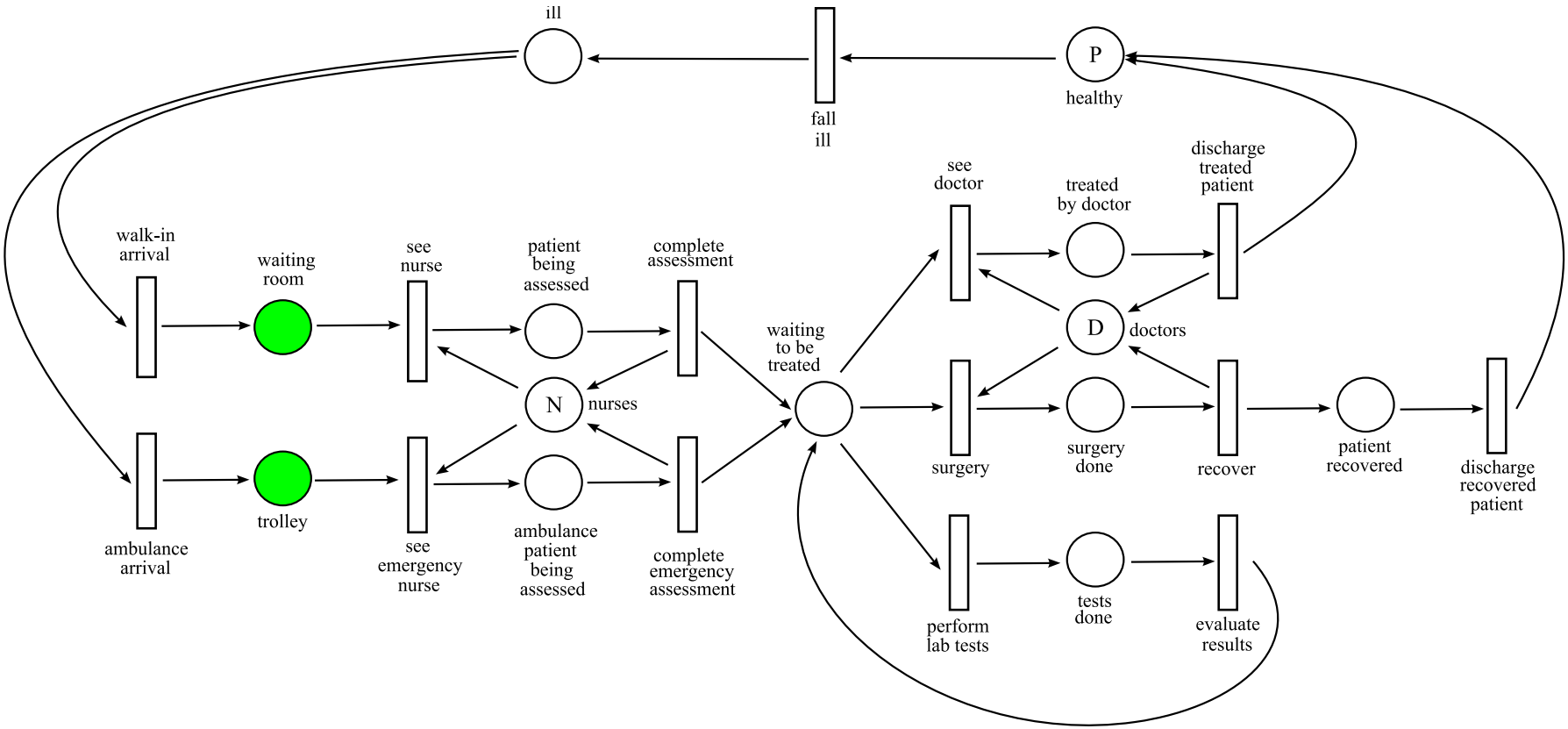

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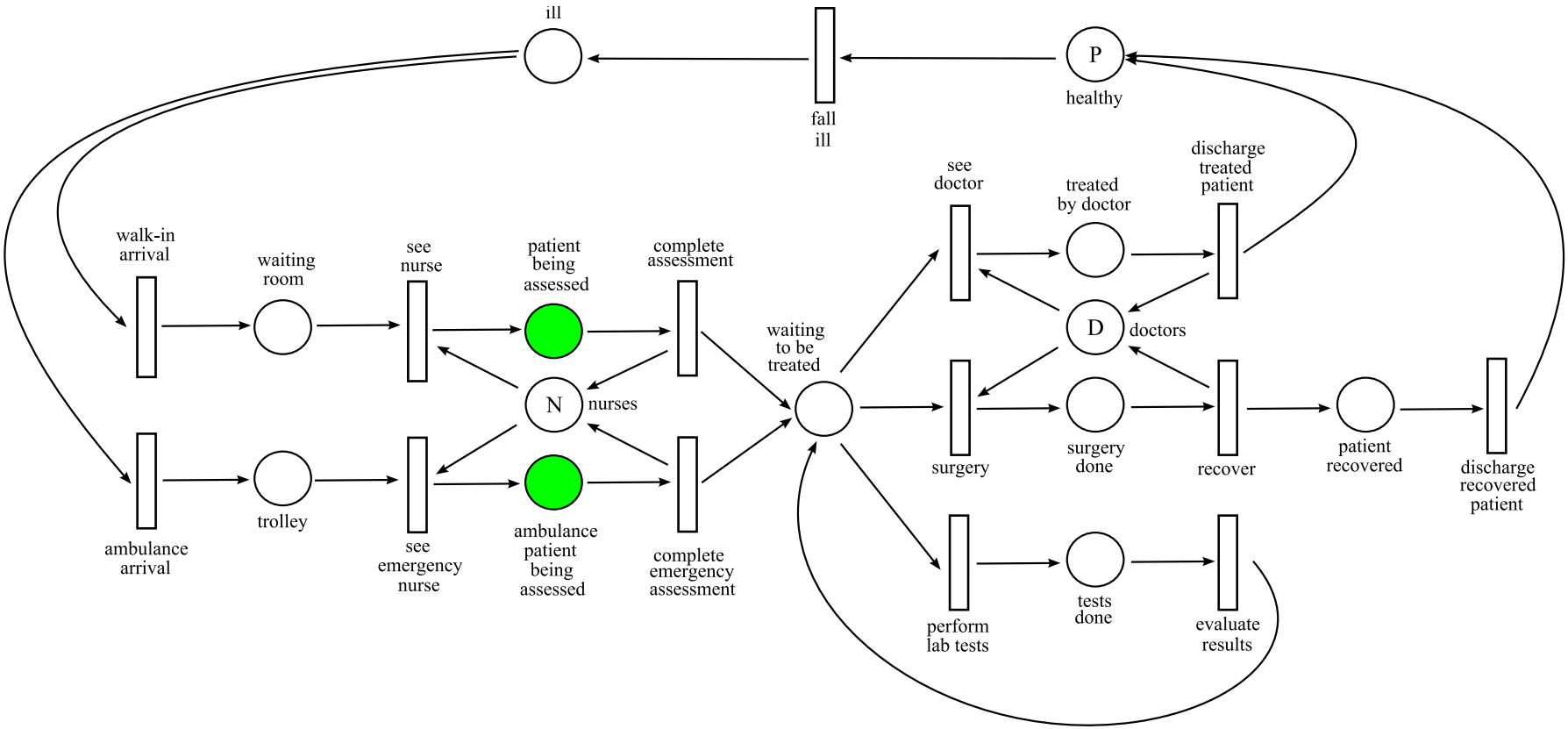

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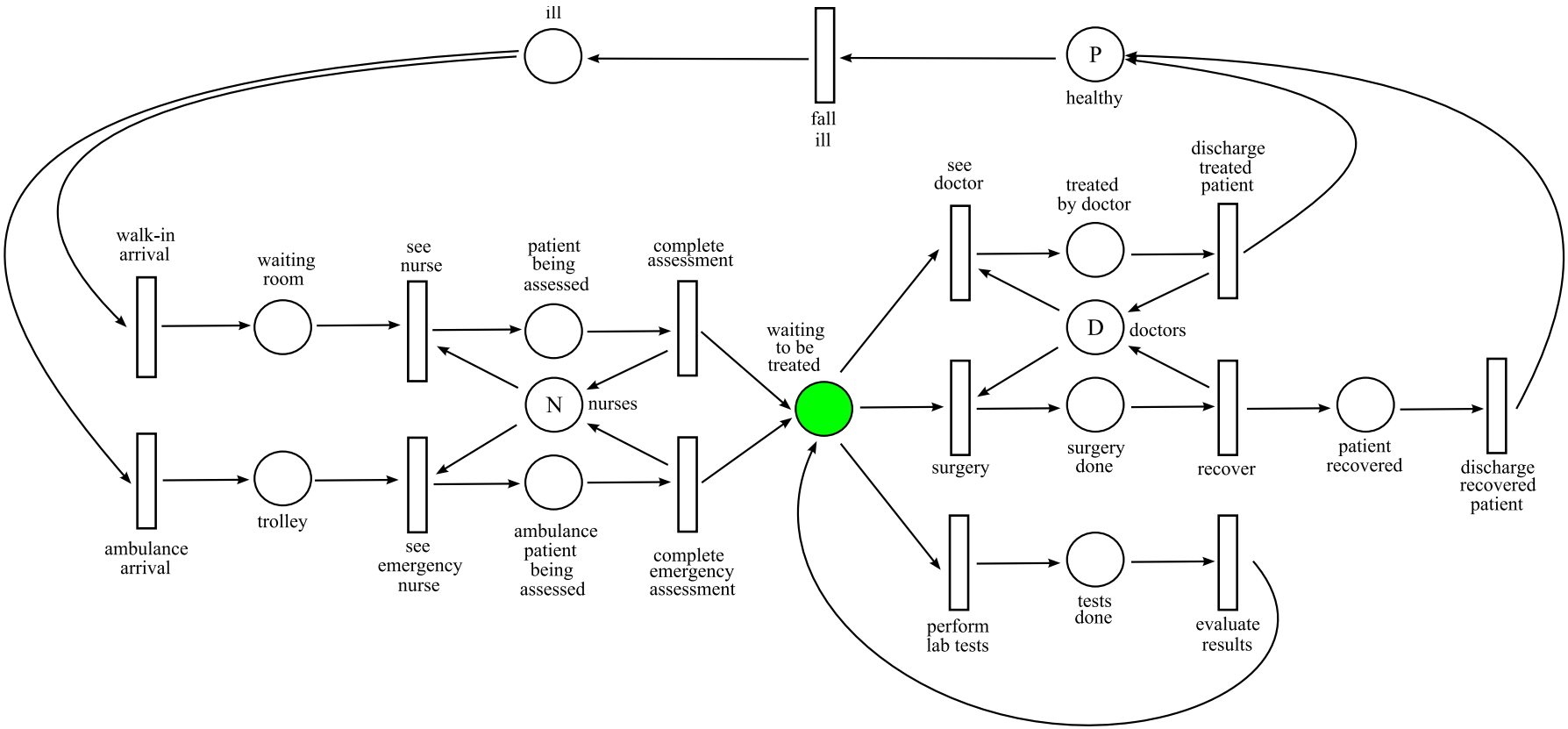

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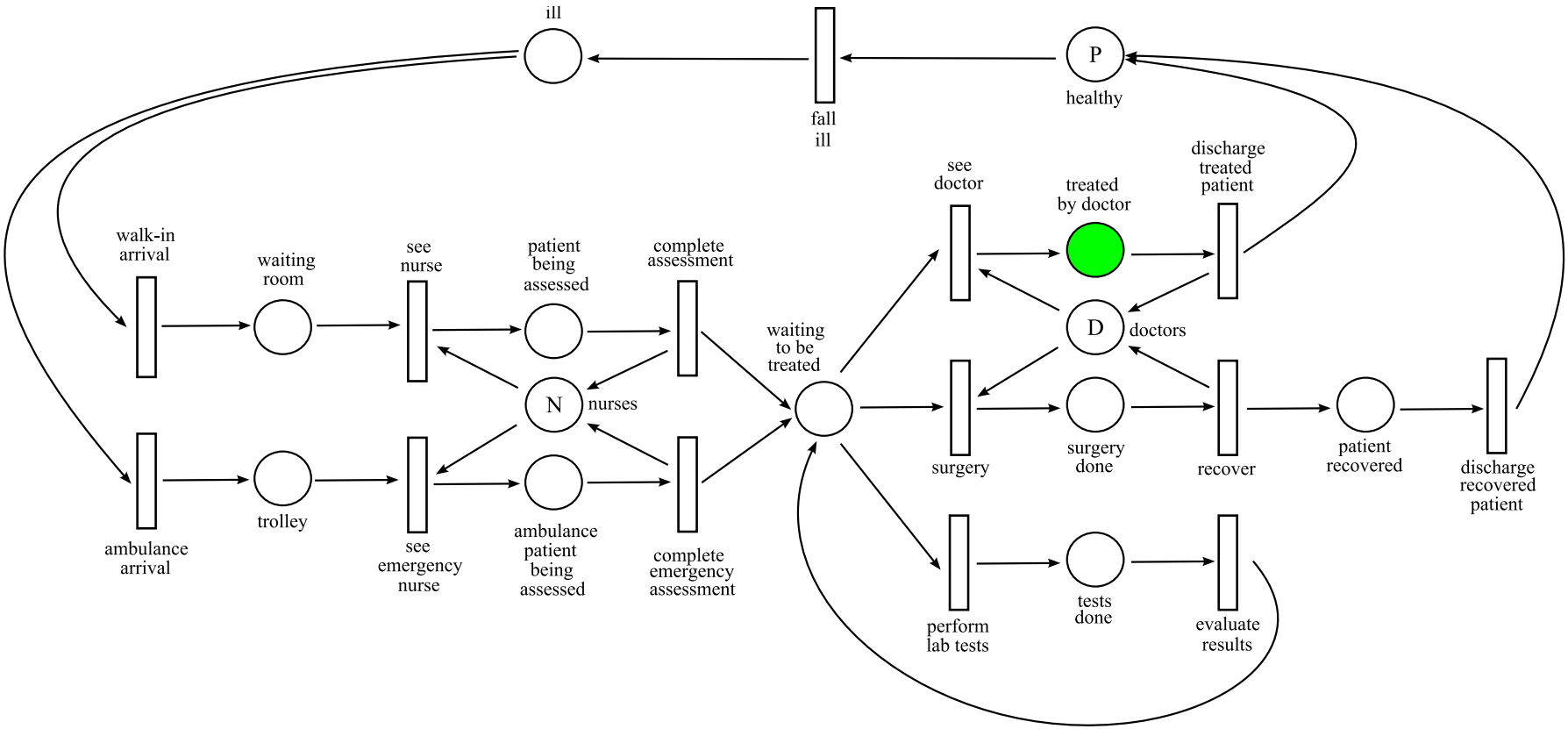

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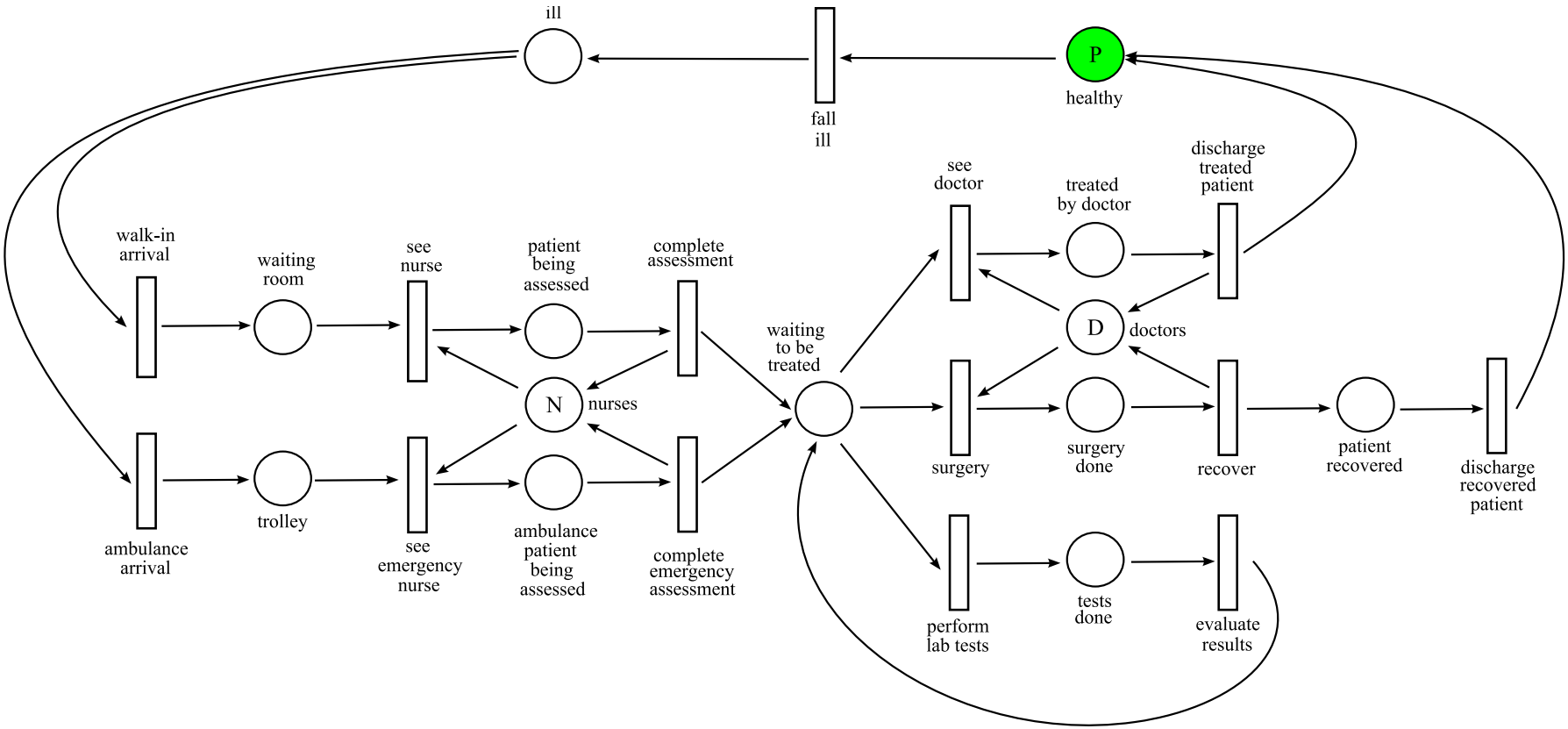

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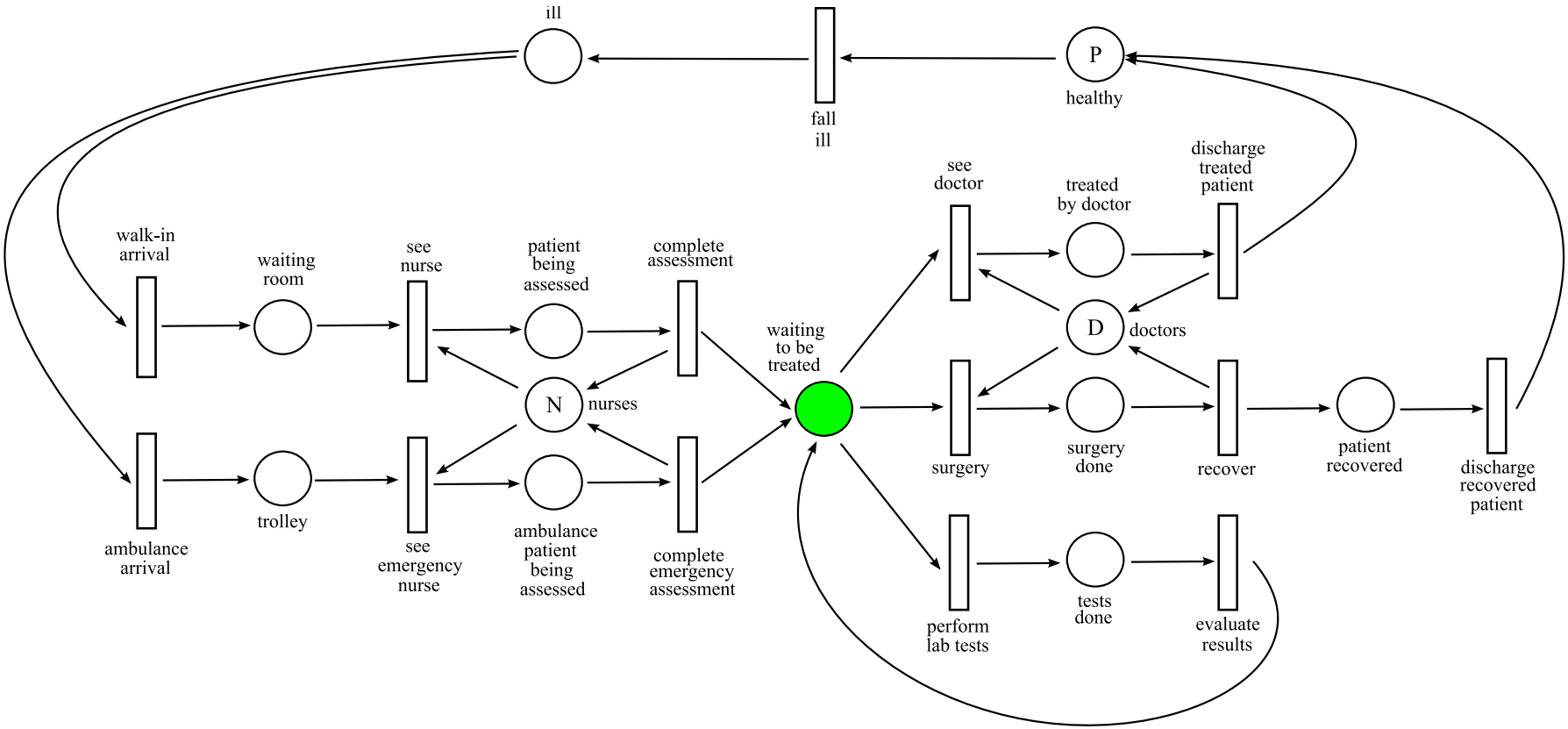

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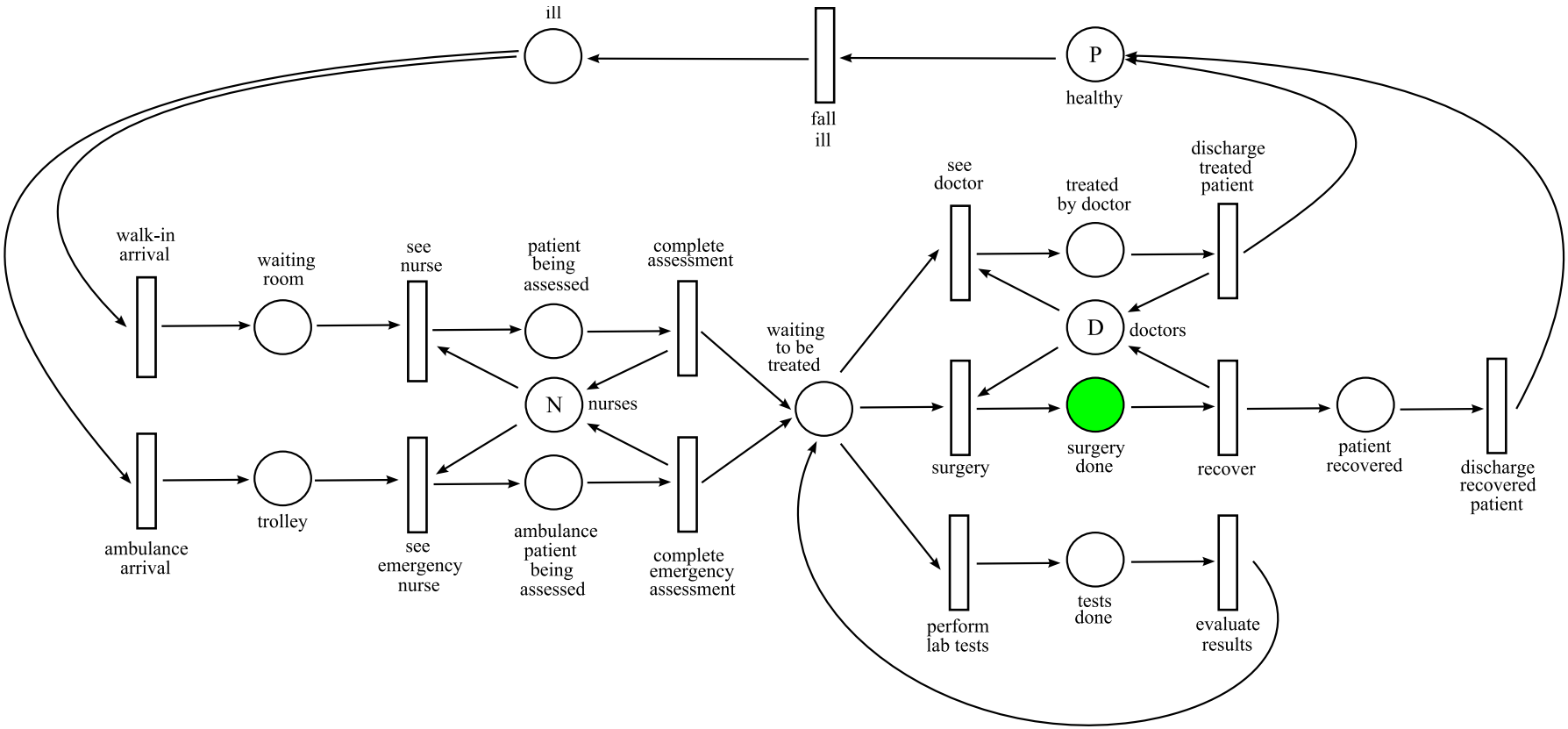

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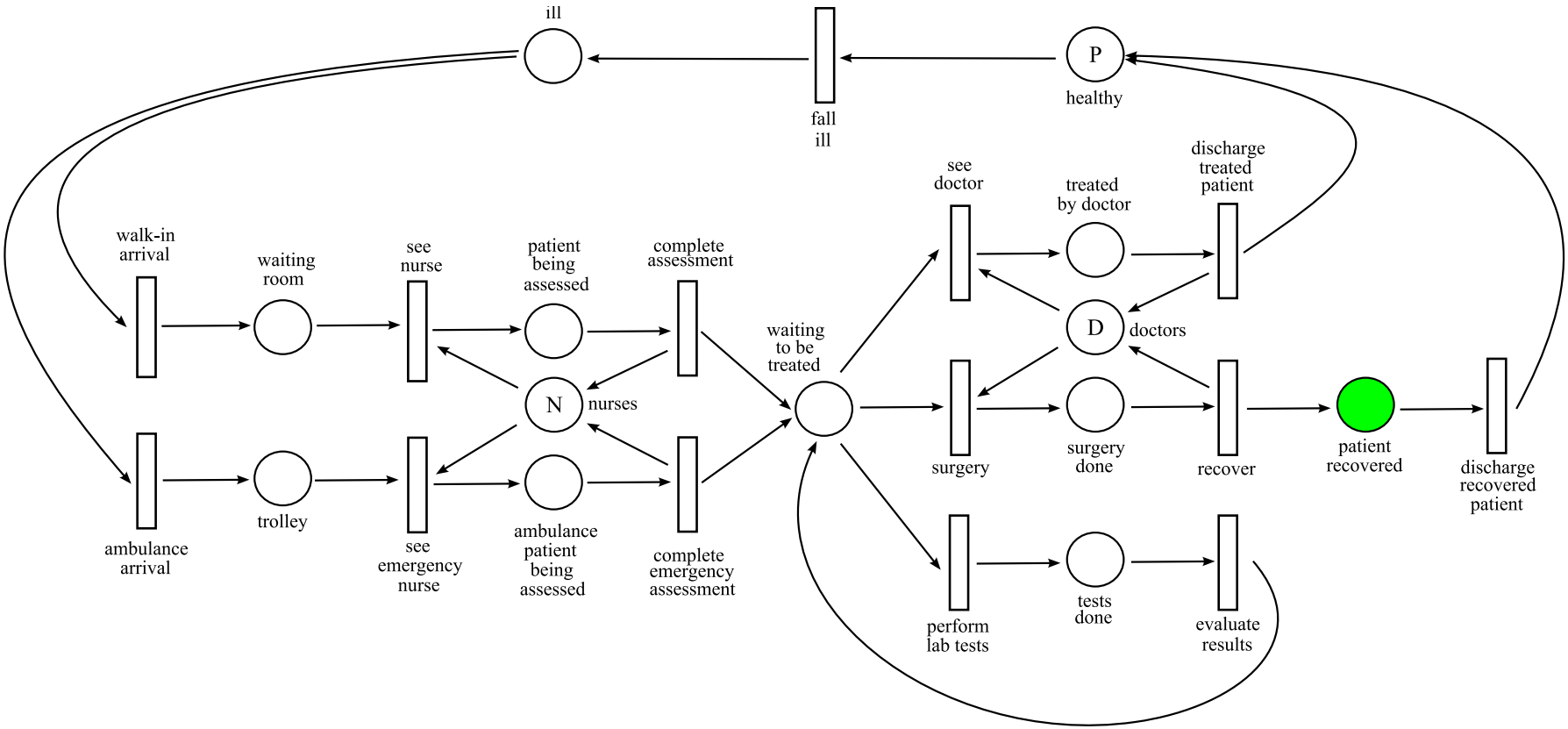

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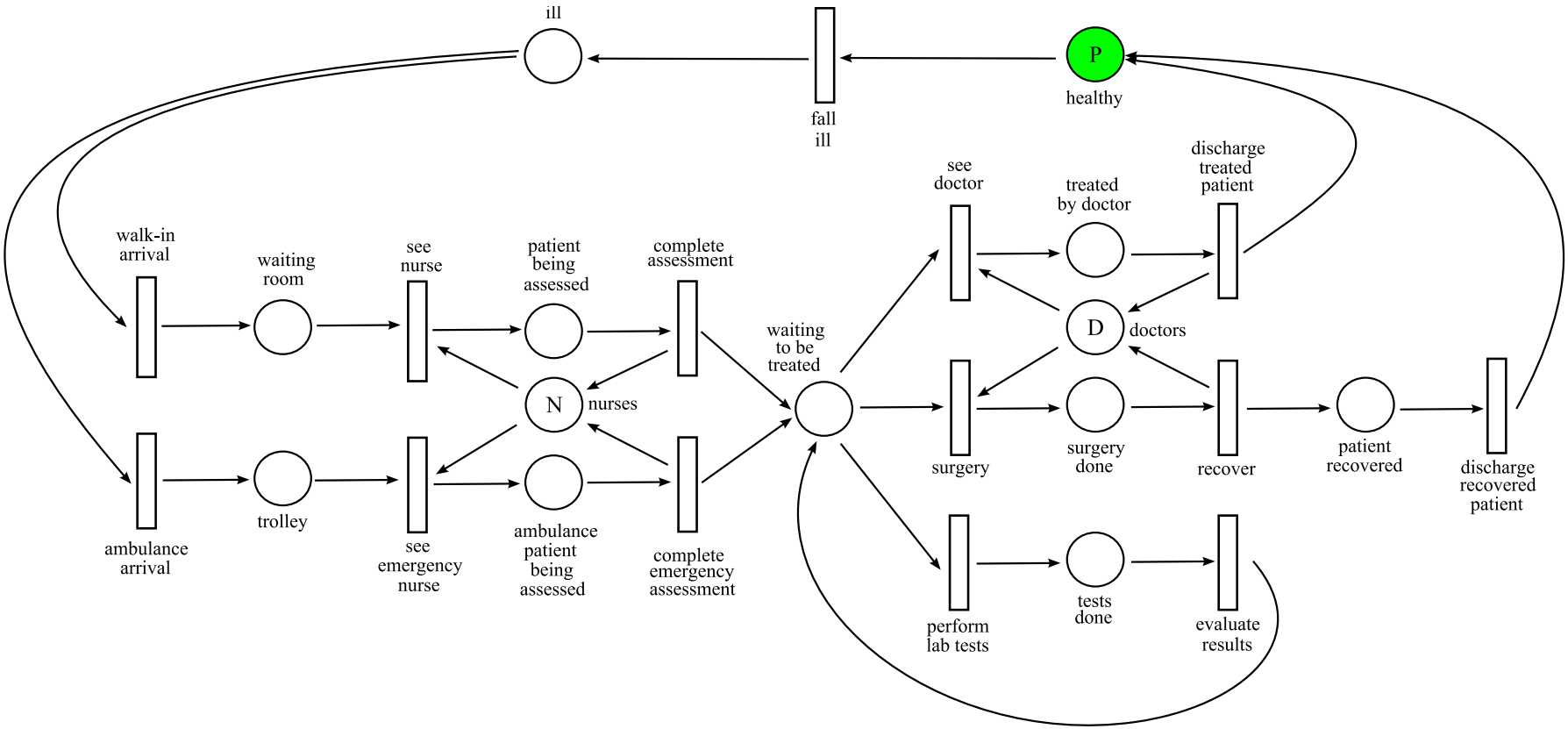

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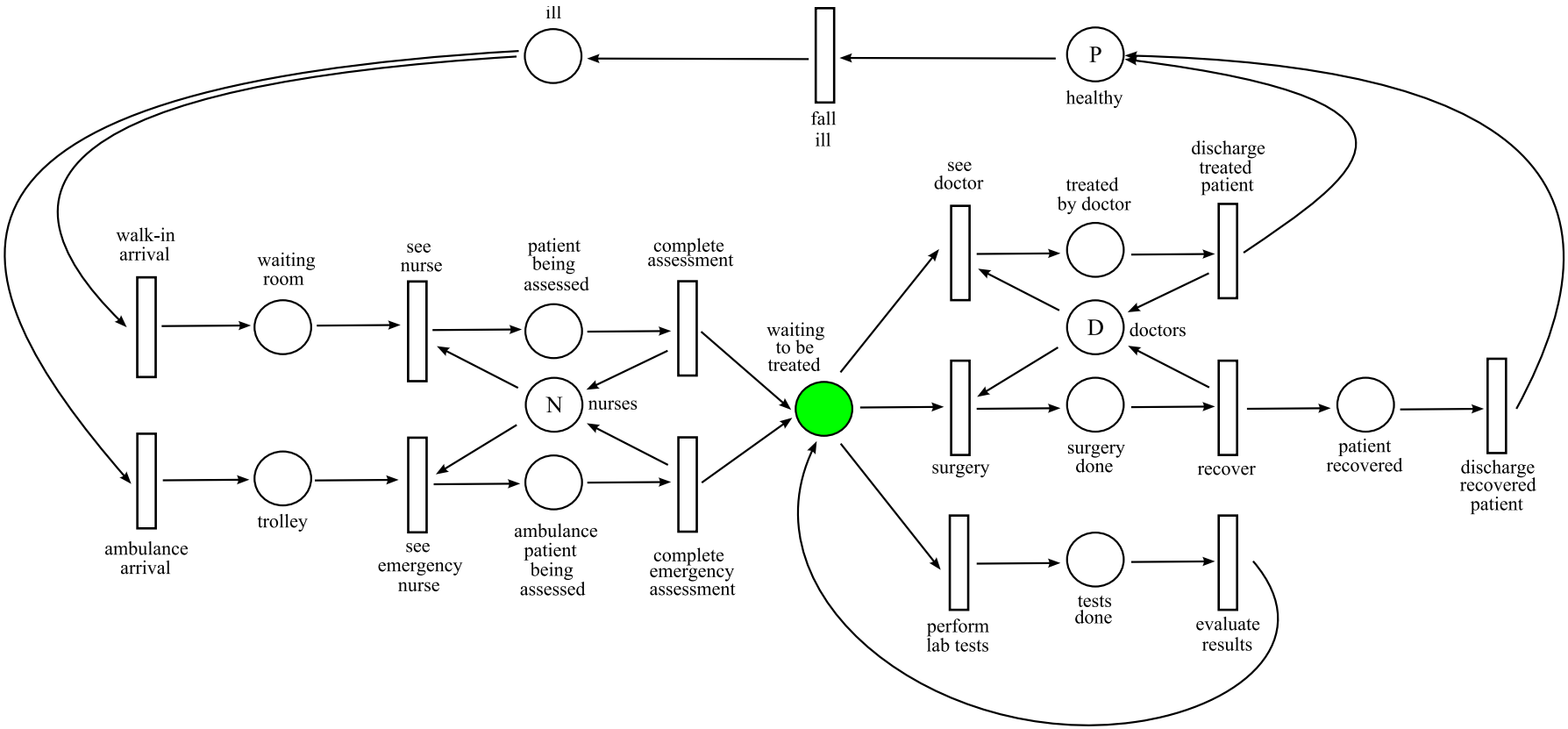

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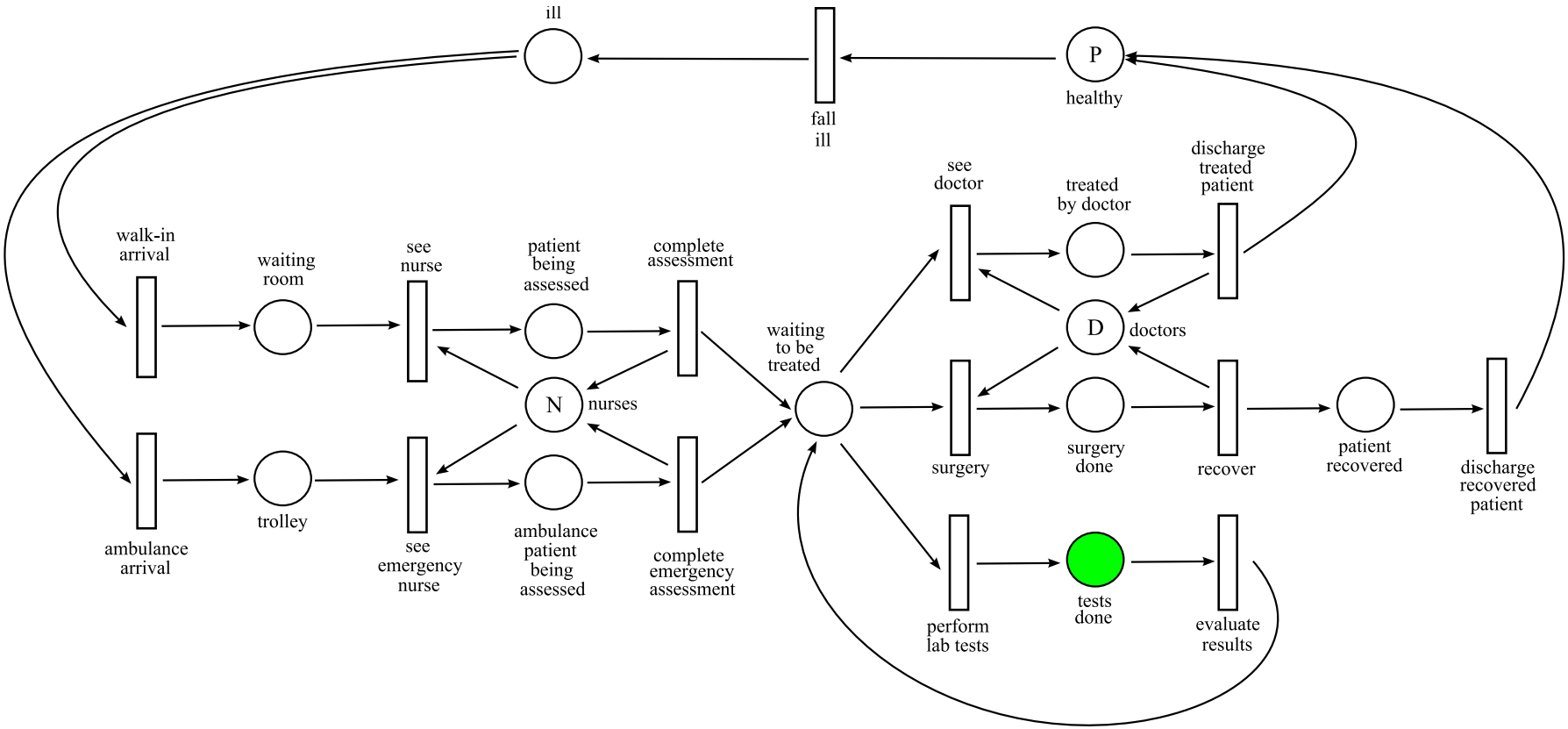

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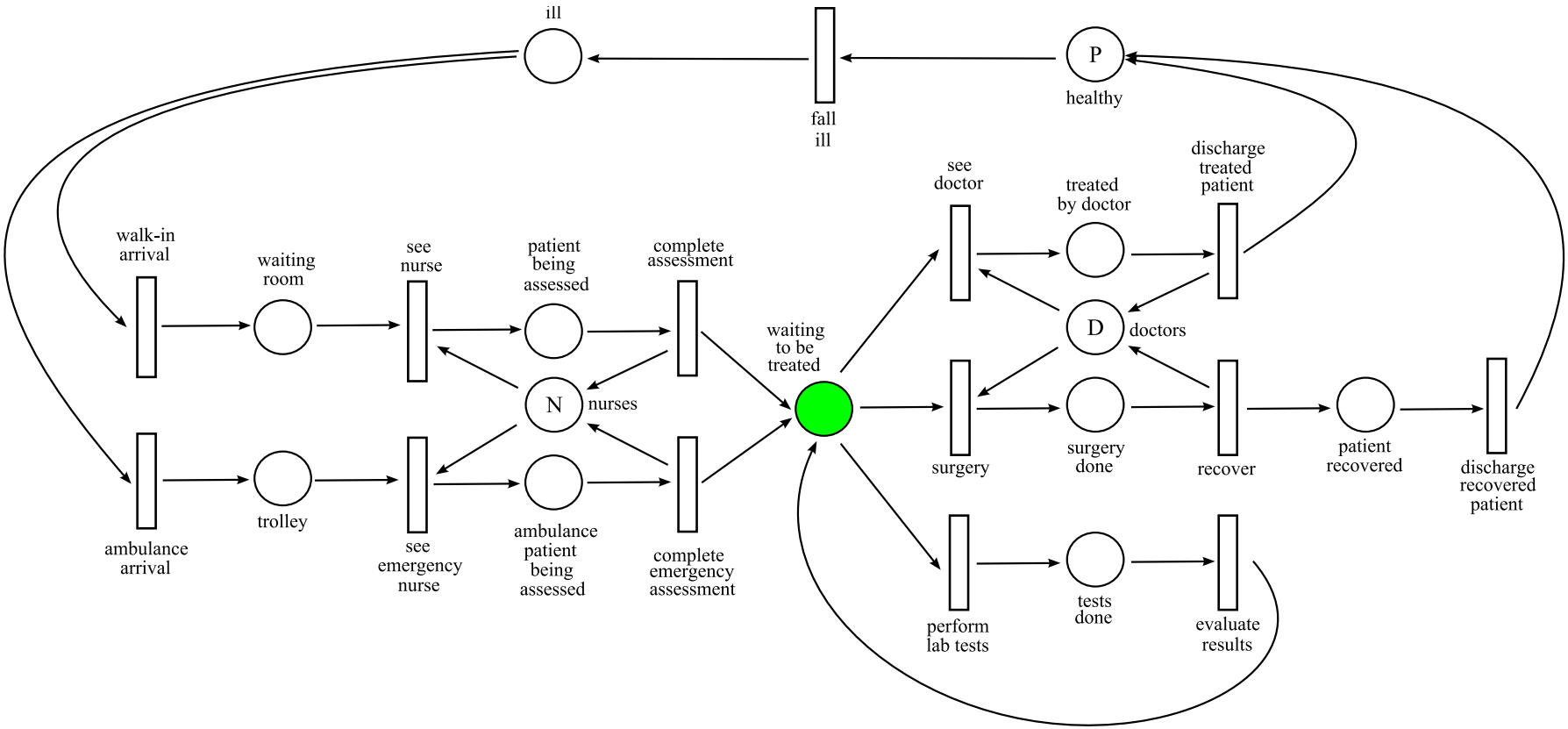


Example 1

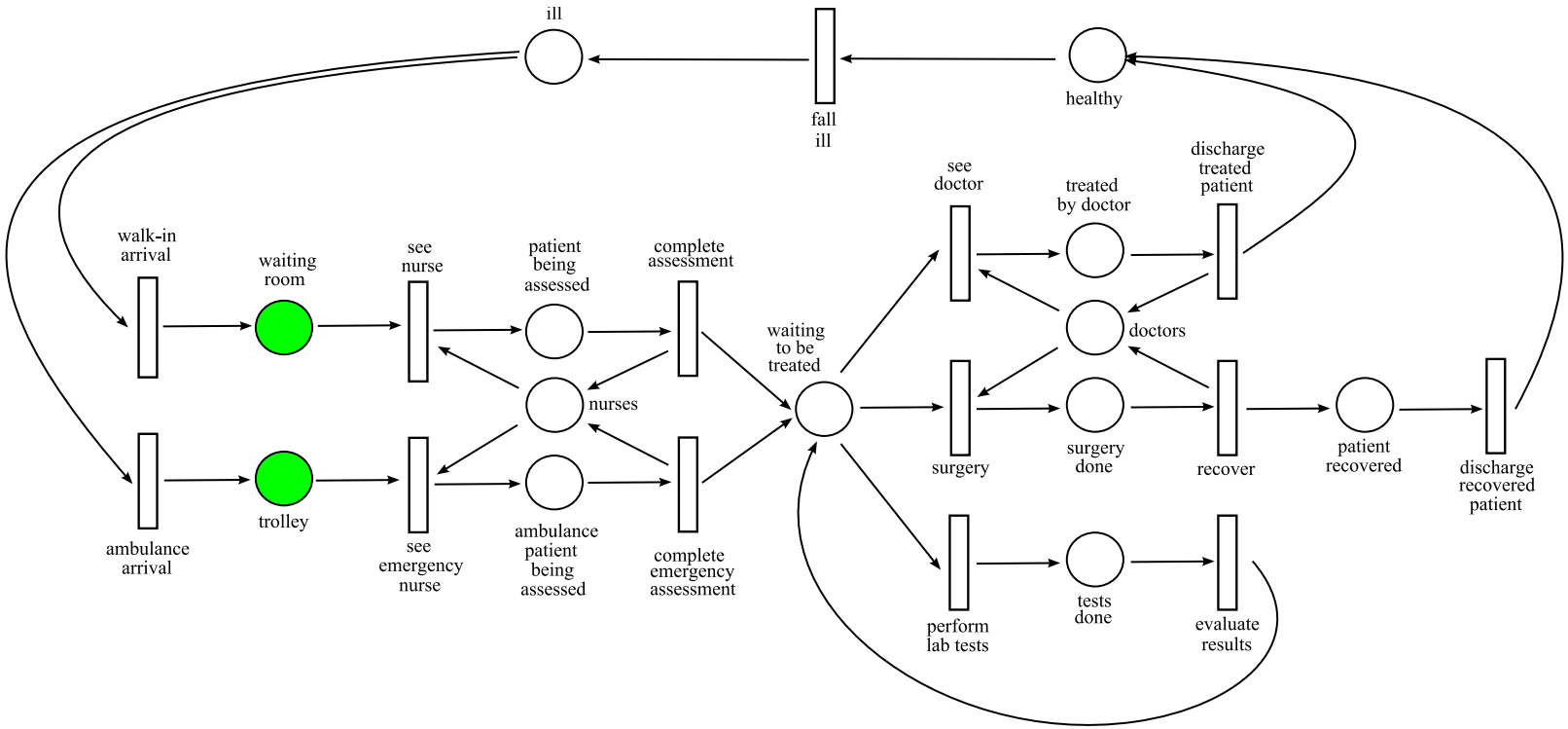
Example

"Is the time from when a patient is admitted to the hospital to the time of discharge less than 4 hours (240 minutes) at least 98% of the time?"

- Need to augment the model to be able to track an individual tagged patient
- Need to define state labels that identify the start and target states

Example 1

$$\textit{admitted} := (\textit{patient} \mathbin{@} \textit{waiting room}) \vee (\textit{patient} \mathbin{@} \textit{trolley})$$
$$\textit{discharged} := (\textit{patient} \mathbin{@} \textit{healthy})$$



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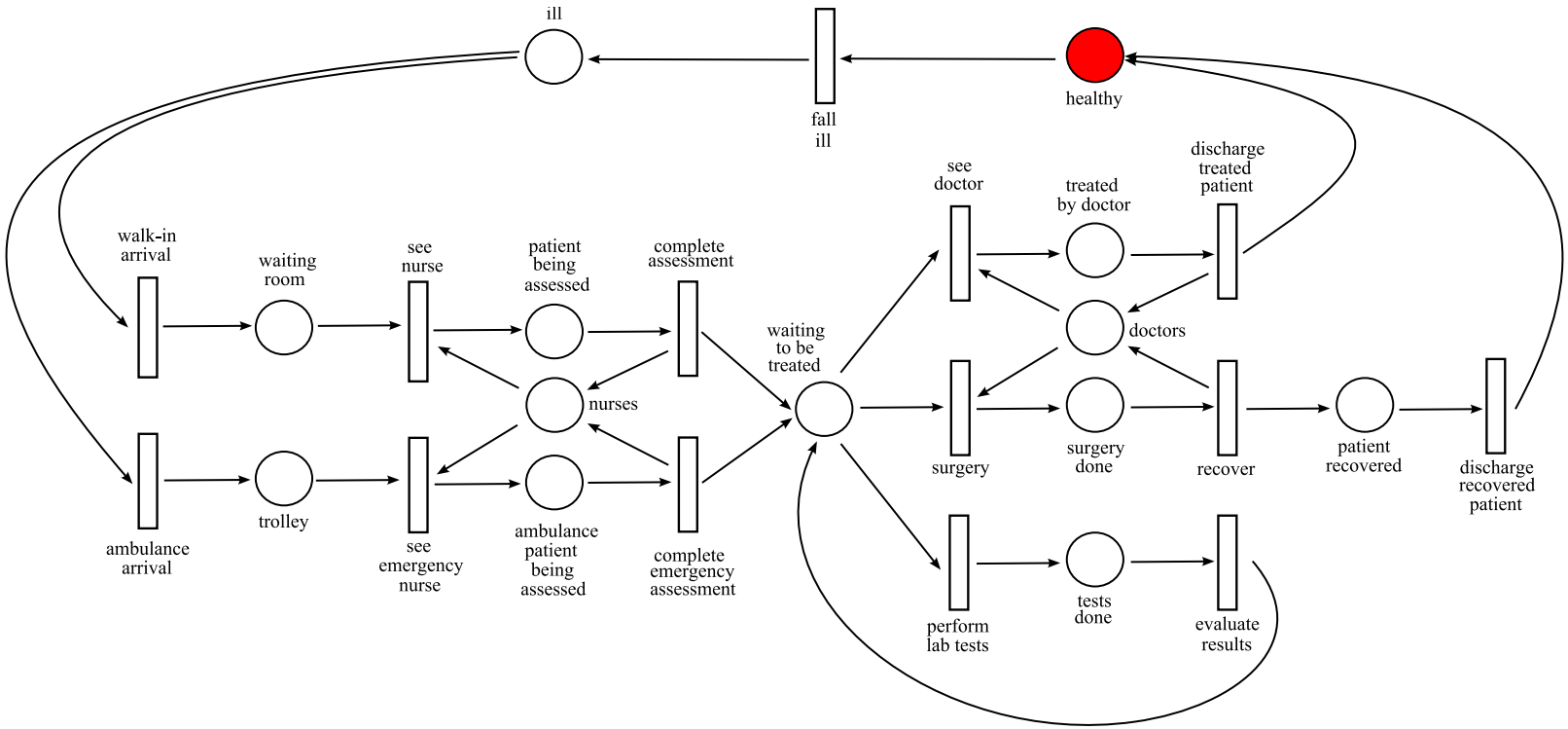

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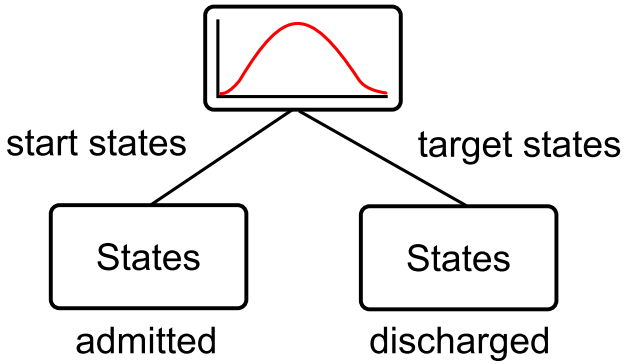

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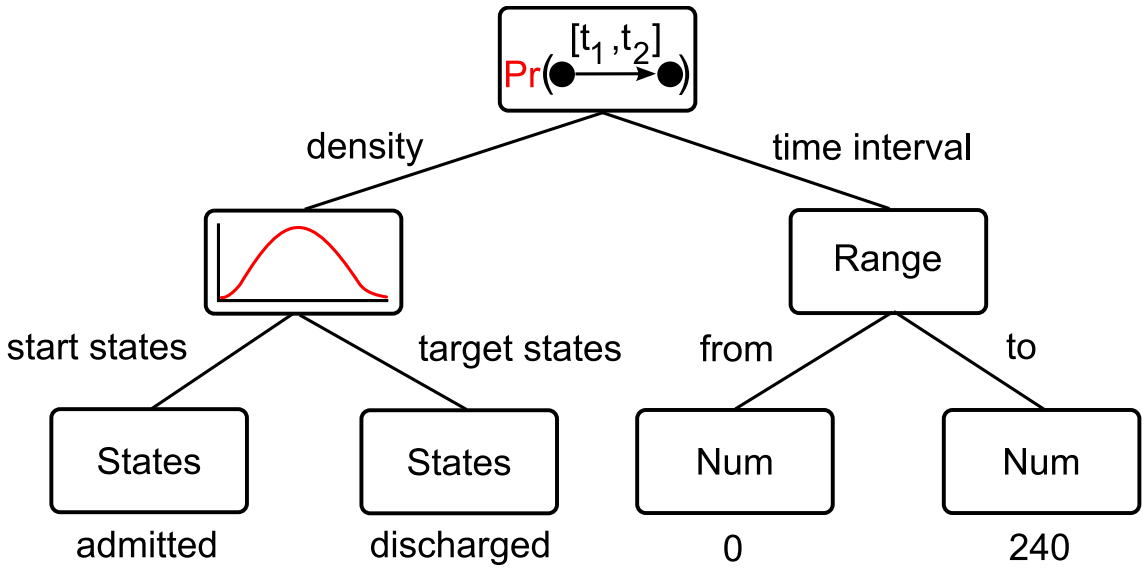

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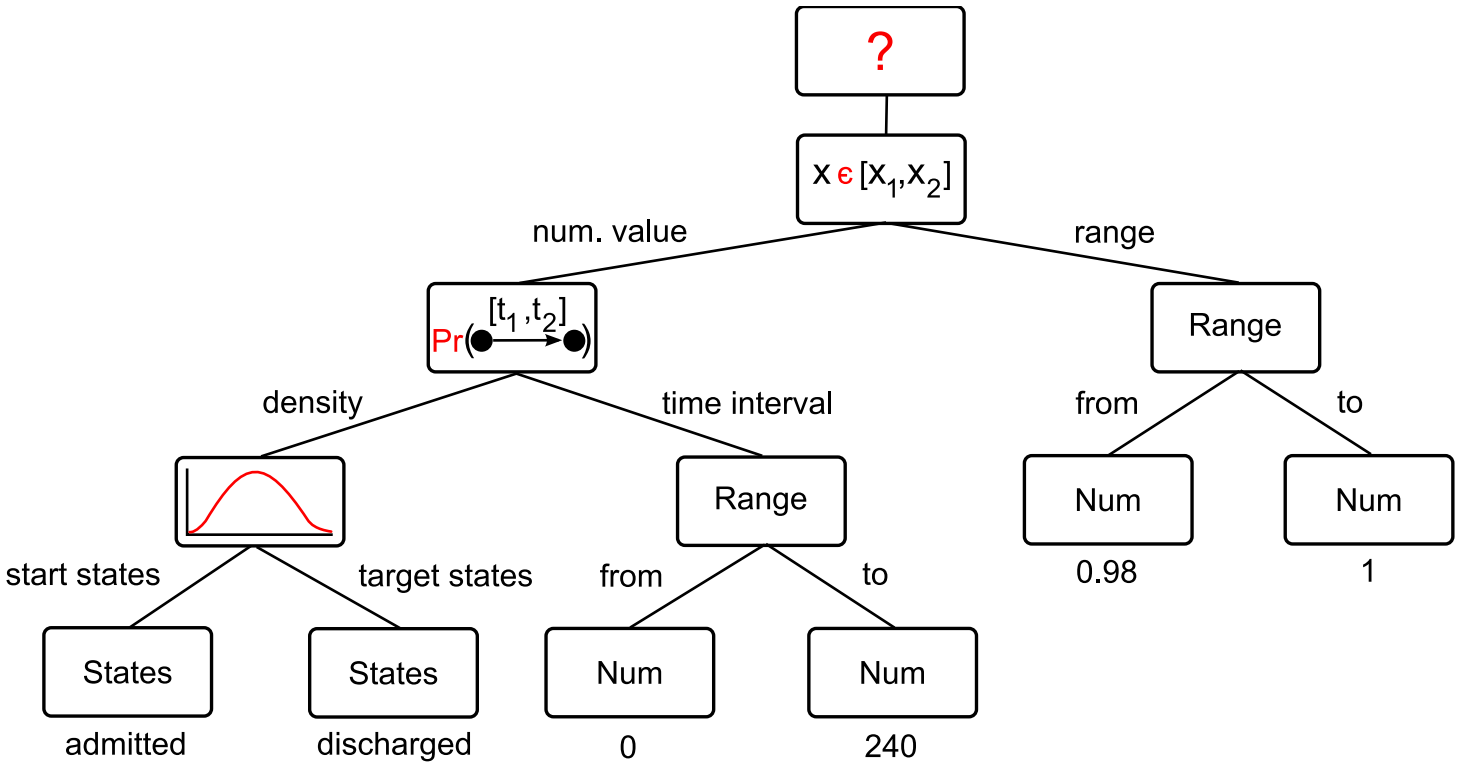


Example 2

Example

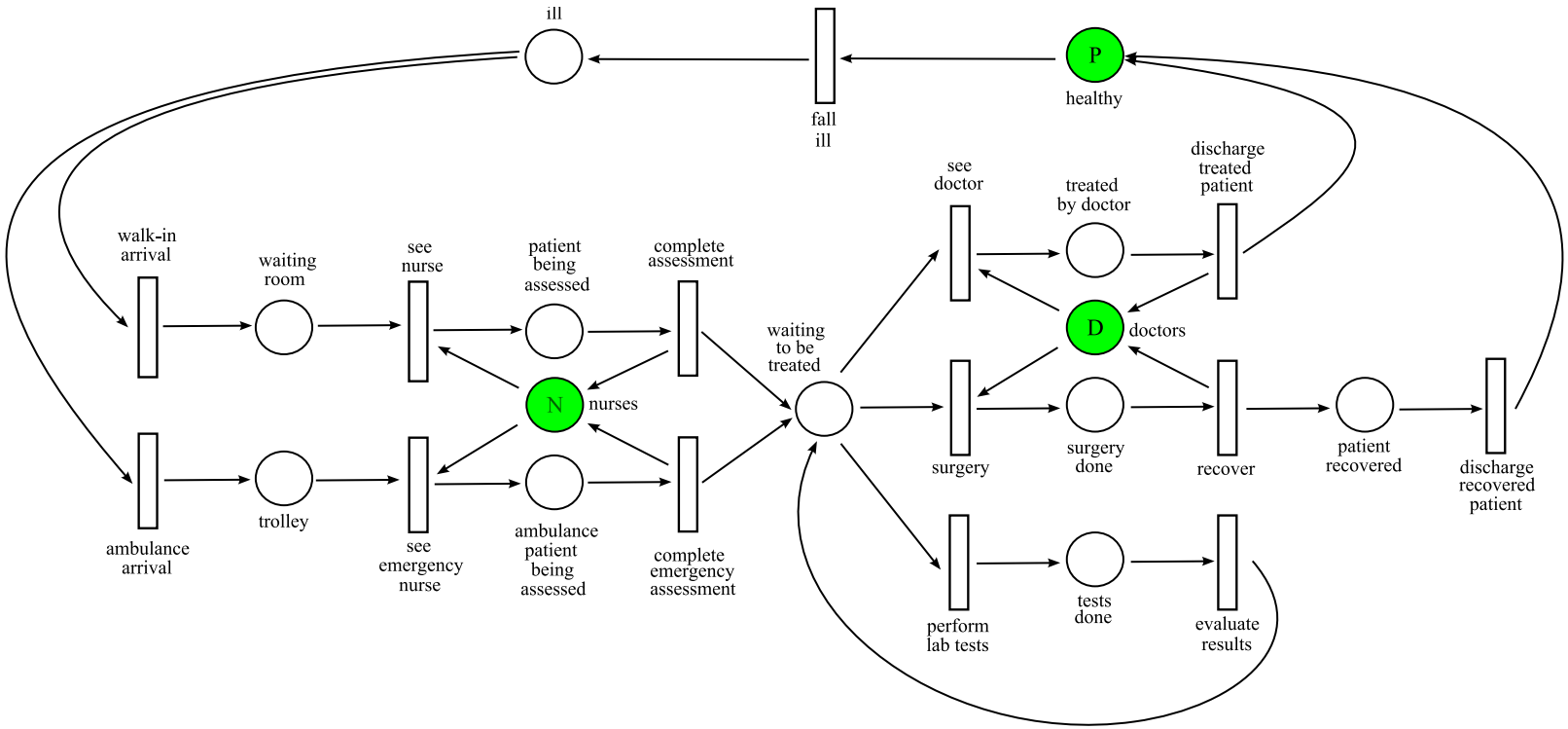
“Is the probability of having less than 3 patients in recovery after surgery at time instant 120 greater than 0.7?"

- Need to define state labels for the start state and the set of states we’re observing at the given time instant

Example 2

$$initial := (\#(healthy) = P) \wedge (\#(nurses) = N) \wedge (\#(doctors) = D)$$

$$< 3\ patients\ recovering := (\#(surgery\ done) < 3)$$



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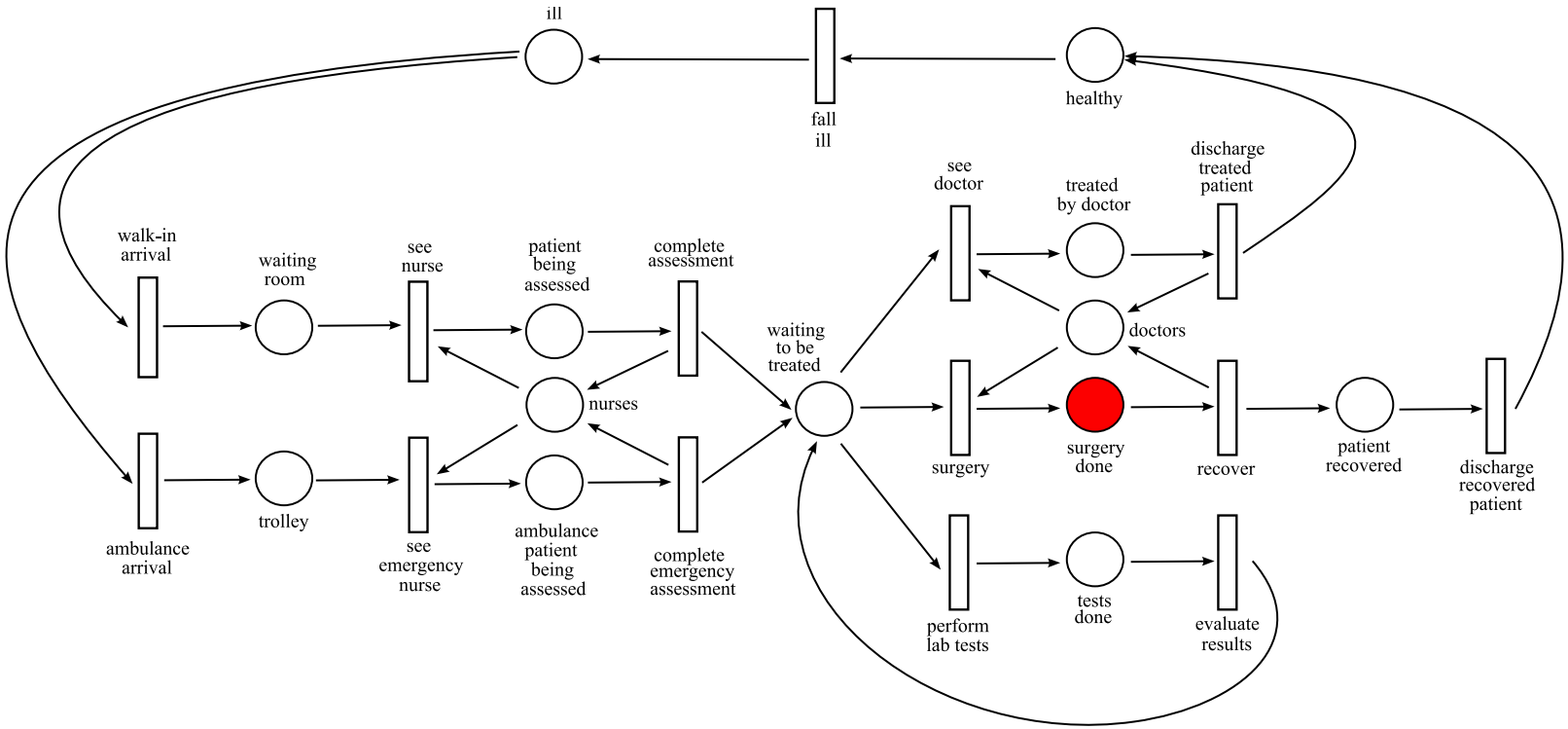

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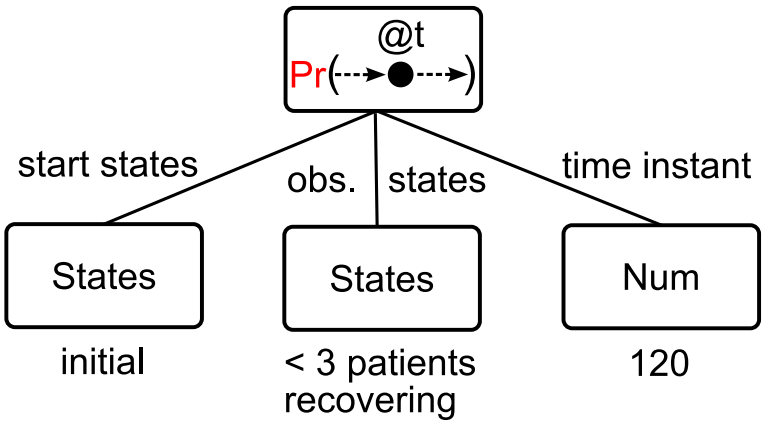

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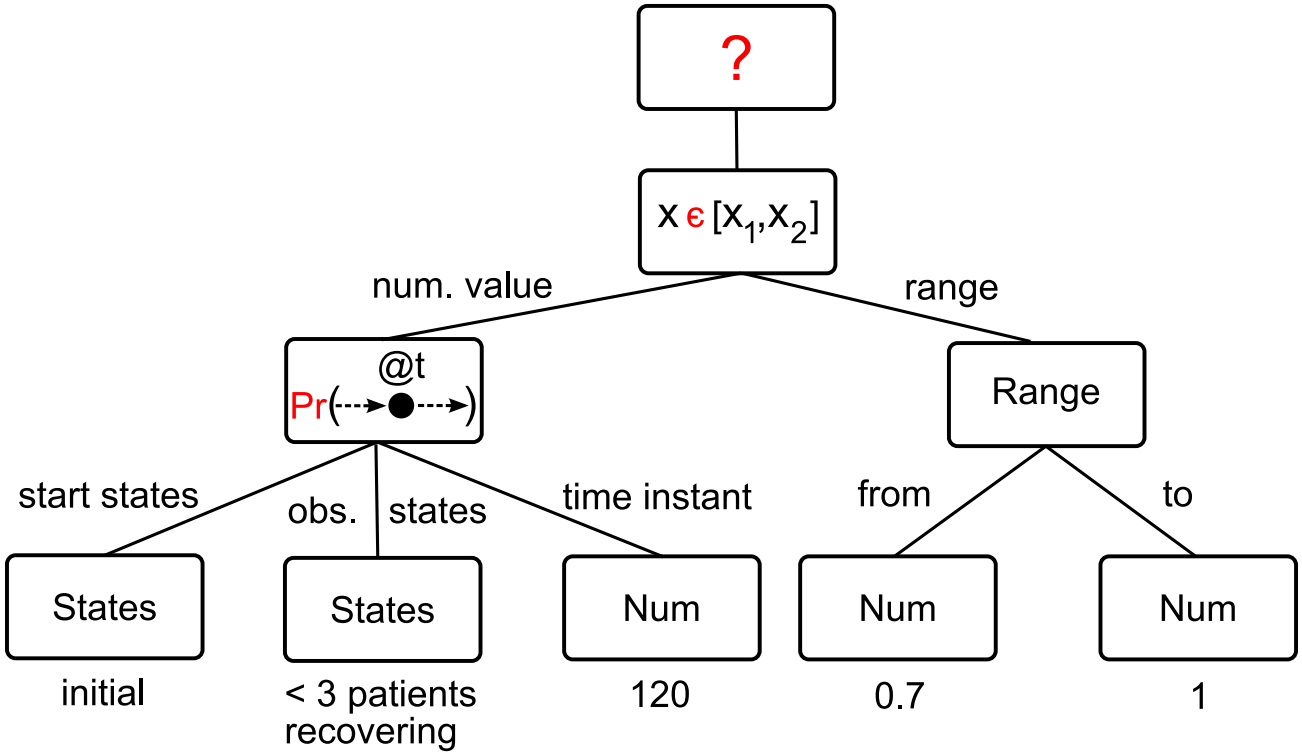


Example 3

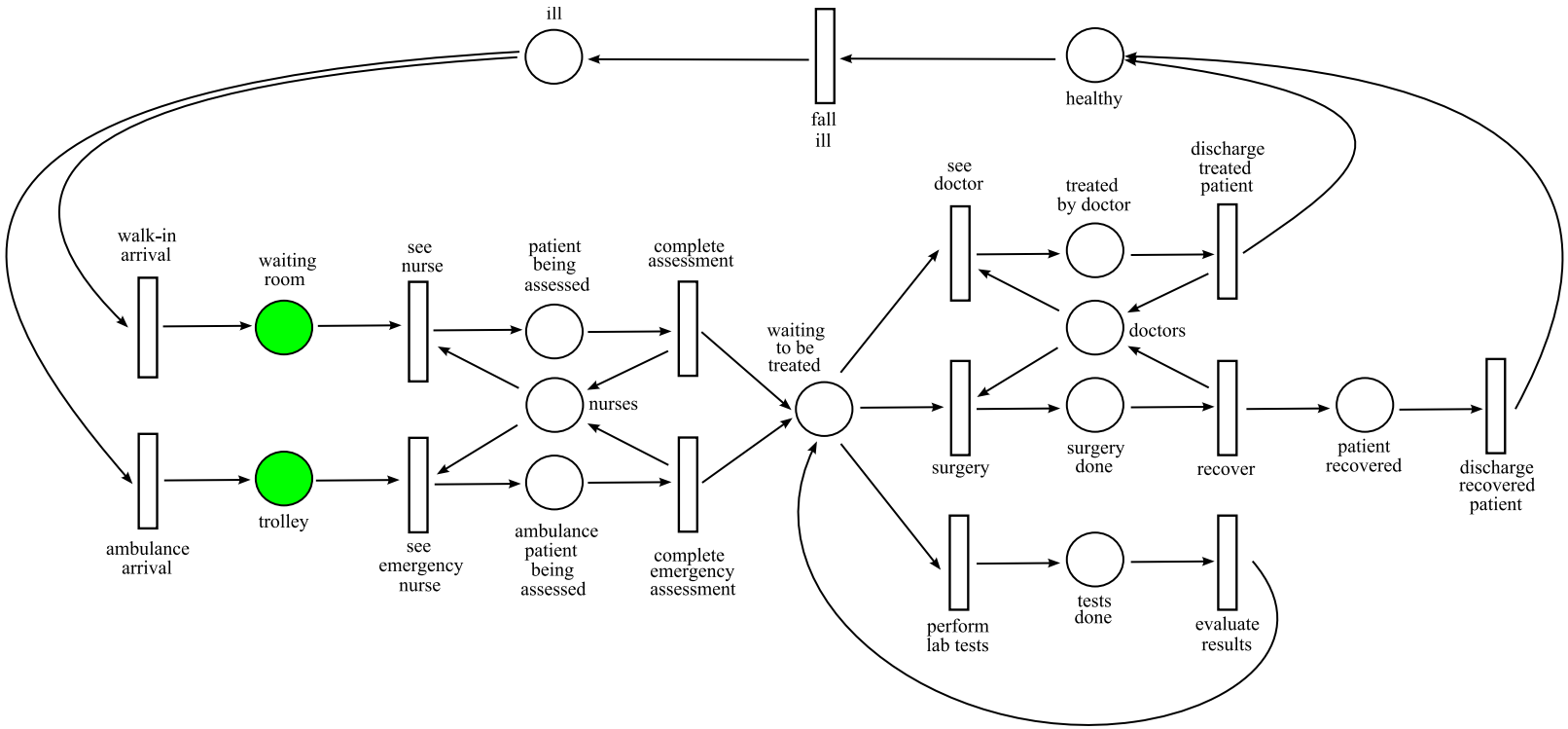
Example

“What is the coefficient of variation (the ratio of the standard deviation to the mean) of the time for a patient to be seen, treated and discharged from the hospital?"

- Need to define relevant state labels for the set of start states and the target state
- We also need to cope with multiple start states

Example 3

$$\textit{patient arrived} := (\textit{patient @ waiting room}) \vee (\textit{patient @ trolley})$$
$$\textit{discharged} := (\textit{patient @ healthy})$$



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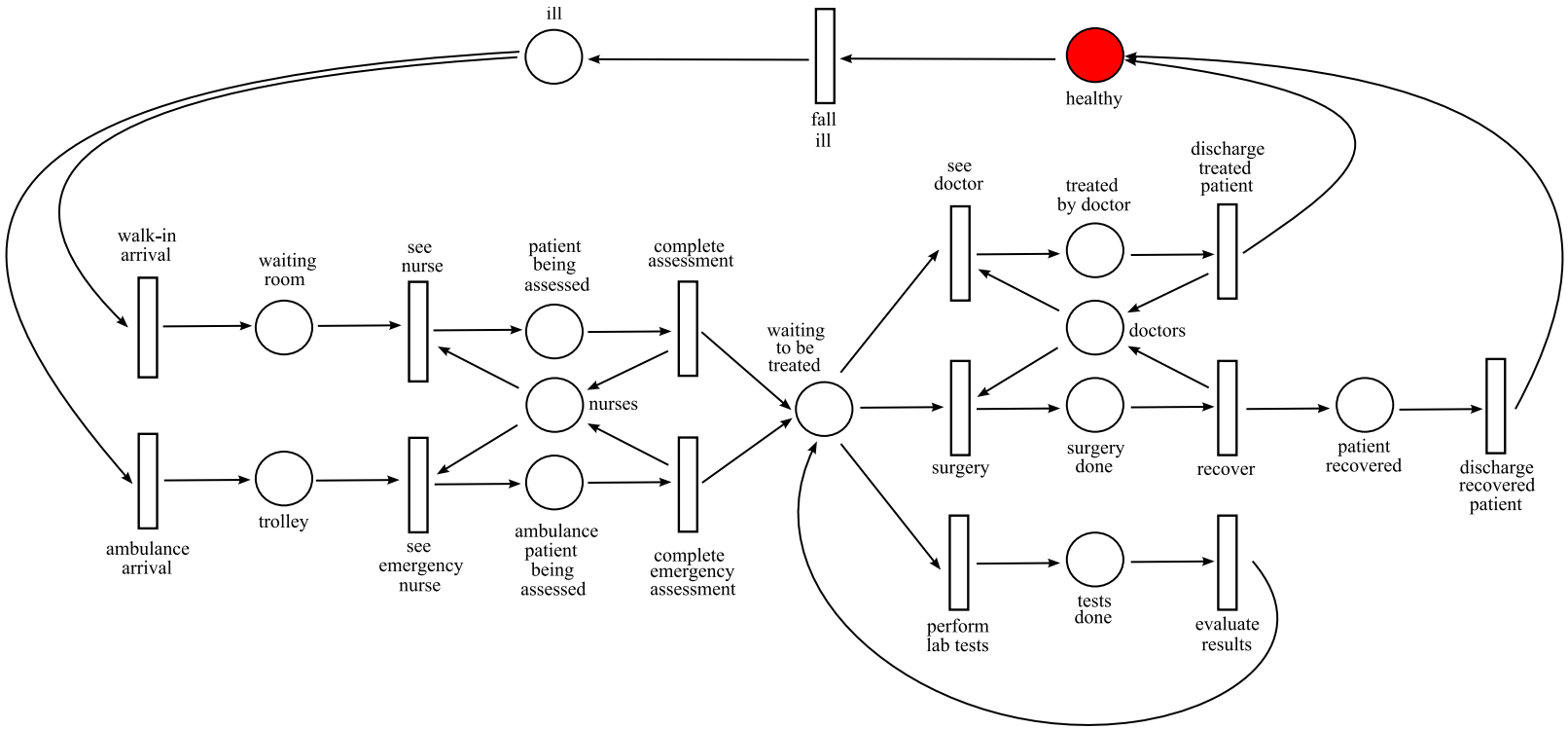

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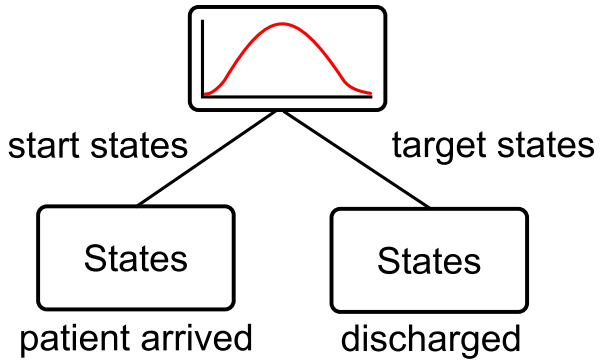

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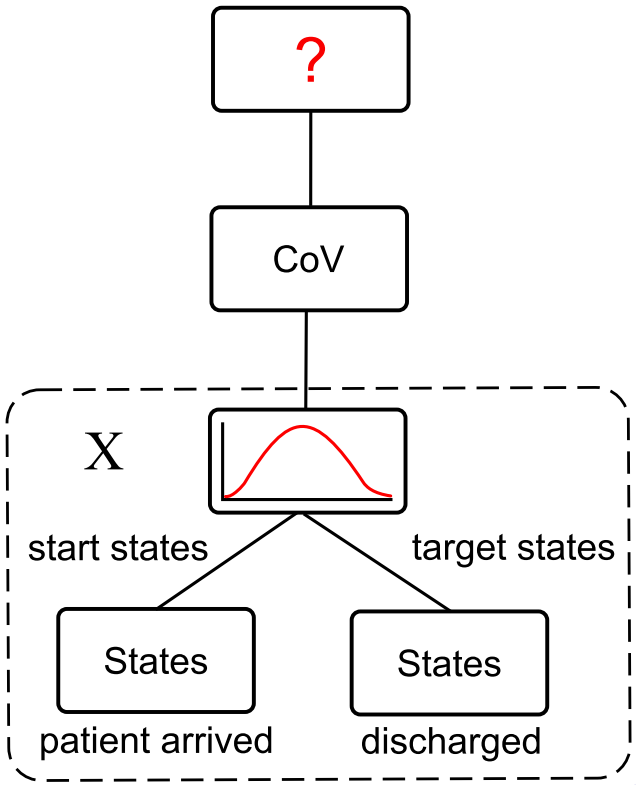

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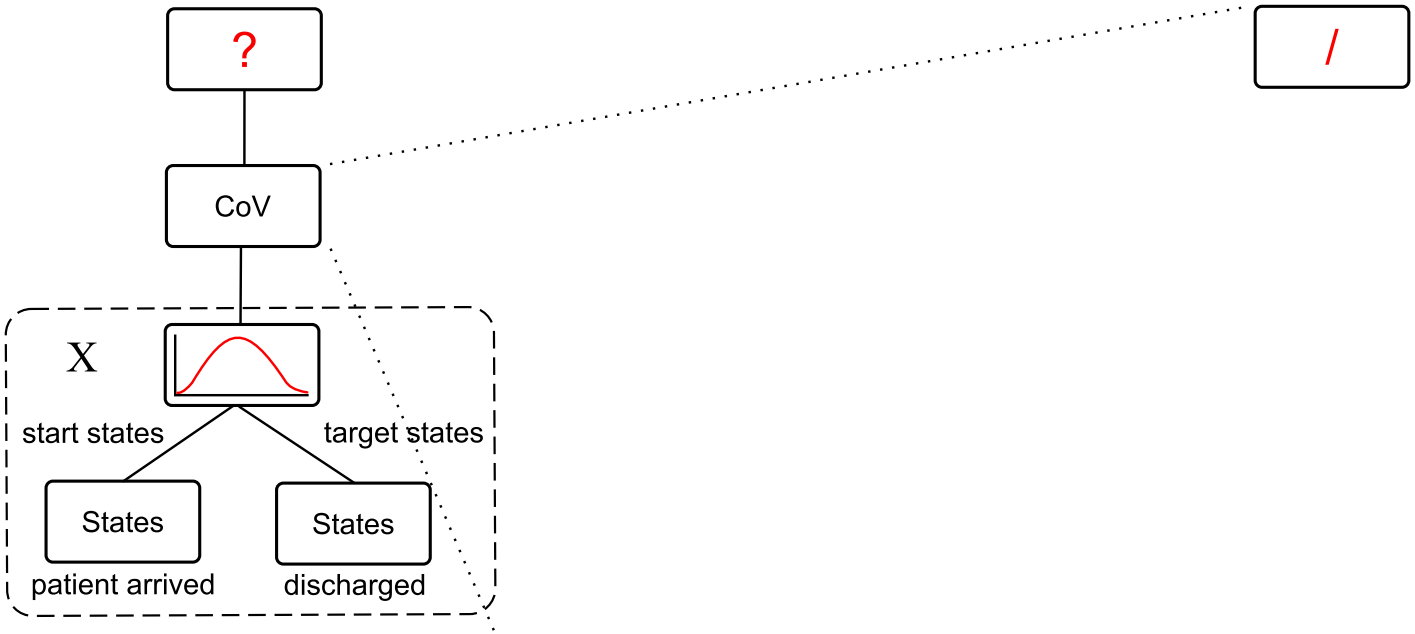

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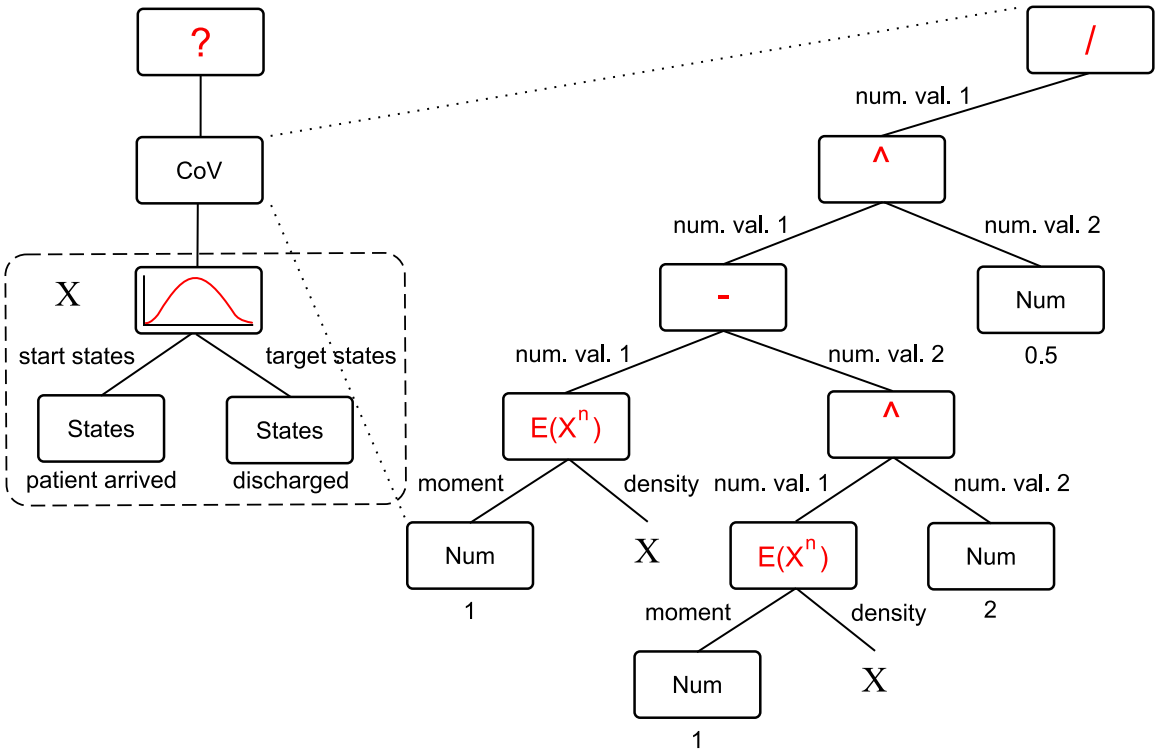

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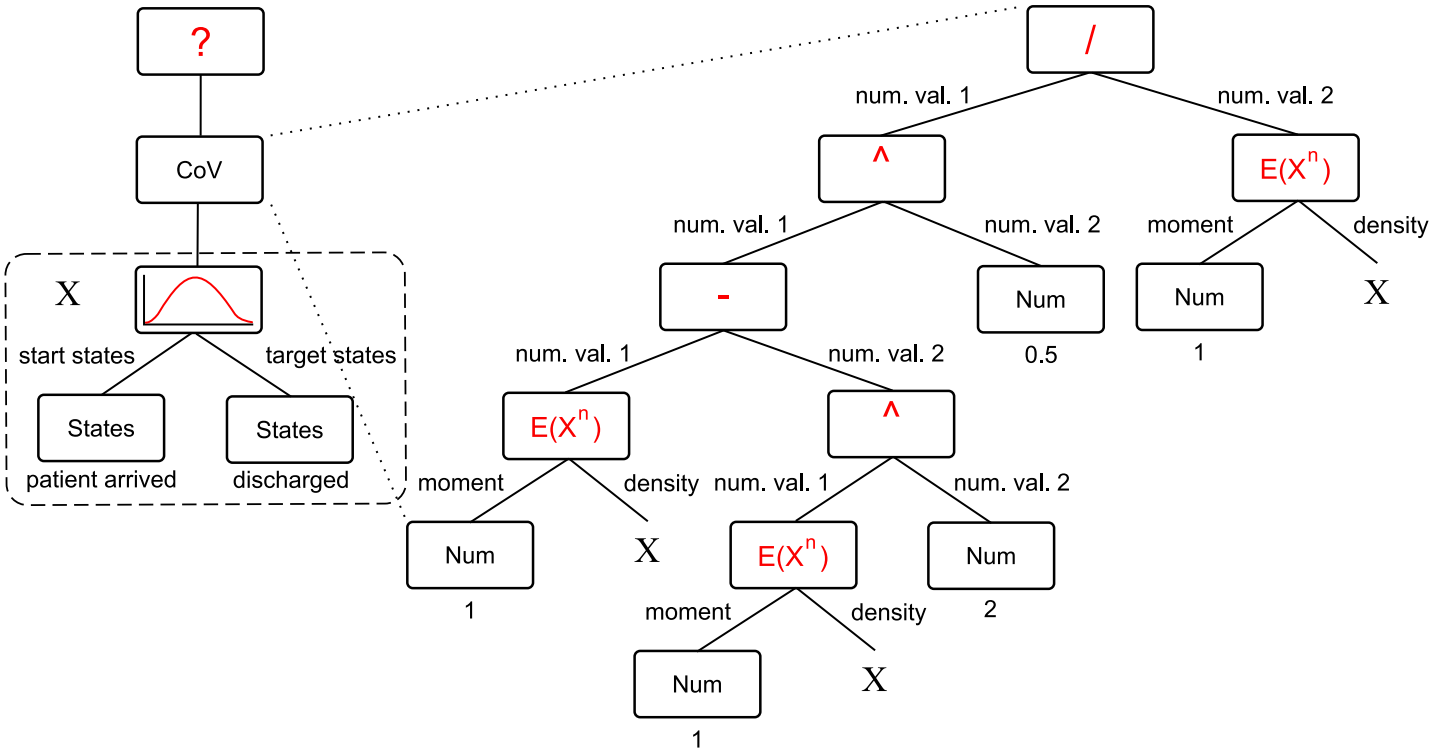


Example 4

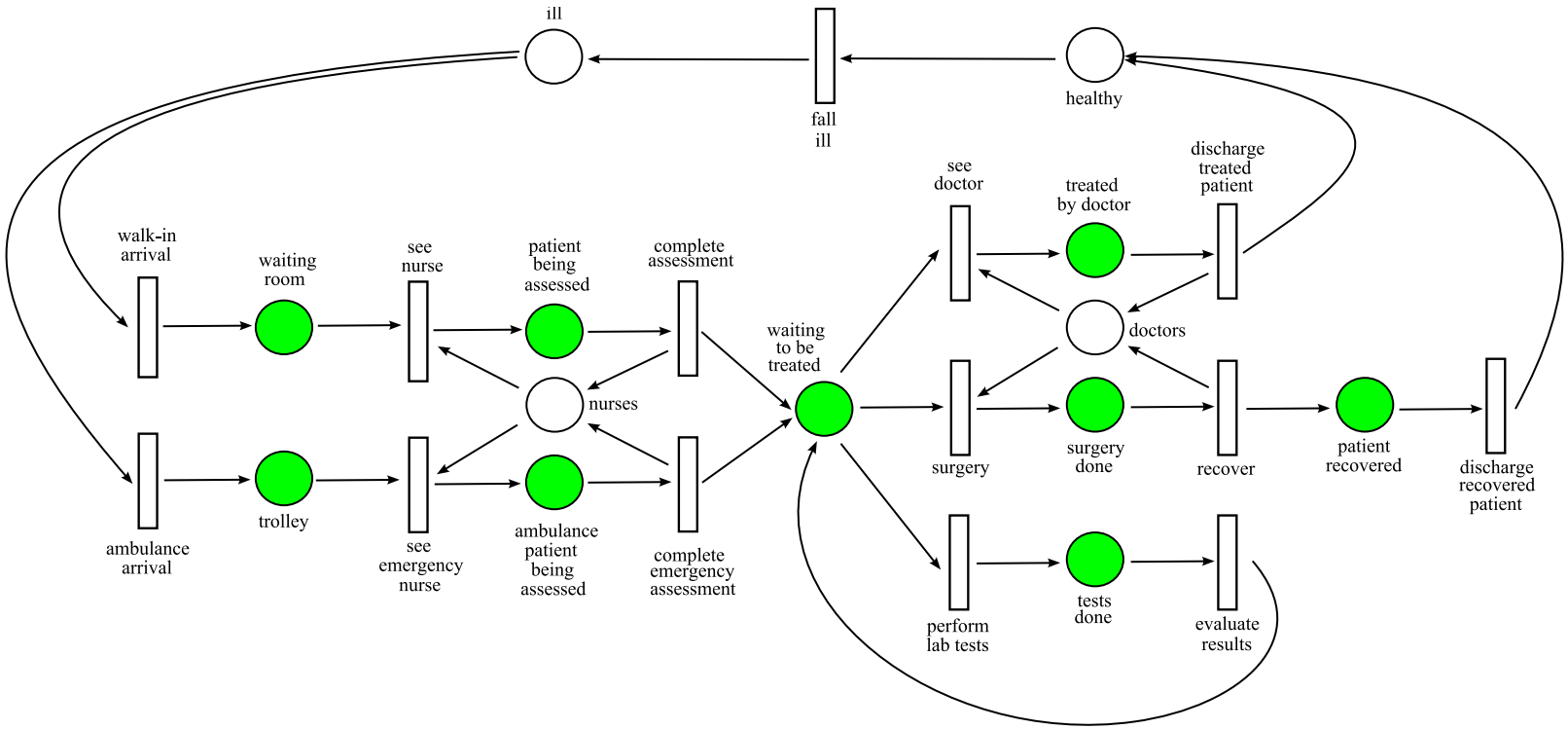
Example

“What is the average rate of occurrence of surgeries and what is the steady-state probability distribution of the number of patients waiting for treatment and of the number of patients inside and outside of the hospital?"

- Need to define state function labels

Example 4

$$
\begin{aligned}
\mathit{all} &:= \mathit{true} \\
\#(\mathit{in\ hospital}) &:= (P - \#(\mathit{outside\ hospital})) \\
\#(\mathit{outside\ hospital}) &:= (\#(\mathit{healthy}) + \#(\mathit{ill}))
\end{aligned}
$$



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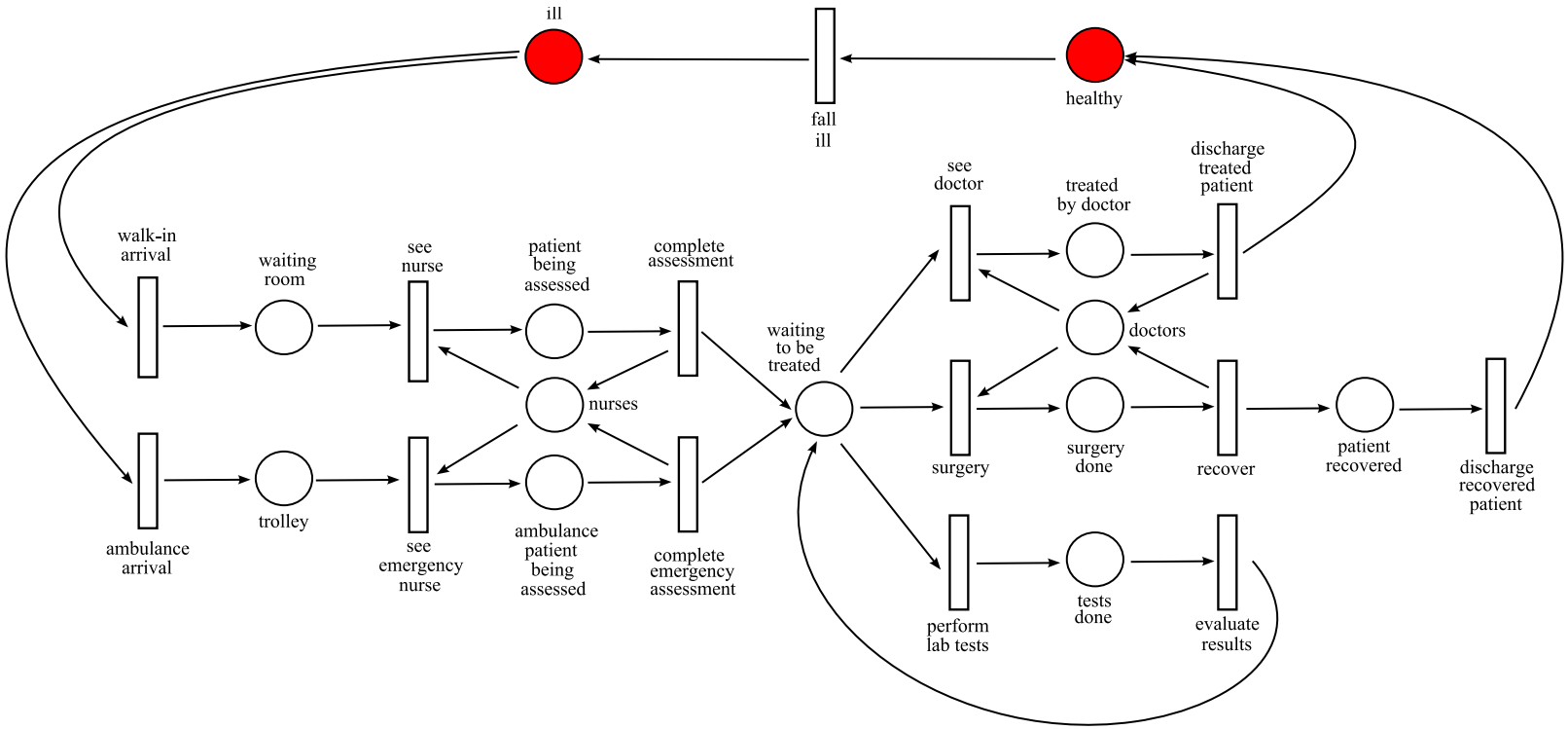

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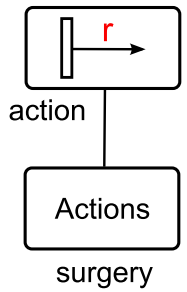

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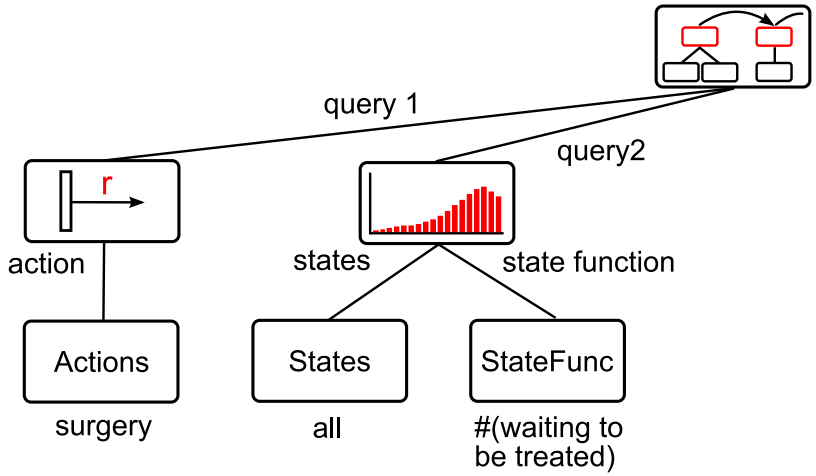

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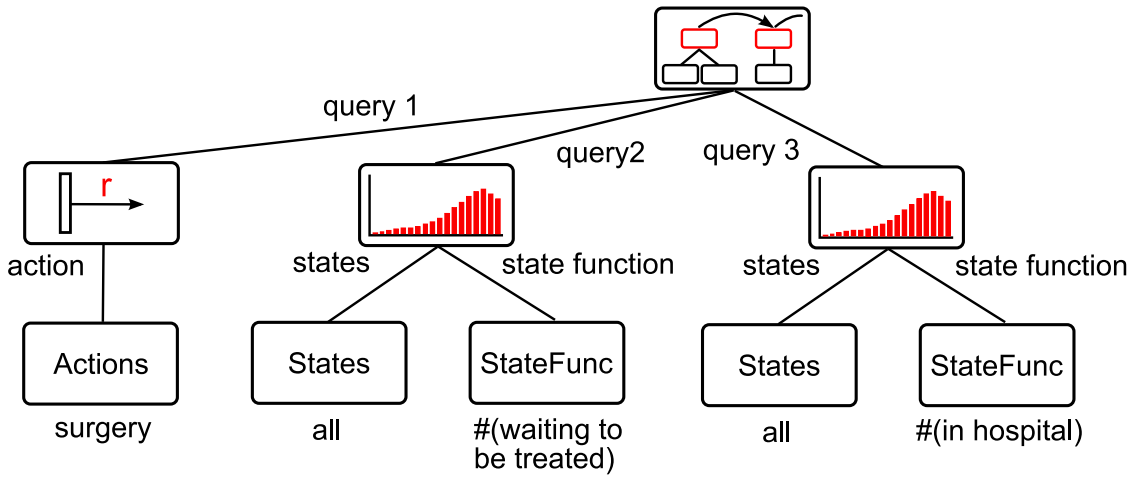
"What is the average rate of occurrence of surgeries and what is the steady-state probability distribution of the number of patients waiting for treatment and of the number of patients inside and outside of the hospital?"



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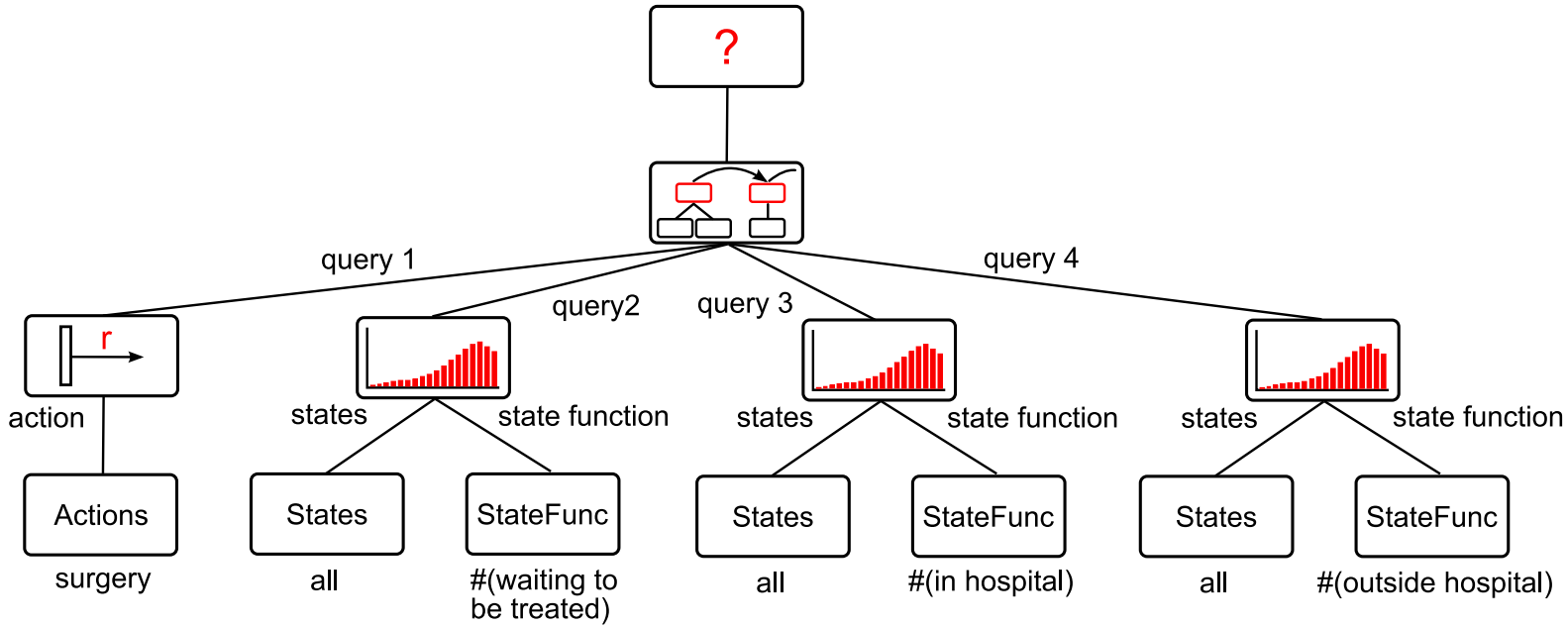
"What is the average rate of occurrence of surgeries and what is the steady-state probability distribution of the number of patients waiting for treatment and of the number of patients inside and outside of the hospital?"



Prototype Tool Support

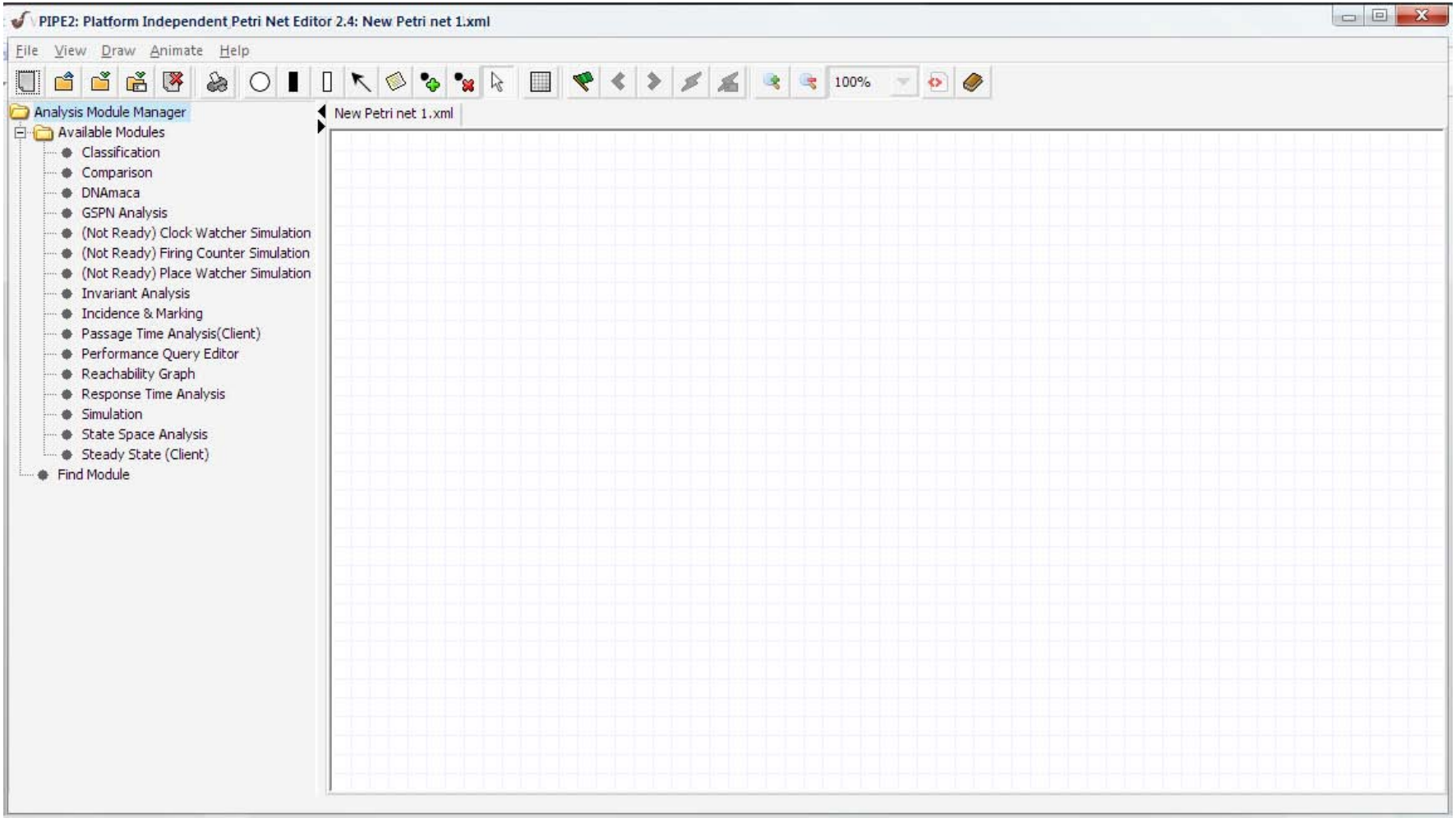
- Performance Trees are supported by an extension of the *PIPE2* Petri net editor
- Provides a simple and convenient way of specifying performance queries
- See for yourselves...

Prototype Tool Support

Example

“Is the probability of having less than 3 patients in recovery after surgery at time instant 120 greater than 0.7?"

Prototype Tool Support



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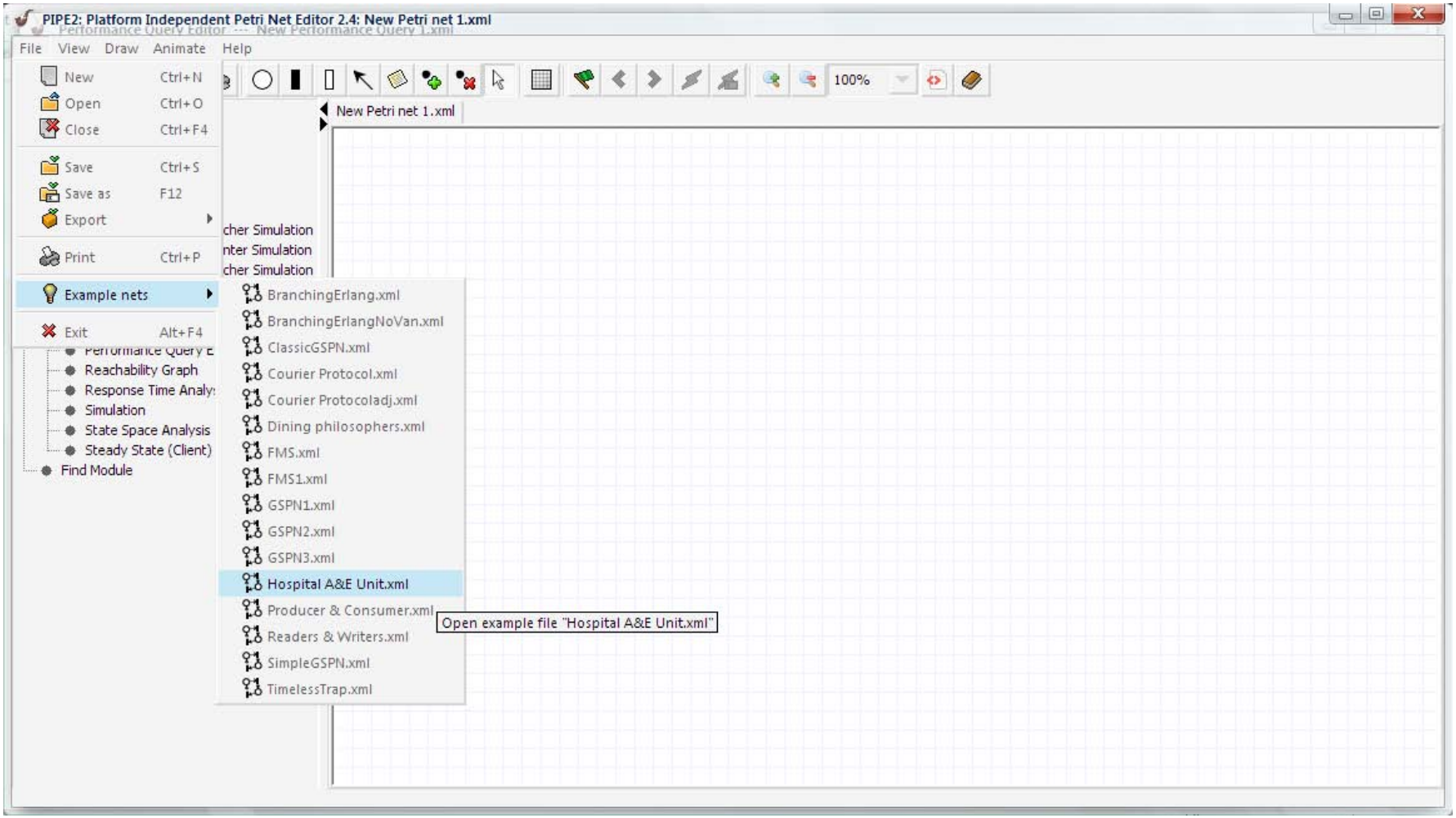

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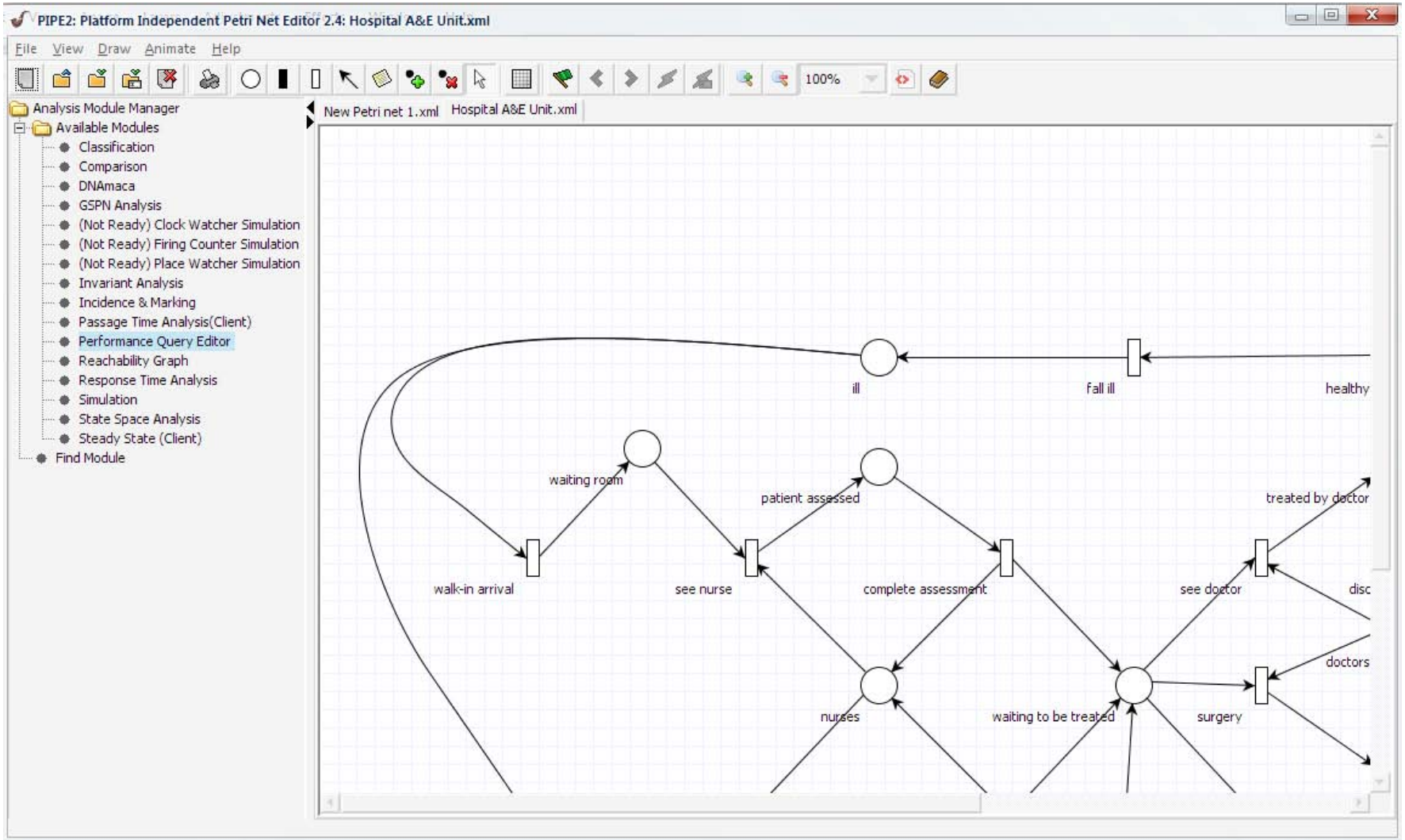

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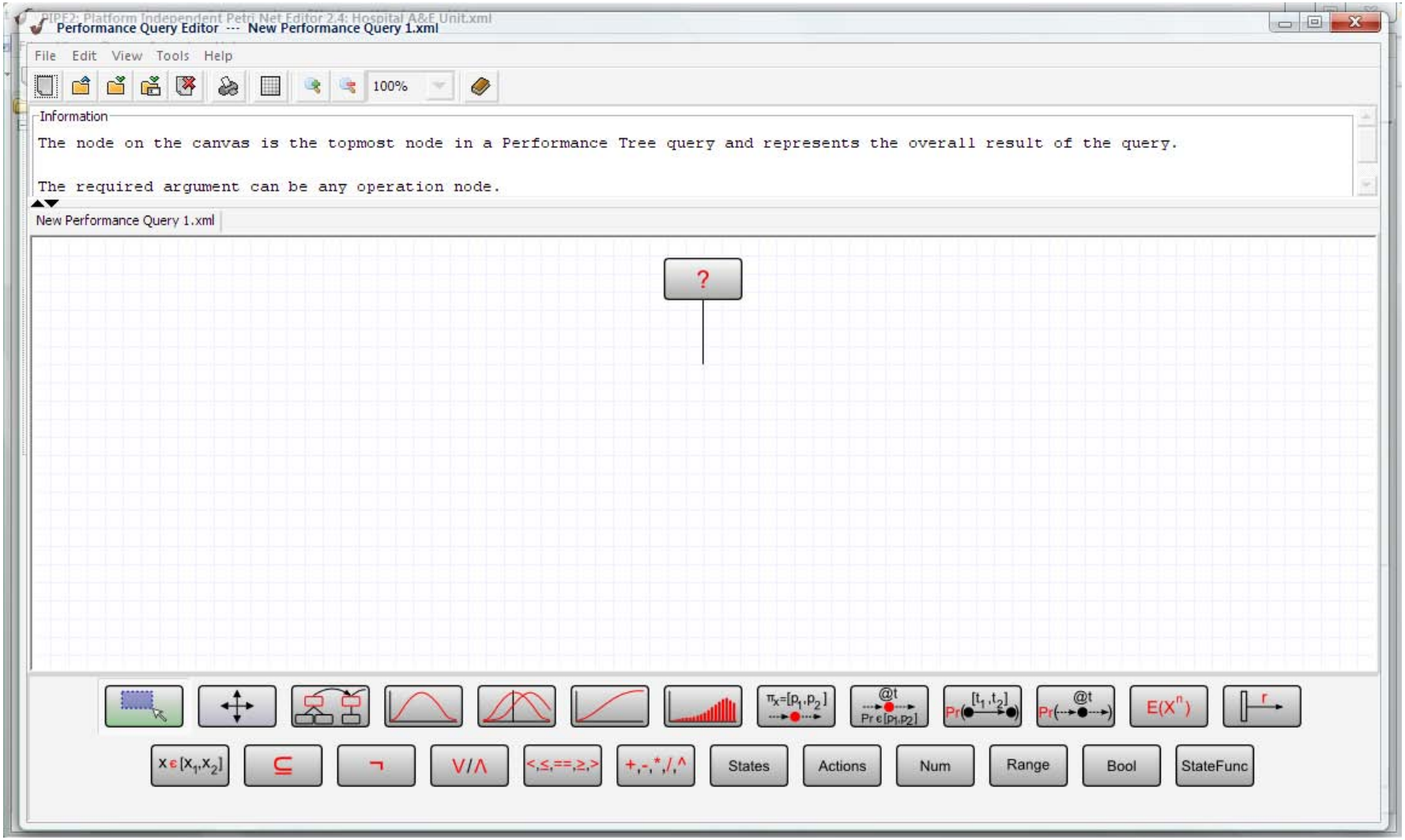

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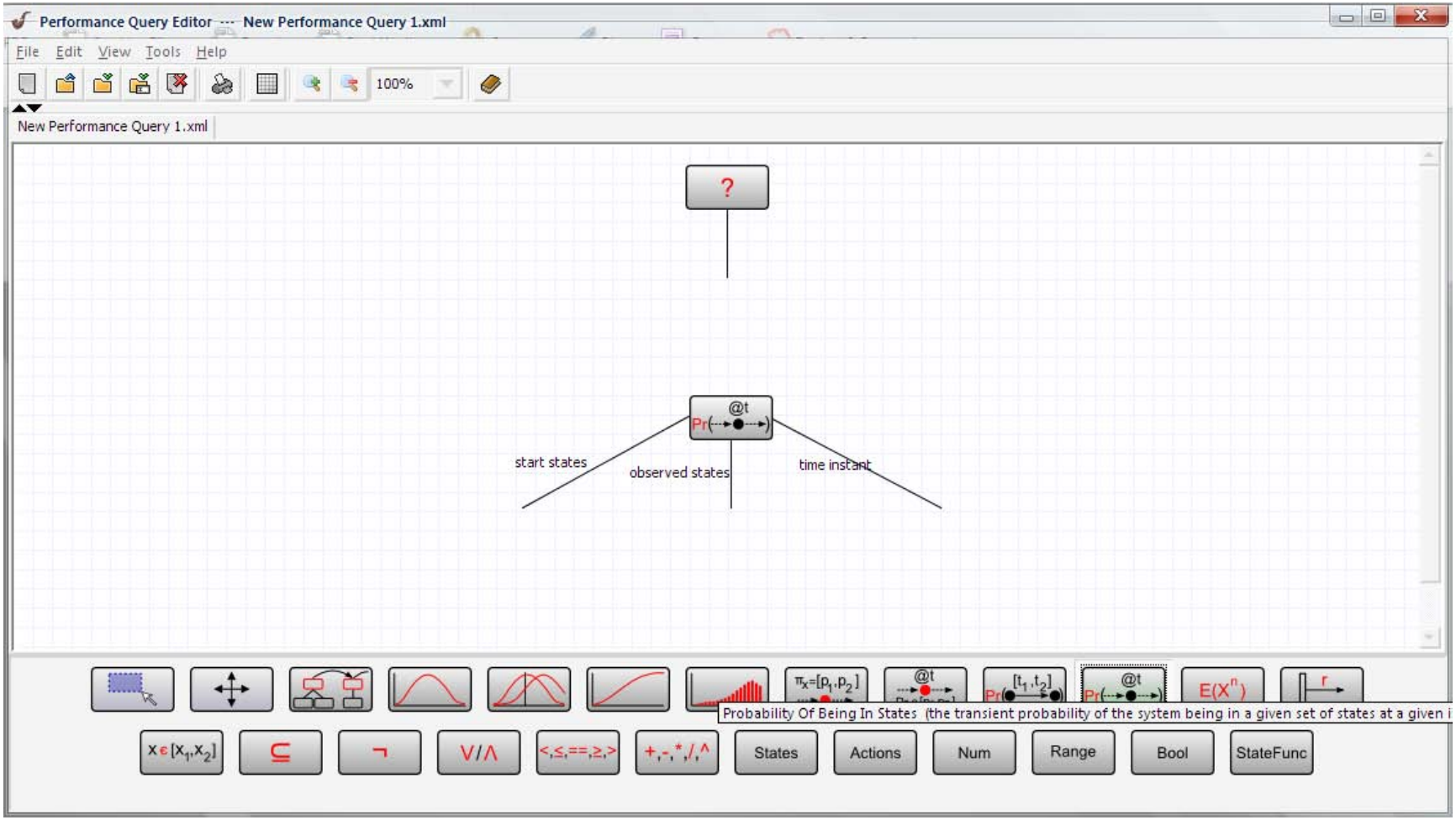

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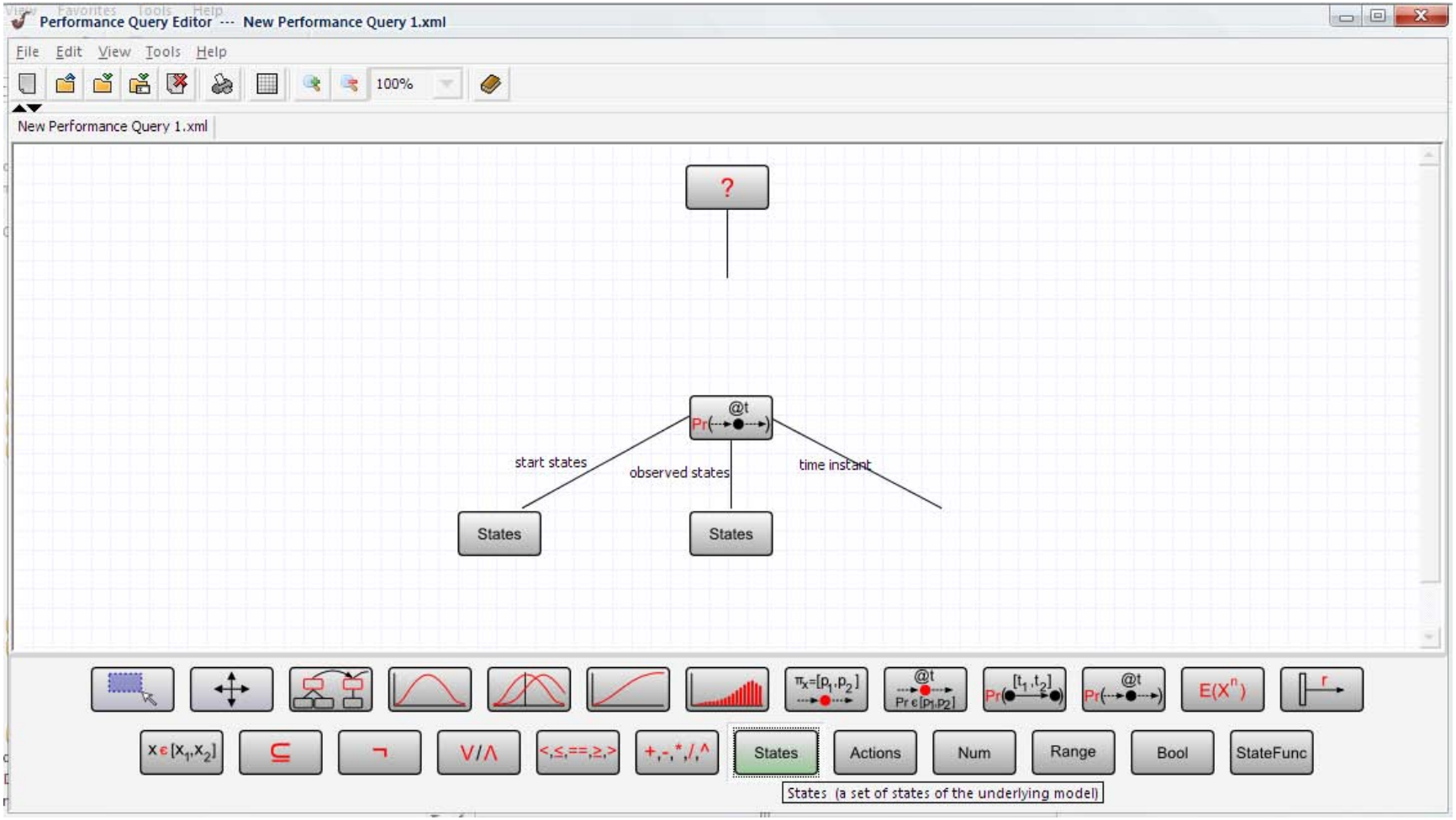

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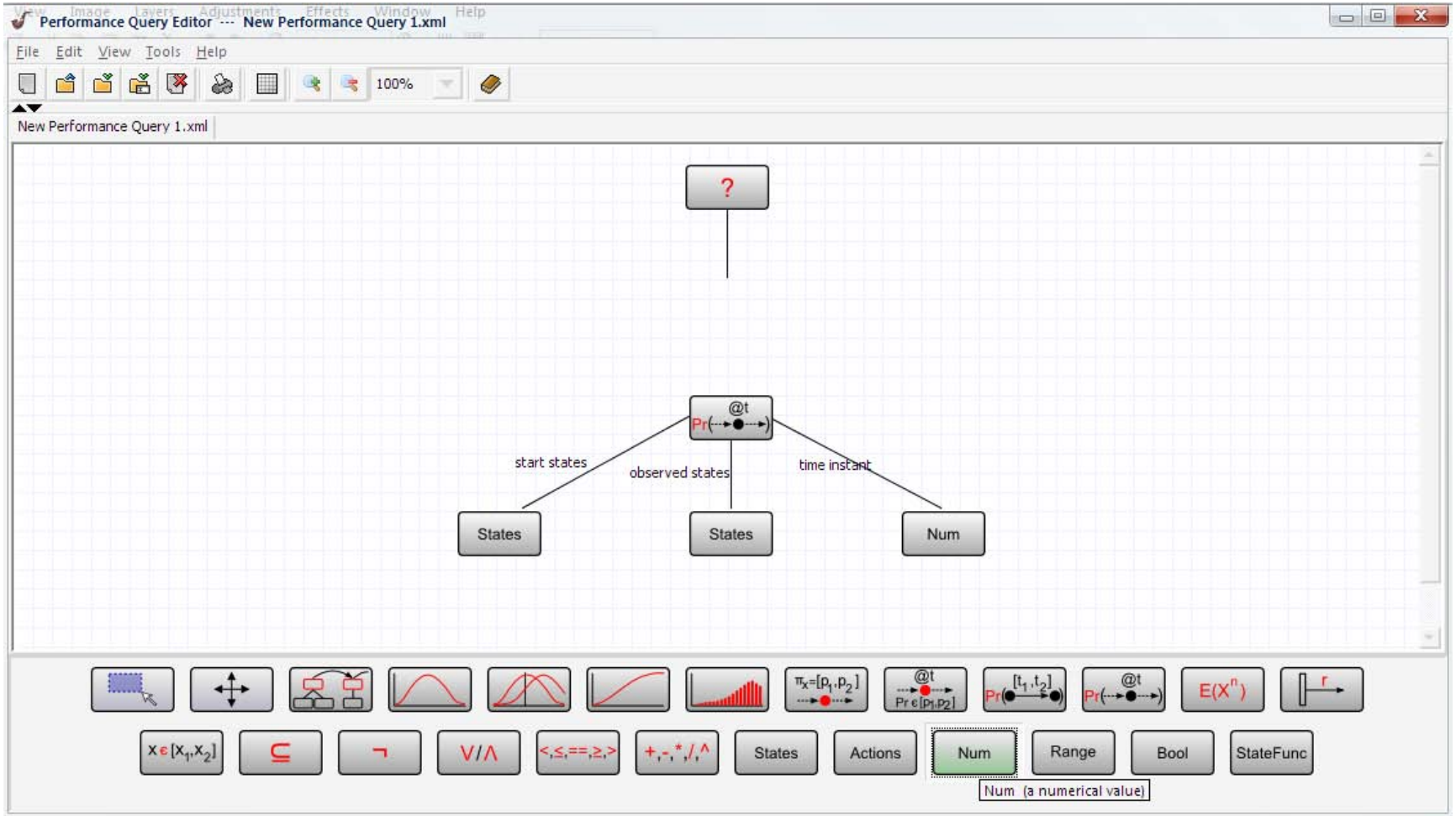

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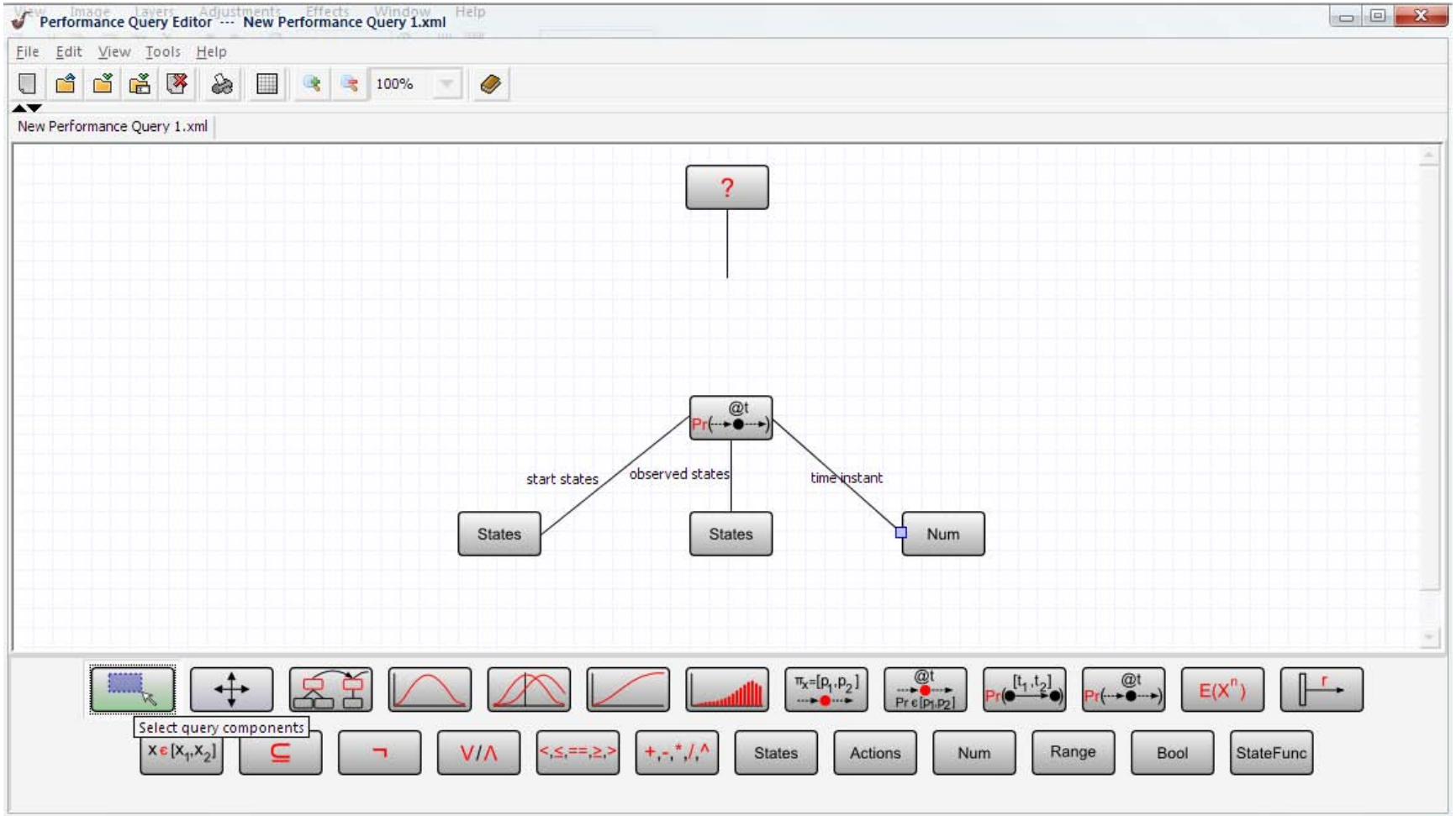

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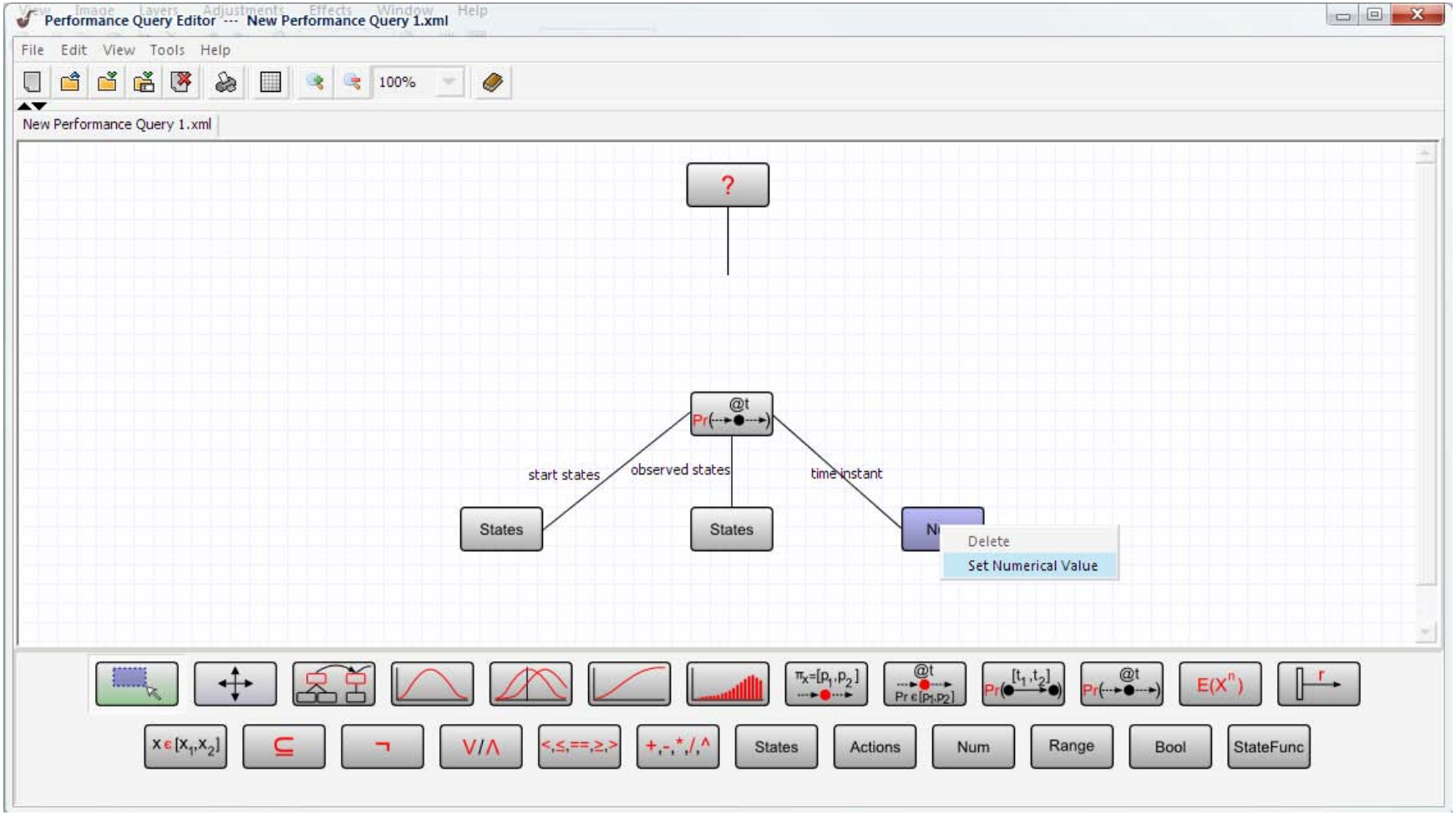

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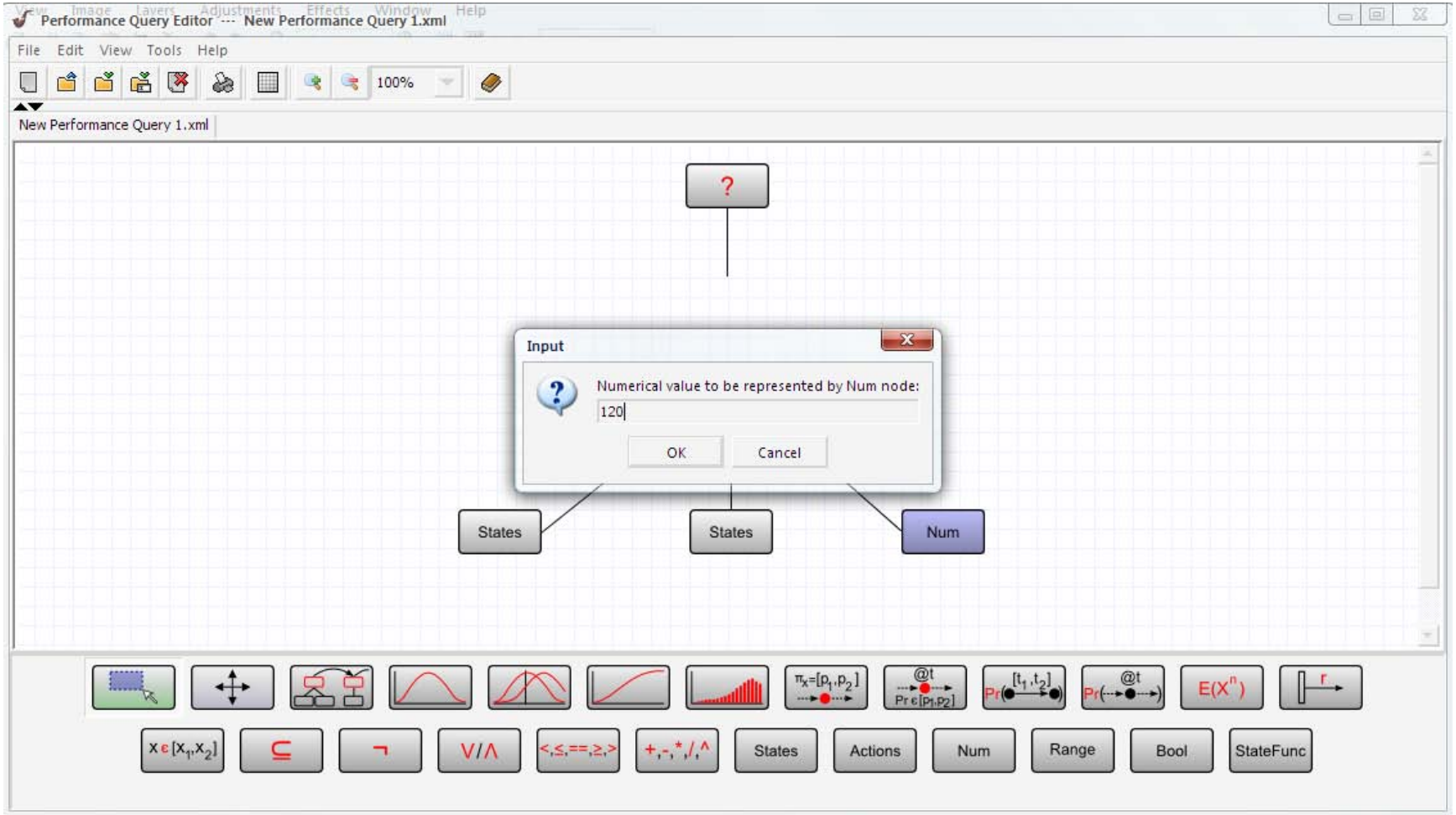

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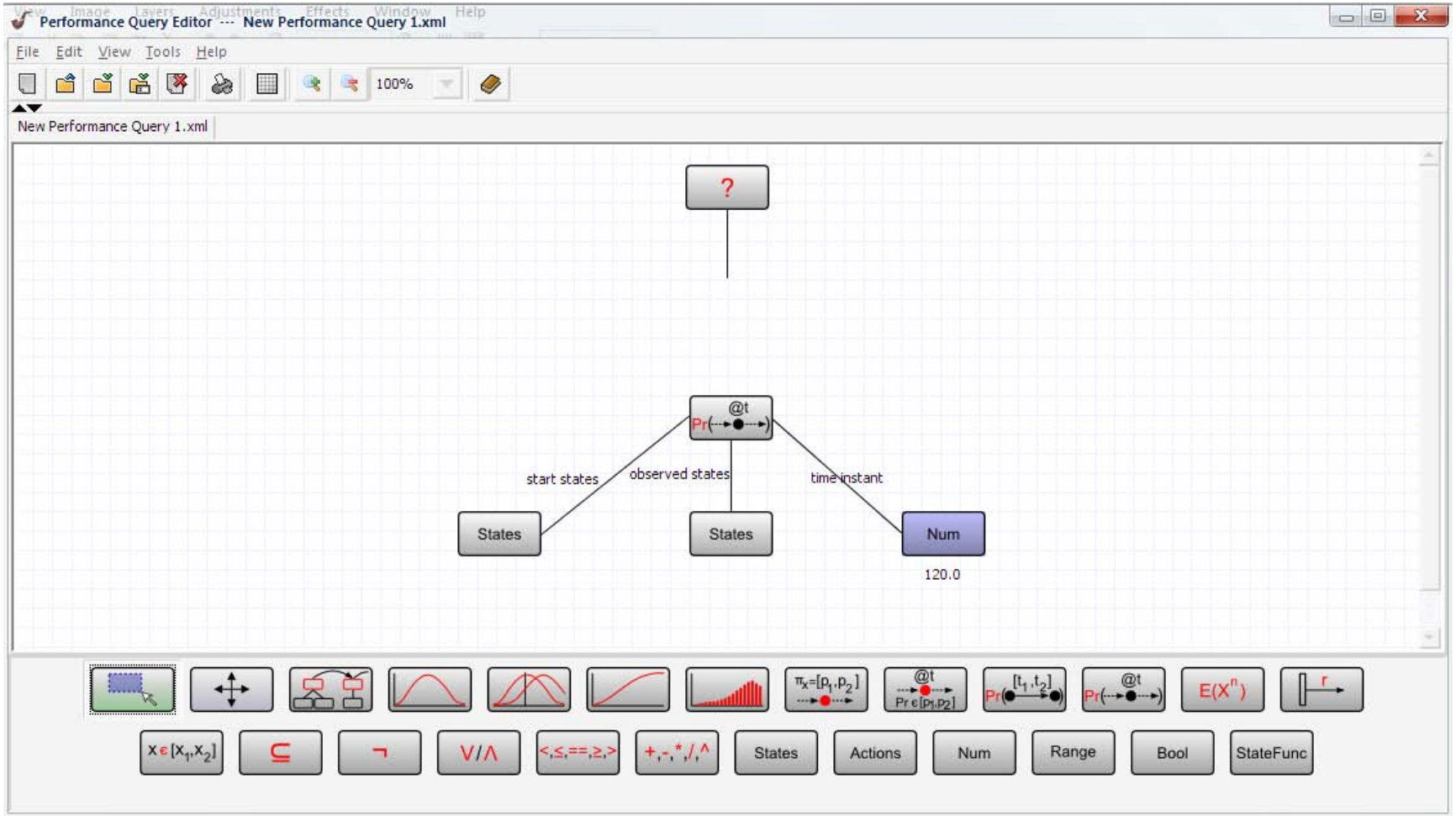

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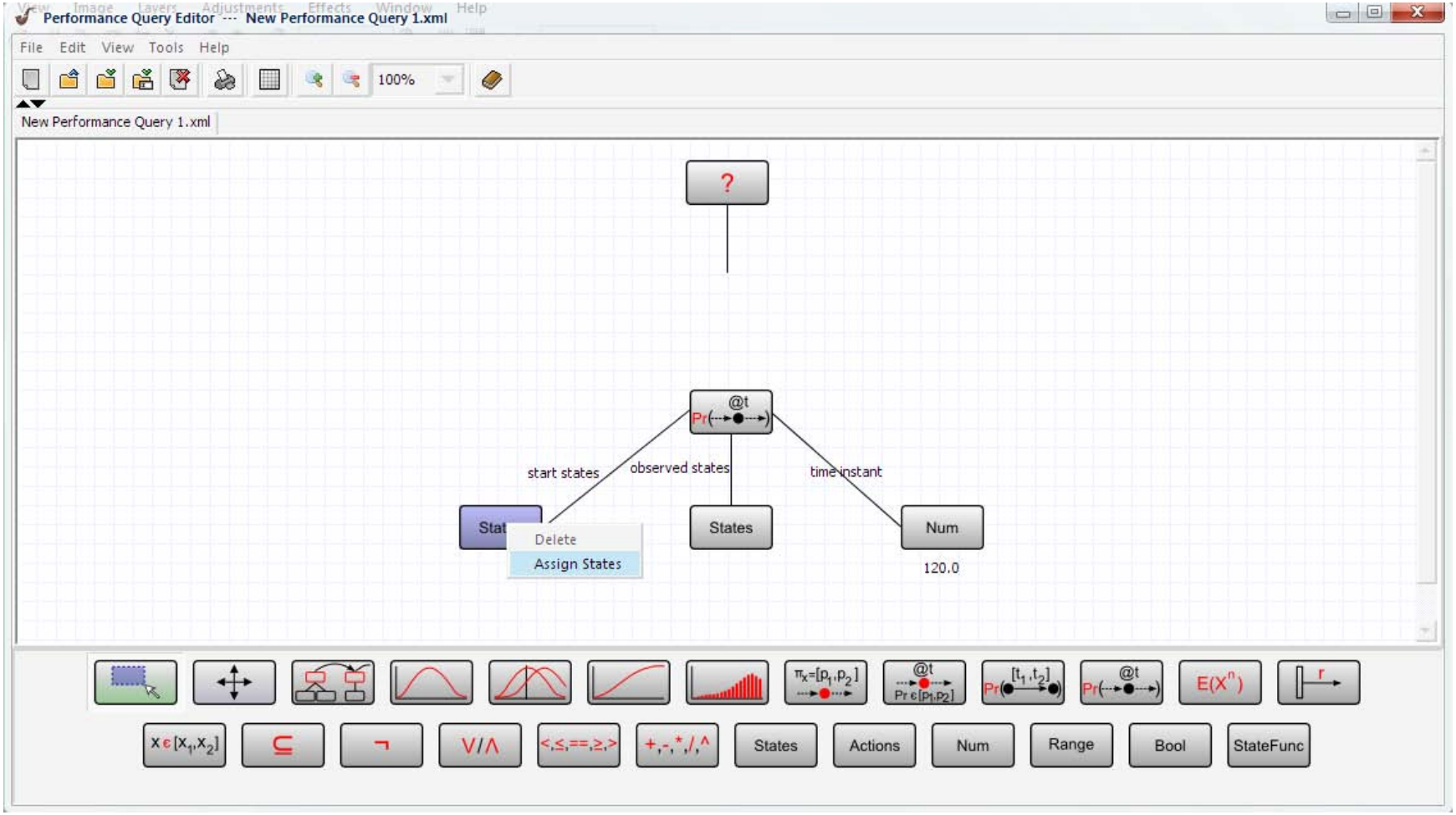

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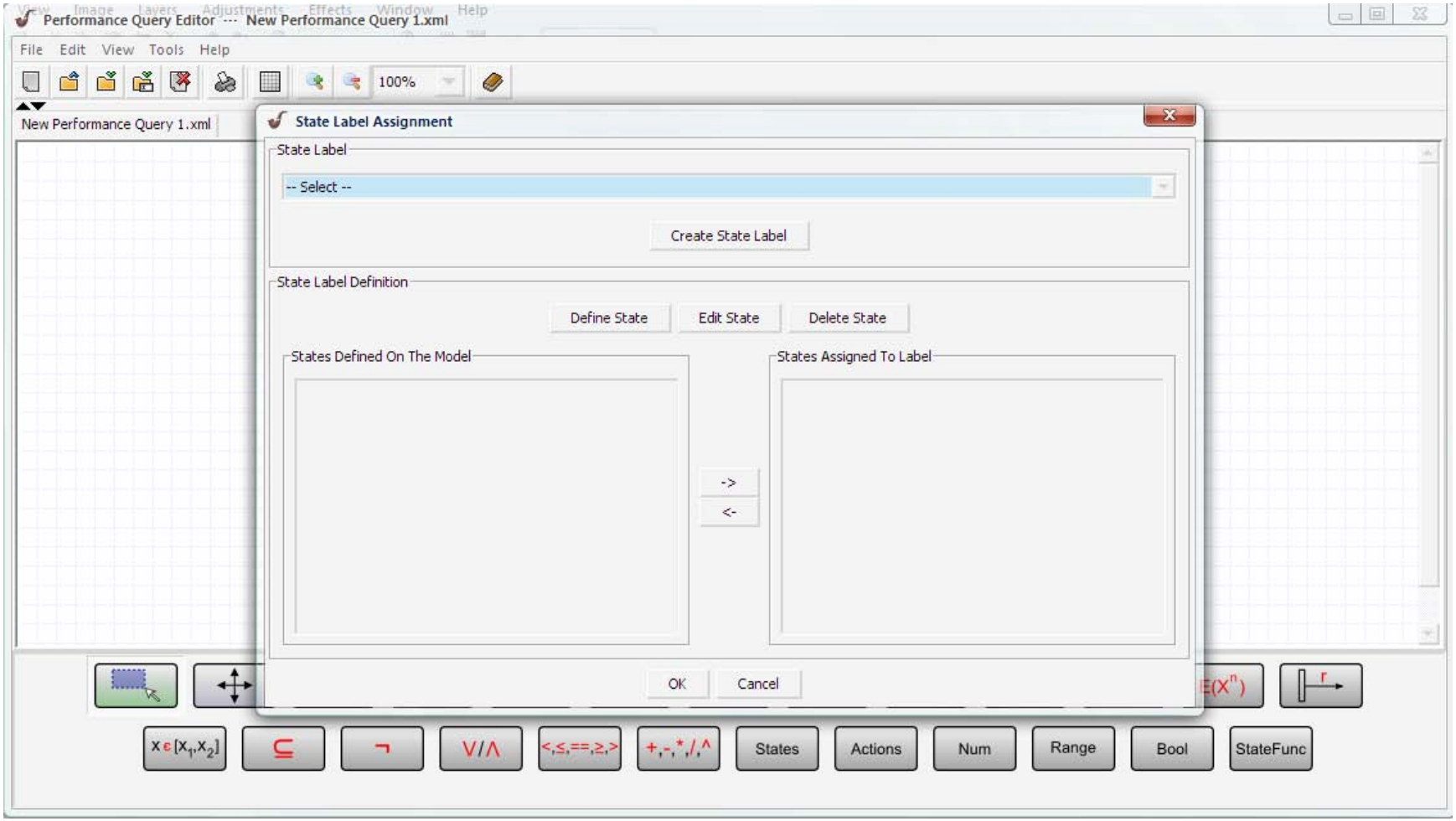

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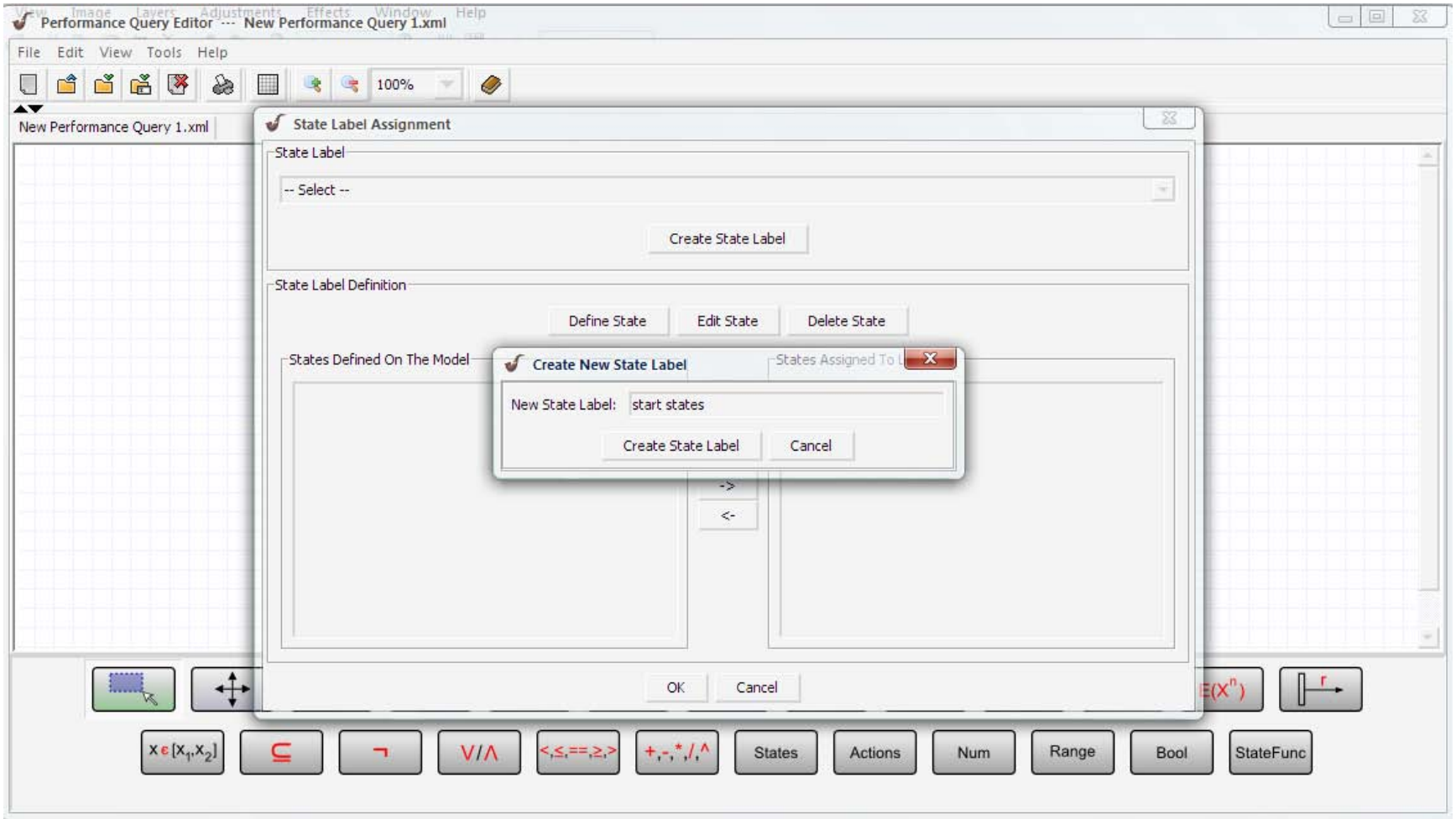

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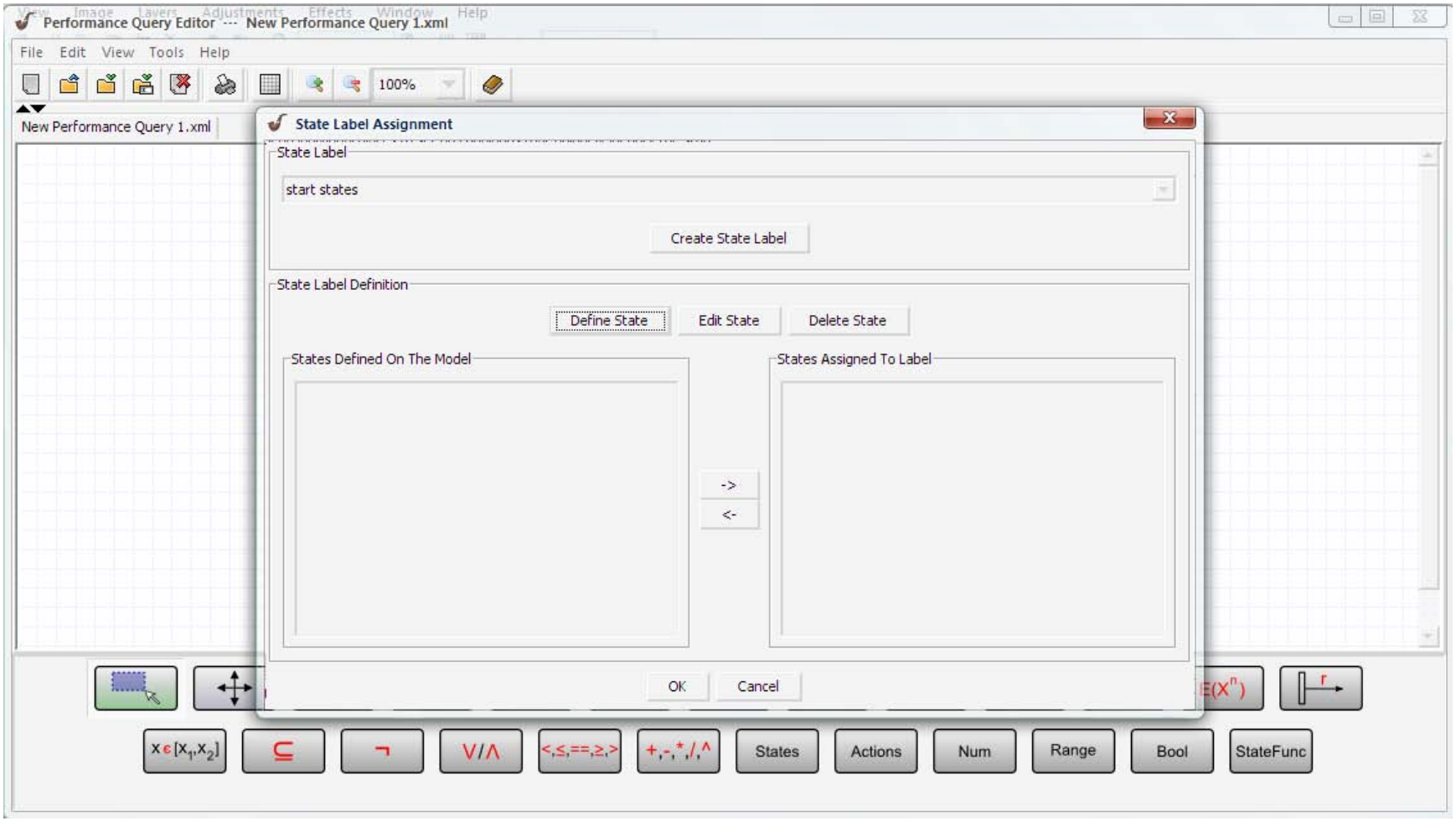

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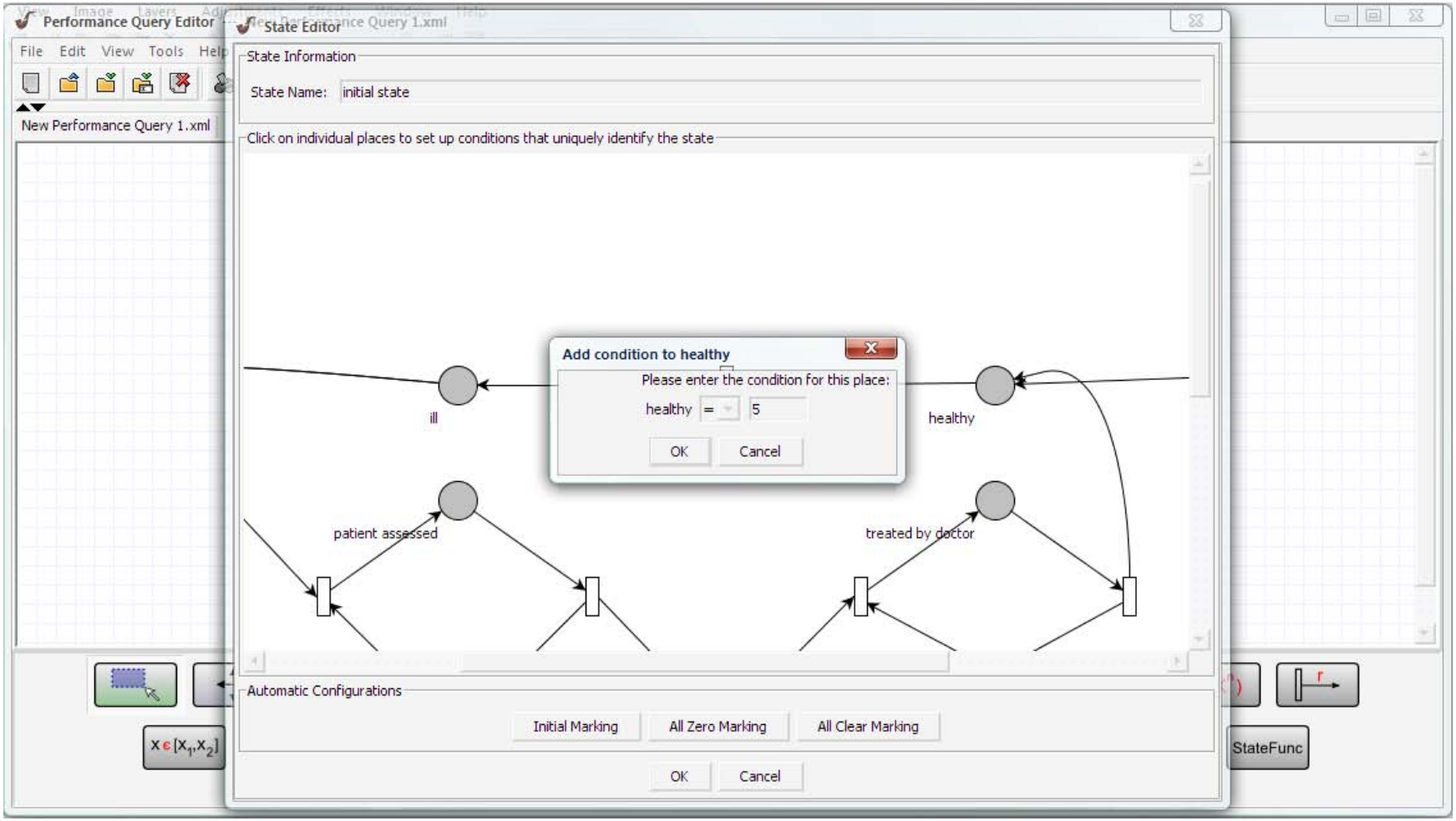

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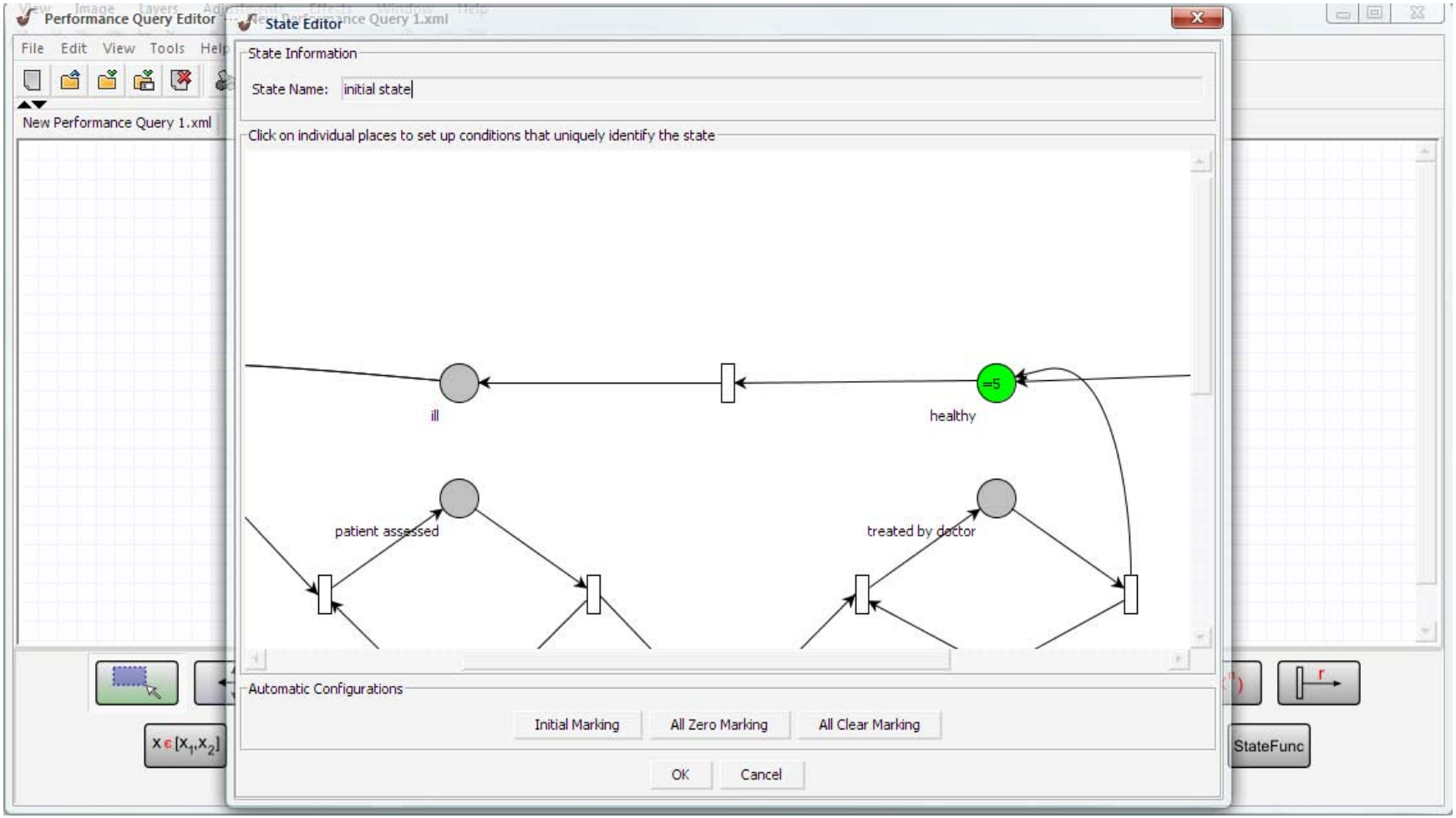

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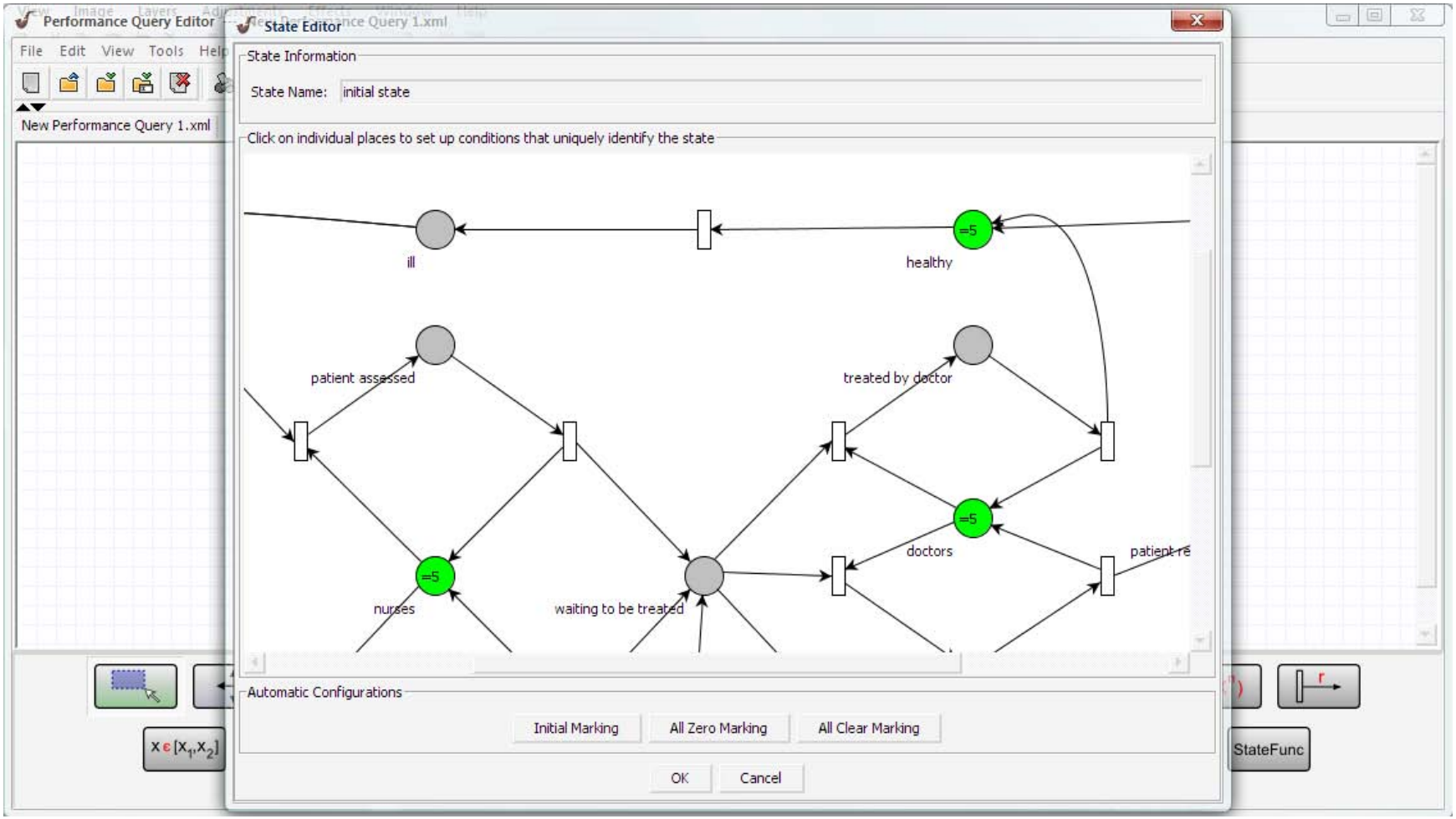

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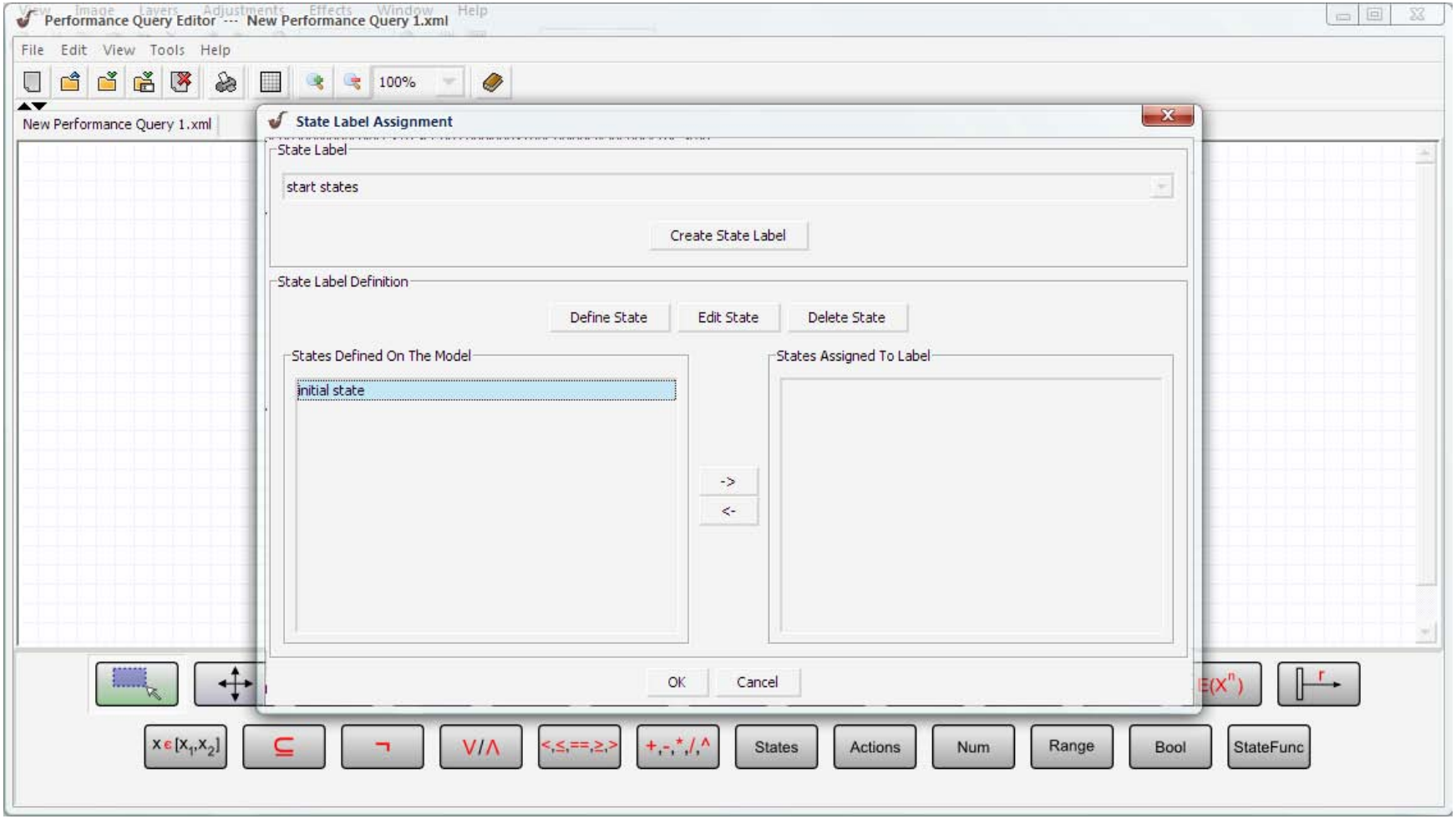

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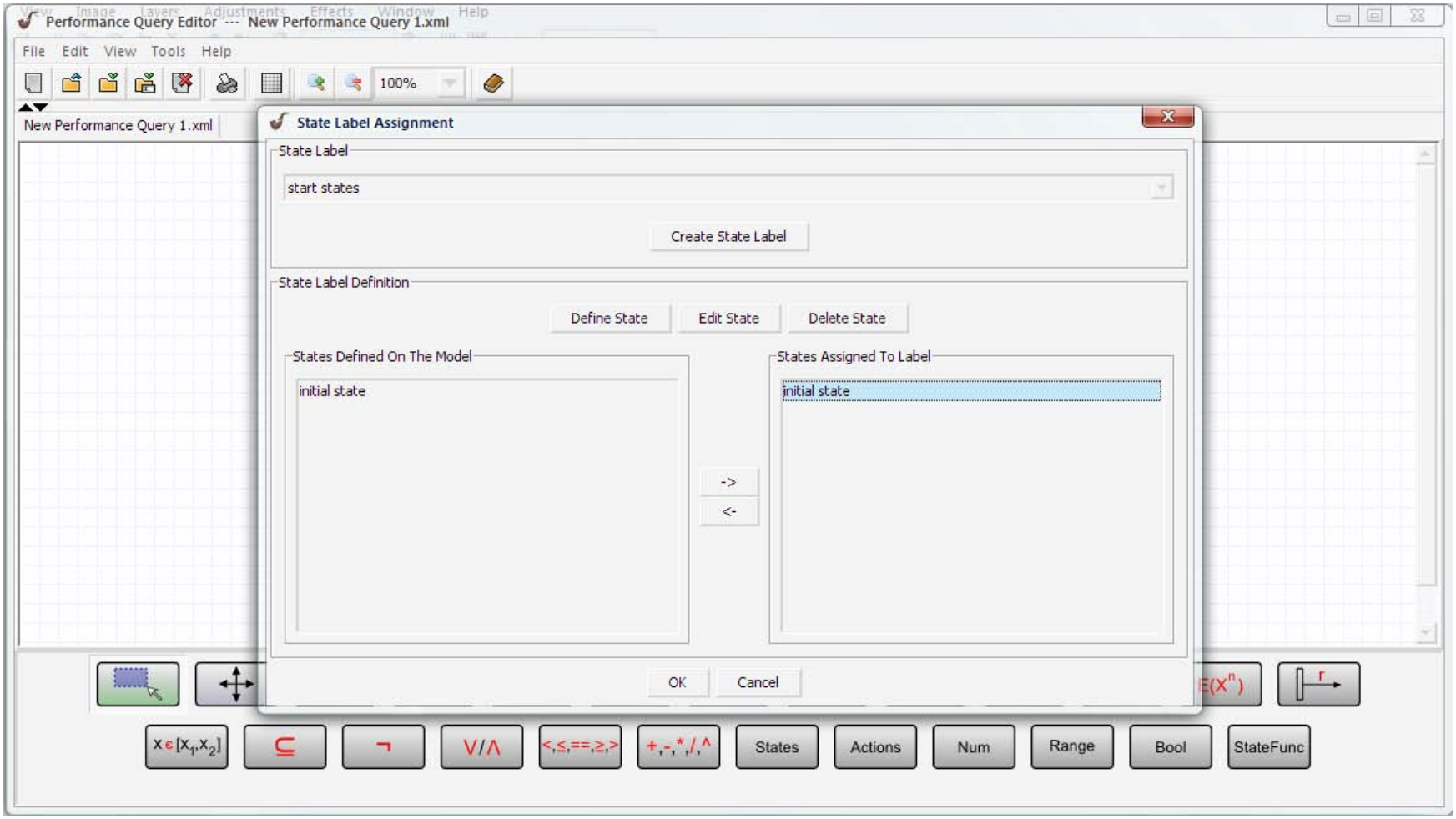

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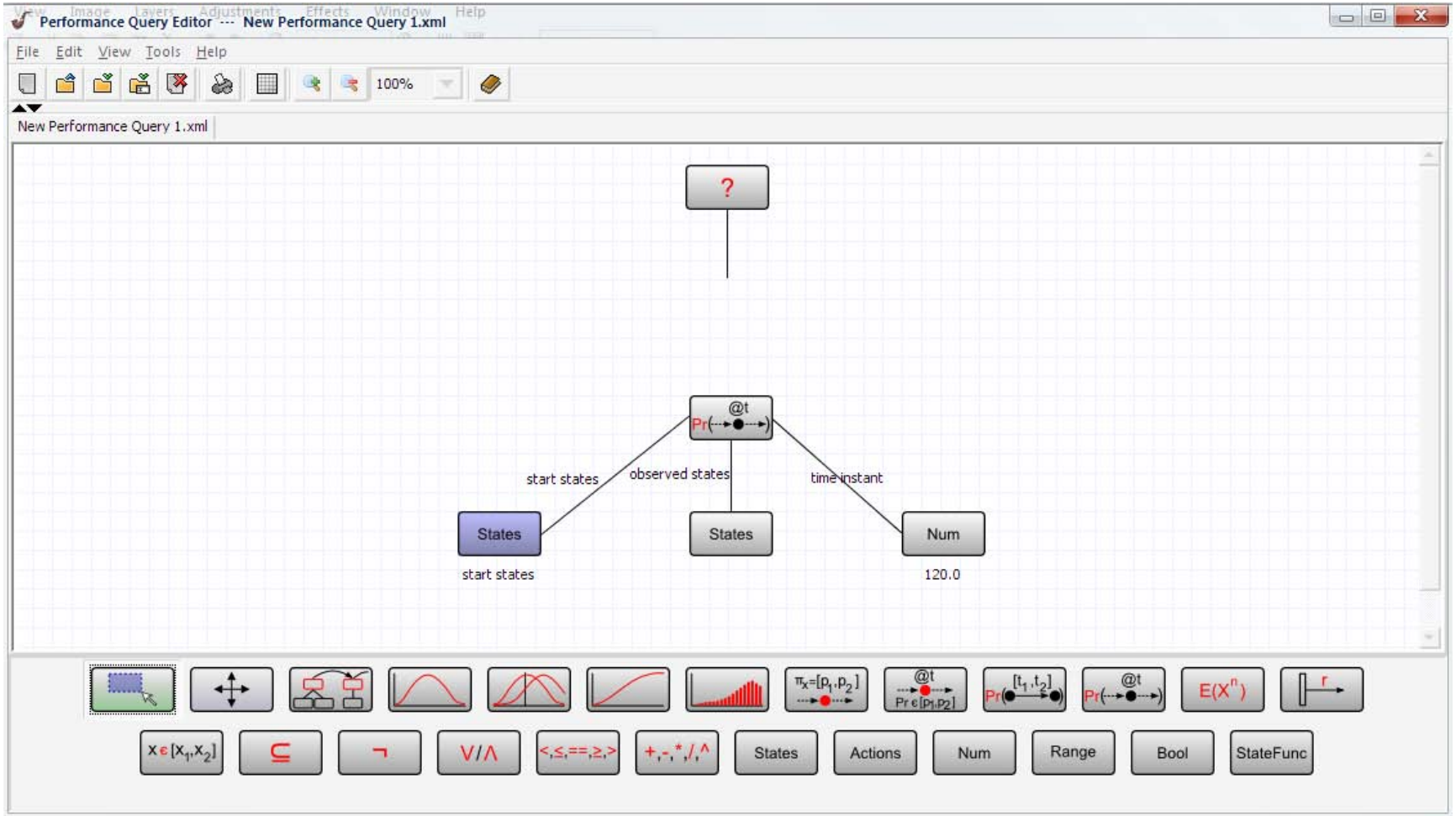

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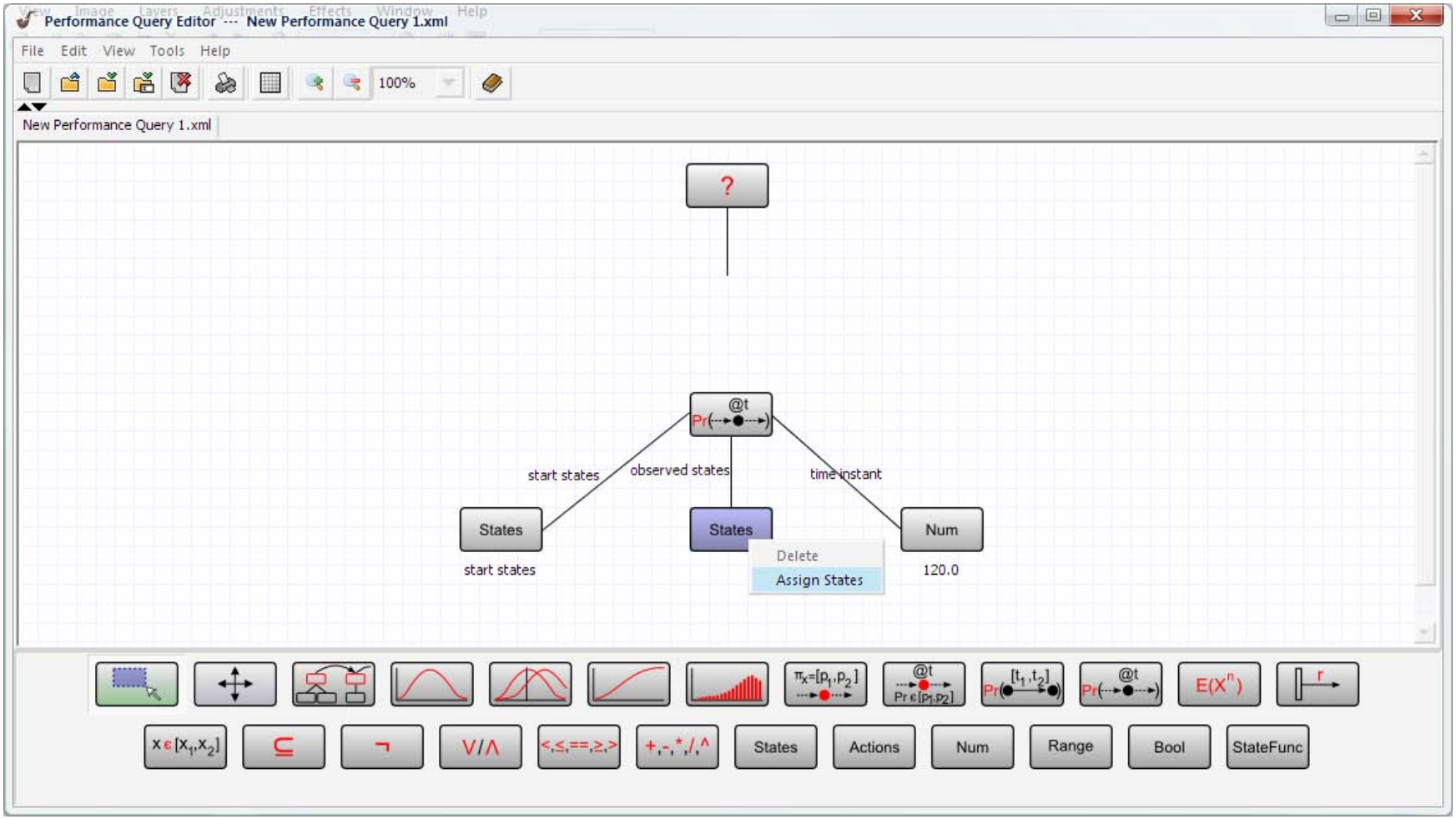

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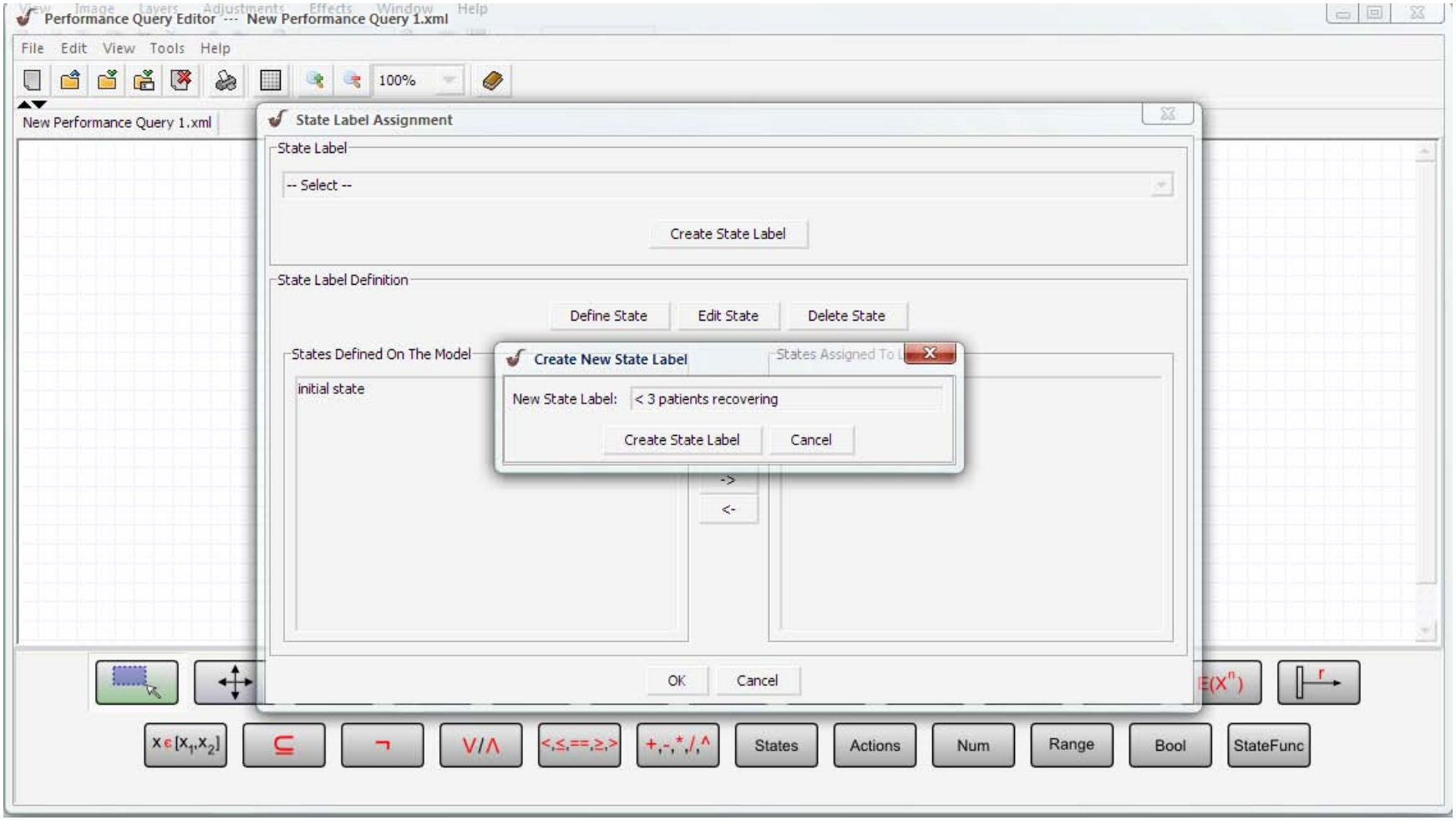

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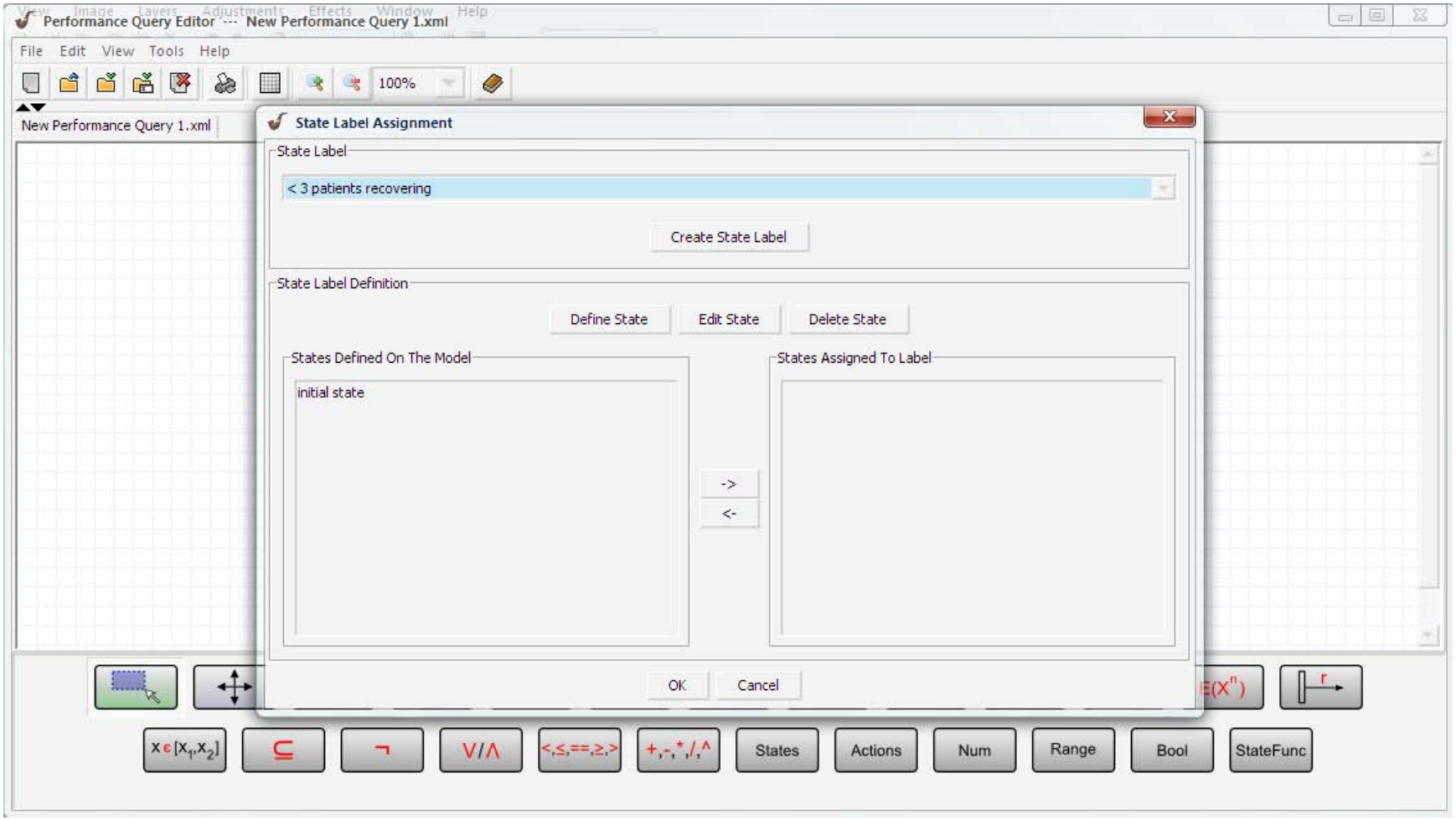

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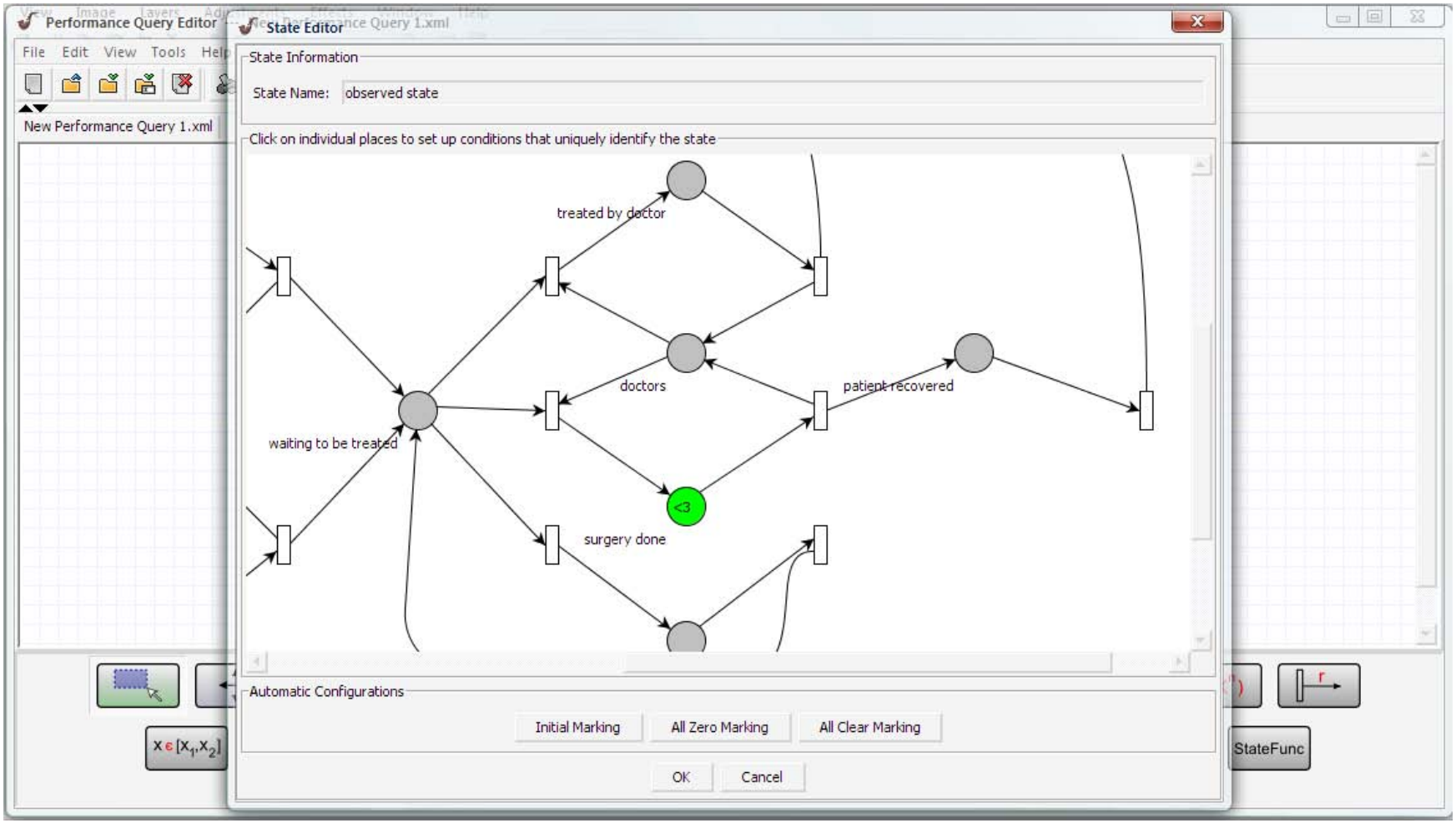

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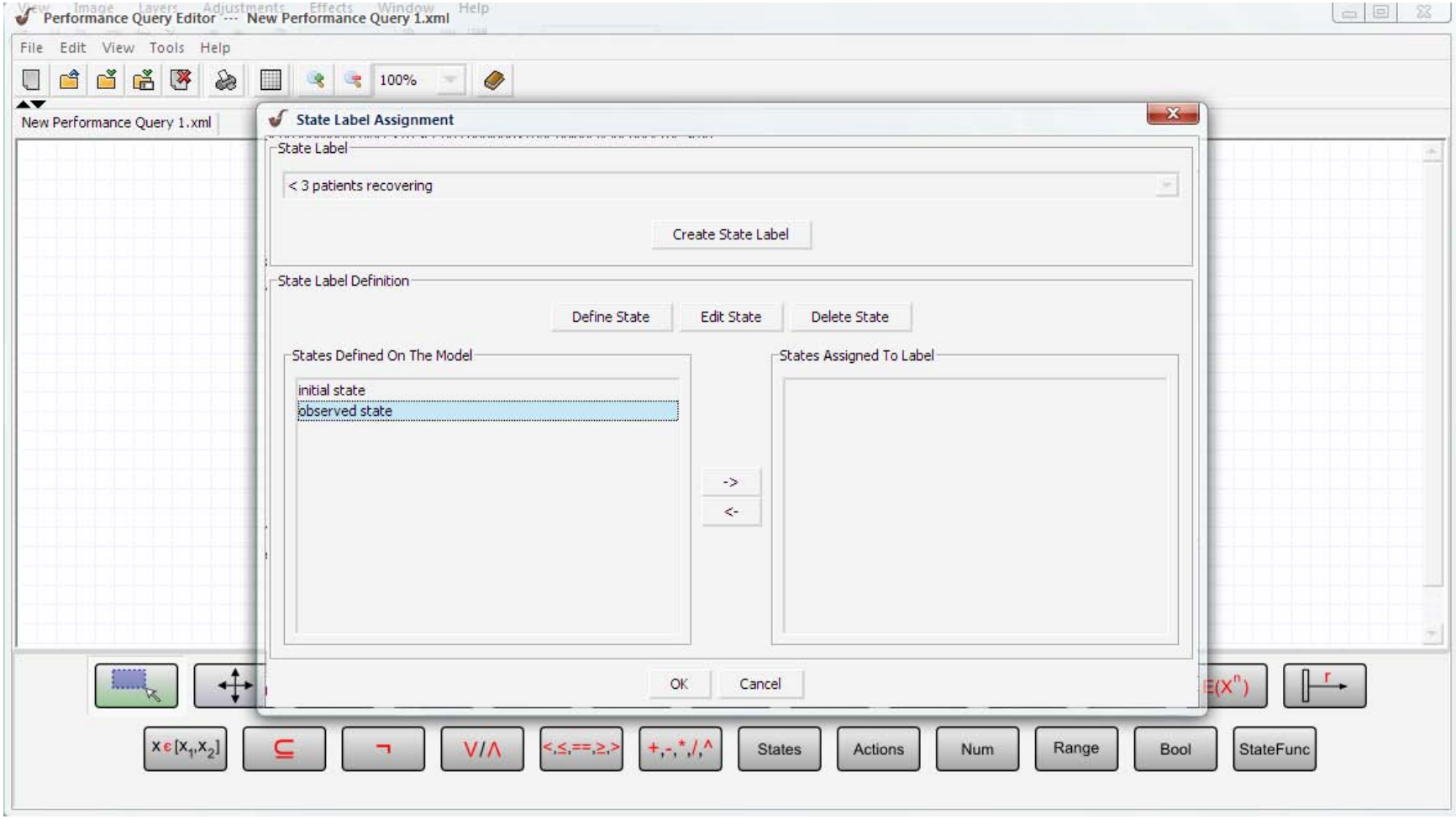

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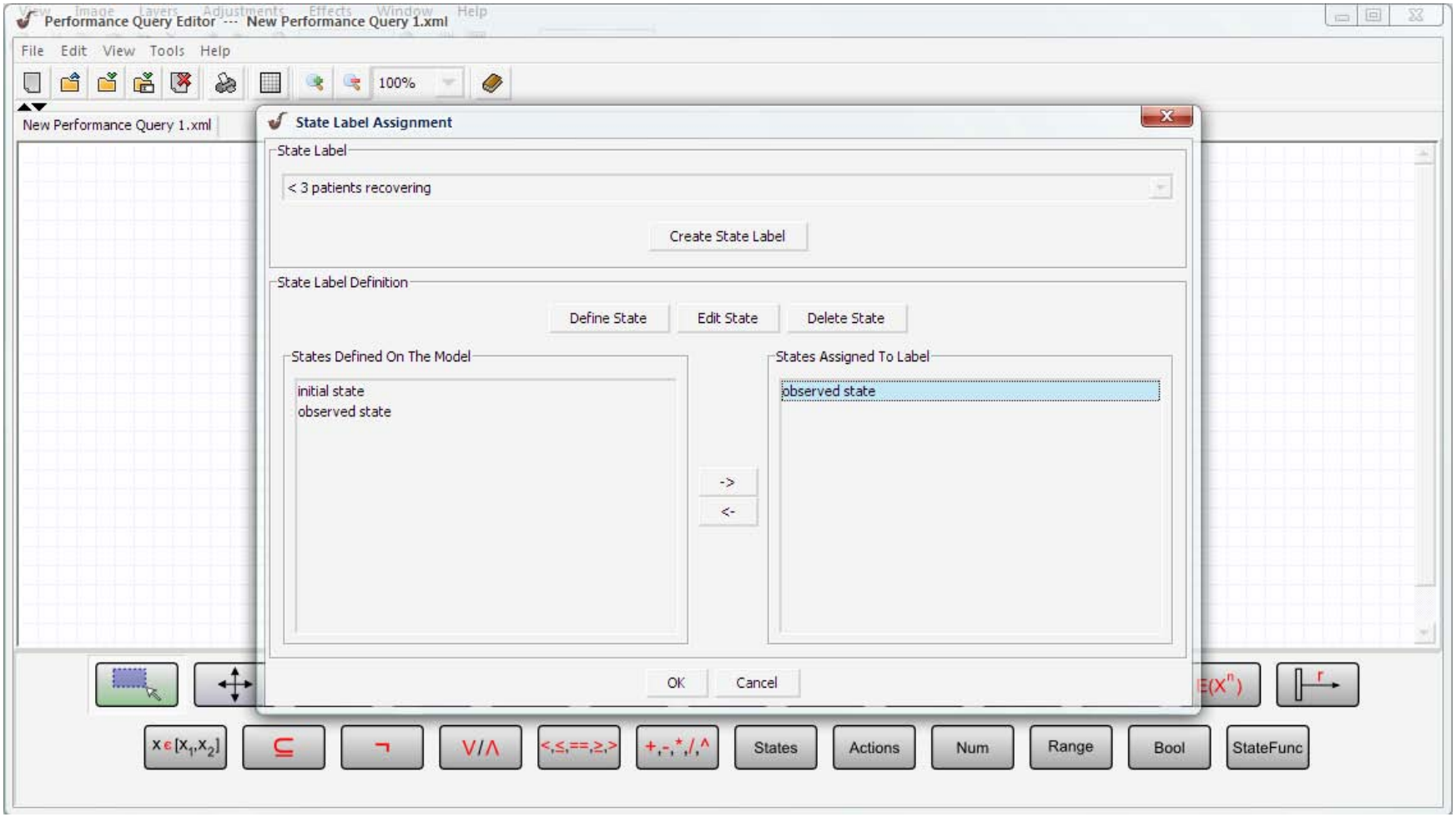

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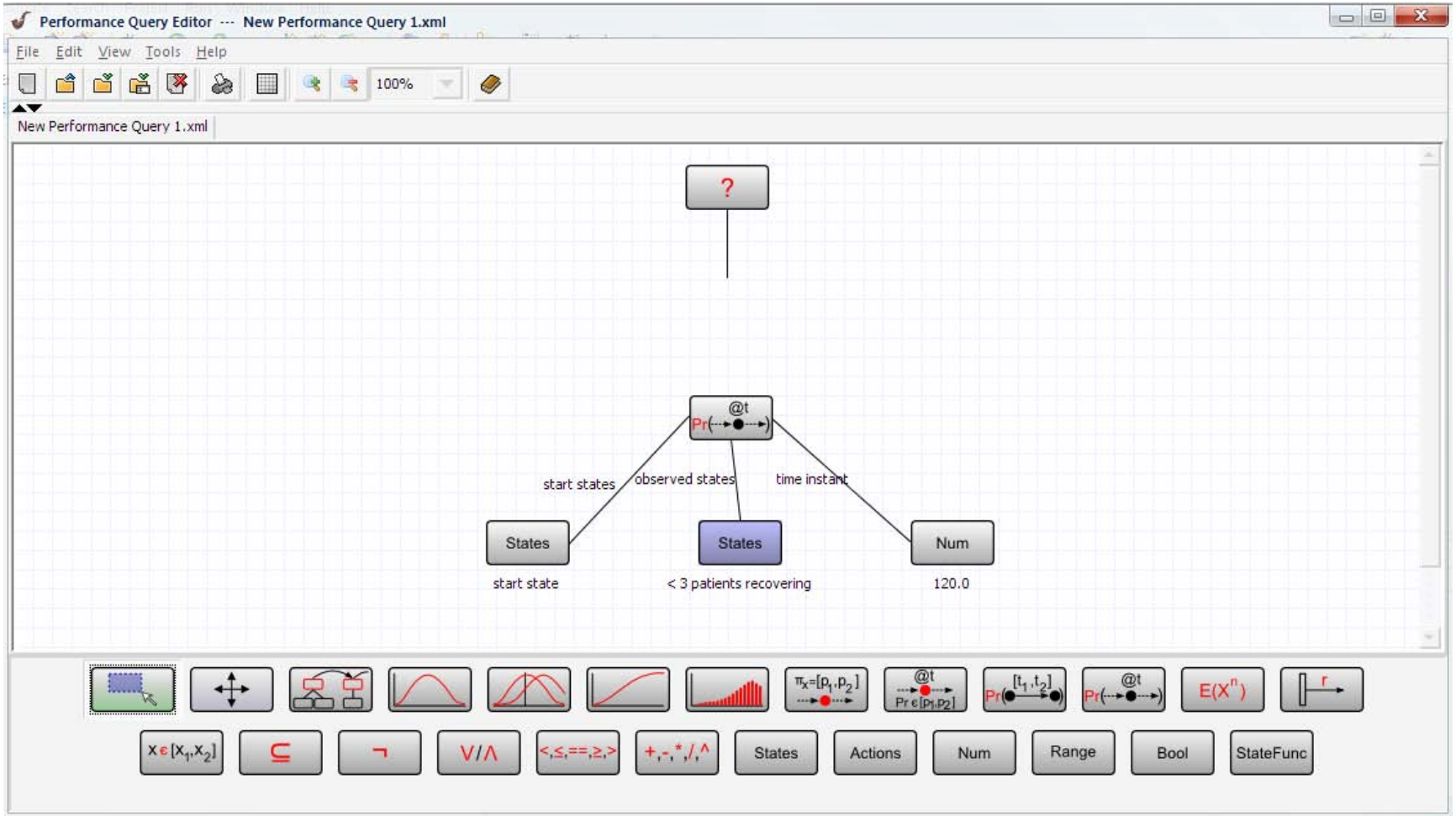

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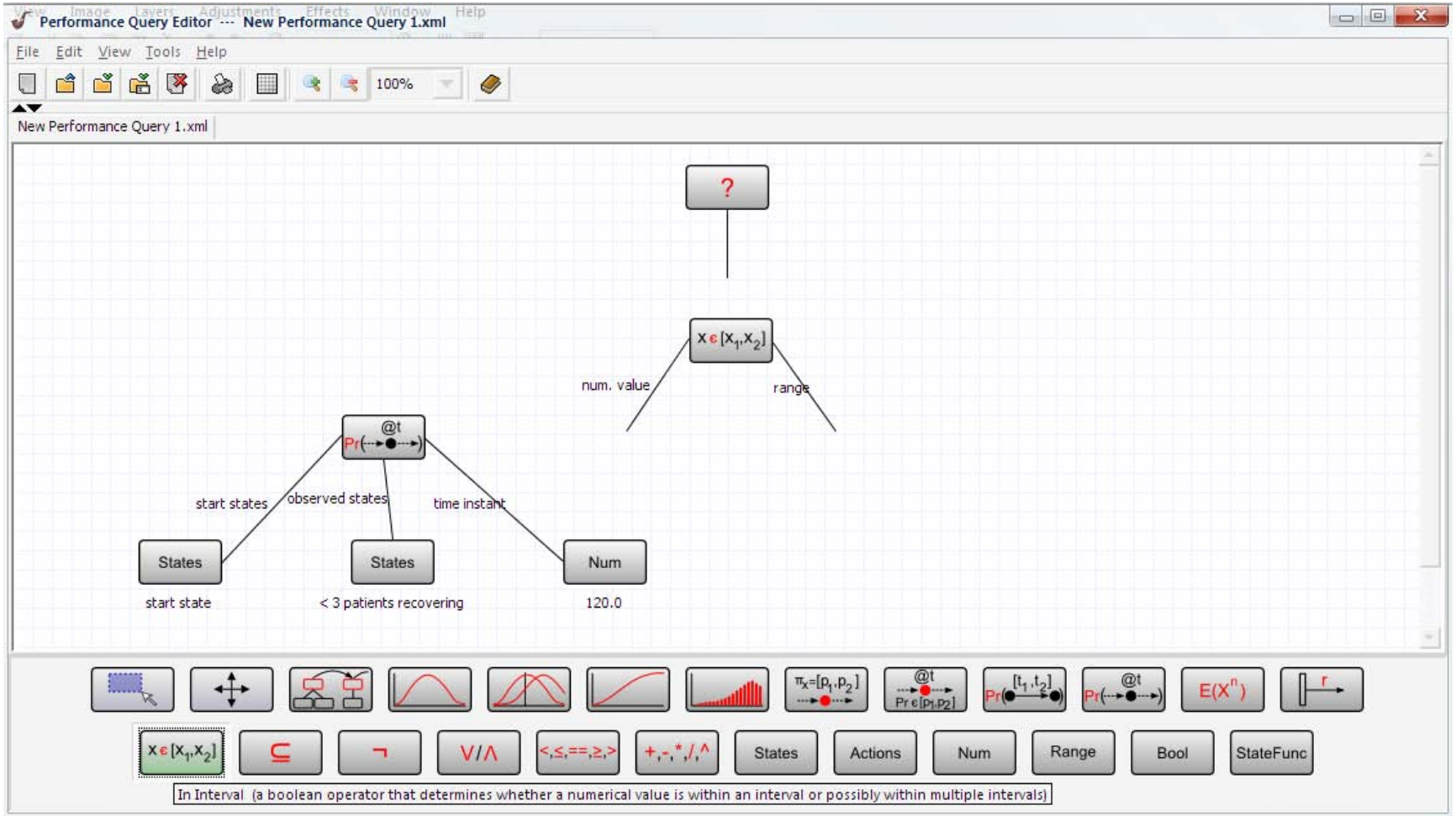

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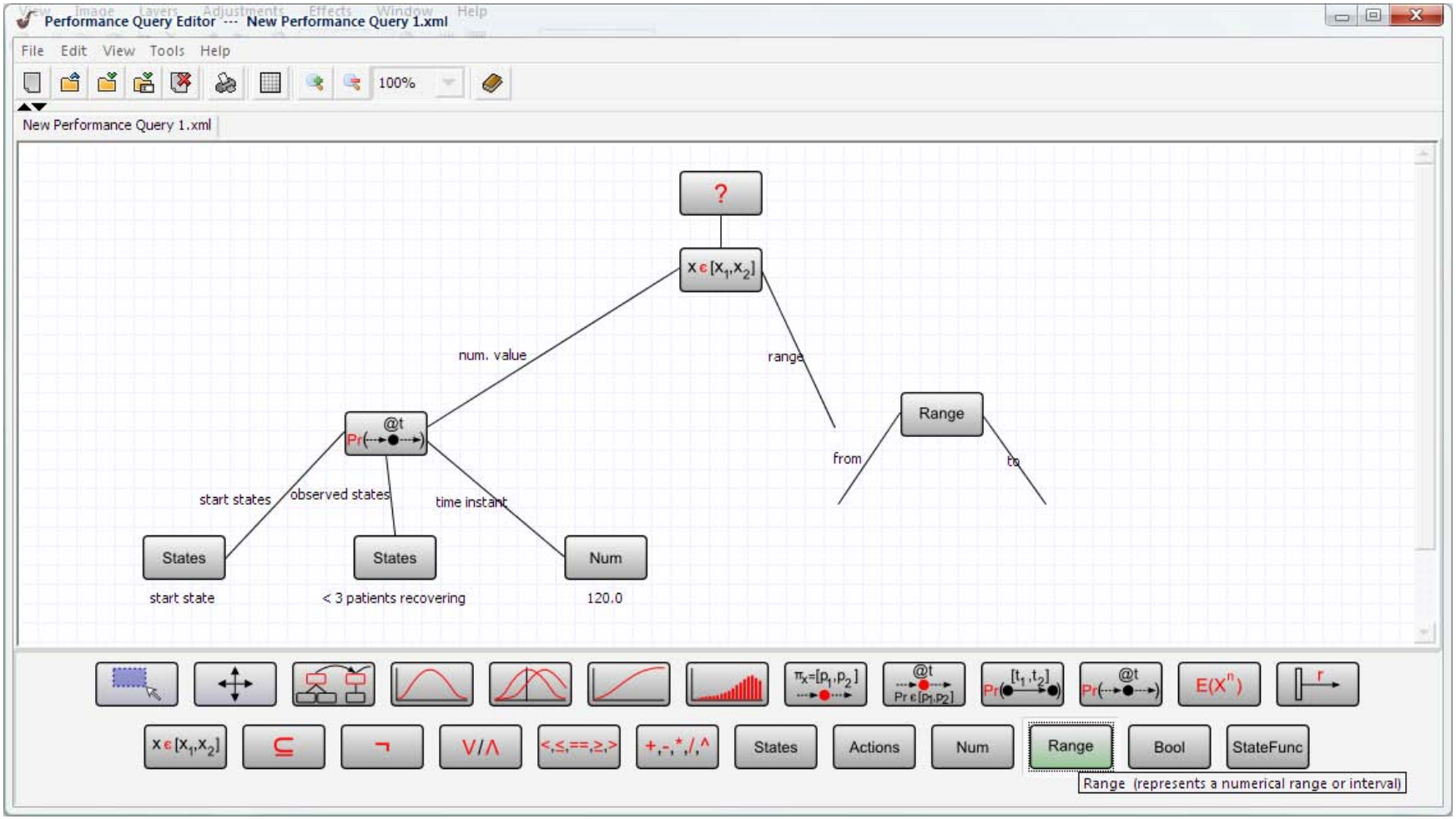

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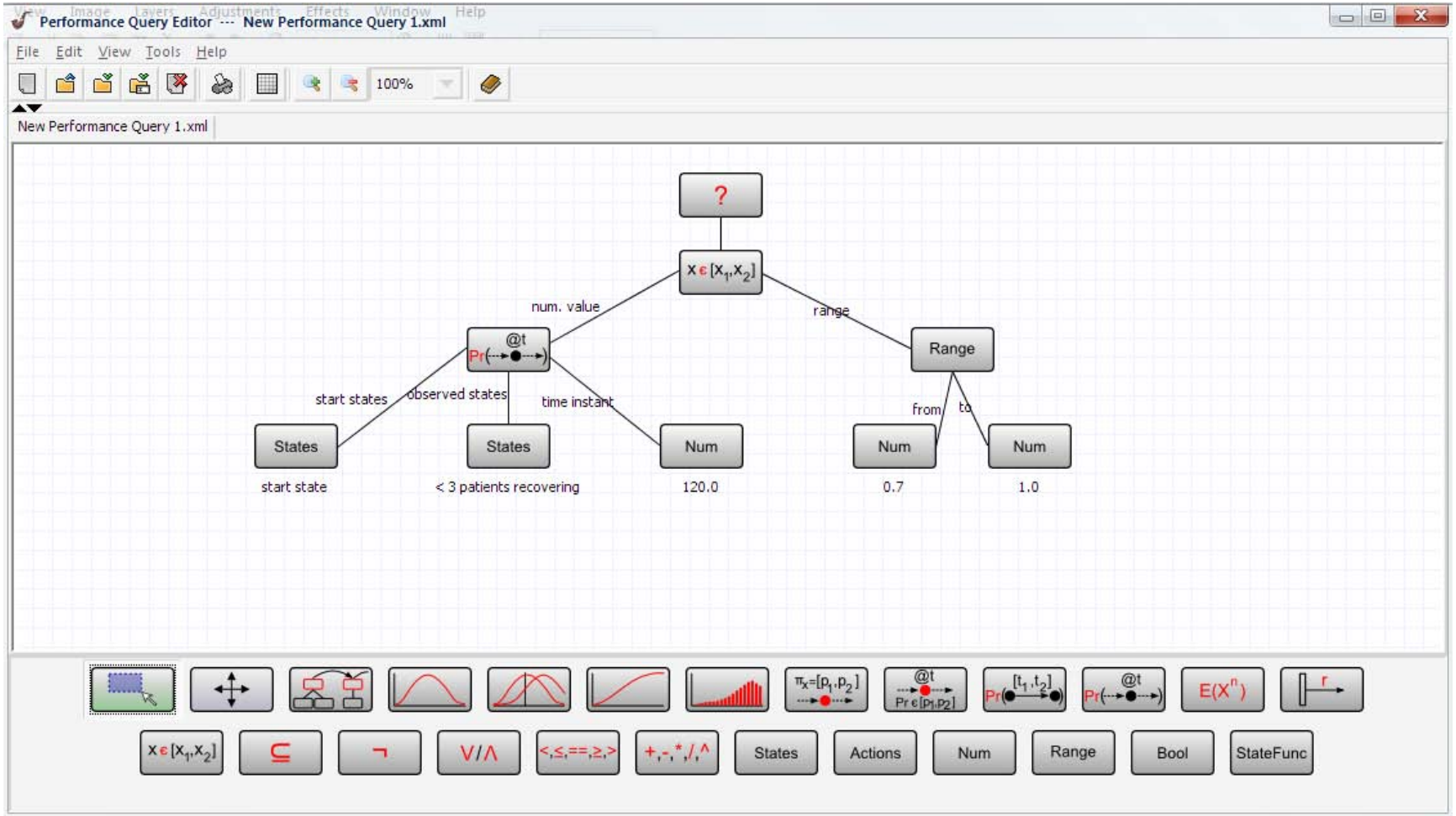

Quantitative Semantics

- Evaluation of Performance Tree operators is either trivial or possible using existing scalable algorithms
- Semantics give the formal mathematical meaning of operators but do not dictate solution techniques
- Full semantics for each operator are available

Conclusions

- We have presented Performance Trees, a new formalism for performance query specification
- We believe that they are an accessible alternative to existing query specification formalisms, such as stochastic logics
- We have introduced a prototype tool that enables the graphical composition of Performance Tree queries
- Our paper also addresses quantitative semantics underlying Performance Trees

Future Work

- Grid-based computational back-end, combining existing toolkits, to provide analysis capabilities for very large models
- Integration of query specification front-end and analysis back-end into a complete performance analysis toolset
- Support for state specification on other modelling formalisms
- Optimisation strategies to increase evaluation efficiency

The End

Thank you for your attention.

Any questions?