I N T R O D

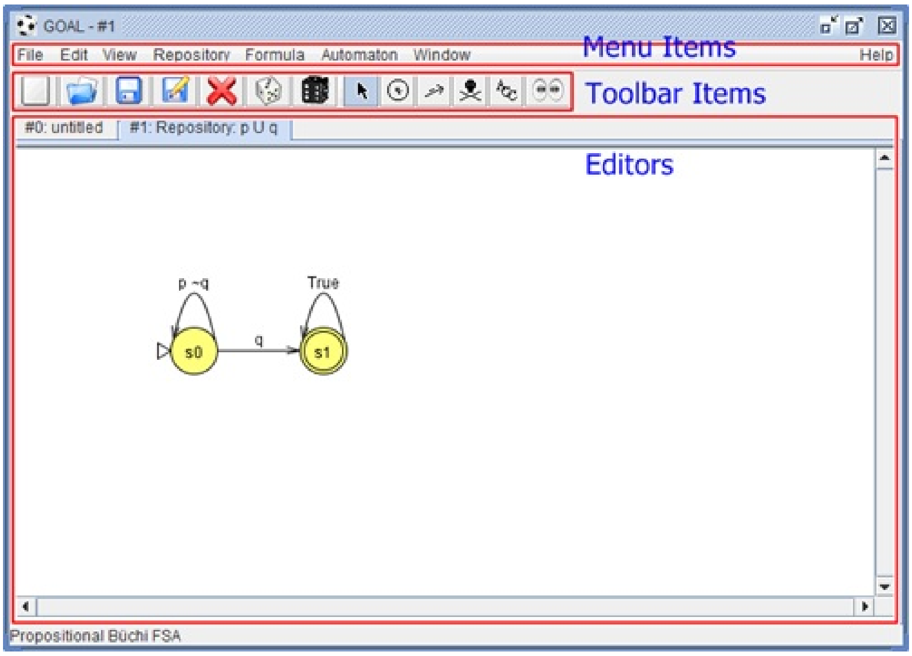
GOAL [TCT+07, TCT+08, TTH13] is a graphical interactive tool for defining and manipulating ω-automata and temporal logic formulae. The GOAL tool can be used for educational purposes, helping the user get a better understanding of how ω-automata work and how they are related to linear temporal logics. It may also be used to construct correct and smaller specification automata, supplementing model checkers such as SPIN that adopt the automata-theoretic approach. Most functions can be accessed by programs or scripts, making GOAL convenient for supporting research.

The acronym GOAL was originally derived from “Graphical Tool for Omega-Automata and Logics”. It also stands for “Games, Omega-Automata, and Logics”, as we gradually add support for omega-regular games. Our long-term goal is for the tool to handle all the common variants of ω-automata and the logics that are expressively equivalent to these automata. Therefore, the GOAL tool will constantly be extended and improved.

Quick links: GOAL Windows, Editors, Menu Items, Command-Line Mode (commands) , Extending GOAL, Terminology, References

G O A L W

A GOAL window is a tabbed window with extensible editors, menu items, and toolbar items.



GOAL window

Common Toolbar Items

Create a new object.

Open a file.

Save the active object.

Save the active object to a specified file in a specified format.

Close the active tab.

Create a randomly generated finite state automaton.

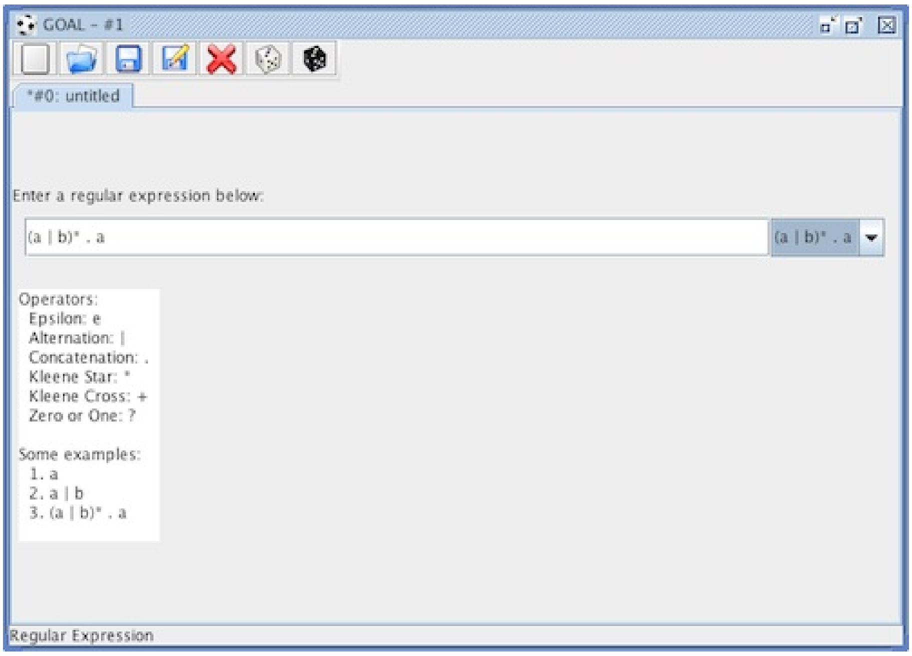
Create a randomly generated QPTL formula.

E D I T O

Editors are used to define logic formulae, such as temporal formulae, and automata, such as finite state automata, alternating automata, or games. Once a logic formula, an automaton, or a game has been defined, it can be manipulated by the functions included in the menu items that are accessible from the menu bar of a GOAL window.

In the default installation, there are editors for the following objects: Regular Expression, ω-Regular Expression, QPTL Formula, ACTL Formula, Automaton, Alternating Automaton, Two-Way Alternating Automaton, and Game.

Regular Expression



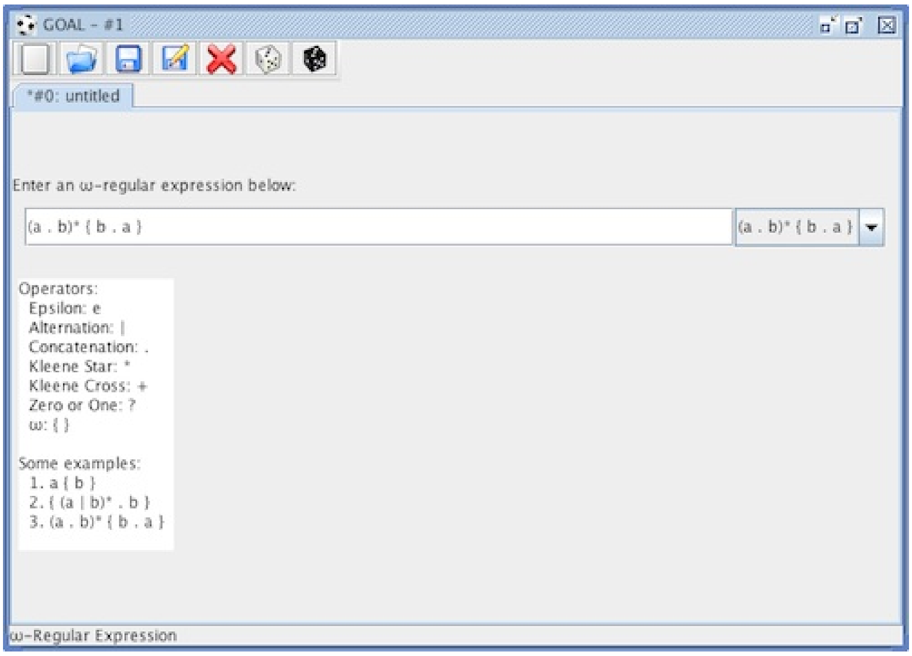
Regular expression editor

A regular expression can be empty (φ, denoted by E), an empty string (ε, denoted by ε, e or epsilon), a symbol, a concatenation (denoted by spaces) of two regular expressions, a union (denoted by |) of two regular expressions, or the Kleene star (denoted by *) of a regular expression. The Kleene cross (denoted by +) is defined as $a^+ \equiv a\,a^*$ while the zero or one occurrence (denoted by ?) is defined as $a? \equiv e|a$.

Operators

	Format
Concatenation	a b
Alternation	a | b
Kleene Star	a*
Kleene Cross	a+
Zero or One	a?

ω-Regular Expression

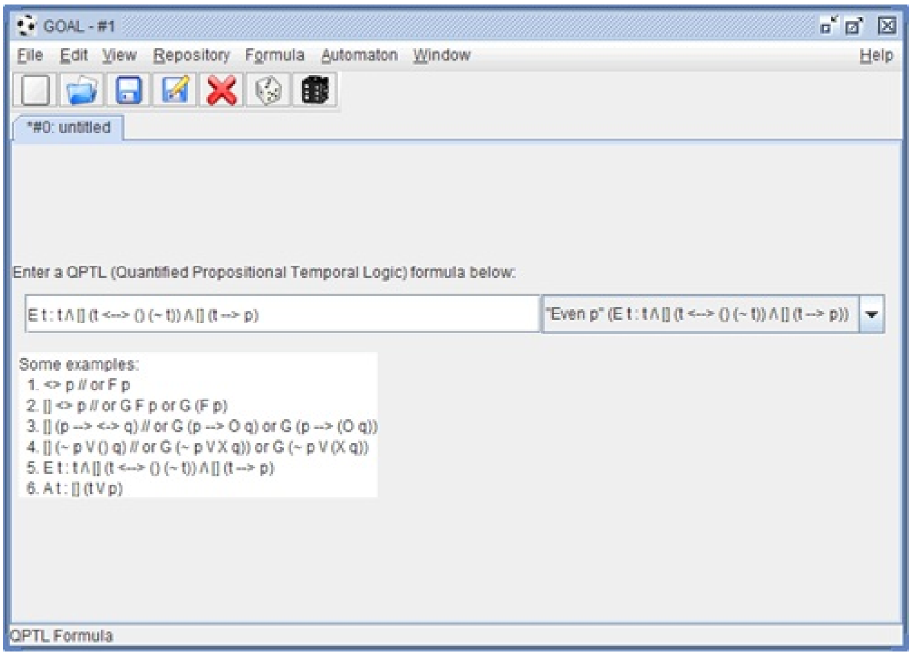


ω-regular expression editor

An ω-regular expression is the union of simple ω-regular expressions, which are of the form $u\,v^\omega$, represented by u { v } in GOAL, where u is a regular expression and v is a regular expression containing no empty string.

QPTL Formula

The editor for [QPTL]() is just a single-line text editing field.



QPTL editor

The QPTL is first advocated by Sistla in 1983. A QPTL formula is a PTL formula with propositional quantifiers. PTL here refers to the pure propositional version of linear temporal logic (LTL) as defined in Manna and Pnueli's book [MP92]. Currently GOAL can handle a subset of the full QPTL formulae, namely those with quantifiers that do not fall in the scope of temporal operators. This subset is as expressive as the full set of QPTL formulae [GPSS80, Gab87]. To avoid excessive parentheses, every operator has a corresponding precedence.

Syntax

▪ ≡ ~ | () | <> | [] | (-) | (~) | <-> | [-]

▫ ≡ ∧ | ∨ | --> | <--> | U | W | R | S | B | T

φ ≡ AP | ▪ φ | φ ▫ φ | E AP : φ | A AP : φ

where AP is a set of atomic propositions.

Quantifiers

	Format
Universal	A
Existential	E

Boolean Operators

	Format 1	Format 2
Negation	~	!
Conjunction	∧	&, &&
Disjunction	∨	|, ||
Implication	-->	->
Equivalence	<-->	<->

Future Temporal Operators

	Format 1	Format 2
Next	()	X
Eventually (Sometime)	<>	F
Henceforth (Always)	[]	G
Wait-for (Unless)	W	
Until	U	
Release	R	V

Past Temporal Operators

	Format 1	Format 2
Previous	(-)	Y
Before	(~)	Z
Once	<->	O
So-for	[-]	H
Since	S	
Back-to	B	
Trigger	T	

Spaces are required to separate unary temporal operators in format 2 except GF and FG. For example, X G p is equivalent to () [] p and GF p is equivalent to [] <> p while both XGp and GFp are atomic propositions. All the boolean and temporal operators are right-associative. Thus, p U q U r is equivalent to p U (q U r).

For quantifications, GOAL allows the following shorthands:

- A x : E y : f(x,y) ≡ A x E y : f(x,y)
- E x E y : f(x, y) ≡ E x y : f(x,y)

GOAL assumes the following binding precedence:

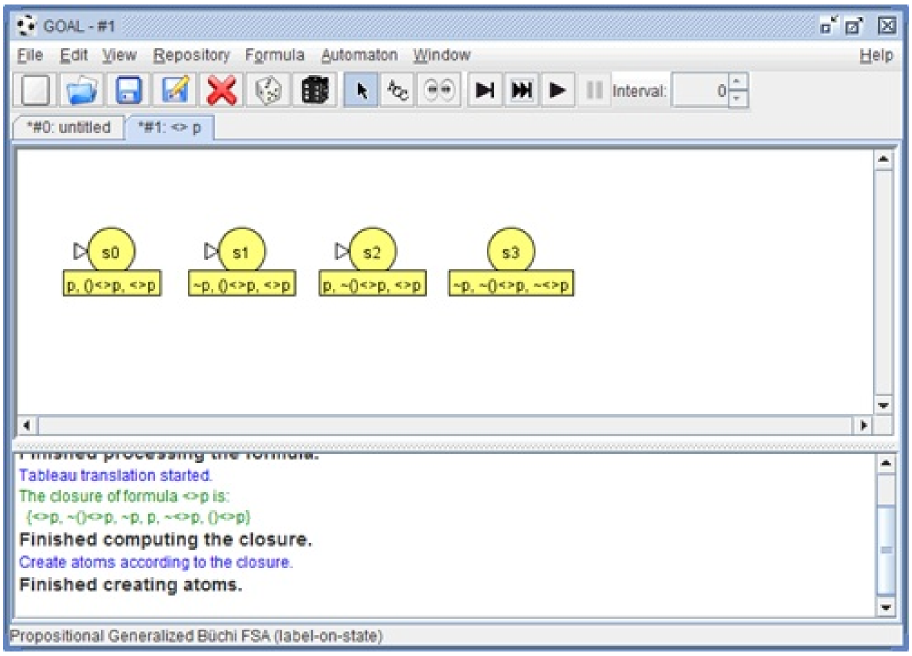
```
Unary Operators > Temporal Binary Operators > Conjunction > Disjunction > Implication > Equivalence > Quantification
```

Examples

- <> p or F p
- []<> p or G F p or G (F p)
- [](p --> <> q) or G (p --> F q) or G (p --> (F q))
- [](p --> <-> q) or G (p --> O q) or G (p --> (O q))
- [](~p ∨ ()q) or G (~p ∨ X q) or G (~p ∨ (X q))
- [] p S q or G p S q or (G p) S q
- [] (p --> p S q) or G (p --> p S q) or G (p --> (p S q))
- E t : t ∧ [] ((t --> p) ∧ (t <--> () (~ t)))

Step-by-Step Translation

A QPTL formula can be step-by-step translated into an equivalent automaton by various translation algorithms. The step-by-step translation is controlled by additional toolbar items with a read-only automaton editor and a message panel.



Step-by-step QPTL translation

The toolbar items used to control the translation algorithm are listed below.

Perform a minor step.

Perform a major step. A major step may contain several minor steps.

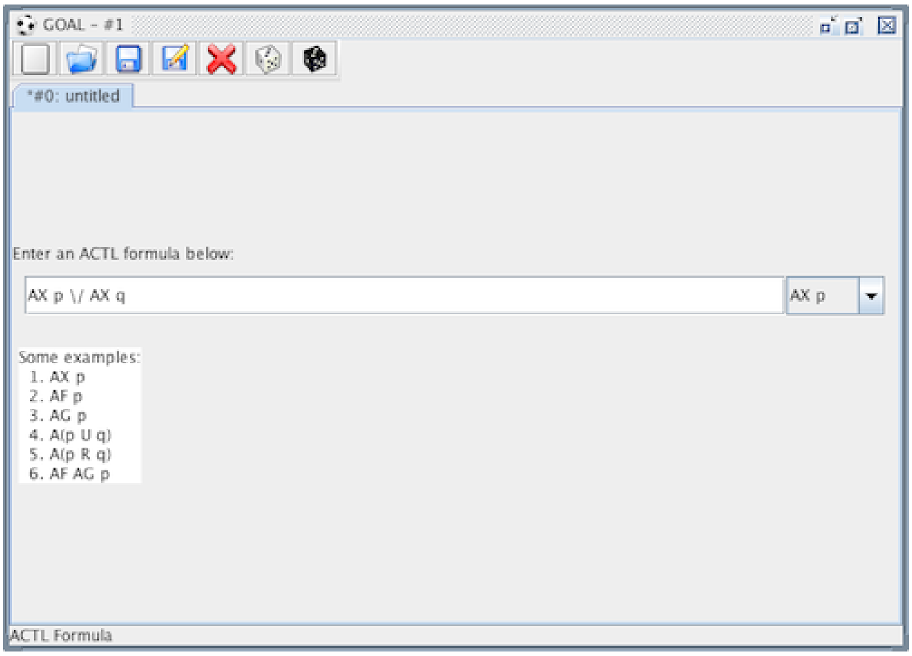
Play the translation algorithm. A minor step will be performed automatically after every user-defined time interval.

Pause the process invoked by ▶.

Set the time interval (in seconds) between every two successive steps in the process invoked by ▶.

ACTL Formula

The editor for ACTL is just a single-line text editing field.



ACTL editor

ACTL is a fragment of CTL where paths can only be quantified by ∀. This fragment is first identified in [GL94] for modular verification.

Syntax

ψ ≡ AP | ~ ψ | ψ ∧ ψ | ψ ∨ ψ | ψ --> ψ | ψ <--> ψ

φ ≡ ψ | φ ∧ φ | φ ∨ φ | AX φ | AF φ | AG φ | A(φ U φ) | A(φ R φ)

where AP is a set of atomic propositions.

Boolean Operators

	Format 1	Format 2
Negation	~	!
Conjunction	∧	&
Disjunction	∨	|
Implication	-->	->
Equivalence	<-->	<->

Temporal Operators

	Format 1	Format 2
Next	AX	
Eventually (Sometime)	AF	
Henceforth (Always)	AG	
Until	A(φ U ψ)	
Release	A(φ R ψ)	A(φ V ψ)

GOAL assumes the following binding precedence:

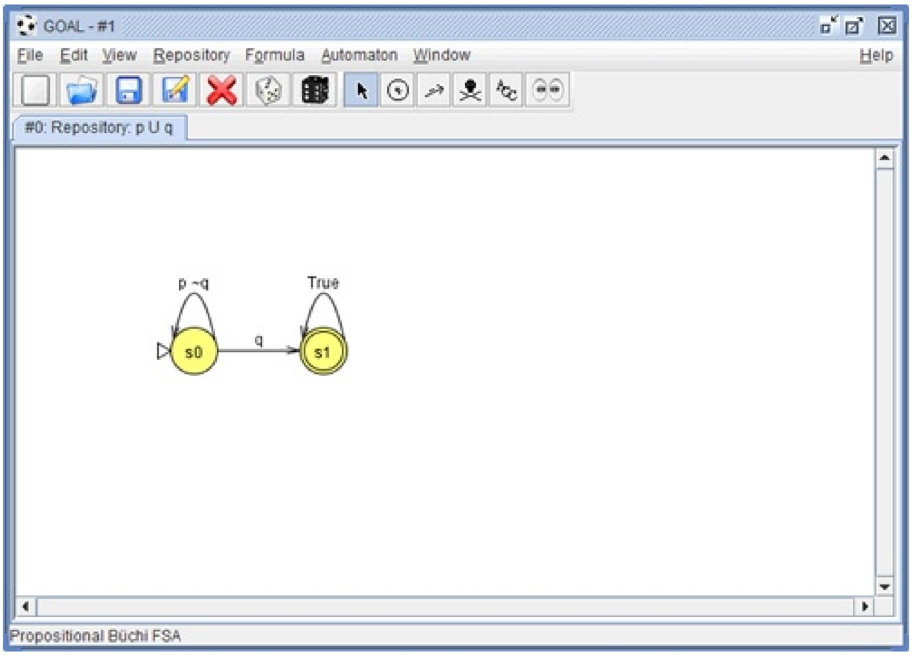
```
Unary Operators = Temporal Operators > Conjunction > Disjunction > Implication > Equivalence
```

Examples

- AX p ∨ AX q
- AG AF p

Finite State Automaton

This class includes classic finite word automata (NFW or NFA), Büchi automata (NBW or BA), co-Büchi automata (NCW), generalized Büchi automata (NGBW or GBA), Muller automata (NMW), Rabin automata (NRW), Streett automata (NSW), parity automata (NPW), transition Büchi automata (NTBW or TBA), transition generalized Büchi automata (NTGBW or TGBA), transition Muller automata (NTMW), transition Rabin automata (NTRW), transition Streett automata (NTSW) and transition parity automata (NTPW).



Automaton editor

Toolbar Items

Select states, move states, change the transition curvature, and double click on a transition to edit its label.

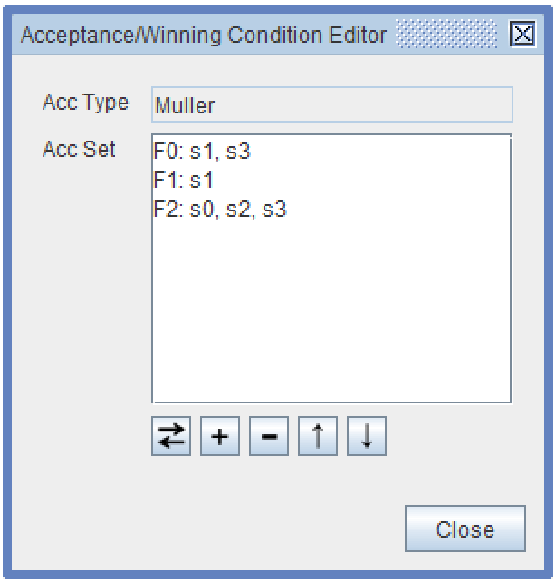
Click on the editor to create a new automaton state.

Click on a state s, hold on the left mouse button, and release on another state t to create a transition from s to t. When the left mouse button is released, a text field will appear to edit the label of the transition to be created. The label must be a valid symbol in the alphabet of the automaton. If the symbol does not exist in the alphabet, GOAL will try to expand the alphabet automatically for the user. There are two types of alphabet.

1. **Propositional Alphabet** - A propositional symbol is represented by a string, consisting of blank-separated strings (literals), that encodes a truth assignment to the atomic propositions appearing in the intended temporal formula. For temporal formulae with two atomic propositions p and q, the alphabet will be {p q, p ~q, ~p q, ~p ~q}, where "p q", "p ~q", "~p q", and "~p ~q" are the four "symbols" encoding all four possible truth assignments. The symbol "p ~q", for instance, encodes the truth assignment that p is true and q is false. A transition labled with a partially specified symbol "p" will be treated as two transitions labeled respectively with "p q" and "p ~q". The order in which the propositional literals appear is immaterial, but they must be separated by a blank space.
2. **Classical Alphabet** - A classical symbol is represented by a character string without blank spaces. For example, the alphabet may be {stop, go, turn}, where "stop", "go", and "turn" are the three symbols.

Click on a state, a transition label, or some state of the selected states to delete the state, the transition, or all the selected states.

Open the acceptance condition editor. When this toolbar item is enabled and an acceptance set in the accetpance condition editor is selected, click on a state to insert/remove it to/from the selected acceptance set. For Büchi acceptance condition, there is only one acceptance set and thus it is automatically selected.

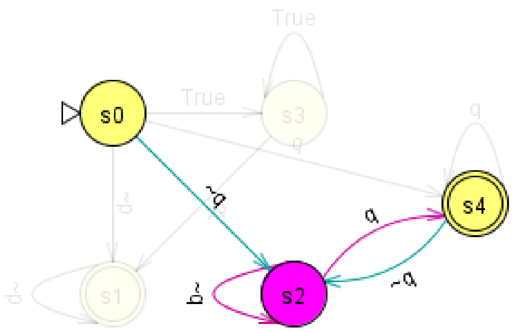


Acceptance condition and winning condition editor

The buttons in the acceptance condition editor are listed below.

- ⇄ - Toggle a state in/out the selected acceptance set.
- + - Insert a new acceptance set or acceptance pair.
- − - Remove an acceptance set or acceptance pair.
- ↑ - Move an acceptance set or acceptance pair up.
- ↓ - Move an acceptance set or acceptance pair down.

Click on a state to focus on it and its neighbors. Other states will become transparent. The incoming transitions and the outgoing transitions of the focused state will be drawn in different colors.



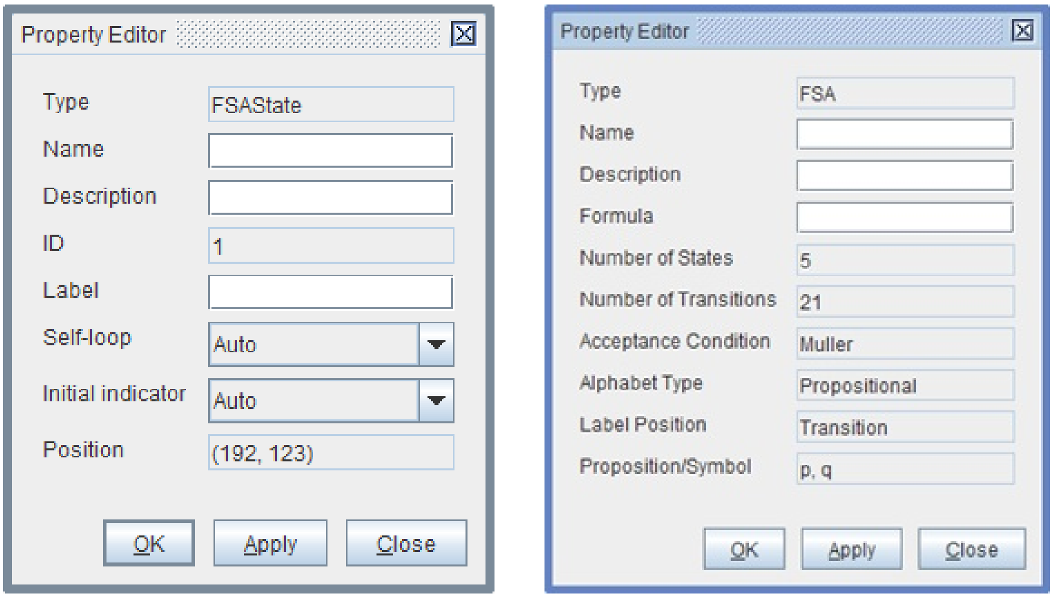
Effect of the focus tool

Click on a state or a transition to change its color.

Popup Menu Items

Whenever the right mouse button is clicked inside an automaton editor, a popup menu will appear. Whenever the right mouse button is clicked on a state, a transition, or a set of selected states and transitions, some items in the popup menu will become enabled to adjust properties of states and transitions.

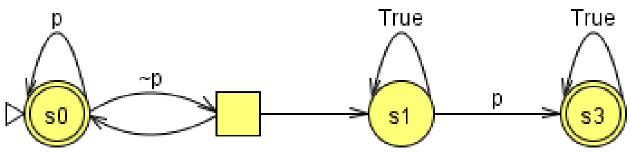
- **Initial State** - Checked if the selected state is an initial state.
- **Final State** - Checked if the selected state is a final state in a two-way alternating automaton.
- **State Attributes** - Choose the attributes to be shown below a state.
- **State Name** - Specify how to show the name of a state. There are four options.
  - **Custom Name** - Display the state name specified by the user. If there is no such name, display an initial state prefix followed by the state ID.
  - **Initial + ID** - Display an initial state prefix followed by the state ID.
  - **ID** - Display the state ID.
  - **None** - Display nothing.
- **Reorder States** - Reorder state IDs by a DFS.
- **Alignment** - Align the selected states.
- **Full Transition Display** - Checked if the transition symbols are not simplified. When the transition symbols are simplified, GOAL will, for example, use a transition labeled with "p" to represent two transitions labeled with "p q" and "p ~q" for an automaton with a propositional alphabet {p q, p ~q, ~p q, ~p ~q}.
- **Transition Attributes** - Choose the attribute to be shown on a transition.
- **Reset All Curves** - Reset the curature of all transitions.
- **Direction** - Set the direction of a transition in a two-way alternating automaton.
- **Player** - Change the owner player of a game state.
- **Color** - Change the fill color of a state or the line color of a transition.
- **Text Color** - Change the text color.
- **Opacity** - Set the opacity of selected states and transitions.
- **Layout** - Lay out an automaton by various layou algorithms. See here for more details.
- **Properties** - Open a dialog to edit the properties of a selected state, a selected transition, or an automaton.



Property editor for various objects

Alternating Automaton

The standard presentation of an alternating automaton contains universal-states and existential-states. In GOAL, a universal-state is represented by a box node, while an existential-state is represented by a circle node. GOAL only supports alternating automata in disjunctive normal form (DNF) and conjunctive normal form (CNF). For an alternating automaton in DNF, an existential-state can have transitions with labels to universal-states and existential-states, while a universal-state can only have transitions without any label to existential-states. For example, below is an NABW equivalent to "[]<> p". When a "~p" is consumed in state s0, the successors will be {s0, s1}.



Similarly, for an alternating automaton in CNF, a universal-state can have transitions with labels to universal-states and existential-states, while an existential-state can only have transitions without any label to universal-states.

Toolbar Items

See also the toolbar items for finite state automata.

Click on the editor to create a new existential-state in a DNF alternating automaton.

Click on the editor to create a new universal-state in a DNF alternating automaton.

Click on the editor to create a new universal-state in a CNF alternating automaton.

Click on the editor to create a new existential-state in a CNF alternating automaton.

See also the toolbar items for finite state automata.

See also the toolbar items for finite state automata.

See also the toolbar items for finite state automata.

See also the toolbar items for finite state automata.

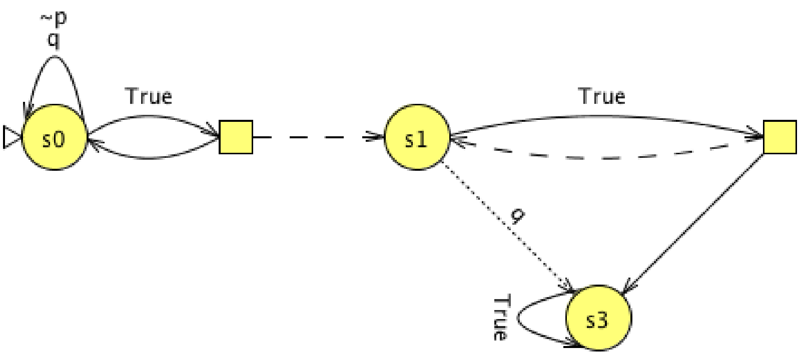
See also the toolbar items for finite state automata.

Two-Way Alternating Automaton

In a two-way alternating automaton, after reading a symbol w_i in a word w_0 w_i … w_{i-1} w_i w_{i+1} …, the next symbol to be read can be w_{i-1} or w_{i+1}. Thus, a node in the run tree of a two-way alternating automaton remembers not only the current state in the automaton but also a position in the word indicating which symbol is to be read. If the position in a node is i, then the position in its children may be $i+1$ or $i-1$. (The children may have different positions.)

A two-way alternating automaton in GOAL may have the following three different types of transitions:

- A (forward) transition with a solid line: The position is incremented by 1.
- A (backward) transition with a dashed line: The position is decremented by 1.
- A transition with a dotted line: This transition actually represents two transitions with the same symbol, one with a solid line and the other with a dashed line.



Toolbar Items

The toolbar items of the editor for two-way alternating automata are the same as those of the editor for alternating automata. The type of a transition can be changed in the popup menu of the transition.

Game

GOAL only supports two-player games. The states owned by player 0 are represented by circle nodes, while the states owned by player 1 are represented by box nodes.

 The player of a game state can be changed in the popup menu.

Toolbar Items

See also the toolbar items for finite state automata.

Click on the editor to create a new state owned by player 0.

Click on the editor to create a new state owned by player 1.

See also the toolbar items for finite state automata.

See also the toolbar items for finite state automata.

Open the winning condition editor. See also  for finite state automata.

See also the toolbar items for finite state automata.

See also the toolbar items for finite state automata.

MENU I

The menu items listed in the following come from the default installation.

Quick links: File, Edit, View, Repository, Formula, Automaton, Game, Window, Help

File

- **New** - Create a new editable object.
- **Open File...** - Open a file. The supported file formats are listed in the following.
  - GFF (GOAL File Format) - The XML file format used by GOAL.
  - Antichain Format - The file format used by mh for checking universality of NBW.
  - BA Format - A file format used in Ramsey-based containment testing. See here for more details.
  - JFLAP File Format (JFF) - The file format used by JFLAP. Currently, only finite state automata in JFF are supported.
  - LTL2Buchi Format - The XML file format output by LTL2Buchi with the argument -o xml.
  - MoDeLLa Format - The XML file format output by MoDeLLa with the argument -n.

    - PGSolver Format - The file format used by PGSolver to define parity games.
    - Promela Never Claim - The file format used by SPIN to define Büchi automata. The Promela never claim can be output by SPIN, by LTL2Buchi with the `-o promela` argument, by MoDeLLa with the `-s` argument, or by other tools.

- **Close** - Close the active tab.
- **Close All** - Close all tab.
- **Save** - Save the active object to a file.
- **Save As...** - Save the active object to a specified file in a specified format that can be decoded back. The supported file formats are listed in the following.
    - GOAL File Format (GFF)
    - Antichain Format - This output format is available only for Büchi automata with alphabets of size 2.
    - BA Format - This output format is available only for Büchi automata with classical alphabets.
    - JFLAP File Format (JFF) - This output format is available only for classic finite state automata.
    - PGSolver - This output format is available only for parity games. Note that the output will discard all transition labels.
    - Promela Never Claim - This output format is available only for Büchi automata.
- **Save All** - Save all objects.
- **Import** - Import objects from other formats.
- **Export**
    - **Single** - Export an object to a file in a format that may not be decoded back to the object. The supported file formats are listed in the following.
        - GOAL File Format (GFF)
        - Antichain Format - This output format is available only for Büchi automata with alphabets of size 2.
        - BA Format - This output format is available only for Büchi automata with classical alphabets.
        - DOT Format - A file format used by Graphviz. This output format is available only for Büchi automata.
        - GasTeX - GasTeX is a LaTeX package for drawing graphs and automata.
        - JFLAP File Format (JFF) - This output format is available only for classic finite state automata.
        - JGraph XML - JGraph is a general drawing library. This output format is available only for finite state automata.
        - JPEG
        - PGSolver - This output format is available only for parity games.
        - Portable Network Graphics (PNG)
        - Promela Never Claim - This output format is available only for Büchi automata.
        - Scalable Vector Graphics (SVG)
        - TikZ - TikZ/PGF is a LaTeX package for generating graphics.
        - Vaucanson-G - Vaucanson-G is a LaTeX package for drawing automata.
    - **Multiple** - Export multiple objects to a single file. The file is always in GOAL File Format (GFF).
- **Print** - Print the active object.
- **Recent Files** - Open a recent file, open all recent files, or clear the recent file history.

> Use Ctrl-Shift-R or CMD-Shift-R (in Mac OS) and number keys to quickly open recent files.

- **Exit** - Quit GOAL.

Edit

- **Undo** - Undo an action.
- **Redo** - Redo an action.
- **Select All** - Select all states and transitions in the active automaton.
- **Search** - Search states in the active automaton.
- **Cut** - Cut text in a formula editor or copy states in an automaton editor.
- **Copy** - Copy text in a formula editor or copy states in an automaton editor to the clipboard.
- **Paste** - Paste text to a formula editor or paste states to an automaton editor.
- **Delete** - Delete selected automaton components or selected text.
- **Merge** - Merge selected states.
- **Copy As** - Copy selected states in an automaton editor to the clipboard in various plain text formats. If no state is selected, the whole automaton will be copied.
    - **Promela**
    - **LaTeX (GasTeX)**
    - **LaTeX (Tikz)**
    - **LaTeX (Vaucanson-G)**
- **Preferences** - Set the user preferences.

View

- **Property Editor** - Toggle the display of the property editor.
- **Recent Files** - Open a dialog for selecting recent files by number keys 0-9.
- **Snap To Grid** - Snap the center of a state to a grid.
- **Display Gridlines** - Display gridlines.
- **Display Guidelines** - Display some guidelines when dragging a state.
- **Floatable Toolbar** - Make the toolbars floatable.
- **Zoom** - Set the zoom level of an automaton.

> Use Ctrl-MouseWheel or Mac trackpad (pinch open & close) to zoom in or out quickly.

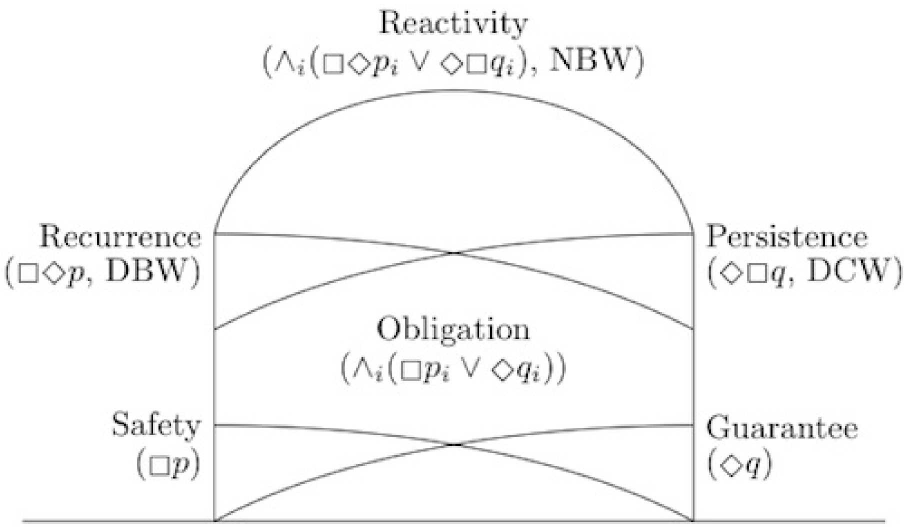
Repository

- **Local Büchi Repository** - Display the local repository containing the system-defined and the user-defined automata.
- **Online Büchi Repository** - Display the automata on the Büchi Store [TTCC11, TTCC13].
- **Büchi Store Uploader** - Upload the active automaton to the Büchi Store [TTCC11, TTCC13].

Formula

- **Satisfiability** - Test if a formula is satisfiable.
- **Validity** - Test if a formula is valid

- **Temporal Hierarchy** - Classify a QPTL formula into the Temporal Hierarchy [MP90].
    - **Syntax-Based**: Classify a QPTL formula into standard κ-formulae where κ is the classes of the Temporal Hierarchy [CMP92]. A standard κ-formula specifies a κ-property. A property specifiable by temporal logics is a κ-property if and only if it is specifiable by a future standard κ-formula.
    - **Language-Based**: Classify the language of a QPTL formula into the Temporal Hierarchy.



The Temporal Hierarchy where p, q, p_i, and q_i are past formulae.

- **Negation Normal Form** - Convert a logic formula into negation normal form if it is possible.
- **Prenex Normal Form** - Convert a logic formula into prenex normal form if it is possible.
- **Simplify** - Simplify a logic formula or an algebraic expression syntactically.
- **Past/Future Separation** - Separate the past operators and the future operators in a QPTL formula [Gab87]. The QPTL formula is required to be convertible to prenex normal form.
- **Translate RE To NFW** - Translate a regular expression to an equivalent NFW.
- **Translate ORE To NFW** - Translate an ω-regular expression to an equivalent NBW.
- **Translate QPTL** - Translate a QPTL formula to an equivalent automaton.
    - **To NGBW (Label-On-State)** - Translate a QPTL formula to a label-on-state NGBW.
        - **Tableau (MP)** - An implementation of the translation algorithm in [MP95].
        - **Incremental Tableau (KMMP)** - An implementation of the translation algorithm in [KMMP93].
        - **Temporal Tester (KP)** - An implementation of the translation algorithm in [KP00].
        - **Extended On-The-Fly (GPVW)** - An extended version of the original on-the-fly translation algorithm GPVW [GPVW95]. The extension allows the translation of quantified formulae and past formulae.
        - **Extended On-The-Fly (GPVW+)** - An extended version of the on-the-fly algorithm GPVW+ [GPVW95]. The extension allows the translation of quantified formulae.
        - **Extended LTL2AUT (DGV)** - An extended version of the LTL2AUT translation algorithm [DGV99]. The extension allows the translation of quantified formulae and past formulae.
        - **Extended LTL2AUT+ (DGV)** - A slightly improved version of the extended LTL2AUT translation algorithm.
        - **Extended MoDeLLa (ST)** - An implementation of the MoDeLLa translation algorithm [ST03] with extensions for past operators.
        - **Step-By-Step Tableau (MP)**
        - **Step-By-Step Extended On-The-Fly (GPVW)**
        - **Step-By-Step Extended On-The-Fly (GPVW+)**

        - **Step-By-Step Extended LTL2AUT (DGV)**
        - **Step-By-Step Extended LTL2AUT+ (DGV)**
        - **Step-By-Step Extended MoDeLLa (ST)**
    - **To NBW (Label-On-State)** - Translate a QPTL formula to a label-on-state NBW.
        - **Tableau (MP)**
        - **Incremental Tableau (KMMP)**
        - **Temporal Tester (KP)**
        - **Extended On-The-Fly (GPVW)**
        - **Extended On-The-Fly (GPVW+)**
        - **Extended LTL2AUT (DGV)**
        - **Extended LTL2AUT+ (DGV)**
        - **Extended MoDeLLa (ST)**
    - **To NGBW** - Translate a QPTL formula to an NGBW.
        - **Tableau (MP)**
        - **Incremental Tableau (KMMP)**
        - **Temporal Tester (KP)**
        - **Extended On-The-Fly (GPVW)**
        - **Extended On-The-Fly (GPVW+)**
        - **Extended LTL2AUT (DGV)**
        - **Extended LTL2AUT+ (DGV)**
        - **Extended MoDeLLa (ST)**
    - **To NBW** - Translate a QPTL formula to an NBW.
        - **Tableau (MP)**
        - **Incremental Tableau (KMMP)**
        - **Temporal Tester (KP)**
        - **Extended On-The-Fly (GPVW)**
        - **Extended On-The-Fly (GPVW+)**
        - **Extended LTL2AUT (DGV)**
        - **Extended LTL2AUT+ (DGV)**
        - **KP02** - An implementation of the inductive translation algorithm in [KP02]. The QPTL formula is not required to be in prenex normal form.
        - **Extended MoDeLLa (ST)**
        - **LTL2BA (GO)** - An implementation of the translation algorithm in [GO01] . In this implementation, the simplification of LTL formulae applied in the paper is not fully implemented. The definitions of transition relations are also different in this implementation.
        - **PLTL2BA (GO)** - An implementation of the translation algorithm in [GO03].
        - **Extended Couvreur's Algorithm** - An implementation of the Couvreur's translation algorithm [Cou99] with extensions for past operators.
        - **Extended LTL2BUCHI (GL)** - An implementation of the LTL2BUCHI translation algorithm [GL02] with extensions for past operators.
        - **CCJ09** - An implementation of the translation algorithm in [CCJ09]. The supported formula patterns include:
            - $<>(p1 \land ()(p_1 \land ()(\ldots \land ()p_1))) \land <>(p_2 \land ()(p_2 \land ()(\ldots \land ()p_2))) \land \ldots$
            - $<>(p_1 \land <>(p_2 \land <>(\ldots \land <>p_n))) \land <>(q_1 \land <>(q_2 \land <>(\ldots \land <>q_m))) \land \ldots$

        - $[]<>p_1 \wedge []<>p_2 \wedge \ldots \wedge []<>p_n$
        - $<>[]p_1 \vee <>[]p_2 \vee \ldots \vee <>[]p_n$
    - **QPTL2BA** - A translation developed by the GOAL development team from a QPTL formula in canonical forms to an equivalent Büchi automaton. Past sub-formulae are required to be in prenex normal form. Formulae that have boolean operators, future operators, and quantifications applied outside sub-formulae in canonical forms are also supported. See the Temporal Hierarchy for more details of canonical forms.

Algorithm	Supported Formulae
Tableau (MP)	QPTL in prenex normal form
Incremental Tableau (KMMP)	QPTL in prenex normal form
Temporal Tester (KP)	QPTL in prenex normal form
Extended On-The-Fly (GPVW)	QPTL in prenex normal form
Extended On-The-Fly (GPVW+)	Future QPTL in prenex normal form
Extended LTL2AUT (DGV)	QPTL in prenex normal form
Extended LTL2AUT+ (DGV)	QPTL in prenex normal form
KP02	QPTL
Extended MoDeLLa (ST)	QPTL in prenex normal form
LTL2BA (GO)	Future QPTL in prenex normal form
PLTL2BA (GO)	QPTL in prenex normal form
Extended Couvreur's Algorithm	QPTL in prenex normal form
Extended LTL2BUCHI (GL)	QPTL in prenex normal form
QPTL2BA	QPTL formulae constructed from canonical forms

A table of formulae supported by the above translation algorithms.

- **To NTGBW** - Translate a QPTL formula to an NTGBW.
    - **LTL2BA (GO)**
    - **PLTL2BA (GO)**
    - **Extended Couvreur's Algorithm**
    - **Extended LTL2BUCHI (GL)**
- **To NABW** - Translate a QPTL formula to an NABW.
    - **QPTL2BA** - A translation developed by the GOAL development team from a QPTL formula without past operators to an equivalent alternating Büchi automaton.
- **To NACW** - Translate a QPTL formula to an NACW.
    - **LTL2VWAA (GO)** - The translation from an LTL formula to an equivalent VWAA used by LTL2BA.
- **To NTWACW** - Translate a QPTL formula to a two-way NACW.
    - **PLTL2TWVWAA (GO)** - The translation from an LTL formula to an equivalent two-way VWAA used by PLTL2BA.
    - **QPTL2BA** - A translation developed by the GOAL development team from a QPTL formula in canonical forms to an equivalent two-way alternating co-Büchi automaton. Past sub-formulae

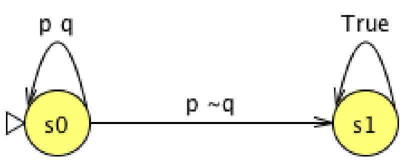
are required to be in prenex normal form. See the [Temporal Hierarchy] for more details of canonical forms.

- **Translate ACTL** - Translate an ACTL formula f to a Kripke structure A interpreted as a label-on-state automaton such that for all Kripke structure B, B |= f iff B ≤ A. For more details about |= and ≤, please refer to [GL94].
  - **To NGBW (label-on-state)**
    - **PMT02** - An implementation of a variant tableau construction based on [PMT02].

Automaton

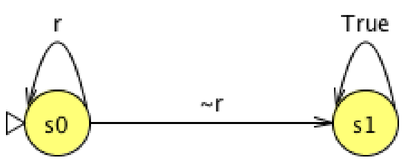
- **Alphabet** - Operations on the alphabet of the active automaton.
  - **Display Propositions/Symbols** - Display the propositions or the classical symbols in the alphabet of the active automaton.
  - **Expand Alphabet** - Expand the alphabet of the active automaton by a proposition or a classical symbol.
  - **Contract Alphabet (Projection)** - Project out a proposition or a classical symbol from the alphabet of the active automaton.
  - **Rename Proposition/Symbol** - Rename a proposition or a classical symbol to another literal.
  - **Alphabet Abstraction** - abstract the alphabet of an automaton that has
    - a propositional alphabet,
    - labels on transitions, and
    - an acceptance condition on states.

    The original propositions of the automaton will be replaced by new propositions defined as predicates of the original propositions. For example, consider the following automaton with an alphabet formed by the atomic propositions {p, q},



An automaton before the alphabet abstraction

If the only new proposition r is defined as p ∧ q. Then, the alphabet of the automaton after the abstraction will become {"r", "¬ r"} and the automaton after the abstraction is shown as the following.



An automaton after the alphabet abstraction

- **Convert Alphabet Type** - Convert between propositional alphabet and classical alphabet.

- **Duplicate** - Duplicate the active automaton.
- **Merge** - Merge an automaton into the active automaton. The acceptance conditions are also merged.
- **Acceptance Condition** - Operations on the acceptance condition of the active automaton.
  - **Reset Acceptance Condition** - Reset the acceptance condition of the active automaton.
  - **Maximize Acceptance Set** - Maximize the Büchi acceptance set of the active NBW without changing its language.
  - **Minimize Acceptance Set** - Simplify the Büchi acceptance set of the active NBW without changing its language.
  - **Parity Interpretation** - Change a parity condition from an interpretation to another interpretation. The parity interpretation can be min-even, min-odd, max-even, or max-odd. Note that GOAL uses min-even.
  - **Parity Compression** - Compress parity conditions.
  - **Parity Propagation** - Propagate parities of states in a parity condition.

- **Utilities**
  - **Find MSCCs** - Display the maximal strongly connected components (MSCC) in the active automaton.
  - **Find Elementary Cycles** - Display the elementary cycles in the active automaton. This is an implementation of the algorithm in [Joh75].
  - **Compute Simulation Relations (Naive)** - Display the direct and the reverse simulation relations [SB00] baed on a naive computation procedure.
  - **Compute Simulation Relations (SchematicSimilarity1)** - Display the direct and the reverse simulation relations baed on the SchematicSimilarity1 procedure in [HHK95].
  - **Compute Simulation Relations (RefinedSimilarity)** - Display the direct and the reverse simulation relations baed on the RefinedSimilarity procedure in [HHK95].
  - **Compute Simulation Relations (EfficientSimilarity)** - Display the direct and the reverse simulation relations baed on the EfficientSimilarity procedure in [HHK95].
  - **Compute Delayed Simulation Relation** - Display the delayed simulation relation of a Büchi automaton based on the procedure in [EWS01]. Instead of small progress measure applied in the papers, we use the user-default parity game solver to solve delayed simulation games.
  - **Compute Fair Simulation Relation** - Display the fair simulation relation of a Büchi automaton based on the procedure in [EWS01] for label-on-transition Büchi automata or the procedure in [GBS02] for label-on-state Büchi automata. Instead of small progress measure applied in the papers, we use the user-default parity game solver to solve fair simulation games.
  - **ε-Transition Elimination** - Eliminate ε-transitions of a classic finite state automaton with a classical alphabet.
  - **ω Operation** - Creates an NBW that accepts L^ω where L is the language of the active NFW.

- **Layout** - Lay out the active automaton by various layout algorithms, including layout creation algorithms and layout adjustment algorithms.
  - **Circle Layout** - Place states around a circle.
  - **FR Layout** - An implementation of the FR layout algorithm [FR91].
  - **Force-Scan Algorithm (FSA)** - An implementation of the force-scan algorithm [EL92, MELS95, LE98].
  - **Force-Transfer Algorithm (FTA)** - An implementation of the force-transfer algorithm [HL03, HLSG07].
  - **GEM Layout** - An implementation of the GEM layout algorithm [FLM94].
  - **ISOM Layout** - An implementation of the ISOM layout algorithm [Mey98].

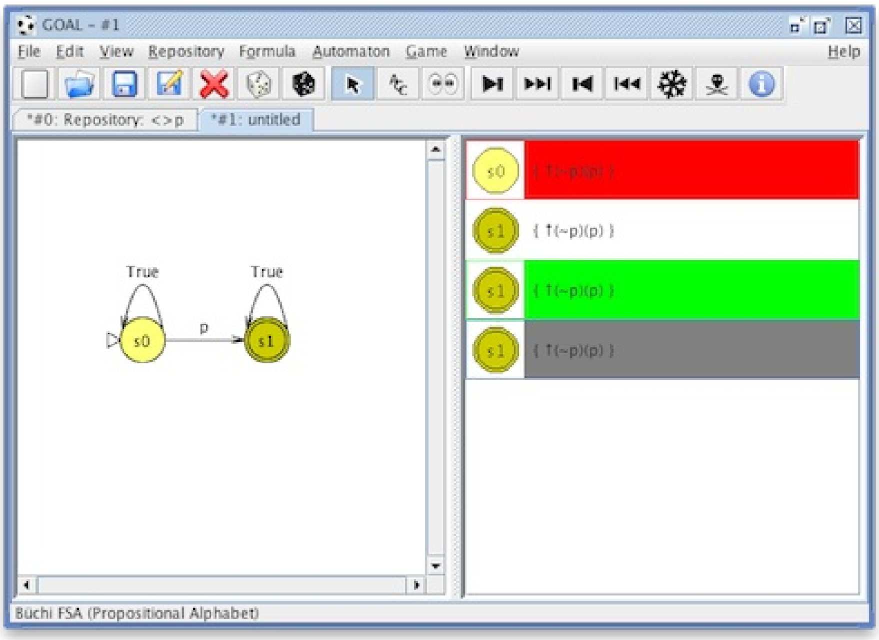
- **Improved Push Force-Scan Algorithm** - An implementation of the improved push force-scan algorithm [HIMF98, HIMF02].
- **KK Layout** - An implementation of the KK layout algorithm [KK89].
- **Random Layout** - Place states in random locations.
- **SA Layout** - An implementation of the SA layout algorithm [DH96].
- **Tree Layout** - An implementation of a naive tree layout.

Press Shift and do the layout to play layout animation.

- **Input Test** - Test if a word is accepted by the active automaton.

A finite word is a sequence of symbols $w_0\ w_1\ \ldots\ w_n$ where each symbol w_i may be enclosed in parentheses. An infinite word uv^ω is denoted by $w_0\ w_1\ \ldots\ w_i\ \{\ w_{i+1}\ \ldots\ w_n\ \}$ where $u = w_0\ w_1\ \ldots\ w_i$ and $v = w_{i+1}\ \ldots\ w_n$. For example, assuming that p and q are the atomic propositions, (p q)(p ~q)(~p ~q) { (p q)(~p q) } is a valid infinite word. When spaces and parentheses are omitted in a word, GOAL will decompose the word string into valid symbols automatically (though the decomposition may be ambiguous). Thus, pqp~q~p~q{pq~pq} is exactly the same as (p q)(p ~q)(~p ~q) { (p q)(~p q) }.

- **Direct Input Test** - Test if a word is accepted by the active automaton. The result will be displayed on the screen directly.
- **Input Simulator** - Display an interactive input simulator to see if a word is accepted.



Input simulator

The left-hand side in the input simulator is a read-only editor containing an automaton, while the right-hand side is a list containing the runs of the automaton on a word computed so far. A run in the list is displayed as a current state and the word with an "↑" indicating the next symbol to be read (the symbol after "↑"). A run is respectively colored by red or green if it is respectively rejecting or accepting. A run is colored by gray if it is frozen. A frozen run will not read any symbol until it is thawed. There are several toolbar icons for controlling the input simulator as shown below.

Read the next symbol.

Read the next 10 symbols.

Go one step backward. Note that deleted and dead runs will not be recovered.

Reset all.

Freeze or thaw a run.

Delete a run.

Show the details of a run.

- **Run Tree** - Interactively display the run tree of the active automaton on a word.
- **Run DAG** - Interactively display the run DAG of the active automaton on a word.
- **Split Tree** - Interactively display the split tree of the active automaton on a word.
- **Reduced Split Tree** - Interactively display the reduced split tree of the active automaton on a word.

- **Emptiness** - Test if the language of the active automaton is empty.
- **Containment** - Test if the language of the active automaton is contained in the language of another automaton by checking if the intersection of the active automaton and the complement of the other automaton is empty or not. If the intersection is empty, the active automaton is contained in the other automaton.
  - **With Naive Approach** - Explicitly construct the intersection of the first automaton and the complement of the second automaton. The complement is constructed explicitly by the default complementation construction. If the intersection is empty, then the first automaton is contained in the second automaton.
  - **On-The-Fly With Safra's Construction** - On-the-fly construct the intersection of the first automaton and the complement of the second automaton. The complement is constructed on-the-fly by the Safra's construction [Saf88].
  - **On-The-Fly With Modified Safra's Construction** - On-the-fly construct the intersection of the first automaton and the complement of the second automaton. The complement is constructed on-the-fly by the modified Safra's construction. See here for more information.
  - **On-The-Fly With Muller-Schupp Construction** - On-the-fly construct the intersection of the first automaton and the complement of the second automaton. The complement is constructed on-the-fly by the Muller-Schupp construction [MS95, ATW06].
  - **On-The-Fly With Safra-Piterman Construction** - On-the-fly construct the intersection of the first automaton and the complement of the second automaton. The complement is constructed on-the-fly by the Safra-Piterman construction [Pit06].
  - **On-The-Fly With Slice-Based Construction** - On-the-fly construct the intersection of the first automaton and the complement of the second automaton. The complement is constructed on-the-fly by the slice-based construction [KW08, VW07].
- **Equivalence** - Test if two automata are equivalent, that is, they have the same language.
- **Simulated**
  - **Direct Simulated By** - Test if an automaton is direct simulated by another automaton.
  - **Delayed Simulated By** - Test if a Büchi automaton is delayed simulated by another Büchi

automaton [EWS01].

  - **Fairly Simulated By** - Test if a Büchi automaton is fairly simulated by another Büchi automaton [EWS01, GBS02].

- **Simulation Equivalence** - Test if two automata are simulation equivalent, that is, the initial state of an automaton can simulate the initial state of the other automaton, and vice versa.
- **Deterministic**
  - **Syntactically Deterministic** - Test if an automaton is syntactically deterministic.
  - **Semantically Deterministic** - Test if an automaton is semantically deterministic, that is, it is equivalent to a DBW.
- **Aperiodic (Star-Free)** - Test the aperiodicity of an automaton or the language of an automaton based on [DG08]. Currently, only classic finite automata and Büchi automata are supported.

  Let L be a regular language. Then the followings are equivalent.

  1. L is first-order definable.
  2. L is star-free.
  3. L is aperiodic.
  4. The syntactic monoid of L (the transition monoid of the minimal deterministic automaton that recognizes L) is aperiodic.

  Let L be an ω-regular language. Then the followings are equivalent.

  1. L is first-order definable.
  2. L is star-free.
  3. L is aperiodic.
  4. L is definable in LTL.
  5. There is a counter-free Büchi automaton A with L = L(A).
  6. There is an aperiodic Büchi automaton A with L = L(A).

  Let A be an Büchi automaton.

  1. If A is counter-free, then A is aperiodic.
  2. If A is deterministic and aperiodic, then A is counter-free.

- **Morphism**
  - **Homomorphism** - Test if an automaton is homomorphic to another automaton.
  - **Isomorphism** - Test if two automata are isomorphic.
- **Temporal Hierarchy** - Classify an automaton into the Temporal Hierarchy [MP90].
- **Closure** - Take the safety closure of the active automaton.
- **Convert** - Convert the active automaton to another automaton type, logic formula, or algebraic expression.
  - **Label Position** - Convert an automaton with labels on states to an automaton with labels on transitions and vice versa.
  - **Alternation Style** - Convert a DNF alternating automaton to a CNF alternating automaton and vice versa.
  - **To Regular Expression** - Convert a classic finite state automaton with a classical alphabet to an equivalent regular expression.
  - **To ω-Regular Expression** - Convert an ω-automaton with a classical alphabet to an equivalent ω-regular expression.
  - **To Game** - Convert a deterministic ω-automaton to a turn-based game. The automaton is required to have a propositional alphabet, an acceptance condition on states, and labels on transitions. The

propositions are treated as Boolean variables and partitioned into two sets, of which one set is controlled by a player and the other set is controlled by its opponent. In the context of synthesis, Player P0 acts as a module and Player P1 acts as the environment of the module.

  - **To NBW** - Convert an automaton to an equivalent Büchi automaton.
  - **To NCW** - Convert an automaton to an equivalent co-Büchi automaton.
  - **To NGBW** - Convert an automaton to an equivalent generalized Büchi automaton.
  - **To NMW** - Convert an automaton to an equivalent Muller automaton.
  - **To NRW** - Convert an automaton to an equivalent Rabin automaton.
  - **To NSW** - Convert an automaton to an equivalent Streett automaton.
  - **To NPW** - Convert an automaton to an equivalent parity automaton.
  - **To NTBW** - Convert an automaton to an equivalent transition Büchi automaton.
  - **To NTGBW** - Convert an automaton to an equivalent transition generalized Büchi automaton.
  - **To...** - Apply a custom conversion where several direct conversions may be chained.

- **Determinize** - Determinize the active automaton to an equivalent deterministic automaton.
  - **To DFW** - Determinize an NFW to an equivalent DFW.
  - **To DBW (Boker-Kupferman)** - Determinize an automaton to an equivalent DBW through DCW by the approach in [BK09] if the determinization is possible.
  - **To DBW (Landweber)** - Determinize an automaton to an equivalent DBW through DMW by the approach in [Lan69] if the determinization is possible.
  - **To DRW (Safra)** - Determinize an NBW to an equivalent DRW by Safra's construction [Saf88]. Schewe's history trees [Sch09b] are also implemented as an option.
  - **To DRW (Modified Safra)** - Determinize an NBW to an equivalent DRW by modified Safra's construction. See here for more information.
  - **To DRW (Muller-Schupp)** - Determinize an NBW to an equivalent DRW by Muller-Schupp construction [MS95, ATW06].
  - **To DPW (Safra-Piterman)** - Determinize an NBW to an equivalent DPW by Safra-Piterman construction [Pit06]. Schewe's history trees [Sch09b] are also implemented as an option.

- **Minimization** - Minimize a classic finite word automaton.
  - **By Classical Approach** - Minimize a classic finite word automaton by a classical approach.
  - **By Hopcroft's Algorithm** - Minimize a classic finite word automaton by the Hopcroft's algorithm [Hop71].

- **Product** - Take the synchronous or asynchronous product of two finite state automata. The two automata must have the same type of alphabet and have labels on transitions. The automaton structure of the product will be the same as that of the first automaton (the active one). The acceptance condition of the product only depends on the second automaton (the selected one in the options dialog). Let $A_1 = (\Sigma, Q_1, q_{10}, \delta_1, F_1)$ and $A_2 = (\Sigma, Q_2, q_{20}, \delta_2, F_2)$ be two ω-automata. The synchronous product of A_1 and A_2 is $P = (\Sigma, Q, q_0, \delta, F)$ where
  - $Q = Q_1 \times Q_2$,
  - $q_0 = (q_{10}, q_{20})$,
  - for all $a \in \Sigma$, $s_1, t_1 \in Q_1$, and $s_2, t_2 \in Q_2$, $((s_1, s_2), a, (t_1, t_2)) \in \delta$ iff $(s_1, a, t_1) \in \delta_1$ and $(s_2, a, t_2) \in \delta_2$.

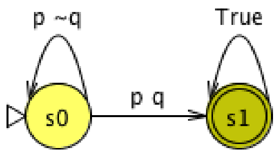
  The asynchronous product of A_1 and A_2 is $P = (\Sigma, Q, q_0, \delta, F)$ where
  - $Q = Q_1 \times Q_2$,
  - $q_0 = (q_{10}, q_{20})$,
  - for all $a \in \Sigma$, $s_1, t_1 \in Q_1$, and $s_2, t_2 \in Q_2$, $((s_1, s_2), a, (t_1, t_2)) \in \delta$ iff

- $(s_1, a, t_1) \in \delta_1$ and $s_2 = t_2$, or
- $(s_2, a, t_2) \in \delta_2$ and $s_1 = t_1$.

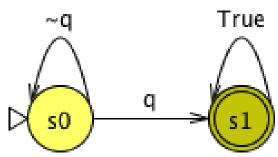
In the synchronous setting, a mapping M from the propositions of the second automaton to the predicates on the propositions of the first automaton may be provided. In this case, the second automaton may have a different alphabet. Let M(l) for a literal l be M(l) if l is positive and ¬M(l) otherwise. Then, the synchronous product of A_1 and A_2 with the mapping M is $P = (\Sigma, Q, q_0, \delta, F)$ where

- $Q = Q_1 \times Q_2$,
- $q_0 = (q_{10}, q_{20})$,
- for all $a \in \Sigma$, $s_1, t_1 \in Q_1$, and $s_2, t_2 \in Q_2$, $((s_1, s_2), a, (t_1, t_2)) \in \delta$ iff
  - $(s_1, a, t_1) \in \delta_1$ and
  - there is $(s_2, b, t_2) \in \delta_2$ such that for all literal $l \in b$, M(l) is satisfied by a.

For example, consider the following two Büchi automata.

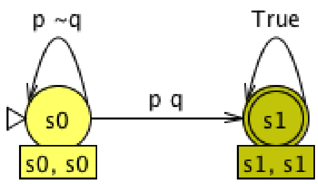


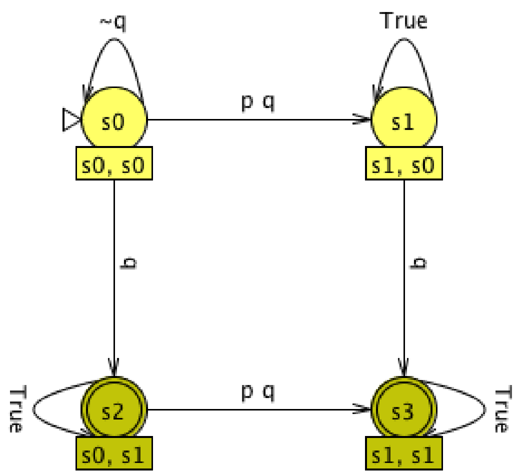
A_1

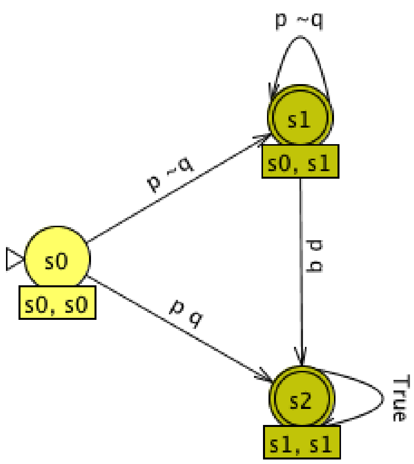


A_2

The synchronous product, asynchronous product, and synchronous product with a mapping are shown in the following.







The synchronous product

The asynchronous product

The synchronous product with a mapping
M where M(p) = True and M(q) = p ∨ q

- **Intersection** - Take the intersection of two compatible automata.
- **Union** - Take the union of two compatible automata.
- **Complement** - Complement the active automaton.
  - **Classic Complementation** - Complement a classic finite word automaton.
  - **Kurshan's Construction** - Complement a DBW by Kurshan's construction [Kur87].
  - **Ramsey-Based Construction** - Complement an NBW by Ramsey-based construction [Buc62, SVW87].
  - **Safra's Construction** - Complement an NBW based on Safra's construction [Saf88]. Schewe's history trees [Sch09b] are also implemented as an option.
  - **Modified Safra's Construction** - This is the same as Safra's construction, except that when constructing Safra trees, the steps of computing successors and creating sons are exchanged.
  - **Muller-Schupp Construction** - Complement an NBW based on Muller-Schupp construction [MS95, ATW06].
  - **Via Weak Alternating Parity Automaton** - Complement an NBW via a weak alternating parity automaton [Tho99].
  - **Via Weak Alternating Automaton** - Complement an NBW via a weak alternating automaton [KV01].
  - **Safra-Piterman Construction** - Complement an NBW based on Safra-Piterman construction [Pit06]. Optimization heuristics in [TFVT10] are implemented. Schewe's history trees [Sch09b] are also implemented as an option.
  - **Rank-Based Construction** - Complement an NBW by rank-based construction [KV01] with optimizations proposed in [Sch09a].
  - **Slice-Based Construction** - Complement an NBW by the slice-based construction [KW08, VW07]. Optimization heuristics in [TFVT10] are also implemented.

    Note: The slice-based construction is contributed by Kähler and Wilke in [KW08]. Its preliminary version is stated in [VW07].
  - **To Complement DBW** - Converts a DCW to a complement DBW.
  - **To Complement DCW** - Converts a DBW to a complement DCW.
  - **To Complement DMW** - Converts a DMW to a complement DMW.
  - **To Complement DRW** - Converts a DSW to a complement DRW.
  - **To Complement DSW** - Converts a DRW to a complement DSW.
  - **To Complement DPW** - Converts a DPW to a complement DPW.
  - **To Complement NABW** - Converts an NCW to a complement NABW.
  - **To Complement NACW** - Converts an NBW to a complement NACW.
  - **To Complement NAPW** - Converts an NAPW to a complement NAPW.
- **Complement (Step-by-Step)** - Complement the active automaton step-by-step by various constructions. The toolbar items used to control the complementation algorithms are the same as in Step-by-Step Translation.
  - **Safra's Construction** - NBW → DRW → complement DSW → complement NBW
  - **Modified Safra's Construction** - NBW → DRW → complement DSW → complement NBW
  - **Muller-Schupp Construction** - NBW → DRW → complement DSW → complement NBW
  - **Via Weak Alternating Parity Automaton** - NBW → NAPW → complement NBW
  - **Via Weak Alternating Automaton** - NBW → complement UCBW → complement VWAA →

complement NBW
  - **Safra-Piterman Construction** - NBW → DPW → complement DPW → complement NBW
  - **Rank-Based Construction**
  - **Slice-Based Construction**

- **Concatenation** - Concatenate an NFW and an ω-automaton such that the concatenation accepts the concatenation of the language of the NFW and the language of the ω-automaton.
- **Replacement** - Constructs an automaton M for a source automaton M_1, a pattern automaton M_2 ($\varepsilon \notin L(M_2)$), and a replacement automaton M_3 such that $L(M) = \{w_1\, c_1\, w_2\, c_2 \ldots w_k\, c_k\, w_{k+1} \mid k > 0, w_1\, x_1\, w_2\, x_2 \ldots w_k\, x_k\, w_{k+1} \in L(M_1), \forall\, i, x_i \in L(M_2), w_i$ does not contain any substring accepted by $M_2, c_i \in L(M_3)\}$. The implementation is based on [YBCI08].
- **Reverse** - Reverse the transitions, initial states, and accepting states of an NFW such that the output accepts the reverse of the language of the input.
- **Simplify** - Simplify an automaton without changing its language.
  - **By Reducing Unreachable/Dead States** - Remove unreachable states and dead states.
  - **By Reducing Alternating Connectors** - Remove unnecessary alternating connectors.
  - **By Pruning Fair Sets** - Simplify an NGBW by pruning fair sets [SB00].
  - **By Simulation** - Simplify an ω-automaton by direct simulation and reverse simulation [SB00].
  - **By Wring Approach** - Simplify an NGBW by pruning fair sets and simulation repeatedly until a fix-point is reached.
  - **By Delayed Simulation** - Simplify an NBW by delayed simulation [EWS01]. Instead of small progress measure applied in the paper, we use McNaughton-Zielonka to solve delayed simulation games.
  - **By Fair Simulation** - Simplify an NBW by fair simulation [GBS02]. Instead of small progress measure applied in the paper, we use McNaughton-Zielonka to solve fair simulation games. Similar to small progress measure that can reuse previously computed progress measures, we use the results of McNaughton-Zielonka to reduce fair simulation games during the simplification.
  - **Through Rabin Index Computation** - Simplify the parity condition based on the computation of Rabin index [CM99].

- **Promela** - Display the Promela code of an NBW.

Game

- **Solve** - Solve a game.
  - **By...** - Solve a game directly. A solved game with coloring annotations will be returned. If the annotated game is saved as a GFF file, the winning regions and winning strategies will also be saved. In the default installation, there are one solver for reachability games, one solver for Büchi games, and six solvers for parity games.

    Reachability Game Solvers

      - **Reachability**

    Büchi Game Solvers

      - **Classical Büchi**

    Parity Game Solvers

      - **Recursive**: a recursive algorithm based on induction on the number of parities [Zie98]. This implementation follows the description in [Kus01].

        - **McNaughton-Zielonka**: an algorithm orignates from the work of McNaughton [McN93] and was first presented for parity games by Zielonka [Zie98, Kus01] . The implementation follows the description in [JPZ06].
        - **Dominion Decomposition**: a deterministic subexponential algorithm based on dominion decomposition [JPZ06].
        - **Small Progress Measure**: an implementation of the algorithm based on small progress measure [Jur00]. This implementation does include the optimizations described in [Jur00].
        - **Big Steps**: an algorithm which combines McNaughton's fixed point algorithm with a preprocessing step where a variant of the Jurdziński's small progress measure is applied to find dominions [Sch07]. In this implementation, the winning strategies for a 3-parity subgame are partially computed.
        - **Global Optimization**: an algorithm which applies solver-independent global optimizations to the input parity game before delegating the game solving to another solver. The global optimizations include some heuristics described in [FL09].

        The parity conditions in GOAL are min-even.

    - **Step-By-Step By...** - Solve a game step-by-step.
- **Convert** - Convert a game to another equivalent game.
- **Product** - Take the synchronous product of a game and a finite state automaton. The game and the automaton must have the same type of alphabet and both have labels on transitions. The returned product will be a game with an acceptance condition that only depends on the automaton. A mapping from the propositions of the automaton to predicates on the propositions of the game may be provided. See the automaton product for more details.

Window

- **New Window** - Open a new GOAL window.
- **Next Window** - Switch to the next window.
- **Previous Window** - Switch to the previous window.
- **Detach Tab** - Detach the active tab from the current window.
- **Next Tab** - Switch to the next tab.
- **Previous Tab** - Switch to the previous tab.

    Use Mac trackpad (swipe left or right with three fingers) to quickly switch among tabs.

- **Move Tab to Next Window** - Move the active tab to the next window.
- **Move Tab to Previous Window** - Move the active tab to the previous window.
- **Move Tab to...** - Move the active tab to a specified window.

Help

- **Help Contents** - Display the help contents.
- **Check for Updates** - Check for updates of GOAL.
- **About** - Display information about the GOAL development team.

C O M M A N

The GOAL command-line mode can be either single mode or batch mode. In the single mode, only one command can be executed each time. In the batch mode, a sequence of commands can be executed. A single command is an instr while a sequence of command is a block in the grammar rules (see the Grammar section).

To execute a single command, the command and its arguments should be preceded by the GOAL launcher (goal.bat on Windows and goal on UNIX). To execute a sequence of commands, you can write GOAL scripts and use the batch command to execute the statements in the scripts. For example, suppose the file SCRIPT contains a sequence of commands. You can run these commands by invoking GOAL in the following way:

```
$ ./goal batch SCRIPT
```

Unlike the execution of a single command, in a GOAL script, variables can be used to capture the results of commands.

Set the shell variable GOAL_DEBUG to true to show exceptions thrown during execution.

Grammar

```
block := ( stmt )*

stmt := instr ";" | for_stmt | while_stmt | if_stmt | try_stmt

instr :=
    "help" [ --html ] [ keyword ]
  | "interactive"
  | "exit"
  | "break" ( expr )?
  | "continue" ( expr )?
  | lval ("=" | "+=" | "-=" | "*=" | "/=" | "%=" | "&=" | "|=") ( expr | cmd_expr )
  | "(" lval ( "," lval )* ")" "=" ( expr | cmd_expr )
  | cmd_expr

for_stmt := "for" lval "in" expr "do" block "done"

while_stmt := "while" expr "do" block "done"

if_stmt := "if" expr "then" block
           ( "elif" expr "then" block )*
           ( "else" block )?
           "fi"

try_stmt := "try" "{"
              block
            "}" "catch" "(" lval ")" "{"
              block
            "}"

cmd_expr := cmd ( arg )*

arg :=
    "-" string
  | "--" string
  | expr

expr :=
```

```
    expr ( "\/" | "|" ) expr
  | expr ( "/\" | "&" ) expr
  | expr "==" expr
  | expr "!=" expr
  | expr "<" expr
  | expr ">" expr
  | expr "<=" expr
  | expr ">=" expr
  | expr "+" expr
  | expr "-" expr
  | expr "*" expr
  | expr "/" expr
  | expr "%" expr
  | "-" expr
  | "!" expr
  | array
  | list
  | number
  | bool
  | string
  | lval
  | "time"
  | "(" expr ")"
  | "`" shell_cmd "`"

array := "{" [ string ":" ] expr ("," [ string ":" ] expr)* "}"

list := "[" expr (", " expr)* "]"

number := int | float

formula_or_lval := string | lval

file_or_lval := file | string

int_or_lval := int | lval

string_or_lval := string | lval

bool := "true" | "false"

lval := "$" id

int := (["0"-"9"])+

float := (["0"-"9"])+ "." (["0"-"9"])+

file := (["a"-"z","A"-"Z","0"-"9","_","-",".","/"])+

id := ["a"-"z","A"-"Z"] ( ["a"-"z","A"-"Z","0"-"9","_"] )*

shell_cmd := ( ~["`","\n","\r"] )*

AUTOMATON_TYPE := LOSNFW | LOSNREW | LOSNBW | LOSNCW | LOSNGBW | LOSNMW | LOSNRW | LOSNSW | LOSNPW |
                  DFW | DREW | DBW | DCW | DGBW | DMW | DRW | DSW | DPW |
                  NFW | NREW | NBW | NCW | NGBW | NMW | NRW | NSW | NPW |
                  DTBW | DTCW | DTGBW | DTMW | DTRW | DTSW | DTPW |
                  NTBW | NTCW | NTGBW | NTMW | NTRW | NTSW | NTPW |
                  DNFNABW | DNFNACW | DNFNAGBW | DNFNAMW | DNFNARW | DNFNASW | DNFNAPW |
                  CNFNABW | CNFNACW | CNFNAGBW | CNFNAMW | CNFNARW | CNFNASW | CNFNAPW |
                  DNFNTWABW | DNFNTWACW | DNFNTWAGBW | DNFNTWAMW | DNFNTWARW | DNFNTWASW | DNFNTWAPW |
                  CNFNTWABW | CNFNTWACW | CNFNTWAGBW | CNFNTWAMW | CNFNTWARW | CNFNTWASW | CNFNTWAPW |
                  UCW | WAA | WAPA | VWAA | TWVWAA | TWLWAA

GAME_TYPE := DBG | DCG | DFG | DGBG | DMG | DPG | DREG | DRG | DSG |
             NBG | NCG | NFG | NGBG | NMG | NPG | NREG | NRG | NSG

ALPHABET_TYPE := PROPOSITIONAL | CLASSICAL
```

Each command expression cmd_expr starts with a command name followed by the arguments. The command names and the arguments for a particular command depend on what commands are installed.

Variables

In GOAL scripts, every variable name should start with "$". You don't need to declare the type of a variable before using it. For example, below are some acceptable variable names:

```
$var
$v0
$v_0
```

There are some special variables: $0, $1, $2, ..., $#, $*, and $@, which can be used in a GOAL script. $0 is the name of the GOAL script, $1 is the first argument, $2 is the second argument, and so forth. $# is the number of arguments. $* and $@ denote all the arguments.

Lists

One way to create a list is to execute the readline command which reads a file line by line. Each element in the list is a line in the file. For example, the following statement will read the file "input" and put each line as an element in the list variable $list.

```
$list = readline "input";
```

Arrays (Maps)

An array is a map from an object convertible to a string to an object. Basically, you can use any object as the index of an array. For example, the following commands are acceptable.

```
$arr[0] = 0;
$arr["number"] = 10;
$arr = {
        1,
        "key" : "value" ,
        { "nested" : {2, 3, 4} }
      };
```

Lists

A list is a sequence of items. When iterating over a list, only list items will be returned. This is different from arrays (maps) where indices are returned. Below is an example of lists.

```
$algorithms = ["-m piterman -r", "-m rank -r", -m slice -r];
for $alg in $algorithms do
  $o = complement --option $alg $aut;
done
```

Multiple Assignments

A multiple assignment tries to split an object and assign the results to a set of variables. Note that the number of left elements should be less than or equal to the number of right elements. A string can be split by spaces, tabs, and newlines. For example, the following statement will split the string into "1" and "2". If you want to use delimiters rather than spaces, tabs, and newlines, you can use the split command.

```
($x, $y) = "1 2";
```

The values of elements of a list can be assigned to a set of variables by the following statement.

```
($elm_1, $elm_2, ..., $elm_n) = $list
```

The key set of an array can be assigned to a set of variables by the following statement.

```
($key_1, $key_2, ..., $key_n) = $arr
$arr[$key_1] = 0;
$arr[$key_2] = 1;
...
```

Statements

A statement can be an instruction (command) with a trailing ";", a for-statement, while-statement, an if-statement, or a try-statement. A for-statement iterates on the elements of a list or the key set of an array. For examples, below is a for-statements which iterates on a list.

```
$list = readline "input";
for $elm in $list do
  echo $elm;
done
```

Below is a for-statements which iterates on an array.

```
for $key in $arr do
  echo $arr[$key];
done
```

Shell Commands

A shell command can be invoked by putting the command between two `. For example, the following command will invoke the shell command "seq 1 10" and the variable $x will capture both the standard output and the error output of this shell command.

```
$x = `seq 1 10`;
```

Below is another example that prints numbers from 1 to 10 on the screen.

```
for $x in `seq 1 10` do
  echo $x;
done
```

A GOAL variable can be used in a shell command directly. The interpreter of GOAL scripts will replace the GOAL variable with its value in the shell command before executing the shell command. For example, the following script will display "Hello World!" on the screen.

```
$x = "Hello World!";
```

```
`echo $x`;
```

If a variable in a shell command is not a declared GOAL variable, the interpreter will not replace the variable as the variable may be a shell variable. For example, the following script will display a random variable.

```
`echo $RANDOM`;
```

If GOAL variables and shell variables have name conflicts, use "\" to force the interpreter to treat a variable as a shell variable. For example, the following script will output the string "random" followed by a random number.

```
$RANDOM = "random";
`echo $RANDOM\$RANDOM`;
```

Runtime Arguments

only for scripts

Variable expansion: "—option $var" is replaced by the content of $var

The command-line argument "--option string" is reserved to specify arguments known at runtime.

For example, the evaluation of

Background: the arguments of a command are passed as a List<Expression> to the constructor of this command. For example in "goal aperiodic -a -s aut.gff", the List<Expression> ["-a", "-s", "aut.gff"] is passed to the constructor of AperiodicCommand.

If in a a script there is
$var = "-a -s";
aperiodic $var aut.gff;
then the List<Expression> passed to the constructor is ["$var", "aut.gff"]. That is, the variable $var is not expanded (replaced with its content).
If however we write
aperiodic —option $var aut.gff;
then the List<Expression> is ["-a", "-s", "aut.gff"]. That is, $var has been expanded, and this is exactly what we want.

```
cmd --option $x $file;
```

is the same as the evaluation of

For the arguments that are indicated as FILE_OR_LVAL in the descriptions, variable expansion always takes place and thus such an argument can be specified with a variable without the need of the —option syntax. For example, if we have
$in= a.gff;
$out = a_compl.gff;
complement -m slice -o $out $in;
$in and $out are expanded and the created List<Expression> is ["-m", "slice", "-o", "a_compl.gff", "a.gff"]

```
cmd -opt1 -opt3 $file;
```

if the value of $x is "-opt1 -opt3" at runtime.

There is a caveat with the —option expansion: the expanded expressions (contents of expanded vars) are always positioned at the head of List<Expression>. For example, if we have this fantasy example
$o1 = "-b -c";
$o2 = "-e";
mycmd -a --option $o1 -d --option $o2 -f aut.gff;
then the List<Expression> created is ["-b", "-c", "-e". "-a", "-d", "-f". "aut.gff"], This will be evaluated similarly as the execution of "mycmd -b -c -e -a -d -f aut.gff", however one wanted to execute "mycmd -a -b -c -d -e -f aut.gff". For example, in
$t = "qptl";
$n = 3;
generate -t —option $t -n —option $n;
the List<Expression> passed to the constructor of GenerateCommand is ["qptl", "3", "-t", "-n"] which comes to the same as executing "generate qptl 3 -t -n" which is nonsense. We would expect the List<Expression> to be ["-t", "qptl", "-n", "3"], but this is not the case.
This prepending happens only for variables expanded with —option, not for variables that specify FILE_OR_LVAL arguments.
For example, "aperiodic -a -s $aut" yields the List<Expression> ["-a", "-s", "aut.gff"], that is, the order is preserved.

Note: FILE_OR_LVAL variables are actually not expanded in the List<Expression>, but present in their literal form (e.g. "$aut"). But then they are treated by a CmdUtil.castOrLoadXX method, which expands them. This works, because it is known exactly which arguments are FILE_OR_LVAL.

COMMANDS

Below is the list of available commands.

Edit: simple variables are also expanded in scripts, but they can be used only to specify *values of options*. From my e-mail to Ming-Hsien:

A simple variable can be used to specify only the value of an option.
OK:
$n = 3; generate -n $n;
Wrong:
$n = "-n 3"; generate $n;
$n = "-n"; generate $n 3;

--option $var can be used to specify any part of the argument list.
OK:
$n = "-n 3"; generate --option $n;
$n = "-n"; generate --option $n 3;
$n = -n 3 -t"; generate --option $n qptl;
However, just keep in mind the change of order that I described in the last e-mail. Therefore, it's safest to use it only for full options, and not fractions of it, so that the change of order of the arguments in the argument list doesn't matter.

- acc
- alphabet
- aperiodic
- batch
- classification
- clone
- close
- complement
- concatenation
- containment
- convert
- deterministic
- determinization
- echo
- emptiness
- equivalence

- generate
- homomorphism
- import
- input
- intersection
- isomorphism
- layout
- load
- minimization
- names
- omega
- open
- parity
- preference
- product
- promela
- property
- qptl
- readline
- reduce
- replace
- repository
- reverse
- satisfiability
- save
- separation
- seq
- simequiv
- simplify
- simulated
- sleep
- solve
- split
- stat
- test
- translate
- union
- validity

The details of these commands are described in the following.

- acc -

NAME

acc - Maximize or minimize Buchi acceptance condition of a finite state automaton. Note that this operation will be applied directly on the input automaton.

SYNOPSIS

acc [-max | -min] FILE_OR_LVAL

DESCRIPTION

Maximize or minimize Buchi acceptance condition of a finite state automaton.

-max Maximize the Buchi acceptance condition.

-min Minimize the Buchi acceptance condition.

EXAMPLE

```
acc -max $aut;
```

- alphabet -

NAME

alphabet - Manipulate the alphabet of an automaton or a game.

SYNOPSIS

alphabet -s [-ap] FILE_OR_LVAL

alphabet -e EXPR [-ap] FILE_OR_LVAL

alphabet -c EXPR [-ap] FILE_OR_LVAL

alphabet -r EXPR [-ap] FILE_OR_LVAL

alphabet -a EXPR [-R | -A | -S EXPR | -P EXPR | -ap] FILE_OR_LVAL

DESCRIPTION

Manipulate the alphabet of an automaton (or a game). This operation is directly applied to the input automaton. The returned value is always the new alphabet of the automaton (or the new atomic propositions if -ap is present).

-s Simply return the alphabet of the input automaton or game.

-ap Return the atomic propositions (or classical symbols) instead of the alphabet.

-e Expand the alphabet by a list of propositions.

-c Contract the alphabet by removing a list of propositions.

-r Rename the propositions based on a map from a proposition to its new name.

-a Abstract the alphabet based on a map from a predicate to its definition.

-R Retain the transition symbols in alphabet abstraction.

-A Only annotate the transitions with properties specified by -S and -P.

-S Specify the name of the property that will store the symbols on the transitions in alphabet abstraction.

-P Specify the name of the property that will store the evaluations of the predicates in alphabet abstraction.

EXAMPLE

```
alphabet -e "r" aut.gff
alphabet -c "p" aut.gff
alphabet -r "p=>r,q=>s" aut.gff
alphabet -a "r=>p/\q" aut.gff
alphabet -a "r=>p/\q" -A -P "Predicates" aut.gff
```

- aperiodic -

NAME

aperiodic - Test the aperiodicity of an automaton or a language.

SYNOPSIS

aperiodic [-A | -a | -s] FILE_OR_LVAL

DESCRIPTION

Return "true" if (1) -A is specified and the input automaton is aperiodic or (2) -A is not specified and the language of the automaton is aperiodic. Return "false" otherwise.

-A Test the aperiodicity of the automaton rather than the language of the automaton. By default, this command tests the aperiodicity of the language of the input automaton.

-a Test the aperiodicity of the automaton first. By default, this option is off.

-s Skip rejected strings. By default, this option is off.

EXAMPLE

```
aperiodic -a -s aut.gff
```

- batch -

NAME

batch - Execute a script.

SYNOPSIS

batch FILE_OR_LVAL

DESCRIPTION

Execute the statement in a GOAL script. If the argument is not a file, it will be parsed as a statement.

EXAMPLE

```
batch script
batch "echo Hello; echo World;"
```

- classification -

NAME

classification - Classify an automaton or a QPTL formula based on the Manna-Pnueli Temporal Hierarchy.

SYNOPSIS

classification [-c | -t | -s] [FILE_OR_LVAL | FORMULA_OR_LVAL]

DESCRIPTION

Classify an automaton or a QPTL formula based on the Manna-Pnueli temporal hierarchy.

-c
: Use DCW instead of DMW to construct DBW. By default, this options is off.

-t
: Classify in a top-down manner. By default, this option is off.

-s
: Return classes of the Temporal Hierarchy such that a class κ is returned if and only if the QPTL formula is a standard κ-formula.

EXAMPLE

```
classification "[](p U q) U q"
```

- clone -

NAME

clone - Make a clone of an object.

SYNOPSIS

clone EXPR

DESCRIPTION

Make a clone of an object.

EXAMPLE

```
clone $aut;
```

- close -

NAME

close - Close a GOAL window.

SYNOPSIS

close [-f] INT_OR_LVAL

DESCRIPTION

Close the GOAL window with a specified index.

-f Close the window without saving changes.

EXAMPLE

```
close 1
```

- complement -

NAME

complement - Complement an automaton.

SYNOPSIS

complement [-m ALGORITHM | -o FILE_OR_LVAL | -s EXPR | -t EXPR | ALGORITHM_DEPENDENT_ARGUMENTS] FILE_OR_LVAL

Options for complementation construction. All unknown arguments (everything except -m, -o, -s, -t and their immediately following args) are taken as options to the complementation construction. The position doesn't matter. Thus, "complement -r2c -m1 -m fribourg -r -o out.gff -rr in.gff" is valid. All the unknown args are gathered, transformed to a List<Expression>, and passed to getOptions() of XXComplementInterface, which parses the Expressions (Strings) and raises an exception if there is an invalid one.

DESCRIPTION

Compute the complement of the input automaton by a specified complementation algorithm.

COMMON ARGUMENTS

A consequence of this is that a complementation construction option may not be called -m, -o, -s, or -t, because then it would not be "unknown" and thus not regarded as a complementation construction option.

-m Choose the complementation algorithm. Below is a list of available complementation algorithms:

A maybe better way to handle complementation construction options would be to require that they all follow -m ALGORITHM, e.g. -m fribourg -r2c -m1 -r -rr. But then we need a way to indicate that the options are over. There are two possible ways for this:
1) A special token, e.g. —: complement -m fribourg -r2c -m1 -r — -o out.gff in.gff
All the arguments between fribourg and — are complementation construction options
2) Require -m ALGORITHM to be the last option: complement -o out.gff -m fribourg -r2c -m1 -r in.gff
All the arguments between fribourg and the very last arg, which is always the automaton, are compl. constr. options.

Both ways allow that complementation construction options to be called -m, -o, -s, or -t. However, of course they may be cumbersome for the user. It's easy to forget the — or to make -m not the last option.

- classic
- deterministic
- kurshan
- modifiedsafra
- ms
- piterman
- ramsey
- rank
- safra
- slice
- waa
- wapa

Default complementation algorithms for automaton types:

- NFW: classic
- NBW: piterman

-o Output to a designated file. By default, the result will show on the screen.

-s Stop the complementation algorithm at a given stage and output the intermediate result. If the stage is 0, the complementation algorthm will be performed completely. Kurshan's construction does not have middle stage.

-t Give the timeout (second). By default, the timeout is 0, i.e., no timeout.

ARGUMENTS FOR modifiedsafra

-atl Apply the heuristic of simplifying accepting true loops. By default, this option is off.

-sa Apply the heuristic of marking nodes that have only accepting successors green. By default, this option is off.

ARGUMENTS FOR piterman

-ht Use Schewe's history trees instead of compact Safra trees. By default, this option is off.

-eq Apply local optimization of merging equivalent states during the. conversion from an NBW to an equivalent NBW. By default, this option is off.

-macc Maximize the accepting set of the target automaton. By default, this option is off.

-sim Simplify the complement NPW by simulation relations. By default, this option is off.

-sp Simplify the parity condition based on the computation of Rabin index. By default, this option is off.

-ro Reduce transitions in the conversion from NPW to NBW based on the idea in the slice-based construction. By default, this option is off.

-r Remove unreachable and dead states from the complement. By default, this option is off.

ARGUMENTS FOR ramsey

-macc Maximize the accepting set of the target automaton. By default, this option is off.

-min Minimize the intermediate DFW. By default, this option is off

-r Remove unreachable and dead states from the complement. By default, this option is off.

ARGUMENTS FOR rank

-r Remove unreachable and dead states from the resulting automaton. By default, this option is off.

-tr Apply tight rank construction. By default, this option is off.

-cp Apply turn wise cut-point construction. By default, this option is off.

-ro Apply the option of reducing outdegree. This implies tight rank. By default, this option is off.

-macc Maximize the accepting set of the target automaton. By default, this option is off.

ARGUMENTS FOR safra

-ht Use Schewe's history trees instead of compact Safra trees. By default, this option is off.

-atl Apply the heuristic of simplifying accepting true loops. By default, this option is off.

- -sa Apply the heuristic of marking nodes that have only accepting successors green. By default, this option is off.

ARGUMENTS FOR slice

- -p Use the preliminary version.
- -r Remove unreachable and dead states from the resulting automaton. By default, this option is off.
- -cp Apply turn wise cut-point construction. By default, this option is off.
- -ro Apply the option of reducing outdegree. By default, this option is off.
- -macc Maximize the accepting set of the target automaton. By default, this option is off.
- -tt Make the transition relation of the input automaton total. By default, this option is off.
- -bfs Use breadth-first search when expanding the complement automaton. By default, depth-first search will be used.
- -madj Merge adjacent 0-sets or *-sets. By default, this option is off.
- -eg Apply the enhanced guessing. By default, this option is off.

EXAMPLE

```
complement -m classic -o b.gff a.gff
complement -m deterministic a.gff
```

- concatenation -

NAME

concatenation - Concatenate an NFW and an ω-automaton or objects as a string.

SYNOPSIS

concatenation [-o FILE_OR_LVAL] FILE_OR_LVAL FILE_OR_LVAL

concatenation [-g EXPR] LVAL

DESCRIPTION

Concatenate an NFW and an ω-automaton such that the result accepts the concatenation of the language of the NFW and the language of the omega automaton. This command can also be used to concatenate the string representations of objects.

- -o Output to a designated file. By default, the result will show on the screen.
- -g The glue between each string representation of the objects.

EXAMPLE

```
concatenation -o c.gff a.gff b.gff
concatenation -g ", " $objs
```

- containment -

NAME

containment - Check whether an automaton is contained in another.

SYNOPSIS

containment [-m CONTAINMENT_ALG] [-macc | -pre | -sim | -rand] FILE_OR_LVAL FILE_OR_LVAL

DESCRIPTION

Check whether the first input automaton is contained in the second one. Return "(true, null)" if it is the case, and "(false, CE)" otherwise where CE is a counterexample.

-m	Specify the algorithm used for checking containment. The value can be naive, ms, safra, modifiedsafra, piterman, slice. By default, naive is be used.
-macc	Maximize the acceptance sets of the input automata. This option applies to ms, safra, modifiedsafra, piterman, and slice. By default, this option is off.
-pre	Simplify the input automata by simulation relations. This option applies to ms, safra, modifiedsafra, piterman, and slice. By default, this option is off.
-sim	Utilize the simulation relation between the input automata. This option applies to safra, modifiedsafra, ms, piterman, and slice. By default, this option is off.
-rand	Apply random search. This option applies to ms, safra, modifiedsafra, piterman, and slice. By default, this option is off.

EXAMPLE

```
containment a.gff b.gff
containment -m piterman a.gff b.gff
```

- convert -

NAME

convert - Convert an automaton into another type of automaton, a regular expression, an ω-regular expression, or a game, or convert a game into a game of another type.

SYNOPSIS

convert [-t AUTOMATON_TYPE | -o FILE_OR_LVAL] FILE_OR_LVAL

convert [-t GAME_TYPE | -o FILE_OR_LVAL] FILE_OR_LVAL

convert [-t ALPHABET_TYPE | -o FILE_OR_LVAL] FILE_OR_LVAL

convert -t game -p FILE_OR_LVAL [-o FILE_OR_LVAL] FILE_OR_LVAL

DESCRIPTION

Convert an automaton into another type of automaton, a regular expression, or an ω-regular expression, or convert a game into another type of game.

-t Specify the target type of the automaton or game to be converted.

-o Write the result to the specified file.

-p Specify the propositions controlled by Player P0. The expacted value of this argument is a string of comma-separated propositions.

EXAMPLE

```
convert -t nbw -o output.gff input.gff
convert -t re nfw.gff
convert -t ore nbw.gff
convert -t npg game.gff
convert -t game -p "ack1,ack2" dpw.gff
```

- deterministic -

NAME

deterministic - Test if an automaton is syntactically deterministic or semantically deterministic. By default, syntactic determinism is tested.

SYNOPSIS

deterministic [-t EXPR] FILE_OR_LVAL

DESCRIPTION

By default, return "true" if the input automaton is syntactically deterministic, or "false" otherwise. If "-t semantics" is specified, return "true" if the input automaton is semantically deterministic.

-t The argument can be either "syntax" or "semantics" which specify whether syntactic determinism or semantic determinism is tested.

EXAMPLE

```
deterministic abc.gff
```

- determinization -

NAME

determinization - Determinize a nondeterministic automaton to an equivalent deterministic automaton.

SYNOPSIS

determinization [-m DETERMINIZATION_ALG | -o FILE_OR_LVAL] FILE_OR_LVAL

DESCRIPTION

Compute the determinization of the input automaton. The type of the resulting automaton depends on the algorithm you choose. When the algorithm is landweber or bk09, the returned automaton may be null if the input automaton is not DBW-recognizable.

-m	Choose the determinization algorithm. Below is a list of available parameters and their corresponding determinization algorithms: • classic: determinizing a classic automaton to a deterministic classic automaton. • safra: Safra's Construction for determinizing NBW to DRW. • modifiedsafra: Modified Safra's Construction for determinizing NBW to DRW. • ms: Muller-Schupp Construction for determinizing NBW to DRW. • piterman: Safra-Piterman Construction for determinizing NBW to DPW. • landweber: Landweber's Construction for determinizing DMW to DBW. • bk09: The construction through DCW in [BK09]. By default, classic will be used for classic automaton and Safra's construction will be used for Büchi automaton.
-o	Output to a designated file. By default, the result will show on the screen.
-ht	Use Schewe's history trees. This option is available for Safra's construction and Safra-Piterman construction. Some optimizations for Safra's construction may not be implemented for history trees. By default, this option is off.
-atl	Apply the heuristic of simplifying accepting true loops. This options applies to the Safra's construction and the modified Safra's construction. By default, this options is off.

EXAMPLE

```
determinization -m classic -o b.gff a.gff
determinization -m safra -o b.gff a.gff
```

- echo -

NAME

echo - Output objects on the screen.

SYNOPSIS

echo [-n | -spin | -unicode] [EXPR ...]

DESCRIPTION

Output an expression on the screen.

-n	Do not output the trailing newline.
-spin	Output a formula in SPIN format.
-unicode	Output a formula in unicode.

EXAMPLE

```
echo "Hello World!"
```

- emptiness -

NAME

emptiness - Check emptiness of an automaton.

SYNOPSIS

emptiness FILE_OR_LVAL

DESCRIPTION

Return "true" if the input automaton is empty, and "false" otherwise.

EXAMPLE

```
emptiness abc.gff
```

- equivalence -

NAME

equivalence - Check whether two automata accept the same language.

SYNOPSIS

equivalence FILE_OR_LVAL FILE_OR_LVAL

DESCRIPTION

Check whether the first input automaton and the second one accept the same language. Return "true" if it is the case, and "false" otherwise.

EXAMPLE

```
equivalence a.gff b.gff
```

- generate -

NAME

generate - Generate a finite state automaton, QPTL formulae, an integer, or a floating point number randomly.

SYNOPSIS

generate -t fsa [-a EXPR | -A EXPR | -m EXPR | -s EXPR | -n EXPR | -pt EXPR | -ps EXPR | -pa EXPR | -dt EXPR | -da EXPR | -r | -S]

generate -t game [-a EXPR | -A EXPR | -m EXPR | -s EXPR | -n EXPR | -pt EXPR | -ps EXPR | -pa EXPR | -dt EXPR | -da EXPR | -pr | -r | -S]

generate -t qptl [-l EXPR | -n EXPR | -r | -of | -mcp | -w EXPR EXPR EXPR | -plain | -spin] EXPR

generate -t int EXPR [EXPR]

generate -t float EXPR [EXPR]

DESCRIPTION

Randomly generate a finite state automaton, QPTL formulae, an integer, or a floating point number.

When generating random integers or random floating point numbers, the range of the random numbers must be specified as (1) a minimal number (inclusive) and a maximal number (exclusive), or (2) a maximal number (exclusive), in which case the minimal number will be 0 (inclusive).

-a	Specify the type of the structure. The type can be nfw, nrew, nbw, ncw, ngbw, nmw, nrw, nsw, npw, ntbw, ntgbw, ntmw, ntrw, ntsw, ntpw, dfw, drew, dbw, dcw, dgbw, dmw, drw, dsw, dpw, dtbw, dtgbw, dtmw, dtrw, dtsw, or dtpw for finite state automata. The type can be nfg, nreg, nbg, ncg, ngbg, nmg, nrg, nsg, npg, dfg, dreg, dbg, dcg, dgbg, dmg, drg, dsg, or dpg for games. The default automaton type is nbw while the default game type is nbg.
-A	Specify the alphabet type. The type can be propositional or classical. The default type is propositional alphabet.
-m	Specify the generation model of transitions and acceptance condition. The model can be probability or density. The default model is probability.
-s	Specify the desired number of states in the generated omega automaton. The default value is 5.
-n	Specify the number of atomic propositions. The default value is 2 (atomic propositions). In random formulae generation, each atomic proposition will occur at least once in each formula.
-pt	Specify the probability of whether there should be transitions from one state to another state. The value of the probability should be in the range from 0 to 1. By default, the probability is decided randomly every time.
-ps	Specify the probability of labeling a symbol on a transition. Assume there n states, the alphabet size is m, the probability specified by -pt is p1, and the probability specified by -ps is p2. The expected number of transitions is (n * n * p1) * (m * p2).
-pa	Specify the probability of adding a state to an acceptance set.
-dt	Specify the transition density. The default value is 0.
-da	Specify the acceptance density. The default value is 0.
-pr	Specify the ratio of (player 0 states / player 1 states).
-r	In random automata generation, this means to count the number of states after removing unreachable and dead states. Note that if this option is on, it will take longer to generate an automaton. In random formulae generation, this means to allow repeated formulae generated. By default, GOAL does not generate the same formula twice.
-S	Count the number of states after applying simulation simplification. Note that if this option is on, it will take longer to generate an automaton.
-l	Specify the length of the generated formulae.
-w	Specify the weights of operators which determine the probability of choosing which operator. The following three values are weight of boolean commands, weight of future operators, and weight of past operators. For example, the posibility of choosing a boolean operator is (WEIGHT_BOOLEAN/(WEIGHT_BOOLEAN+WEIGHT_FUTURE+WEIGHT_PAST)). At least one of them must have a positive weight. None of them can have a negative weight.
-of	The outmost operator of every generated formula is a future operator.
-mcp	Every generated formula must contain at least one past operator if the weight of past operators is greater than 1.
-plain	Output formulae in plain text instead of GFF.
-spin	Output formulae that can be accepted by SPIN.

EXAMPLE

```
generate -t fsa -a nbw -s 10 -n 3
generate -t fsa -a npw -s 5 -n 2 -as 4
generate -t qptl -w 1 2 0 -n 2 -l 8 10
generate -t int 0 10
```

- homomorphism -

NAME

homomorphism - Check if the first automaton is homomorphic to the second automaton.

SYNOPSIS

homomorphism FILE_OR_LVAL FILE_OR_LVAL

DESCRIPTION

Check if the first automaton is homomorphic to the second automaton. Return a homomorphism if it is the case, and "false" otherwise.

EXAMPLE

```
homomorphism a.gff b.gff
```

- Import -

NAME

import - Import objects from a string.

SYNOPSIS

import [-c EXPR] LVAL STRING_OR_LVAL

DESCRIPTION

Import objects from a string.

-c A codec used to decode the specified string.

EXAMPLE

```
import -c BA a.gff "[0]\nb,[0]->[1]\na,[1]->[1]\n[1]"
```

- input -

NAME

input - Check if a word is accepted by an automaton.

SYNOPSIS

input FILE_OR_LVAL STRING_OR_LVAL

DESCRIPTION

Check if a word is accepted by an automaton. Return "true" if the word is accepted, and "false" otherwise.

EXAMPLE

```
input a.gff "(p ~q)(p q){ (~p ~q) }"
input a.gff "(a)(b){ (a)(b)(a) }"
```

- intersection -

NAME

intersection - Compute the intersection of the two input automata.

SYNOPSIS

intersection [-o FILE_OR_LVAL] FILE_OR_LVAL FILE_OR_LVAL

DESCRIPTION

Compute the intersection (synchronous product) of the two input automata and output the resulting automaton.

-o Output to a designated file. By default, the result will show on the screen.

EXAMPLE

```
intersection -o c.gff a.gff b.gff
```

- isomorphism -

NAME

isomorphism - Check if two automaton are isomorphic.

SYNOPSIS

isomorphism FILE_OR_LVAL FILE_OR_LVAL

DESCRIPTION

Check if two automata are isomorphic. Return an isomorphism if it is the case, and "false" otherwise.

EXAMPLE

```
isomorphism a.gff b.gff
```

- layout -

NAME

layout - Layout an automaton or the active automaton in a GOAL window.

SYNOPSIS

layout [-m EXPR] FILE_OR_LVAL

DESCRIPTION

Specify a window ID to lay out the active automaton in the window or specify an automaton to lay out it offscreen.

-m	Specify the layout algorithm. Use the command "names layout" to see all available layout algorithms.

EXAMPLE

```
layout 1
  layout -m "Circle Layout" aut.gff
```

- load -

NAME

load - Load a file into a variable. If the file contains multiple objects, the variable will be a list.

SYNOPSIS

load [-c EXPR] [LVAL] FILE_OR_LVAL

DESCRIPTION

Load a file into a variable.

-c	Specify the codec used to decode the object. By default, the first applicable codec will be used. Use the command "names codec" to see al available codecs.

EXAMPLE

```
load $omega input.gff
$x = load input.gff
```

- minimization -

NAME

minimization - Compute the minimization of the input classic automaton.

SYNOPSIS

minimization [-o FILE_OR_LVAL] FILE_OR_LVAL

DESCRIPTION

Compute the minimization of the input classic automaton.

-o	Output to a designated file. By default, the result will show on the screen.

EXAMPLE

```
minimization -o b.gff a.gff
```

- names -

NAME

names - Print names of some extensions.

SYNOPSIS

names EXPR

DESCRIPTION

Print names of some extensions and types. The argument can be "alphabet", "automaton", "codec", "command", "complement", "game", "layout", "player", "simulation", "simulation2", "solver", or "translate".

EXAMPLE

```
names codec
```

- omega -

NAME

omega - Performing the ω operation on an NFW.

SYNOPSIS

omega FILE_OR_LVAL

DESCRIPTION

Given an NFW, create an NBW such that a word is accepted by the NBW iff the word can be partitioned into segments and every word segment is accepted by the NFW.

EXAMPLE

```
omega abc.gff
```

- open -

NAME

open - Open a file as an editable object in a GOAL window.

SYNOPSIS

open [-w ID] FILE_OR_LVAL

DESCRIPTION

Open a file as an editable object in a GOAL window. The return value is the index of the GOAL window.

-w Specified the GOAL window for the opened editable object.

EXAMPLE

```
open input.gff
```

- parity -

NAME

parity - Operations on parity conditions.

SYNOPSIS

parity convert EXPR EXPR FILE_OR_LVAL

parity compress FILE_OR_LVAL

parity propagate FILE_OR_LVAL

DESCRIPTION

Convert the interpretation of parity conditions, compress parity conditions, or propagate parities of states in a parity condition. For the conversion of parity interpretations, the first argument is the source parity interpretation, the second argument is the target parity interpretation, and the third argument is a parity automaton (or a parity game).

EXAMPLE

```
parity convert min-even max-even aut.gff
parity compress aut.gff
```

- preference -

NAME

preference - Return user preferences or adjust user preferences at runtime.

SYNOPSIS

preference [EXPR [EXPR]]

DESCRIPTION

Return user preferences or adjust user preferences at runtime. The first argument is the name of the preference. The second argument is the new value of the preference. If the second argument is absent, the current value of the user preference with the specified name will be returned. If both arguments are absent, all user preferences and their values will be returned.

EXAMPLE

```
preference ComplementAlgorithm
preference LayoutAlgorithm org.svvrl.goal.core.layout.KKLayout
```

- product -

NAME

product - Take the product of the two finite state automata or a game and a finite state automaton.

SYNOPSIS

product [-o FILE_OR_LVAL | -m EXPR | -a] FILE_OR_LVAL FILE_OR_LVAL

DESCRIPTION

Take the product of two finite state automata or a game and a finite state automaton. The inputs must have the same type of alphabet and have labels on transitions. The structure of the product will be the same as that of the first automaton (or game). The acceptance condition of the product only depends on the second automaton.

-o	Output to a designated file. By default, the result will show on the screen.
-a	Take an asynchronous product. If this option is absent, this command will take a synchronous product.
-m	Specify a map from the propositions of the second automaton to predicates on the propositions of the first automaton (or game).

EXAMPLE

```
product -o c.gff a.gff b.gff
product -m "a: p/\\q, b: q\\/r" a.gff b.gff
```

- promela -

NAME

promela - Convert a Büchi automaton into Promela code.

SYNOPSIS

promela [-o FILE_OR_LVAL] FILE_OR_LVAL

DESCRIPTION

Convert a Büchi automaton into Promela code.

-o Output the Promela code to a file. By default, the Promela code will be displayed on the screen.

EXAMPLE

promela -o output input.gff

- property -

NAME

property - Get or set properties of an editable object such as automata.

SYNOPSIS

property FILE_OR_LVAL [EXPR [EXPR]]

DESCRIPTION

Get or set properties of an editable object. The first argument is the object. The second argument is the name of the property. The third argument is the new value of the property. If the third argument is absent, the current value of the property with the specified name will be returned. If both optional arguments are absent, all properties and their values will be returned.

EXAMPLE

```
property $aut Formula
property $aut Description
```

- qptl -

NAME

qptl - Manipulate QPTL formulae.

SYNOPSIS

qptl [-f | -l | -p | -r EXPR EXPR] FORMULA

DESCRIPTION

Manipulate QPTL formulae.

- -f Get the free variables in a QPTL formula.
- -l Get the length of a QPTL formula.
- -p Check if a QPTL formula contains any past operator.
- -r Rename a free variable in a QPTL formula. The first argument is an existing proposition and the second argument is a replacement of the existing proposition.

EXAMPLE

```
qptl -l "[] p"
```

- readline -

NAME

readline - Read the input file line by line and put the results in a list.

SYNOPSIS

readline FILE_OR_LVAL

DESCRIPTION

Read the input file line by line and put the results in a list.

EXAMPLE

```
readline input.gff
```

- reduce -

NAME

reduce - Remove unreachable and dead states from an automaton.

SYNOPSIS

reduce [-o FILE_OR_LVAL | -u | -d] FILE_OR_LVAL

DESCRIPTION

Given an automaton, remove the unreachable and dead states (if -u and -d are both present or both absent).

-o Output to a designated file. By default, the result will show on the screen.

-u Reduce only unreachable states.

-d Reduce only dead states.

EXAMPLE

```
reduce -o b.gff a.gff
```

- replace -

NAME

replace - Replace matched substrings.

SYNOPSIS

replace EXPR EXPR EXPR

DESCRIPTION

Replace matched substrings. An automaton that recognizes the replacement results will be returned. The first argument is the source automaton (or regular expression), the second argument is the pattern automaton (or regular expression), and the third argument is the replacement automaton (or regular expression). If a string in the language of the source automaton contains substrings recognized by the pattern automaton, the matched substrings will be replaced by the strings recognized by the replacement automaton.

EXAMPLE

```
replace m1.gff m2.gff m3.gff
replace m1.gff "a+" "c"
```

- repository -

NAME

repository - Access the local and remote repositories.

SYNOPSIS

repository [-t EXPR | -min | -f EXPR] ("local" | "remote")

DESCRIPTION

Access the automata or the formulae in the local repository or in the remote repository.

-t Specify the return type, either "automaton" or "formula". By default, pairs of a formula and an automaton will be returned.

-min Only return the smallest automata.

-f Search for a formula.

EXAMPLE

```
repository -t automaton local
repository -t formula remote
```

- reverse -

NAME

reverse - Reverse a classic finite state automaton.

SYNOPSIS

reverse [-o FILE_OR_LVAL] FILE_OR_LVAL

DESCRIPTION

Reverse a classic finite state automaton such that the output accepts the reverse of the language of the input.

-o Output to a designated file. By default, the result will show on the screen.

EXAMPLE

```
reverse -o b.gff a.gff
```

- satisfiability -

NAME

satisfiability - Check whether a formula is satisfiable.

SYNOPSIS

satisfiability FORMULA_OR_LVAL

DESCRIPTION

Check whether the input formula is satisfiable. Return "true" if it is the case, and "false" otherwise.

EXAMPLE

```
satisfiability "(p U q) U ~q"
```

- save -

NAME

save - Save an object to a file.

SYNOPSIS

save [-c EXPR] LVAL FILE_OR_LVAL

DESCRIPTION

Save an object to a file.

-c Specify the codec used to encode the object. By default, the GFF codec will be used.

EXAMPLE

```
save $omega output.gff
```

- separation -

NAME

separation - Separate the past operators and the future operators in a QPTL formula.

SYNOPSIS

separation FORMULA

DESCRIPTION

Separate the past operators and the future operators in a QPTL formula. The formula is required to be convertible to prenex normal form.

-e Perform an equivalent rewrite such that the result is equivalent to the input formula. By default, a congruent rewrite is performed.

-plain Output formulae in plain text instead of GFF.

-spin Output formulae that can be accepted by SPIN.

EXAMPLE

```
separation "[] (p --> <-> q)"
```

- seq -

NAME

seq - Generate a sequence of numbers.

SYNOPSIS

seq LAST

seq FIRST LAST

seq FIRST INCREMENT LAST

DESCRIPTION

Generate a sequence of numbers. The LAST, FIRST, and INCREMENT in SYNOPSIS are all expressions.

EXAMPLE

```
$numbers = seq 1 10
```

- simequiv -

NAME

simequiv - Check whether two automata are simulation equivalent.

SYNOPSIS

simequiv EXPR EXPR

DESCRIPTION

Check whether the two automata are simulation equivalent. Return "true" if it is the case, and "false" otherwise.

EXAMPLE

```
simequiv a.gff b.gff
```

- simplify -

NAME

simplify - Simplify an automaton or a formula.

SYNOPSIS

simplify [-m EXPR | -o FILE_OR_LVAL | OPTIONS] FILE_OR_LVAL

Options for simulation: -dse | -ds | -rse | -rs | -ru | -rd

Options for pruningfairset: -ifs | -rfs | -lfs | -t4 | -t5 | -t6 | -t7 | -t8 | -t9

DESCRIPTION

Simplify the input automaton and return the resulting equivalent automaton of the same type, or simplify the input logic formula.

-m Specify the algorithm used for simplification. The value can be simulation, delayed, fair, pruningfairset, wring, or rabinindex. By default, simulation will be used.

-o Output to a designated file. By default, the result will show on the screen.

-dse	Enable simplification by direct simulation equivalence.
-ds	Enable simplification by direct simulation.
-rse	Enable simplification by reverse simulation equivalence.
-rs	Enable simplification by reverse simulation.
-ru	Enable reducing unreachable states.
-rd	Enable reducing dead states.
-ifs	Enable pruning states not in the final set.
-rfs	Enable pruning states not reaching the final set.
-lfs	Enable pruning fair sets that contains another fair set of the final set.
-t4	Enable pruning fair sets by Theoram 4.
-t5	Enable pruning fair sets by Theoram 5.
-t6	Enable pruning fair sets by Theoram 6.
-t7	Enable pruning fair sets by Theoram 7.
-t8	Enable pruning fair sets by Theoram 8.
-t9	Enable pruning fair sets by Theoram 9.

EXAMPLE

```
simplify -o b.gff a.gff
simplify "[] [] p"
```

- simulated -

NAME

simulated - Check whether the first automaton can be simulated by the second automaton.

SYNOPSIS

simulated [-m EXPR] EXPR EXPR

simulated -d EXPR EXPR

simulated -f EXPR EXPR

DESCRIPTION

Check whether the first automata can be simulated by the second automaton. Return "true" if it is the case, and "false" otherwise.

-m	Specify the name of the simulation computation procedure. If this argument is absent, the default simulation procedure will be used. Use the command "names simulation2" to see all available procedures.
-d	Use delayed simulation relation. If this argument is present, then both the automata should be Büchi automata.

-f Use fair simulation relation. If this argument is present, then both the automata should be Büchi automata.

EXAMPLE

```
simulated a.gff b.gff
```

- sleep -

NAME

sleep - Delay for a specified amount of time in seconds.

SYNOPSIS

sleep EXPR

DESCRIPTION

Delay for a specified amount of time in seconds.

EXAMPLE

```
reduce -o b.gff a.gff
```

- solve -

NAME

solve - Solve a game and return a solution. The input game will be annotated with winning regions and winning strategies.

SYNOPSIS

solve [-m SOLVER] [-g | -r | -s | -p PLAYER] [SOLVER_SPECIFIC_ARGIMENTS] FILE_OR_LVAL

DESCRIPTION

Solve a game and return a map m where m["Game"] is a colored, annotated game and m[PLAYER_NAME] is the winning region and the winning strategy for the game player of the name PLAYER_NAME. The winning region and the winning strategy of a game player is also represented by a map w where w["WinningRegion"] is the winning region and w["WinningStrategy"] is the winning strategy. The name of the game player can be: P0, P1. If -g, -r, or -s is provided, only parts of the results will be returned.

-m Specify the name of the game solver. Available game solvers:

- bigstep: an algorithm due to Schewe for parity games
- cb: a classical algorithm for Buchi games
- dominiondec: a deterministic subexponential algorithm based on dominion decomposition for parity games
- globalopt: a generic solver with solver-independent global optimizations for parity games
- mz: a recursive algorithm due to McNaughton-Zielonka for parity games
- reachability: an algorithm for reachability games
- recursive: a recursive algorithm due to Zielonka for parity games
- smallprog: an algorithm based on small progress measure for parity games

-g Return only the solved game.

-r Return only the winning regions.

-s Return only the winning strategies.

-p Return the winning region or the winning strategy only for the specified player. This option should be used with -r or -s.

SOLVER globalopt

-solver Specify the delegated game solver.

-pp Propagate parities of states. The default is off.

-pc Compress parity conditions. The default is off.

-ps Preprocess states with self-loops. The default is off.

-sd Decompose the game into strongly-connected components. The default is off.

SOLVER reachability

-max Maximize the strategies for both players. Disabled by default.

EXAMPLE

```
solve game.gff
solve -m mz game.gff
```

- split -

NAME

split - Split an object into a set of elements.

SYNOPSIS

split [-d STRING_OR_LVAL] [EXPR | CMD_EXPR]

DESCRIPTION

If the object is a list, this command will return a set of list elements. If the object is an array, this command will return the key set of the array. Otherwise, this command will convert the object into a string and split the string according the delimiter. The default delimiter is spaces, tabs, and newlines.

-d Specify the delimiter.

EXAMPLE

```
$keys = split $arr
$elements = split -d ":" "1:2:3"
```

- stat -

NAME

stat - Get statistical data of an automaton or a QPTL formula.

SYNOPSIS

stat [-s | -t | -a] FILE_OR_LVAL

DESCRIPTION

Get statistical data of an automaton or a QPTL formula. For automata, the statistical data include the number of states, the number of transitions, and the number of acceptance sets. For QPTL formulae, the statistical data include the number of alternations of past and future temporal operators.

-s Get the number of states only.

-t Get the number of transitions only.

-a Get the number of acceptance sets (or states) only.

EXAMPLE

```
stat -s a.gff
stat -t a.gff
stat a.gff
stat "[](p --> <-> q)"
```

- test -

NAME

test - Perform internal tests.

SYNOPSIS

test ???

DESCRIPTION

This command is for internal usage.

- translate -

NAME

translate - Translate a logic formula into an automaton.

SYNOPSIS

translate [RE | ORE | QPTL | ACTL] [-m TRANSLATE_ALG | -o FILE_OR_LVAL | -t AUTOMATON_TYPE | -sa | -se | -sf | -sg | -sb | -stgb | -sp | -si | -sr | -rbm | -dt | -mp | -art | -pi | -pe] FORMULA_OR_LVAL

DESCRIPTION

Translate a logic formula into an automaton. By default, this command translates a QPTL formula into a non-deterministic Büchi word automaton. RE stands for regular expressions while ORE stands for ω-regular expressions. The translation for an ACTL formula produces a fair Kripke structure interpreted as a label-on-state automaton base on [PMT02].

-m	Choose the translation algorithm (tableau, inctableau, temporaltester, gpvw, gpvw+, ltl2aut, ltl2aut+, ltl2ba, pltl2ba, couvreur, ltl2buchi, modella, kp02, ccj09, or qptl2ba). This option applies to QPTL translation only. By default, the tableau algorithm will be used.
-o	Output to a designated file. By default, the result will show on the screen.
-t	Choose the type of the target automaton (ngbw or nbw). This option applies to QPTL translation only. By default, it will be a non-deterministic Büchi word automaton (NBW).
-se	Simplify the input (ω-)regular expression. By default, this option is off.
-sa	Simplify the intermediate automata during the translation of ω-regular expressions. By default, this option is off.
-sf	Simplify the input QPTL formula before translation. By default, this option is off.
-sg	Simplify the intermediate NGBW during the translation. By default, this option is off
-sb	Simplify the NBW during the translation. By default, this option is off.
-stgb	Simplify the NTGBW by simulation. By default, this option is off.
-sp	Simplify the NBW after projecting quantifiers. By default, this option is off.
-si	Simplify intermediate NBW during translation. By default, this option is off.
-sr	Apply superset reduction to the generalized Büchi acceptance condition. By default, this option is off.
-rbm	Reduce dead states before merging equivalent NBW states if the algorithm is LTL2BA. By default, this option is off.
-dt	Delegate the translation of unquantified formulae to another translation algorithm. By default, this option is off.
-mp	Minimize the automata of past formulae for QPTL2BA. By default, this option is off.
-art	Apply advanced reduction of NTGBW transitions during the conversion from two-way VWAA for PLTL2BA. By default, this option is off.
-pi	Apply prime implicants to simplify covers for LTL2AUT+. By default, this option is off.
-pe	Apply postponed expansion of refined states for GPVW, LTL2AUT, LTL2AUT+, MoDeLLa, LTL2Buchi, and Couvreur. By default, this option is off.
-ru	Reduce unreachable states of label-on-state NGBW obtained by Tableau. By default, this option is off.

-rd Reduce dead states of label-on-state NGBW obtained by Tableau. By default, this option is off.

EXAMPLE

```
translate -m gpvw -t nbw -o Fp.gff "<>p"
translate ORE "(a|b)* { b }"
```

- union -

NAME

union - Compute the union of the two input automata.

SYNOPSIS

union [-o FILE_OR_LVAL] FILE_OR_LVAL FILE_OR_LVAL

DESCRIPTION

Compute the union of the two input automata and output the resulting automaton.

-o Output to a designated file. By default, the result will show on the screen.

EXAMPLE

```
union -o c.gff a.gff b.gff
```

- validity -

NAME

validity - Check whether a formula is valid.

SYNOPSIS

validity FORMULA_OR_LVAL

DESCRIPTION

Check whether the input formula is valid. Return "true" if it is the case, and "false" otherwise.

EXAMPLE

```
validity "[](p U q) U q <--> p U q"
```

E X T E N D

GOAL uses Java Plugin Framework (JPF) to export extension points and thus several GOAL functions can be extended. This document does not provide a tutorial on writing plugins and extensions. For the readers that are interested in extending GOAL, they are encouraged to visit the JPF website.

GOAL Libraries

When the user wants to extend GOAL, the development environment should include GOAL classes as libraries. To do this, the user may use the script *mklib* or *mklib.bat* to build GOAL libraries. The created GOAL libraries will be placed in the *lib* directory.

Codecs

The codecs can be extended by implementing the interface Codec. A codec is an encoder, a decoder, or both. An encoder is capable of encoding a QPTL formula, a finite state automaton, an alternating automaton, a game, or other kinds of objects to a file. A decoder is capable of decoding a file back to an object supported by GOAL.

Extension Point Declaration

```
<extension-point id="Codec">
  <parameter-def id="class" />
  <parameter-def id="priority" type="number" />
</extension-point>
```

class

: The class implementing `Codec`.

priority

: When there are more than one codecs supporting an object, the codec with a highest priority (lower number) will be used if not specified.

Command-Line Commands

The command-line commands can be extended by extending CommandExpression or implementing the interface CommandExtension. Basically, an object of CommandExpression represents an invocation of the provided command (together with the arguments for the command), that is, roughly the cmd_expr in Grammar. More precisely, a cmd_expr corresponds to an object of CommandExecutor, which is used as a wrapper of a command. When an object of CommandExecutor is evaluated, it evaluates the runtime arguments specified by --option, instantiates the underlying command with all the arguments, and then evaluates the underlying command.

An object of CommandExtension provides meta-information (command name, full name, and help message) about the provided command. Since static meta-information can be written in plugin.xml, CommandExtension is used mainly when the meta-information contains dynamic contents that are known at runtime.

The class extending CommandExpression must have a constructor taking a list of Expression as the only argument, and implement the function eval.

An implement of CommandExtension must have a constructor taking no parameter and should provide the class of the provided command, the unique command name, the full name, and the help message either in the class itself or in plugin.xml.

Extension Point Declaration

```
<extension-point id="CommandExpression">
  <parameter-def id="class" />
  <parameter-def id="name" />
  <parameter-def id="full name" multiplicity="none-or-one" />
```

```
  <parameter-def id="help" />
</extension-point>
```

class

: The class extending CommandExpression.

name

: The unique command name.

full name

: The full name to be displayed as the title of the provided command in help messages.

help

: The help message of the provided command.

```
<extension-point id="CommandExtension">
  <parameter-def id="class" />
  <parameter-def id="name" />
  <parameter-def id="full name" multiplicity="none-or-one" />
  <parameter-def id="help" multiplicity="none-or-one" />
</extension-point>
```

class

: The class implementing CommandExtension.

name

: The unique command name.

full name

: The full name to be displayed as the title of the provided command in help messages.

help

: The help message of the provided command.

Constructions Supported by Complement Command

See here for more details.

Solvers Supported by Solve Command

See here for more details.

Complement Construction

The complementation constructions for containment and equivalence testing can be extended by extending ComplementConstruction. The implementation must have a constructor taking a single parameter that extends Automaton. The complementation constructions extended can be found in ComplementRepository.

The complementation constructions available for the complement command can be extended by adding a ComplementConstructionInterface object to CommandRepository via CommandRepository.addComplementConstructionInterface(ComplementConstructionInterface). If the interface object provides the default construction for a type of automata, it should be added by CommandRepository.addComplementConstructionInterface(ComplementConstructionInterface, AutomatonType). The interface object must provide a unique name for the provided construction, a help message, and the class of the provided construction either directly in the object or in plugin.xml. Note that some common arguments (see ComplementExpression) will be consumed before being passed to the interface object.

Extension Point Declaration

```
<extension-point id="ComplementConstruction">
  <parameter-def id="class" />
  <parameter-def id="name" />
</extension-point>
```

class

The class implementing ComplementConstruction.

name

The name of this complementation construction.

The extension point of complementation constructions for the complement command is described below.

```
<extension-point id="ComplementConstructionInterface">
  <parameter-def id="class" />
  <parameter-def id="default for" multiplicity="none-or-one" />
  <parameter-def id="name" multiplicity="none-or-one" />
  <parameter-def id="construction" multiplicity="none-or-one" />
  <parameter-def id="help" multiplicity="none-or-one" />
</extension-point>
```

class

The class implementing ComplementConstructionInterface.

default for

Set the provided construction the default for the specified type of automata.

name

The name of the provided complementation construction.

construction

The class path of the provided complementation construction.

help

The help message.

Console Handlers

Cost Functions

Drawers

Editable

Editors

Formula Rewriter

Game Solvers

The game solvers can be extended by implementing the interface GameSolver. The implementation must have a constructor taking no parameter. Once a game solver is plugged, it can be accessed by methods in GameSolverRepository or by the Solve menu item in the graphical user interface.

To make the solve command-line command support a game solver, a class implementing GameSolverInterface is required. A GameSolverInterface provides an interface between the command-line arguments and a game solver, and it can configure the game solver based on specified command-line arguments.

Extension Point Declaration

For the core package and the gui package,

```
<extension-point id="GameSolver">
  <parameter-def id="class" />
  <parameter-def id="acc" />
</extension-point>
```

class

The class implementing GameSolver.

acc

The class of the acceptance condition supported by the game solve.

For the command-line package,

```
<extension-point id="GameSolverInterface">
  <parameter-def id="class" />
  <parameter-def id="name" />
  <parameter-def id="solver" />
  <parameter-def id="description" />
  <parameter-def id="help" />
</extension-point>
```

class

The class implementing GameSolverInterface.

name

A unique name of the game solver. This name will be used in the solve command-line command

solver

The class implementing GameSolver.

description

A simple description about the provided solver. The description will be displayed in the help message of the solve command.

help

The help message of the provided solver.

Layout Algorithms

The layout algorithms can be extended by implementing the interface Layout. The implementation must have a constructor taking no parameter.

Extension Point Declaration

```
<extension-point id="Layout">
  <parameter-def id="class" />
  <parameter-def id="name" />
  <parameter-def id="mnemonic" multiplicity="none-or-one" />
  <parameter-def id="tooltip" multiplicity="none-or-one" />
</extension-point>
```

class
: The class implementing `Layout`.

name
: The name of this layout algorithm.

mnemonic
: The mnemonic of the menu item for this layout algorithm.

tooltip
: The tooltip text of the menu item for this layout algorithm.

Menu

The menu and menu items can be extended by extending UIMenu and WindowAction. The implementation must have a constructor taking a single Window parameter.

Extension Point Declaration

```
<extension-point id="Menu">
  <parameter-def id="class" />
  <parameter-def id="container" />
  <parameter-def id="location" />
  <parameter-def id="name" multiplicity="none-or-one" />
  <parameter-def id="mnemonic" multiplicity="none-or-one" />
  <parameter-def id="accelerator" multiplicity="none-or-one" />
  <parameter-def id="tooltip" multiplicity="none-or-one" />
  <parameter-def id="small_icon" multiplicity="none-or-one" />
  <parameter-def id="large_icon" multiplicity="none-or-one" />
  <parameter-def id="style" multiplicity="none-or-one" />
  <parameter-def id="group" multiplicity="none-or-one" />
  <parameter-def id="separator" type="boolean" multiplicity="none-or-one" />
</extension-point>
```

class
: The class implementing `UIMenu` or `WindowAction`. If this class does not exist, a default `UIMenu` object will be created.

container
: The container of this `UIMenu` or `WindowAction`, represented by the container's canonical class name. For example, a top menu in the menu bar is in the container org.svvrl.goal.gui.MenuBar.

location

The location of this UIMenu or WindowAction in its container. A location can be "first", "after=class", "before=class", or "last" where class is the canonical class name of its sibling.

name

The name of this UIMenu or WindowAction.

mnemonic

The mnemonic of this UIMenu or WindowAction.

accelerator

The accelerator of this UIMenu or WindowAction.

tooltip

The tooltip text of this UIMenu or WindowAction.

small_icon

The small icon of this UIMenu or WindowAction.

large_icon

The large icon of this UIMenu or WindowAction.

style

The visual style of this WindowAction. Possible values are "button", "check", and "radio" representing JMenuItem, JCheckBoxMenuItem, and JRadioButtonMenuItem respectively.

group

The button group of this WindowAction.

separator

True if there should be a separator before this UIMenu or WindowAction.

Preference Panels

Property Editors

Toolboxes

UI Handlers

T E R M I N

A

ACTL (∀CTL)

∀ Computational Tree Logic

B

BFS
    Breadth-First Search

D

DBW
    Deterministic Büchi Word Automaton

DCW
    Deterministic Co-Büchi Word Automaton

Dead State
    A state is *dead* if it does not occur in any accepting run.

DFS
    Depth-First Search

DFW (DFA)
    Deterministic Classic Finite Word Automaton

DGBW
    Deterministic Generalized Büchi Word Automaton

DMW
    Deterministic Muller Word Automaton

DPW
    Deterministic Parity Word Automaton

DRW
    Deterministic Rabin Word Automaton

DSW
    Deterministic Streett Word Automaton

L

LTL
    Linear Temporal Logic

N

NABW
    Nondeterministic Alternating Büchi Word Automaton

NACW
    Nondeterministic Alternating Co-Büchi Word Automaton

NAGBW
: Nondeterministic Alternating Generalized Büchi Word Automaton

NAMW
: Nondeterministic Alternating Muller Word Automaton

NAPW
: Nondeterministic Alternating Parity Word Automaton

NARW
: Nondeterministic Alternating Rabin Word Automaton

NASW
: Nondeterministic Alternating Streett Word Automaton

NBW
: Nondeterministic Büchi Word Automaton

NCW
: Nondeterministic Co-Büchi Word Automaton

NFW (NFA)
: Nondeterministic Classic Finite Word Automaton

NGBW
: Nondeterministic Generalized Büchi Word Automaton

NMW
: Nondeterministic Muller Word Automaton

NPW
: Nondeterministic Parity Word Automaton

NRW
: Nondeterministic Rabin Word Automaton

NSW
: Nondeterministic Streett Word Automaton

NTBW
: Nondeterministic Transition Büchi Word Automaton

NTCW
: Nondeterministic Transition Co-Büchi Word Automaton

NTGBW
: Nondeterministic Transition Generalized Büchi Word Automaton

NTMW
: Nondeterministic Transition Muller Word Automaton

NTPW
: Nondeterministic Transition Parity Word Automaton

NTRW

Nondeterministic Transition Rabin Word Automaton

NTSW

Nondeterministic Transition Streett Word Automaton

P

PTL

Propositional Temporal Logic

Q

QPTL

Quantified Propositional Temporal Logic, which subsumes LTL

U

UCBW

Universal Co-Büchi Word Automaton, NACW in CNF

Unreachable State

A state is *unreachable* if it cannot be reached from the initial state.

V

VWAA

Very Weak Alternating Automaton

R E F E R E

ATW06

Christoph Schulte Althoff, Wolfgang Thomas and Nico Wallmeier. Observations on determinization of Büchi automata. Theoretical Computer Science, 363(2):224-233, 2006.

BK09

Udi Boker and Orna Kupferman. Co-ing Büchi Made Tight and Useful. In Proceedings of the 24th Annual IEEE Symposium on Logic in Computer Science (LICS), pages 245-254. IEEE Computer Society, 2009.

Buc62

J. Richard Büchi. On a Decision Method in Restricted Second Order Arithmetic. In Congress on Logic, Method, and Philosophy of Science 1960. Logical Methods in Computer Science, 5(1), 2009.

CCJ09

Jacek Cichoń and Adam Czubak and Andrzej Jasiński. Minimal Büchi Automata for Certain Classes of LTL Formulas. In Proceedings of the Fourth International Conference on Dependability of Computer Systems (DepCoS-RELCOMEX), pages 17-24. IEEE Computer Society, 2009.

CM99

Olivier Carton, Ramón Maceiras. Computing the Rabin Index of a Parity Automaton. In Informatique Théorique et Applications (ITA), 33(6):495-506, 1999.

CMP92

Edward Y. Chang, Zohar Manna, Amir Pnueli. Characterization of Temporal Property Classes. In Automata, Languages and Programming (ICALP), LNCS 623, pages 474-486. Springer, 1992.

Cou99

Jean-Michel Couvreur. On-the-Fly Verification of Linear Temporal Logic. In World Congress on Formal Methods (FM), LNCS 1708, pages 253-271. Springer, 1999.

DG08

Volker Diekert and Paul Gastin. First-order definable languages. Logic and Automata, volume 2 of Texts in Logic and Games, pages 261-306, 2008.

DGV99

Marco Daniele, Fausto Giunchiglia and Moshe Y. Vardi. Improved Automata Generation for Linear Temporal Logic. In Computer Aided Verification (CAV), LNCS 1633, pages 249-260. Springer, 1999.

DH96

Ron Davidson and David Harel. Drawing Graphs Nicely Using Simulated Annealing. ACM Transactions on Graphics, 15(4):301-331, 1996.

WDMR08

Martin De Wulf, Laurent Doyen, Nicolas Maquet, Jean-François Raskin. Antichains: Alternative Algorithms for LTL Satisfiability and Model-Checking. In Tools and Algorithms for the Construction and Analysis of Systems (TACAS), LNCS 4963, pages 63-77. Springer, 2008.

EH00

Kousha Etessami and Gerard J. Holzmann. Optimizing Büchi Automata. In Concurrency Theory (CONCUR), LNCS 1877, pages 153-167. Springer, 2000.

EL92

Peter Eades and Wei Lai. Algorithms for Disjoint Node Images. In Australasian Computer Science Conference (ACSC), pages 253-265. 1992.

EWS01

Kousha Etessami, Thomas Wilke, and Rebecca A. Schuller. Fair Simulation Relations, Parity Games, and State Space Reduction for Büchi Automata. In International Colloquium on Automata, Languages and Programming (ICALP), LNCS 2076, pages 694-707. Springer, 2001.

Far02

Berndt Farwer. ω-Automata. In Automata, Logics, and Infinite Games: A Guide to Current Research. LNCS 2500, pages 3-20, Springer Verlag, 2002.

FL09

Oliver Friedmann and Martin Lange. Solving Parity Games in Practice. In Automated Technology for Verification and Analysis (ATVA), LNCS 5799, pages 182-196. Springer, 2009.

FLM94

Arne Frick, Andreas Ludwig and Heiko Mehldau. A Fast Adaptive Layout Algorithm for Undirected Graphs. In Graph Drawing (GD), LNCS 894, pages 388-403. Springer, 1994.

FR91

Thomas M. J. Fruchterman and Edward M. Reingold. Graph Drawing by Force-directed Placement. Software: Practice and Experience, 21(11):1129-1164, 1991.

Gab87

Dov M. Gabbay. The Declarative Past and Imperative Future: Executable Temporal Logic for Interactive Systems. In Temporal Logic in Specification, LNCS 398, pages 409-448. Springer, 1987.

GBS02

Sankar Gurumurthy, Roderick Bloem, and Fabio Somenzi. Fair Simulation Minimization. In Computer Aided Verification (CAV), LNCS 2404, pages 610-624. Springer, 2002.

GL94

Orna Grumberg and David E. Long. Model Checking and Modular Verification. ACM Transactions on Programming Languages and Systems (TOPLAS), 16(3): 843-871, 1994.

GL02

Dimitra Giannakopoulou and Flavio Lerda. From States to Transitions: Improving Translation of LTL Formulae to Büchi Automata. In Formal Techniques for Networked and Distributed Systems (FORTE), LNCS 2529, pages 308-326. Springer, 2002.

GO01

Paul Gastin and Denis Oddoux. Fast LTL to Büchi Automata Translation. In Computer Aided Verification (CAV), LNCS 2102, pages 53-65. Springer, 2001.

GO03

Paul Gastin and Denis Oddoux. LTL with Past and Two-Way Very-Weak Alternating Automata. In Mathematical Foundations of Computer Science (MFCS), LNCS 2747, pages 439-448. Springer, 2003.

GPSS80

Dov M. Gabbay, Amir Pnueli, Saharon Shelah and Jonathan Stavi. On the Temporal Analysis of Fairness. In ACM SIGPLAN-SIGACT Symposium on Principles of Programming Languages (POPL), pages 163-173, 1980.

GPVW95

Rob Gerth, Doron Peled, Moshe Y. Vardi, and Pierre Wolper. Simple on-the-fly Automatic Verification of Linear Temporal Logic. In Protocol Specification, Testing, and Verification (PSTV), pages 3-18. Chapman & Hall, 1995.

HHK95

Monika Rauch Henzinger, Thomas A. Henzinger, Peter W. Kopke. Computing Simulations on Finite and Infinite Graphs. In Foundations of Computer Science (FOCS), pages 453-462. IEEE Computer Society, 1995: 453-462

HIMF98

Kunihiko Hayashi, Michiko Inoue, Toshimitsu Masuzawa and Hideo Fujiwara. A Layout Adjustment Problem for Disjoint Rectangles Preserving Orthogonal Order. In Graph Drawing (GD), LNCS 1547, pages 183-197. Springer, 1998.

HIMF02

Kunihiko Hayashi, Michiko Inoue, Toshimitsu Masuzawa and Hideo Fujiwara. A Layout Adjustment Problem for Disjoint Rectangles Preserving Orthogonal Order. Systems and Computers in Japan, 33(2):31-42, 2002.

HL03

Xiaodi Huang and Wei Lai. Force-Transfer: A New Approach to Removing Overlapping Nodes in Graph Layout. In Australasian Computer Science Conference (ACSC), CRPIT 16, pages 349-358. Australian Computer Society, 2003.

HLSG07

Xiaodi Huang, Wei Lai, A. S. M. Sajeev and Junbin Gao. A New Algorithm for Removing Node Overlapping in Graph Visualization. Information Sciences, 177(14):2821-2844, 2007.

Hop71

John Hopcroft. An n log n algorithm for minimizing states in a finite automaton. In Theory of Machines and Computations, pages 186-196. Academic Press, 1971. 177(14):2821-2844, 2007.

Joh75

Donald B. Johnson. Finding all the Elementary Circuits of a Directed Graph. SIAM Journal on Computing, 4(1):77-84, 1975.

JPZ06

Marcin Jurdziński, Mike Paterson, and Uri Zwick. A Deterministic Subexponential Algorithm for Solving Parity Games. Journal on Computing, 38(4):1519-1532, 2008.

Jur00

Marcin Jurdziński. Small Progress Measures for Solving Parity Games. In Symposium on Theoretical Aspects of Computer Science (STACS), LNCS 1770, pages 290-301. Springer, 2000.

KB06

Joachim Klein and Christel Baier. Experiments with deterministic ω-automata for formulas of linear temporal logic. Theoretical Computer Science, 363(2):182-195, 2006.

KK89

Tomihisa Kamada and Satoru Kawai. An Algorithm for Drawing General Undirected Graphs. Information Processing Letters, 31:7-15, 1989.

KMMP93

Yonit Kesten, Zohar Manna, Hugh McGuire, and Amir Pnueli. A Decision Algorithm for Full Propositional Temporal Logic. In Computer Aided Verification (CAV), LNCS 697, pages 97-109. Springer, 1993.

KP00

Yonit Kesten and Amir Pnueli. Verification by Augmented Finitary Abstraction. Information and Computation, 163(1):203-243, 2000.

KP02

Yonit Kesten and Amir Pnueli. Complete Proof System for QPTL. Journal of Logic and Computation, 12(5):701-745, 2002.

Kur87

Robert P. Kurshan. Complementing Deterministic Büchi Automata in Polynomial Time. Journal of Computer and System Sciences (JCCS), 35(1): 59-71, 1987.

Kus01

Ralf Küsters. Memoryless Determinacy of Parity Games. In Automata, Logics, and Infinite Games, LNCS 2500, pages 95-106. Springer 2001.

KV01

Orna Kupferman and Moshe Y. Vardi. Weak Alternating Automata are not that Weak. ACM Transactions on Computational Logic (TOCL), 2(3):408-429, 2001.

KW08

Detlef Kähler and Thomas Wilke. Complementation, Disambiguation, and Determinization of Büchi Automata Unified. In International Colloquium on Automata, Languages and Programming (ICALP), LNCS 5125, pages 724-735. Springer, 2008.

LAN69

Lawrence H. Landweber. Decision Problems for ω-Automata. Mathematical Systems Theory, 3(4):376-384, 1969.

LE98

Wei Lai and Peter Eades. Routing Drawings in Diagram Displays. In Asian Pacific Computer and Human Interaction (APCHI), pages 291-297. IEEE Computer Society, 1998.

McN93

Robert McNaughton. Infinite Games Played on Finite Graphs. Annals of Pure and Applied Logic, 65(2): 149-184, 1993.

MELS95

Kazuo Misue, Peter Eades, Wei Lai and Kozo Sugiyama. Layout Adjustment and the Mental Map. Journal of Visual Languages and Computing, 6(2):183-210, 1995.

Mey98

Bernd Meyer. Self-Organizing Graphs - A Neural Network Perspective of Graph Layout. In Graph Drawing (GD), LNCS 1547, pages 246-262. Springer, 1998.

MH84

Satoru Miyano and Takeshi Hayashi. Alternating Finite Automata on ω-Words. Theoretical Computer Science, 32(3), 321-330, 1984.

Moo56

Edward F. Moore. Gedanken-experiments on sequential machines. In Automata Studies, Annals of Mathematics Studies, no. 34, pages 129–153. Princeton University Press, 1956.

MP90

Zohar Manna and Amir Pnueli. A Hierarchy of Temporal Properties. In Proceedings of the 9th Annual ACM Symposium on Principles of Distributed Computing (PODC), pages 377-410. ACM, 1990.

MP92

Zohar Manna and Amir Pnueli. The Temporal Logic of Reactive and Concurrent Systems. Springer, 1992.

MP95

Zohar Manna and Amir Pnueli. Temporal Verification of Reactive Systems: Safety. Springer, 1995.

MS95

David E. Muller and Paul E. Schupp. Simulating Alternating Tree Automata by Nondeterministic Automata: New Results and New Proofs of the Theorems of Rabin, McNaughton and Safra. Theoretical Computer Science, 141(1&2):69-107, 1995.

Pit06

Nir Piterman. From Nondeterministic Büchi and Streett Automata to Deterministic Parity Automata. In

Logic in Computer Science (LICS), pages 255-264. IEEE Computer Society, 2006.

PMT02

Hong Peng, Yassine Mokhtari, and Sofiène Tahar. Environment Synthesis for Compositional Model Checking. In Computer Design (ICCD), pages 70-75. IEEE Computer Society, 2002.

Saf88

Shmuel Safra. On the Complexity of ω-Automata. In Foundations of Computer Science (FOCS), pages 319-327. IEEE Computer Society, 1988.

SB00

Fabio Somenzi and Roderick Bloem. Efficient Büchi Automata from LTL Formulae. In Computer Aided Verification (CAV), LNCS 1855, pages 248-263. Springer, 2000.

Sch07

Sven Schewe. Solving Parity Games in Big Steps. In Foundations of Software Technology and Theoretical Computer Science (FSTTCS), LNCS 4855, pages 449-460. Springer, 2007.

Sch09a

Sven Schewe. Büchi Complementation Made Tight. In Symposium on Theoretical Aspects of Computer Science (STACS), pages 661-672. 2009.

Sch09b

Sven Schewe. Tighter Bounds for the Determinisation of Büchi Automata. In Symposium on Foundations of Software Science and Computational Structures (FOSSACS), LNCS 5504, pages 167-181. 2009.

ST03

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