Taxonomies of Regular Tree Algorithms

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Where innovation starts

PSC 2009, Prague, September 2nd 2009

Overview

- Context
  History & relevance, deficiencies, role of taxonomies & toolkits
- Domain
  Trees, patterns & matching, regular tree grammars
- Taxonomies
  Algorithm taxonomies, taxonomies of regular tree algorithms
- Tree Acceptance Taxonomy
  Algorithms b/o tree automata, match sets, stringpath matching
- Concluding Remarks

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Context
Regular Tree Language Theory

- *Regular Tree Grammar (RTG), Finite Tree Automaton (TA), Regular Tree Expression*

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Regular Tree Language Theory

- *Regular Tree Grammar (RTG), Finite Tree Automaton* (*TA*),
  Regular Tree Expression
- Algorithmic Problems
    - *Membership/Tree Acceptance*
    - *Tree Pattern Matching*
    - *Tree Parsing*

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- 1960s
  - Equivalence between formalisms (except Deterministic Top-Down/ Root-to-Frontier TA), transformations between them
  - Construct and use *TA* based on *RTG* or pattern set

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- 1960s
  - Equivalence between formalisms (except Deterministic Top-Down/ Root-to-Frontier TA), transformations between them
  - Construct and use *TA* based on *RTG* or pattern set
- Since ca. 1975
  - Applications in instruction selection, term rewriting, model checking
  - Many *TA* constructions, algorithms

Context
Appearance of algorithms

- *Brainerd, 1967 & 1969*
- *Kron, 1975*
- *Hoffmann & O'Donnell, 1980 & 1982*
- *Hatcher, 1985; Hatcher & Christopher, 1986*
- *Turner, 1986*
- *van Dinther, 1987*
- *Chase, 1987*
- *Aho, Ganapathi & Tjang, 1985, 1988*
- *van de Meerakker, 1988*
- *Weisgerber & Wilhelm, 1989*
- *Hemerik & Katoen, 1989*
- *Balachandran, Dhamdhere & Biswas, 1990*
- *Ferdinand, Seidl & Wilhelm, 1994*
- *Wilhelm & Mauer, 1995*
- *Comon et al., 2003*
- *Cleophas, Hemerik & Zwaan, 2005 & 2006*
- *Cleophas, 2008*

Context
Motivation

- Domain deficiencies
  - inaccessible, difficult to find
  - difficult to compare, choose
  - separation between theory and practice

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  - well-established theory
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    Tree Acceptance, *Tree Pattern Matching* (*TPM*), *Tree Parsing*

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    Tree Acceptance, *Tree Pattern Matching* (*TPM*), *Tree Parsing*
- hence
  - taxonomies (*Cleophas, Hemerik & Zwaan, 2005/2006; Cleophas, 2008*)
    systematic classifications of problems & solutions in (algorithmic) domain, to bring order to the domain
  - toolkit (*Strolenberg, 2007; Cleophas, 2008*)
    taxonomy-based

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Trees, Patterns, Tree Pattern Matching

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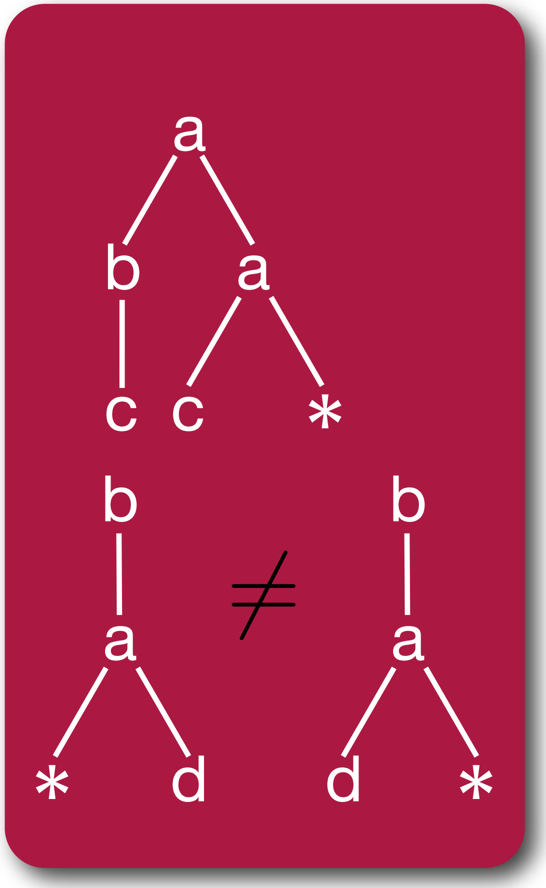
- *Node-labeled, ordered, ranked trees*
- Generalization of strings:
  Allow symbols of arity/rank › 1
  - Fixed arity per symbol



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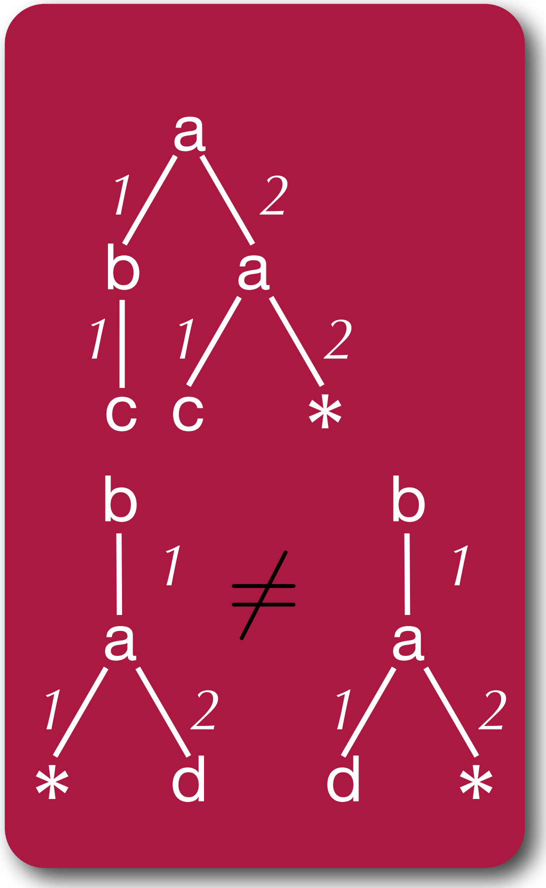

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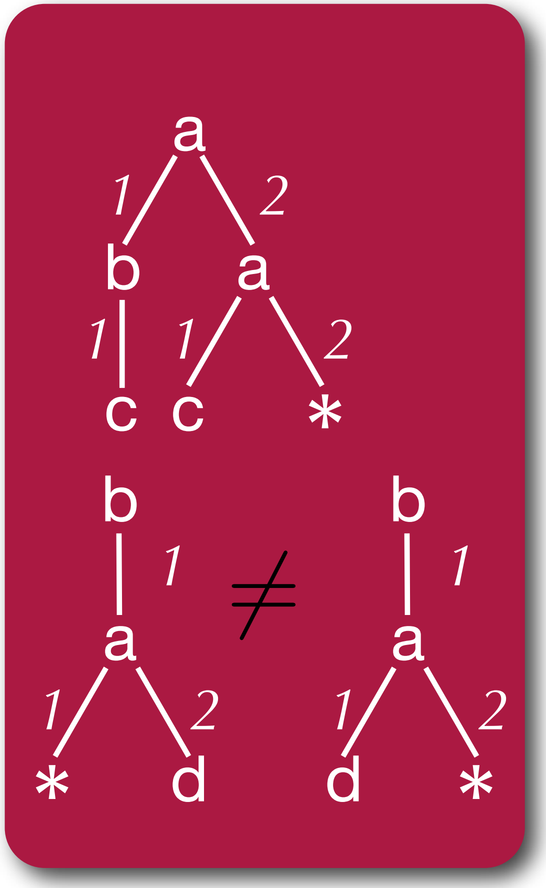
- Tree patterns with wildcards at leaves



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- Generalization of regular string grammar
  - Recall right regular string grammar production forms

$$A \rightarrow wB, A \rightarrow w \quad (w \in \Sigma^*)$$

Domain
Regular Tree Grammars

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$$A \rightarrow wB, A \rightarrow w \quad (w \in \Sigma^*)$$

- Regular tree grammar
  - Form $A \rightarrow t$ with t a tree, nonterminals at leaves

Domain
Regular Tree Grammars

(1) $S \to \begin{array}{c} a \\ / \quad \backslash \\ B \qquad d \end{array}$,

(2) $S \to \begin{array}{c} a \\ / \quad \backslash \\ b \qquad B \\ | \qquad\quad \\ c \qquad\quad \end{array}$,

(3) $S \to c,$

(4) $B \to \begin{array}{c} b \\ | \\ B \end{array}$,

(5) $B \to S,$

(6) $B \to d$

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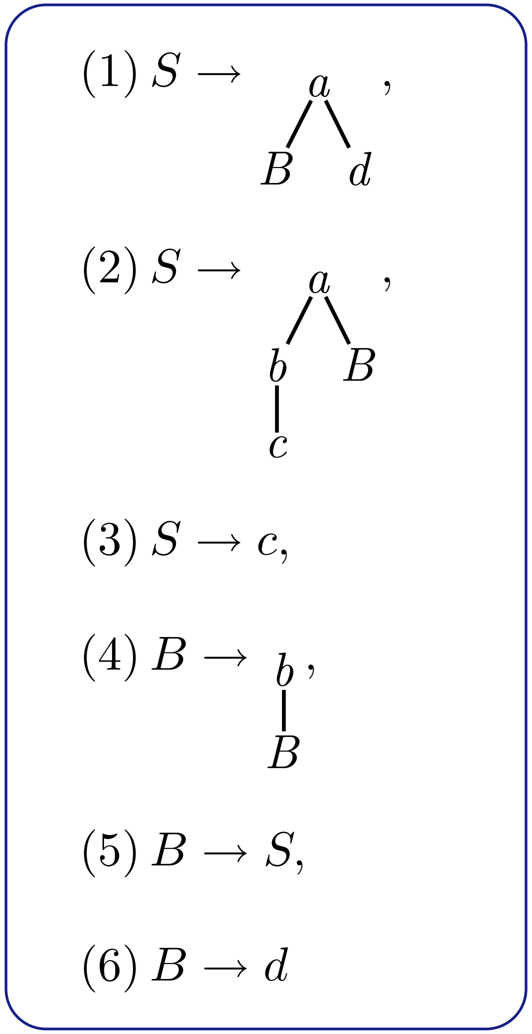

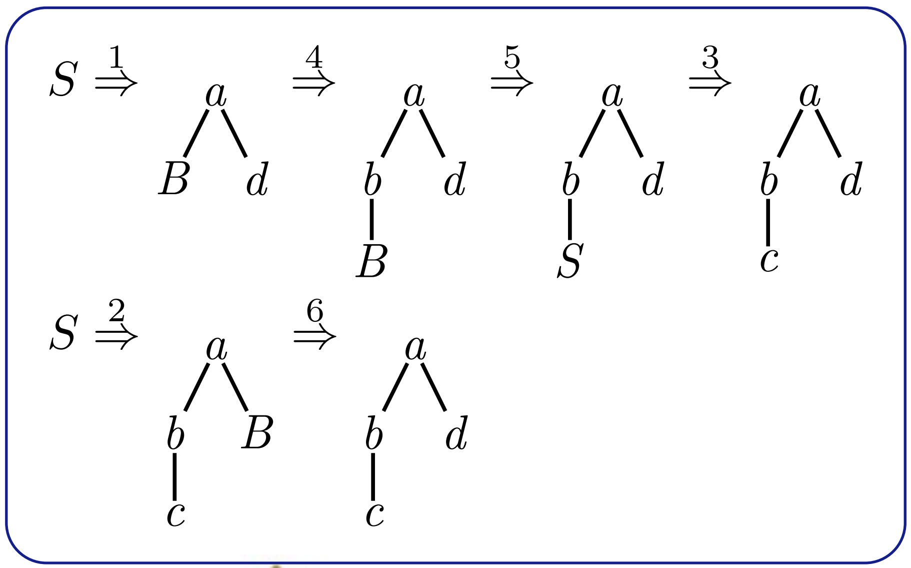

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Taxonomies
Algorithm Taxonomies

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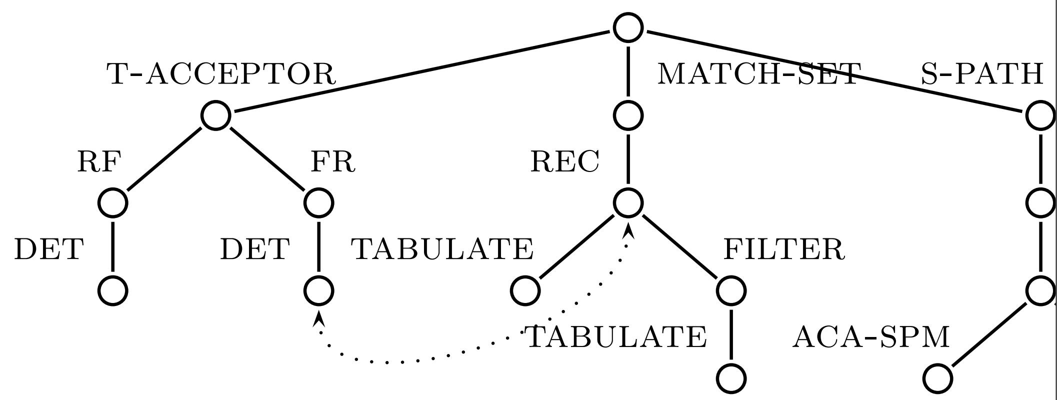

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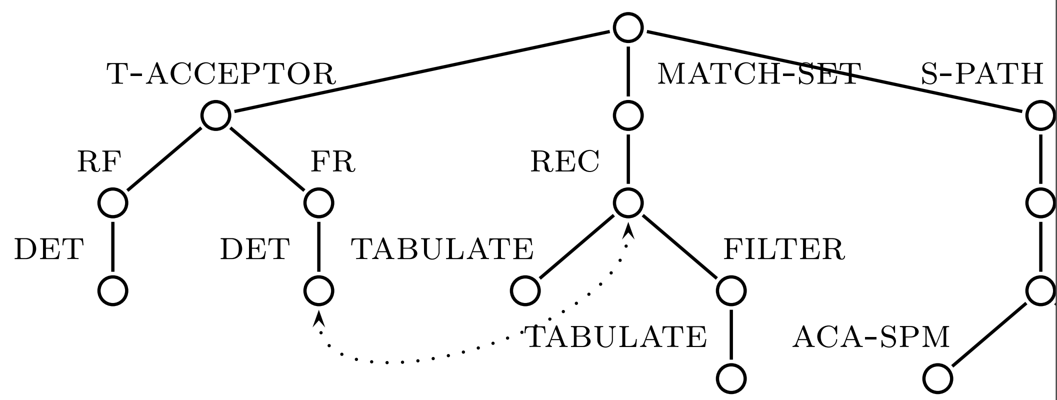

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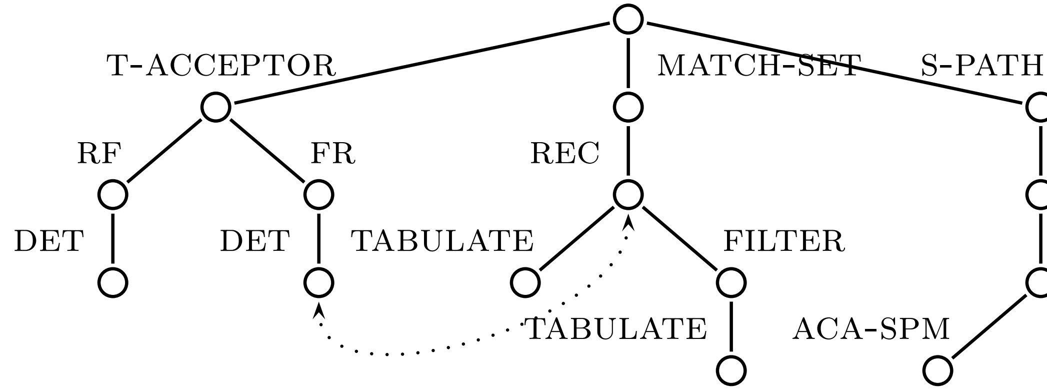

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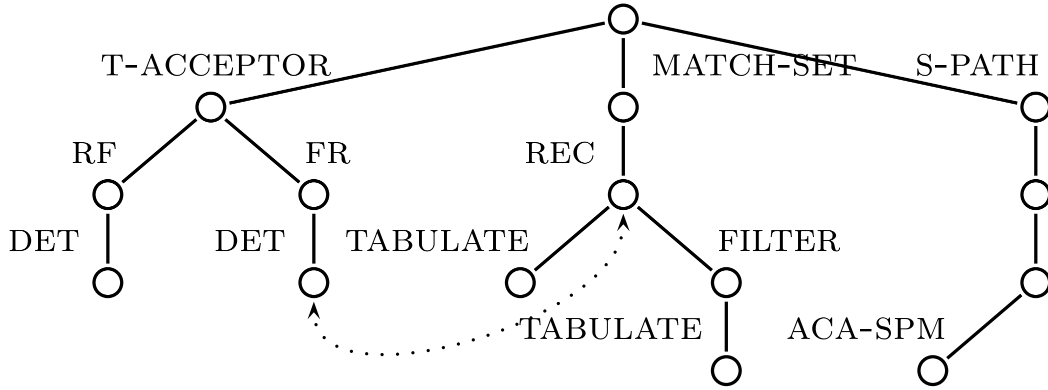

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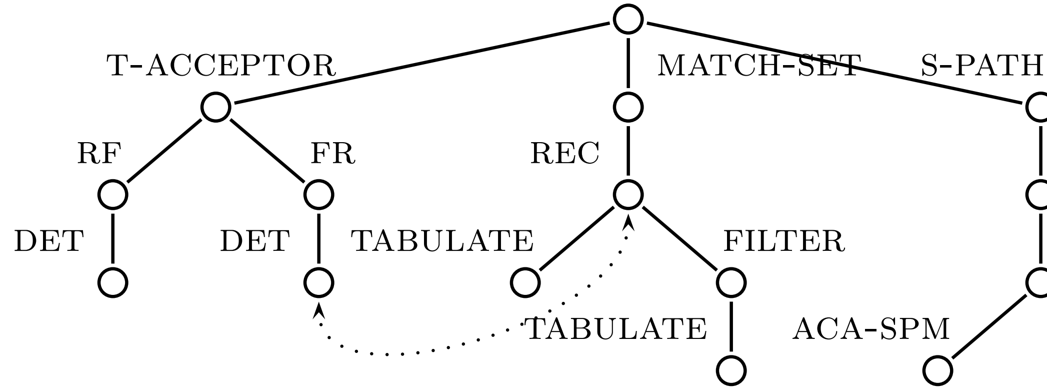

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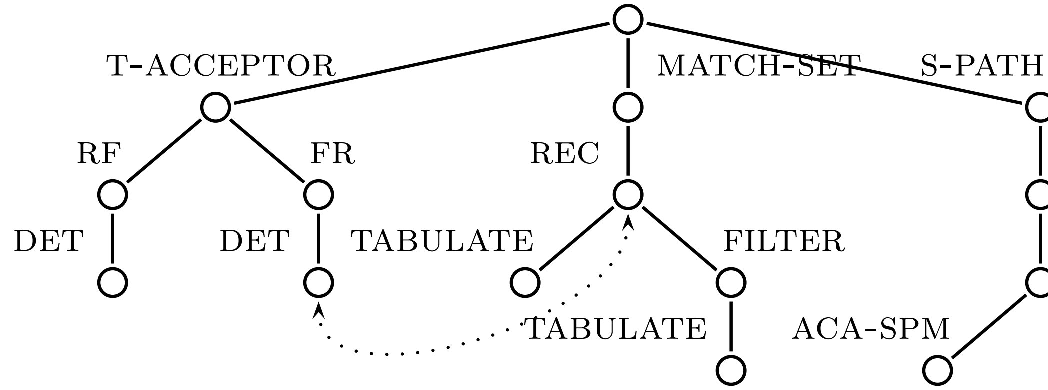
- From abstract, general to concrete, specific
- Properties (details) explicit
- Allow comparison, discovery of new algorithms



Taxonomies
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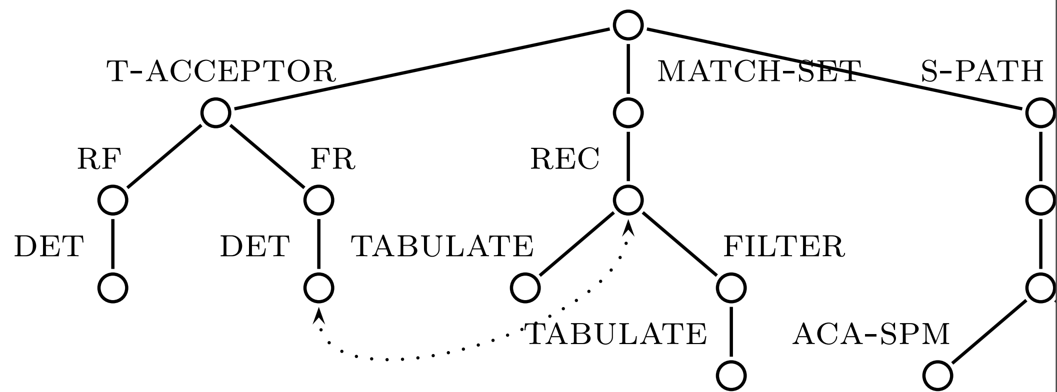
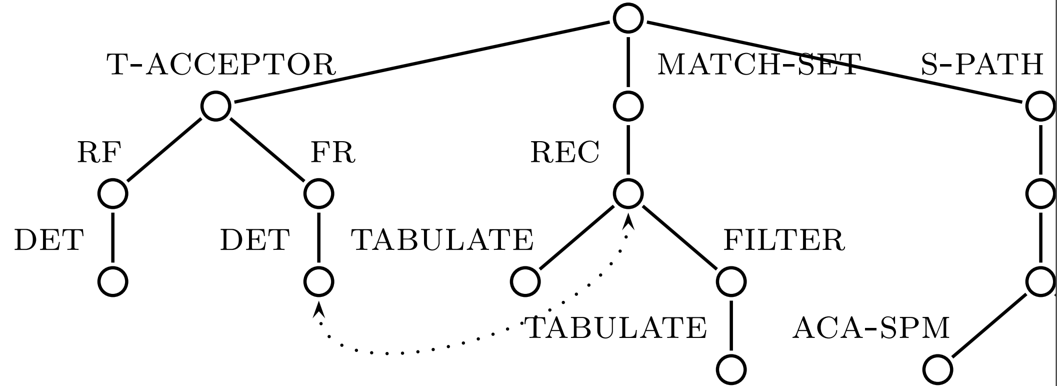


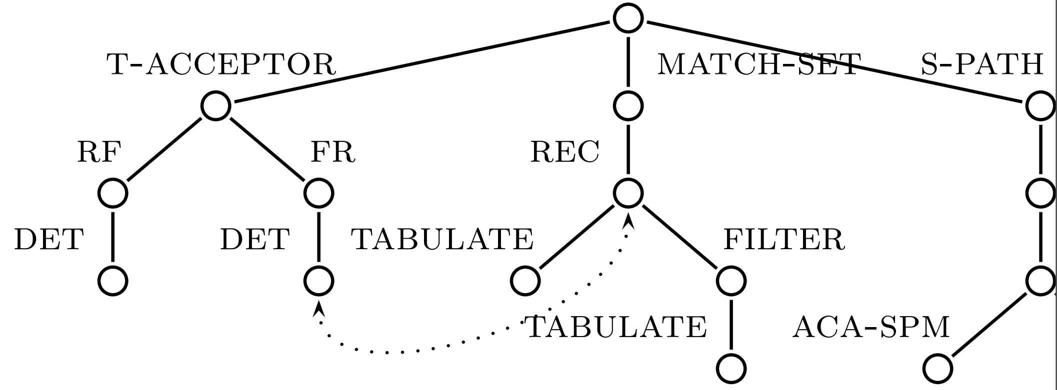
Taxonomies
Construction

- Bottom-up



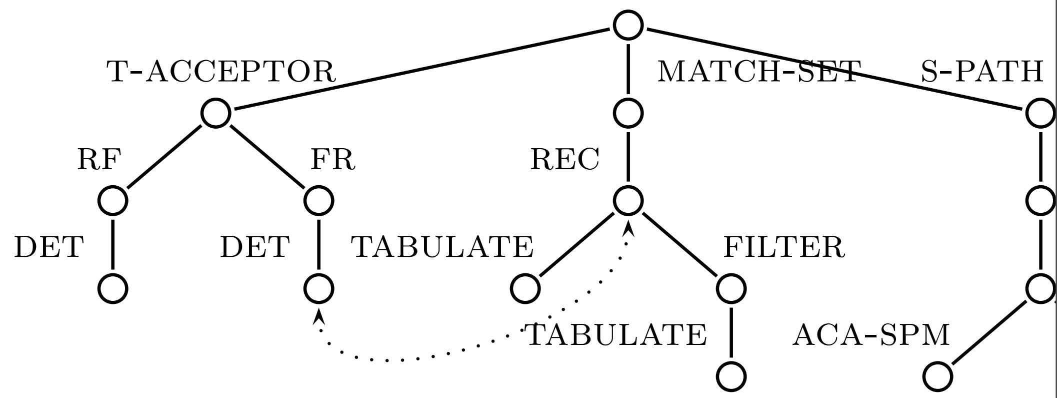
Taxonomies Construction

- Bottom-up
- Literature survey



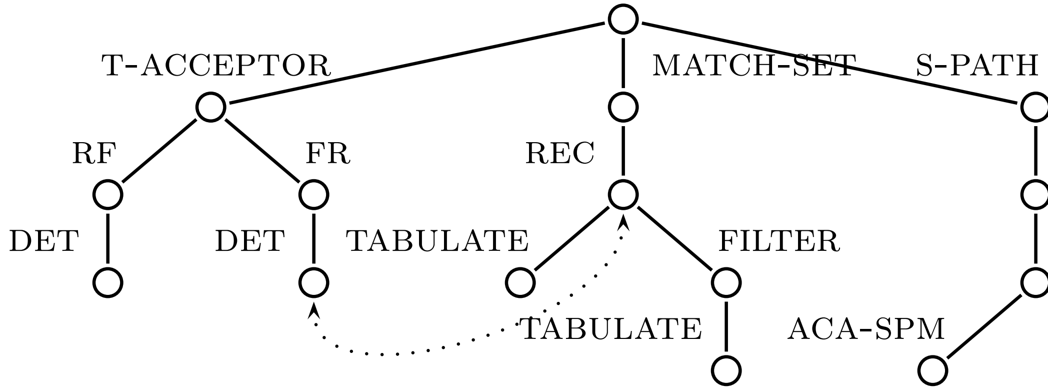
Taxonomies
Construction

- Bottom-up
- Literature survey
- Rephrase algorithms in common presentation style



Taxonomies Construction

- Bottom-up
- Literature survey
- Rephrase algorithms in common presentation style
- Analyze to determine essential details



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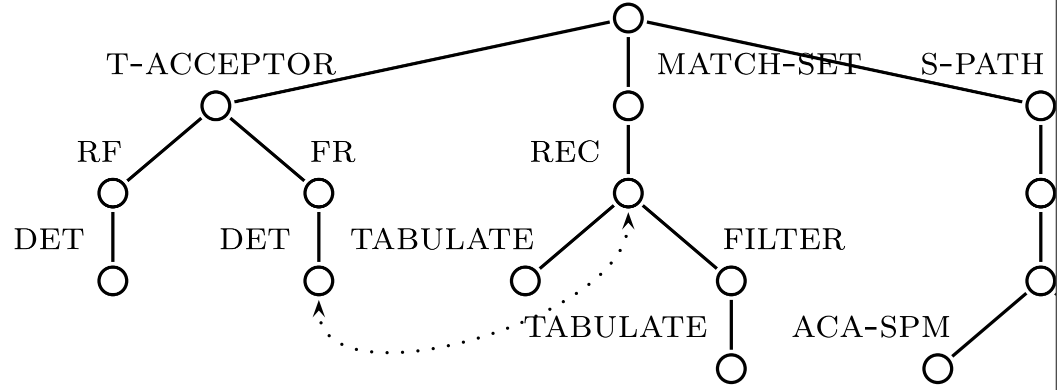
- Abstracting over details of algorithms yields common ancestors



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Taxonomies
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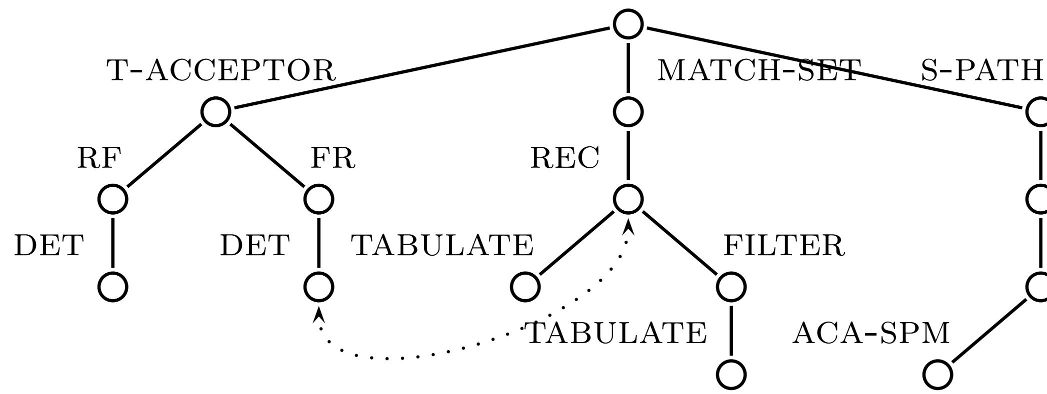
- Bottom-up
- Literature survey
- Rephrase algorithms in common presentation style
- Analyze to determine essential details
- Abstracting over details of algorithms yields common ancestors
- New combinations may lead to new algorithms



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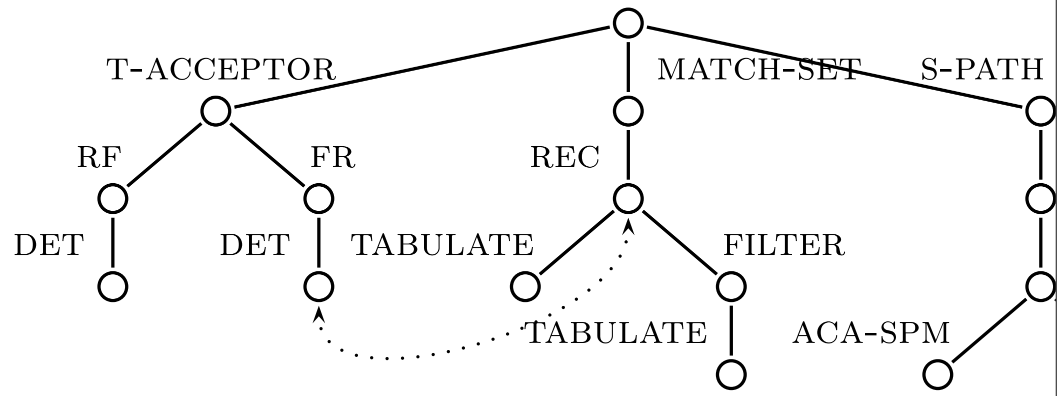
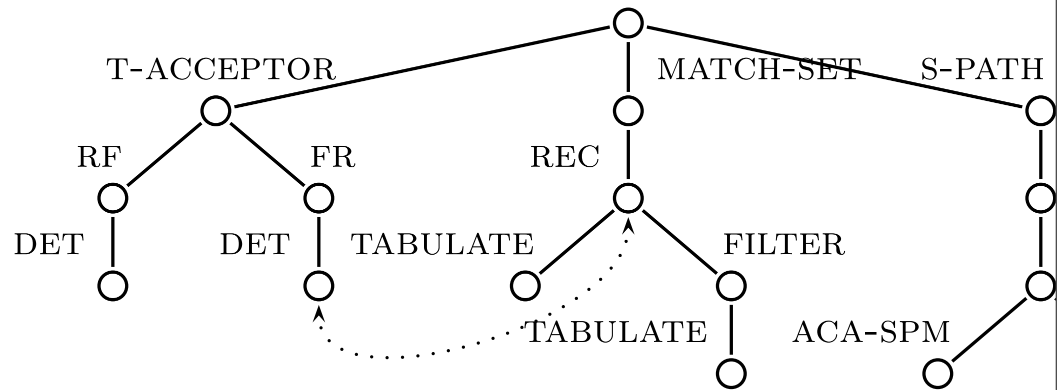
Taxonomies
Presentation & Correctness

- Top-down



Taxonomies
Presentation & Correctness

- Top-down
- Root represents high-level algorithm
  - Correctness easily shown



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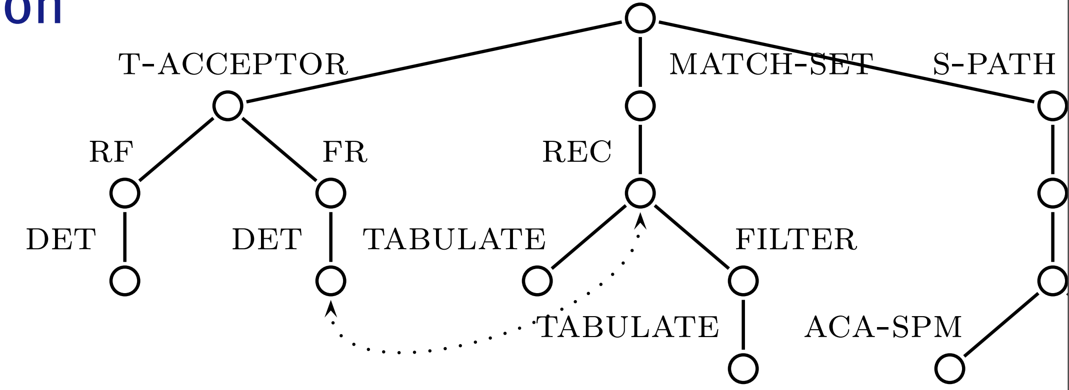
- Adding *detail*
  - Obtains (new) refinement/variation
  - Branch connecting algorithm node to child node
  - Associated correctness arguments



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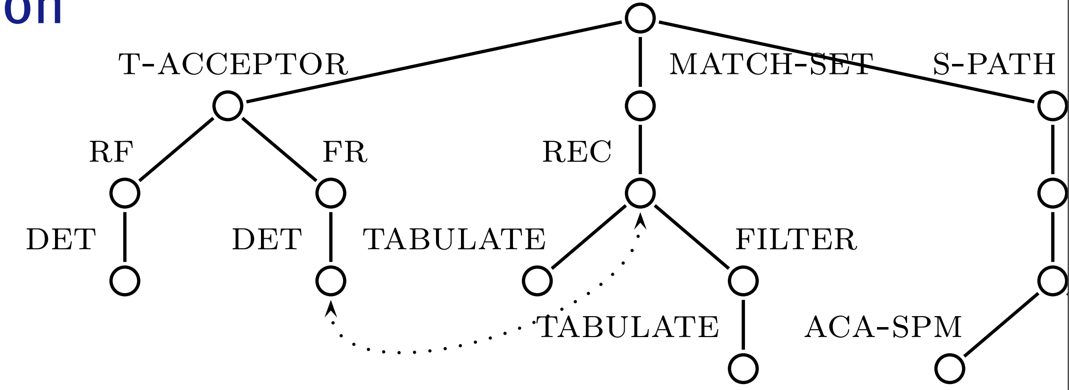
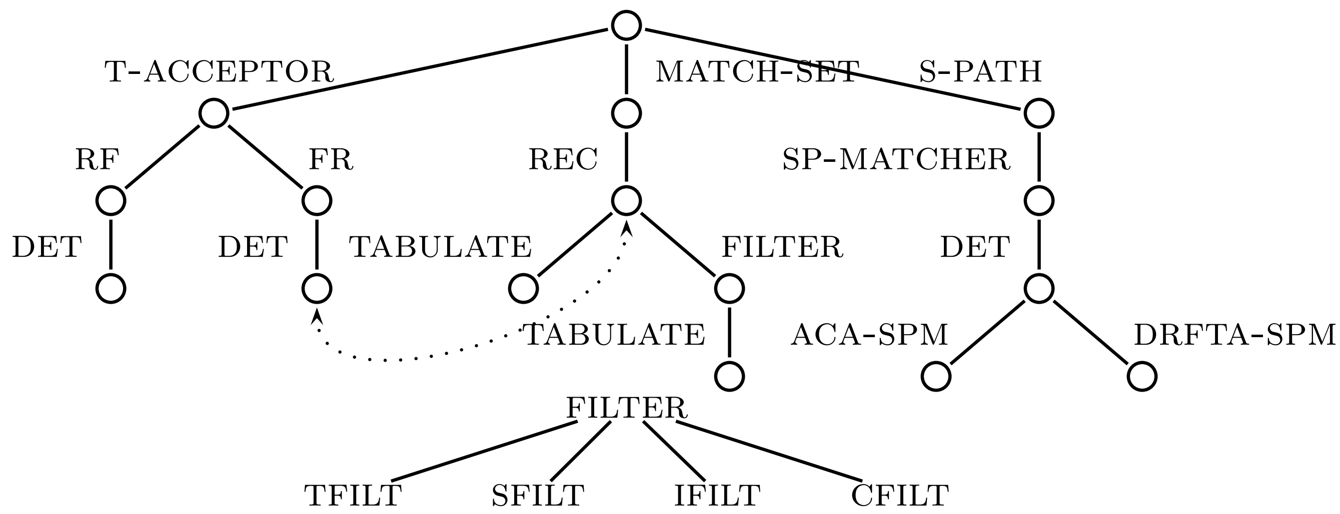
- Correctness of root and of details on rootpath imply correctness of node



Taxonomies
Tree Acceptance Taxonomy



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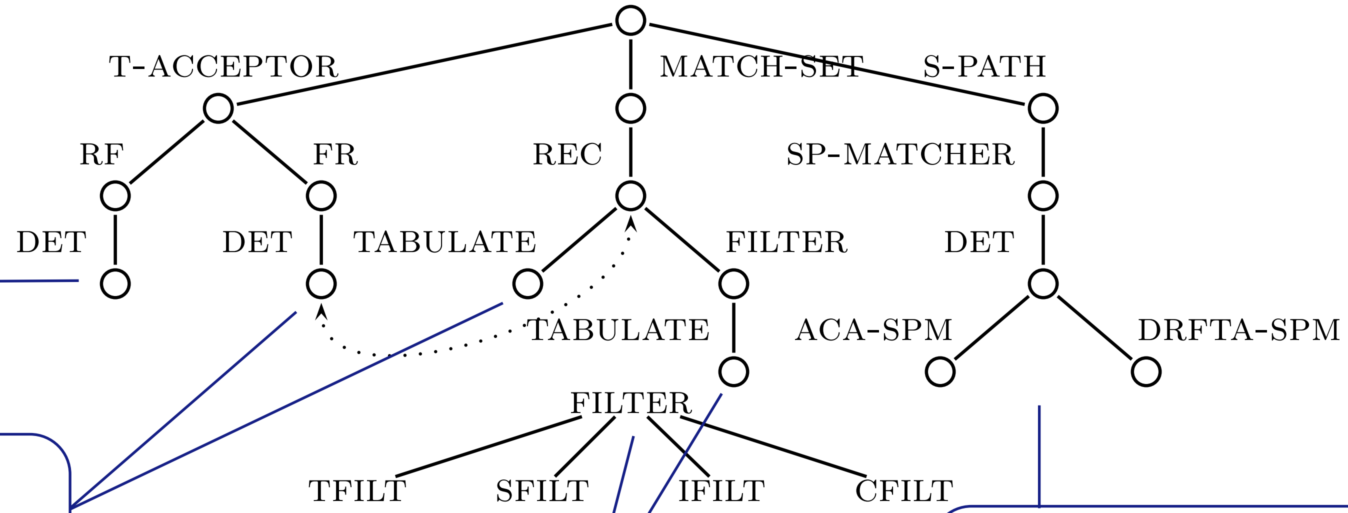

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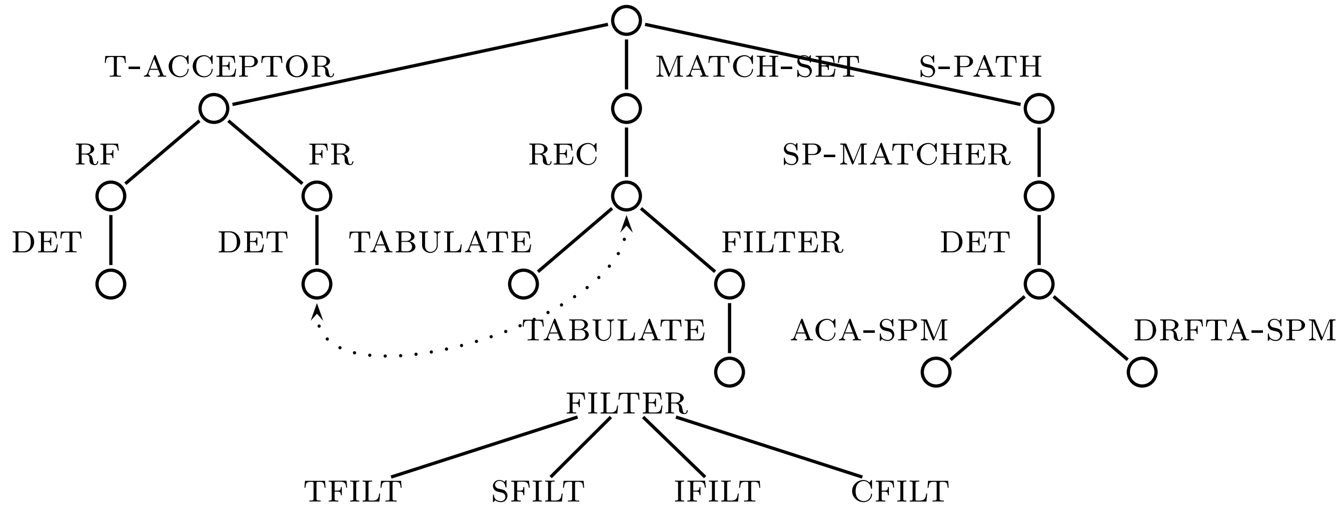

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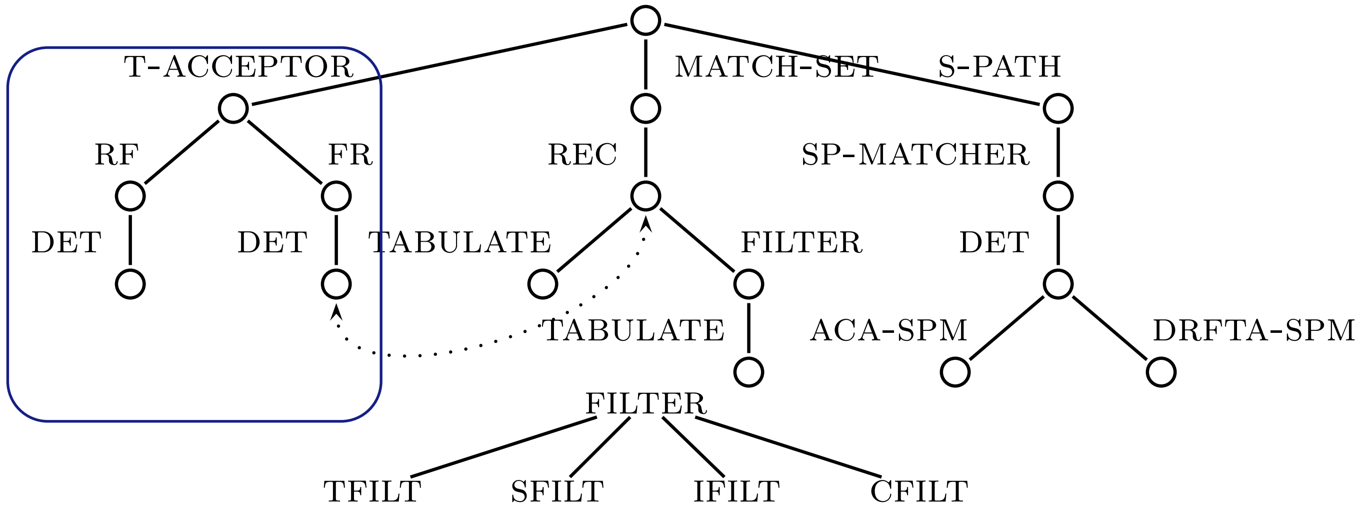

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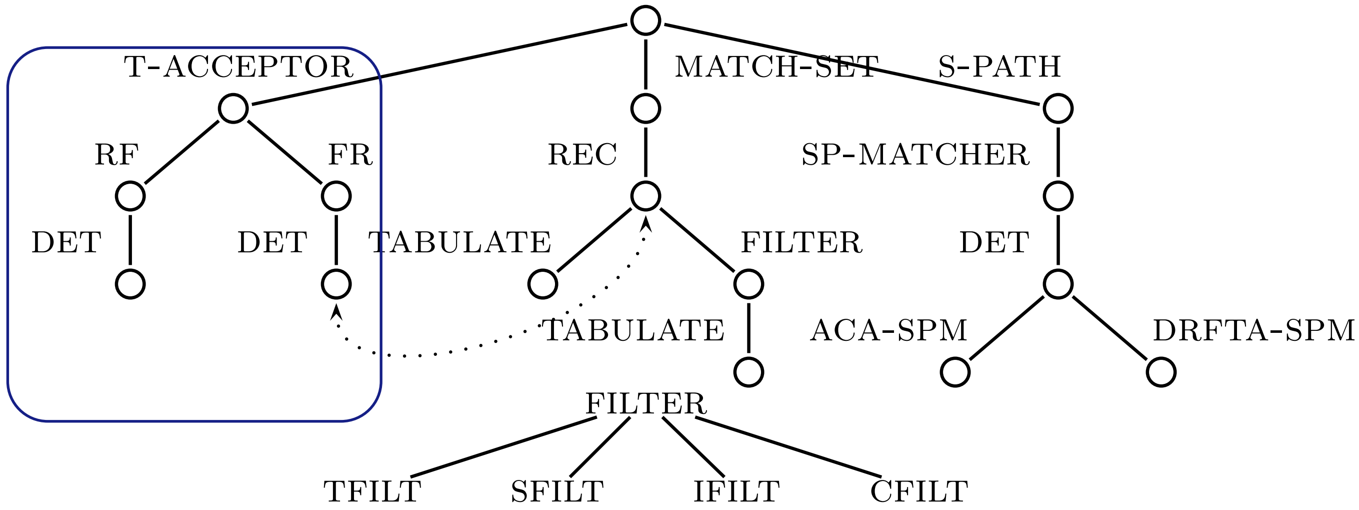

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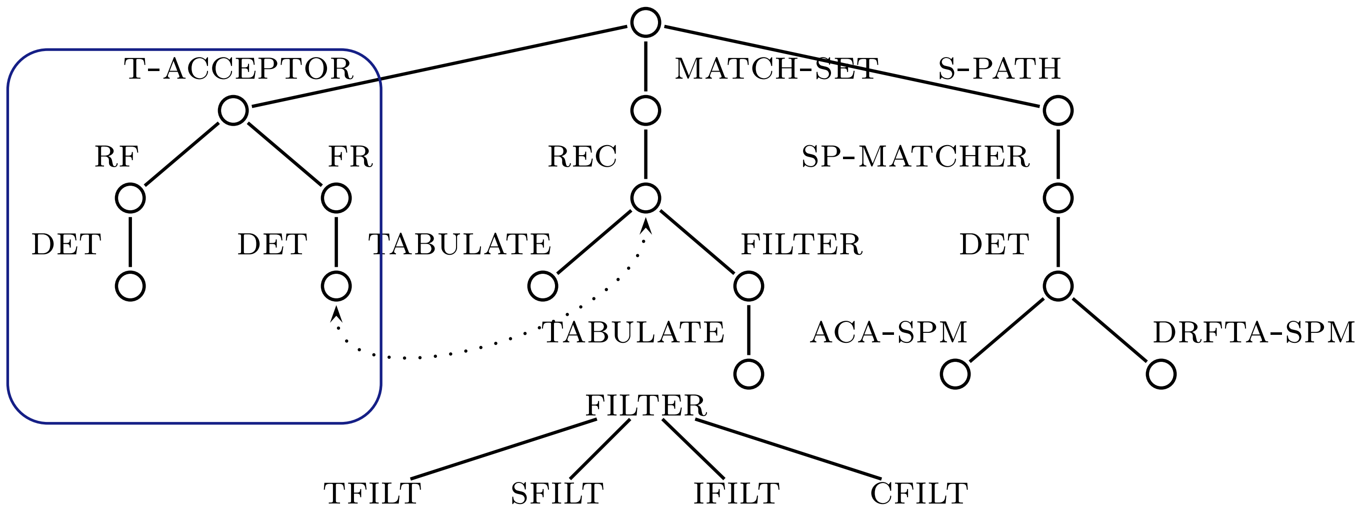

- Algorithms based on correspondence between Regular Tree Grammars and Finite Tree Automata
  - For every RTG, undirected TA can be constructed
  - Adding details e.g. direction, determinacy, restricting grammar elements used for state set leads to other constructions

Tree Acceptance Taxonomy
String Automata, Tree Automata

a b b

Tree Acceptance Taxonomy
String Automata, Tree Automata

- View automata as assigning states to positions ‘in between’ symbols

a b b

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$$\begin{array}{ccccccc} & a & & b & & b & \\ q_0 & & q_1 & & q_2 & & q_3 \end{array}$$

$(q_0, q_1) \in R_a$ *etc.*

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q_0

a

q_1

b

q_2

b

q_3

$\perp$

$(q_0, (q_1)) \in R_a$ etc.

Note $(q_3, ()) \in R_\perp$

Tree Acceptance Taxonomy
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- View automata as assigning states to positions 'in between' symbols
- For tree case, assigning states to positions of tree

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 & a & & b & & b & \\
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$$

$$
\begin{array}{ll}
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 & a \\
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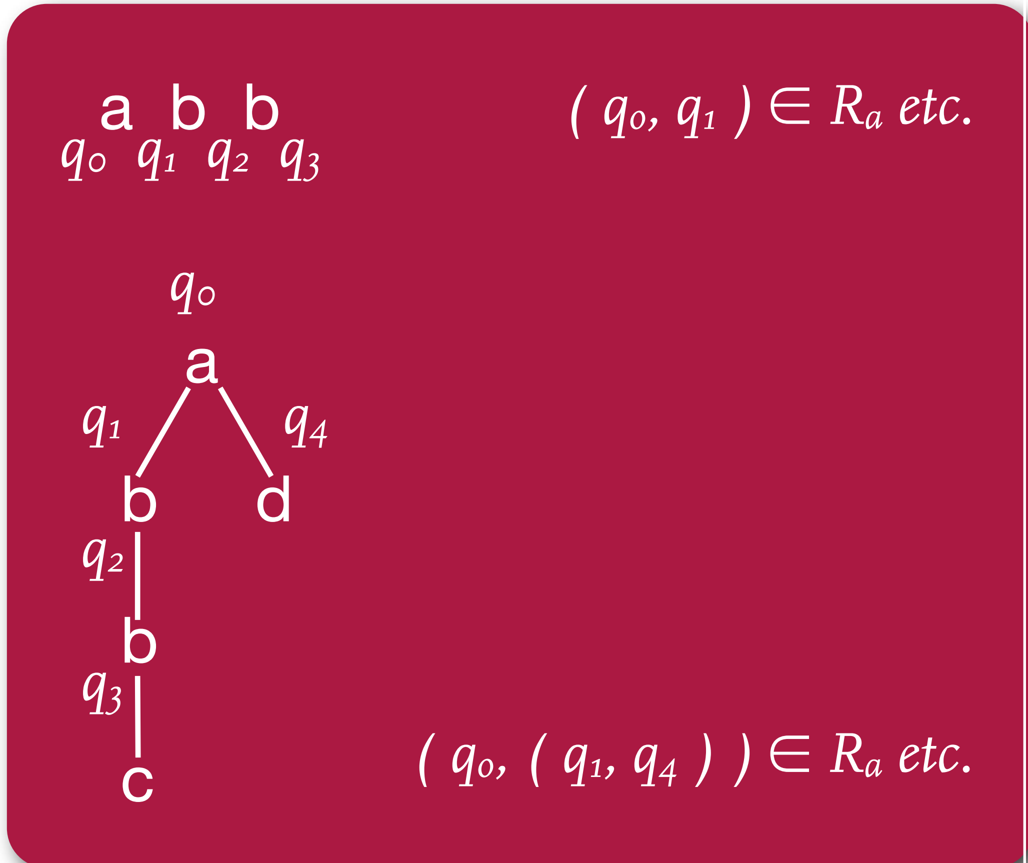

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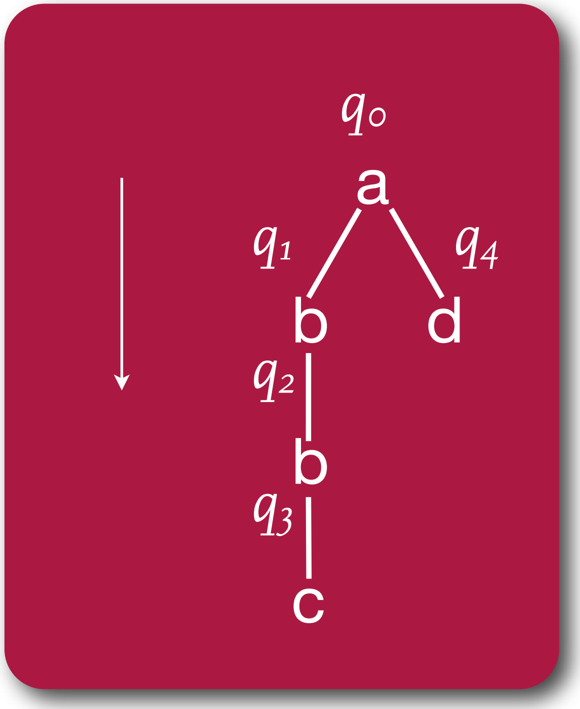
- Direction
  - Top-Down (Root-to-Frontier)



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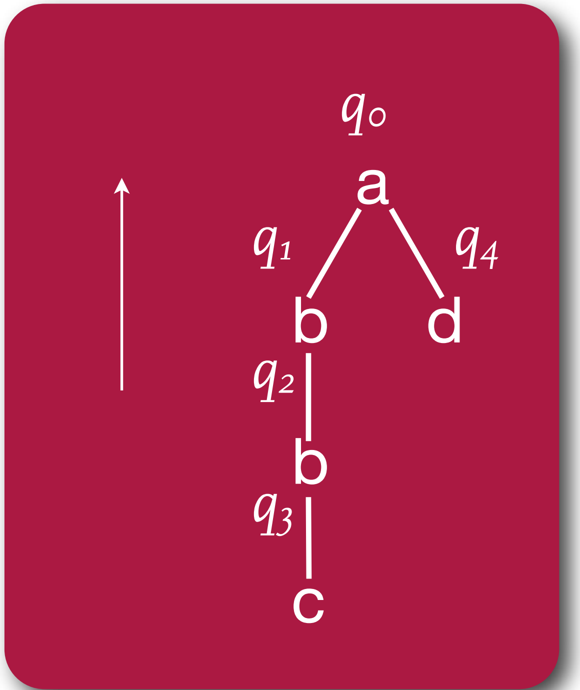
  - Bottom-Up (Frontier-to-Root)



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Tree Acceptance Taxonomy
Tree Automata Constructions

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- About 50 different constructions in tree acceptance and tree pattern matching taxonomies

Tree Acceptance Taxonomy
Tree Automata Constructions

- About 50 different constructions in tree acceptance and tree pattern matching taxonomies
- Construction presentation
  - uniform style
  - defines state set, transition relation, ...
  - gives example
  - discusses correctness arguments
  - discusses related constructions and literature
  - identified by sequence of labels indicating details, e.g. (TGA-TA:ALL-SUB:REM-Epsilon:FR:SUBSET)

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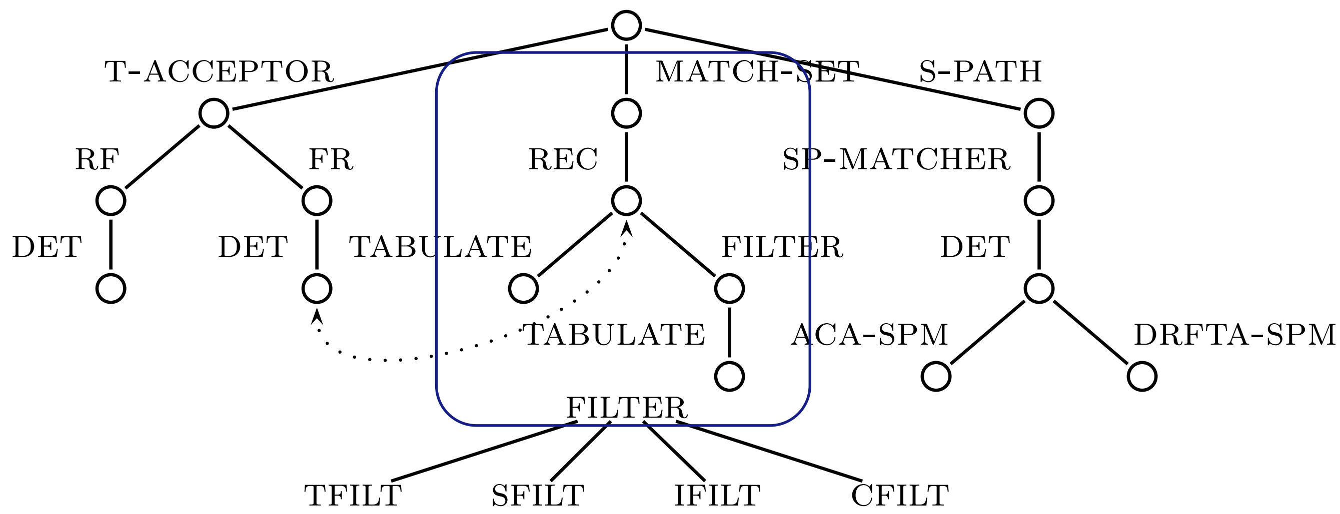
Tree Acceptance Taxonomy Overview - II



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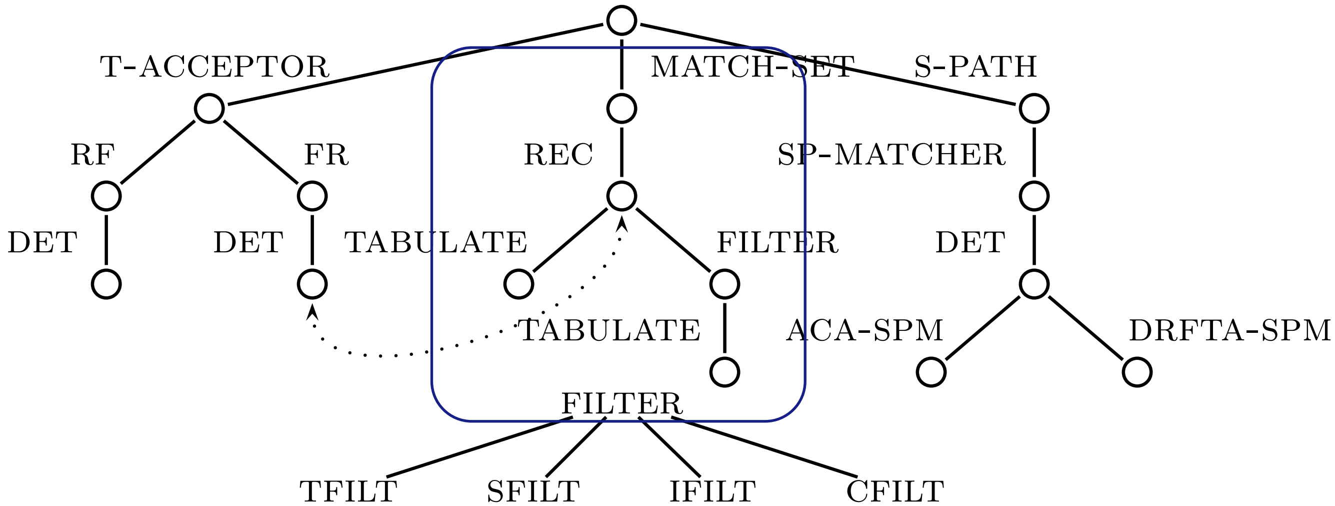

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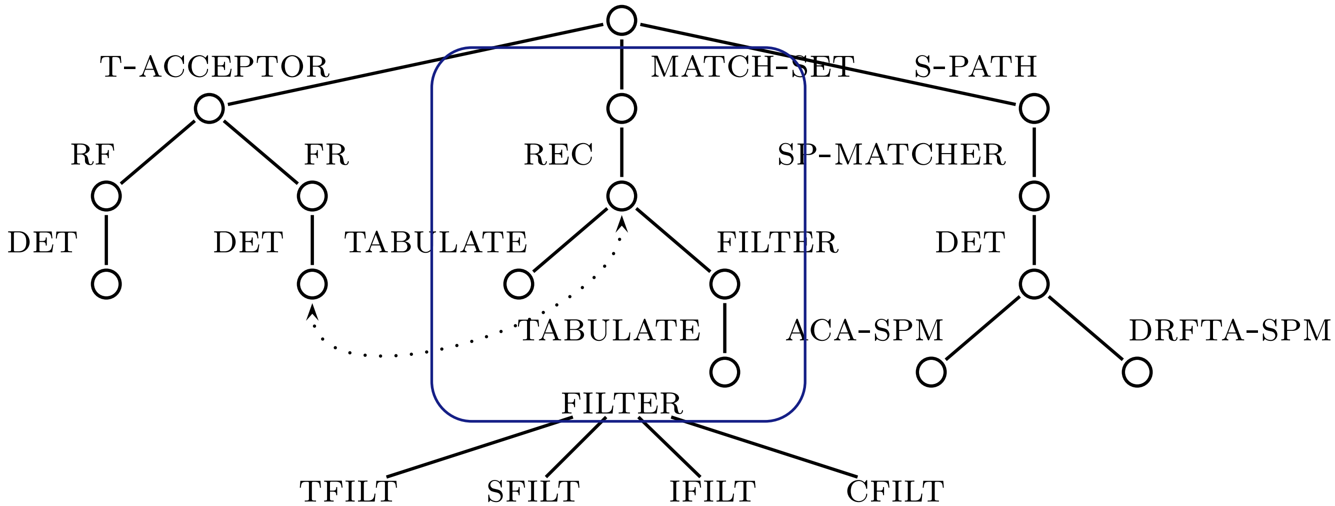

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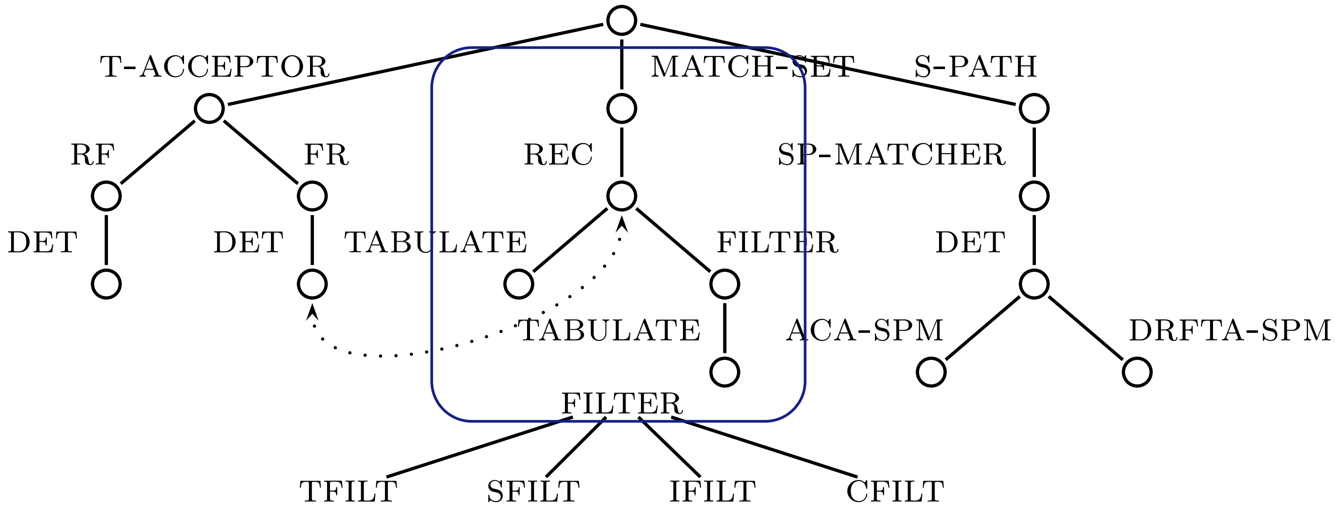

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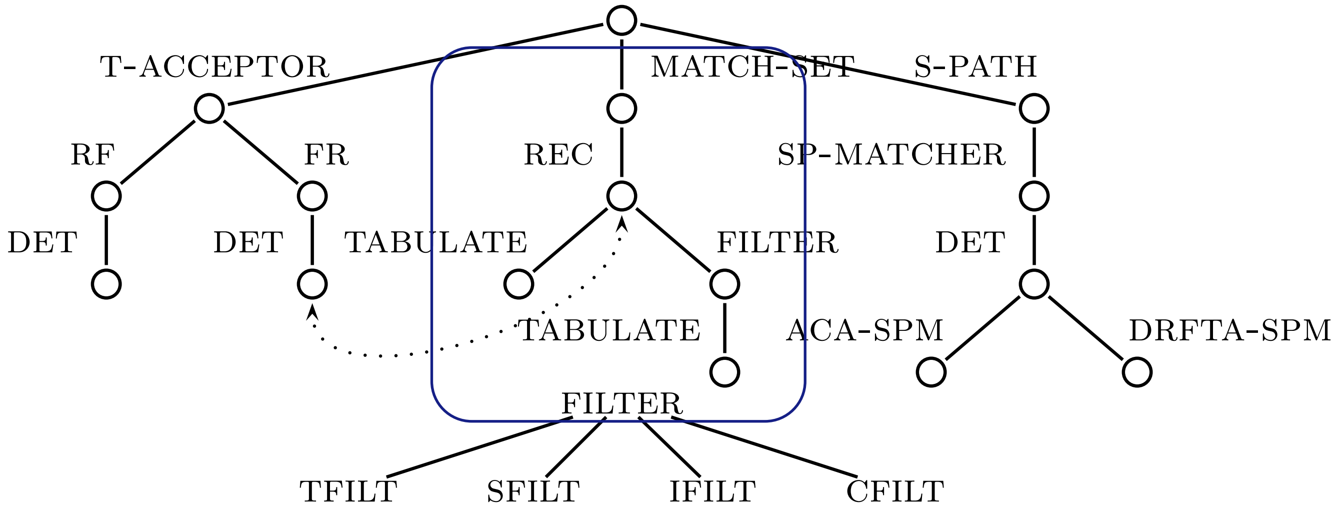

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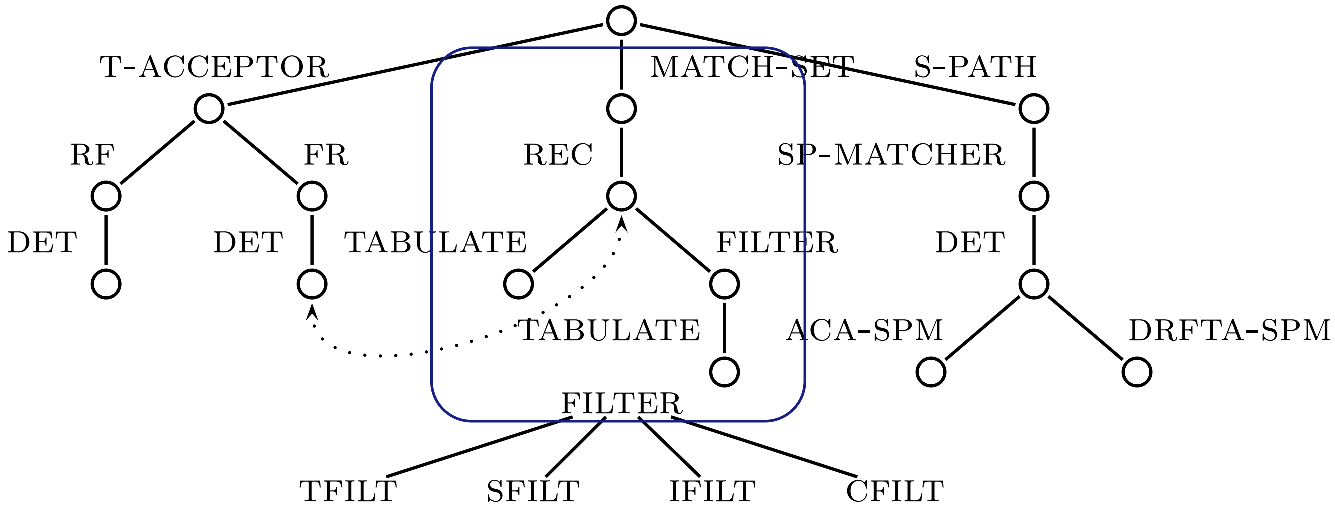

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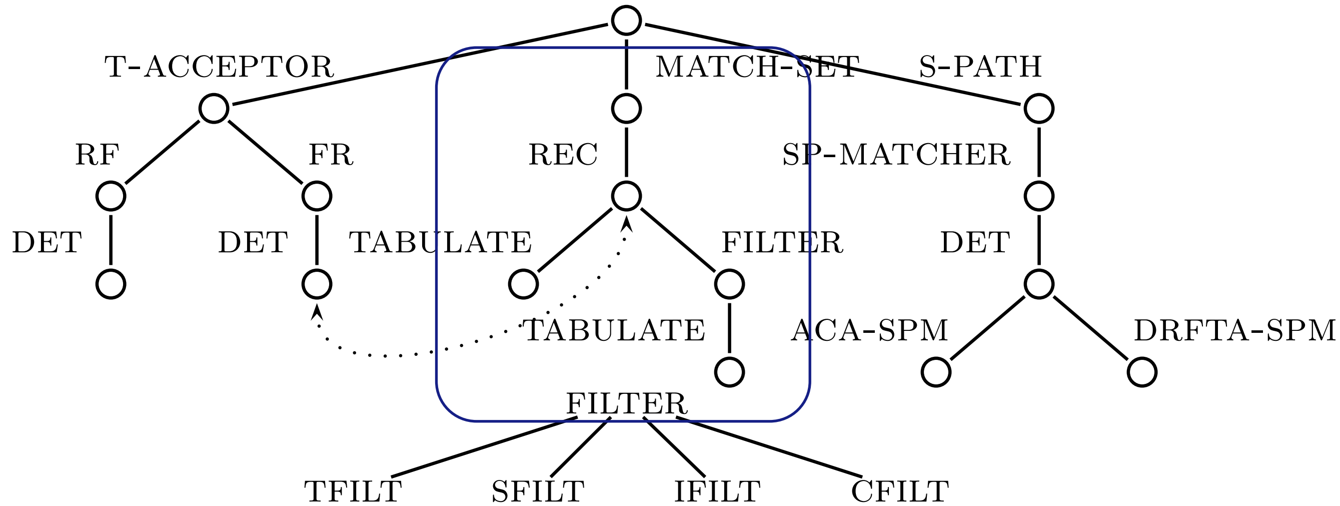

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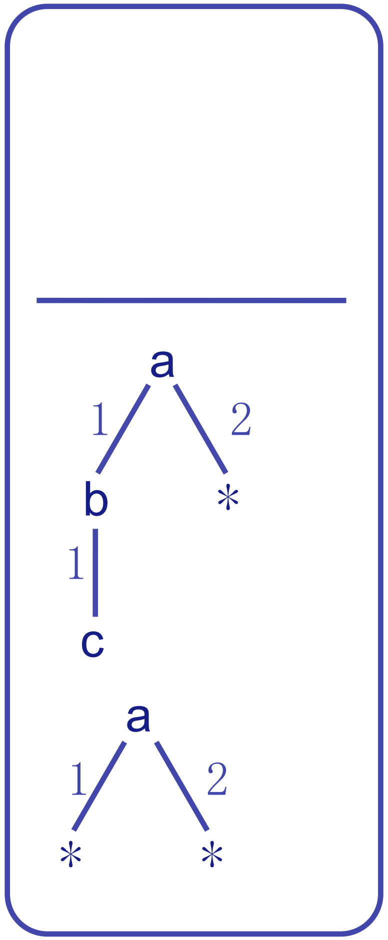
  - Just a different view on TAs!

Tree Acceptance Taxonomy

Computing match sets; tree automata



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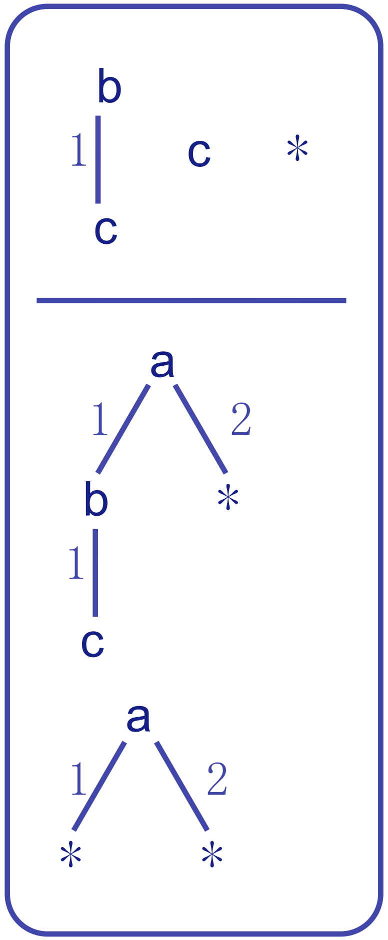

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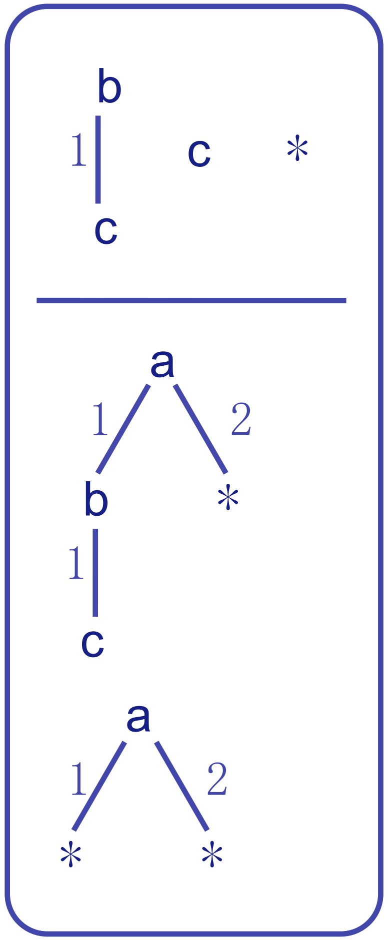

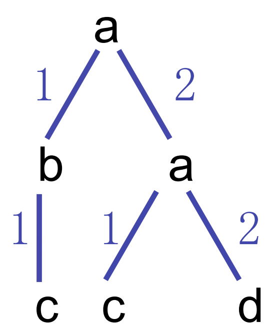

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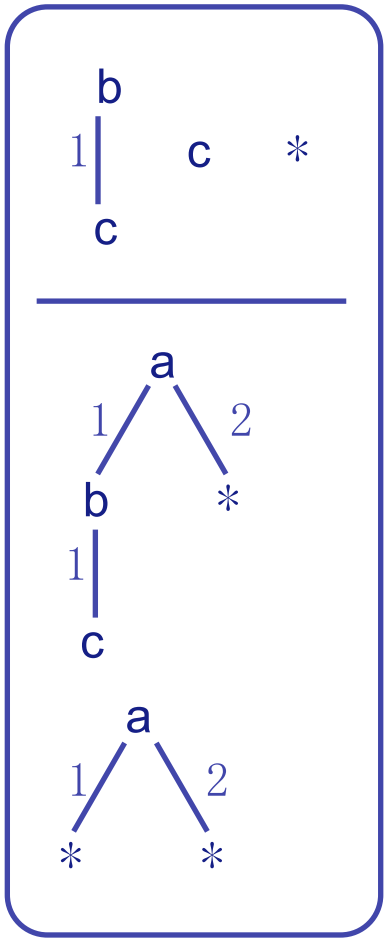

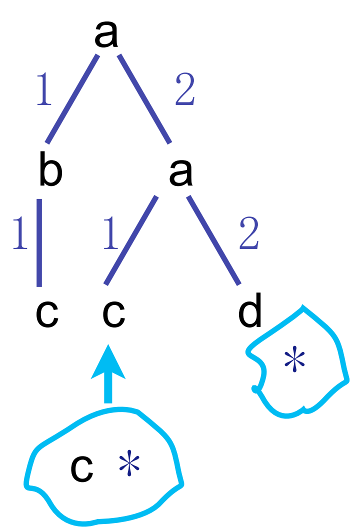

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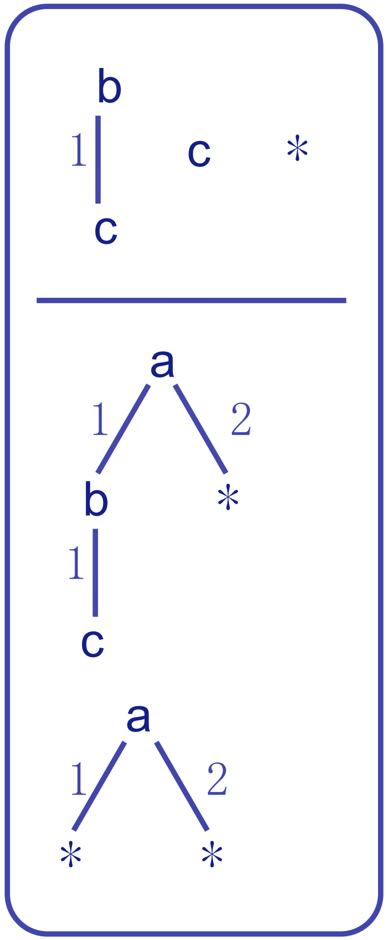

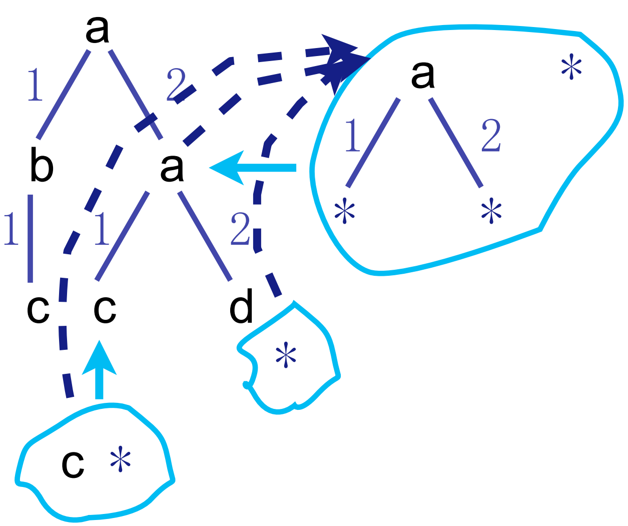

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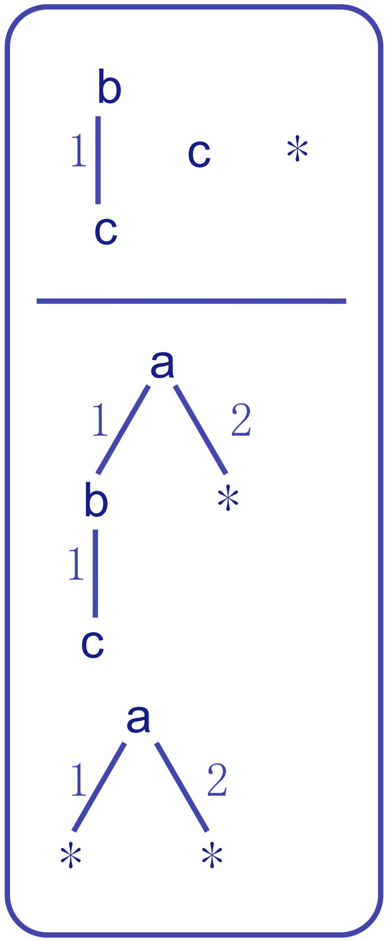

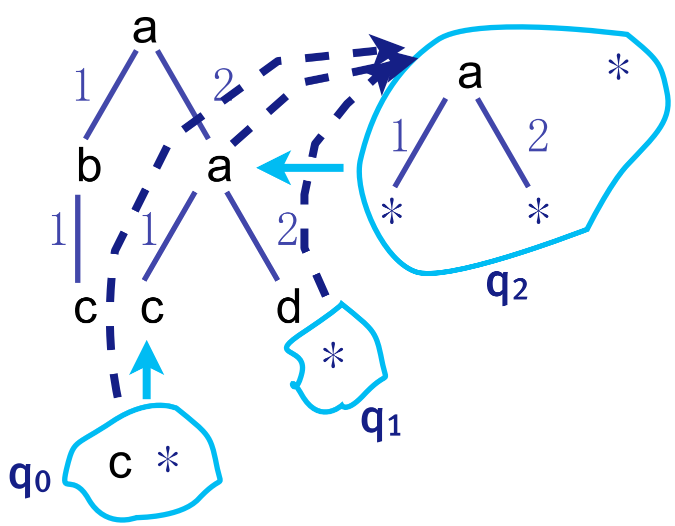

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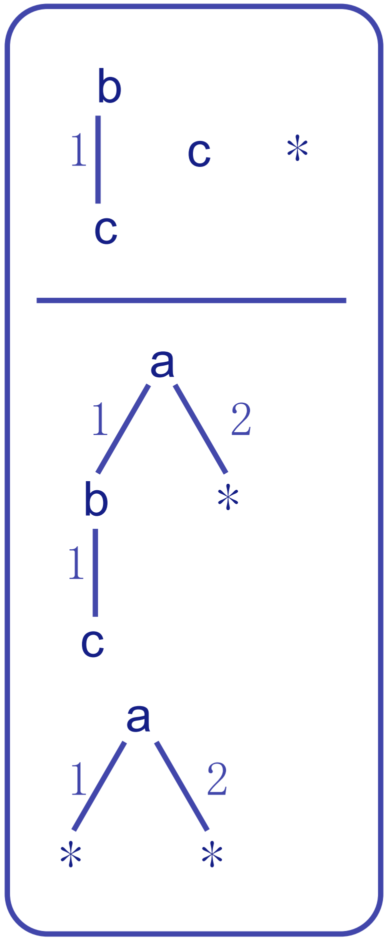
b
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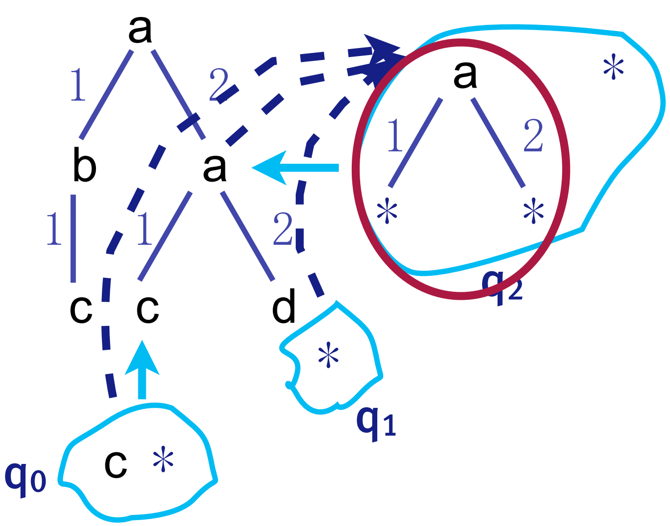
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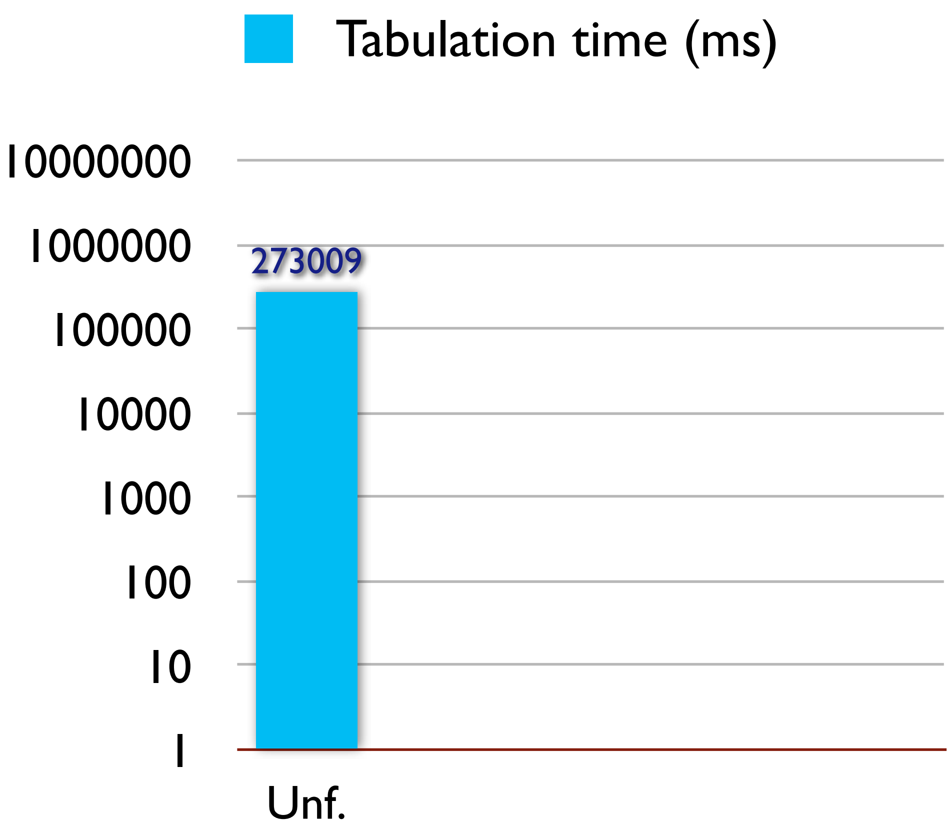
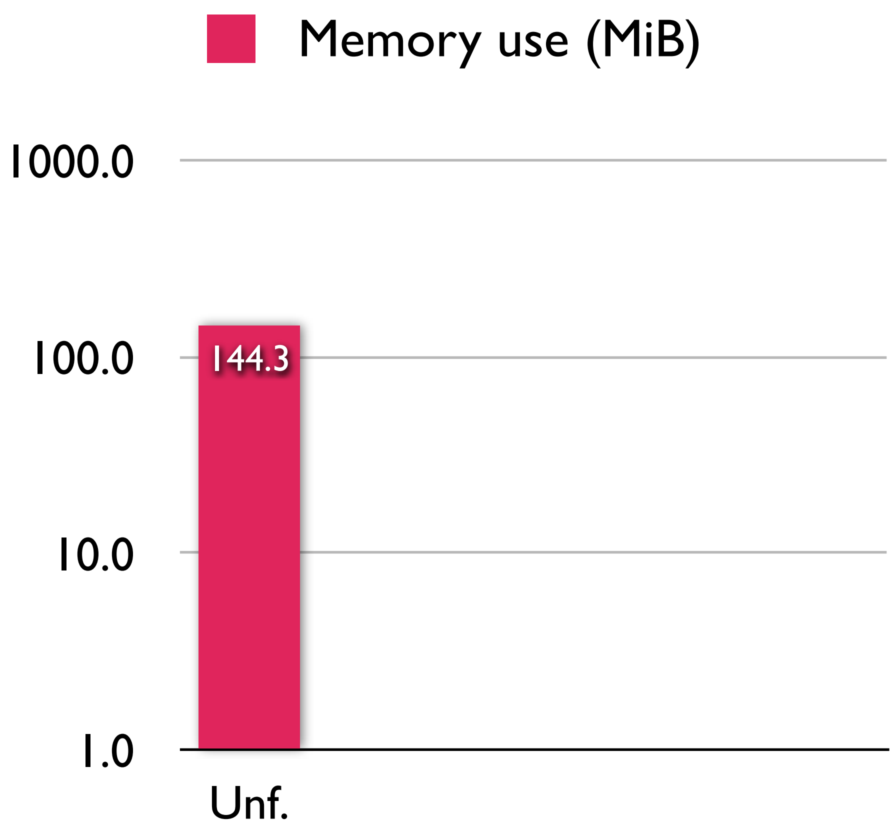
Tree Acceptance Taxonomy
Practical Results - *Filtering match sets for instruction selection*

- Intel X86 CPU





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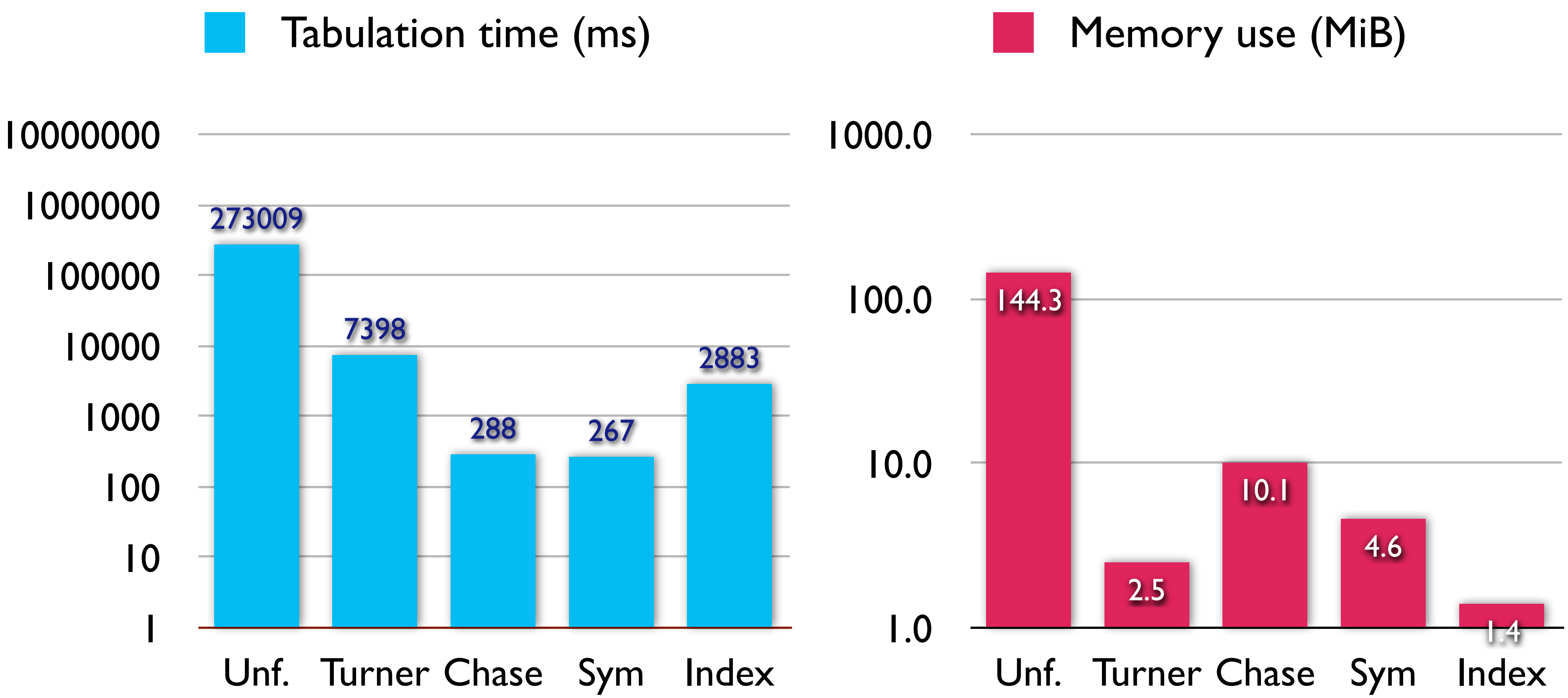
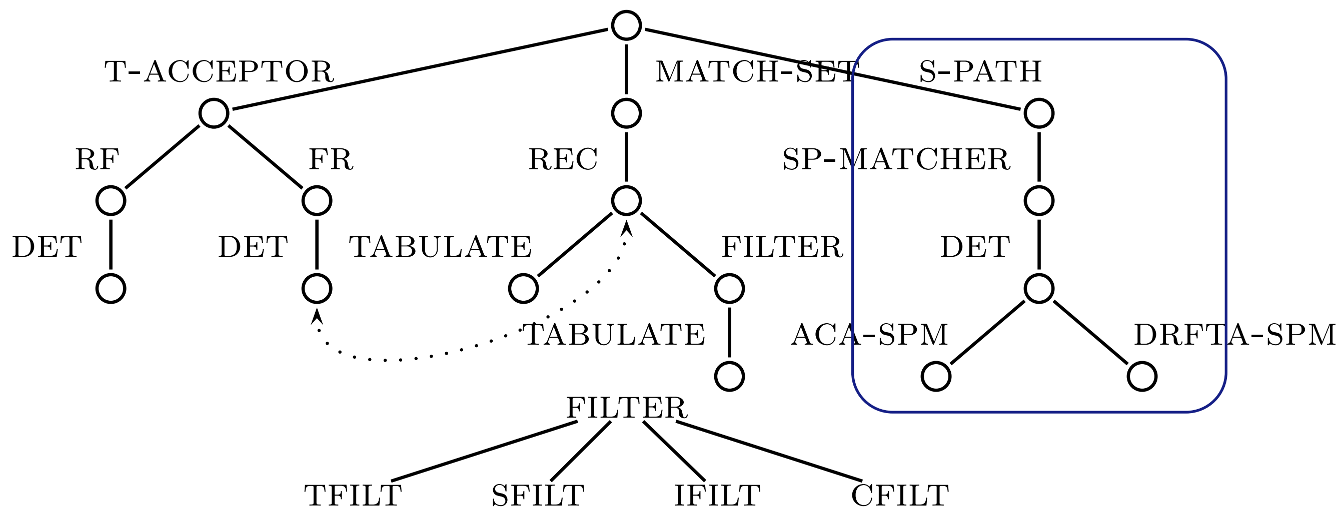


Tree Acceptance Taxonomy Overview - III



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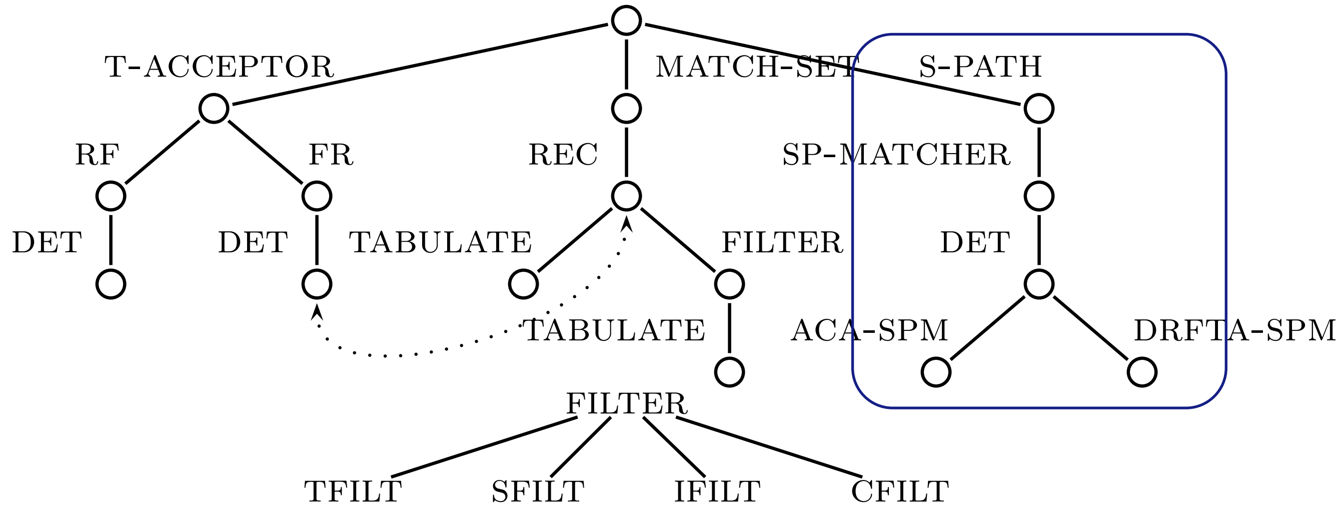

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Wednesday, September 2, 2009

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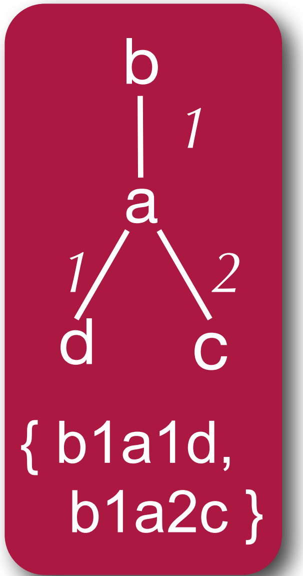

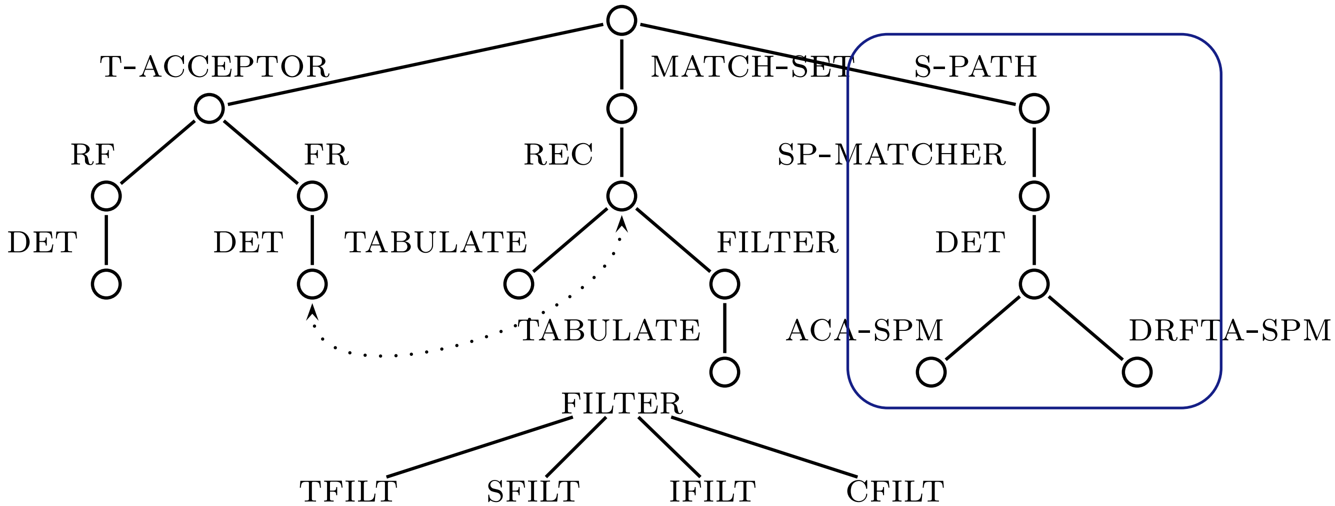

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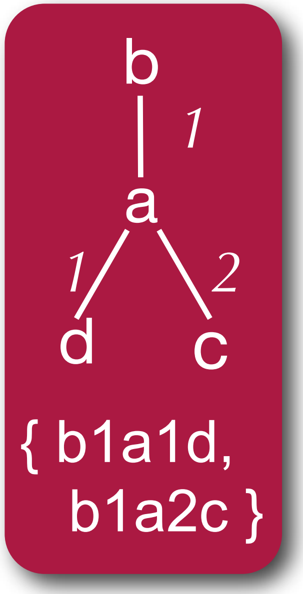

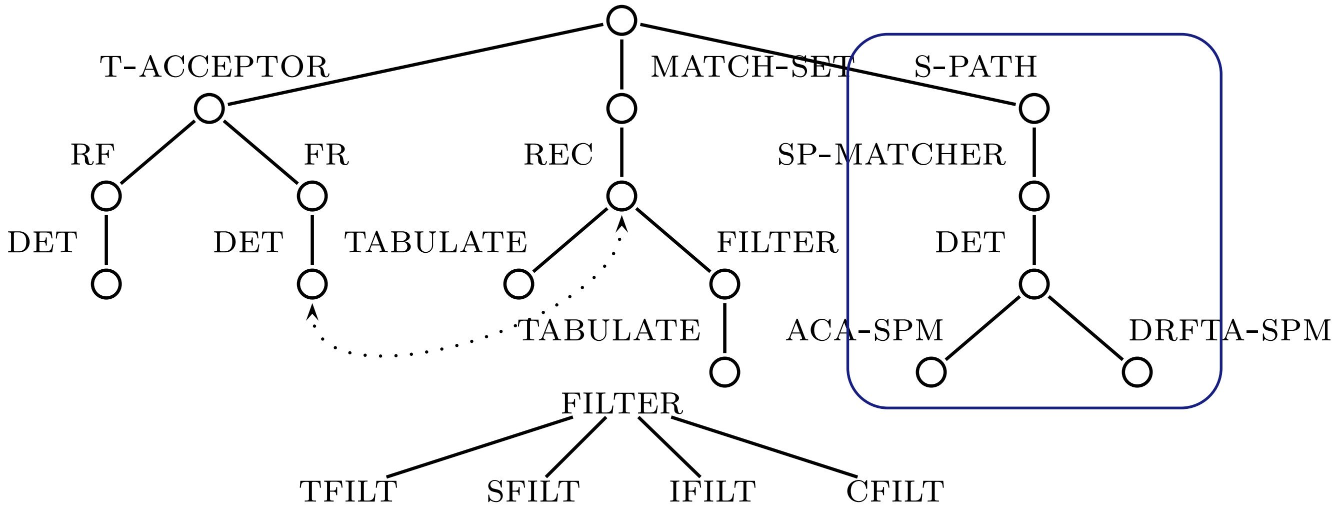

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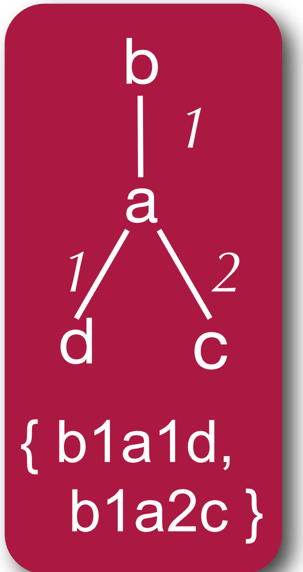

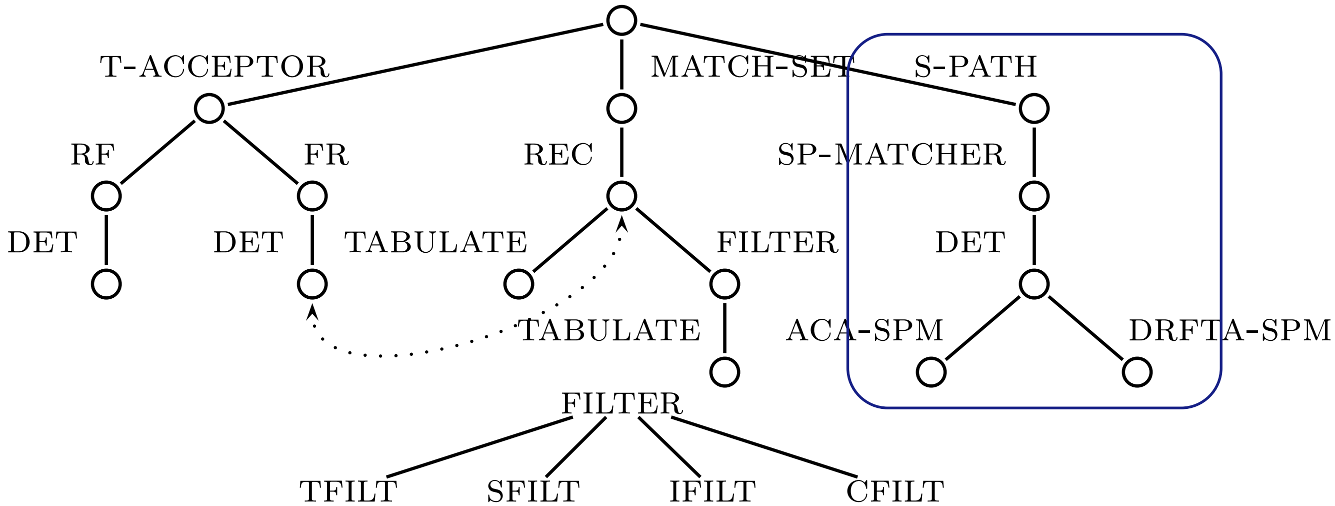

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  - Different automata may be used for stringpath matching

Overview

- Context
  History & relevance, deficiencies, role of taxonomies & toolkits
- Domain
  Trees, patterns & matching, regular tree grammars
- Taxonomies
  Algorithm taxonomies, taxonomies of regular tree algorithms
- Tree Acceptance Taxonomy
  Algorithms b/o tree automata, match sets, stringpath matching
- Concluding Remarks

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- Lead to new/rediscovered algorithms/constructions
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- Implementation
  - *Forest FIRE* toolkit, *FIRE Wood* GUI; 138 interfaces/classes, ~16K LOC
  - *Java*, *SWT*, multi-platform
  - Available via http://www.fastar.org