Syntactic analysis

Input: token sequence

Tasks:

Parsing: construct derivation according to **concrete syntax**,
Tree construction according to **abstract syntax**,
Error handling (detection, message, recovery)

Result: abstract program tree

Compiler module parser:

deterministic stack automaton, augmented by actions for tree construction

top-down parsers: leftmost derivation; tree construction top-down or bottom-up

bottom-up parsers: rightmost derivation backwards; tree construction bottom-up

Abstract program tree (condensed derivation tree):

represented by a **data structure in memory** for the translation phase to operate on,
linear **sequence of nodes on a file** (costly in runtime),
sequence of calls of functions of the translation phase.

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Objectives:

Relation between parsing and tree construction

In the lecture:

- Explain the tasks, use example on CI-16.
- Sources of prerequisites:
- context-free grammars: "Grundlagen der Programmiersprachen (2nd Semester), or "Berechenbarkeit und formale Sprachen" (3rd Semester),
- Tree representation in prefix form, postfix form: "Modellierung" (st Semester); see CI-5.

Suggested reading:

Kastens / Übersetzerbau, Section 4.1

Concrete and abstract syntax

concrete syntax	**abstract syntax**
context-free grammar	context-free grammar
defines the structure of source programs	defines abstract program trees
unambigous	usually ambiguous
specifies derivation and parser	translation phase is based on it
parser actions specify the --->	tree construction
some chain productions only for syntactic purpose `Expr ::= Fact` have no action	keep only semantically relevant ones no node created

symbols of syntactic chain productions comprised in symbol classes `Exp={Expr,Fact}`

same action at structural equivalent productions:

```
Expr ::= Expr AddOpr Fact &BinEx
Fact ::= Fact MulOpr Opd    &BinEx
```

terminal symbols	keep only semantically relevant ones as tree nodes
given the concrete syntax and the actions and	the symbol classes the abstract syntax can be generated

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Objectives:

Distinguish roles and properties of concrete and abstract syntax

In the lecture:

- Use the expression grammar of CI-39, CI-40 for comparison.
- Construct abstract syntax systematically.
- Context-free grammars specify trees - not only strings! Is also used in software engineering to specify interfaces.

Suggested reading:

Kastens / Übersetzerbau, Section 4.1

Exercises:

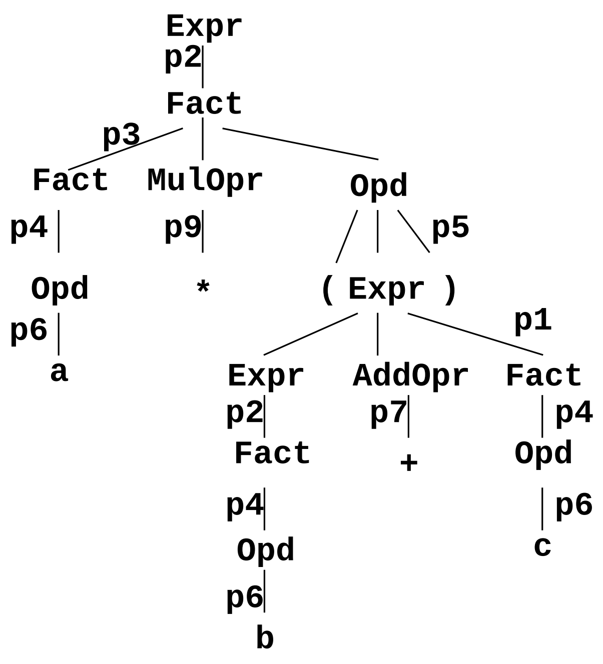
- Generate abstract syntaxes from concrete syntaxes and symbol classes.
- Use Eli for that task. Exercise 10

Questions:

- Why is no information lost, when an expression is represented by an abstract program tree?
- Give examples for semantically irrelevant chain productions outside of expressions.
- Explain: XML-based languages are defined by context-free grammars. Their sentences are textual representations of trees.

Example: concrete expression grammar

name	production	action
p1:	`Expr ::= Expr AddOpr Fact`	*BinEx*
p2:	`Expr ::= Fact`	
p3:	`Fact ::= Fact MulOpr Opd`	*BinEx*
p4:	`Fact ::= Opd`	
p5:	`Opd ::= '(' Expr ')'`	
p6:	`Opd ::= Ident`	*IdEx*
p7:	`AddOpr ::= '+'`	*PlusOpr*
p8:	`AddOpr ::= '-'`	*MinusOpr*
p9:	`MulOpr ::= '*'`	*TimesOpr*
p10:	`MulOpr ::= '/'`	*DivOpr*



derivation tree for `a * (b + c)`

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Objectives:

Illustrate comparison of concrete and abstract syntax

In the lecture:

- Repeat concepts of "GdP" (slide GdP-2.5): Grammar expresses operator precedences and associativity.
- The derivation tree is constructed by the parser - not necessarily stored as a data structure.
- Chain productions have only one non-terminal symbol on their right-hand side.

Suggested reading:

Kastens / Übersetzerbau, Section 4.1

Suggested reading:

slide GdP-2.5

Questions:

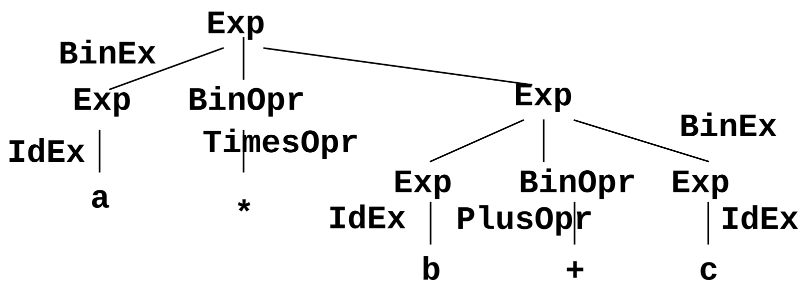
- How does a grammar express operator precedences and associativity?
- What is the purpose of the chain productions in this example.
- What other purposes can chain productions serve?

Example: abstract expression grammar

name **production**

```
BinEx:     Exp    ::= Exp BinOpr Exp
IdEx:      Exp    ::= Ident
PlusOpr:   BinOpr ::= '+'
MinusOpr:  BinOpr ::= '-'
TimesOpr:  BinOpr ::= '*'
DivOpr:    BinOpr ::= '/'
```

abstract program tree for **`a * (b + c)`**



symbol classes: `Exp = { Expr, Fact, Opd }, BinOpr = { AddOpr, MulOpr }`

Actions of the concrete syntax: **productions** of the abstract syntax to create tree nodes for **no action** at a concrete chain production: **no tree node** is created

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Objectives:

Illustrate comparison of concrete and abstract syntax

In the lecture:

- Repeat concepts of "GdP" (slide GdP-2.9):
- Compare grammars and trees.
- Actions create nodes of the abstract program tree.
- Symbol classes shrink node pairs that represent chain productions into one node

Suggested reading:

Kastens / Übersetzerbau, Section 4.1

Suggested reading:

slide GdP-2.9

Questions:

- Is this abstract grammar unambiguous?
- Why is that irrelevant?

Recursive descent parser

top-down (construction of the **derivation** tree), **predictive** method

Sytematic transformation of a context-free grammar into a set of functions:

non-terminal symbol X	function X
alternative productions for X	branches in the function body
decision set of production pi	decision for branch pi
non-terminal occurrence X ::= ... Y ...	function call Y()
terminal occurrence X ::= ... t ...	accept a token t an read the next token

Example:

```
p1: Stmt ::= Variable ':=' Expr  p2: Stmt ::= 'while' Expr 'do' Stmt
```

Function:

```
void Stmt ()
{  switch (CurrSymbol)
   {
case decision set for p1:       case decision set for p2:
   Variable();                     accept(whileSym);
   accept(assignSym);              Expr();
   Expr();                         accept(doSym);
   break;                          Stmt();
                                   break;

   default: Fehlerbehandlung();
}  }
```

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Objectives:

Understand the construction schema

In the lecture:

Explanation of the method:

- Relate grammar constructs to function constructs.
- Each function plays the role of an acceptor for a symbol.
- accept function for reading and checking of the next token (scanner).
- Computation of decision sets on CI-42.
- Decision sets must be pairwise disjoint!

Suggested reading:

Kastens / Übersetzerbau, Section 4.2

Questions:

- A parser algorithm is based on a stack automaton. Where is the stack of a recursive descent parser? What corresponds to the states of the stack automaton?
- Where can actions be inserted into the functions to output production sequences in postfix or in prefix form?

Grammar conditions for recursive descent

A context-free grammar is **strong LL(1)**, if for any pair of productions that have the same symbol on their left-hand sides, the **decision sets are disjoint**:

productions:	A ::= u		A ::= v	
decision sets:	First (u Follow(A))	$\cap$	First (v Follow(A))	= $\emptyset$

First set and **follow set:**

First (u) := { $t \in T$ \| $v \in V^*$ exists and a derivation $u \Rightarrow^* t\ v$ } and $\varepsilon \in$ First (u) if $u \Rightarrow^* \varepsilon$ exists

Follow (A) := { $t \in T$ \| $u,v \in V^*$ exist, $A \in N$ and a derivation $S \Rightarrow^* u\ A\ v$ such that $t \in$ First (v) }

Example:

	production		decision set
p1:	Prog	::= Block #	begin
p2:	Block	::= begin Decls Stmts end	begin
p3:	Decls	::= Decl ; Decls	new
p4:	Decls	::=	Ident begin
p5:	Decls	::= new Ident	new
p6:	Stmts	::= Stmts ; Stmt	begin Ident
p7:	Stmts	::= Stmt	begin Ident
p8:	Stmt	::= Block	begin
p9:	Stmt	::= Ident := Ident	Ident

non-terminal X

	First(X)	**Follow(X)**
Prog	begin	
Block	begin	# ; end
Decls	ε new	Ident begin
Decl	new	;
Stmts	begin Ident	; end
Stmt	begin Ident	; end

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Objectives:

Strong LL(1) can easily be checked

In the lecture:

- Explain the definitions using the example.
- First set: set of terminal symbols, which may begin some token sequence that is derivable from u.
- Follow set: set of terminal symbols, which may follow an A in some derivation.

Suggested reading:

Kastens / Übersetzerbau, Section 4.2, LL(k) conditions, computation of First sets and Follow sets

Questions:

The example grammar is not strong LL(1).

- Show where the condition is violated.
- Explain the reason for the violation.
- What would happen if we constructed a recursive descent parser although the condition is violated?

Grammar transformations for LL(1)

Consequences of strong LL(1) condition: A strong LL(1) grammar can not have

- **alternative productions that begin with the same symbols**
- **productions that are directly or indirectly left-recursive.**

Simple grammar transformations that keep the defined language invariant:

	non-LL(1) productions	transformed
• **left-factorization:** $u, v, w \in V^*$; $X \in N$ does not occur in the original grammar	A ::= v u A ::= v w	A ::= v X X ::= u X ::= w
• **elimination of direct recursion :**	A ::= A u A ::= v	A ::= v X X ::= u X X ::=

EBNF constructs can avoid violation of strong LL(1) condition:

for example repetition of u:	A ::= v (u)* w
additional condition:	$First(u) \cap First(w\ Follow(A)) = \emptyset$
branch in the function body:	v **while (CurrToken in First(u)) { u }** w

correspondingly for EBNF constructs u^+, [u]

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Objectives:

Understand transformations and their need

In the lecture:

- Argue why strong LL(1) grammars can not have such productions.
- Show why the transformations remove those problems.
- Replacing left-recursion by right recursion would usually distort the structure.
- There are more general rules for indirect recursion.
- Show EBNF productions in recursive descent parsers.

Questions:

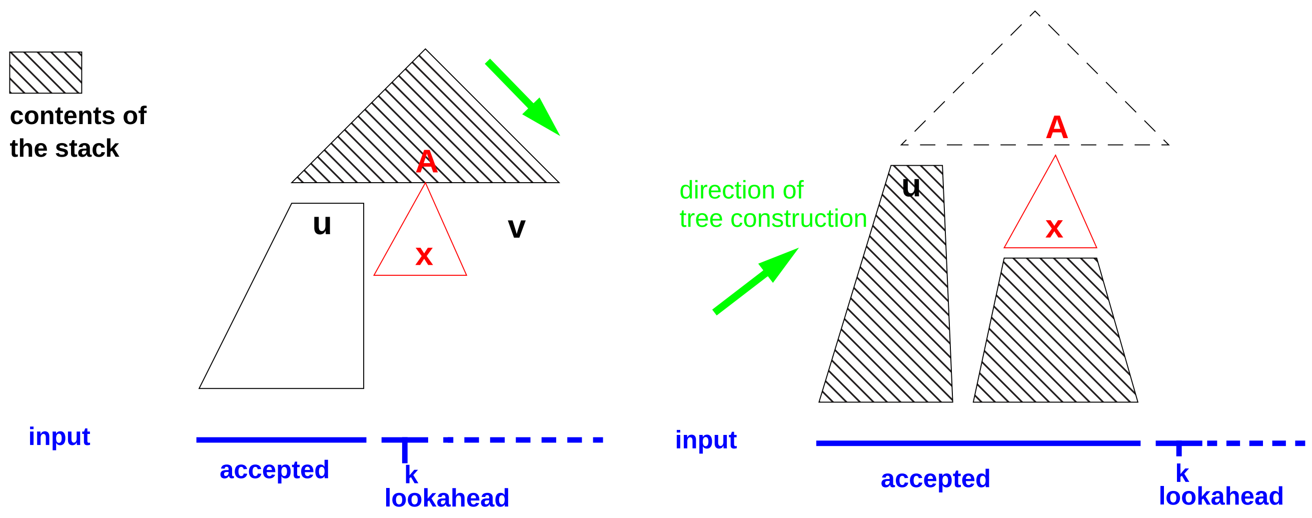
- Apply recursion elimination for expression grammars.
- Write a strong LL(1) expression grammar using EBNF.

Comparison: top-down vs. bottom-up

Information a stack automata has when it decides to apply production A ::= x :

top-down, predictive
leftmost derivation

bottom-up
rightmost derivation backwards



A bottom-up parser has seen more of the input when it decides to apply a production.

Consequence: **bottom-up** parsers and their grammar classes are more **powerful**.

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Objectives:

Understand the decision basis of the automata

In the lecture:

Explain the meaning of the graphics:

- role of the stack: contains states of the automaton,
- accepted input: will not be considered again,
- lookahead: the next k symbols, not yet accepted
- leftmost derivation: leftmost non-terminal is derived next; rightmost correspondingly,
- consequences for the direction of tree construction,

Abbreviations

- LL: (L)eft-to-right, (L)eftmost derivation,
- LR: (L)eft-to-right, (R)ightmost derivation,
- LALR: (L)ook(A)head LR

Suggested reading:

Kastens / Übersetzerbau, Section Text zu Abb. 4.2-1, 4.3-1

Questions:

Use the graphics to explain why a bottom-up parser without lookahead (k=0) is reasonable, but a top-down parser is not.

LR(1) automata

LR(k) grammars introduced 1965 by Donald Knuth; non-practical until subclasses were defined.

LR parsers construct the derivation tree **bottom-up,** a right-derivation backwards.

LR(k) grammar condition can not be checked directly, but
a context-free grammar is LR(k), iff the (canonical) **LR(k) automaton is deterministic**.

We consider only **1 token lookahead: LR(1).**

The **stacks** of LR(k) (and LL(k)) automata **contain states**.
The construction of LR and LL states is based on the notion of **items** (also called situations):

An **item** represents the progress of analysis with respect to one production:

[A ::= u . v R] z. B. **[B ::= (. D ; S) {#}]**

. position of analysis

R expected **right context,** i. e. a set of terminals which may follow after the application of the complete production. (for general k: R contains terminal sequences not longer than k)

Reduce item:

[A ::= u v . R] z. B. **[B ::= (D ; S) . {#}]**

characterizes a reduction using this production if the next input token is in R.

Each **state** of an automaton represents **LL: one item** **LR: a set of items**

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Objectives:

Fundamental notions of LR automata

In the lecture:

Explain

- meaning of an item,
- lookahead in the input and right context in the automaton.
- There is no right context set in case of an LR(0) automaton.

Suggested reading:

Kastens / Übersetzerbau, Section 4.3

Questions:

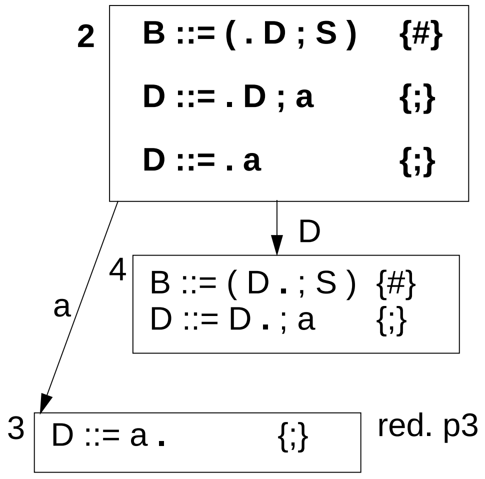
- What contains the right context set in case of a LR(3) automaton?

LR(1) states and operations

A **state of an LR automaton represents a set of items**
Each item represents a way in which analysis may proceed from that state.

A shift transition is made under
a **token read** from input or
a **non-terminal** symbol
obtained from a **preceding reduction.**
The state is pushed.

A **reduction** is made according to a reduce item.
n states are popped for a production of length n.



Operations:	**shift**	read and push the next state on the stack
	reduce	reduce with a certain production, pop n states from the stack
	error	error recognized, report it, recover
	stop	input accepted

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Objectives:

Understand LR(1) states and operations

In the lecture:

Explain

- Sets of items,
- shift transitions,
- reductions.

Suggested reading:

Kastens / Übersetzerbau, Section 4.3

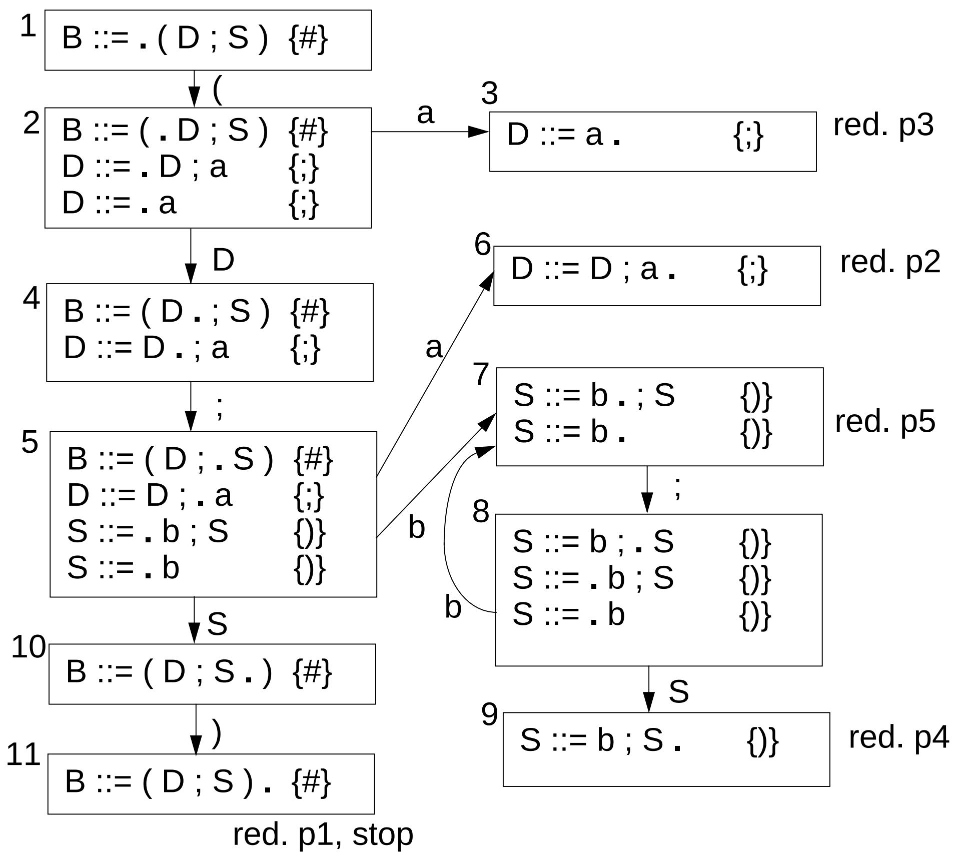
Questions:

- Explain: A state is encoded by a number. A state represents complex information which is important for construction of the automaton.

Example for a LR(1) automaton

Grammar:

p1	B ::= (D ; S)
p2	D ::= D ; a
p3	D ::= a
p4	S ::= b ; S
p5	S ::= b



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Objectives:

Example for states, transitions, and automaton construction

In the lecture:

Use the example to explain

- the start state,
- the creation of new states,
- transitions into successor states,
- transitive closure of item set,
- push and pop of states,
- consequences of left-recursive and right-recursive productions,
- use of right context to decide upon a reduction,

erläutern.

Suggested reading:

Kastens / Übersetzerbau, Section 4.3

Questions:

- Describe the subgraphs for left-recursive and right-recursive productions. How do they differ?
- How does a LR(0) automaton decide upon reductions?

Construction of LR(1) automata

Create the start state; create transitions and states as long as new ones can be created.

Transitive closure is to be applied to each state:

If **[A ::= u . B v R]** is in state q,
with the analysis position before a non-terminal B,
then for each production **B ::= w**
[B ::= . w First (v R)]
has to be added to state q.

before:

```
B ::= ( . D ; S )  {#}
```

after:

```
2  B ::= ( . D ; S )  {#}
   D ::= . D ; a      {;}
   D ::= . a          {;}
```

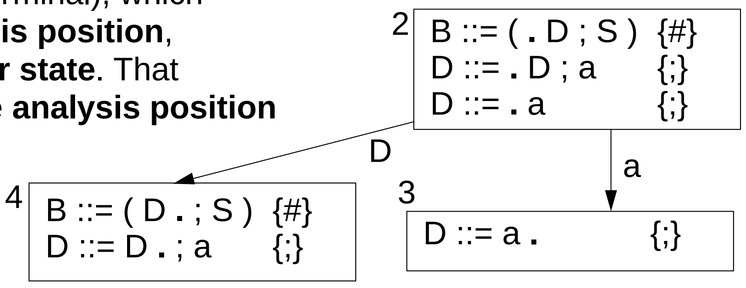
Start state:

Closure of **[S ::= . u {#}]**
S ::= u is the **unique start production**,
# is an **artificial end symbol** (eof)

```
1  B ::= . ( D ; S )  {#}
```

Successor states:

For each **symbol x** (terminal or non-terminal), which occurs in some items **after the analysis position**, a **transition** is created **to a successor state**. That contains a corresponding item with the **analysis position advanced behind the x** occurrence.



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Objectives:

Understand the method

In the lecture:

Explain using the example on CI-47:

- transitive closure,
- computation of the right context sets,
- relation between the items of a state and those of one of its successor

Suggested reading:

Kastens / Übersetzerbau, Section 4.3

Questions:

- Explain the role of the right context.
- Explain its computation.

Operations of the LR(1) automaton

shift x (terminal or non-terminal):
from current state q
under x into the**successor state q‘** ,
push q‘

reduce p:
apply production p B ::= u ,
pop as many states,
as there are **symbols in u**, from the
new current state make a **shift with B**

error:
the current state has no transition
under the next input token,
issue a **message** and **recover**

stop:
recuce start production,
see # in the input

Example:

stack	**input**	**reduction**
1	(a ; a ; b ; b) #	
1 2	a ; a ; b ; b) #	
1 2 3	; a ; b ; b) #	p3
1 2	; a ; b ; b) #	
1 2 4	; a ; b ; b) #	
1 2 4 5	a ; b ; b) #	
1 2 4 5 6	; b ; b) #	p2
1 2	; b ; b) #	
1 2 4	; b ; b) #	
1 2 4 5	b ; b) #	
1 2 4 5 7	; b) #	
1 2 4 5 7 8	b) #	
1 2 4 5 7 8 7	) #	p5
1 2 4 5 7 8	) #	
1 2 4 5 7 8 9	) #	p4
1 2 4 5	) #	
1 2 4 5 10	) #	
1 2 3 5 10 11	#	p1
1	#	

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Objectives:

Understand how the automaton works

In the lecture:

Explain operations

Questions:

- Why does the automaton behave differently on a-sequences and b-sequences?
- Which behaviour is better?

LR conflicts

An **LR(1) automaton that has conflicts is not deterministic**. Its **grammar is not LR(1)**; correspondingly defined for any other LR class.

2 kinds of conflicts:

reduce-reduce conflict:
A state contains two reduce items, the **right context sets** of which are **not disjoint**:

```
...
A ::= u .   R1
B ::= v .   R2
...
```

R1, R2 not disjoint

shift-reduce conflict:
A state contains
a **shift item** with the **analysis position in front of a t** and
a **reduce item with t in its right context set**.

```
...
A ::= u .t v   R1
B ::= w .      R2
...
```

t ∈ R2

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Objectives:

Understand LR conflicts

In the lecture:

Explain: In certain situations the given input token t can not determine

- Reduce-reduce: which reduction is to be taken;
- Shift-reduce: whether the next token is to be shifted, a reduction is to be made.

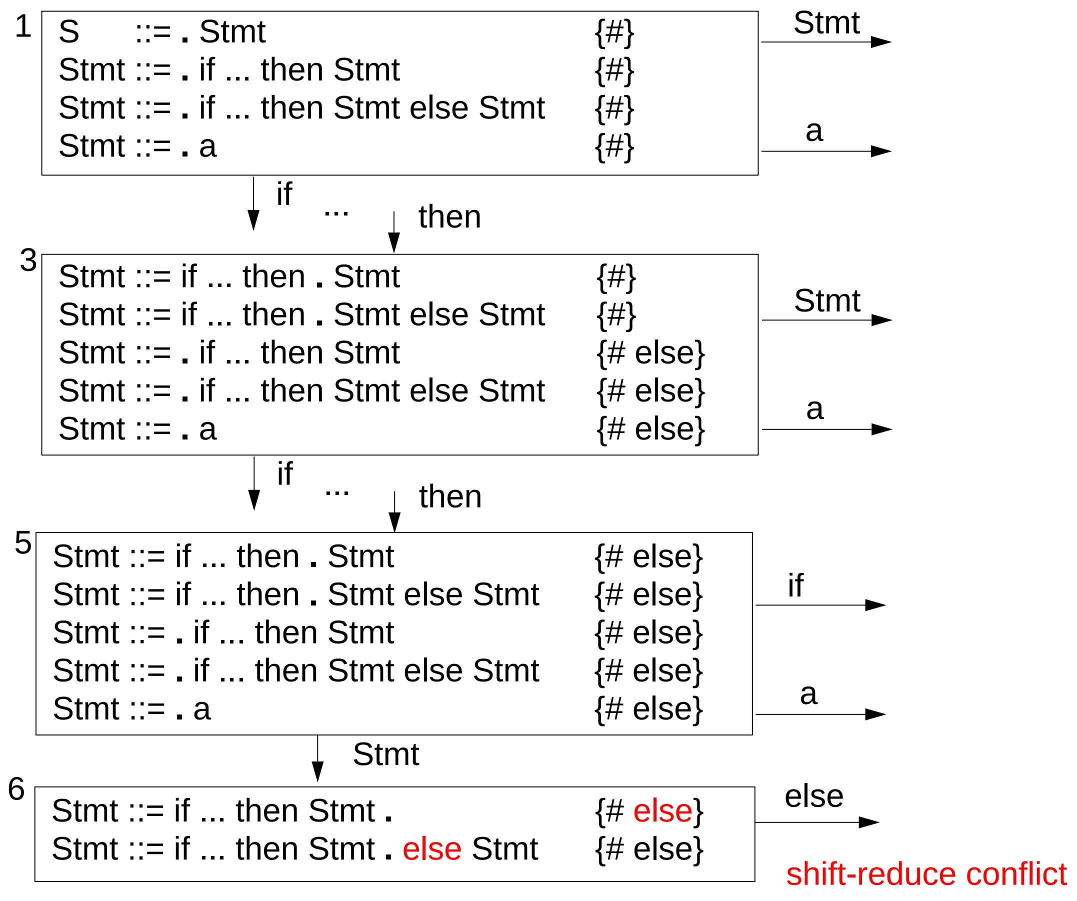
Suggested reading:

Kastens / Übersetzerbau, Section 4.3

Questions:

- Why can a shift-shift conflict not exist?
- In LR(0) automata items do not have a right-context set. Explain why a state with a reduce item may not contain any other item.

Shift-reduce conflict for „dangling else“ ambiguity



1

S ::= **.** Stmt	{#}
Stmt ::= **.** if ... then Stmt	{#}
Stmt ::= **.** if ... then Stmt else Stmt	{#}
Stmt ::= **.** a	{#}

3

Stmt ::= if ... then **.** Stmt	{#}
Stmt ::= if ... then **.** Stmt else Stmt	{#}
Stmt ::= **.** if ... then Stmt	{# else}
Stmt ::= **.** if ... then Stmt else Stmt	{# else}
Stmt ::= **.** a	{# else}

5

Stmt ::= if ... then **.** Stmt	{# else}
Stmt ::= if ... then **.** Stmt else Stmt	{# else}
Stmt ::= **.** if ... then Stmt	{# else}
Stmt ::= **.** if ... then Stmt else Stmt	{# else}
Stmt ::= **.** a	{# else}

6

Stmt ::= if ... then Stmt **.**	{# else}
Stmt ::= if ... then Stmt **.** else Stmt	{# else}

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Objectives:

See a conflict in an automaton

In the lecture:

Explain

- the construction
- a solution of the conflict: The automaton can be modified such that in state 6, if an else is the next input token, it is shifted rather than a reduction is made. In that case the ambiguity is solved such that the else part is bound to the inner if. That is the structure required in Pascal and C. Some parser generators can be instructed to resolve conflicts in this way.

Suggested reading:

Kastens / Übersetzerbau, Section 4.3

Simplified LR grammar classes

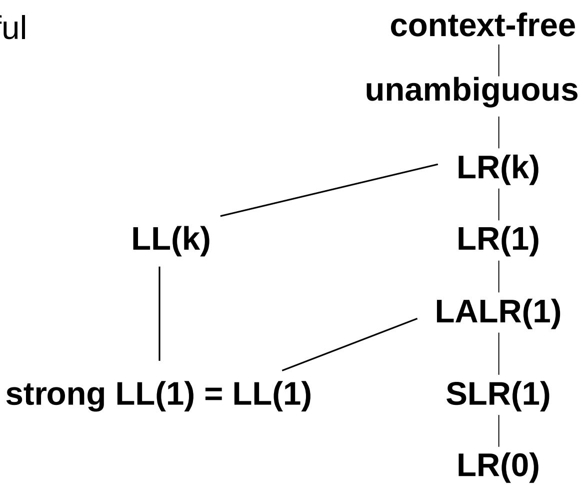
LR(1):
too many states for practical use
Reason: right-contexts distinguish many states
Strategy: simplify right-contexts sets,
fewer states, grammar classes are less powerful

LR(0):
all items **without right-context**
Consequence: reduce items only in
singleton sets

SLR(1):
LR(0) states; in reduce items
use larger right-context sets for decision:
[A ::= u . Follow (A)]

LALR(1):
identify LR(1) states if their items differ only
in their right-context sets, unite the sets for those items;
yields the states of the **LR(0) automaton**
augmented by the "exact" LR(1) right-context.
State-of-the-art parser generators accept LALR(1)

Grammar hierarchy:
(strict inclusions)



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Objectives:

Understand relations between LR classes

In the lecture:

Explain:

- LALR(1), SLR(1), LR(0) automata have the same number of states,
- compare their states,
- discuss the grammar classes for the example on slide CI-47.

Suggested reading:

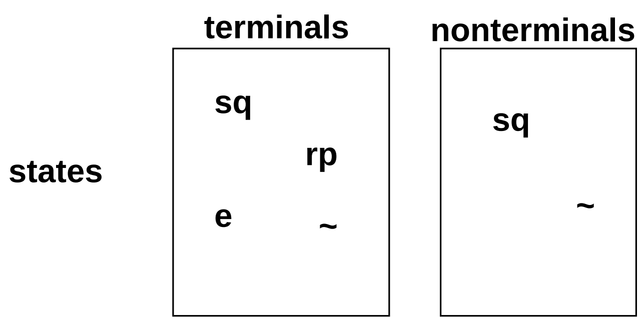
Kastens / Übersetzerbau, Section 4.3

Questions:

- Assume that the LALR(1) contruction for a given grammar yields conflicts. Classify the potential reasons using the LR hierarchy.

Implementation of LR automata

Table-driven:



sq: shift into state q

rp: reduce production p

e: error

~: never reached

Compress tables:

- **merge rows or columns** that differ only in irrelevant entries; method: graph coloring
- extract a **separate error matrix** (bit matrix); increases the chances for merging
- **normalize the values of rows or columns**; yields smaller domain; supports merging
- **eliminate LR(0) reduce states**; new operation in predecessor state: **shift-reduce** eliminates about 30% of the states in practical cases

About 10-20% of the original table sizes can be achieved!

Directly programmed LR-automata are possible - but usually too large.

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Objectives:

Implementation of LR tables

In the lecture:

Explanation of

- pair of tables and their entries,
- unreachable entries,
- compression techniques, derived from general table compression,
- Singleton reduction states yield an effective optimization.

Questions:

- Why are there no error entries in the nonterminal part?
- Why are there unreachable entries?
- Why does a parser need a shift-reduce operation if the optimization of LR(0)-reduction states is applied?

Error handling: general criteria

- **recognize error as early as possible**
  LL and LR can do that
- **report the symptom in terms of the source text**
- **continue parsing short after the error position**
- **avoid avalanche errors**
- **build a tree that has a correct structure**
- **do not backtrack, do not undo actions**
- **no runtime penalty for correct programs**

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Objectives:

Accept strong requirements

In the lecture:

- The reasons for and the consequences of the requirements are discussed.
- Some of the requirements hold for error handling in general - not only that of the syntactic analysis.

Error position

Error recovery: Means that are taken by the parser after recognition of a syntactic error in order to continue parsing

Correct prefix: The token sequence w ∈ T* is a correct prefix in the language L(G), if there is an u ∈ T* such that **w u ∈ L(G)**; i. e. w can be extended to a sentence in L(G).

Error position: t is the (first) error position in the **input w t x** , where t ∈ T and w, x ∈ T*, if **w is a correct prefix** in L(G) and **w t is not a correct prefix**.

Example: $\underbrace{\texttt{int compute (int i) \{ a = i *}}_{w}\ \underset{t}{\texttt{/}}\ \texttt{c; return i;\}}$

LL and LR parsers recognize an error at the error position; they can not accept t in the current state.

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Objectives:

Error position from the view of the parser

In the lecture:

Explain the notions with respect to parser actions using the examples.

Questions:

Assume the programmer omitted an opening parenthesis.

- Where is the error position?
- What is the symptom the parser recognizes?

Error recovery

Continuation point:
The token d at or behind the error position t such that
parsing of the input continues at d.

Error repair
with respect to a consistent derivation - regardless the intension of the programmer!

Let the input be w t x with the error position at t and let w t x = w y d z,
then the recovery (conceptually) **deletes y** and **inserts v**,
such that **w v d is a correct prefix** in L(G), with d $\in$ T and w, y, v, z $\in$ T*.

Examples:

```
____w____ y d __z__
 a = i * / c;...
 a = i *   c;...
```

delete /

```
____w____ yd  __z___
 a = i * / c;...
 a = i *e/ c;...
```

insert error id. e

```
____w____  __y d z___
 a = i * / c;...
 a = i * e  ;...
```

delete / c
and **insert** error id. **e**

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Objectives:

Understand error recovery

In the lecture:

Explain the notions with respect to parser actions using the examples.

Questions:

Assume the programmer omitted an opening parenthesis.

What could be a suitable repair?

Recovery method: simulated continuation

Problem: Determine a continuation point close to the error position and reach it.

Idea: Use parse stack to determine a set of tokens as potential continuation points.

Steps of the method:

1. **Save the contents of the parse stack** when an error is recognized. Skip the error token.
2. **Compute a set D $\subseteq$ T of tokens that may be used as continuation point** (**anchor set**)
   Let a modified parser run to completion:
   Instead of reading a token from input it is inserted into D; (modification given below)
3. **Find a continuation point d**: Skip input tokens until a token of D is found.
4. **Reach the continuation point d**:
   Restore the saved parser stack as the current stack.
   Perform dedicated transitions until d is acceptable.
   Instead of reading tokens (conceptually) insert tokens. Thus a correct prefix is constructed.
5. **Continue normal parsing**.

Augment parser construction for steps 2 and 4:
For each parser state select a transition and its token,
such that the parser empties its stack and terminates as fast as possible.
This selection can be **generated automatically**.
The quality of the recovery can be improved by influence on the computation of D.

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Objectives:

Error recovery can be generated

In the lecture:

- Explain the idea and the steps of the method.
- The method yields a correct parse for any input!
- Other, less powerful methods determine sets D statically at parser construction time, e. g. semicolon and curly bracket for errors in statements.

Questions:

- How does this method fit to the general requirements for error handling?

Parser generators

PGS	Univ. Karlsruhe; in Eli	**LALR(1), table-driven**
Cola	Univ. Paderborn; in Eli	**LALR(1), optional: table-driven or directly programmed**
Lalr	Univ. / GMD Karlsruhe	**LALR(1), table-driven**
Yacc	Unix tool	**LALR(1), table-driven**
Bison	Gnu	**LALR(1), table-driven**
Llgen	Amsterdam Compiler Kit	**LL(1), recursive descent**
Deer	Univ. Colorado, Bouder	**LL(1), recursive descent**

Form of grammar specification:
EBNF: Cola, PGS, Lalr; **BNF**: Yacc, Bison

Error recovery:

simulated continuation, automatically generated:	Cola, PGS, Lalr
error productions, hand-specified:	Yacc, Bison

Actions:
statements in the implementation language

at the end of productions:	Yacc, Bison
anywhere in productions:	Cola, PGS, Lalr

Conflict resolution:

modification of states (reduce if ...)	Cola, PGS, Lalr
order of productions:	Yacc, Bison
rules for precedence and associativity:	Yacc, Bison

Implementation languages:
C: Cola, Yacc, Bison **C, Pascal, Modula-2, Ada**: PGS, Lalr

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Objectives:

Overview over parser generators

In the lecture:

Explain the significance of properties

Suggested reading:

Kastens / Übersetzerbau, Section 4.5