CSE443
Compilers

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symbol tables

One table per scope

Solid interface functions (constructors, accessors and mutators)

Good encapsulation and information hiding

Flexible design

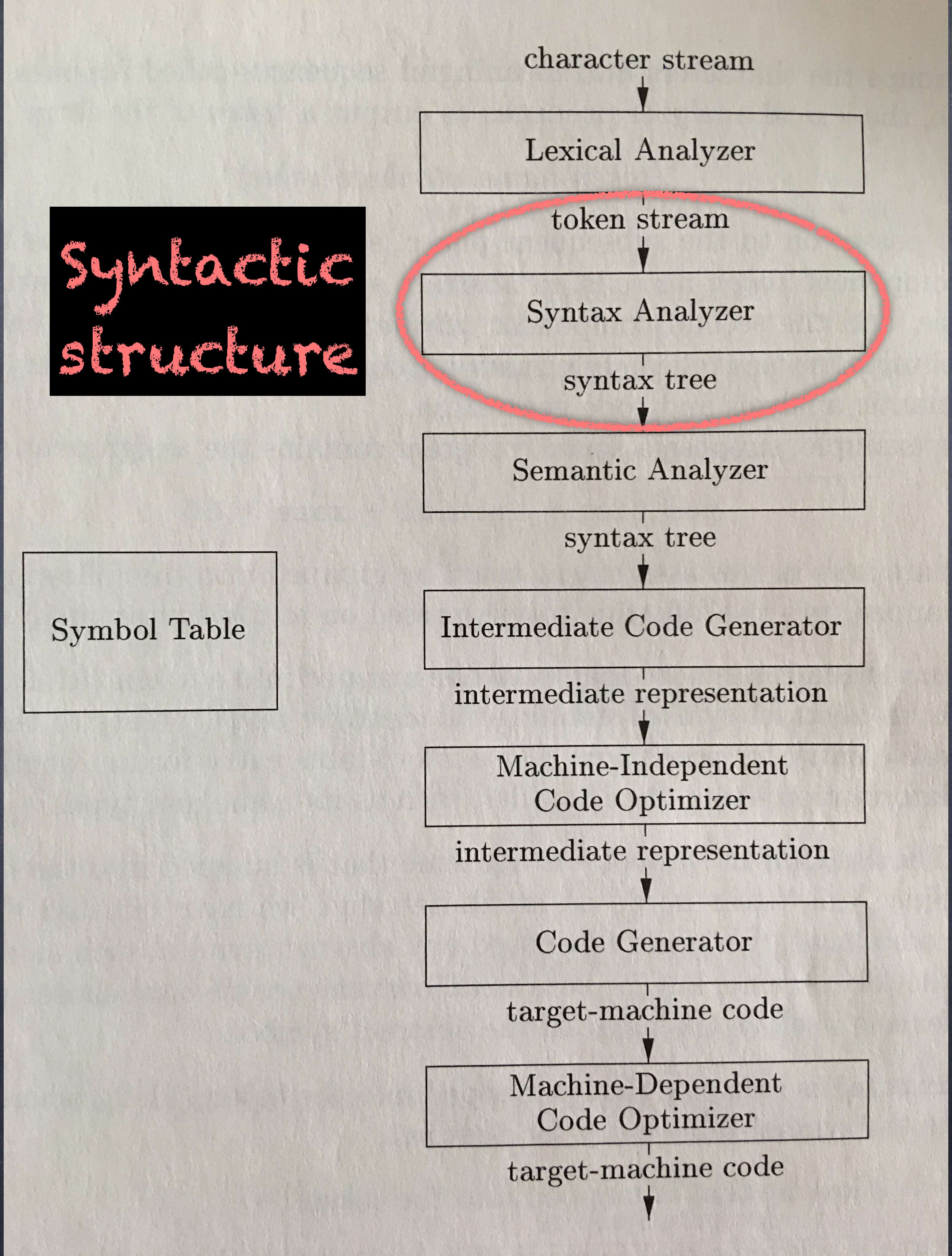
```
/******************************************************************************
 Types
 ******************************************************************************/

struct SymbolTable;
struct SymbolTableList;
struct SymbolTableEntry;

/* Every symbol table entry must denote either a TYPE, a FUNCTION, or a
   VARIABLE.

   The type EntryCategory is used to express the kind of symbol table entry:

     TYPE is used for entries that denote types
     FUNCTION is used for entries that denote functions
     VARIABLE is used for entries that denote variables
*/
enum EntryCategory { TYPE, FUNCTION, VARIABLE };

/* Every type belongs to one of the following categories:

   PRIMITIVE is used for primitive types (such as integer, real, character,
   Boolean)

   PRODUCT is used for Cartesian products of types (i.e. structs/records)

   SUM is used for union (or sum) types; alpha does not currently support
   this category of type.

   MAPPING is used for mapping types: function types and array types

   UNDEFINED is used for expressions whose type is ill-defined
*/
enum TypeCategory { UNDEFINED, MAPPING, PRIMITIVE, PRODUCT, SUM };
```

```
/*******************************************************************************
 Constructors
   These functions build new values of the type indicated by the return type
   specification.
 *******************************************************************************/

/* Build and return a pointer to a new SymbolTable.  Every symbol table has a
   unique parent, except the top-level symbol table.  The top-level symbol
   table is created by the call:

       newSymbolTable(NULL)

*/
struct SymbolTable* newSymbolTable(struct SymbolTabe* parent);

/* Build and return a pointer to a new SymbolTableList.  The SymbolTableList
   has one member, table.
 */
struct SymbolTableList* newSymbolTableList(struct SymbolTable* table);

/* Build and return a pointer to a new SymbolTableEntry, of the indicated
   category.
 */
struct SymbolTableEntry* newSymbolTableEntry(enum EntryCategory category);
```

```
/*******************************************************************************
 Mutators
*******************************************************************************/

void addEntryToSymbolTable(struct SymbolTable* table, struct SymbolTableEntry* entry);

void addChildToSymbolTable(struct SymbolTable* parent, struct SymbolTable* child);
```

```
/******************************************************************************
 Accessors
 ******************************************************************************/

struct SymbolTable* getSymbolTable(void);

struct SymbolTable* getParent(struct SymbolTable* table);

struct SymbolTableList* getChildren(struct SymbolTable* table);

struct SymbolTableList* getRestOfChildren(struct SymbolTableList* list);

struct SymbolTable* getFirstOfChildren(struct SymbolTableList* list);

struct SymbolTableEntry* getEntryInSymbolTable(struct SymbolTable* table, char* name, bool ancestorSearch);

char * getName(struct SymbolTableEntry* entry);

enum EntryCategory getEntryCategory(struct SymbolTableEntry* entry);

enum TypeCategory getTypeCategory(struct SymbolTableEntry* entry);

struct SymbolTableEntry* getType(struct SymbolTableEntry* entry);

bool hasInit(struct SymbolTableEntry* entry);

int_least32_t makeSymbolTableID(int lineNumber, int colNumber);

struct SymbolTable* getSymbolTable(struct SymbolTableEntry* entry);
```

Phases of a compiler



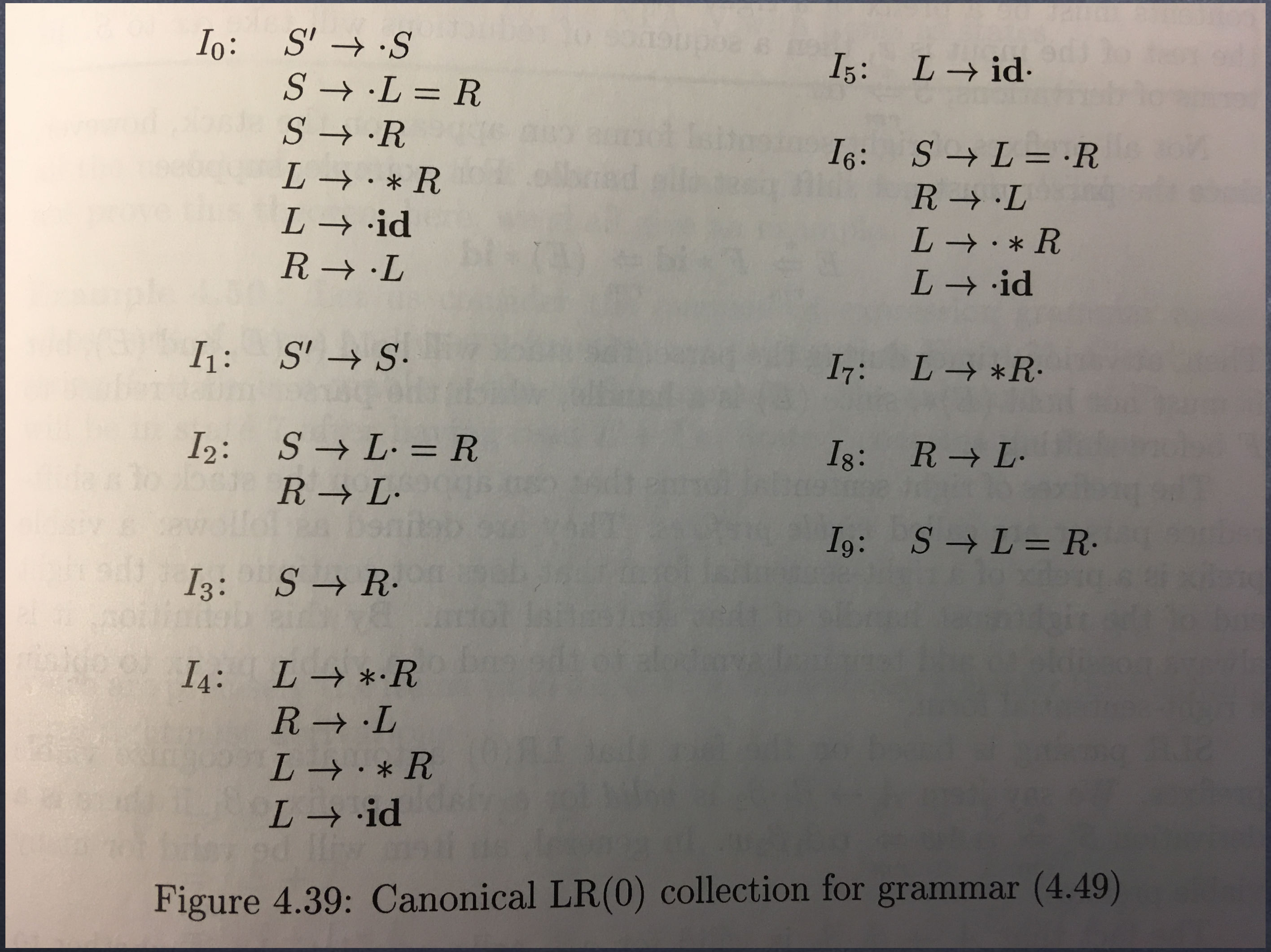
Syntactic structure

Figure 1.7, page 5 of text

Example 4.51 [p. 260]

Grammar from example 4.48:

S -> L = R | R
L -> *R | id
R -> L



I_0: $S' \to \cdot S$
$S \to \cdot L = R$
$S \to \cdot R$
$L \to \cdot * R$
$L \to \cdot \mathbf{id}$
$R \to \cdot L$

I_1: $S' \to S \cdot$

I_2: $S \to L \cdot = R$
$R \to L \cdot$

I_3: $S \to R \cdot$

I_4: $L \to * \cdot R$
$R \to \cdot L$
$L \to \cdot * R$
$L \to \cdot \mathbf{id}$

I_5: $L \to \mathbf{id} \cdot$

I_6: $S \to L = \cdot R$
$R \to \cdot L$
$L \to \cdot * R$
$L \to \cdot \mathbf{id}$

I_7: $L \to * R \cdot$

I_8: $R \to L \cdot$

I_9: $S \to L = R \cdot$

Figure 4.39: Canonical LR(0) collection for grammar (4.49)

Example 4.51 [p. 260]

Grammar from example 4.48:

S -> L = R | R
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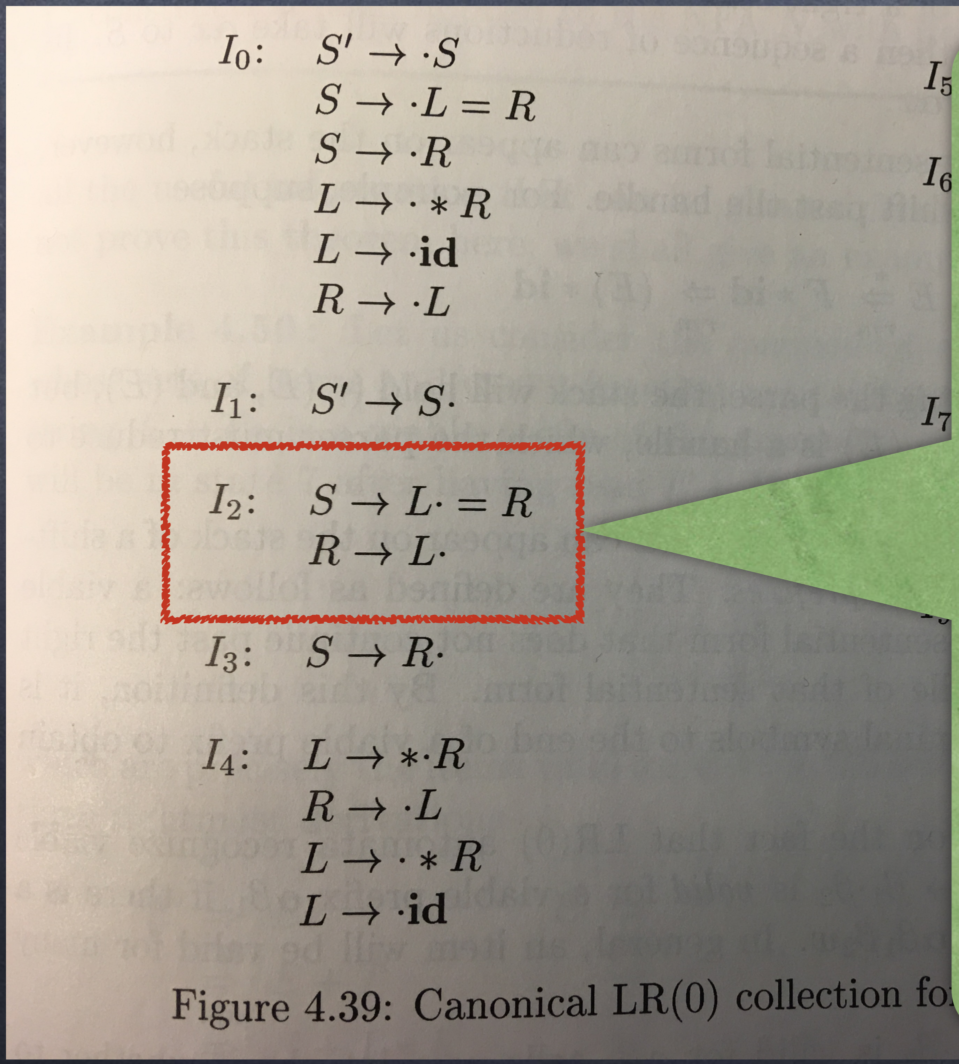

I_0: $S' \to \cdot S$
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I_1: $S' \to S \cdot$

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I_3: $S \to R \cdot$

I_4: $L \to * \cdot R$
$R \to \cdot L$
$L \to \cdot * R$
$L \to \cdot \mathbf{id}$

Figure 4.39: Canonical LR(0) collection fo

"[This grammar] is not ambiguous. This shift/reduce conflict arises [because] SLR parser construction method [does not] remember enough left context..."

[p. 255]

Viable prefix

"Why can LR(0) automata be used to make shift-reduce decisions? The LR(0) automaton for a grammar characterizes the strings of grammar symbols that can appear on the stack... The stack contents must be a prefix of a right-sentential form. If the stack holds α and the rest of the input is x, then a sequence of reductions will take αx to S. In terms of derivations, $S \Rightarrow_{rm*} \alpha x$." [p. 256]

Viable prefix

"Not all prefixes of right-sentential forms can appear on the stack...since the parser must not shift past the handle." [p. 256]

$E \Rightarrow_{rm*} F * id \Rightarrow_{rm} (E) * id$

Viable prefix

"Not all prefixes of right-sentential forms can appear on the stack...since the parser must not shift past the handle." [p. 256]

$$E \Rightarrow_{rm*} F * id \Rightarrow_{rm} \underline{(E)} * id$$

(E) is a handle of
F -> (E)

Viable prefix

(parser configurations shown)

($, '(' id ')' * id $)
($ '(' , id ')' * id $)
($ '(' id , ')' * id $)
($ '(' F , ')' * id $)
($ '(' T , ')' * id $)
($ '(' E , ')' * id $)
($ '(' E ')' , * id $)
($ F , * id $)
($ T , * id $)
($ T * , id $)
etc.

Cannot shift '*' here, because
'(' E ')'
is a handle.

Viable prefix

"The prefixes of right sentential forms that can appear on the stack of a shift-reduce parser are called viable prefixes." [p. 256]

Viable prefix

($, '(' id ')' * id $)
($ '(' , id ')' * id $)
($ '(' id , ')' * id $)
($ '(' F , ')' * id $)
($ '(' T , ')' * id $)
($ '(' E , ')' * id $)
($ '(' E ')' , * id $)
($ F , * id $)
($ T , * id $)
($ T * , id $)
etc.

Cannot shift '*' here, because
'(' E ')'
is a handle.

Therefore
'(' E ')' *
is not a viable prefix.

LR(1) items

"…in the SLR method, state I calls for reduction by $A \rightarrow \alpha$ if the set of items I_i contains item $[A \rightarrow \alpha \bullet]$ and input symbol a is in FOLLOW(A)." [p. 260]

LR(1) items

"In some situations, however, when state I appears on top of the stack the viable prefix $\beta\alpha$ on the stack is such that βA cannot be followed by a in any right-sentential form." [p. 260]

Example 4.51 [p. 260]

Grammar from example 4.48:

S -> L = R | R

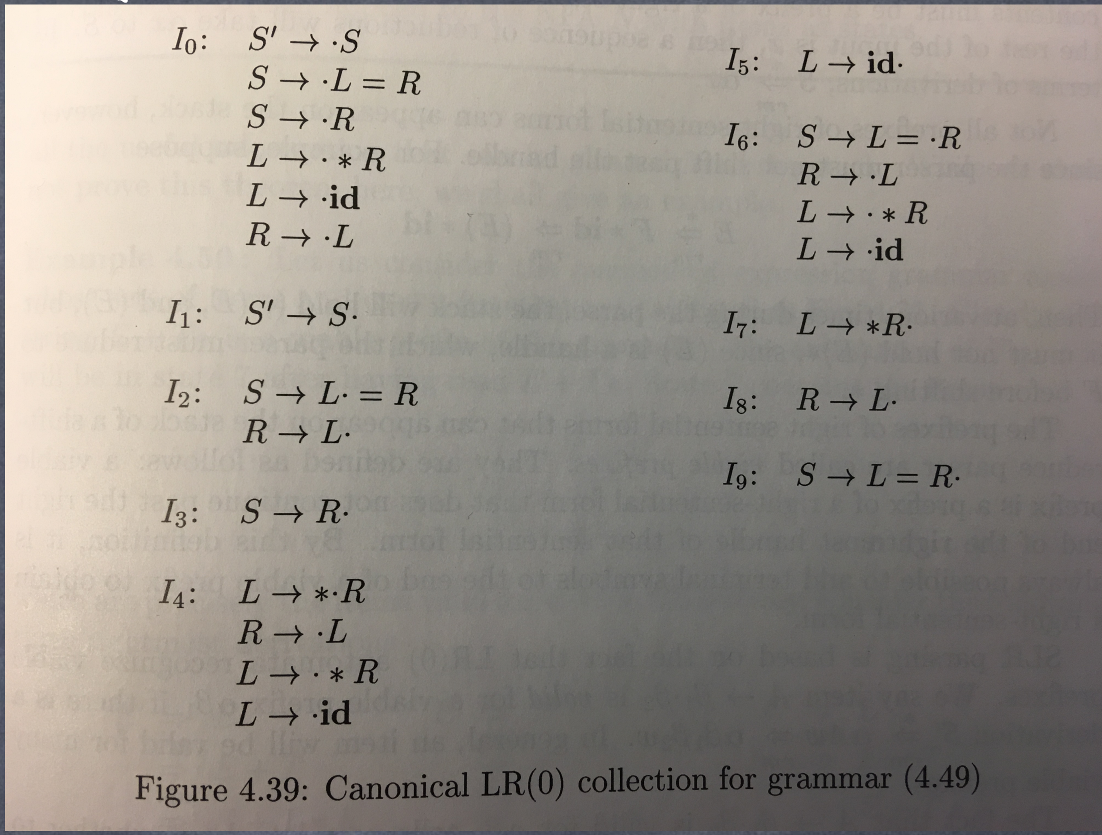
L -> *R | id

R -> L

State I2 from figure 4.39

S -> L • = R

R -> L •



I_0: $S' \to \cdot S$
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Figure 4.39: Canonical LR(0) collection for grammar (4.49)

"Consider the set of items I2. The first item in this set makes ACTION[2,=] be 'shift 6'. Since FOLLOW(R) contains = [...] the second item sets ACTION[2,=] to reduce R -> L." [p. 255]

"...the SLR parser calls for reduction by R -> L in state 2 with = as the next input (the shift action is also called for ...). However, there is no right-sentential form of the grammar ... that begins R = ... Thus state 2, which is the state corresponding to viable prefix L only, should not really call for reduction of that L to R." [p. 260]

See section 4.7.5 (p. 270) for more discussion of this example.

LR(1) items

"By splitting states when necessary, we can arrange to have each state ... indicate exactly which input symbols can follow a handle α for which there is a possible reduction to A." [p. 260]

"The general form of an item becomes

$$[\ A \rightarrow \alpha \bullet \beta,\ a]$$

where A -> $\alpha\beta$ is a production and a is a terminal or ... \$." [p. 260]

LR(1) items

"The lookahead has no effect in an item of the form [A -> α • β, a], where β is not ε, but an item of the form [A -> α •, a] calls for reduction by A -> α only if the next input symbol is a. [...] The set of such a's will always be a subset of FOLLOW(A), but it could be a proper subset ..." [p. 260]

LALR (lookahead LR)

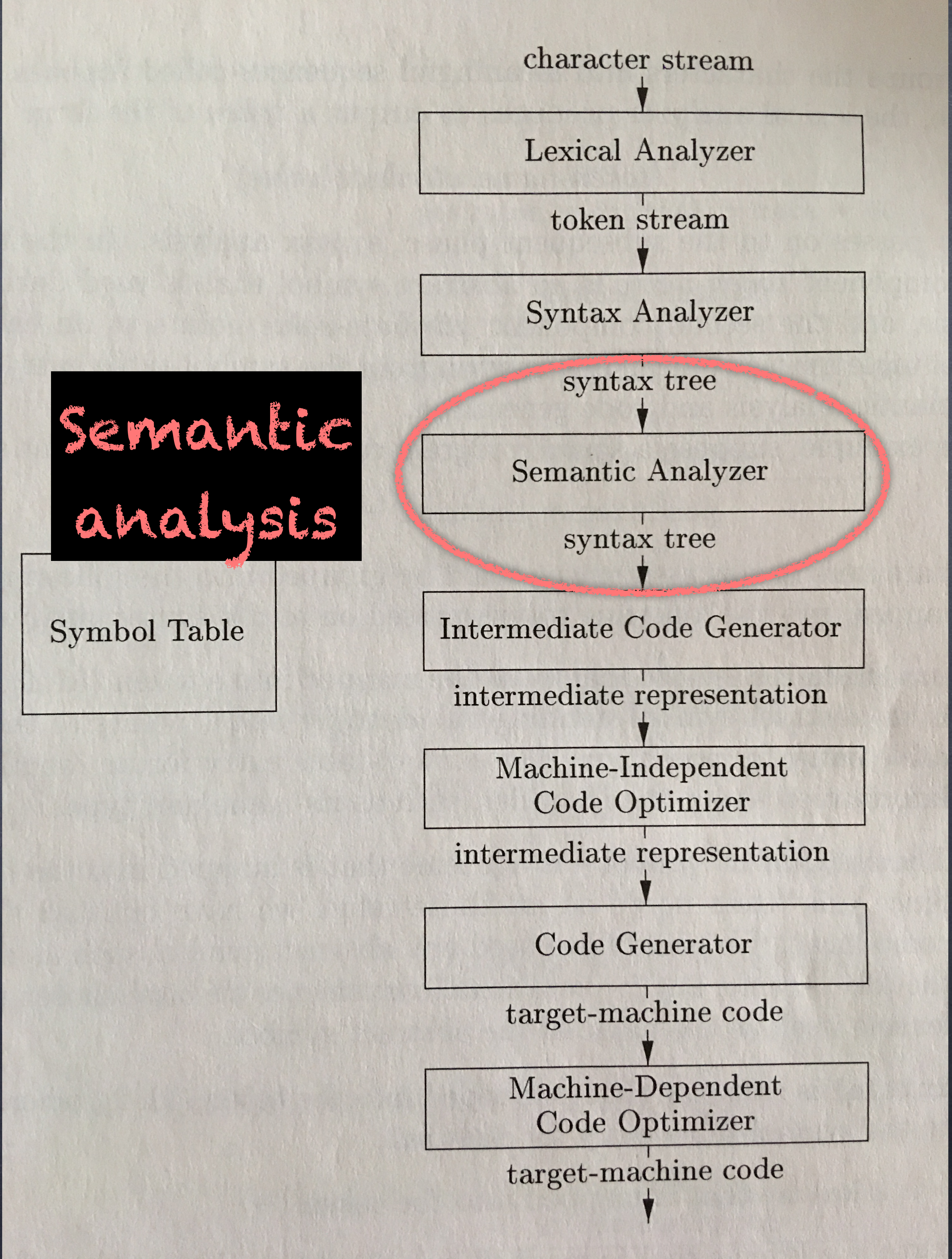
"SLR and LALR tables … always have the same number of states." [p. 266]

Idea: merge sets of LR(1) items with the same core.

Cannot introduce Shift/Reduce conflicts, may introduce Reduce/Reduce conflicts.

Bison and YACC produce LALR parsers.

Phases of a compiler



Semantic analysis

Figure 1.6, page 5 of text

Semantics

- “Semantics” has to do with the meaning of a program.

- We will consider two types of semantics:

  - Static semantics: semantics which can be enforced at compile-time.

  - Dynamic semantics: semantics which express the run-time meaning of programs.

Static semantics

- Semantic checking which can be done at compile-time
- Type-compatibility is a prime example
  - **`int`** can be assigned to **`double`** (type coercion)
  - **`double`** cannot be assigned to **`int`** without explicit type cast
- Type-compatibility can be captured in grammar, but only at expense of larger, more complex grammar

Ex: adding type rules in grammar

- Must introduce new non-terminals which encode types:
- Instead of a generic grammar rule for assignment:
  - **`<stmt> → <var> '=' <expr> ';'`**
- we need multiple rules:
  - **`<stmt> → <doubleVar> '=' <intExpr> | <doubleExpr> ';'`**
  - **`<stmt> → <intVar> '=' <intExpr> ';'`**

- Of course, such rules need to handle all the relevant type possibilities (e.g. **`byte`**, **`char`**, **`short`**, **`int`**, **`long`**, **`float`** and **`double`**).

Alternative: attribute grammars

- Attribute grammars provide a neater way of encoding such information.
- Each syntactic rule of the grammar can be decorated with:
  - a set of semantic rules/functions
  - a set of semantic predicates

Attributes

- We can associate with each symbol X of the grammar a set of attributes A(X). Attributes are partitioned into:

  synthesized attributes S(X) – pass info up parse tree

  inherited attributes I(X) – pass info down parse tree

Semantic rules/functions

- We can associate with each rule R of the grammar a set of semantic functions.

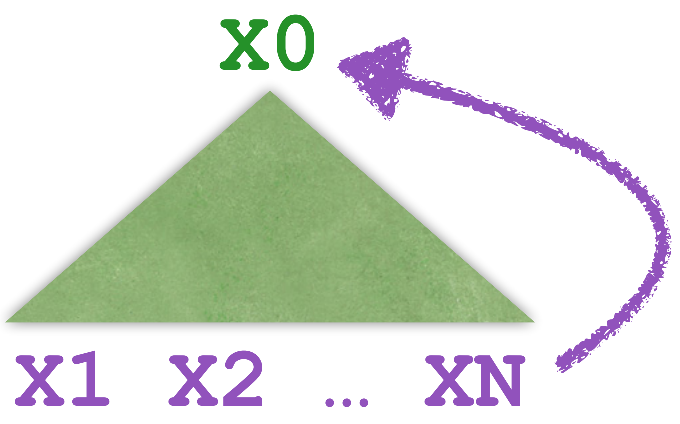
- For rule **`X0 → X1 X2 … Xn`**
  - synthesized attribute of LHS:

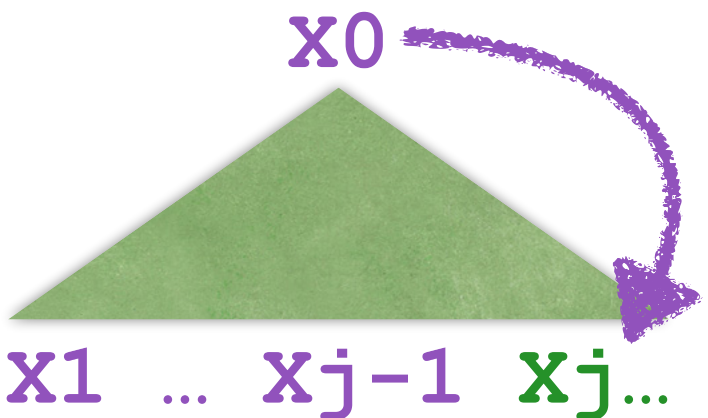
    `S(X0) = f(A(X1), A(X2), …, A(Xn))`

  - inherited attribute of RHS member:

    `for 1<=j<=n, I(Xj) = f(A(X0),…,A(Xj-1))`

    (note that dependence is on siblings to left only)





Predicates

- We can associate with each rule R of the grammar a set of semantic predicates.
- Boolean expression involving the attributes and a set of attribute values
- If **`true`**, node is ok
- If **`false`**, node violates a semantic rule