Error Recovery
Error detection
Error recovery
Error correction
Error repair

Table driven error recovery
Algorithm
Cost

Def. Insert and delete cost of terminal symbol
For all $a \in \Sigma$, insertion and deletion costs are defined as ***positive*** *numbers, and denoted as Ic(a) and Dc(a), respectively.*

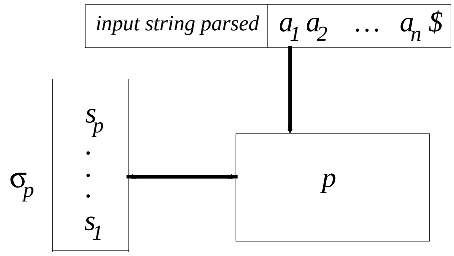
Def. Insert and delete cost of terminal string
Let $x = a_1 \dots a_n \in \Sigma^*$. Then

$$Ic(x) = \begin{cases} Ic(a_1) + \dots + Ic(a_n), & \text{if } x \neq \varepsilon (n \geq 1), \\ 0 & \text{, if } x = \varepsilon. \end{cases}$$

$$Dc(x) = \begin{cases} Dc(a_1) + \dots + Dc(a_n), & \text{if } x \neq \varepsilon (n \geq 1), \\ 0 & \text{, if } x = \varepsilon. \end{cases}$$

Parsing Configuration

current state	p,
stack content(LL, LR)	σ_p,
input string to be parsed	$a_1 \dots a_n\$$.



Parsing configuration(σ_p, $a_1 \dots a_n\$$)

Error symbol a_1
Error recovery with insert only
Insert some terminal string x, which guarantees continuation of parsing with xa_1.
single lookahead string

Least Cost Insertion String
Def. *Let parsing configuration be (σ_p, az\$). Then the locally least cost insertion terminal string, Lci(σ_p, a), is defined as follows,*

$$Lci(\sigma_p, a) = x, \text{ if } Ic(x) \leq Ic(y) \text{ for all } y \text{ such that}$$
$$(\sigma_p, xaz\$) \vdash^{\pm} (\sigma, z\$), \text{ and}$$
$$(\sigma_p, yaz\$) \vdash^{\pm} (\sigma', z\$).$$
$$= ?, \text{ otherwise,}$$

where $? \notin \Sigma$ and $Ic(?) = \infty$.

Algorithm: Least cost insertion string error recovery with deletion.

Input: *Parsing configuration(σ_p, $a_1 \dots a_n\$$)*
Output: *Error recovery*

```
var i: integer;
    x, y: Terminal_string;

begin
    i := 1;
    x := Lci(σp, ai);
    y := Lci(σp, ai+1);
    while Ic(x) > Dc(ai) + Ic(y) do
        delete(ai);
        i := i + 1;
        x := y;
        y := Lci(σp, ai+1)
        od
    insert(x)
end.
```

Def. Deletion cost of end marker.
DC($) = ∞.

Def. Immediate Error Detection Property(IEDP).
IEDP holds if the error is detected without any improper action in parsing.

IEDP holds for LR(1) parsing.

IEDP holds for LALR(1) parsing except for reduce actions.
IEDP holds for LALR(1) parsing, if all reduce actions after the last shift action are recovered.

Reduce stack:
Reduce stack is cleared for every shift action.
When error is encountered the parsing configuration is recovered with reduce stack.

Def. Least cost derivable string, and least cost derivable prefix string for a terminal symbol.

Let $X \in V$ and $a \in \Sigma$. Then

$Lcd(X) = x$ if $\exists x$ s.t. $X \overset{*}{\Rightarrow} x$, and
$IC(x) \le IC(y)$ $\forall y$ s.t. $X \overset{*}{\Rightarrow} y$.
$Lcp(X, a) = x$, if $\exists x$ s.t. $X \overset{*}{\Rightarrow} xaz$, and
$IC(x) \le IC(y)$,
$\forall y$ s.t. $X \overset{*}{\Rightarrow} yaz'$, where $z,z' \in \Sigma^*$.
$= ?$, otherwise

Extension.
Let $\alpha \in V^*$ and $a \in \Sigma$. Then
$Lcd(\alpha) = x$ if $\exists x$ s.t. $\alpha \overset{*}{\Rightarrow} x$, and
$IC(x) \le IC(y)$ $\forall y$ s.t. $\alpha \overset{*}{\Rightarrow} y$.
$Lcp(\alpha, a) = x$, if $\exists x$ s.t. $\alpha \overset{*}{\Rightarrow} xaz$,
$IC(x) \le IC(y)$,
$\forall y$ s.t. $\alpha \overset{*}{\Rightarrow} yaz'$, where $z,z' \in \Sigma^*$.
$= ?$, otherwise

Some properties of Lcd and Lcp

$Lcd(a) = a$
$Lcp(a,b) = \varepsilon$ if $a = b$
$= ?$ otherwise

$Lcd(\alpha) \ne ?$

$Lcd(\alpha) = Lcd(X_1 \dots X_n)$
$= Lcd(X_1) \cdot \dots \cdot Lcd(X_n)$

$Lcp(\varepsilon, a) = ?$

$Lcp(X\alpha, a) = min(Lcp(X, a), Lcd(X) \cdot Lcp(\alpha, a))$
Proof
i)

$Lcp(X_1 \dots X_n, a) = min($
$Lcp(X_1, a),$
$Lcd(X_1) . Lcp(X_2, a)$
$\dots$
$Lcd(X_1) \cdot \dots \cdot Lcd(X_{n-1}) \cdot Lcp(X_n, a)$
$)$

Expected Vocabulary String for a Left Context in LR-based Parsing

Let a left context be σ_p, where $\sigma_p = s_1 \dots s_p$. Then

$Evc(\sigma_p) =$
$\{\alpha_2 . Evci(\sigma_p, [A \to \alpha_1.\alpha_2])$
$\mid [A \to \alpha_1.\alpha_2] \in Kernel(s_p)\}$, where

$Evci(\sigma_p, [A \to \alpha_1.\alpha_2]) =$
$\{\beta_2 . Evci(\sigma_{p-|\alpha 1|}, [B \to \beta_1.A\beta_2])$
$\mid [B \to \beta_1.A\beta_2] \in s_{p-|\alpha 1|} \}$

Theorem
$Lci(\sigma_p,a) = Lcp(Evc(\sigma_p), a)$

Lalr(p, [$A \to \alpha_1.\alpha_2$]) vs. Evci(σ_p, [$A \to \alpha_1.\alpha_2$])

1. *state vs. left context(sequence of state)*
2. *for all possible Pred states vs. unique state in the parse stack(left context)*
3. *set of terminal strings vs. set of vocabulary strings*
4. *infix first operator(⊕) vs. concatenation(.)*

New LALR Formalism

Evci(σ_p, [$A \to \alpha_1.\alpha_2$]) =

$\{\beta_2$. *Path(A', A)* .*Evci*($\sigma_{p-|\alpha 1|}$, [$B \to \beta_1.A'\beta_2$])

$|$ *A' L* A*, [$B \to \beta_1.A'\beta_2$] $\in$ *Kernel*($s_{p-|\alpha 1|}$)}

Input parameters

```
    Stack: array[SP_Ran] of State;

function Lci(Top: SP_Ran; a: Σ): Σ*?;
var x: Σ*?;

function Lcd(α: V*): Σ*; external;
function Lcp(α: V*; a: Σ): Σ*?; external;

function MinIs(α:V*; var y: Σ*): boolean;
begin
   if x ≥ y + Lcp(α,a) → x := y.Lcp(α,a)
    | x ≤ y + Lcp(α,a) → skip
   fi;
   if x ≥ y + Lcd(α) → y:=y.Lcd(α); return true
    | x ≤ y + Lcd(α) → return false
   fi
end; (* MinIs *)
```



```
procedure Back(Sp:SP_Ran; A:N ; y: Σ*);
var y': Σ*; more: boolean;
begin
   for [B→β1.A'β2] ∈ Kernel(Stack[Sp]) and
                          A' L* A do
      y' := y;   more := MinIs(Path(A', A).β2, y');
      if more  → Back(Sp-|β1|, A', y')
       | not more → skip
      fi
   od
end; (* Back *)

var y: Σ*; more: boolean;
begin
    x := ?;
    for [A→α1.α2] ∈ Kernel(Stack[Top]) do
        y := ε;  more := MinIs(α2, y);
        if more → Back(Top-|α1|, A, y)
         | not more → skip
        fi
    od;
    return x
end; (* Lci *)
```


Heuristics for insertion and deletion costs

1. DC is greater than that of IC

2. IC and DC for frequently used symbols(eg. ***identifiers***, *,, ;, ...) are small*

3. IC for the symbols that open structures(e.g., ***procedure***, ***begin***, ***if***, ***while***, *...) are high, and IC for the symbols that close structures(e.g.,* ***end***, ***;***, *...) are low.*