Recursive Descent Parser

Compilers: 1 module at a time; recursive descent fine for most programs.

Recursive Descent Parsing

- Top-down parsers can be implemented *as recursive descent* or table-driven
- Recursive descent parsers utilize the machine stack to keep track of parse tree expansion. This is very convenient, but may be less inefficient in larger compilers due to function calls
- Every nonterminal has a function, which does prediction if needed and then applies one RHS
- Errors can be accumulated but the simplest case error displays message and terminates the parser

Termination Condition: Stack empty(nothing is running) and EOFtoken.
Need something auxiliary at bottom of stack… auxiliary function.

- Recursive descent parser starts with some auxiliary function called, which then
    - Gets the first token from the scanner
    - Calls the function for the starting nonterminal
        - When this function returns, the auxiliary function checks that the next token is EOFtk and declares success or error
- Every function works the same way
    - If there is a single RHS, process it
    - Otherwise, predict one RHS based on the current token from the scanner
        - Select the RHS whose FIRST set contains the token
        - Otherwise, if there is the empty production, return from the function
        - Otherwise an error
- Processing the predicted RHS involves:
    - Process the symbols in that RHS left to right, one at a time
        - If it is a token
            - If it matches the token from the scanner, get new token from the scanner and continue next symbol
            - Else an error
        - If it is a nonterminal, call its function
        - At the end of RHS, return
- Implementation notes
    - Implement the extra auxiliary function to check the termination condition
    - Implement one function per nonterminal
    - Each function is called with unconsumed token, and returns with unconsumed token
    - Each function is `void` to allow building the tree later
    - Do not use implicit returns

implicit returns: reach end of function and no return;

Example

Build recursive descent parser for

S -> bA | c FIRST(bA)={b} FIRST(c)={c} thus LL(1)

A -> dSa | ε FIRST(dSa)={d} FOLLOW(A)={a EOFtk} thus LL(1)

Assume `tk` is a token storage available and modifiable in all functions, and assume `scanner()` returns the next token.

```
void parser(){
        tk=scanner();         //Get the first token
        S();
        if (tk.ID == EOFtk)
     Message saying program was OK  // continue, parse was ok
        else error();         // error message, exit, no recovery
        return;
}
void S() {      Need node
        if (tk.ID == b) {    // predicts S->bA since b∈First(bAa)      //First of first production for
                                                                         S; process Left to Right
                tk=scanner();        // processing b, consume matching tokens
                A();                 // processing A   //process next in first production for s
                return;
        }
        else if (tk.ID == c) {       // predict S□□c     //First of second production for S
                tk=scanner();        // consume c
                return;   return     // explicit return
                          node
        }
        else error();
}
void A() {
        if (tk.ID == d) {            // predicts A->dSa
                tk=scanner();        // processing d   //call next token
                S();                 // processing S
                if (tk.ID == a) {    // processing a
                        tk=scanner();  If token = a; consume it
                        return;
                }
                else error();     //epsilon empty production
        }
        else                         // predicts A->ε
                        return;      // explicit return
```

Tree Generation in recursive-Descent Parser

- The parser above can be easily modified to generate parse tree, with the following changes
  - every function generates zero or one node and returns null or pointer to what was generated
  - every function stores or disposes tokens that are consumed
    - structural tokens are disposed
    - semantics tokens are stored in the node

Useful assumptions and suggestions to modify recursive descent parser to generate the parse tree

- Every node will contain
  - Label identifying the function that created the label (and thus nonterminal)
  - Potential token(s) **2 tokens**
  - Potential chidren **4 children**
- Every function making calls to other nonterminal function(s) will collect returned pointers and attach to its node children pointers
- Every function will return its node or null
- Every function will store processed tokens carrying any semantics information (ID, number, operator)
- The maximum number of children is the maximum number of nonterminal in any production

Example

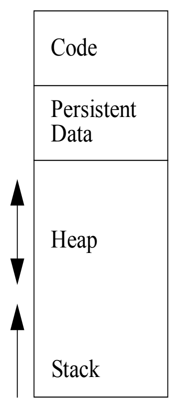
Modify the previous code to generate the parse tree. Suppose **b** and **d** tokens need to be retained while **a** and and **c** do not.
Max one child needed per node since at most one nonterminal on the right hand side of any production.
Max two tokens need to be stored in a node as one production use two semantics tokens.
Assume `node_t` structure with label, token1, token2, and child.
Assume `getNode(label)` allocates `node_t` node and labels it.

Recursive Descent Parser

```
node t* parser(){
       node t* root;
       tk=scanner();
       root = S();
       if (tk.ID == EOFtk)
                             // continue, parse was ok
       else error();         // error message, exit, no recovery
       return root;
}
node t* S() {
       node t* p = getNode(S);
       if (tk.ID == b) {     // predicts S->bA since bϵFirst(bAa)
              p->token1 = tk;     // b needed to be stored
              tk=scanner();       // processing b, consume matching tokens
              p->child = A();                     // processing A
              return p;
       }
       else if (tk.ID == c) {     // predict S->c
              tk=scanner();       // consume c, no need to store
              return p;           // explicit return
       }
       else error();
}
node t* A() {
       if (tk.ID == d) {                    // predicts A->dSa
              token t* = genNode(A);        // now we know we need node
              p->token = tk;                // d needed to be stored
              tk=scanner();                 // processing d
              p->child = S();                              // processing S
              if (tk.ID == a) {             // processing a
                     tk=scanner();
              }
              else error();
              return p;
       }
       else                                 // predicts A->ε
              return NULL;
```

Process Space and Stack

- Each process operates in its own (virtual) process space
    - size depending the addressing space and user's quota
    - in older OS heap space could have been common between processes, resulting in one process bring down other processes or even the OS
    - a process doesn't have direct access outside of the process space
- Process space parts
    - Code
        - main, functions
    - Persistent space
        - global data, local persistent data
    - Stack
        - function call management with Activation Records (AR) including local data and parameters
    - Heap
        - dynamic memory, controlled by heap manager and managed by programmer (C/C++) or garbage collection (Java)



System Stack and Activation Records

- System tack is accessed indirectly (HLL) to manage
    - Function calls
    - Memory for local scopes
- Compiler generates one AR per function
    - AR is a memory template specifying the relative location of the AR elements
        - Automatic data
        - Parameters and returning data
        - Address of the next instruction
        - Static Link
            - used for accessing data in enclosed scopes

        - not needed in languages w/o scoped functions or blocks
    - Dynamic Link
        - pointing to the previous AR
- Actual activation records are allocated on the stack for each function call
    - multiple allocations for recursive calls
    - TOS is always the AR for the currently active function

Example

Example of ARs and runtime stack. Assume main calls f(2). Details of the AR for main are not shown

```
int global;

void f(int x) {
  g(x); // intr 1
}
void g(int y) {
  int g1;
 if (y>1) g(y-1);
  else return; // instr 3
}
```