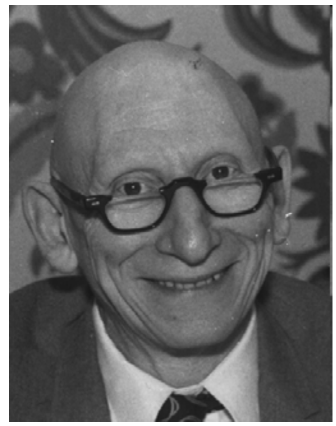
**"A programming language that doesn't change the way you think is not worth learning."**

Alan Perlis, *Epigrams in Programming*



**Alan Perlis, 1922-1990**

*first head of CMU CS department*
*first president of ACM*
*first Turing Award winner*

# AWK

- **a language for pattern scanning and processing**
  - Al Aho, Brian Kernighan, Peter Weinberger, at Bell Labs, ~1977
- **intended for simple data processing:**
- **selection, validation:**

  "Print all lines longer than 80 characters"

```
length > 80
```

- **transforming, rearranging:**

  "Replace the 2nd field by its logarithm"

```
{ $2 = log($2); print }
```

- **report generation:**

  "Add up the numbers in the first field,
  then print the sum and average"

```
     { sum += $1 }
END  { print sum, sum/NR }
```

## Structure of an AWK program:

- **a sequence of pattern-action statements**

```
pattern      { action }
pattern      { action }
…
```

- **"pattern" is a regular expression, numeric expression, string expression or combination of these**
- **"action" is executable code, similar to C**
- **usage:**

```
awk 'program' [ file1 file2 ... ]
awk -f progfile [ file1 file2 ... ]
```

- **operation:**

```
for each file
  for each input line
    for each pattern
      if pattern matches input line
        do the action
```

## AWK features:

- **input is read automatically across multiple files**
  - lines are split into fields ($1, ..., $NF; $0 for whole line)
- **variables contain string or numeric values (or both)**
  - no declarations: type determined by context and use
  - initialized to 0 and empty string
  - built-in variables for frequently-used values
- **operators work on strings or numbers**
  - coerce type / value according to context
- **associative arrays (arbitrary subscripts)**
- **regular expressions** (like egrep)
- **control flow statements similar to C: if-else, while, for, do**
- **built-in and user-defined functions**
  - arithmetic, string, regular expression, text edit, ...
- **`printf` for formatted output**
- **`getline` for input from files or processes**

# Basic AWK programs, part 1

```
{ print NR, $0 }          precede each line by line number
{ $1 = NR; print }        replace first field by line number
{ print $2, $1 }          print field 2, then field 1
{ temp = $1; $1 = $2; $2 = temp; print }   flip $1, $2
{ $2 = ""; print }        zap field 2
{ print $NF }             print last field

NF > 0                print non-empty lines
NF > 4                print if more than 4 fields
$NF > 4               print if last field greater than 4
/regexpr/             print matching lines (egrep)
$1 ~ /regexpr/        print lines where first field matches
```

# Basic AWK programs, part 2

```
NF > 0 {print $1, $2}   print two fields of non-empty lines

END { print NR }        line count

    { nc += length($0) + 1; nw += NF }   wc command
END { print NR, "lines", nw, "words", nc, "characters" }

length($0) > max { max = length($0); line = $0 }
END      { print max, line }       print longest line
```

## Control flow

- **if-else, while, for, do...while, break, continue**
  - as in C, but no switch
- **for (i in array)**
  - go through each subscript of an associative array
- **next** start next iteration of main loop
- **exit** leave main loop, go to END block

```
{ sum = 0
  for (i = 1; i <= NF; i++)
     sum += $i
  print sum
}
```

```
{ for (i = 1; i <= NF; i++)
     sum += $i
}
END { print sum }
```

## Awk text formatter

```
#!/bin/sh
# f - format text into 60-char lines

awk '
/./  { for (i = 1; i <= NF; i++)
           addword($i) }
/^$/ { printline(); print "" }
END  { printline() }

function addword(w) {
    if (length(line) + length(w) > 60)
        printline()
    line = line space w
    space = " "
}

function printline() {
    if (length(line) > 0)
        print line
    line = space = ""
}
' "$@"
```

# Arrays

- **common case: array subscripts are integers**
- **reverse a file:**

```
     { x[NR] = $0 }   # put each line into array x
END  { for (i = NR; i > 0; i--)
           print x[i] }
```

- **make an array:**

```
n = split(string, array, separator)
```

  - splits "string" into array[1] ... array[n]
  - returns number of elements
  - optional "separator" can be any regular expression

# Associative Arrays

- **array subscripts can have <u>any</u> value, not just integers**
- **canonical example: adding up name-value pairs**
- **input:**

| | |
|---|---|
| pizza | 200 |
| beer | 100 |
| pizza | 500 |
| beer | 50 |

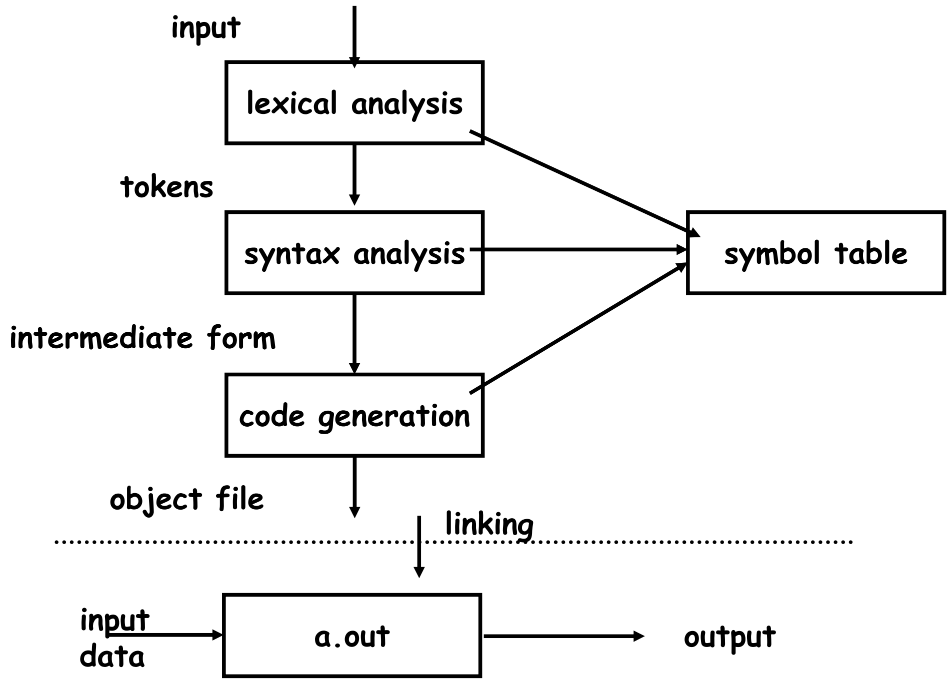
- **output:**

| | |
|---|---|
| pizza | 700 |
| beer | 150 |

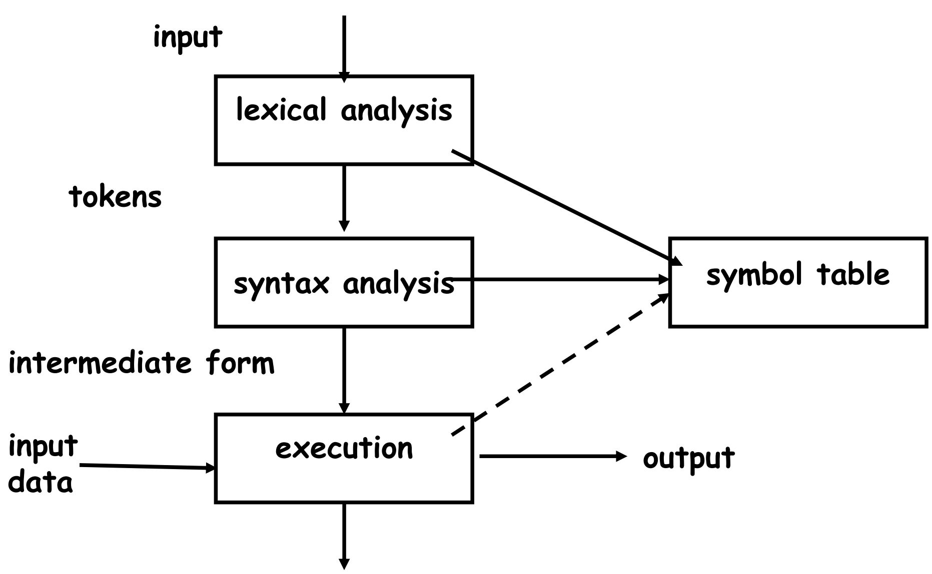
- **program:**

```
    { amount[$1] += $2 }
END { for (name in amount)
          print name, amount[name] | "sort +1 -nr"
}
```

# Anatomy of a compiler




# Anatomy of an interpreter



# YACC and LEX

- **languages/tools for building [parts of] compilers and interpreters**
- **YACC: "yet another compiler compiler" (S. C. Johnson, ~ 1972)**
  - converts a grammar and semantic actions into a parser for that grammar
- **LEX: lexical analyzer generator (M. E. Lesk, ~ 1974)**
  - converts regular expressions for tokens into a lexical analyzer that recognizes those tokens
- **parser calls lexer each time it needs another input token**
- **lexer returns a token and its lexical type**
- **when to think of using them:**
  - real grammatical structures (e.g., recursively defined)
  - complicated lexical structures
  - rapid development time is important
  - language design might change

# YACC-based calculator

```
%{
#define   YYSTYPE   double    /* data type of yacc stack */
%}
%token    NUMBER
%left     '+' '-'     /* left associative, same precedence */
%left     '*' '/'     /* left associative, higher precedence */
%%
list:  expr '\n'         { printf("\t%.8g\n", $1); }
     | list expr '\n'    { printf("\t%.8g\n", $2); }
     ;
expr: NUMBER          { $$ = $1; }
     | expr '+' expr  { $$ = $1 + $3; }
     | expr '-' expr  { $$ = $1 - $3; }
     | expr '*' expr  { $$ = $1 * $3; }
     | expr '/' expr  { $$ = $1 / $3; }
     | '(' expr ')'   { $$ = $2; }
     ;
%%
#include <stdio.h>
#include <ctype.h>
main() { yyparse() }
yylex()   {         /* calculator lexical analysis */
   int c;
   while ((c=getchar()) == ' ' || c == '\t') ;
   if (c == EOF) return 0;
   if (c == '.' || isdigit(c)) {        /* number */
          ungetc(c, stdin);
          scanf("%lf", &yylval);        /* lexical value */
          return NUMBER;                /* lexical type */
   }
   return c;
}
yyerror(char *s) { fprintf(stderr, "%s\n", s); } /* called for yacc syntax error */
```

# YACC overview

- **YACC converts grammar rules & semantic actions into parsing fcn yyparse()**
  - yyparse parses programs written in that grammar, performs semantic actions as grammatical constructs are recognized
- **semantic actions usually build a parse tree**
  - each node represents a particular syntactic type, children are components
- **code generator walks the tree to generate code**
  - may rewrite tree as part of optimization
- **an interpreter could**
  - run directly from the program (TCL)
  - interpret directly from the tree (AWK, Perl?):
    at each node, interpret children (recursion), do operation of node itself, return result
  - generate byte code output to run elsewhere (Java)
  - generate internal byte code (Python?, …)
  - generate C to be compiled later
- **compiled code runs faster**
  - but compilation takes longer, needs object files, less portable, …
- **interpreters start faster, but run slower**
  - for 1- or 2-line programs, interpreter is better
  - on the fly / just in time compilers merge these (e.g., .NET, some Java)

# Grammar specified in YACC

- **grammar rules give syntax**
- **the action part of a rule gives semantics**
  - usually used to build a parse tree

```
statement :
    IF ( expression ) statement
                create node(IF, expr, stmt, 0)
    IF ( expression ) statement ELSE statement
                create node(IF, expr, stmt1, stmt2)
    WHILE (expression ) statement
                create node(WHILE, expr, stmt)
    variable =  expression
                create node(ASSIGN, var, expr)
    …
expression :
    expression + expression
    expression - expression
    ...
```

- **YACC creates a parser from this**
- **when the parser runs, it creates a parse tree**
- **a compiler walks the tree to generate code**
- **an interpreter walks the tree to execute it**

# Excerpt from a real grammar

```
term:
   term '/' ASGNOP term   { $$ = op2(DIVEQ, $1, $4); }
 | term '+' term          { $$ = op2(ADD, $1, $3); }
 | term '-' term          { $$ = op2(MINUS, $1, $3); }
 | term '*' term          { $$ = op2(MULT, $1, $3); }
 | term '/' term          { $$ = op2(DIVIDE, $1, $3); }
 | term '%' term          { $$ = op2(MOD, $1, $3); }
 | term POWER term        { $$ = op2(POWER, $1, $3); }
 | '-' term %prec UMINUS  { $$ = op1(UMINUS, $2); }
 | '+' term %prec UMINUS  { $$ = $2; }
 | NOT term %prec UMINUS
             { $$ = op1(NOT, notnull($2)); }
 | BLTIN '(' patlist ')'
             { $$ = op2(BLTIN, itonp($1), $3); }
 | DECR var               { $$ = op1(PREDECR, $2); }
 | INCR var               { $$ = op1(PREINCR, $2); }
 | var DECR               { $$ = op1(POSTDECR, $1); }
 | var INCR               { $$ = op1(POSTINCR, $1); }
```

# Excerpts from a real grammar

```
term:
 | term '+' term          { $$ = op2(ADD, $1, $3); }
 | term '-' term          { $$ = op2(MINUS, $1, $3); }
 | term '*' term          { $$ = op2(MULT, $1, $3); }
 | term '/' term          { $$ = op2(DIVIDE, $1, $3); }
 | term '%' term          { $$ = op2(MOD, $1, $3); }
 | '-' term %prec UMINUS  { $$ = op1(UMINUS, $2); }
 | INCR var               { $$ = op1(PREINCR, $2); }
 | var INCR               { $$ = op1(POSTINCR, $1); }

stmt:
 | while {inloop++;} stmt  {--inloop; $$ = stat2(WHILE,$1,$3);}
 | if stmt else stmt       { $$ = stat3(IF, $1, $2, $4); }
 | if stmt                 { $$ = stat3(IF, $1, $2, NIL); }
 | lbrace stmtlist rbrace  { $$ = $2; }

while:
   WHILE '(' pattern rparen    { $$ = notnull($3); }
```

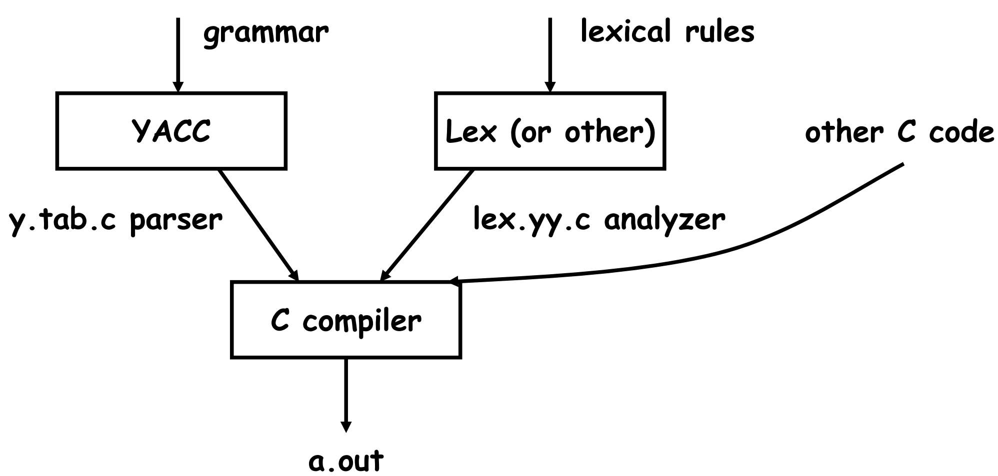
# Excerpts from a LEX analyzer

```
"++"         { yylval.i = INCR; RET(INCR); }
"--"         { yylval.i = DECR; RET(DECR); }

([0-9]+(\.?)[0-9]*|\.[0-9]+)([eE](\+|-)?[0-9]+)? {
    yylval.cp = setsymtab(yytext, tostring(yytext),
                    atof(yytext), CON|NUM, symtab);
    RET(NUMBER); }

while   { RET(WHILE); }
for     { RET(FOR); }
do      { RET(DO); }
if      { RET(IF); }
else    { RET(ELSE); }
return  { if (!infunc)
             ERROR "return not in function" SYNTAX;
          RET(RETURN);
        }
•       { RET(yylval.i = yytext[0]); /* everything else */ }
```

# The whole process



# AWK implementation

- **source code is about 6000 lines of C and YACC**
- **compiles (almost) without change on Unix/Linux, Windows, Mac**

- **parse tree nodes:**

```
typedef struct Node {
    int  type;  /* ARITH, … */
    Node *next;
    Node *child[4];
} Node;
```

- **leaf nodes (values):**

```
typedef struct Cell {
    int  type;   /* VAR, FLD, … */
    Cell *next;
    char *name;
    char *sval;  /* string value */
    double fval; /* numeric value */
    int state;   /* STR | NUM | ARR … */
} Cell;
```

# Using Awk for testing RE code

- **regular expression tests are described in a very small specialized language:**

```
^a.$    ~       ax
                aa
        !~      xa
                aaa
                axy
```

- **each test is converted into a command that exercises awk:**

```
echo 'ax' | awk '!/^a.$'/ { print "bad" }'
```

- **illustrates**
  - little languages
  - programs that write programs
  - mechanization

# Unit testing

- **code that exercises/tests small area of functionality**
  - single method, function, ...
- **helps make sure that code works and stays working**
  - make sure small local things work so can build larger things on top
- **very often used in "the real world"**
  - e.g., can't check in code unless has tests and passes them
- **often have tools to help write tests, run them automatically**
  - e.g., JUnit

```
struct {
  int yesno; char *re; char *text;
} tests[100] = {
  1, "x", "x",
  0, "x", "y",
  0, 0, 0
};
main() {
   for (int i = 0; tests[i].re != 0; i++) {
      if (match(tests[i].re, tests[i].text) != tests[i].yesno)
         printf("%d failed: %d [%s] [%s]\n", i,
            tests[i].yesno, tests[i].re, tests[i].text);
  }
}
```

# Record keeping

- **record of all bug fixes since August 1987**

**Nov 26, 2009:**

- fixed a long-standing issue with when FS takes effect. a change to FS is now noticed immediately for subsequent splits.
- changed the name getline() to awkgetline() to avoid yet another name conflict somewhere.

**Feb 11, 2009:**

- temporarily for now defined HAS_ISBLANK, since that seems to be the best way through the thicket. isblank arrived in C99, but seems to be arriving at different systems at different times.

**Oct 8, 2008:**

- fixed typo in b.c that set tmpvec wrongly. no one had ever run into the problem, apparently. thanks to alistair crooks.

**Oct 23, 2007:**

- minor fix in lib.c: increase inputFS to 100, change malloc for fields to n+1.
- fixed memory fault caused by out of order test in setsval. thanks to david o'brien, freebsd, for both fixes.

...

**Feb 21, 2007:**

- fixed quotation in b.c; thanks to Hal Pratt and the Princeton Dante Project.

# Lessons

- **people use tools in unexpected, perverse ways**
  - compiler writing: implementing languages and other tools
  - object language (programs generate Awk)
  - first programming language
- **existence of a language encourages programs to generate it**
  - machine generated inputs stress differently than people do
- **mistakes are inevitable and hard to change**
  - concatenation syntax
  - ambiguities, especially with >
  - function syntax
  - creeping featurism from user pressure
  - difficulty of changing a "standard"

**"One thing [the language designer] should not do is to include untried ideas of his own."**

(C. A. R. Hoare, *Hints on Programming Language Design*, 1973)