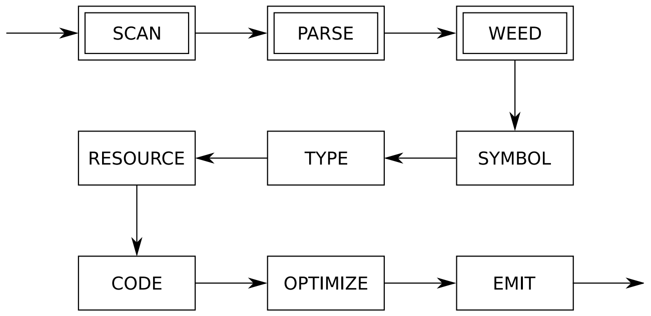
Abstract Syntax Trees

COMP 520: Compiler Design (4 credits)

Professor Laurie Hendren

`hendren@cs.mcgill.ca`



What did we learn from assignment #1?

Examples to look at

`http://www.cs.mcgill.ca/~cs520/2015/` contains examples for Tiny and Joos for both flex/bison and sableCC2/3.

What to work on next?

- Read Chapter 7 of “Crafting a Compiler" and/or Chapter 4 of “Modern Compiler Implementation in Java".
- Building the AST and a pretty printer of the AST for MiniLang (this will be part of individual assignment #2). You can do this after today’s lecture.
- Think about what sorts of semantic and type checks should be made for MiniLang, variables declared?, types correct? anything else? This phase will also be part of individual assignment #2.
- On Tuesday Vincent will give an overview of the subset of Go that we will be working on. At that point all groups can start working on their scanners and parsers for either Go or OncoTime.

A compiler *pass* is a traversal of the program.

A compiler *phase* is a group of related passes.

A *one-pass* compiler scans the program only once. It is naturally single-phase. The following all happen at the same time:

- scanning
- parsing
- weeding
- symbol table creation
- type checking
- resource allocation
- code generation
- optimization
- emitting

This is a terrible methodology:

- it ignores natural modularity;
- it gives unnatural scope rules; and
- it limits optimizations.

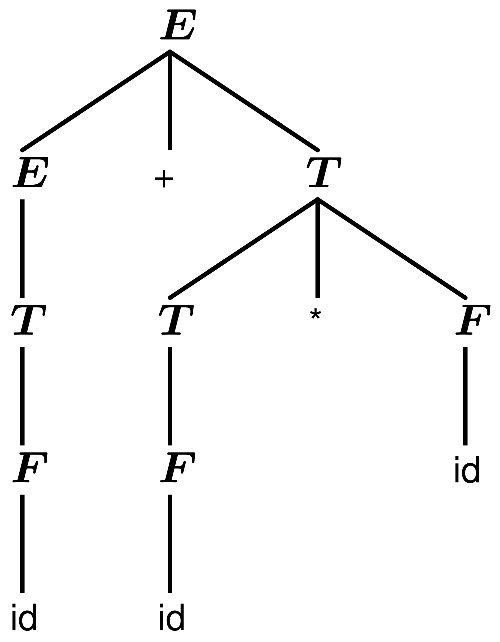
However, it used to be popular:

- it's fast (if your machine is slow); and
- it's space efficient (if you only have 4K).

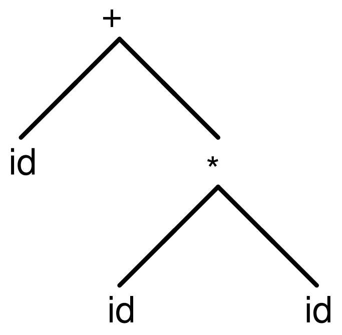
A modern *multi-pass* compiler uses 5–15 phases, some of which may have many individual passes: you should skim through the optimization section of 'man gcc' some time!

A multi-pass compiler needs an *intermediate representation* of the program between passes.

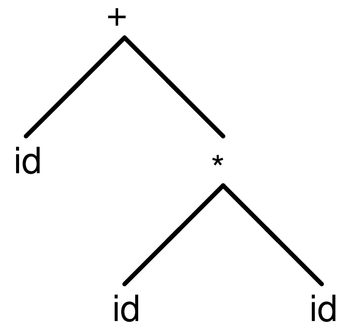
We could use a parse tree, or *concrete syntax tree* (CST):



or we could use a more convenient *abstract syntax tree* (AST), which is essentially a parse tree/CST but for a more abstract grammar:



Instead of constructing the tree:



a compiler can generate code for an internal compiler-specific grammar, also known as an *intermediate language*.

Early multi-pass compilers wrote their IL to disk between passes. For the above tree, the string `+(id,*(id,id))` would be written to a file and read back in for the next pass.

It may also be useful to write an IL out for debugging purposes.

Examples of modern intermediate languages:

- Java bytecode
- C, for certain high-level language compilers
- Jimple, a 3-address representation of Java bytecode specific to Soot, created by Raja Vallee-Rai at McGill.
- Simple, the precursor to Jimple, created for McCAT by Prof. Hendren and her students
- Gimple, the IL based on Simple that `gcc` uses

In this course, you will generally use an AST as your IR without the need for an explicit IL.

Note: somewhat confusingly, both industry and academia use the terms IR and IL interchangeably.

```
$ cat tree.h tree.c # AST construction for Tiny language
[...]
typedef struct EXP {
  enum {idK,intconstK,timesK,divK,plusK,minusK} kind;
  union {
    char *idE;
    int intconstE;
    struct {struct EXP *left; struct EXP *right;} timesE;
    struct {struct EXP *left; struct EXP *right;} divE;
    struct {struct EXP *left; struct EXP *right;} plusE;
    struct {struct EXP *left; struct EXP *right;} minusE;
  } val;
} EXP;

EXP *makeEXPid(char *id)
{ EXP *e;
  e = NEW(EXP);
  e->kind = idK;
  e->val.idE = id;
  return e;
}

[...]
```

```
EXP *makeEXPminus(EXP *left, EXP *right)
{ EXP *e;
  e = NEW(EXP);
  e->kind = minusK;
  e->val.minusE.left = left;
  e->val.minusE.right = right;
  return e;
}
```

```
$ cat tiny.y # Tiny parser that creates EXP *theexpression
%{
#include <stdio.h>
#include "tree.h"

extern char *yytext;
extern EXP *theexpression;

void yyerror() {
  printf ("syntax error before %s\n", yytext);
}
%}

%union {
   int intconst;
   char *stringconst;
   struct EXP *exp;
}

%token <intconst> tINTCONST
%token <stringconst> tIDENTIFIER
%type <exp> program exp
[...]
```

```
%start program
%left '+' '-'
%left '*' '/'
%%
program: exp
       { theexpression = $1; }
;

exp : tIDENTIFIER
     { $$ = makeEXPid ($1); }
    | tINTCONST
     { $$ = makeEXPintconst ($1); }
    | exp '*' exp
     { $$ = makeEXPmult ($1, $3); }
    | exp '/' exp
     { $$ = makeEXPdiv ($1, $3); }
    | exp '+' exp
     { $$ = makeEXPplus ($1, $3); }
    | exp '-' exp
     { $$ = makeEXPminus ($1, $3); }
    | '(' exp ')'
     { $$ = $2; }
;
%%
```

Constructing an AST with `flex`/`bison`:

- AST node kinds go in `tree.h`

```
enum {idK,intconstK,timesK,divK,plusK,minusK} kind;
```

- AST node semantic values go in `tree.h`

```
struct {struct EXP *left; struct EXP *right;} minusE;
```

- Constructors for node kinds go in `tree.c`

```
EXP *makeEXPminus(EXP *left, EXP *right)
{ EXP *e;
  e = NEW(EXP);
  e->kind = minusK;
  e->val.minusE.left = left;
  e->val.minusE.right = right;
  return e;
}
```

- Semantic value type declarations go in `tiny.y`

```
%union {
   int intconst;
   char *stringconst;
   struct EXP *exp;
}
```

- (Non-)terminal types go in `tiny.y`

```
%token <intconst> tINTCONST
%token <stringconst> tIDENTIFIER
%type <exp> program exp
```

- Grammar rule actions go in `tiny.y`

```
exp : exp '-' exp { $$ = makeEXPminus ($1, $3); }
```

A “pretty”-printer:

```
$ cat pretty.h pretty.c
#ifndef PRETTY_H
#define PRETTY_H
#include "tree.h"
void prettyEXP(EXP *e);
#endif /* !PRETTY_H */

#include <stdio.h>
#include "pretty.h"

void prettyEXP(EXP *e)
{ switch (e->kind) {
    case idK:
         printf("%s",e->val.idE);
         break;
    case intconstK:
         printf("%i",e->val.intconstE);
         break;
    case timesK:
         printf("(");
         prettyEXP(e->val.timesE.left);
         printf("*");
         prettyEXP(e->val.timesE.right);
         printf(")");
         break;

    [...]

    case minusK:
         printf("(");
         prettyEXP(e->val.minusE.left);
         printf("-");
         prettyEXP(e->val.minusE.right);
         printf(")");
         break;
  }
}
```

The following pretty printer program:

```
$ cat main.c
```

```
#include "tree.h"
#include "pretty.h"

void yyparse();

EXP *theexpression;

void main()
{ yyparse();
  prettyEXP(theexpression);
}
```

will on input:

```
a*(b-17) + 5/c
```

produce the output:

```
((a*(b-17))+(5/c))
```

Phases contribute information to the IR:

As mentioned before, a modern compiler uses 5–15 phases. Each phase contributes extra information to the IR (AST in our case):

- scanner: line numbers;
- symbol tables: meaning of identifiers;
- type checking: types of expressions; and
- code generation: assembler code.

Example: adding line number support.

First, introduce a global `lineno` variable:

```
$ cat main.c
[...]

int lineno;

void main()
{ lineno = 1; /* input starts at line 1 */
  yyparse();
  prettyEXP(theexpression);
}
```

Second, increment `lineno` in the scanner:

```
$ cat tiny.l # modified version of previous exp.l
%{
#include "y.tab.h"
#include <string.h>
#include <stdlib.h>

extern int lineno;   /* declared in main.c */
%}

%%
[ \t]+ /* ignore */; /* no longer ignore \n */
\n     lineno++;    /* increment for every \n */

[...]
```

Third, add a `lineno` field to the AST nodes:

```
typedef struct EXP {
  int lineno;
  enum {idK,intconstK,timesK,divK,plusK,minusK} kind;
  union {
    char *idE;
    int intconstE;
    struct {struct EXP *left; struct EXP *right;} timesE;
    struct {struct EXP *left; struct EXP *right;} divE;
    struct {struct EXP *left; struct EXP *right;} plusE;
    struct {struct EXP *left; struct EXP *right;} minusE;
  } val;
} EXP;
```

Fourth, set `lineno` in the node constructors:

```
extern int lineno;   /* declared in main.c */

EXP *makeEXPid(char *id)
{ EXP *e;
  e = NEW(EXP);
  e->lineno = lineno;
  e->kind = idK;
  e->val.idE = id;
  return e;
}

EXP *makeEXPintconst(int intconst)
{ EXP *e;
  e = NEW(EXP);
  e->lineno = lineno;
  e->kind = intconstK;
  e->val.intconstE = intconst;
  return e;
}

[...]

EXP *makeEXPminus(EXP *left, EXP *right)
{ EXP *e;
```

```
  e = NEW(EXP);
  e->lineno = lineno;
  e->kind = minusK;
  e->val.minusE.left = left;
  e->val.minusE.right = right;
  return e;
}
```

The SableCC 2 grammar for our Tiny language:

```
Package tiny;

Helpers
  tab   = 9;
  cr    = 13;
  lf    = 10;
  digit = ['0'..'9'];
  lowercase = ['a'..'z'];
  uppercase = ['A'..'Z'];
  letter  = lowercase | uppercase;
  idletter = letter | '_';
  idchar  = letter | '_' | digit;

Tokens
  eol   = cr | lf | cr lf;
  blank = ' ' | tab;
  star  = '*';
  slash = '/';
  plus  = '+';
  minus = '-';
  l_par = '(';
  r_par = ')';
  number  = '0'| [digit-'0'] digit*;
  id    = idletter idchar*;

Ignored Tokens
  blank, eol;
```

The Productions section:

```
Productions
  exp =
      {plus}    exp plus factor |
      {minus}   exp minus factor |
      {factor}  factor;

  factor  =
      {mult}    factor star term |
      {divd}    factor slash term |
      {term}    term;

  term  =
      {paren}   l_par exp r_par |
      {id}      id |
      {number}  number;
```

SableCC generates subclasses of the 'Node' class for terminals, non-terminals and production alternatives:

- Node classes for terminals: 'T' followed by (capitalized) terminal name:

  `TEol, TBlank, ..., TNumber, TId`

- Node classes for non-terminals: 'P' followed by (capitalized) non-terminal name:

  `PExp, PFactor, PTerm`

- Node classes for alternatives: 'A' followed by (capitalized) alternative name and (capitalized) non-terminal name:

  `APlusExp (extends PExp), ..., ANumberTerm (extends PTerm)`

```
Productions
  exp =
      {plus}    exp plus factor |
      {minus}   exp minus factor |
      {factor}  factor;
...
```

SableCC populates an entire directory structure:

```
tiny/
    |--analysis/  Analysis.java
    |             AnalysisAdapter.java
    |             DepthFirstAdapter.java
    |             ReversedDepthFirstAdapter.java
    |
    |--lexer/     Lexer.java lexer.dat
    |             LexerException.java
    |
    |--node/      Node.java TEol.java ... TId.java
    |             PExp.java PFactor.java PTerm.java
    |             APlusExp.java ...
    |             AMultFactor.java ...
    |             AParenTerm.java ...
    |
    |--parser/    parser.dat Parser.java
    |             ParserException.java ...
    |
    |-- custom code directories, e.g. symbol, type, ...
```

Given some grammar, SableCC generates a parser that in turn builds a concrete syntax tree (CST) for an input program.

A parser built from the Tiny grammar creates the following CST for the program ‘`a+b*c`’:

```
            Start
              |
           APlusExp
          /        \
   AFactorExp    AMultFactor
     |            /        \
ATermFactor  ATermFactor  AIdTerm
     |          |            |
  AIdTerm    AIdTerm         c
     |          |
     a          b
```

This CST has many unnecessary intermediate nodes. Can you identify them?

We only need an abstract syntax tree (AST) to operate on:

```
     APlusExp
     /     \
AIdExp    AMultExp
  |       /      \
  a     AIdExp  AIdExp
         |        |
         b        c
```

Recall that `bison` relies on user-written actions after grammar rules to construct an AST.

As an alternative, SableCC 3 actually allows the user to define an AST and the CST$\longrightarrow$AST transformations formally, and can then translate CSTs to ASTs automatically.

AST for the Tiny expression language:

```
Abstract Syntax Tree
exp =
  {plus}        [l]:exp [r]:exp |
  {minus}       [l]:exp [r]:exp |
  {mult}        [l]:exp [r]:exp |
  {divd}        [l]:exp [r]:exp |
  {id}          id |
  {number}      number;
```

AST rules have the same syntax as rules in the `Production` section except for CST$\longrightarrow$AST transformations (obviously).

Extending Tiny productions with CST⟶AST transformations:

```
Productions
cst_exp {-> exp} =
  {cst_plus}    cst_exp plus factor
                {-> New exp.plus(cst_exp.exp,factor.exp)} |
  {cst_minus}   cst_exp minus factor
                {-> New exp.minus(cst_exp.exp,factor.exp)} |
  {factor}      factor {-> factor.exp};

factor {-> exp} =
  {cst_mult}    factor star term
                {-> New exp.mult(factor.exp,term.exp)} |
  {cst_divd}    factor slash term
                {-> New exp.divd(factor.exp,term.exp)} |
  {term}        term {-> term.exp};

term {-> exp} =
  {paren}       l_par cst_exp r_par {-> cst_exp.exp} |
  {cst_id}      id {-> New exp.id(id)} |
  {cst_number}  number {-> New exp.number(number)};
```

A CST production alternative for a plus node:

```
cst_exp = {cst_plus} cst_exp plus factor
```

needs extending to include a CST⟶AST transformation:

```
cst_exp {-> exp} =
  {cst_plus} cst_exp plus factor
             {-> New exp.plus(cst_exp.exp,factor.exp)}
```

- `cst_exp {-> exp}` on the LHS specifies that the CST node `cst_exp` should be transformed to the AST node `exp`.
- `{-> New exp.plus(cst_exp.exp, factor.exp)}` on the RHS specifies the action for constructing the AST node.
- `exp.plus` is the kind of `exp` AST node to create. `cst_exp.exp` refers to the transformed AST node `exp` of `cst_exp`, the first term on the RHS.

5 types of explicit RHS transformation (action):

1. Getting an existing node:

   ```
   {paren}  l_par cst_exp r_par {-> cst_exp.exp}
   ```

2. Creating a new AST node:

   ```
   {cst_id} id {-> New exp.id(id)}
   ```

3. List creation:

   ```
   {block} l_brace stm* r_brace {-> New stm.block([stm])}
   ```

4. Elimination (but more like nullification):

   ```
   {-> Null}
   {-> New exp.id(Null)}
   ```

5. Empty (but more like deletion):

   ```
   {-> }
   ```