Handling declarations and expressions

Overview of declarations

- Action routines for simple declarations
- Action routines for advanced features
  - Constants
  - Enumerations
  - Subtypes
  - Arrays
  - Pointers
  - Packages/modules
  - Structs/classes

Simple declarations

- Declarations of simple types

  ```
  INT x;
  FLOAT f;
  ```

- Semantic action should
  - Get the type and name of identifier
  - Check to see if identifier is already in the symbol table
    - If it isn't, add it, if it is, error

Simple declarations (cont.)

- How do we get the type and name of an identifier?

```
var_decl → var_type id;

var_type → INT | FLOAT

id → IDENTIFIER
```

- Where do we put the semantic actions?

Simple declarations (cont.)

- How do we get the type and name of an identifier?

```
var_decl → var_type id; #decl_id

var_type → INT #int_type | FLOAT #float_type

id → IDENTIFIER #id
```

- Where do we put the semantic actions?
  - When we process #int_type and #id, can store the type and identifier name and pass them to #decl_id
- When creating activation record, allocate space on stack based on type (why?)

Constants and ranges

- Constants
  - Symbol table needs a field to store constant value
  - In general, the constant value may not be known until runtime (`static final int i = 2 + j;`)
  - At compile time, we create code that allows the initialization expression to assign to the variable, then evaluate the expression at run-time
- Range types (like in Pascal)

  ```
  Type alpha = ‘a’ .. ‘z’
  ```

  - Need an entry for the type as well as the upper and lower bounds

Enums

- Enumeration types: `enum days {mon, tue, wed, thu, fri, sat, sun};`
    - Create an entry for the enumeration type itself, and an entry for each member of the enumeration
        - Entries are usually linked
    - Processing enum declaration sets the "enum counter" to lower bound (usually 0)
    - Each new member seen is assigned the next value and the counter is incremented
        - In some languages (*e.g.*, C), enum members may be assigned particular values. Should ensure that enum value isn't reused

Arrays

- Fixed size (static) arrays

  `int A[10];`

  - Store type and length of array
  - When creating activation record, allocate enough space on stack for array

- What about variable size arrays?

  `int A[M][N]`

  - Store information for a *dope vector*
    - Tracks dimensionality of array, size, location
    - Activation record stores dope vector
    - At runtime, allocate array at top of stack, fill in dope vector

Pointers

- Need to store type information and length of what it points to
  - Needed for pointer arithmetic

    ```
    int * a = &y;
    z = *(a + 1);
    ```

- Need to worry about forward declarations
  - The thing being pointed to may not have been declared yet

    ```
    Class Foo;
    Foo * head;
    Class Foo { ... };
    ```

Packages and modules

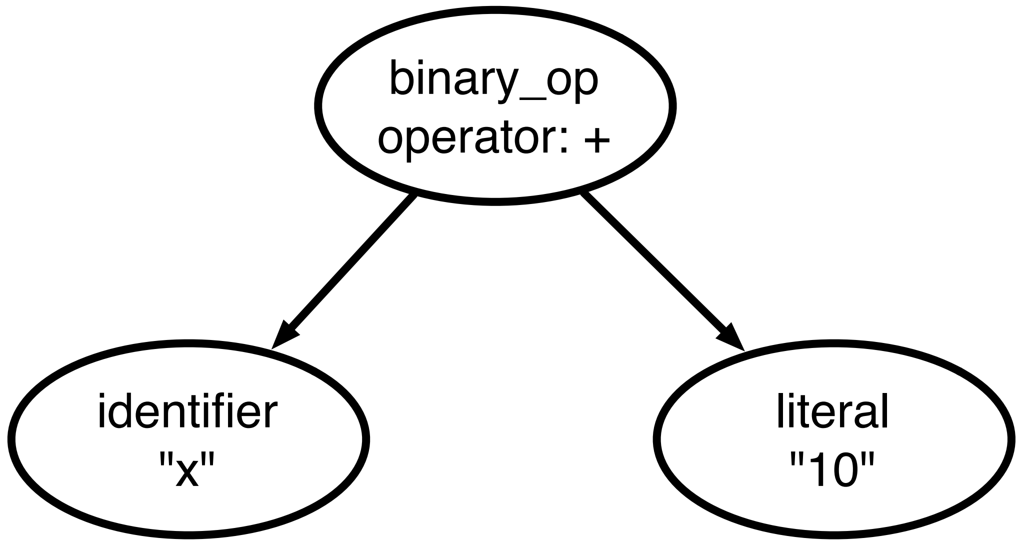
- Package/module can have members declared inside
  - Need pointer to package-specific symbol table
- Need to track information about visibility of members
  - public/private
  - Can be stored with package/module entry, or with entry for member

Structs/classes

- Similar to package/module
  - Can have variables/methds declared inside, need extra symbol table
  - Need to store visibility of members
- Complication: can create multiple instances of a struct or class!
  - Need to store *offset* of each member in struct

Abstract syntax trees

- Tree representing structure of the program
  - Built by semantic actions
  - Some compilers skip this
- AST nodes
  - Represent program construct
  - Store important information about construct



ASTs for References

Referencing identifiers

- Different behavior if identifier is used in a declaration vs. expression
  - If used in declaration, treat as before
  - If in expression, need to:
    - Check if it is symbol table
    - Create new AST node with pointer to symbol table entry
    - Note: may want to directly store type information in AST (or could look up in symbol table each time)

Referencing Literals

- What about if we see a literal?

  primary → INTLITERAL | FLOATLITERAL

- Create AST node for literal
- Store string representation of literal
  - "155", "2.45" etc.
- At some point, this will be converted into actual representation of literal
  - For integers, may want to convert early (to do *constant folding*)
  - For floats, may want to wait (for compilation to different machines). Why?

More complex references

- Arrays
  - A[i][j] is equivalent to

    `A + i*dim_1 + j`
  - Extract `dim_1` from symbol table or dope vector
- Structs
  - A.f is equivalent to

    `&A + offset(f)`
  - Find `offset(f)` in symbol table for f
- Strings
  - Complicated–depends on language

Expressions

- Three semantic actions needed
  - eval_binary (processes binary expressions)
    - Create AST node with two children, point to AST nodes created for left and right sides
  - eval_unary (processes unary expressions)
    - Create AST node with one child
  - process_op (determines type of operation)
    - Store operator in AST node

Expressions example

- $x + y + 5$

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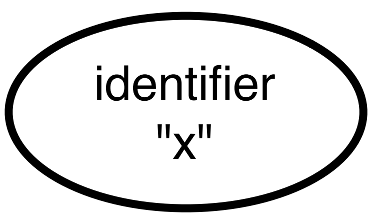

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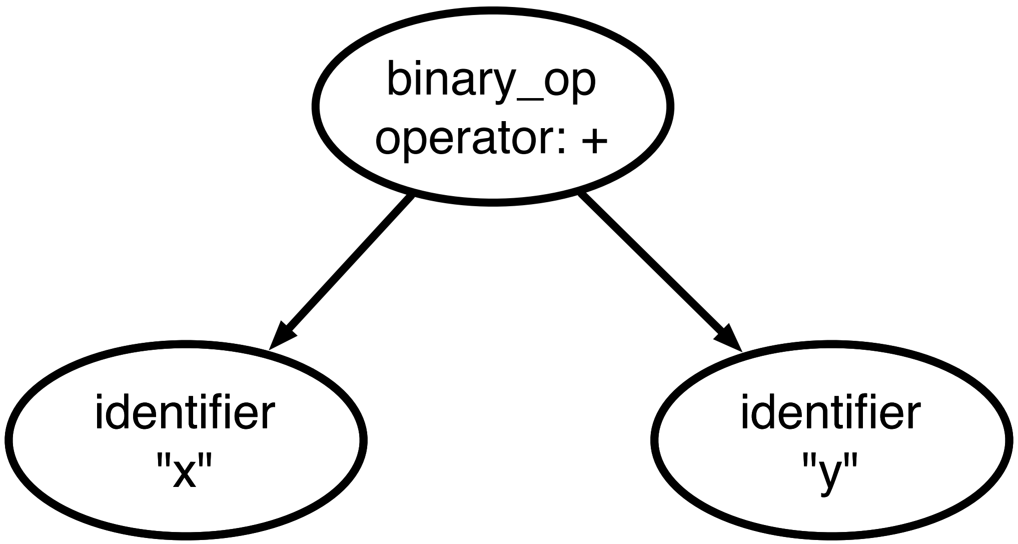

Expressions example

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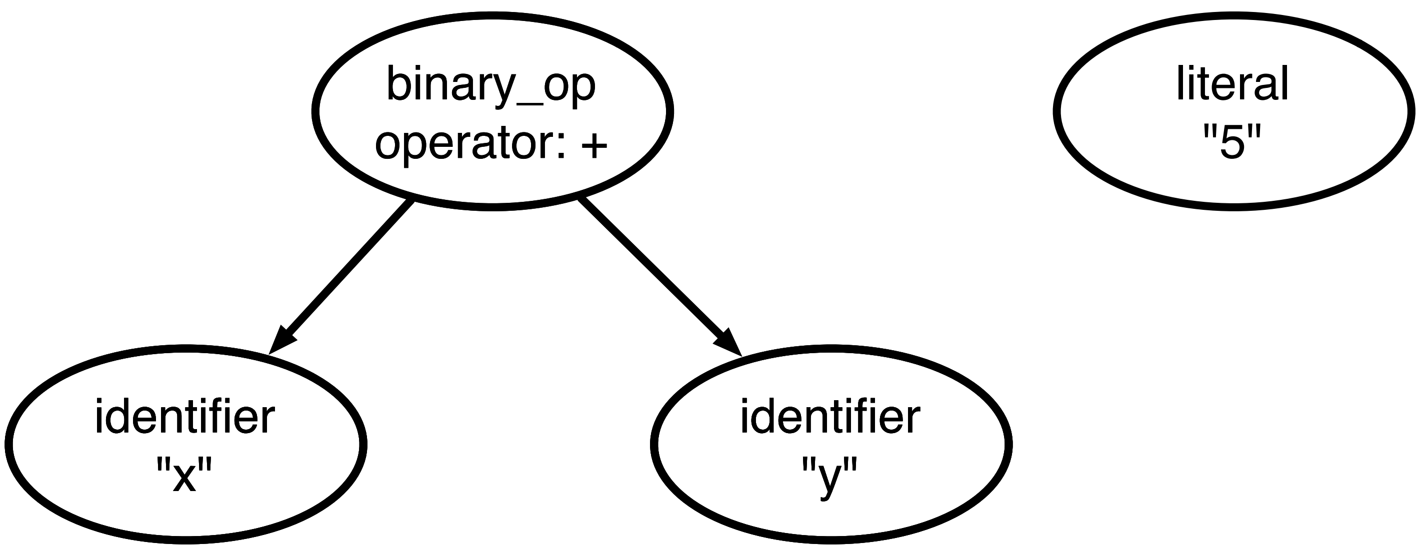

Expressions example

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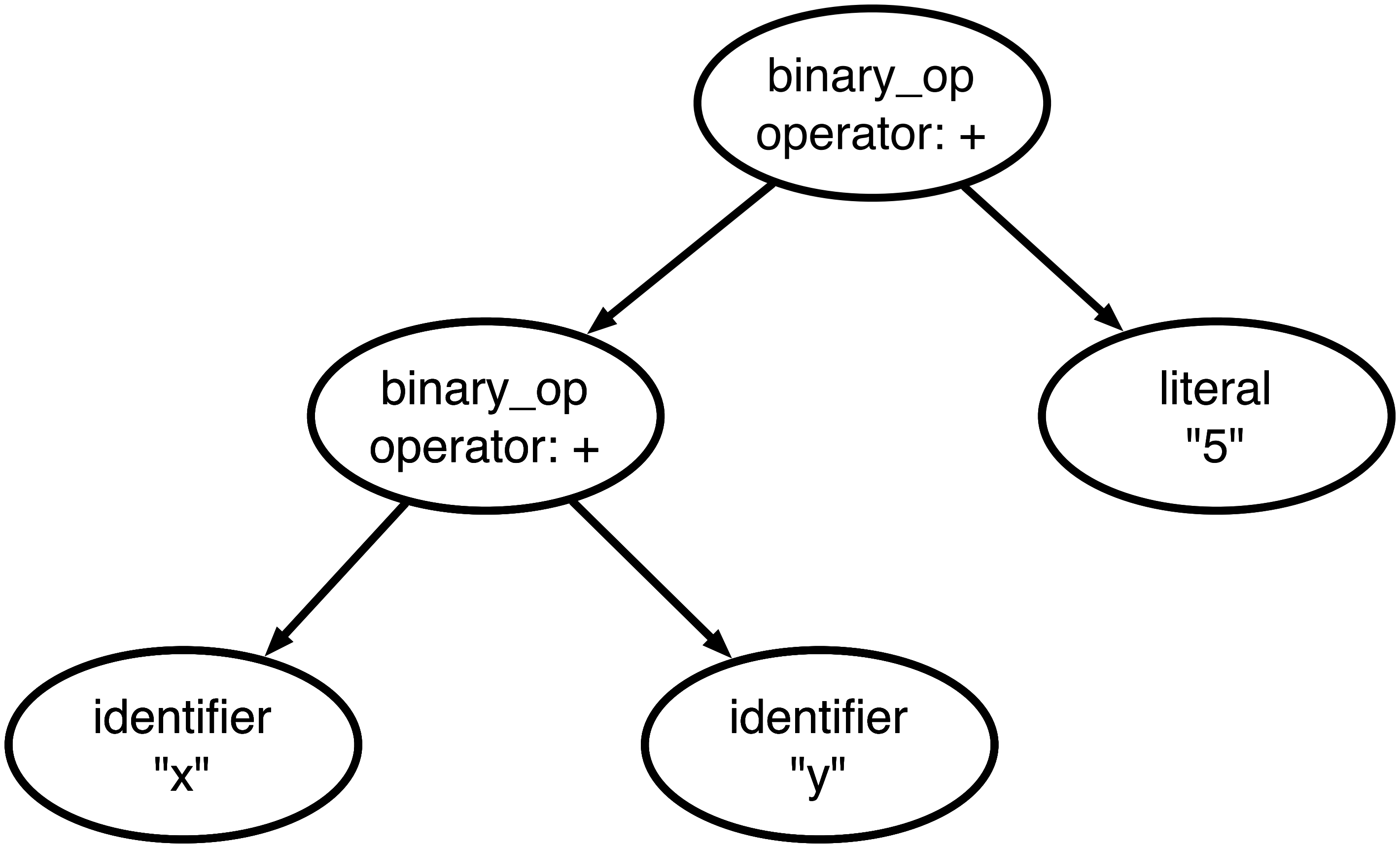

Generating three-address code

- For project, will need to generate three-address code
  - op A, B, C //C = A op B
- Can do this directly or after building AST

Generating code from an AST

- Do a post-order walk of AST to generate code, pass generated code up

```
data_object generate_code() {
  data_object lcode = left.generate_code();
  data_object rcode = right.generate_code();
  return generate_self(lcode, rcode);
}
```

- Important things to note:
  - A node generates code for its children before generating code for itself
  - Data object can contain code or other information
  - Code generation is *context free*
    - What does this mean?

Generating code directly

- This is very similar
    - Why?
    - Because post-order traversal is essentially what happens when you evaluate semantic actions as you pop them off stack
        - LL parser: evaluate left child before right child
        - LR parser: evaluate right child before left child
    - AST nodes are just semantic records
- If you are unsure how to generate code directly, come see me in office hours

L-values vs. R-values

- L-values: addresses which can be stored to
- R-values: data (often loaded from addresses)
  - Expressions operate on R-values
- Assignment statements:

  `L-value := R-value`

- Consider the statement `a := a`
  - the `a` on LHS refers to the memory location referred to by `a` and we store to that location
  - the `a` on RHS refers to data *stored in* memory location referred to by `a` so we will load from that location to produce the R-value

Temporaries

- Can be thought of as an unlimited pool of registers (with memory to be allocated at a later time)
- Need to declare them like variables
- Name should be something that cannot appear in the program (*e.g.*, use illegal character as prefix)
- Memory must be allocated if address of temporary can be taken (e.g. $a := \&b$)
- Temporaries can hold either L-values or R-values

Data objects

- Records various important info
  - The temporary storing the result of the current expression
  - Flags describing value in temporary
    - Constant, L-value, R-value
  - Code for expression

Simple cases

- Generating code for constants/literals
  - Store constant in temporary
  - Optional: pass up flag specifying this is a constant
- Generating code for identifiers
  - Generated code depends on whether identifier is used as L-value or R-value
    - Do we load from it? Or store to it?
    - One solution (may be inefficient): store address in temporary, let next level decide what to do with it
    - Set flag specifying this is an L-value

Generating code for expressions

- Create a new temporary for result of expression
- Examine data-objects from subtrees
- If temporaries are L-values, load data from them into new temporaries
    - Generate code to perform operation
- If temporaries are constant, can perform operation immediately
    - No need to perform code generation!
- Store result in new temporary
    - Is this an L-value or an R-value?
- Return code for entire expression

Generating code for assignment

- Store value of temporary from RHS into address specified by temporary from LHS
  - Why does this work?
  - Because temporary for LHS holds an address
    - If LHS is an identifier, we just stored the address of it in temporary
    - If LHS is complex expression

      ```
      int *p = &x
      ```

      ```
      (p + 1) = 7;
      ```

      it *still* holds an address, even though the address was computed by an expression