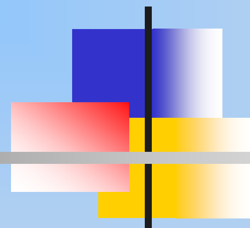
CSE302: Compiler Design



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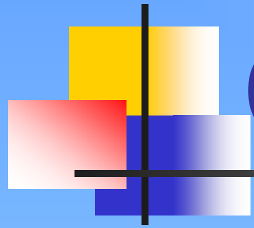


Outline

- Recap
  - Three address code generation
- Type checking
- Brief introduction to runtime environments
- Summary

Translation of Expressions

- S → id = E ;
  - S.code = E.code || gen(top.get(id.lexeme) '=' E.addr)
- E → E1 + E2
  - E.addr = new Temp()
  - E.code = E1.code || E2.code
    || gen(E.addr '=' E1.addr '+' E2.addr)
- E → - E1
  - E.addr = new Temp()
  - E.code = E1.code || gen(E.addr '=' 'minus' E1.addr)
- E → (E1)
  - E.addr = E1.addr
  - E.code = E1.code
- E → **id**
  - E.addr = top.get(id.lexeme)
  - E.code = ''

SDT of Array Type Declaration

- T $\rightarrow$ B {t = B.type; w = B.width;} C {
  T.type = C.type; T.width = C.width;
  }
- B $\rightarrow$ **int** {B.type = integer; B.width = 4;}
- B $\rightarrow$ **float** {B.type = float; B.width = 8;}
- C $\rightarrow$ [**num**] C1 {
  C.type = array(**num**.value, C1.type);
  C.width = **num**.value $\times$ C1.width;
  }
- C $\rightarrow$ ε {C.type = t; C.width = w;}

Translation of Array References

- L→ **id** [E]
  - L.array = top.get(id.lexeme)
  - L.type = L.array.type.elem
  - L.addr = **new** Temp()
  - gen(L.addr '=' E.addr '*' L.type.width)
- L→ L1 [E]
  - L.array = L1.array
  - L.type = L1.type.elem
  - t = **new** Temp()
  - L.addr = **new** Temp()
  - gen(t '=' E.addr '*' L.type.width)
  - gen(L.addr '=' L1.addr '+' t)
- S → L = E ;
  - gen(L.array.base '[' L.addr ']' '=' E.addr
- E → L
  - E.addr = new Temp()
  - gen(E.addr '=' L.array.base '[' L.addr ']')

Translation of Control Flows and Boolean Expressions

- S→if({B.true=newlabel(); B.false=S.next;}
  B) S1 {S.code=B.code || label(B.true) || S1.code
  - if B goto L1
  - goto L2
  - L1: S1
  - L2:
- B → B1 || B2
- S → if({B.true=newlabel(); B.false=S.next;
  B1.true=B.true; B1.false=newlabel();
  B2.true=B.true; B2.false=B.false;}
  B1||B2) {B.code=B1.code || label(B1.false) || B2.code}
  S1 {S.code=B.code || label(B.true) || S1.code
  - if B1 goto L1
  - goto L2
  - L2: if B2 goto L1
  - goto L3
  - L1: S1
  - L3:

Translation of Boolean Expressions

- B → B1 && B2
- S → if({ B.true=newlabel(); B.false=S.next;
  B1.true=newlabel(); B1.false=B.false;
  B2.true=B.true; B2.false=B.false;}

  B1&&B2) {B.code=B1.code || label(B1.true) || B2.code}

  S1 {S.code=B.code || label(B.true) || S1.code

- B → !B1
- S → if({B.true=newlabel(); B.false=S.next;
  B1.true=B.false; B1.false=B.true;}

  !B1) {B.code=B1.code}

  S1 {S.code=B.code || label(B.true) || S1.code}

- B → E1 rel E2
- S → if({B.true=newlabel(); B.false=S.next;}

  E1 rel E2) {B.code=E1.code || E2.code ||
  gen('if E1.addr rel.op E2.addr 'goto' B.true ||
  gen('goto' B.false);
  }

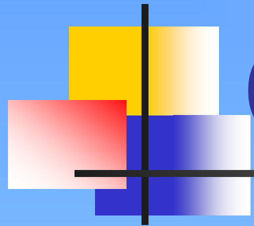
  S1 {S.code=B.code || label(B.true) || S1.code}

An Example

- while(a<b && a<c) a=(a+d)

An Example

- B → B1 && B2
- S → if({B.true=newlabel(); B.false=S.next; B1.true=newlabel();
  B1.false=B.false; B2.true=B.true; B2.false=B.false;}
  B1&&B2)   {B.code=B1.code || label(B1.true) || B2.code}
  S1   {S.code=B.code || label(B.true) || S1.code
- B → E1 rel E2
- S → if({B.true=newlabel(); B.false=S.next;}
  E1 rel E2)   {B.code=E1.code || E2.code ||
  gen('if E1.addr rel.op E2.addr 'goto' B.true || gen('goto' B.false); }
  S1   {S.code=B.code || label(B.true) || S1.code}
- S → while({begin = newlabel();
  B.true=newlabel(); B.false=S.next;}
  B)   {S1.next=begin;}
  S1   {S.code=label(begin) || B.code || label(B.true) ||
  S1.code || gen('goto' begin);}
- E → **id**   {E.addr = top.get(id.lexeme); E.code = '';}
- S → id = E ;   {S.code = E.code || gen(top.get(id.lexeme) '=' E.addr);}
- E → E1 + E2   {E.addr = new Temp();
  E.code = E1.code || E2.code || gen(E.addr '=' E1.addr '+' E2.addr);}



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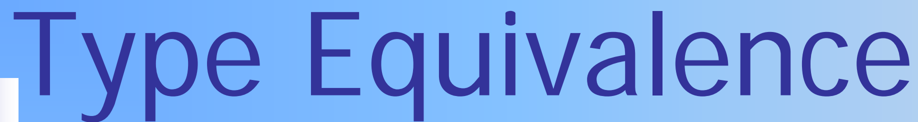
Type Expressions

- Declarations
  - $D \rightarrow T\ \textbf{id};\ D \mid \varepsilon$
  - $T \rightarrow B\ C \mid \textbf{record}\ \text{'\{'}\ D\ \text{'\}'}$
  - $B \rightarrow \textbf{int} \mid \textbf{float}$
  - $C \rightarrow [\textbf{num}]\ C \mid \varepsilon$
- A type expression
  - A basic type
  - A type constructor
    - array
    - record
    - $\rightarrow$

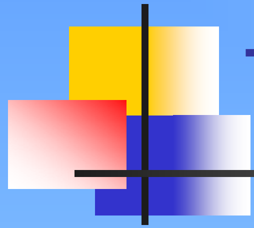


Type Equivalence

- **if** two type expressions are equal
  then return a certain type
  else error
  - Same basic type
  - Same constructor applied to structurally equivalent types
  - A type name denoting the other
    - ```
      typedef int aaa, bbb, ccc;
      /* all ints */
      aaa    int1;
      bbb    int2;
      ccc    int3;
      ```
    - ```
      struct _node
      {
          char *name;
          char *value;
          struct _node *next;
      };
      typedef struct _node Node;
      ```

Type Checking

- Each component has a type expression assigned
  - Conform to the type system
  - Strongly typed languages



Type Synthesis

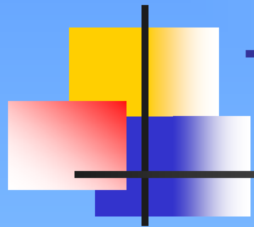
- if f has type $s \rightarrow t$ and x has type s then expression $f(x)$ has type t
- Type declarations are needed
- A type conversion SDD
  - E → E1 + E2
    - E.addr = new Temp()
    - E.code = E1.code || E2.code
      || gen(E.addr '=' E1.addr '+' E2.addr)

Type Conversion Hierarchy

- Double, float, long, int, short, char, byte
  - Widening conversion hierarchy
  - Narrowing conversion hierarchy
- Addr widen(Addr a, Type t, Type w) {

```
Addr widen(Addr a, Type t, Type w) {
        if (t=w) return a;
        else if (t=int and w=float) {
                temp = new Temp();
                gen(temp '=' '(float)' a);
                return temp;
        }
        else error;
}
```

- max(t1,t2)



Type Synthesis

- if f has type $s \rightarrow t$ and x has type s then expression $f(x)$ has type t
- A type conversion SDD
  - E → E1 + E2
    - E.type = max(E1.type, E2.type)
    - a1 = widen(E1.addr, E1.type, E.type)
    - a2 = widen(E2.addr, E2.type, E.type)
    - E.addr = new Temp()
    - E.code = E1.code || E2.code
      || gen(E.addr '=' a1 '+' a2)

Function/Operator Overloading

- void err() {…}; void err(String s) {…}
- 1+2; A+B;

- if f have type $s_i \rightarrow t_i$ and x has type s_k then expression $f(x_k)$ has type t_k

Type Inference

- No need to declare type before usage
- A Scheme example
  - *length*.scm
  - (+ (length '("String A" "String B")) (length '(1 2 3)))
  - The type expression of *length*
    - $\forall\alpha.\ list(\alpha) \rightarrow integer$

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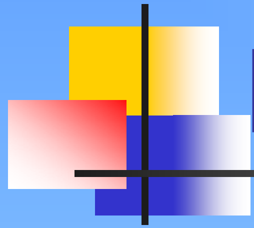
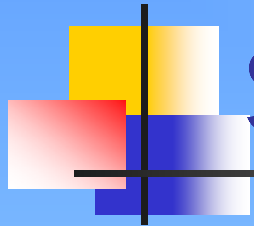
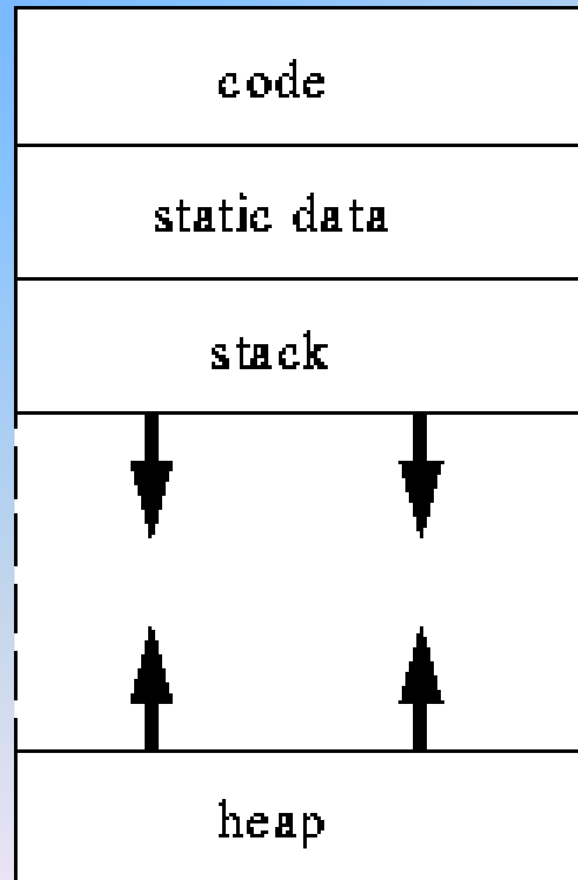


Run-Time Environments

- Storage layout and allocation
- Subprogram linkages
- Variable reference accessing mechanisms
- Parameter passing mechanisms
- Interface to OS and I/O



Storage Organization



Subprogram Linkages

- Activation record instance
  - Stack frame
- Subprogram call
  - Push stack frames
- Subprogram exit
  - Pop stack frames
- Stack-dynamic variable

Heap-dynamic Variables

- C
  - **malloc** and **free**
- C++
  - **new** and **delete**

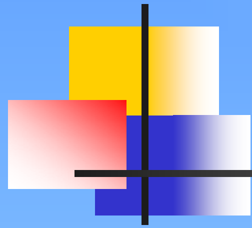
  int *intnode;

  ...

  intnode = **new int**;

  ...

  delete intnode;
- Java
  - All objects

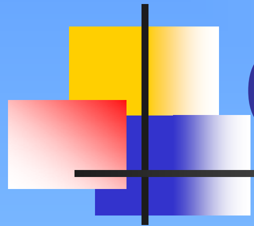


Heap Management

- Reference counters (eager approach)
  - Maintain a counter in every cell that store the number of pointers currently pointing at the cell
- Garbage collection (lazy approach)
  - Allocate and disconnect until all available cells allocated; then begin gathering all garbage

Garbage Collection

- Every heap cell has an extra bit used by collection algorithm
- All cells initially set to garbage
- All pointers traced into heap, and reachable cells marked as not garbage
- All garbage cells returned to a list of available cells



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