

Names, Scopes, and Bindings

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Names, Scopes, and Bindings

- 1 Bindings
- 2 Symbol Tables
- 3 Complications

Bindings

- 1 Bindings
 - Names
 - Scopes
 - Binding Time
- 2 Symbol Tables
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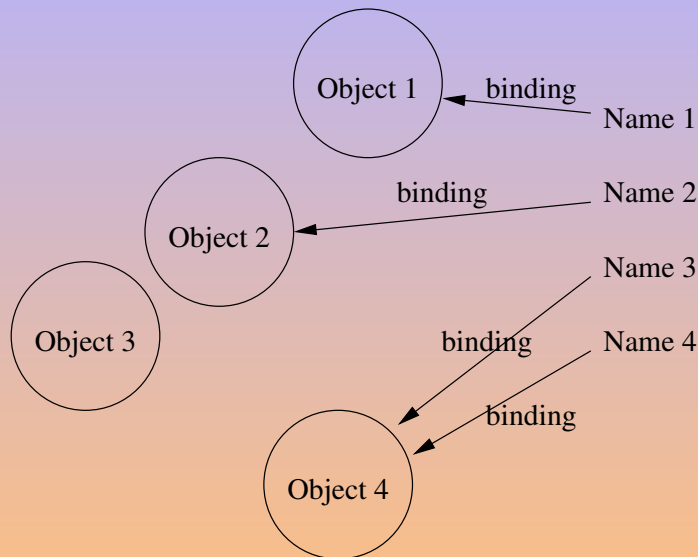
Names, Identifiers, Symbols

- *Name (Identifiers, Symbols)*
- *reference*
- *address*
- *value*
- To refer to some entities: variable, type, function, namespace, constant, control structure (e.g., named `next`, `continue` in Perl), etc.

Identifiers

- usually alphanumeric and underscore, letter first, without white spaces.
- ALGOL 60, FORTRAN ignore white spaces.
- limitation on the length
 - 6 characters for the original FORTRAN (Fortran 90: 31),
 - ISO C: 31
 - no limit for most others.
- case insensitive in Modula-2 and Ada.

Names, Objects, and Bindings [Edwards, 2003]



Names, Objects, and Bindings

- When are objects created and destroyed?
Lifetimes (deferred to a later lecture).
- When are names created and destroyed?
Scopes.
- When are bindings created and destroyed?
Binding times.

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Scopes

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 - **Scopes**
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When are names created, visible, and destroyed?

Scope

The **textual** region in the **source** in which the binding is active.

Static Scoping

The scope can be computed at compile-time.

Dynamic Scoping

The scope depends on runtime conditions such as the function calls.

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Why Scopes?

- Scopes are the first form of structure/modularity
- No scopes in assembly
- No scopes in MFS
(First generation of the Macintosh File System)
- Without scopes, names have a global influence
- With scopes, the programmer can focus on local influences
- Scopes in correct programs with unique identifiers are “useless”
- C++ namespaces are “pure scopes”

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Declaration

Blocks determine scopes.

- local variables
- non local variables
- global variables

```
int global;

int outer(void)
{
    int local, non_local;

    int inner(void)
    {
        return global + non_local;
    }

    return inner;
}
```

Static Scoping

- In most languages (Ada, C, Tiger, FORTRAN, Scheme, Perl (my), etc.).
- Enables static binding.
- Enables static typing.
- Enables strong typing (Ada, ALGOL 68, Tiger).
 - safer
 - faster
 - clearer

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Dynamic Scoping

- In most scripting/interpreted languages (Perl (`local`), Shell Script, \TeX etc.) but also in Lisp (as opposed to Scheme).

Dynamic Scoping in \TeX

```
% \x, \y undefined.
{
  % \x, \y undefined.
  \def \x 1
  % \x defined, \y undefined.
  \ifnum \a < 42
    \def \y 51
  \fi
  % \x defined, \y may be defined.
}
% \x, \y undefined.
```

- Prevents static typing

An identifier may refer to different values, with different types.

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Scopes in Tiger

Many different `t`, including several “variables”.

```
t time
```

```
let
```

```
  type      t = { h: int, t: t }
```

```
  function  t (h: int, t: t) : t =  
            t { h = h, t = t }
```

```
  var      t := t (12, nil)
```

```
  var      t := t (12, t)
```

```
in
```

```
  t.t = t
```

```
end
```

ML

```
structure M = struct
  structure E = struct
    val a = 5;
  end
  structure N = struct
    val b = 10;
    val a = E.a + b;
  end
  structure D = struct
    val d = E.a + N.a;
  end
end
```

Java (fwd declaration allowed)

```
package M;
class E {
  static int a = 5;
}
class N {
  static int b = 10;
  static int a = E.a + b;
}
class D {
  static int d = E.a + N.a;
}
```

Scopes [Appel, 1998]

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end
```

$\sigma_0 =$ Prelude

$\sigma_1 = \{a : int\}$

$\sigma_2 = \{E : \sigma_1\}$

$\sigma_3 = \{b : int, a : int\}$

$\sigma_4 = \{N : \sigma_3\}$

$\sigma_5 = \{d : int\}$

$\sigma_6 = \{D : \sigma_5\}$

$\sigma_7 = \sigma_2 + \sigma_4 + \sigma_6$

$\sigma_0 + \sigma_2 \vdash N : \sigma_3$ (ML)

$\sigma_0 + \sigma_2 + \sigma_4 \vdash N : \sigma_3$ (Java)

$\sigma_0 + \sigma_2 + \sigma_4 + \sigma_6 \vdash M : \sigma_7$

Lifetime (or extent)

- Lifetime is a different matter, related to the execution (as opposed to visibility).
- Extent bound to lifetime of block tend to promote global variables (Pascal).
- *Static local variables* as in C (*static*), ALGOL 60 *own*, PL/I. Initialization?
- Modules tend to replace this block related feature.

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Binding Time

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Binding Time [Edwards, 2003]

When a binding from a name to an object is made.

Binding Time	Examples
language design	if
language implementation	data width
program writing	foo, bar
compilation	static objects, code
linkage	relative addresses
loading	shared objects
execution	heap objects

Binding Time: the moving IN

Roughly, flexibility and efficiency

- are mutually exclusive
- depend on binding time.

The Moving IN

binding-time

early -----> late

INflexibility	flexibility
efficiency	INEfficiency

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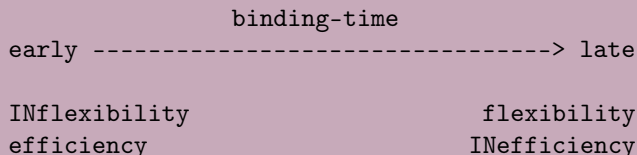
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The Moving IN



Dynamic Binding: virtual in C++

Dynamic dispatch is roughly **runtime** overloading.

Dynamic Dispatch in C++

```
struct Shape
{
    virtual void draw() const = 0;
};
```

```
struct Square : public Shape
{
    void draw() const override {};
};
```

```
struct Circle : public Shape
{
    void draw() const override {};
};
```

Dynamic Dispatch in C++

```
#include <vector>
#include "shapes.hh"

using shapes_type = std::vector<Shape*>;

int main()
{
    auto ss = shapes_type{new Circle, new Square};

    for (auto s: ss)
        // Inclusion polymorphism.
        s->draw();
}
```

- Most interpreted languages support eval (explicit or not): runtime code evaluation.
- Enables language extensions.

try/catch in Perl

```
try {  
    die "phooey";  
} catch {  
    /phooey/ and print "unphooey\n";  
};
```


Late Code Binding: eval

- Most interpreted languages support eval (explicit or not): runtime code evaluation.
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```
try/catch in Perl
```

```
sub eval ($code) {  
    my ($try, $catch) = @$code;  
    eval { $try };  
    if ($?) {  
        local $_ = $try;  
        $try->eval;  
    }  
    eval { $catch };  
    if ($?) {  
        local $_ = $catch;  
        $catch->eval;  
    }  
}  
  
sub catch ($code) {  
    $code->eval;  
}  
  
try {  
    die "phooey";  
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};
```

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try/catch in Perl

```
sub try (&@) {
    my ($try, $catch) = @_;
    eval { &$try }; # Explicit eval.
    if ($?) {
        local $_ = $?;
        &$catch;
    }
}

sub catch (&) {
    $_[0]; # implicit eval.
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Binding Times in Tiger [Edwards, 2003]

Design Keywords

Program Identifiers

Compile Function code, frames, types

Execution Records, arrays addresses

Little dynamic behavior

Symbol Tables

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Visiting an ast

For statically scoped languages

- many traversals check **uses** against **definitions**
- most traversals need a form of memory (binding, type, escapes, inlining, translation, etc.)
- this memory is related to scopes
- we need some reversible memory (do/undo)

Similarly for narrow compilers without ast

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Symbol Tables: Scopes

Handle scopes?

- not needed if all the names are unique
- or if there exists a unique identifier
- required otherwise

Handle scopes explicitly?

- yes: the tables support ordered, scoped symbol tables
- do not rely on automatic variables

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(Non Scoped) Symbol Tables

An **associative array**

- put
- get

Implementation

- a list
- a tree
- a hash
- ...

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Scoped Symbol Table: `symbol::Table`

```
class Table
```

```
template <typename Entry_T>
class Table
{
public:
    Table();

    auto put(symbol key, Entry_T& val) -> void;
    auto get(symbol key) const -> Entry_T*;

    auto scope_begin() -> void;
    auto scope_end() -> void;

    auto print(std::ostream& ostr) const -> void;
};
```

Not very C++ (iterators instead of pointers, `operator []`, etc.)

Scoped Symbol Table Implementations

- Mixing Stacks and Associative Arrays
- Copying, or not copying?
- Functional (Non Destructive) Versions
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When do you deallocate associated data?

`scope end` deallocate everything since the latest `scope_begin`

`pass end` deallocate auxiliary data after the traversal is completed

`ast` bind the data to the `ast` and delegate deallocation

by hand thanks God for Valgrind

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Memory Management: Deallocate on scope exit

But then...

Twice foo

```
let var foo := 42
    var foo := 51
in foo end
```

Two lets

```
let var foo := 42 in
let var foo := 51
in foo end end
```

but then again...

Escaping type

```
let type rec = {}
in rec {} end <> nil
```

Segmentation violation...

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Segmentation violation...
Courtesy of Arnaud Fabre.

Memory Management: Deallocate with the AST

- annotate each node of ast
- annotate each scoping node with a symbol table and link them
- leave tables outside

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Bind the names/Label by definition address

- annotates uses with links to their definitions
- uses scoped symbol tables
- or regular containers and recursion
- checks multiple definitions
- checks missing definitions
- and also binds...

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- uses scoped symbol tables
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Complications

1 Bindings

2 Symbol Tables

3 **Complications**

- Overloading
- Non Local Variables

Overloading

- 1 Bindings
- 2 Symbol Tables
- 3 Complications
 - Overloading
 - Non Local Variables

Overloading

Overloading: Homonyms

Several entities bearing the same name, but **statically** distinguishable, e.g., by their arity, type etc.

```
// foo is overloaded.  
int foo(int);  
int foo(float);
```

Aliasing: Synonyms

One entity bearing several names.

```
// x and y are aliases.  
int x;  
int& y = x;
```

Operator Overloading

Overloading is meant to simplify the user's life. Since FORTRAN!

Overloading in Caml

```
# 1 + 2;;
```

```
- : int = 3
```

```
# 1.0 + 2.0;;
```

```
Characters 0-3:
```

```
  1.0 + 2.0;;
```

```
  ^^^
```

This expression has type float but is here used with type int

```
# 1.0 +. 2.0;;
```

```
- : float = 3.
```

Thank God, C was invented to improve Caml:

```
int  a = 1 + 2;;
```

```
float b = 1.0 + 2.0;;
```

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```
int  a = 1  + 2;;
```

```
float b = 1.0 + 2.0;;
```

Of course this is unfair: Caml has type inference.

Function Overloading

Usually based on the arguments
(Ada, C++, Java...; not C, ALGOL 60, Fortran...).

ALGOL 60

```
integer I;  
real X;  
...  
PUTSTRING("results are: "); PUTINT(I); PUTREAL(X);
```

Ada [ARM, 1983]

```
I : INTEGER;  
X : REAL;  
...  
PUT("results are: "); PUT(I); PUT(X);
```

Overloading is Syntactic Sugar

Overloaded

```
#include <string>

void foo(int);
void foo(char);
void foo(const char*);
void foo(std::string);

int
main ()
{
    foo(0);
    foo('0');
    foo("0");
    foo(std::string("0"));
}
```

Un-overloaded

```
#include <string>

void foo_int(int);
void foo_char(char);
void foo_char_p(const char*);
void foo_std_string(std::string);

int
main ()
{
    foo_int(0);
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```


Overloading is Syntactic Sugar

Usually solved by renaming/mangling.

g++-2.95, como

```
f__Fi  -> int f(int);  
f__FPc -> int f(char*);
```

g++-3.2, icc

```
_Z1fi  -> int f(int);  
_Z1fPc -> int f(char*);
```

Overloading in Tiger

Ordering `<`, `<=`, `>`, and `>=`
overloaded for pairs of integers, or strings.

Identity `=` and `<>`
overloaded for (type coherent) pairs of integers, strings,
arrays or records.

Non Local Variables

- 1 Bindings
- 2 Symbol Tables
- 3 Complications
 - Overloading
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Lambda Shifting

With nested functions

```
int global;

int outer(void)
{
    int local, non_local;

    int inner(void)
    {
        return
            global + non_local;
    }

    return inner();
}
```

Without

```
int global;

int outer_inner_(int* non_local)
{
    return global + *non_local;
}

int outer(void)
{
    int local, non_local;
    return outer_inner_(&non_local);
}
```

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}
```

Non Local Variables

```
let
  function outer(): int =
    let
      nonlocal var outer := 0
    in
      let
        function inner() : int =
          let
            var inner := 1
          in
            inner + outer
          end
        in
          inner()
        end
      end
    in
      outer ()
  end
```

Non Non Local Variables

```
let
```

```
  let
```

```
    local var outer := 0
```

```
  in
```

```
    let
```

```
      let
```

```
        var inner := 1
```

```
      in
```

```
        inner + outer
```

```
      end
```

```
    in
```

```
  end
```

```
end
```

```
in
```

```
end
```

Non Non Local Variables

```
let
  function outer(): int =
    let
      local var outer := 0
    in
      let
        let
          var inner := 1
        in
          inner + outer
        end
      in
        end
      end
    in
      outer()
  end
```


The Escapes and Functional Programming

```
let
  function add(nonlocal a: int, b: int) : int =
    let
      function add_a(x: int) : int = a + x
    in
      add_a(b)
    end
in
  print_int(add(1, 2));
  print("\n")
end
```

Closures

```
let
  function add_gen(nonlocal a: int) : int -> int =
    let
      function add_a(x: int) : int = a + x
    in
      add_a
    end
  incr = add_gen(1);
in
  print_int(incr(2));
  print("\n");
end
```

The Escapes & Recursion

```
let
  function one(input : int) =
    let
      function two() =
        (print("two: "); print_int(input);
         print("\n");
         one(input))
    in
      if input > 0 then
        (input := input - 1;
         two(); print("one: ");
         print_int(input); print("\n"))
      end
    in
      one (3)
  end
```

Escaping Variables/Arguments

Technically **escaping** means “cannot be stored in a register”.

In C

- Large values (arrays, structs).
- Variables whose address is taken.
- Variable arguments.

In Tiger

- variables/arguments from outer functions.
- not variables/arguments from outer scopes.

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