Names, Scopes, and Bindings

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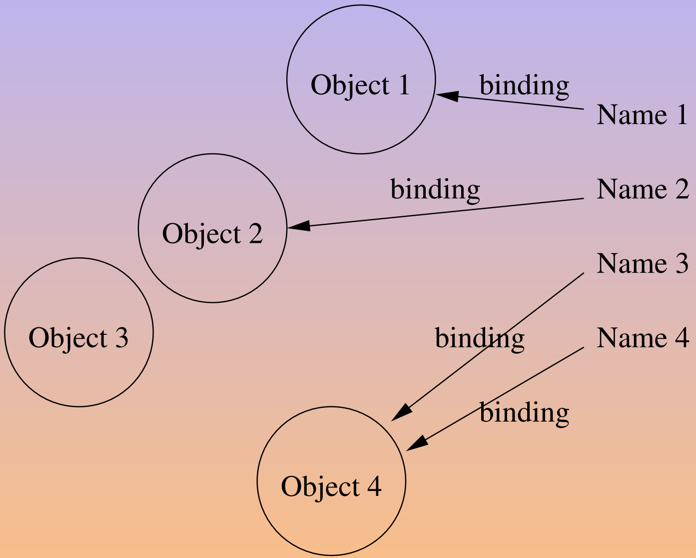
Names

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.


Object 1
binding
Name 1
binding
Name 2
Object 2
Name 3
Object 3
binding
Name 4
binding
Object 4

- 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

Scopes [Edwards, 2003]

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

```c
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
```

Scopes [Appel, 1998]

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;
}
```

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```

$$
\begin{aligned}
\sigma_0 &= \text{Prelude} \\
\sigma_1 &= \{a : int\} \\
\sigma_2 &= \{E : \sigma_1\} \\
\sigma_3 &= \{b : int, a : int\} \\
\sigma_4 &= \{N : \sigma_3\} \\
\sigma_5 &= \{d : int\} \\
\sigma_6 &= \{D : \sigma_5\} \\
\sigma_7 &= \sigma_2 + \sigma_4 + \sigma_6
\end{aligned}
$$

$$
\begin{aligned}
\sigma_0 + \sigma_2 &\vdash N : \sigma_3 \quad \text{(ML)} \\
\sigma_0 + \sigma_2 + \sigma_4 &\vdash N : \sigma_3 \quad \text{(Java)} \\
\sigma_0 + \sigma_2 + \sigma_4 + \sigma_6 &\vdash M : \sigma_7
\end{aligned}
$$

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?
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Binding Time

1. Bindings
   - Names
   - Scopes
   - Binding Time
2. Symbol Tables
3. Complications

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
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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
{
  virtual void draw() const override {};
};

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

Dynamic Binding: virtual in C++

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();
}
```

Late Code Binding: `eval`

- 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";
};
```

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```
sub try (&@) {
  my ($try, $catch) = @_;
  eval { &$try };
  if ($@) {
    local $_ = $@;
    &$catch;
  }
}
sub catch (&) {
  $_[0];
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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

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

Visiting an ast

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- or if there exists a unique identifier
- required otherwise

Handle scopes explicitly?

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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++...

Scoped Symbol Table Implementations

- Mixing Stacks and Associative Arrays
- Copying, or not copying?
- Functional (Non Destructive) Versions
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Memory Management

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
- never

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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
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Segmentation violation...

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Courtesy of Arnaud Fabre.

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

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- but how can you guarantee unique names
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Bind the names/Label by definition address

Binder

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- uses scoped symbol tables
- or regular containers and recursion
- checks multiple definitions
- checks missing definitions
- and also binds...

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Complications

Overloading

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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```

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
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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

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
      non-local 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(non-local 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(non-local 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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Annotating the ast

- being non local means having non local uses
- obviously non local variables need to be accessible from inner functions
- to simplify the compiler, it is easier to leave them on the stack
- hence the translation to intermediate representation needs to know which variables are non local from their definitions
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