COMP-520 – GoLite Tutorial

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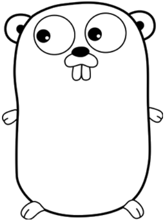

Plan

- Target languages
- Language constructs, emphasis on special cases
  - General execution semantics
  - Declarations
  - Types
  - Statements
  - Expressions
- Implementation advice

Feel free to ask questions at any time.

Reference compiler

- ssh <socs_username>@teaching.cs.mcgill.ca
- `~cs520/golitec {keyword} < {file}`
- Codegen outputs C++ code (can be compiled with `g++ --std=c++11 {file}`)
- If you find errors in the reference compiler, bonus points!

Reminder

We know that previous year's submissions are available online. There are 3 requirements for this class:

1. You must come up with your own solutions; any inspiration that comes from other sources must be reported.
2. You must have permission to use any outside resources from the original authors.
3. No grading material may be used at any point, under any circumstance, nor may it be published.

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- Low-level vs. high-level
- Statically-typed vs. dynamically-typed
- Similarity to Go
- (No C++ as this is used in the reference implementation)

Target language

Previous years

- C
- Java
- Swift
- JavaScript
- TypeScript
- Python
- Java Bytecode
- LLVM
- x86

Go execution

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During program execution, Go is:

- Pass-by-value
- Return-by-value
- (Mostly) left-to-right evaluation order

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```
package main

func init() { ... } // init1

func main() { ... }

func init() { ... } // init2
```

In which order are the functions executed?

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Declarations

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- Variable declarations
- Type declarations

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- Naming conflicts with keywords
- Scoping differences
- Blank identifiers

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Naming conflicts

Naming conflicts occur when an identifier is legal in Go, but a keyword in the target language.

```
var restrict int    // Conflict in C

func None() {}      // Conflict in Python
```

What approach avoids all possible keyword conflicts?

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What approach avoids all possible keyword conflicts?

Renaming all identifiers with a unique prefix/suffix

Be careful, we must ensure that the renaming does not cause any further conflicts.

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Function declarations consist of a name, set of parameters, and an optional return type.

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typedef the struct

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- Shadowing of `true` and `false` constants

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var true bool = false
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- Scoping

Variable declarations

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Scoping rules vary widely and wildly between different programming languages.

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    var b int = a
    var a int = a  // ‘a’ points to the parent scope
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Can we directly translate the above code to C? JavaScript?

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Renaming!

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Defined types are only required for the purpose of type-checking. In terms of storage it makes no difference.

Declarations

Blank identifiers

Blank identifiers may be used in:

- Function names
- Function parameters
- Variable names (declarations/assignments)
- Struct fields

Blank functions and struct fields are easy to generate. Why?

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- Struct fields

Blank functions and struct fields are easy to generate. Why?

They may never be accessed and can thus be ignored

Declarations

Blank parameters

If a function has blank parameters, they must still be generated as function calls will include the arguments.

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func foo(_ int, a int, _ int) { ... }

func main() {
    foo(1, 2, 3)
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What problem will occur in the above code?

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Temporary variable names

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Can we therefore eliminate the declaration?

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No!

```
func foo() int {
    println("foo")
    return 0
}

var _ int = foo()
```

Expressions evaluated as part of declarations may have side-effects and should still be executed.

Types

Basic types:

- `int` (may be either 32 or 64 bit depending on the architecture)
- `float64`
- `bool`
- `rune`
- `string`

Composite types:

- Arrays
- Slices
- Structs

Arrays

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In Go they have two interesting properties:

- Bounds checking
- Equality

Go provides bounds checking for arrays, producing runtime error if the index is out of bounds.

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var a [5]int
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Arrays

Equality

Go also provides element-wise equality for arrays, returning true iff all elements are equal.

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var a, b [5]int
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Beware! Arrays can contain other arrays or structures - your helper methods must account for this.

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As the size of the slice changes, the header is updated and the underlying array reallocated if needed.

You will likely face a trade-off between correctness and efficiency.

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The special function is trickier for slices - it must use the dynamic size from the slice header.

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Objects, records, etc.

We will not check nor implement any low-level details such as alignment or padding.

Structs

Equality

Go provides field-wise equality for structs, returning true iff all *non-blank* fields are equal. Empty structs are trivially equal.

```
var a, b struct {
    f int
    _ float64
}
println(a == b) // Ouputs true

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Statements

- Assignments
- Short declarations
- Increment/decrement
- Ifs
- For loops
- Switches
- Returns
- Prints

Assignments

An assignment statement:

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An assignment statement:

- Copies the value of the expression to the variable
- Ignores assignments of blank identifiers
- May assign multiple values *simultaneously*

```
var a, b int
a = 5          // ``Copies'' 5 to the variable `a'

_ = 5          // Ignored

a, b = b, a    // Swaps the values of `a' and `b'
```

Assignments

Are the copying semantics different for composite types?

```
var a, b [5]int

b = a
a[0] = 1

var c, d []int
c = append(c, 0)

d = c
c[0] = 1

var e, f struct { f int; }

f = e
e.f = 1
```

What are the values for `b[0]`, `d[0]` and `f.f` respectively?

Assignments

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No!

```
var a, b [5]int

b = a       // Copies the contents of 'a'
a[0] = 1    // Does not change 'b'

var c, d []int
c = append(c, 0)

d = c       // Copies the *header* of 'c'
c[0] = 1    // *Does* change 'd'!

var e, f struct { f int; }

f = e       // Copies the contents of 'e'
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What are the values for `b[0]`, `d[0]` and `f.f` respectively? **0, 1, 0**

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Blank assignments

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No! The expression must still be evaluated

How can we implement the swapping semantics of multiple assignments?

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Use temporaries to store old values of all RHS expressions before assigning

```
int tmp__0 = b;
int tmp__1 = a;

a = tmp__0;
b = tmp__1;
```

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Most languages support this functionality. If not, you can carefully generate another equivalent operation.

Beware! The following statements are *not* equivalent.

```
a[foo()]++  // foo() called once
```

```
a[foo()] = a[foo()] + 1  // foo() called twice
```

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The conditions are evaluated lexically until one evaluates to true and the branch is executed. Otherwise, the else branch is taken.

If statements

Init scoping

Be careful of scoping when translating to your target language - `init` statements are visible to all subsequent branches.

```
if a := false; a {            // Branch 1
    ...
} else if a := true; !a {    // Branch 2
    ...
} else if a {                 // Branch 3
    ...
} else {                      // Branch 4
    ...
}
```

Which branch executes?

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Decompose “else if” into “else { if”

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What two approaches can we use to solve this?

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What two approaches can we use to solve this?

1. **Renaming (again)!**
2. **Nesting the entire if structure in another scope**

The above is valid for `for` *and* `switch` *init statements as well*

For loops

Infinite loops

Easy! Implicitly, the condition is always `true`.

```
for {
    ...
}
```

Still easy! The condition is a simple expression evaluated every iteration.

```
var a, b int
for a + b == 0 {
    ...
}
```

For loops
3-part loops

Very hard! We now have optional `init` and `post` statements.

```
for a, b := 0, 1; a < b; a, b = b, a {
    ...
    if (a > b) {
        continue
    }
    ...
}
```

What issues are present? How can we correctly translate the above code?

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1. **Initialization may be several target statements**

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1. **Initialization may be several target statements**
2. **Post may be several target statements**

For loops

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for a, b := 0, 1; a < b; a, b = b, a {
    ...
    if (a > b) {
        continue
    }
    ...
}
```

What issues are present? How can we correctly translate the above code?

1. **Initialization may be several target statements**
2. **Post may be several target statements**
3. `continue` **may conditionally execute**

For loops

3-part loops

In most languages, representing the 3-part loop as a `while` loop is natural. For `continue` we can use labels and jumps.

```
{
    int tmp__0 = 0;
    int tmp__1 = 1;
    int a = tmp__0;
    int b = tmp__1;
    while (a < b) {
        if (a > b) {
            goto continue__lbl;
        }
      continue__lbl:
        int tmp__2 = b;
        int tmp__3 = a;
        a = tmp_2;
        b = tmp_3;
    }
}
```

Beware! You must be *very* careful of scoping issues when placing the post-statement in the loop body.

Switch statements

Switch statements in Go consist of:

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- Optional switch expression

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Switch statements in Go consist of:

- Optional init statement
- Optional switch expression
- Zero-or more cases
  - List of one-or-more non-constant expressions
  - Body
  - Optional break(s)
- Optional default case

Phew! Likely the hardest statement kind to implement correctly.

Switch statements

We want to codegen the following Go program fragment in C.

```
switch foo() {
    case a, baz():
        if (b > c) {
            break
        }
    default:
}
```

Switch statements

Proposal 1: Implement switches using `switch` from C.

Does it work?

Switch statements

Proposal 1: Implement switches using `switch` from C.

Does it work?

No!

```
switch (foo()) {
    case a:
    case baz():  // Problem: illegal in C
        if (b > c) {
            break;
        }
        break;
    default:
}
```

Switch statements

Proposal 2: Implement switches using `if-elseif-else`.

Does it work?

Switch statements

Proposal 2: Implement switches using `if-elseif-else`.

Does it work?

Mostly! Two smaller issues

```
// Problem 1: foo() is evaluated twice
if (foo() == a || foo() == bar()) {
    if (b > c) {
        break;  // Problem 2: illegal in C
    }
} else {
    // Default branch
}
```

Switch statements

Proposal 3: Implement switches using `if-elseif-else` from C using:

- Temporary for the condition
- Labels for break

Does it work?

Switch statements

Proposal 3: Implement switches using `if-elseif-else` from C using:

- Temporary for the condition
- Labels for break

Does it work?

Yes!

```
int tmp__0 = foo()
if (tmp__0 == a || tmp__0 == bar()) {
    if (b > c) {
        goto break__lbl;
    }
} else {
    // Default branch
}

break__lbl:;
```

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```
var a [5]int
var b []int // b = append(b, 0)
var c struct { f int; }

func foo() [5]int { return a; }
func bar() []int { return b; }
func baz() struct{ f int; } { return c; }

func main() {
    var d, e, f = foo(), bar(), baz()

    d[0], e[0], f.f = 1, 1, 1
}
```

What are the values for `a[0]`, `b[0]` and `c.f` respectively?

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What are the values for `a[0]`, `b[0]` and `c.f` respectively? **0, 1, 0**

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- Separate expressions by spaces
- End with a newline

```
println(5, 4)  // 5 4    [newline]
print(5, 4)    // 54     [no newline]
```

Print statements

What are the printing formats for basic types?

```
// Integers
print(255)
print(0377)

// Floats
print(0.12)

// Booleans
print(true)

// Runes
print('L')

// Strings
print("hello\n")
print(`hello\n`)
```

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// Booleans
print(true)   // true

// Runes
print('L')    // 76

// Strings
print("hello\n") // hello [newline]
print(`hello\n`) // hello\n
```

Binary expressions

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- Bit clear (`&^`) may be missing

You should also implement string concatenation and comparisons.

```
var a string = "apple"
var b string = "Apple"

println(a + b)
println(a < b)
```

What does the above program print?

Binary expressions

Binary expressions are the same throughout most languages.
Two possible exceptions:

- Integer vs. float division
- Bit clear (`&^`) may be missing

You should also implement string concatenation and comparisons.

```
var a string = "apple"
var b string = "Apple"

println(a + b)
println(a < b)
```

What does the above program print?

appleApple
false

Call expressions

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```
func foo(a [5]int, b []int, c struct{ f int; }) {
    a[0] = 1
    b[0] = 1
    c.f = 1
}

func main() {
    var a [5]int
    var b []int // b = append(b, 0)
    var c struct { f int; }

    foo(a, b, c)
}
```

What are the values for `a[0]`, `b[0]` and `c.f` respectively?

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}

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    var a [5]int
    var b []int // b = append(b, 0)
    var c struct { f int; }

    foo(a, b, c)
}
```

What are the values for `a[0]`, `b[0]` and `c.f` respectively? **0, 1, 0**

Append expressions

Recall: Slices are dynamically sized containers of homogeneous data implemented using a header and an underlying array.

The `append` built-in function adds data onto the end of the underlying array, and updates the header.

- If `len < cap`, the same underlying array is used
- If `len == cap`, a new underlying array is allocated and the data copied

Beware! This creates very unnerving behaviour if you're not careful (and of course we test it).

Append expressions

Slice growth

How does the capacity/length change over time?

```
var a []int

for i := 0; i < 10; i++ {
    println("Cap:", cap(a), ", len:", len(a))
    a = append(a, 0)
}
```

Append expressions

Slice growth

How does the capacity/length change over time?

```
var a []int

for i := 0; i < 10; i++ {
    println("Cap:", cap(a), ", len:", len(a))
    a = append(a, 0)
}
```

Cap: 0 , len: 0
Cap: 2 , len: 1
Cap: 2 , len: 2
Cap: 4 , len: 3
Cap: 4 , len: 4
Cap: 8 , len: 5
Cap: 8 , len: 6
Cap: 8 , len: 7
Cap: 8 , len: 8
Cap: 16 , len: 9

Append expressions

Edge cases

```
var a, b []int
a = append(a, 0)
b = a

// ‘a’ and ‘b’ headers: len=1, cap=2, ptr=0xDEADBEEF

a = append(a, 1)
```

What are the length and capacity of `a` and `b`?

Append expressions

Edge cases

```
var a, b []int
a = append(a, 0)
b = a

// 'a' and 'b' headers: len=1, cap=2, ptr=0xDEADBEEF

a = append(a, 1)
```

What are the length and capacity of `a` and `b`?

a: len=2, cap=2
b: len=1, cap=2

Interestingly, `b[1]` is out of bounds.

Append expressions

Edge cases

```
var a, b []int
a = append(a, 0)
b = a

// 'a' and 'b' headers: len=1, cap=2, ptr=0xDEADBEEF

a = append(a, 1)
b = append(b, 2)
```

What are the values of `a[1]` and `b[1]`?

Append expressions

Edge cases

```
var a, b []int
a = append(a, 0)
b = a

// 'a' and 'b' headers: len=1, cap=2, ptr=0xDEADBEEF

a = append(a, 1)
b = append(b, 2)
```

What are the values of `a[1]` and `b[1]`?

Both 2

Yes, we can overwrite data if we're not careful!

Append expressions

Edge cases

```
var a, b []int
a = append(a, 0)
// a = append(a, 1)
b = a

// ‘a’ and ‘b’ headers: len=1, cap=2, ptr=0xDEADBEEF

a = append(a, 13)
a[0] = 1
```

What are the values of `a[0]` and `b[0]`?

Append expressions

Edge cases

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var a, b []int
a = append(a, 0)
// a = append(a, 1)
b = a

// 'a' and 'b' headers: len=1, cap=2, ptr=0xDEADBEEF

a = append(a, 13)
a[0] = 1
```

What are the values of `a[0]` and `b[0]`?

Both 1

Append expressions

Edge cases

```
var a, b []int
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b = a

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a = append(a, 2)
a[0] = 13
```

What are the values of `a[0]` and `b[0]`?

Append expressions

Edge cases

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var a, b []int
a = append(a, 0)
a = append(a, 1)
b = a

// 'a' and 'b' headers: len=2, cap=2, ptr=0xDEADBEEF

a = append(a, 2)
a[0] = 13
```

What are the values of `a[0]` and `b[0]`?

a[0] = 13, b[0] = 0

Yes, we can change the underlying array of one header but not another!

Length expressions

The length built-in supports the following types:

- Strings
- Arrays
- Slices

Given an expression, it returns the current number of elements. For strings and arrays this is easy.

The length of a slice uses the header information and not the size of the underlying array.

Capacity expressions

The capacity built-in supports the following types:

- Arrays
- Slices

Given an expression, it returns the allocated number of elements - again easy for arrays.

The capacity of a slice uses the header information and returns the size of the underlying array.

Cast expressions

Easy! But be sure to correctly implement string casting.

```
var a int = 65
println(string(a))
```

What is the output of the above progam?

Cast expressions

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var a int = 65
println(string(a))
```

What is the output of the above progam?

A

Order of evaluation

Go uses left-to-right order of evaluation in *most* instances.

Implementing the correct order of evaluation if your language is different (e.g. C or C++) is very hard, so it is **not** required.

```
var a int = 0

func foo() int {
    a++
    return a
}

func main() {
    var b, c, d int = foo(), a, foo()
}
```

What are the values of `b`, `c` and `d`?

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What are the values of `b`, `c` and `d`?

1, 1, 2

A nice, simple, understandable outcome which is perfectly left-to-right. But then...

Order of evaluation

```go
var a int = 0

func foo() int {
    a++
    return a
}

func main() {
    b, c, d := foo(), a, foo()
}
```

What are the values of `b`, `c` and `d`?

Order of evaluation

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var a int = 0

func foo() int {
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    return a
}

func main() {
    b, c, d := foo(), a, foo()
}
```

What are the values of `b`, `c` and `d`?

1, 2, 2

Go decomposes the expressions and evaluates all function calls *before* other operations in assignments and short declarations.

Order of evaluation

We can also look at the order of operation with logicals.

```
var g int = 0

func bar(a string) int {
    println(a)
    g++
    return g
}

func main() {
    var a, b, c = bar("lhs1") == 2 || bar("rhs1") == 3,
g, bar("call3")
}
```

In which order are the functions called, and what is the value of `b`?

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    return g
}

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    a, b, c := bar("lhs1") == 2 || bar("rhs1") == 3, g,
bar("call3")
}
```

In which order are the functions called, and what is the value of `b`?

lhs1, call3, rhs1, and **3**

Go decomposes the function calls on the LHS of logical operators, and leaves the RHS untouched.

Recursive types

Recursive types are also quite tricky depending on the language - C++ being hard. We will not evaluate this feature.

Useful addresses

- `http://golang.org`
- `http://play.golang.org`
- `http://golang.org/ref/spec`

References

- Gopher: `http://golang.org/doc/gopher/frontpage.png`
- Vincent Foley-Bourgon
- David Herrera
- Classes of 2015-2019

Advice

- This is a project that takes a lot of time: start early!
- Pick an target language that you know well enough to not get painted into a corner.
- Don't be afraid of asking questions and using the Facebook group.
- Build a test set of semantics programs using the slides and test often!

Gophers!

Thanks Google :)