COMP-520 – GoLite Tutorial

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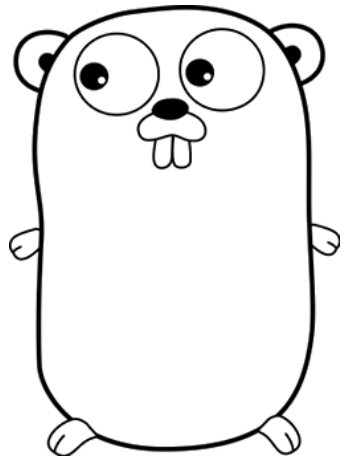
Sable Lab
McGill University

Winter 2020



Announcements (Monday, March 30th)

- Welcome to Zoom!
- Lectures:
  - 2x GoLite Tutorial
  - 2x Codegen (either GPU or register allocation)
  - 1x Course Summary
- Office hours (Alex): Zoom
  - Monday: 5:00-6:00 PM
  - Wednesday: 11:30-12:30 PM
- Office hours (Adrian): Email/FB (if needed, @mention in the group as the notification may not arrive)
- If you have any concerns, please reach out. Stay safe!

Announcements (Monday, March 30th)

- Project
  - Milestone 2 due: **Tomorrow** (Tuesday, March 31st 11:59 PM on GitHub)
  - Milestone 3: **Cancelled**
  - Milestone 4 due: **Friday, April 24th 11:59 PM** on GitHub
  - Final project due: **Friday, May 1st 11:59 PM** on GitHub
- Peephole due: **Tuesday, April 14th 11:59 PM** on myCourses
- Final exam: **Cancelled**

Weights have been shifted to the final project (25%), midterm (20%), and peephole (15%).

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 and may not replace your own work.
2. No copying from previous years, even with citation; no code/tests may be copied even in part (1 line is too many).
3. No grading material may be used at any point, under any circumstance, nor may it be published.

You are responsible for ensuring all material you use is permitted. If in doubt, please ask!

Target Language

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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

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  - Or... stick with something you have time to learn
- Dynamically-typed languages are “easier” (but more error prone and slow)
  - Javascript
  - Python

Target language

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Remember, the choice of target language has huge impact on your project.

- Stick with something you know
  - Or... stick with something you have time to learn
- Dynamically-typed languages are “easier” (but more error prone and slow)
  - Javascript
  - Python
- Statically-typed languages are “harder” (but are usually upfront/informative and fast)

Execution

Go execution

An executable Go program consists of:

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- Zero-or-more `init` functions

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During program execution, Go is:

- Pass-by-value
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- (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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- Blank identifiers

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

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var restrict int    // Conflict in C

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What approach avoids all possible keyword conflicts?

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

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Function declarations consist of a name, list of parameters, an optional return type, and a body of statements.

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Renaming!

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

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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.

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

func main() {
    foo(1, 2, 3)
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Temporary variable names

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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

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

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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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1. **Use a container with built-in bounds checking**
2. **Wrap all indexes in a "bounds-checking" function**

```
func check(index int, bound int) int {
    if (index < bound) {
        return index
    }
    panic("out-of-bounds")
}

a[check(10, 5)] = 0
```

Arrays

Equality

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

```
var a, b [5]int
println(a == b) // Ouputs true

b[0] = 1
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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 new 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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Beware! 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

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Announcements (Wednesday, April 1st)

- Happy April Fool's!
- Project
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Statements

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

Assignments

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```
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

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’
```

These rules apply for basic as well as composite types.

Assignments

Copying

Given the following example with 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

Copying

Given the following example with composite types

```
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’
e.f = 1     // Does not change ‘f’
```

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

Assignments

Blank assignments

Can we eliminate blank assignments altogether?

```
_ = ...
```

Assignments

Blank assignments

Can we eliminate blank assignments altogether?

```
_ = ...
```

No! The expression must still be evaluated

Assignments

Multiple assignments

How can we implement the swapping semantics of multiple assignments?

```
var a, b int

a, b = b, a  // Swaps the values of ‘a’ and ‘b’
```

Assignments

Multiple assignments

How can we implement the swapping semantics of multiple assignments?

```
var a, b int

a, b = b, a  // Swaps the values of ‘a’ and ‘b’
```

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;
```

Short declarations

Short declarations are a cross between assignments and declarations.

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Increment/decrement

Increment/decrement statements change the value of a numerical variable by 1. This is valid for:

- `int`
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- `int`
- `float64`
- `rune`

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
```

If statements

If statements in Go consist of:

If statements

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- Optional init statement

If statements

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If statements in Go consist of:

- Optional init statement
- Condition expression
- True branch
- Zero-or-more else-if branches
  - Optional init statement
  - Condition expression
- Optional else branch

The conditions are evaluated lexically top-down until one evaluates to true and the corresponding 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?

If statements

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    ...
} else if a {                       // Branch 3
    ...
} else {                            // Branch 4
    ...
}
```

Which branch executes?

Branch 3

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} else if a {                   // Branch 3
    ...
} else {                        // Branch 4
    ...
}
```

Which branch executes?

Branch 3

What approach easily implements this functionality?

If statements

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

Which branch executes?

Branch 3

What approach easily implements this functionality?

Decompose "else if" into "else { if"

If statements

Init scoping

Also note that the init statements are not visible outside of the if statement context.

```
a := true
if a := false; a {
    ...
}
print(a) // true
```

What two approaches can we use to solve this?

If statements

Init scoping

Also note that the init statements are not visible outside of the if statement context.

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a := true
if a := false; a {
    ...
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What two approaches can we use to solve this?

1. **Renaming (again)!**

If statements

Init scoping

Also note that the init statements are not visible outside of the if statement context.

```
a := true
if a := false; a {
    ...
}
print(a) // true
```

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

There are 3 different kinds of loops in Go

- Infinite loop
- While loop
- 3-part loop

For loops

Infinite loops

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

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

For loops

While loops

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?

For loops

3-part loops

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```
for a, b := 0, 1; a < b; a, b = b, a {
    ...
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        continue
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}
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1. **Initialization may be several target statements**

For loops

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for a, b := 0, 1; a < b; a, b = b, a {
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2. **Post may be several target statements**

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for a, b := 0, 1; a < b; a, b = b, a {
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    }
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1. **Initialization may be several target statements**
2. **Post may be several target statements**
3. `continue` **may conditionally execute**

For loops

3-part loops

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```
for a, b := 0, 1; a < b; a, b = b, a {
    ...
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    ...
}
```

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**

Represent the 3-part loop as a `while` loop.

For loops

3-part loops

Does this code work?

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

For loops

3-part loops

Does this code work?

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

No!

For `continue` we can use labels/jumps, try/catch/finally or duplicate the post-statement.

For loops

3-part loops

The reference compiler uses labels to implement `continue`.

```
{
    int tmp__0 = 0;
    int tmp__1 = 1;
    int a = tmp__0;
    int b = tmp__1;
    while (a < b) {
        {
            if (a > b) {
                goto cont;
            }
        }
cont:   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 are a shorthand for if/else-if and consist of:

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- Optional init statement
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- 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` and:

- Temporary for the condition
- Labels for break

Does it work?

Switch statements

Proposal 3: Implement switches using `if-elseif-else` and:

- 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:;
```

Switch statements

For those who dislike a healthy goto, there are also tricks using try/catch and loops!

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

Return statements

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

Expressions

Binary expressions

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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:

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

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var b string = "Apple"

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

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

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?

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What is the output of the above progam?

A

Builtins

Append expressions

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- Implemented using a header and an underlying array

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

Append expressions

Recall, slices are:

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- Implemented using a header and an underlying array

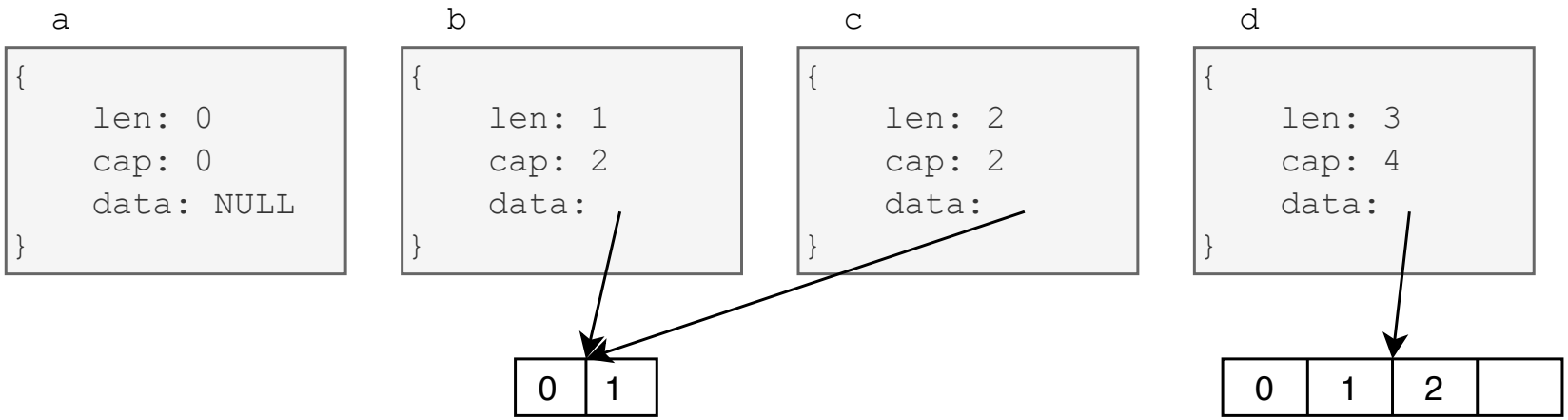
The `append` built-in function adds data onto the end of the underlying array, and updates the *returned* header.

- 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

```
var a []int
var b []int = append(a, 0)
var c []int = append(b, 1)
var d []int = append(c, 2)
```



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)
a[0] = 4
```

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

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)
a[0] = 4
```

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

Both 4

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=2, cap=2, ptr=0xDEADBEEF

a = append(a, 2)
a[0] = 4
```

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

Append expressions

Edge cases

```
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] = 4
```

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

a[0] = 4, 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.

Order of Evaluation

(Not required for the project)

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.

Order of evaluation

Begin by considering the following program with a declaration of 3 local variables and a global counter.

```
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 `a`, `b`, `c` and `d`?

Order of evaluation

Begin by considering the following program with a declaration of 3 local variables and a global counter.

```
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 `a`, `b`, `c` and `d`?

2, 1, 1, 2

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

Order of evaluation

Let's replace the declaration with a *short* declaration.

```
var a int = 0

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

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

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

Order of evaluation

Let's replace the declaration with a *short* declaration.

```
var a int = 0

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

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

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

2, 1, 2, 2

Order of evaluation

Let's replace the declaration with a *short* declaration.

```
var a int = 0

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

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

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

2, 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 a int = 0

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

func main() {
    var b, c, d, e = foo() == 2 || a == 1, a == 1,
                     a == 1 || false, foo()
}
```

What are the values of a–e respectively?

Order of evaluation

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

```
var a int = 0

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

func main() {
    var b, c, d, e = foo() == 2 || a == 1, a == 1,
                     a == 1 || false, foo()
}
```

What are the values of a–e respectively?

2, true, true, true, 2

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

Order of evaluation

Let's replace the declaration with a *short* declaration.

```
var a int = 0

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

func main() {
    b, c, d, e := foo() == 2 || a == 1, a == 1,
                  a == 1 || false, foo()
}
```

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Order of evaluation

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                  a == 1 || false, foo()
}
```

What are the values of a–e respectively?

2, true, false, true, 2

Order of evaluation

Let's replace the declaration with a *short* declaration.

```
var a int = 0

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

func main() {
    b, c, d, e := foo() == 2 || a == 1, a == 1,
                  a == 1 || false, foo()
}
```

What are the values of a–e respectively?

2, true, false, true, 2

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

Recursive types

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

Resources

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 :)