A Comprehensive Exploration of Go

CPSCI 220 - TERM PROJECT

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Introduction:

Go, also referred to as Golang,[1] is a statically typed programming language that has its origins in system programming. It was created at Google by Robert Griesemer, Rob Pike, and Ken Thompson and was first released in 2009. Go was designed with the goal of creating a simple programming language that performs swiftly. The developer team at Google hoped to improve efficiency in terms of both development and execution within their company, but also for programmers around the world. Go can be described as a procedural language; specifically, its paradigm can be defined as a concurrent-imperative and partially object-oriented language.[2]

Our group decided to research Go for a variety of reasons. It was under our radar, since it is a language that, in recent years, has grown popular among software engineers as a result of appealing features such as concurrency, garbage collection, static typing, and good performance.[3] Go is an appealing language for beginners, since it is fairly easy to learn compared to other programming languages.[4] We sought to learn a language that could be picked up quickly, in hopes of being able to dedicate time to testing out its features. Further, we wanted to research concepts that were new to us; concurrency was one of these. We had all been exposed to parallel programming in the past, but we were not familiar with concurrency and its differences as compared to parallelism.[5] Since concurrency was a staple of Go's prominent features, we were drawn to learning the language.

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[1] Team, Google. "Frequently Asked Questions (FAQ)." *Go*, go.dev/doc/faq. Accessed 3 Dec. 2023.
[2] Saif, Zakaria. "Guide to Programming Paradigms in Golang(Go)." *Medium*, Medium, 18 Nov. 2023, medium.com/@zakariasaif/guide-to-programming-paradigms-in-golang-go-eff42b678a40#:~:text=Go%20is%20a%20programming%20language,support%20for%20object%2Doriented%20programming.
[3] Krill, Paul. "Golang Returns to the Top 10." InfoWorld, InfoWorld, 6 Mar. 2023, www.infoworld.com/article/3689949/golang-returns-to-the-top-10.html.
[4] Meritocracy. "Golang: Why You Should Learn Go in 2021." Meritocracy Blog, 6 Apr. 2021, meritocracy.is/blog/2021/04/06/golang-why-you-should-learn-go-in-2021/.
[5] Yarragodula, Rahul. "Go beyond the Basics: Implementing Concurrency and Parallelism." Medium, Level Up Coding, 22 June 2023, levelup.gitconnected.com/how-to-implement-concurrency-and-parallelism-in-go-83c9c453dd2.

This paper aims to offer a comprehensive understanding of the origins of Go, delving into its historical evolution. Additionally, it imparts knowledge on the distinctive characteristics, syntax, semantics, data types, and data structures associated with this programming language. Furthermore, we evaluate the key features that distinguish Go and make it an attractive choice for programmers. Following a candid acknowledgment of Go's potential drawbacks, the paper culminates in an assessment of Go's modern uses and applications, underscoring its pivotal role in the creation of services that significantly impact the daily lives of millions.

History:

Go was created by a developer team consisting of Robert Griesemer, Rob Pike, and Ken Thompson at Google.[6] Go was developed in 2007, but it was not until 2009 that it was launched. At the time of its initial release in 2009, it was launched as an open-source programming language.[7] People were, and still are, able to contribute to the development of Go by submitting new proposals, fixing bugs, and brainstorming ways to make the language faster and generally more efficient. Source code can even be found on GitHub. Go design has received inspiration from many languages, such as C, Algol, Pascal, Modula, Oberon, Smalltalk, and Newsqueak.[8] Some features of Go, such as its concurrency, drew heavy influence from Oberon. Smalltalk influenced Go's inclusion of certain object-oriented programming features. C heavily impacted the new language's syntax, with Go being considered as part of the C-family of programming languages. The developers of Go at Google had three main reasons for launching this project and embarking on a journey to develop a new programming language. They desired to solve the problems of slow compilation when it came to C and C++. Second, they felt that many other

[6] "Go Programming Language (Introduction)." GeeksforGeeks, GeeksforGeeks, 24 Apr. 2023, www.geeksforgeeks.org/go-programming-language-introduction/.
[7] Rob Pike. Google. "Go at Google: Language Design in the Service of Software Engineering." Go, go.dev/talks/2012/splash.article. Accessed 3 Dec. 2023.
[8] "The Evolution of Go." *Go.Dev*, go.dev/talks/2015/gophercon-goevolution.slide#21. Accessed 7 Dec. 2023.

languages at the time were falling short with protection of data, and so they purposely created a strongly and statically typed language that automatically collects garbage. Finally, the developers at Google sought to create a language that was concise, explicit, and easy to read, drawing inspiration from complex and verbose languages like Java.[9]

Type Characteristics, Syntax, Semantics:

Go is a statically typed language, which means that programmers have to declare the type of a variable upon the declaration of that variable.[10] The data types of variables are known and enforced at compile-time; this means that the compiler will catch errors related to data types before the program is run. Pending that the programmer adheres to the proper type characteristics, Golang will compile at a swift speed.[11] Dynamically-typed languages have dynamic compilers that make countless decisions at run time; this can significantly slow down one's program.

The syntax and semantics of Go were designed with a focus on clarity and cleanliness, all while maintaining the overarching objective of modeling certain aspects after C.[12] Go only has 25 key words, which is quite a small number for a language belonging to the C family. To put this number into perspective, some versions of C++ have amassed 95 key words, whereas Go has less keywords than C, C++, C#, and Objective-C.[13] Further, Go can be parsed without type information or a symbol table since there is no type-specific context. Go is case sensitive and does not require semicolons as C++, a language in its family, does.[14] In an effort to design an

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[9] Gumus, Inanc. "About Go Language - an Overview." *Medium*, Learn Go Programming, 4 Apr. 2021, blog.learngoprogramming.com/about-go-language-an-overview-f0bee143597c.
[10] "Go Programming Language (Introduction)." *GeeksforGeeks*, GeeksforGeeks, 24 Apr. 2023, www.geeksforgeeks.org/go-programming-language-introduction/.
[11] Tepakidareekul, Can. "Learn Golang Basic Syntax in 10 Minutes." *Medium*, Medium, 10 Nov. 2019, medium.com/@manus.can/learn-golang-basic-syntax-in-10-minutes-48608a315896.
[12] Pike, *Go at Google*.
[13] Fowler, Daniel S. "Tek Eye." *C-Family of Computer Language Keywords | Tek Eye*, 11 July 2017, tekeye.uk/programming/keywords-for-c-family-languages.
[14] "Go - Basic Syntax." *Tutorials Point*, www.tutorialspoint.com/go/go_basic_syntax.htm. Accessed 7 Dec. 2023.

efficient language, both in terms of speed and space, the developers of Go made a syntactic decision to prevent execution if there are unused variables, unused import packages, or other redundant or unnecessary code constructs.[15]

The semantics of Go are generally similar to C, but there exist a few differences that are worth noting. Programmers are prevented from performing arithmetic operations directly on pointers for memory manipulation, which makes the language safer in reducing the risk of buffer overflows, among other dangerous mistakes.[16] Similarly, array bounds are always checked to prevent the underrunning and overrunning of an array buffer.[17] Once again, these decisions by the developers reiterate their emphasis on creating a safer experience for the programmer.[18] Go does not have type aliases, which helps prevent confusion in type-related operations. Also, ++ and −− are treated as statements instead of expressions, assignment is not an expression, and it is legal to take the address of a stack variable.[19] These semantic decisions impact the language in making it robust and flexible to different inputs, especially inputs that may be unexpected in some way. This ties to the theme of the Go Developer Team's goal to create a programming language that facilitates the production of dependable software.

Data Types:

The data types in Golang are generally similar to those of other popular programming languages such as Python and C++, but also uncommon in that their size can be mutable. The primitive data types in Go are similar to those in Python and other popular languages that are taught in the Hamilton Computer Science Department. These would include integers, floats,

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[15] Pike, *Go at Google*.
[16] Kaksouri, Jamal. "A Comprehensive Guide to Pointers in Go." *Medium*, Medium, 17 May 2023, medium.com/@jamal.kaksouri/a-comprehensive-guide-to-pointers-in-go-4acc58eb1f4d.
[17] Pike, *Go at Google*.
[18] "Pointer and Value Semantics in Go." *Developer 2.0*, developer20.com/pointer-and-value-semantics-in-go/. Accessed 7 Dec. 2023.
[19] Pike, *Go at Google*.

booleans, and strings. Another data type that is unique in Go is a rune, which can be compared to a character in Python.[20] The difference lies in the values that are eligible to be stored in the data type. A character can be any 1 of 256 values in the ASCII table. On the contrary, the rune data type is an alias for int32 and is able to store a unicode value. This value can, as the storage of the data type suggests, be up to 32 bits in size.

```
// Initializing Integer Type
integer := 42

// Initializing Floating-Point Type
floatNum := 3.14

// Initializing Boolean Type
boolean := true

// Initializing Rune Type
char := 'A'

// Initializing String Type
str := "Hello, Golang!"
```

Code Citation[21]

Further, some data types can be broken up into different subtypes depending on specified sizes of a specific variable. That is, a variable may be of type integer, but there can exist both a 32 bit integer and a 64 bit integer. Type mutability is bidirectional, allowing transitions between larger and smaller sizes, as well as vice versa.[22] However, one must be cautious when converting from a larger value to a smaller value, in the context of the data type's size, as they risk losing important data.

[20] "Understanding Data Types in Go." *DigitalOcean*, DigitalOcean, 30 Apr. 2019, www.digitalocean.com/community/tutorials/understanding-data-types-in-go.
[21] Bodner, Jon. Learning Go. O'Reilly Media, 2021.
[22] "Type Conversion in Golang." *Scaler Topics*, Scaler Topics, 14 Mar. 2023, www.scaler.com/topics/golang/type-conversion-in-golang/.

```
// Converts int8 to int32.
var index int8 = 15
var bigIndex int32
bigIndex = int32(index)
```

Code Citation[23]

Data Structures:

The most common and significant data structures in Go are arrays, slices, structs, and maps. Arrays in Go are both similar and different to arrays in other programming languages such as Python. Arrays in Go are statically typed, meaning that they are a collection of data of a specific type; that is, an array may not include values of more than one type, as is possible in dynamically-typed languages such as Python. Further, arrays in Go have a fixed size which is specified at the point of the array's creation. The image below depicts an example of the proper initialization of an array.

```
// Declaration of an array of length 3 with default zero values
var arr [3]int
// Initialization
arr = [3]int{1, 2, 3}

// Print Array
fmt.Println("Here is your array:", arr)
```

Code Citation[24]

Slices are similar to arrays in Go, allowing the programmer to store multiple values of the same type within one variable. These values can, as with arrays, be accessed with the distinct indices that represent them. One important characteristic of arrays in Go is that they are value types. When we pass an array to a function or assign it to another variable, a copy of the entire array is made. This behavior contrasts with slices in Go, which are reference types.[25] That is, slices are passed by reference to functions, which store a memory address to the location where

[23] "How to Convert Data Types in Go." *DigitalOcean*, DigitalOcean, 8 May 2019, www.digitalocean.com/community/tutorials/how-to-convert-data-types-in-go.
[24] Bodner, Jon. *Learning Go*.
[25] "How to Pass an Array to a Function in Golang?" *GeeksforGeeks*, GeeksforGeeks, 2 Mar. 2023, www.geeksforgeeks.org/how-to-pass-an-array-to-a-function-in-golang/.

the data is stored.[26] A slice can be an entire array, or a part of an array, with the difference specified using a start and end index. Another way to think of a slice is as another array that is dynamic in nature, different from a static array that is associated with a "static contiguous memory allocation."[27] A slice's length can be changed at runtime, where the lower bound for this length is zero and the upper bound is the length of the parent array from which the slice is created. As a result of the flexible nature of slices, they are used by Go programmers much more frequently than static arrays.

```
// Declaration and Initialization of a slice
slice := []int{4, 5, 6}

// Print Slice
fmt.Println("Slice:", slice)
```

Code Citation[28]

Structs are a fundamental data structure in Go which are used to create collections of members of different data types into a single variable. From that definition alone, one can deduce that structs provide what arrays lack, which is the ability to combine different data types in a singular setting.[29] Structs facilitate flexibility with data types in Go, since they represent complex data types that combine built-in and user-defined types into one.[30] The syntax for structs in Go closely resembles that of C. The code below demonstrates the structure behind struct creation.

```
type struct_name struct
{
   member1 datatype;
   member2 datatype;
   member3 datatype;
}
```

Code Citation[31]

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[26] "How to Pass an Array to a Function in Golang?" *GeeksforGeeks*, GeeksforGeeks, 2 Mar. 2023, www.geeksforgeeks.org/how-to-pass-an-array-to-a-function-in-golang/.
[27] Debnath, Manoj. "Revisiting Arrays and Slices in Go." *Developer.Com*, 23 Mar. 2022, www.developer.com/languages/arrays-slices-golang/#:~:text=Slices%20in%20Go%20and%20Golang,the%20start%20and%20end%20index.
[28] Bodner, Jon. *Learning Go*.
[29] "Go Structs." *W3Schools*, www.w3schools.com/go/go_struct.php. Accessed 7 Dec. 2023.
[30] Gupta, Prateek. "Learning Go-Maps & Structs." *Medium*, Nerd For Tech, 12 June 2022, medium.com/nerd-for-tech/learning-go-maps-structs-5e131869bd96.
[31] "Go Structs." *W3Schools*, www.w3schools.com/go/go_struct.php. Accessed 7 Dec. 2023.

Another example is provided depicting how we can define a Person data type, represented by a name, age, job, and salary.

```
type Person struct {
  name string
  age int
  job string
  salary int
}
```
Code Citation[32]

Maps are a powerful data structure that consist of a collection of unordered key-value pairs. Maps are used abundantly because they are able to provide fast lookups while also allowing the programmer to efficiently retrieve, update, or delete data with the help of keys.[33] Go maps are essentially an implementation of hash tables, which are commonly used in C++ and other similar languages.[34] Maps are also inexpensive to pass, since they are passed as a reference. There exist rules that govern the behavior of the data structure, such as the fact that a key must be unique and that keys may only be of data types that can be compared through the built-in '==' or '!=' operators. That is, any custom data type or struct can not serve as a key for a map.[35] On the other hand, the associated values in each key-value pair can take on any data type and are not required to be distinct. Aside from being known as hash tables, maps in Go are also referred to as unordered maps and dictionaries among other names.[36]

```
// Creating and initializing empty map using var keyword
var map_1 map[int]int
// Creating and initializing a map
map_2 := map[int]string{
    90: "Dog",
    91: "Cat",
    92: "Cow",
    93: "Bird",
}
```
Code Citation[37]

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[32] Ibid.
[33] "Golang Maps." *GeeksforGeeks*, GeeksforGeeks, 1 Mar. 2023, www.geeksforgeeks.org/golang-maps/.
[34] "Hash Tables Implementation in Go." *Medium*, Medium, 12 Nov. 2022, medium.com/kalamsilicon/hash-tables-implementation-in-go-48c165c54553.
[35] "Golang Maps", *GeeksforGeeks*.
[36] Ibid.
[37] "Golang Maps", *GeeksforGeeks*.

Advantages of Go:

There are various features of Go that set it apart and make it an appealing language for programmers and students across different disciplines. Some of these advantages include the defer feature, the language's simplicity, its independence of virtual machines, and its automatic garbage collection. Despite perceived weaknesses in Go's error handling, Go has a mechanism that can aid in responding to errors. The feature is known as "defer" and its associated "statements are executed before return in reverse order."[38] Another advantage of Go is its simplicity.[39] While Go's simple nature can be seen as a shortcoming, many programmer's benefit from the limited amount of keywords and features.[40] Unlike other popular languages, Go does not require a virtual machine. This saves time and memory, since code can translate directly to machine code without intermediary steps.[41] Another advantage of Go is its built-in garbage collection, which is an automatic feature that is used to rid a programmer's code of both unused items and items that are no longer needed.[42] Once again, this feature was implemented with memory safety in mind since the developers aimed to address the risk of memory leaks in their new project.

Disadvantages of Go:

It is inherent in the evolution of programming languages to exhibit certain limitations, as the production of new languages is rooted in addressing challenges presented by the shortcomings of their predecessors. As a result, Go has some drawbacks of its own, which can be

[38] Peshkov, Sergei. "4 Go Language Criticisms." *Toptal Engineering Blog*, Toptal, 4 Apr. 2018, www.toptal.com/go/4-go-language-criticisms.
[39] Bobade, Chandrakant D. "What Are the Advantages and Disadvantages of Golang?" *Medium*, 30 Apr. 2023, chandrakant22.medium.com/what-are-the-advantages-and-disadvantages-of-golang-4c2b1cb77fbc. Accessed 7 Dec. 2023.
[40] "What Is the Go Programming Language?" *TechTarget*, www.techtarget.com/searchitoperations/definition/Go-programming-language.
[41] "Compiler vs. Interpreter in Programming | Built In." Builtin.com, builtin.com/software-engineering-perspectives/compiler-vs-interpreter.
[42] Debnath, Manoj. "Understanding Garbage Collection in Go." *Developer.com*, 16 Apr. 2022, www.developer.com/languages/garbage-collection-go/. Accessed 7 Dec. 2023.

directly explained by the problems it aimed to combat in the first place. Go was designed to specialize in simple and readable code instead of abstract and implicit code. On one hand, this allows the programming language to be easier to teach and learn, while also making it easier to trace code in the case of errors and bugs. In another effort to not complicate code, Go developers decided to leave error handling primarily to the programmer. The programmer is responsible for writing code that can check and handle errors, having the power to determine how specific and insightful the associated error messages will be.[43] Additionally, Go has a limited standard library as compared to languages such as Python or Java.[44] For programmers that are used to languages with vast and developed standard libraries to aid their code for certain tasks, a transition to Go may be difficult and unpleasant. Further, Go does not support function overloading. Although Go facilitates the implementation of certain features belonging to object-oriented programming, it falls short with the direct implementation of polymorphic properties such as function overloading.[45] Another complaint about Go is that there exists a lack of development on generics.[46] A programmer who wishes to be able to map a function across four different data types may need to create four separate functions, for example. In other languages, a singular, generic function will suffice; the language can take in multiple data types as input.

Special Feature: Concurrency:

In Go, the concept of concurrency addresses concurrent and parallel programming challenges. Concurrency is "the computer science term for breaking up a single process into independent components and specifying how these components safely share data."[47] Go features lightweight threads known as goroutines managed by the Go runtime to allow for the program to

[43] Bobade, Chandrakant D. "What Are the Advantages and Disadvantages of Golang?"
[44] Ibid.
[45] Tech Target, "What Is the Go Programming Language?"
[46] Peshkov, Sergei. "4 Go Language Criticisms".
[47] Bodner, Jon. *Learning Go*.

handle concurrent tasks. The goroutine is the core concept in Go's concurrency model. When a Go program starts, the Go runtime creates threads and launches a single goroutine to actually run our program.[48] The features that facilitate concurrent programming are called channels, which allow goroutines to synchronize execution.[49] Similarly to maps, channels are also reference types, so when we pass a channel to a function, a pointer is being passed instead.[50] Go also has the ability to buffer channels, allowing us to specify a buffer capacity and send that number of messages into the channel at once. When the buffer is filled, the goroutine on the receiving end gets all of the data.[51] Go's approach to concurrency, featuring goroutines and channels, provides an interesting choice for building concurrent software systems.

Special Feature: Interfaces:

Interfaces in Go allow the programmer to achieve polymorphism by defining a collection of methods. A Go interface "defines and describes the exact methods that some other type must have."[52] Essentially, by creating an interface, we are listing down what methods a type must have to be considered part of that interface. Previously, we discussed structs as part of some of the data structures that are provided in Go. Interfaces are constructed in a similar structure with the type keyword, the name, and the interface keyword. Within the body of the interface will be different methods that the programmer can use as part of the interface. To implement an interface, all methods declared within the interface must be implemented in the code. This means that in any Go declaration that has an interface type, any object can be used as long as it satisfies the interface.[35] By doing this, the interface is implemented implicitly.[53] This comes in contrast to

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[48] Ibid.
[49] "Concurrency." *Golang Book*, www.golang-book.com/books/intro/10. Accessed 7 Dec. 2023.
[50] Bodner, Jon. *Learning Go*.
[51] Olusheye, Ifihanagbara. "Concurrency in Go." *Earthly Blog*, 19 July 2023, earthly.dev/blog/concurrency-in-go/.
[52] Edwards, Alex. "Golang Interfaces Explained - Alex Edwards." www.alexedwards.net, www.alexedwards.net/blog/interfaces-explained. Accessed 7 Dec. 2023.
[53] "Interfaces in Golang." GeeksforGeeks, 16 Aug. 2019, www.geeksforgeeks.org/interfaces-in-golang/. Accessed 7 Dec. 2023.

some other languages such as Java, C++, and C#, where to implement an interface, we must define a class and explicitly declare that it implements the interface. Interfaces in Go grant the programmer the ability to outline behaviors that are not tied to specific types. Instead, they are outlined by the interface, which promotes code flexibility and makes it easier to test.

Uses and Applications:

Go is a preferred language for many projects such as distributed network services, cloud-native development and on-demand services, with many companies relying on Go to provide services to their customers. As a result of the language's offering of goroutines and channels, Go is well-suited for developing all sorts of network services such as APIs, web servers, and smaller frameworks for online applications.[54] Further, Go is immensely portable, meaning that it can be compiled and run on various operating systems and hardware architectures successfully without major changes.[55] Go is also capable of controlling big data systems, with this being a major reason why famous media platforms utilize Go for their services.[56] Among these platforms are Youtube, SoundCloud, and Netflix.[57] Additional notable companies whose infrastructures rely on Go include Uber, Twitch, Slack, Trivago, Dropbox, and Riot Games, the makers of League of Legends and VALORANT.[58] Google's own cloud platform, Google Cloud, utilizes Go to amplify its performance and scalability.[59]

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[54] "What Is Golang Used For? 7 Examples of Go Applications - Trio Developers." www.trio.dev, www.trio.dev/blog/what-is-golang-used-for.
[55] "How Portable Is Go | the Go Programming Language Report." Kuree.gitbooks.io, kuree.gitbooks.io/the-go-programming-language-report/content/30/text.html. Accessed 7 Dec. 2023.
[56] "What Is Golang Used For? 7 Examples of Go Applications - Trio Developers."
[57] Team, Codecademy. "What Is Go? An Introduction to the Golang Programming Language." *Codecademy Blog*, 28 July 2022, www.codecademy.com/resources/blog/what-is-go/.
[58] "What Is Golang Used For? 7 Examples of Go Applications - Trio Developers."
[59] Ibid.

Conclusion:

In conclusion, Go should be known as a language that was created from the pursuit of simple and efficient programming. The language's popularity has surged in recent years, appealing to many engineers by offering three main features – concurrency, garbage collection and static typing – all of which facilitate admirable performance. Further, Go's straightforward and familiar learning curve makes the language even more appealing for students to adopt early in their programming journey.

This paper has explored the historical evolution of Go, unraveling its characteristics, syntax, semantics, and core data structures. In acknowledging Go’s many strengths, we also aimed to shed light on possible shortcomings and drawbacks of the language with the hope of presenting the reader with an authentic and complete representation of Go. Through its modern uses and applications, it is evident that Go's impact extends beyond mere programming; it plays a key role in shaping services that impact the lives of millions of people.

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