Exporting Go

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GopherCon Singapore, 2017

Intro

- Go package
  - Namespace
  - Interface (export)
  - Import

- Implementation
  - **Export/import** (this talk)
  - Linker (not this talk)

A long, long time ago, somewhere in New Jersey...

Credits: https://www.bell-labs.com/usr/dmr/www/picture.html

An example

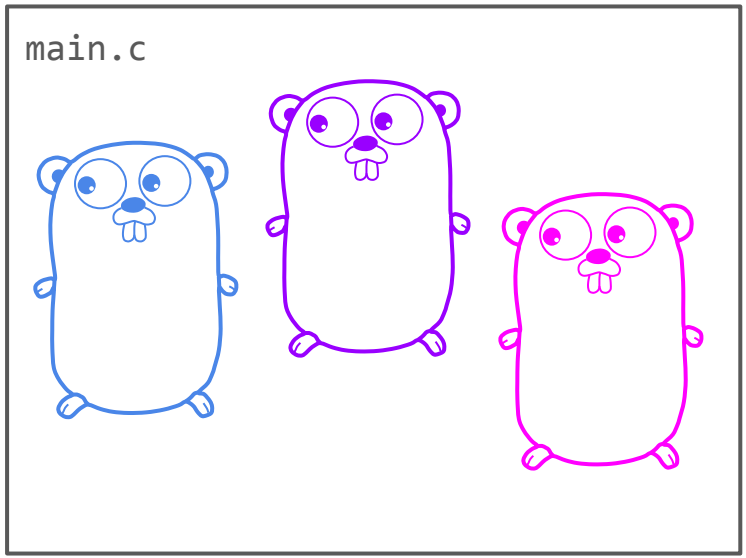
```
   1 == 1
   2 == 2  prime
   3 == 3  prime
   4 == 2^2
   5 == 5  prime
   6 == 2 * 3
   7 == 7  prime
   8 == 2^3
   9 == 3^2
  10 == 2 * 5
  11 == 11 prime
  12 == 2^2 * 3
  ...
 996 == 2^2 * 3 * 83
 997 == 997      prime
 998 == 2 * 499
 999 == 3^3 * 37
1000 == 2^3 * 5^3
```

Go

```
package main
import "fmt"

type List struct {
      Factor, Power int
      Link          *List
}

func Factor(x int) *List { ... }  // returns the list of prime factors of x
func Print(l *List) { ... }       // prints the given list of prime factors

func main() {
      for i := 1; i <= 1000; i++ {
            fmt.Printf("%4d == ", i)
            Print(Factor(i))
            fmt.Printf("\n")
      }
}
```

C

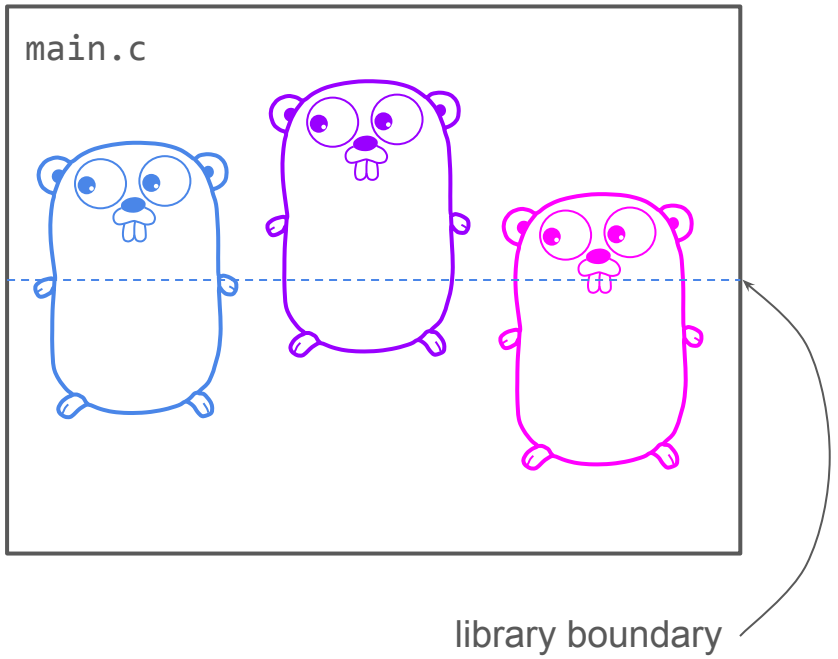
```
#include <stdio.h>
#include <stdlib.h>

struct List {
      int factor, power;
      struct List* link;
};

struct List* Factor(int x) { … }
void Print(struct List* l) { … }

int main() {
      for (int i = 1; i <= 1000; i++) {
            printf("%4d == ", i);
            Print(Factor(i));
            printf("\n");
      }
      return 0;
}
```



(To be accurate, 1970's C didn't permit inline declaration of `i` in the for-loop header. But it doesn't matter for the purpose of this illustration.)

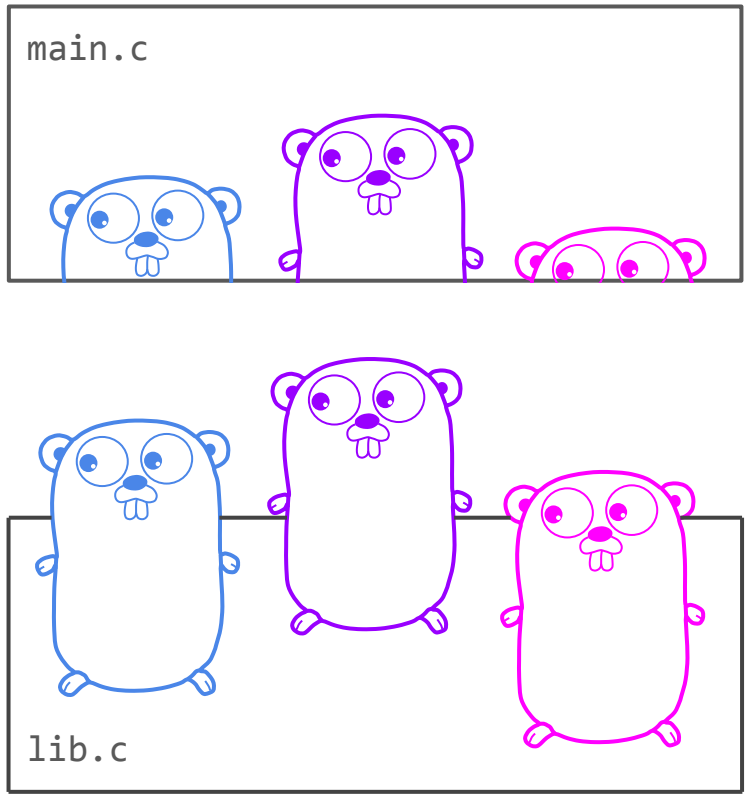
C

```c
#include <stdio.h>
#include <stdlib.h>

struct List {
	int factor, power;
	struct List* link;
};

struct List* Factor(int x) { … }
void Print(struct List* l) { … }

int main() {
	for (int i = 1; i <= 1000; i++) {
		printf("%4d == ", i);
		Print(Factor(i));
		printf("\n");
	}
	return 0;
}
```



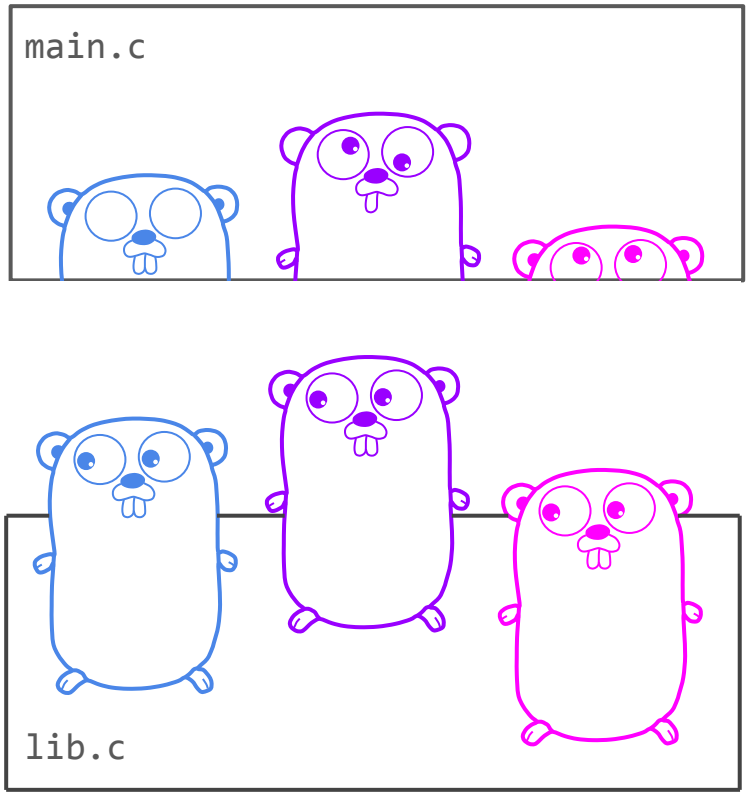
Using a library

```
#include <stdio.h>


struct List {
      int factor, power;
      struct List* link;
};

extern struct List* Factor(int x);
extern void Print(struct List* l);

int main() {
      for (int i = 1; i <= 1000; i++) {
            printf("%4d == ", i);
            Print(Factor(i));
            printf("\n");
      }
      return 0;
}
```



Using a library, not so carefully

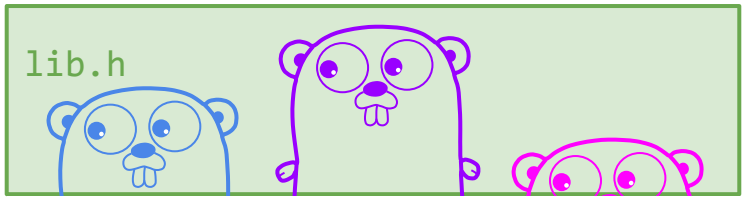
```
#include <stdio.h>


struct List {


};

extern struct List* Factor(float x);
extern void Print(struct List l);

int main() {
      for (int i = 1; i <= 1000; i++) {
            printf("%4d == ", i);
            Print(Factor(i));
            printf("\n");
      }
      return 0;
}
```



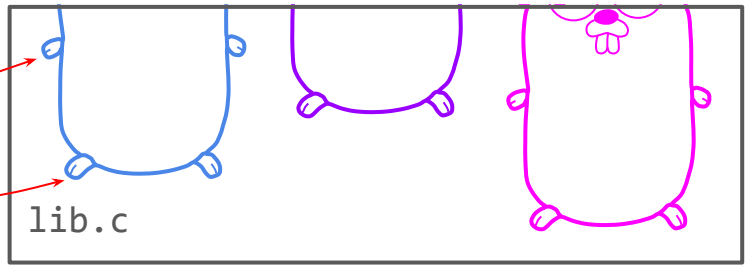
Using a header file

```
#include <stdio.h>
#include "lib.h"

int main() {
      for (int i = 1; i <= 1000; i++) {
            printf("%4d == ", i);
            Print(Factor(i));
            printf("\n");
      }
      return 0;
}
```

main.c



private parts accessible

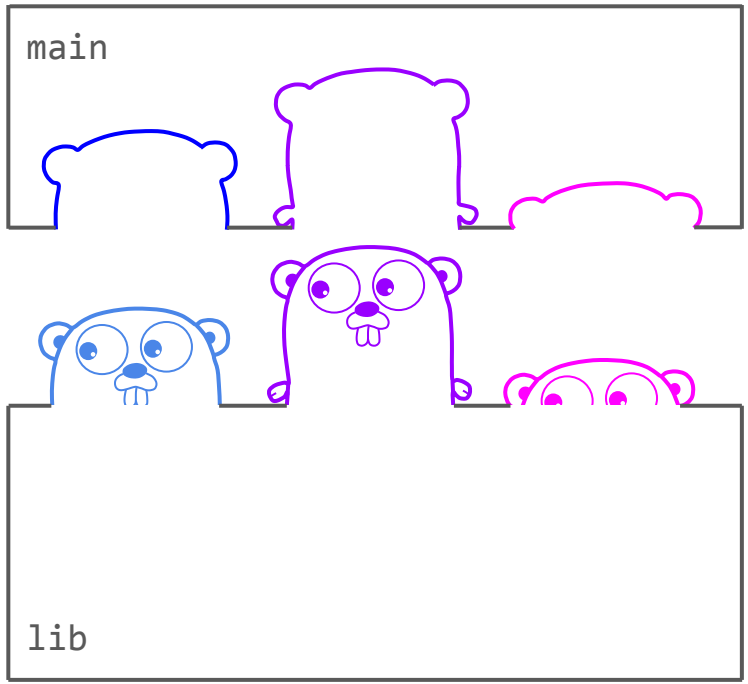


Header files issues

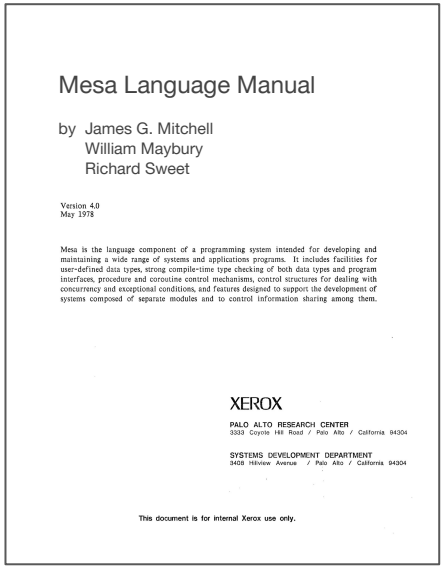
- Include guards (#ifdef, etc.)
- Duplication of definitions
- Information leakage
- Repeated processing (includes of includes)
- Size

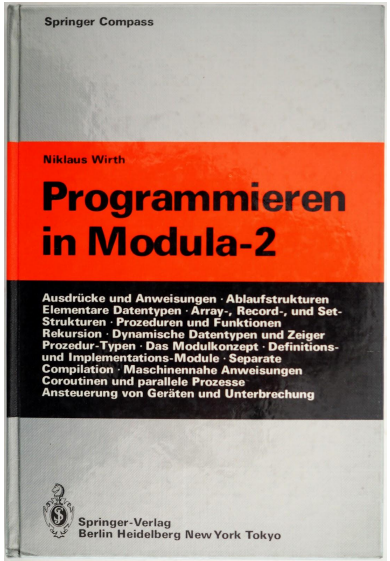
What we really want

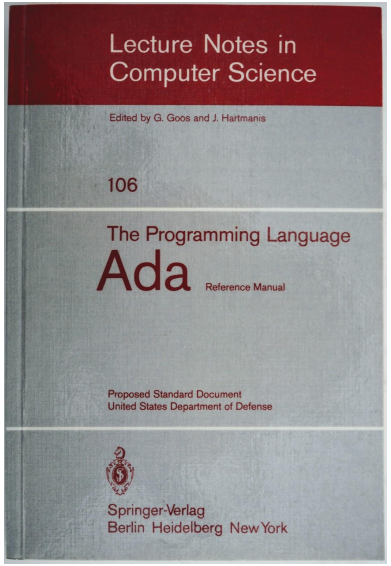
- Dedicated language feature
- No boilerplate
- Less redundancy
- Information hiding
- Efficient implementation
- Self-contained package interface

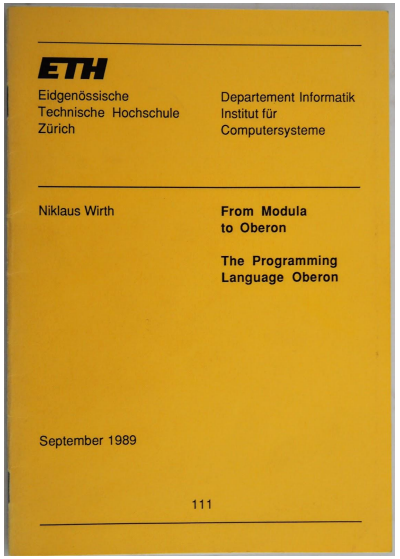


Languages pioneering modularization









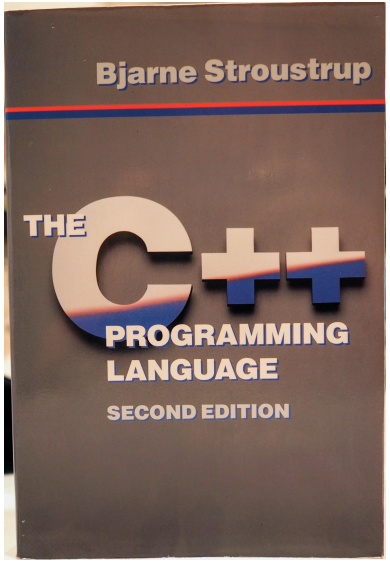
1976 Modula
Mesa

1978 Modula-2

1980 Ada
Modula-3

1986 Oberon

Conspicuously absent ...



1983 C++

Today

- Language support for modularization is commonplace
  - Java/Scala, C#, Swift, Rust, etc. (statically typed)
  - JavaScript (ES6), Python, Ruby, etc. (dynamically typed)
- Similar concepts
- Different implementations
  - e.g., object files vs class files

Implementation

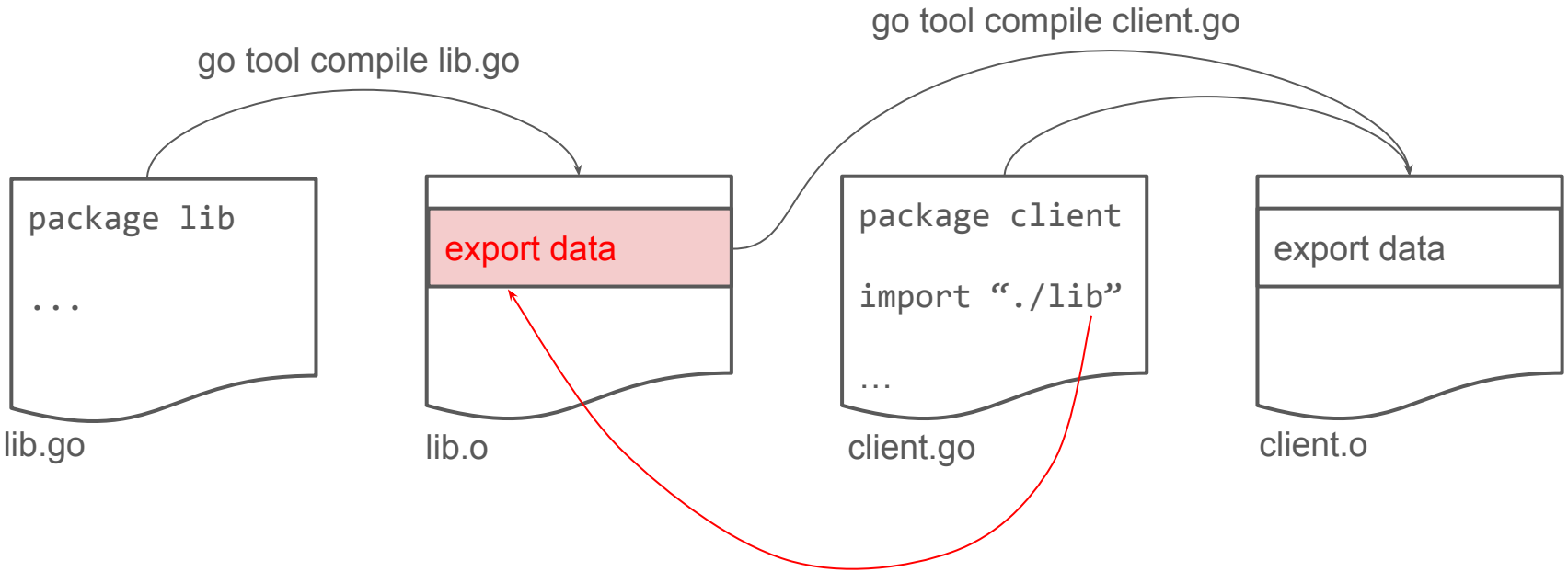
What does a compiler need to compile an import declaration?

- Description of imported library interface for type-checking
- Internal representation of that interface

Internal representation forms a graph, similar to a syntax tree.

- May contain additional implementation-specific information
- May be a DAG, or have cycles

Compiling a package



lib.o before Go 1.7

```
go object darwin amd64 go1.5 X:none

$$
package lib
     import runtime "runtime"
     import fmt "fmt"
     type @"".List struct { Factor int; Power int; Link *@"".List }
     func @"".Factor (@"".xÂ·2 int) (? *@"".List)
     func @"".Print (@"".lÂ·1 *@"".List "esc:0x1")
     func @"".init ()

$$

!
...
```

Issues with textual export data

- Not really Go code
- Go syntax redundant
- References may be long identifiers
- More complicated than necessary to read and write
- But: Human-readability is big plus (for compiler writer)

lib.o after Go 1.7

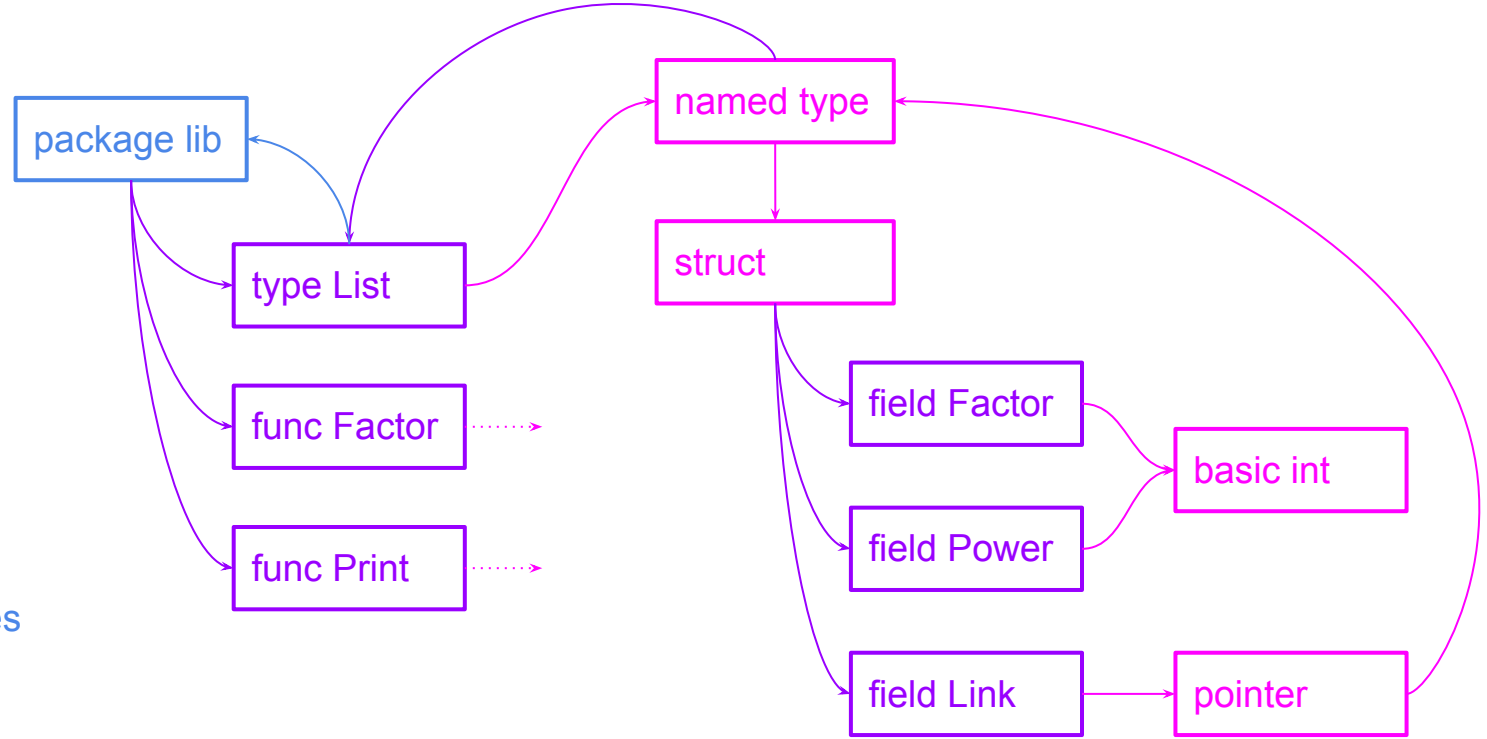
```
go object darwin amd64 devel +86f5f7fdfa Tue May 9 18:35:13 2017 +0000 X:framepointer
----


$$B
version 5

^@^B^A^Elib^@^E^M^?
^M^@    Users^Egri^WGoogle Drive^OGopherSg^Ego1^Klib.go^GList^@^U^F^B^KFactor^B\
^@^@     Power^B^@^B^GLink^W<^@^@         ^R^@^B^B^Ax^@^@^A^W<^@ <       Print^\
@^B^W<^Al^@^Mesc:0x1^@    ^?^B^A^]<autogenerated>^Ginit^@^@^@^K^H^K^@^A^@
$$

!
...
```

Advantages of binary export data

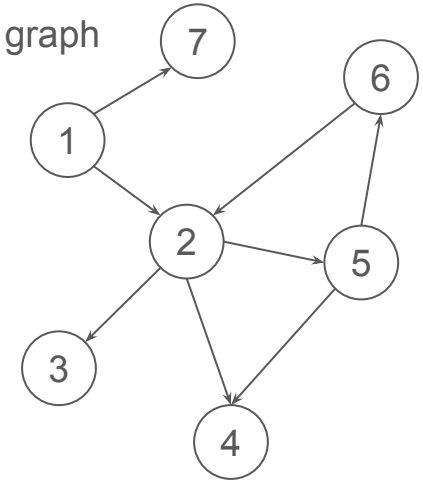
- Easier and faster to write, read
- Format can be very compact
- More easily extensible

- But: Binary format is not human-readable anymore

Exported objects of package lib

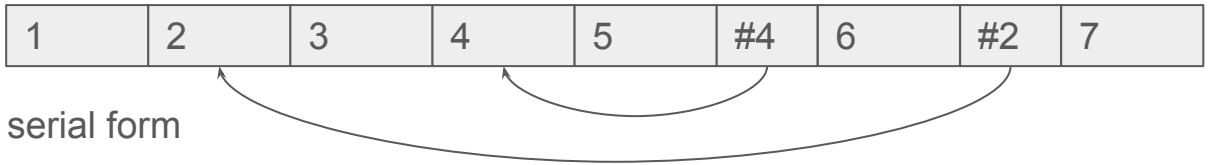


Exporting means serializing a graph

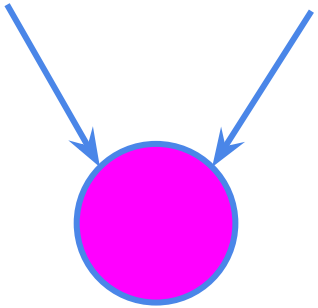


Algorithm:

- Traverse graph recursively
- Write nodes (contents) in order of traversal
- If a node was seen before, write reference instead



Excursion: DAGs in nature



Serialization algorithm

```
var seenBefore = map[Node]int{nil: 0}          // map of nodes already written out

func writeNode(n Node) {
     if index, ok := seenBefore[n]; ok {
          writeInt(index)                      // index >= 0
          return
     }
     seenBefore[n] = len(seenBefore)
     writeInt(-tag(n))                         // -tag(n) < 0
     writeContents(n)                          // may call writeNode recursively
}
```

Deserialization algorithm

```
var seenBefore = []Node{nil: 0}                    // list of nodes already read in

func readNode() *Node {
     i := readInt()
     if i >= 0 {
          return seenBefore[i]
     }
     // i < 0
     n := newNode(-i)
     seenBefore = append(seenBefore, n)
     readContents(n)                               // may call ReadNode recursively
     return n
}
```

Textual export

entity	data to encode	encoding
package lib	packageTag lib “”	package lib
type List	typeTag namedTag List package lib	type @””.List
struct type	structTag len(fields) Factor type int Power type int Link pointerTag type List	struct { Factor int Power int Link *List } ⇐ 72 bytes
func Factor	funcTag Factor package lib	func @””.Factor
…		…

Binary export

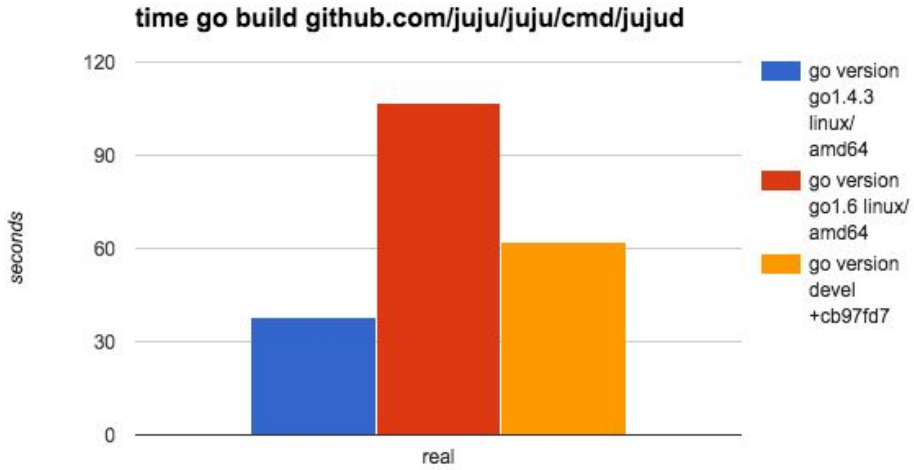
entity	data to encode	encoding	
package lib	packageTag lib “”	-1 -3 l i b 0	
type List	typeTag	-3	
	namedTag List package lib	-7 -4 L i s t 0	
struct type	structTag len(fields)	-11 3	
	Factor type int	-6 F a c t o r 1	
	Power type int	-5 P o w e r 1	
	Link pointerTag type List	-4 L i n k -12 30	⇐ 38 bytes
			~50% of text
func Factor	funcTag Factor package lib	-5 3 0	
…			

Export data sizes after initial commit ae2f54a77

Package	old	new	new/old
archive/tar	13875	3883	28%
archive/zip	19464	5046	26%
bufio	7733	2222	29%
bytes	10342	3347	32%
cmd/addr2line	242	26	11%
cmd/api	39305	10368	26%
cmd/asm/internal/arch	27732	7939	29%
…			
unicode/utf16	1055	148	14%
unicode/utf8	1118	513	46%
vendor/golang.org/x/net/http2/hpack	8905	2636	30%
All packages	**3518505**	**1017774**	**29%**

Good news everyone, since gri's switched to making binary export/import the default, and a few followups from khr the time to build jujud compared to 1.4.3 is now solidly below 2x.

Dave Cheney, 2016-04-28



Future work

- Very large imports
  - Export data must always be read sequentially
  - Inefficient if we only use small part of it
  - Not uncommon with very large exported protobufs
- Possible solutions
  - Stop reading once we have what we need
  - Provide indexed access to export data

Final observations

- Module/package support is “must-have” language feature
- Import/export mechanism makes packages work
- Cheaper workarounds fail, eventually
  - C #includes
- Good implementation requires significant engineering

If the abstraction is right,
it’s worth paying its price.

Thank you!