Beautiful IO

> A tour through standard library pkg/io and various implementations of its interfaces.

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About me

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- Leipzig University Library is involved in a variety of open source projects in the library domain: catalogs, repositories, digitization and image interop frameworks (IIIF), data acquisition, processing and indexing tools
- Go for tools and services
- Co-organizer of Leipzig Gophers

> Explore IO workshop at Golab 2017.

Background

- Go Proverbs (2015)

> The bigger the interface, the weaker the abstraction.

Prominent examples are `io.Reader` and `io.Writer`.

The IO package

- contains basic, widely used interfaces (within and outside standard library)
- utility functions

Why beautiful?

> La bellezza è negli occhi di chi guarda

- small, versatile interfaces
- composable

Praise and love

> This article aims to convince you to use io.Reader in your own code wherever you can. -- @matryer

> "Crossing Streams: a love letter to Go io.Reader" -- @jmoiron

> Which brings me to io.Reader, easily my favourite Go interface. -- @davecheney

What's in pkg/io?

- 25 types
- 21/25 are interfaces
- 12 functions, 3 constants, 6 errors

The concrete types are: `LimitedReader`, `PipeReader`, `PipeWriter`, `SectionReader`; functions: `Copy`, `CopyN`, `CopyBuffer`, `Pipe`, `ReadAtLeast`, `ReadFull`, `WriteString`, `LimitReader`, `MultiReader`, `TeeReader`, `NewSectionReader`, `MultiWriter`

A few Interfaces

	R	W	C	S
io.Reader	x			
io.Writer		x		
io.Closer			x	
io.Seeker				x
io.ReadWriter	x	x		
io.ReadCloser	x		x	
io.ReadSeeker	x			x
io.WriteCloser		x	x	
io.WriteSeeker		x		x
io.ReadWriteCloser	x	x	x	
io.ReadWriteSeeker	x	x		x

Missing interfaces

You might find some missing pieces elsewhere (here: https://github.com/go4org/go4).

https://github.com/go4org/go4/blob/94abd6928b1da39b1d757b60c93fb2419c409

```
33  // A ReadSeekCloser can Read, Seek, and Close.
34  type ReadSeekCloser interface {
35          io.Reader
36          io.Seeker
37          io.Closer
38  }
39
40  type ReaderAtCloser interface {
41          io.ReaderAt
42          io.Closer
43  }
```

How many readers, writers are there?

```
$ guru -json implements /usr/local/go/src/io/io.go:#3309,#3800
```

I counted over 200 implementations of each, io.Reader and io.Writer in the Go tree and subrepositories.

What is a Reader?

```
type Reader interface {
        Read(p []byte) (n int, err error)
}
```

The reader implementation will populate a given byte slice.

- at most `len(p)` bytes are read
- to signal the end of a stream, return `io.EOF`

There is some flexibility around the end of a stream.

> Callers should always process the n > 0 bytes returned before considering the error err. Doing so correctly handles I/O errors that happen after reading some bytes and also both of the allowed EOF behaviors.

Notes on Reader

```
type Reader interface {
        Read(p []byte) (n int, err error)
}
```

- The byte slice is under the control of the caller.

> Implementations must not retain p.

This hints at the streaming nature of this interface.

Notes on Reader

The `Read` function does not guarantee, the passed byte slice will by completely filled. This is up to the implementation.

- `io.ReadAtLeast` -- will fail, if not at least a given number of bytes are read
- `io.ReadFull` -- special case; will fail, if the given byte slices is not completely filled

Implementations

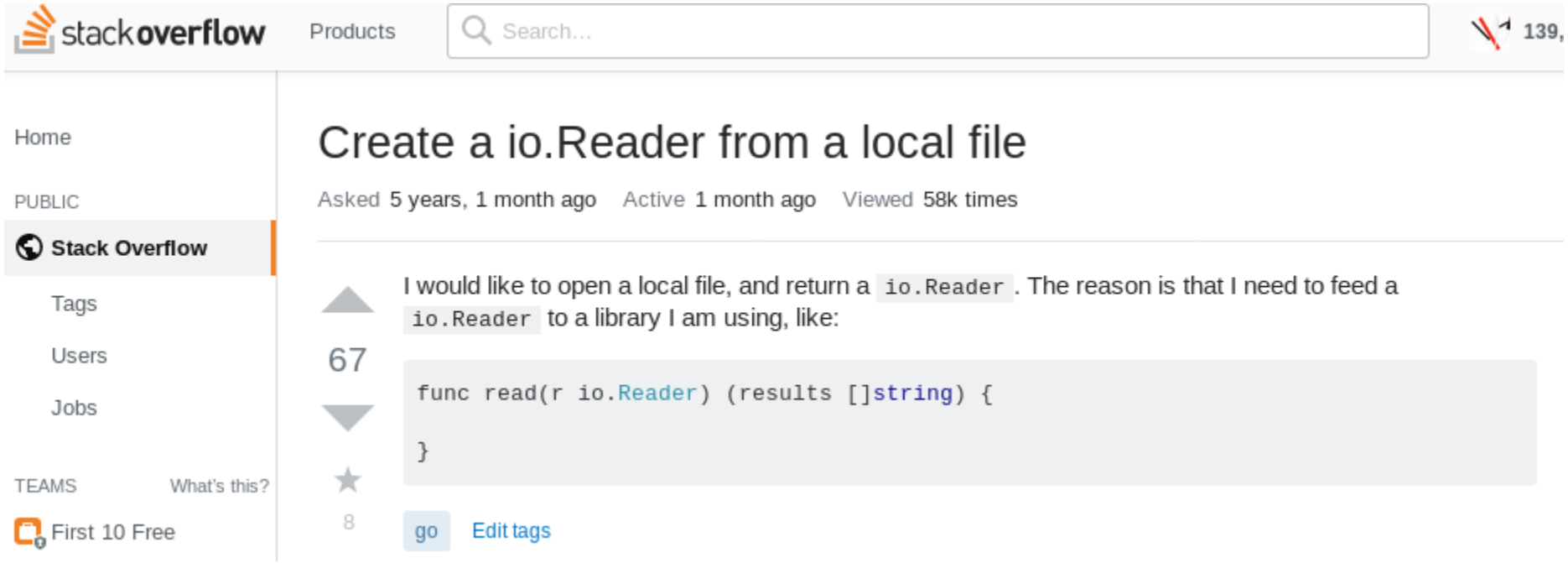
Readers can be:

- files
- network connections
- HTTP response bodies
- standard input
- compression
- serialization
- ...

Writers are use for hash functions, standard output, formatting, and more.

Structural typing

- conversions are not required, a file implements `Read` and hence *is* a *io.Reader*



Streams

As layed out in the *love letter*, the use of `ioutil.ReadAll` is not always the answer. It's in the standard library and useful, but not always necessary.

```
b, err := ioutil.ReadAll(r)
...
```

Streams

- you may lose the advantage to use the `Reader` in other places
- you may consume more memory

> Streams can trivially produce infinite output while using barely any memory at all - imagine an implementation behaving like /dev/zero or /dev/urandom.

- Memory control is an important advantage.

Follow the stream

Instead of writing:

```
b, _ := ioutil.ReadAll(resp.Body) // Pressure on memory.
fmt.Println(string(b))
```

You may want to connect streams:

```
_, _ = io.Copy(os.Stdout, resp.Body)
```

Stream advantages

- memory efficient
- can work with data, that does not fit in memory
- allows to work on different protocol parts differently (e.g. HTTP header vs possibly large HTTP response body)

Another example

Lots of data today comes in JSON, which we need to unmarshal.

```
_ = json.Unmarshal(data, &v) // data might come from ioutil.ReadAll(resp.Body)
```

But we can decode it as well.

```
_ = json.NewDecoder(resp.Body).Decode(&v)
```

In this case, the JSON data must be fully read, so this is a weak example.

Glipse at composition

But what is we want need to preprocess the data, e.g. decompress it. Streams compose well.

```
zr, _ = gzip.NewReader(resp.Body)
_ json.NewDecoder(zr).Decode(&)
```

How do you implement one yourself?

You only need a `Read` method with the correct signature.

- Example: `/dev/zero`

```
type devZero struct{}

func (r *devZero) Read(p []byte) (int, error) {
        for i := 0; i < len(p); i++ {
                p[i] = '\x00'
        }
        return len(p), nil
}
```

This is already an infinite stream.

Embed a reader

Often you want to transform a given data stream, so you embed it.

```
type UpperReader struct {
        r io.Reader // Underlying stream
}

func (r *UpperReader) Read(p []byte) (int, error) {
        n, err := r.r.Read(p)
        copy(p, bytes.ToUpper(p))
        return n, err
}

func main() {
        if _, err := io.Copy(os.Stdout, &UpperReader{os.Stdin}); err != nil {
                log.Fatal(err)
        }
}
```

- Also try: https://tour.golang.org/methods/22 (Reader exercise, ROT13)

The io.Writer interface

Analogous to the `io.Reader` interface.

```
type Writer interface {
        Write(p []byte) (n int, err error)
}
```

> Write writes len(p) bytes from p to the underlying data stream. It returns the number of bytes written from p (0 <= n <= len(p)) and any error encountered that caused the write to stop early.

> Write must return a non-nil error if it returns n < len(p). Write must not modify the slice data, even temporarily.

As with readers:

> Implementations must not retain p.

An example

A writer that does not much, but is still useful - `/dev/null` in Go:

```
type devNull struct{}

func (w *devNull) Write(p []byte) (int, error) {
        return len(p), nil
}

func main() {
        if n, err := io.Copy(&devNull{}, strings.NewReader("Hello World")); err != nil {
                log.Fatal(err)
        } else {
                log.Printf("%d bytes copied", n)
        }
}
```

The standard library implementation is called `ioutil.Discard` (for an interesting/frustrating bug related to ioutil.Discard, I recommend #4589).

Use cases

Implementations may allow:

- to abstract a (physical) resource
- to convert something into a stream
- define buffers
- to enhance functionality - decorate, transform
- mock behaviour (testing)
- to be used as utilities

Resource: os.File

Prototypical stream: A file.

- os.File

And alternatives and substitutions, e.g. dummy files for tests or file that support atomic writes.

Historical note

> A file is simply a sequence of bytes. Its main attribute is its size. By contrast, on more conventional systems, a file has a dozen or so attributes. To specify and create a file it takes endless amount of chit-chat. If you are on a UNIX system you can simply ask for a file and use it interchangeble whereever you want a file. -- (https://www.youtube.com/watch?v=tc4ROCJYbm0, 1982)

If a file is just a sequence of bytes, more things will look like files.

Resource: net.Conn

> Conn is a generic stream-oriented network connection.

```
type Conn interface {
        // Read reads data from the connection.
        // Read can be made to time out and return an Error with Timeout() == true
        // after a fixed time limit; see SetDeadline and SetReadDeadline.
        Read(b []byte) (n int, err error)
        ...
        // Write writes data to the connection.
        // Write can be made to time out and return an Error with Timeout() == true
        // after a fixed time limit; see SetDeadline and SetWriteDeadline.
        Write(b []byte) (n int, err error)
        ...
```

Example HTTP GET

```
conn, _ := net.Dial("tcp", "golang.org:80")
_, _ = io.WriteString(conn, "GET / HTTP/1.0\r\n\r\n")
```

Conversion: strings

Turing strings and byte slices into streams.

```
r := strings.NewReader("might help testing")
// r := bytes.NewReader([]byte("might help testing"))
```

Buffers: bytes.Buffer

> A Buffer is a variable-sized buffer of bytes with Read and Write methods. The zero value for Buffer is an empty buffer ready to use.

The byte slice of the streaming world.

```
var buf bytes.Buffer
_, _ = io.WriteString(&buf, "data")
// buf.String()
// buf.Bytes()
```

Enhancement: bufio.Reader

> Package bufio implements buffered I/O. It wraps an io.Reader or io.Writer object, creating another object (Reader or Writer) that also implements the interface but provides buffering and some help for textual I/O.

```
// Reader implements buffering for an io.Reader object.
type Reader struct {
        buf          []byte
        rd           io.Reader // reader provided by the client
        r, w         int       // buf read and write positions
        err          error
        lastByte     int // last byte read for UnreadByte; -1 means invalid
        lastRuneSize int // size of last rune read for UnreadRune; -1 means invalid
}
```

Enhancement: bufio.Reader

Provides simplifications, e.g. to read up to given delimiters, e.g. linewise reads.

A further abstraction, `bufio.Scanner` is built from a reader, which allows to process a stream, by splitting into a sequence of tokens.

Enhancement: tabwriter.Writer

> A Writer is a filter that inserts padding around tab-delimited columns in its input to align them in the output.

> The Writer treats incoming bytes as UTF-8-encoded text consisting of cells terminated by horizontal ('\t') or vertical ('\v') tabs, and newline ('\n') or formfeed ('\f') characters; both newline and formfeed act as line breaks.

```
8543296|0
6353501|65535
   1346|5140
    881|21588
```

Transformation: compress/gzip

```
data := []byte{
        0x1f, 0x8b, 0x08, 0x00, 0xfc, 0x27, 0xac, 0x5d,
        0x00, 0x03, 0x4b, 0xcf, 0xcf, 0x49, 0x4c, 0xe2,
        0x02, 0x00, 0x4a, 0x77, 0xaa, 0x30, 0x06, 0x00,
        0x00, 0x00,
} // echo golab | gzip -c | xxd -i
gzr, _ := gzip.NewReader(bytes.NewReader(data))
if _, err := io.Copy(os.Stdout, gzr); err != nil {
        log.Fatal(err)
}
```

As I like pigz, I'm a fan of these drop-in compression implementations as well:

- https://github.com/klauspost/compress

Transformation: Serialization

Many subpackages of package encoding provide encoders and decoders for working with streams, e.g. json, xml, gob, base64.

```
// base64.NewDecoder
func NewDecoder(enc *Encoding, r io.Reader) io.Reader
```

```
_ = json.NewEncoder(os.Stdout).Encode(value)
```

Transformation: Blackout

Stranger implementation. A blackout reader that blacks out occurences of certain words.

Example: x/blackout

Mock implementations

Implementations of readers and writers for test purposes.

- simulate failure cases
- infinite stream

Mock: Infinite reader

```
// infiniteReader satisfies Read requests as if the contents of buf
// loop indefinitely.
type infiniteReader struct {
        buf    []byte
        offset int
}

func (r *infiniteReader) Read(b []byte) (int, error) {
        n := copy(b, r.buf[r.offset:])
        r.offset = (r.offset + n) % len(r.buf)
        return n, nil
}
```

Mock: Slow reader

Insert delays into read operations.

- Example: x/slowreader
- Asciicast

Test case reader examples

- bufio_test.slowReader
- bufio_test.errorThenGoodReader
- bufio_test.rot13Reader
- encoding/base64.faultInjectReader

Example from k8s (how do implementations handle slow responses):

```
type readDelayer struct {
        delay time.Duration
        io.ReadCloser
}

func (b *readDelayer) Read(p []byte) (n int, err error) {
        defer time.Sleep(b.delay)
        return b.ReadCloser.Read(p)
}
```

Utilities

Utility implementations and helper functions.

- Side effects: count total bytes read or written
- Patterns: encoding/csv.nTimes
- Sink: ioutil.Discard
- Source: infinite data
- Limits: timeout Reader
- Error handling: stickyErrWriter
- Split stream: TeeReader
- Merge streams: MultiReader

Utility: Counting

An identity transform, with a side effect, e.g. counting.

```
type CountReader struct {
        count int64
        r     io.Reader
}

func (r *CountReader) Read(buf []byte) (int, error) {
        n, err := r.r.Read(buf)
        atomic.AddInt64(&r.count, int64(n))
        return n, err
}

func (r *CountReader) Count() int64 {
        return atomic.LoadInt64(&r.count)
}
```

Again: it would be simple to take the length of a byte slice, a stream is more memory efficient.

Other stats are possible.

Utility: Language Guesser

Guess language of stream with a trigram.

- Example: x/trigram

Utility: Source

From: encoding/csv/reader_test.go

```
// nTimes is an io.Reader which yields the string s n times.
type nTimes struct {
        s   string
        n   int
        off int
}
```

It is used to generate testdata to benchmark the csv implementation.

```
...
r := NewReader(&nTimes{s: rows, n: b.N})
...
```

Utility: Source

Generate infinite data with finite resources.

- zeros
- random data

Example: x/randbase

Utility: Timeout

Encapsulate a timeout in a read operation.

Example: x/timeout

Utility: TeeReader

The `io.TeeReader` function allows to duplicate a stream.

```
r := strings.NewReader("some io.Reader stream to be read\n")
var buf bytes.Buffer
tee := io.TeeReader(r, &buf)
```

Utility: MultiReader

```
rs := []io.Reader{
        strings.NewReader("Hello\n"),
        strings.NewReader("Gopher\n"),
        strings.NewReader("World\n"),
        strings.NewReader("!\n"),
}
r := io.MultiReader(rs...)
if _, err := io.Copy(os.Stdout, r); err != nil {
        log.Fatal(err)
}
```

Possible use cases: Unify multiples of the same thing (e.g. data chunked into files) or a variety of different things, e.g. strings, files and remote resources.

Utility: Duplicating a ReadCloser

A response body is a `io.ReadCloser` and can be read only once.

Example: x/duprc

Utility: Attach an event to a reader

```
type onEOFreader struct {
        r io.Reader
        f func()
}

func (r *onEOFreader) Read(p []byte) (n int, err error) {
        n, err = r.r.Read(p)
        if err == io.EOF {
                r.f()
        }
        return n, err
}

func main() {
        r := onEOFreader{r: os.Stdin, f: func() {
                log.Printf("done reading")
        }}
        _, _ := io.Copy(os.Stdout, &r)
}
```

Utility: stickyErrWriter

Stolen from Hacking with Andrew and Brad.

- Use case: Implement a writer, where an error sticks around across multiple write calls.

```
// stickyErrWriter keeps an error around, so you can *occasionally* check if an error occured.
type stickyErrWriter struct {
        w   io.Writer
        err *error
}

func (sew stickyErrWriter) Write(p []byte) (n int, err error) {
        if *sew.err != nil {
                return 0, *sew.err
        }
        n, err = sew.w.Write(p)
        *sew.err = err
        return
}
```

Copy

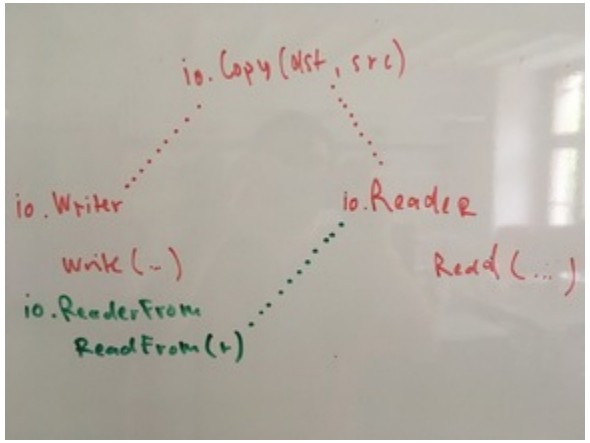
We used `io.Copy` all along.

> Copy copies from src to dst until either EOF is reached on src or an error occurs. It returns the number of bytes copied and the first error encountered while copying, if any.

It uses an internal buffer (of size 32k) to move data from reader to writer.

Copy Optimizations

If the source (a reader) has a `WriteTo(w io.Writer)` methods, or the destination (a writer) has a `ReadFrom(r io.Reader)` method (implements `io.ReadFrom`), then `io.Copy` does not need to use its internal buffer.



Wrap up

- stream interfaces are very versatile
- you will mostly need to implement a single method
- allows to you adopt to a large number of existing components

Thanks