Beautiful IO

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

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About me

SWE @ubleipzig working mostly with Python and Go.

- a variety of open source projects in the library domain: catalogs, repository, digitization and image interop (IIIF), data acquisition, processing and indexing
- 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

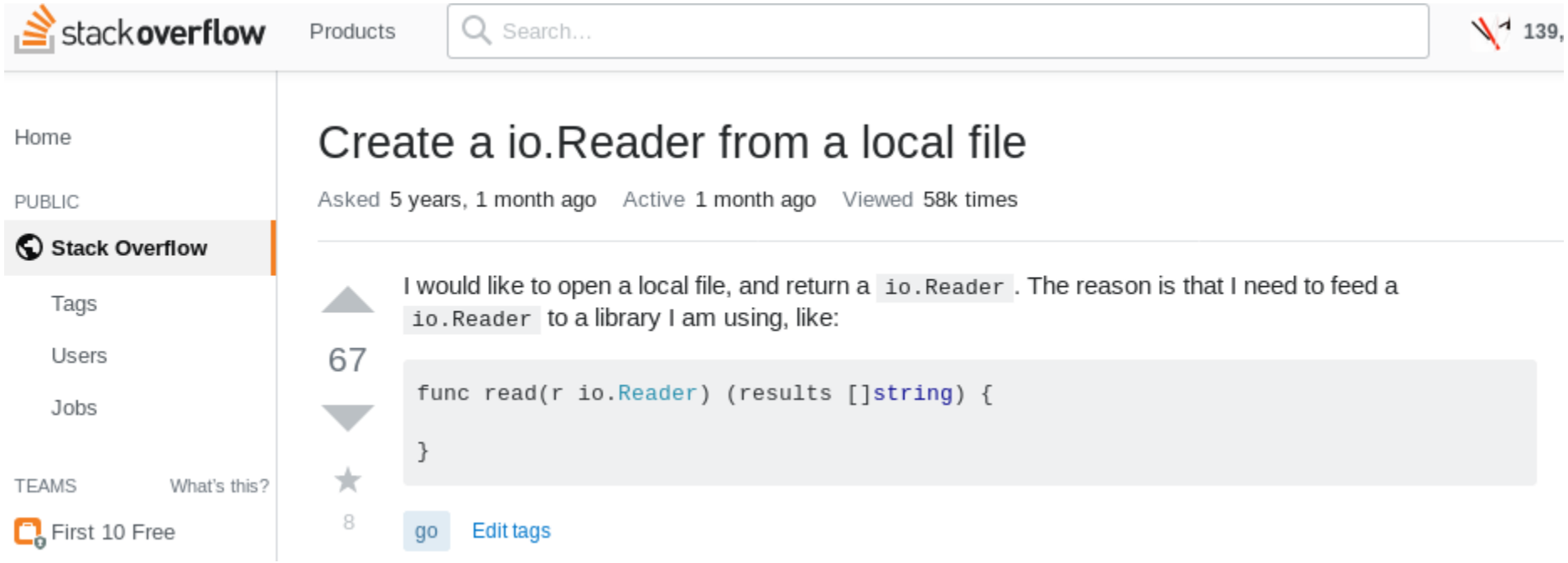
Readers can be:

- 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 HTTP body)

Another example

We often need to unmarshal JSON.

```
_ = 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

Interfaces may:

- abstract a resource
- conversion to stream
- buffers
- enhance functionality - decorate, transform
- mock behaviour (testing)
- 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.

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.

- Counting: count total bytes read or written
- Patterns: encoding/csv.nTimes
- Sink: ioutil.Discard
- Source: infinite data
- Limits: timeout Reader
- Translate: http range requests
- 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

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: 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
}
```

Optimizations

- ReaderFrom

Thanks