

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 be 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 slice is not completely filled

Implementations

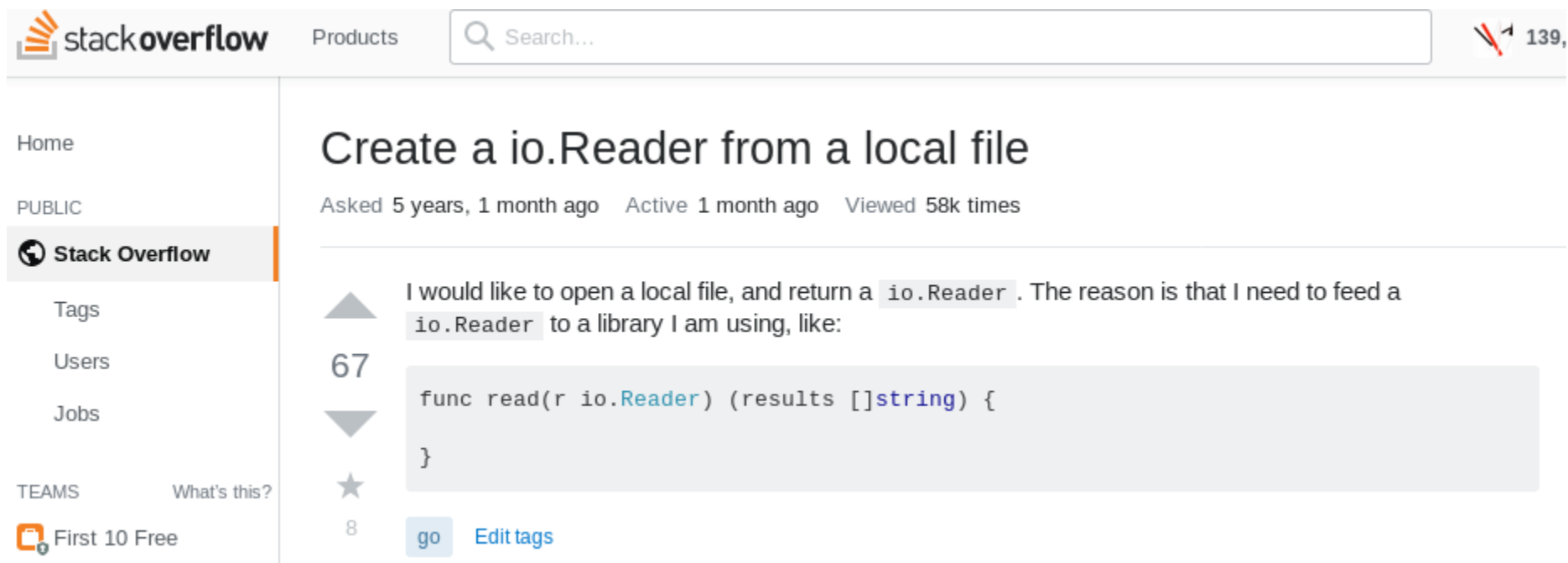
Readers can be:

- 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`



The screenshot shows the Stack Overflow interface. The header includes the Stack Overflow logo, a 'Products' link, a search bar, and a notification icon with '139'. The left sidebar contains navigation links: 'Home', 'PUBLIC', 'Stack Overflow' (selected), 'Tags', 'Users', 'Jobs', 'TEAMS', 'What's this?', and 'First 10 Free'. The main content area displays a question titled 'Create a io.Reader from a local file'. Below the title, it says 'Asked 5 years, 1 month ago', 'Active 1 month ago', and 'Viewed 58k times'. The question text is 'I would like to open a local file, and return a `io.Reader`. The reason is that I need to feed a `io.Reader` to a library I am using, like:'. Below the text is a code block containing a Go function:

```
func read(r io.Reader) (results []string) {  
    }  
}
```

. To the left of the code block are up and down vote arrows, the number '67', a star icon, and the number '8'. At the bottom of the question are 'go' and 'Edit tags' buttons.

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Create a io.Reader from a local file

Asked 5 years, 1 month ago Active 1 month ago Viewed 58k times

I would like to open a local file, and return a `io.Reader`. The reason is that I need to feed a `io.Reader` to a library I am using, like:

```
func read(r io.Reader) (results []string) {  
    }  
}
```

67

8 go Edit tags

Streams

As layed out in the *love letter*, the use of `ioutil.ReadAll` is debatable. 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` ($0 \leq n \leq \text{len}(p)$) and any error encountered that caused the write to stop early.

Write must return a non-nil error if it returns $n < \text{len}(p)$. 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 interchangeably wherever 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
gzh, _ := gzip.NewReader(bytes.NewReader(data))
if _, err := io.Copy(os.Stdout, gzh); 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)
```

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.faultInjectorReader`

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

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 occurred.
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
}
```

Stranger implementation

A blackout reader that blacks out occurrences of certain words.

Example: `x/blackout`

Optimizations

- ReaderFrom

Thanks