The Art of Bondage

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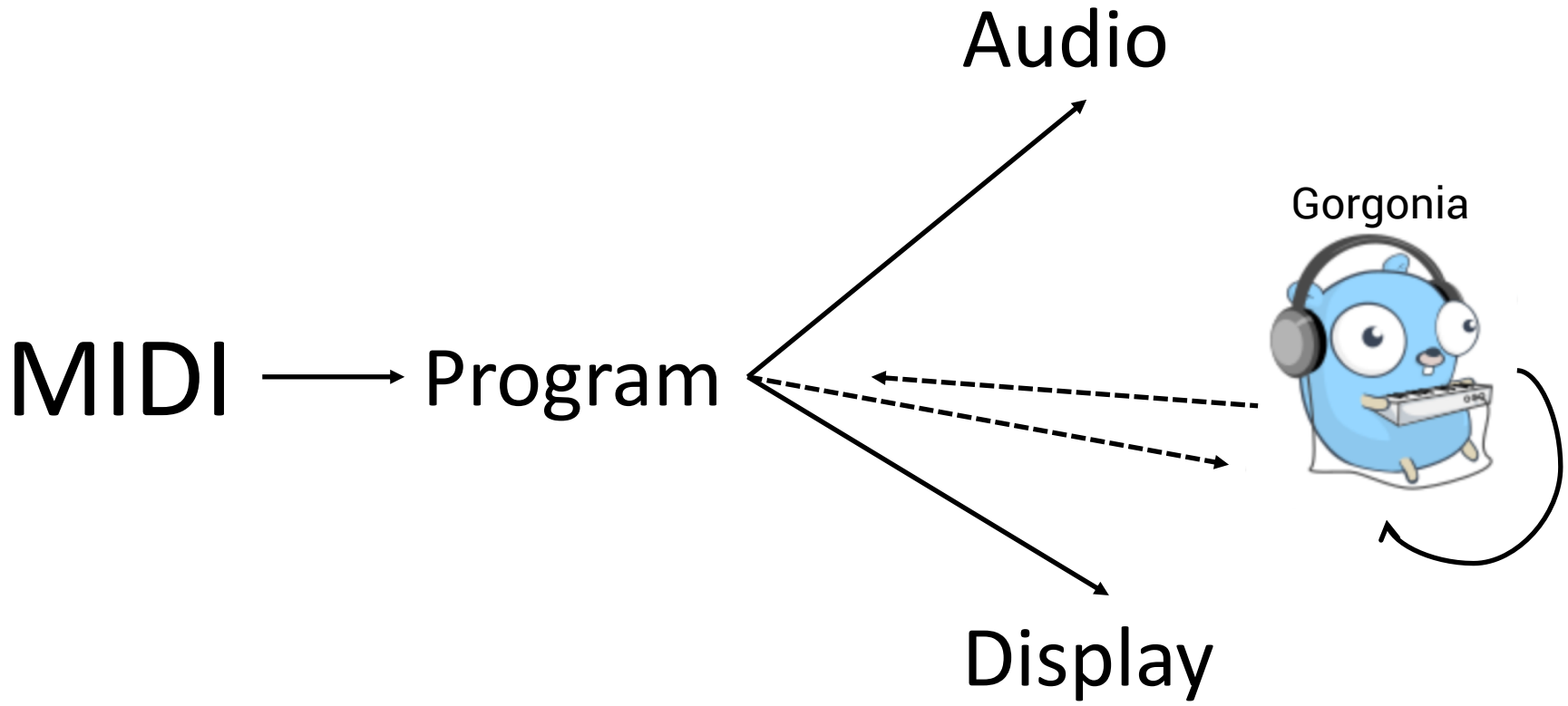
GopherCon Singapore 2018

The Program



Download cuDNN v7.1.3 (April 17, 2018), for CUDA 9.1

cuDNN v7.1.3 Library for Linux

cuDNN v7.1.3 Library for Linux (Power8/Power9)

cuDNN v7.1.3 Library for Windows 7

cuDNN v7.1.3 Library for Windows 10

cuDNN v7.1.3 Runtime Library for Ubuntu16.04 (Deb)

cuDNN v7.1.3 Developer Library for Ubuntu16.04 (Deb)

cuDNN v7.1.3 Code Samples and User Guide for Ubuntu16.04 (Deb)

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Macs are friends too!

:(

WHY?

Why?

- Existing libraries written in C/Fortran

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  - Difficult to port over to Go

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- Existing libraries written in C/Fortran
  - Difficult to port over to Go
- Our motivating example: CUDA libraries
  - `import "gorgonia.org/cu"`
  - `import "gorgonia.org/cu/blas"`
  - `import "gorgonia.org/cu/dnn"`

Some Definitions

C API

```
cudnnStatus_t cudnnCreate(cudnnHandle_t *handle)
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cgo Call

```
C.cudnnCreate(h *C.cudnnHandle_t) C.cudnnStatus_t
```

Some Definitions

C API

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cgo Call

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C.cudnnCreate(h *C.cudnnHandle_t) C.cudnnStatus_t
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Go API

```
func New(h *C.cudnnHandle_t) C.cudnnStatus_t
func New(h *C.cudnnHandle_t) error
func New() (*Handle, error)
func New() *Handle
```

Some Definitions

C API

```
cudnnStatus_t cudnnCreate(cudnnHandle_t *handle)
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cgo Call

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func New(h *C.cudnnHandle_t) C.cudnnStatus_t
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Why Write an API Library?

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- More user friendly.

Why Write an API Library?

- A library that exposes a Go API reduces cognitive overhead.
  - You don't have to know C anymore.
- Abstract away bookkeeping activities.
- More user friendly.
- Provide performance improvements for common use cases.

Why Write an API Library?

In short, provide a great user experience.

This Talk

- Partly about strategies to write bindings.
- Partly about API design.

THE PROCESS: MANUAL WRITING

The Process: Transform from A to B

cgo Call

```
C.cudnnCreate(h *C.cudnnHandle_t) C.cudnnStatus_t
```

The Process: Transform from A to B

cgo Call

```
C.cudnnCreate(h *C.cudnnHandle_t) C.cudnnStatus_t
```

Wrap in one of these

Go API

```
func New(h *C.cudnnHandle_t) C.cudnnStatus_t
func New(h *C.cudnnHandle_t) error
func New() (*Handle, error)
func New() *Handle
```

Simplest Example

```
cudnnStatus_t cudnnCreate(cudnnHandle_t *handle)
```



```
func New(handle *C.cudnnHandle_t) C.cudnnStatus_t
```

Simplest Example

```
func New(handle *C.cudnnHandle_t) C.cudnnStatus_t {
   return C.cudnnCreate(handle)
}
```

Simplest Example

```
func New(handle *C.cudnnHandle_t) C.cudnnStatus_t {
    return C.cudnnCreate(handle)
}
```

The Process

```
type Handle struct{
    internal C.cudnnHandle_t
}

func New() *Handle {
    var h C.cudnnHandle_t
    if st := cudnnCreate(&h); st != C.CUDNN_STATUS_SUCCESS {
        panic(st)
    }
    return &Handle{h}
}
```

The Process

```
type Handle C.cudnnHandle_t

func New() Handle {
    var h C.cudnnHandle_t
    if st := cudnnCreate(&h); st != C.CUDNN_STATUS_SUCCESS {
        panic(st)
    }
    return Handle(h)
}
```

The Process: Go has Methods

- Methods make for nice APIs.

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- Methods make for nice APIs.
- Methods allow for interfaces to be implemented.

Manual Writing

- Forces one to actually think about the API.

Manual Writing

- Forces one to actually think about the API.
  - Result: nicer API based on use case

Manual Writing

- Forces one to actually think about the API.
- Requires one to be deeply familiar with the library.

Good Examples

- github.com/rakyll/portmidi
- github.com/mattn/go-gtk

Manual Writing: Downsides

- A lot of time and effort required.

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- Coverage issues.

Manual Writing: Downsides

- A lot of time and effort required.
- Not consistently replicable.
- Coverage issues.
- Inability to keep up with new versions.


Wait a minute...
We are programmers!
Follow @chewxy on Twitter

AUTOMATIC GENERATION

Automatic Generation

- Repeatable results.

Automatic Generation

- Repeatable results.
- Generate multiple API levels.

Automatic Generation

Automatic generation steps:

1. Parse the C-header.
2. Generate the Go source code.

Good Examples

- github.com/go-gl/glfw
- github.com/go-gl/gl/vX.X-core/gl
  - Uses GLOW: github.com/go-gl/glow

- github.com/martine/gocairo
  - Uses rsc.io/c2go

Immediately Obvious Solution

github.com/xlab/c-for-go

The Devil Is In the Details

- Enums
- Types
- Functions
- Procedures

The Devil Is In the Details

- Enums → Type + Const
- Types
- Functions
- Procedures

The Devil Is In the Details

- Enums → Type + Const
- Types → Type + Getter functions
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The Devil Is In the Details

- Enums → Type + Const
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The Devil Is In the Details

- Enums → Type + Const
- Types → Type + Getter functions
- Functions → Functions/Methods.
- Procedures → Functions/Methods

Note from xlab

*"The **resulting bindings are as low-level as C code**, i.e. it would require knowledge of memory management to carefully use the resulting code, however no more C code is needed to make things done. ... Also **usually a high-level wrapper is created by hand**"*

Solution: Manual Annotation

Annotate the things from the header – what should be a function, what should be a method, etc.

A Balance

Time spent manually annotating functions vs time spent generating code.

Solution: Multi-Stage Generation

1. Generate annotations that can be deduced by rules.
2. Manually check/edit select annotations.
3. Generate library.

CUDA Libraries

- Generated with:
  - github.com/cznic/cc
  - github.com/gorgonia/bindgen
  - go/token
  - go/parser
  - text/template
  - Specific programs to generate each library:
    - gorgonia.org/cu/cmd/genlib
    - gorgonia.org/cu/cmd/gencublas
    - gorgonia.org/cu/cmd/gencudnn

TACTICAL ISSUES WITH AUTOMATIC GENERATION

Issues with Automatic Generation

- Unclear type

Unclear Types

What is the type of `labels`?

```
cudnnStatus_t cudnnGetCTCLossWorkspaceSize(
    cudnnHandle_t                      handle,
    const   cudnnTensorDescriptor_t    probsDesc,
    const   cudnnTensorDescriptor_t    gradientsDesc,
    const   int                       *labels,
    const   int                       *labelLengths,
    const   int                       *inputLengths,
    cudnnCTCLossAlgo_t                 algo,
    const   cudnnCTCLossDescriptor_t   ctcLossDesc,
    size_t                            *sizeInBytes)
```

Unclear Types

What is the type of `labels`?

```
func (ctx *Handle) CTCLossWorkspaceSize(probDesc, gradientsDesc Tensor,
                                        labels ???,
                                        labelLengths ???,
                                        inputLengths ???,
                                        algo CTCLossAlgo,
                                        ctcLossDesc Tensor) (size uintptr)
```

Unclear Types

What is the type of `labels`?

```
cudnnStatus_t cudnnGetCTCLossWorkspaceSize(
    cudnnHandle_t                      handle,
    const   cudnnTensorDescriptor_t    probsDesc,
    const   cudnnTensorDescriptor_t    gradientsDesc,
    const   int                       *labels,
    const   int                       *labelLengths,
    const   int                       *inputLengths,
    cudnnCTCLossAlgo_t                 algo,
    const   cudnnCTCLossDescriptor_t   ctcLossDesc,
    size_t                            *sizeInBytes)
```

Unclear Types

Compare: What is the type of u, v?

```
cudnnStatus_t cudnnGetConvolution2dDescriptor(
    const cudnnConvolutionDescriptor_t  convDesc,
    int                                 *pad_h,
    int                                 *pad_w,
    int                                 *u,
    int                                 *v,
    int                                 *dilation_h,
    int                                 *dilation_w,
    cudnnConvolutionMode_t              *mode,
    cudnnDataType_t                     *computeType)
```

Unclear Types

What is the type of `labels`?

```
cudnnStatus_t cudnnGetCTCLossWorkspaceSize(
    cudnnHandle_t                      handle,
    const   cudnnTensorDescriptor_t    probsDesc,
    const   cudnnTensorDescriptor_t    gradientsDesc,
    const   int                       *labels,
    const   int                       *labelLengths,
    const   int                       *inputLengths,
    cudnnCTCLossAlgo_t                 algo,
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    size_t                            *sizeInBytes)
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Unclear Types

What is the type of `labels`?

```
cudnnStatus_t cudnnGetCTCLossWorkspaceSize(
    cudnnHandle_t                     handle,
    const   cudnnTensorDescriptor_t   probsDesc,
    const   cudnnTensorDescriptor_t   gradientsDesc,
    const   size_t                    labelsSize,
    const   int                       labels[],
    const   int                       labelLengths[],
    const   int                       inputLengths[],
    cudnnCTCLossAlgo_t                algo,
    const   cudnnCTCLossDescriptor_t  ctcLossDesc,
    size_t                           *sizeInBytes)
```

Unclear Types

What is the type of `labels`?

```
cudnnStatus_t cudnnGetCTCLossWorkspaceSize(
    cudnnHandle_t                       handle,
    const   cudnnTensorDescriptor_t     probsDesc,
    const   cudnnTensorDescriptor_t     gradientsDesc,
    const   size_t                      labelsSize,
    const   int                         labels[],
    const   int                         labelLengths[],
    const   int                         inputLengths[],
    cudnnCTCLossAlgo_t                  algo,
    const   cudnnCTCLossDescriptor_t    ctcLossDesc,
    size_t                             *sizeInBytes)
```

To a C compiler, there is no difference between `int*` and `int[]`

Issues with Automatic Generation

- Unclear type
- Unclear use cases

Unclear Use Case

What is the use case of `algo`?

```
cudnnStatus_t cudnnGetCTCLossWorkspaceSize(
    cudnnHandle_t                     handle,
    const   cudnnTensorDescriptor_t   probsDesc,
    const   cudnnTensorDescriptor_t   gradientsDesc,
    const   int                      *labels,
    const   int                      *labelLengths,
    const   int                      *inputLengths,
    cudnnCTCLossAlgo_t                algo,
    const   cudnnCTCLossDescriptor_t  ctcLossDesc,
    size_t                           *sizeInBytes)
```

Unclear Use Case

What is the use case of `algo`?

```
cudnnStatus_t cudnnGetCTCLossWorkspaceSize(
    cudnnHandle_t                      handle,
    const   cudnnTensorDescriptor_t    probsDesc,
    const   cudnnTensorDescriptor_t    gradientsDesc,
    const   int                       *labels,
    const   int                       *labelLengths,
    const   int                       *inputLengths,
    const   cudnnCTCLossAlgo_t         algo,
    const   cudnnCTCLossDescriptor_t   ctcLossDesc,
    size_t                            *sizeInBytes)
```

Hybrid Solution

1. Parse the docs. Add them as constants.
2. Manually annotate specific parameters.
3. Automatic generation as an aid to manual generation.

VARIOUS CONSIDERATIONS

Various Considerations

- Performance
- Contexts and multi-level API
- Error detection
- Reporting

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- Performance
- Contexts and multi-level API
- Error detection
- Reporting

Performance Tip: Batching

```
func NewConvolution(mathType MathType, groupCount int, padding, filterStride, dilation []int, convolutionMode ConvolutionMode, datatype
DataType) (*Convolution, error) {
	var internal C.cudnnConvolutionDescriptor_t
	if err := result(C.cudnnCreateConvolutionDescriptor(&internal)); err != nil { ... }
	if err := result(C.cudnnSetConvolutionMathType(internal, mathType.C())); err != nil { ... }
	if err := result(C.cudnnSetConvolutionGroupCount(internal, C.int(groupCount))); err != nil { ... }
	switch len(padding) {
	case 0, 1:
		return nil, errors.Errorf("Only 2+ dims are allowed")
	case 2:
		// snipped: destructuring of padH, padW, u, v, etc
		if err := result(C.cudnnSetConvolution2dDescriptor(internal, C.int(padH), C.int(padW), C.int(u), C.int(v), C.int(dilationH),
C.int(dilationW), convolutionMode.C(), datatype.C())); err != nil {
			return nil, err
		}
	default:
		// snipped: converting padding, filterStride, dilation to a pointer
		if err := result(C.cudnnSetConvolutionNdDescriptor(internal, C.int(len(padding)), padA, strideA, dilationA,
convolutionMode.C(), datatype.C())); err != nil {
			return nil, err
		}
	}
	retVal := &Convolution{...}
	runtime.SetFinalizer(retVal, destroyConvolution)
	return retVal, nil
}
```

Performance Tip: Batching

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func NewConvolution(mathType MathType, groupCount int, padding, filterStride, dilation []int, convolutionMode ConvolutionMode, datatype
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		if err := result(C.cudnnSetConvolution2dDescriptor(internal, C.int(padH), C.int(padW), C.int(u), C.int(v), C.int(dilationH),
C.int(dilationW), convolutionMode.C(), datatype.C())); err != nil {
			return nil, err
		}
	default:
		// snipped: converting padding, filterStride, dilation to a pointer
		if err := result(C.cudnnSetConvolutionNdDescriptor(internal, C.int(len(padding)), padA, strideA, dilationA,
convolutionMode.C(), datatype.C())); err != nil {
			return nil, err
		}
	}
	retVal := &Convolution{...}
	runtime.SetFinalizer(retVal, destroyConvolution)
	return retVal, nil
}
```

Performance Tip: Batching

```
cudnnStatus_t gocudnnNewConvolution(cudnnConvolutionDescriptor_t *retVal, cudnnMathType_t mathType, const int groupCount,
      const int size, const int* padding, const int* filterStrides, const int* dilation, cudnnConvolutionMode_t convolutionMode,
cudnnDataType_t dataType) {
      cudnnStatus_t status ;
      status = cudnnCreateConvolutionDescriptor(retVal);
      if (status != CUDNN_STATUS_SUCCESS) { return status;  }

      status = cudnnSetConvolutionMathType(*retVal, mathType);
      if (status != CUDNN_STATUS_SUCCESS) { return status;  }

      status = cudnnSetConvolutionGroupCount(*retVal, groupCount);
      if (status != CUDNN_STATUS_SUCCESS) { return status;  }

      switch (size) {
      case 0, 1 :
            return CUDNN_STATUS_BAD_PARAM;
      case 2:
            // snipped : unpacking the params
            status = cudnnSetConvolution2dDescriptor(*retVal, padH, padW, u, v, dilationH, dilationW, convolutionMode, dataType);
            break;
      default:
            status = cudnnSetConvolutionNdDescriptor(*retVal, paddingSize, padding, filterStrides, dilation, convolutionMode,
dataType);
            break;
      }
      return status;
}
```

Performance Tip: Batching

```
func NewConvolution(mathType MathType, groupCount int, padding, filterStride, dilation []int, convolutionMode ConvolutionMode, datatype
DataType) (*Convolution, error) {
	var internal C.cudnnConvolutionDescriptor_t
	if err := result(C.cudnnCreateConvolutionDescriptor(&internal)); err != nil { ... }
	if err := result(C.cudnnSetConvolutionMathType(internal, mathType.C())); err != nil { ... }
	if err := result(C.cudnnSetConvolutionGroupCount(internal, C.int(groupCount))); err != nil { ... }
	switch len(padding) {
	case 0, 1:
		return nil, errors.Errorf("Only 2+ dims are allowed")
	case 2:
		// snipped: destructuring of padH, padW, u, v, etc
		if err := result(C.cudnnSetConvolution2dDescriptor(internal, C.int(padH), C.int(padW), C.int(u), C.int(v), C.int(dilationH),
C.int(dilationW), convolutionMode.C(), datatype.C())); err != nil {
			return nil, err
		}
	default:
		// snipped: converting padding, filterStride, dilation to a pointer
		if err := result(C.cudnnSetConvolutionNdDescriptor(internal, C.int(len(padding)), padA, strideA, dilationA,
convolutionMode.C(), datatype.C())); err != nil {
			return nil, err
		}
	}
	retVal := &Convolution{...}
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}
```

Performance Tip: Batching

```
func NewConvolution(mathType MathType, groupCount int, padding, filterStride, dilation []int, convolutionMode ConvolutionMode, datatype
DataType) (*Convolution, error) {
	// elided: checks

	var internal C.cudnnConvolutionDescriptor_t
	padA := (*C.int)(unsafe.Pointer(&padding[0]))
	strideA := (*C.int)(unsafe.Pointer(&filterStride[0]))
	dilationA := (*C.int)(unsafe.Pointer(&dilation[0]))
	if err = result(C.gocudnnNewConvolution(&internal, mathType.C(), C.int(groupCount), C.int(len(padding)), padA, filterStrideA,
dilationA, convolutionMode.C(), datatype.C())); err != nil {
		return nil, err
	}

	retVal := &Convolution{...}
	runtime.SetFinalizer(retVal, destroyConvolution)
	return retVal, nil
}
```

Performance: Batching Tips

- `astyle` is your friend.
-
```
astyle --style=google  \
       --lineend=linux \
       --indent=tab    \
       --indent-switches     \
       --align-pointer=type  \
       --align-reference=name \
       --delete-empty-lines
```
- http://astyle.sourceforge.net/

Performance Tip: Cache Fields

Opaque types:

```
struct cudnnTensorStruct* cudnnTensorDescriptor_t
```

Go version:

```
type TensorDescriptor struct {
   internal C.cudnnTensorDescriptor_t

   format TensorFormat
   dataType DataType
   shape []int
   strides []int
}
```

Performance Tip: Cache Fields

Opaque types:

```
struct cudnnTensorStruct* cudnnTensorDescriptor_t
```

Go version:

```
type TensorDescriptor struct {
   internal C.cudnnTensorDescriptor_t

   format TensorFormat
   dataType DataType
   shape []int
   strides []int
}
```

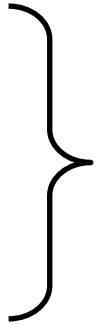
Where did these come from?

Performance Tip: Cache Fields

```
cudnnStatus_t cudnnSetTensor4dDescriptor(
                cudnnTensorDescriptor_t         tensorDesc,
                cudnnTensorFormat_t             format,
                cudnnDataType_t                 dataType,
                int                             n,
                int                             c,
                int                             h,
                int                             w);
```

Performance Tip: Cache Fields

```
cudnnStatus_t cudnnSetTensor4dDescriptor(
                    cudnnTensorDescriptor_t         tensorDesc,
                    cudnnTensorFormat_t             format,
                    cudnnDataType_t                 dataType,
                    int                             n,
                    int                             c,
                    int                             h,
                    int                             w);
```



Here

Performance Tip: Cache Fields

```
cudnnStatus_t cudnnSetTensor4dDescriptor(
                cudnnTensorDescriptor_t            tensorDesc,
                cudnnTensorFormat_t                format,
                cudnnDataType_t                    dataType,
                int                                n,
                int                                c,
                int                                h,
                int                                w);

cudnnStatus_t cudnnGetTensor4dDescriptor(
                const cudnnTensorDescriptor_t      tensorDesc,
                cudnnDataType_t                   *dataType,
                int                               *n,
                int                               *c,
                int                               *h,
                int                               *w,
                int                               *nStride,
                int                               *cStride,
                int                               *hStride,
                int                               *wStride );
```

Performance Tip: Cache Fields

```
cudnnStatus_t cudnnSetTensor4dDescriptor(
                    cudnnTensorDescriptor_t             tensorDesc,
                    cudnnTensorFormat_t                 format,
                    cudnnDataType_t                     dataType,
                    int                                 n,
                    int                                 c,
                    int                                 h,
                    int                                 w);

cudnnStatus_t ~~cudnnGetTensor4dDescriptor~~(
                    const cudnnTensorDescriptor_t       tensorDesc,
                    cudnnDataType_t                    *dataType,
                    int                                *n,
                    int                                *c,
                    int                                *h,
                    int                                *w,
                    int                                *nStride,
                    int                                *cStride,
                    int                                *hStride,
                    int                                *wStride );
```

Guiding Principle

- Make your data structures useful.

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- Start from the use cases.

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- Start from the use cases.
- Eliminate binding calls where unnecessary.

Guiding Principle

- Make your data structures useful.
- Start from the use cases.
- Eliminate binding calls where unnecessary.
- Minimize errors – check them in Go before passing off to cgo.

Various Considerations

- Performance
- Contexts and multi-level API
- Error detection
- Reporting

Contextual Use

Most ~~graphics~~ heterogenous memory related libraries require a thread-lock.

Contextual Use: Generate Multi-Level API

- One that handles the common use case.
- One low level API, leaving it to the user to manage themselves.

CUDA Contexts

```
// CUContext is a CUDA context
type CUContext uintptr
```

CUDA Contexts

```
// CUContext is a CUDA context
type CUContext uintptr

// Ctx is a standalone CUDA Context that is threadlocked.
type Ctx struct{
    CUContext
    // contains filtered or unexported fields
}
```

CUDA Contexts

```
// CUContext is a CUDA context
type CUContext uintptr

// Ctx is a standalone CUDA Context that is threadlocked.
type Ctx struct{
    CUContext
    // contains filtered or unexported fields
}

// BatchedContext is a CUDA context where the CUDA calls are batched up.
type BatchedContext struct {
    Context
    Device
    // contains filtered or unexported fields
}
```

CUDA Context: Synchronize()

```
func Synchronize() (err error) {
   return result(C.cuCtxSynchronize())
}
```

Use in a main-threadlocked function

```
   ...
   handleErr(ctx.Lock())
   handleErr(cu.SetCurrentContext(ctx))
   handleErr(cu.Synchronize())
   handleErr(ctx.Unlock())
```

CUDA Context: Synchronize()

```
// Ctx is a standalone CUDA Context that is threadlocked.
type Ctx struct {
    work    chan (func() error)
    ...
}

func (ctx *Ctx) Do(fn func() error) error {
    ctx.work <- fn
    return <-ctx.errChan
}

func (ctx *Ctx) Synchronize() {
    f := func() error {
        return result(C.cuCtxSynchronize())
    }
    ctx.err = ctx.Do(f)
}
```

Various Considerations

- Performance
- Contexts and multi-level API
- Error detection
- Reporting

Error Detection

- Leverage existing Go source code analysis tools:
  - goimports
  - govet
  - go/token, go/parser, go/ast

Error Detection

- Potential Nil-checks
  - Alias analysis is undecidable[0].
  - Doesn't mean you can't try.
  - Easy to check when functions are small.

[0] G. Ramalingam (1994): The Undecidability of Aliasing.

Various Considerations

- Performance
- Contexts and multi-level API
- Documentation
- Error detection
- Reporting

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- In multistage generation programs – always report back what is not done yet.

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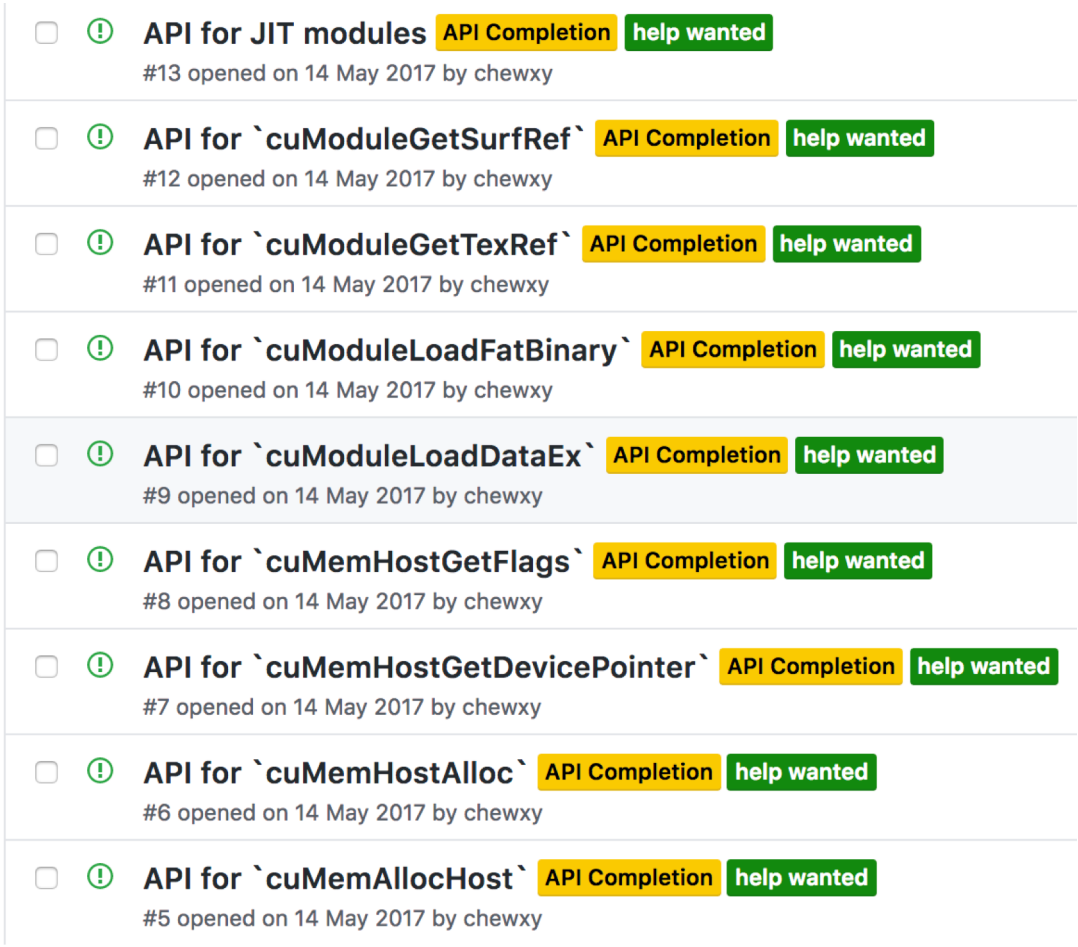

FINALLY...

The source for the demo is online:

https://github.com/chewxy/gopherconsg2018

In This Talk...

- Introduced the *whys* of writing an API library for Go bindings.
- Showed *how* to think about writing an API library.
- Using `gorgonia.org/cu/dnn` and `gorgonia.org/cu` as a concrete examples.

The Ask

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  - `gorgonia.org/gorgonia`
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- Help improve the generation programs:
  - `gorgonia.org/cu/cmd/genlib`
  - `gorgonia.org/cu/cmd/gencudnn`
  - `gorgonia.org/cu/cmd/gencublas`

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THANK YOU GOPHERCON SG!