FACULTY OF ENGINEERING
AND ARCHITECTURE

DEPARTMENT ELECTRONICS AND INFORMATION SYSTEMS
COMPUTER SYSTEMS LAB

PROGRAMMING NVIDIA GPUS WITH CUDANATIVE.JL

Tim Besard – 2017-06-21

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DISCLAIMER

GPU PROGRAMMING:

WHAT, WHY AND HOW?

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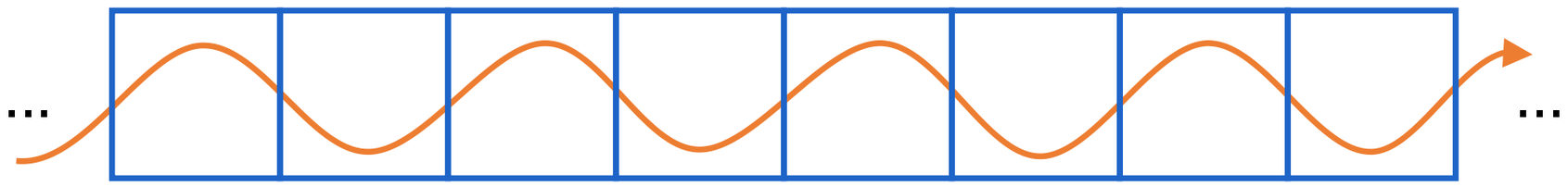
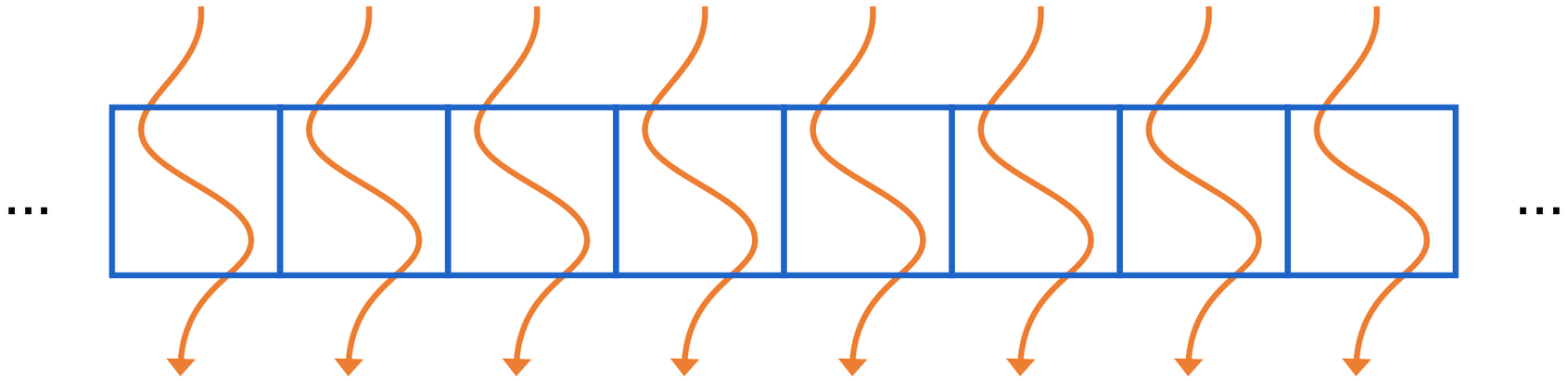
MASSIVE PARALLELISM





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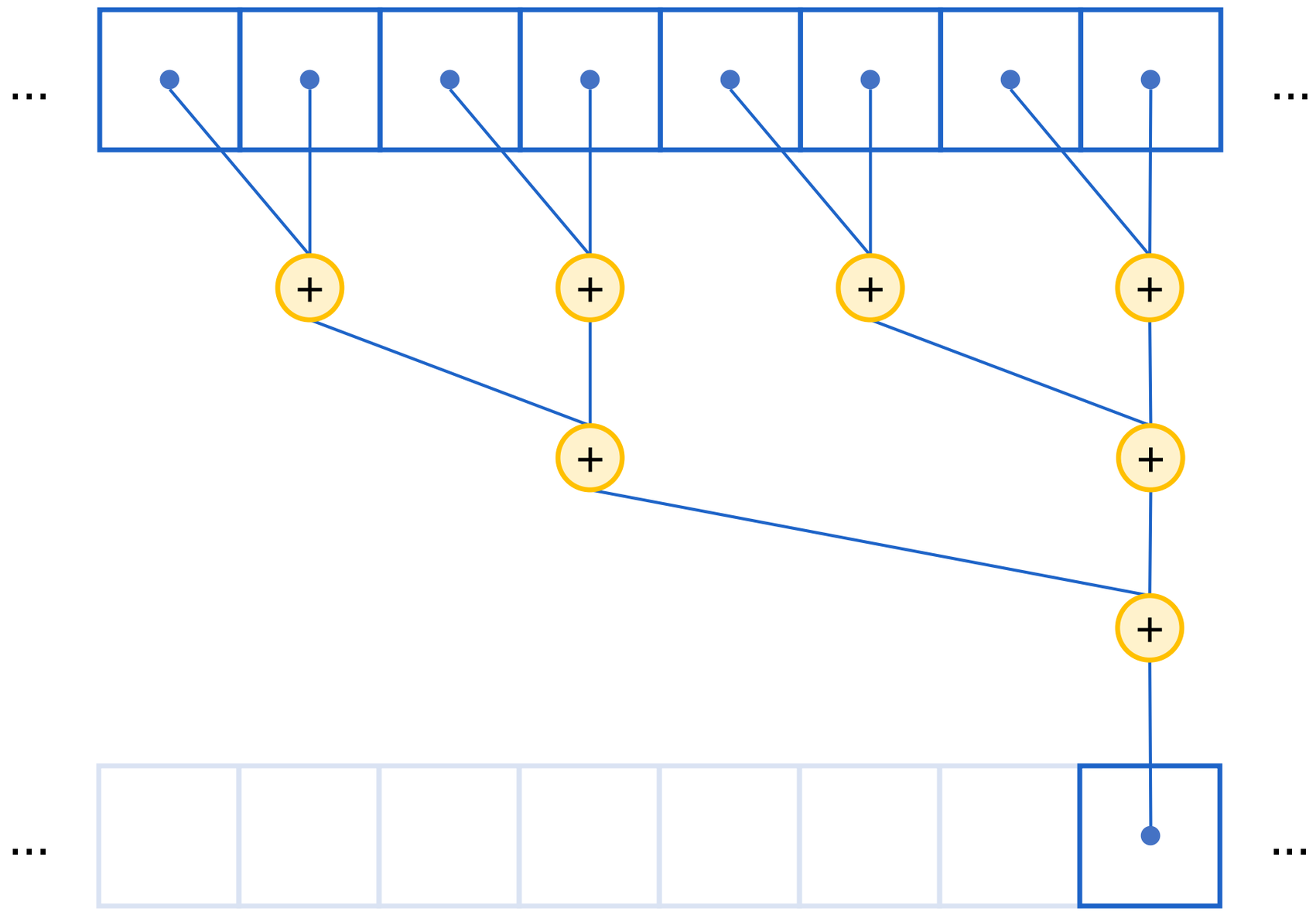
PARALLEL SUM



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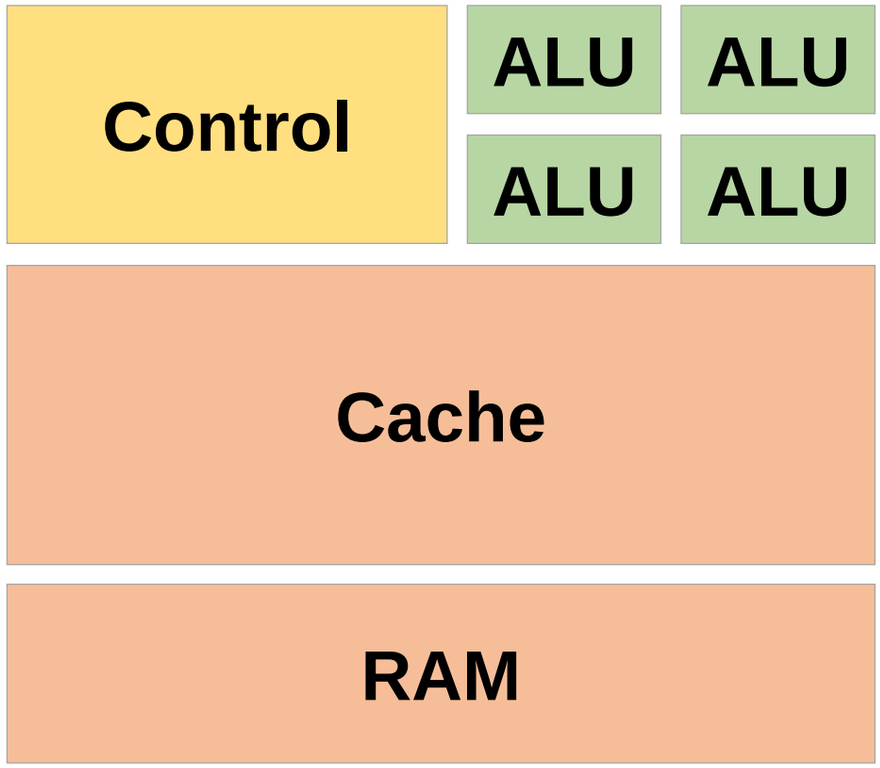
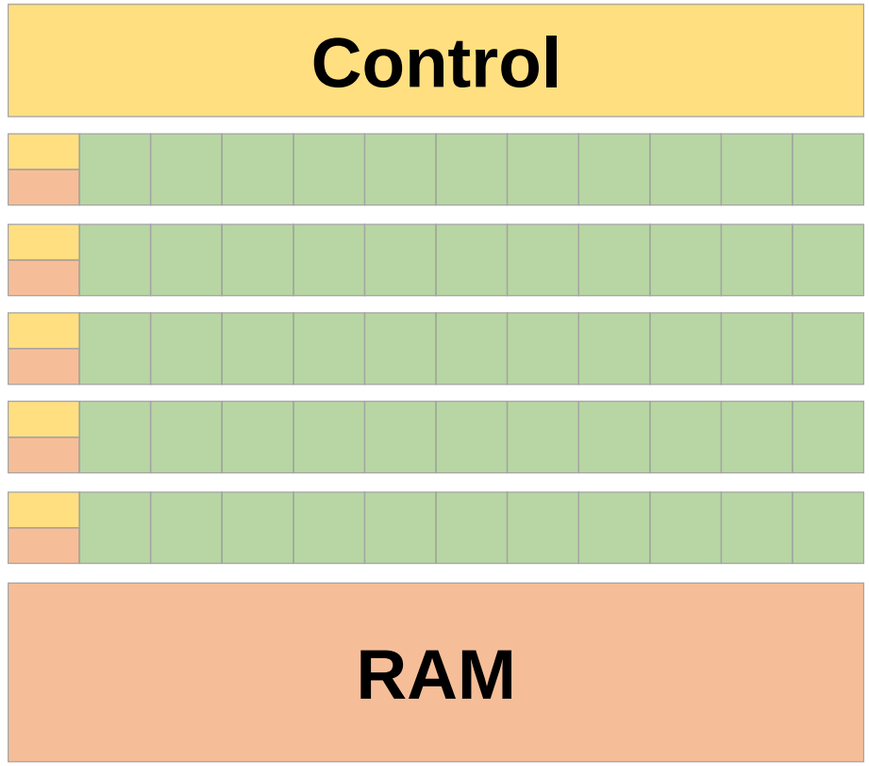
ARCHITECTURE



CPU



GPU

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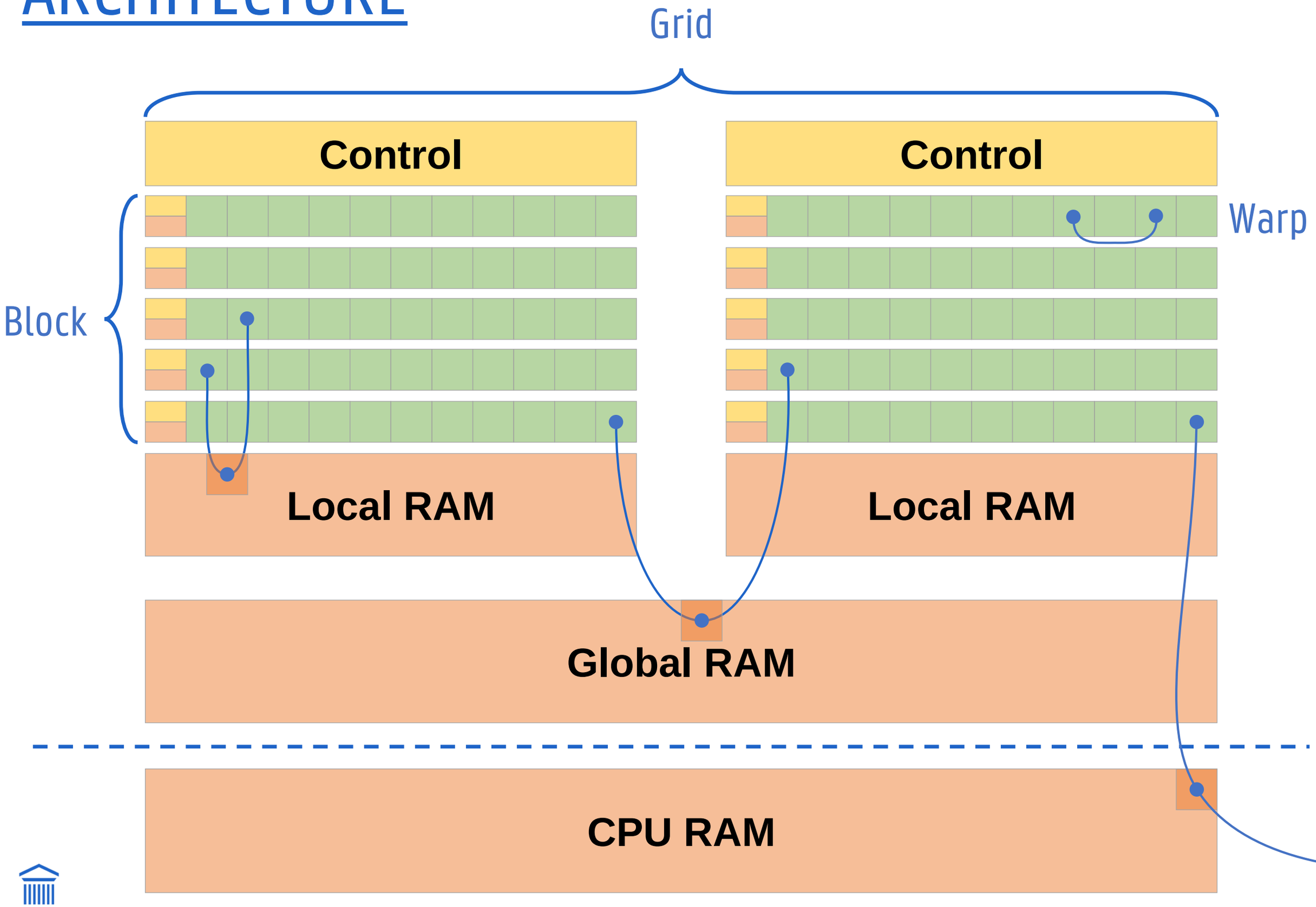
ARCHITECTURE



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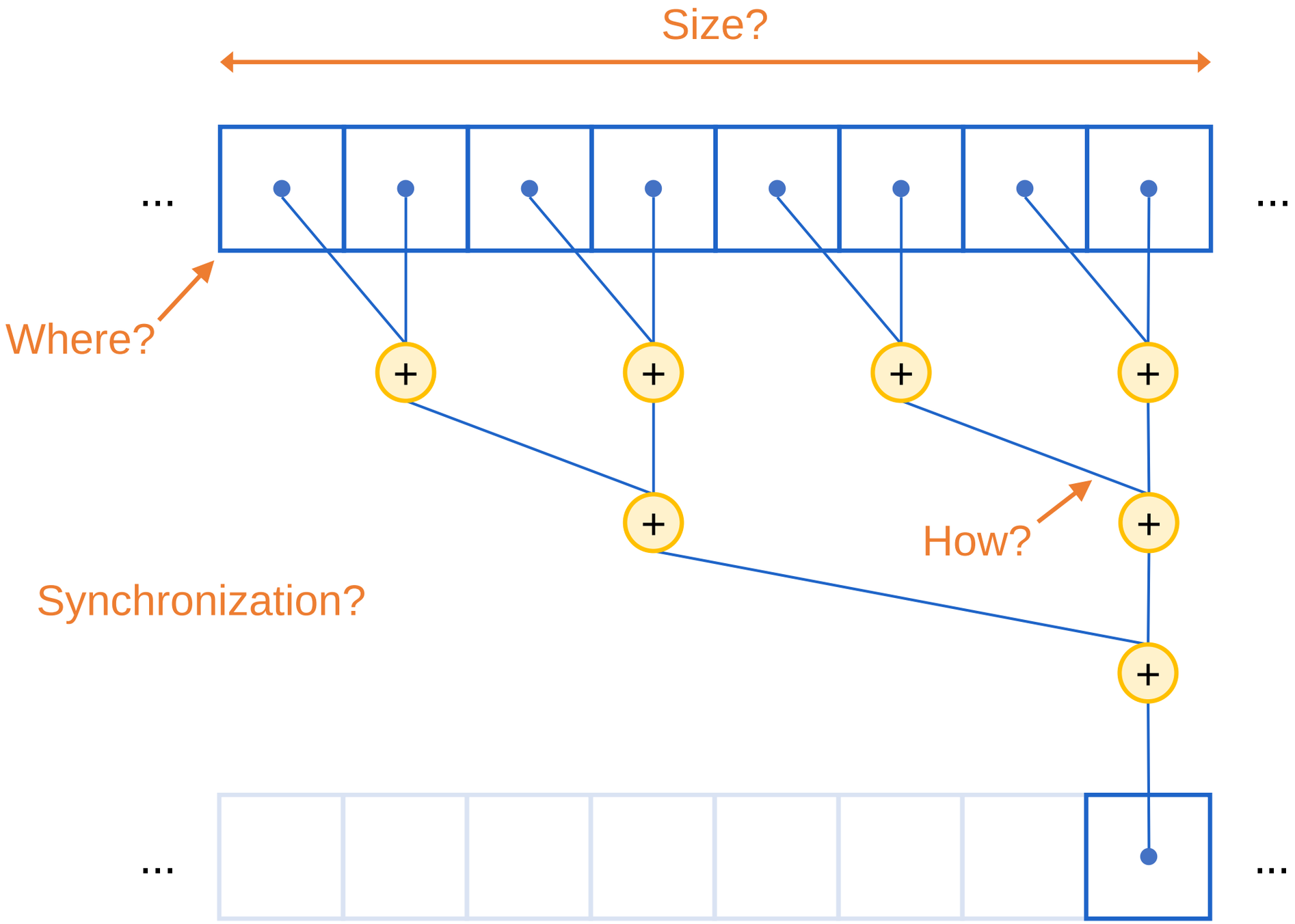
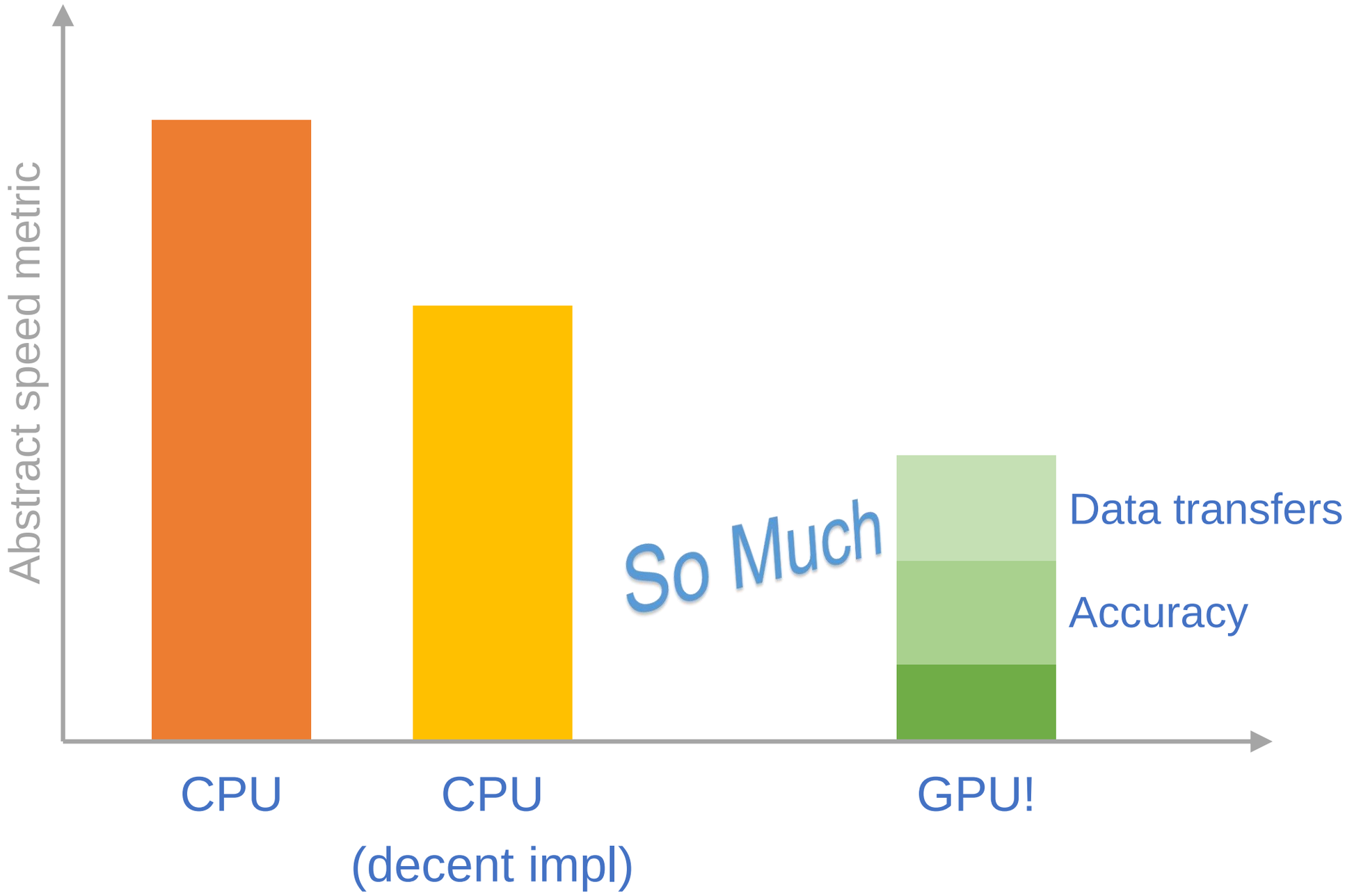
PARALLEL SUM



WHY?



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HOW?

Transparant	Host libraries	Device code
TensorFlow, MXNet	cuBLAS, cuFFT, ... Thrust, CUB ArrayFire	CUDA rt + CUDA C CUDA rt + CUB

HOW?

Implemented using

Transparant	Host libraries	Device code
TensorFlow, MXNet	cuBLAS, cuFFT, ... Thrust, CUB ArrayFire	CUDA rt + CUDA C CUDA rt + CUB

Host libraries	Device code
cuBLAS.jl, cuFFT.jl, ... ArrayFire.jl	CUDArt.jl + CUDA C

CUDANATIVE.JL

Goal: replace CUDA C with Julia

- ✓ intrinsics
- ✓ code generation
- ✓ language integration

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CUDANATIVE.JL

Goal: replace CUDA C

Non-goal: make CUDA fun & easy

- ✗ automatic data management
- ✗ high-level parallelism
- ✗ portability

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CUDANATIVE.JL IN ACTION

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QUICK START

```
Pkg.add("CUDAnative")
```

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QUICK START: VADD

```
using CUDAdrv, CUDAnative

dev = CuDevice(0)
ctx = CuContext(dev)

len = 42
a = rand(Float32, len)
b = rand(Float32, len)

d_a = CuArray(a)
d_b = CuArray(b)
d_c = similar(d_a)
```

```
function vadd(a, b, c)
    i = threadIdx().x
    c[i] = a[i] + b[i]
    return
end

@cuda (1,len) vadd(d_a, d_b, d_c)

c = Array(d_c)
@test a+b ≈ c

destroy!(ctx)
```

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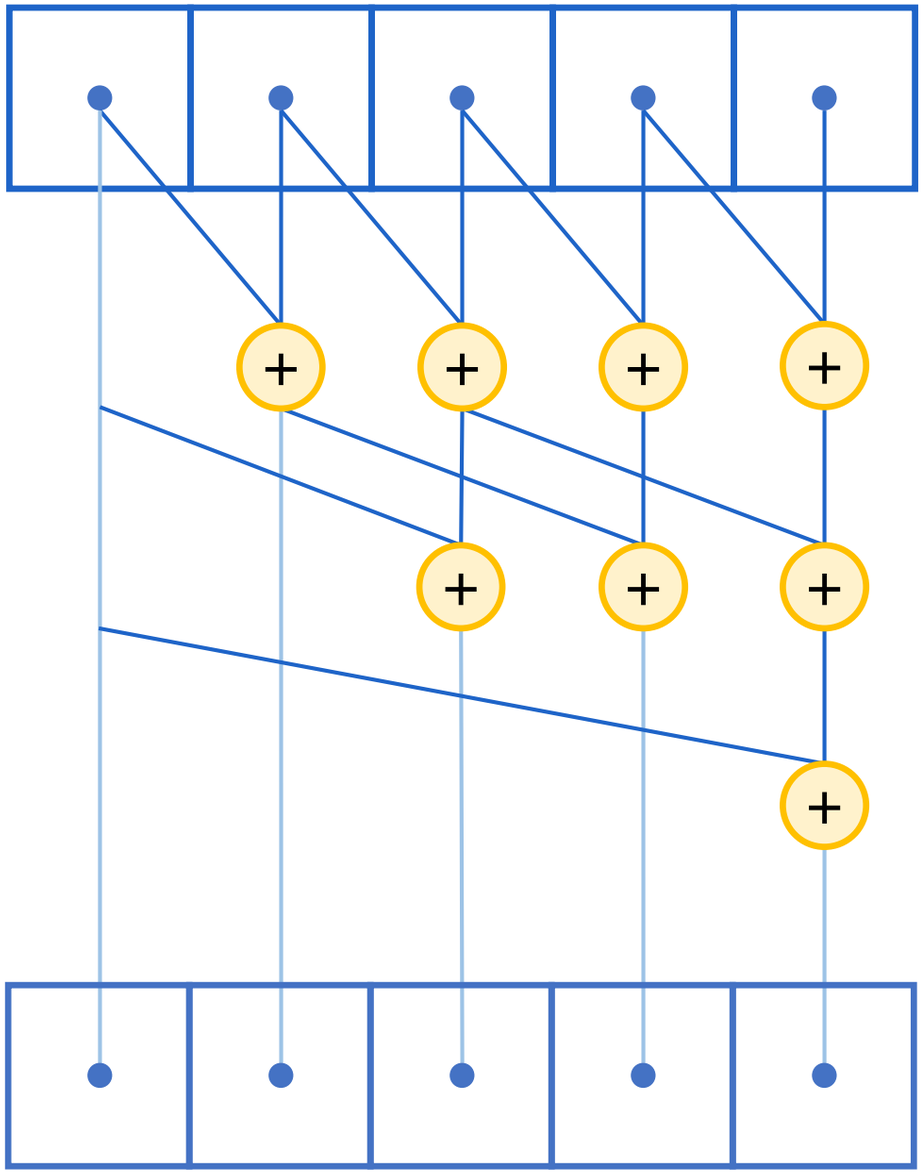
PREFIX SUM



```
function sum!(data)
    i = threadIdx().x

    offset = 1
    while offset < i
        a = data[i]
        b = data[i - offset]
        sync_threads()

        data[i] = a + b
        sync_threads()

        offset *= 2
    end
    return
end

@cuda (1,length(gpu_data))
      reduce!(gpu_data)
```

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PREFIX SUM

```
shmem = @cuStaticSharedMem(Float32, rows)
shmem[row] = data[row]

offset = 1
while offset < row
    sync_threads()
    a = shmem[row]
    b = shmem[row - offset]

    sync_threads()
    shmem[row] = a+b

    offset *= 2
end

sync_threads()
data[row] = shmem[row]
```

```
function sum!(data)
    i = threadIdx().x

    offset = 1
    while offset < i
        a = data[i]
        b = data[i - offset]
        sync_threads()

        data[i] = a + b
        sync_threads()

        offset *= 2
    end
    return
end
```

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PREFIX SUM

```
shmem = @cuStaticSharedMem(Float32, rows)
shmem[row] = data[row]

offset = 1
while offset < row
    sync_threads()
    a = shmem[row]
    b = shmem[row - offset]

    sync_threads()
    shmem[row] = a+b

    offset *= 2
end

sync_threads()
data[row] = shmem[row]
```

- Large arrays
- Intra-warp communication
- Optimize memory accesses

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CUDA C SUPPORT

- ✓ Indexing
- ✓ Synchronization
- ✓ Shared memory types
- ✓ Warp voting & shuffle
- ✓ Formatted output
- ✓ `libdevice`

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CUDA C SUPPORT

- Atomics
- Dynamic parallelism
- Advanced memory types

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JULIA SUPPORT

- `libjulia`
- Dynamic allocations
- Exceptions
- Recursion

Keep kernels simple!

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BEHIND THE SCENES

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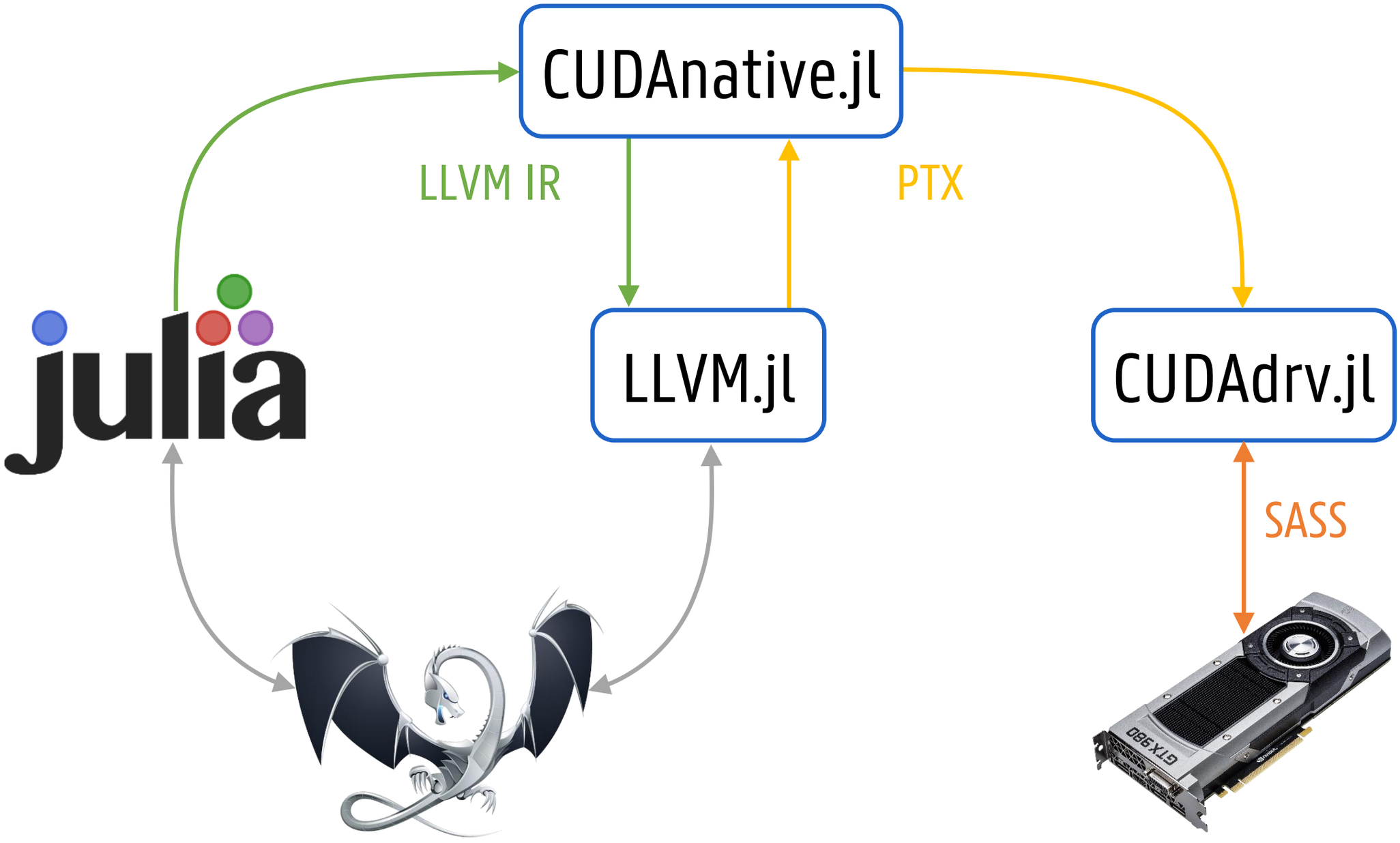
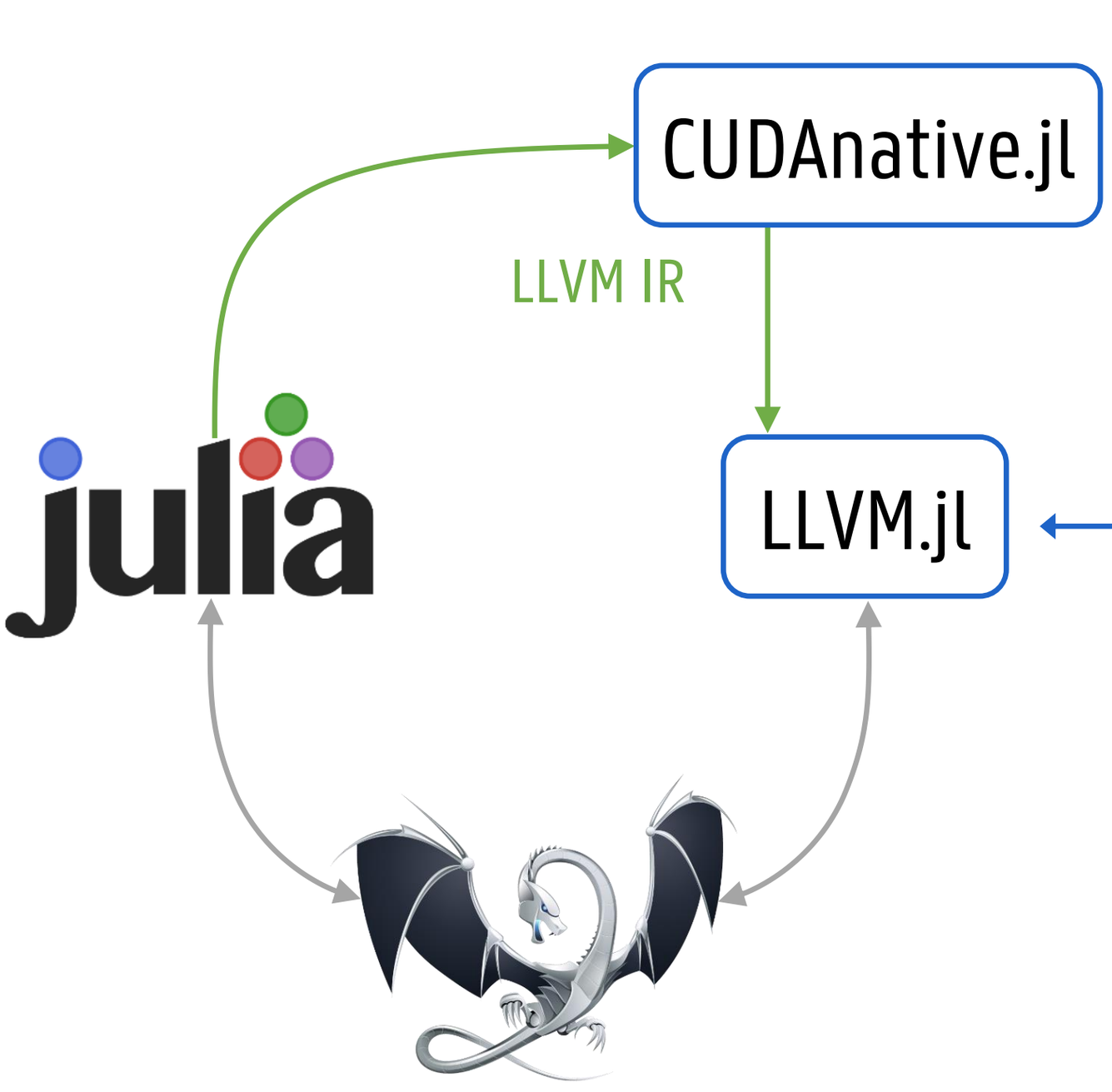
THE BIG PICTURE



CODE GENERATION




```
InferenceParams
InferenceHooks
CodegenParams
CodegenHooks
```

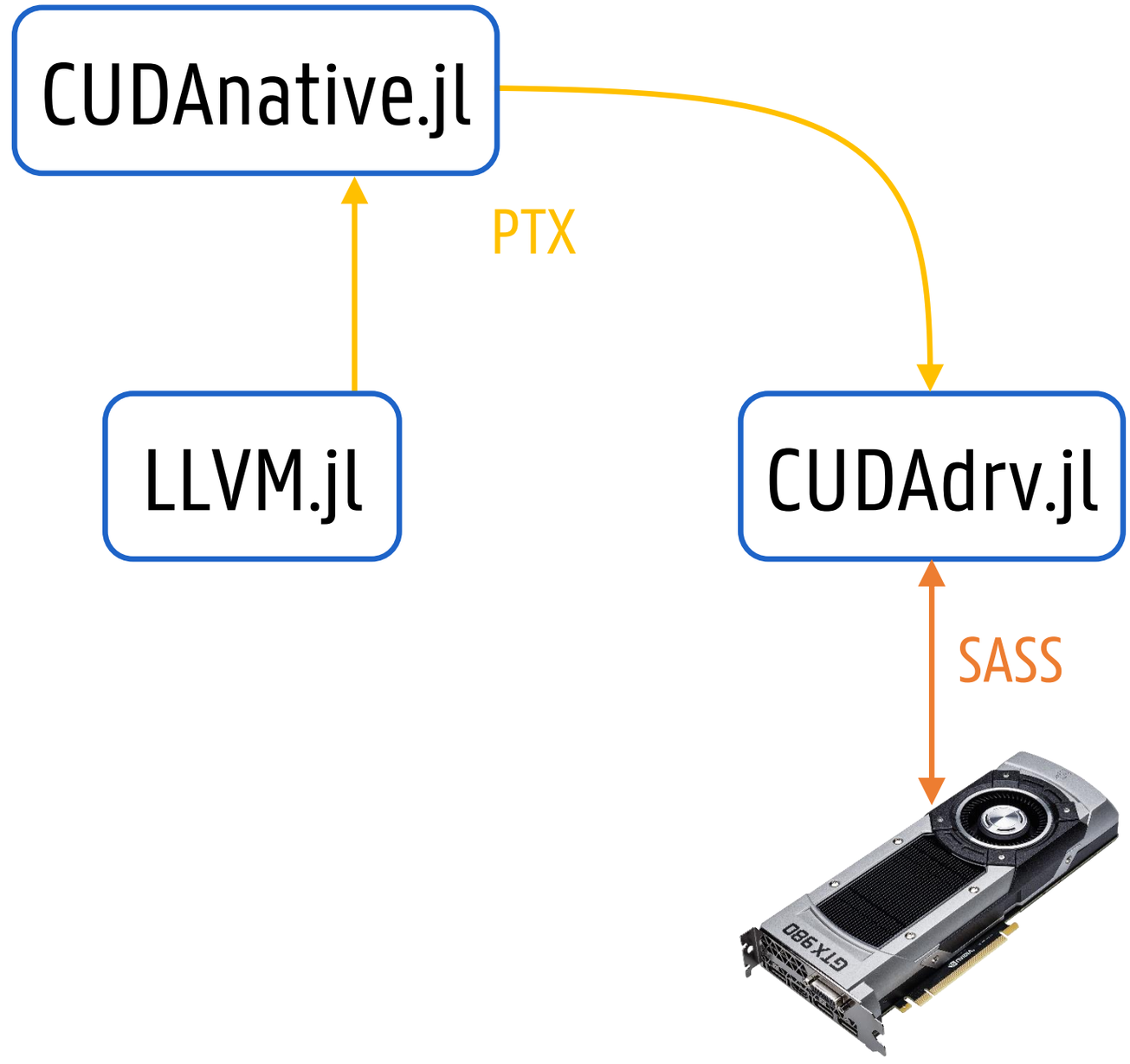
```
emit_exception
```

- link
- optimize
- finalize module

CODE GENERATION

~~NVIDIA: NVVM~~

LLVM: NVPTX



CUDA driver JIT

CODE REFLECTION

```
julia> function add_one(data)
           i = threadIdx().x
           data[i] += one(eltype(data))
           return
       end
```

CODE REFLECTION

```
julia> function add_one(data)

julia> CUDAnative.code_llvm(add_one,
                            Tuple{CuDeviceVector{Int32}})

define void @julia_add_one (%CuDeviceArray*) {
    %1 = tail call i32
        @llvm.nvvm.read.ptx.sreg.ctaid.x()
    ...
    store i32 %9, i32* %7, align 8
    ret void
}
```

CODE REFLECTION

```
julia> function add_one(data)

julia> CUDAnative.code_llvm(add_one,
                            Tuple{CuDeviceVector{Int32}})

julia> a = CuArray{Int32}(N)
julia> CUDAnative.@code_llvm add_one(a)
julia> CUDAnative.@code_llvm @cuda (1,N) add_one(a)
```

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CODE REFLECTION

```
julia> function add_one(data)

julia> @code_ptx add_one(a)

.func add_one(.param .b64 param0) {
    mov.u32 %r2, %ctaid.x;
    ...
    st.u32  [%rd10+-4], %r8;
    ret;
}
```

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CODE REFLECTION

```
julia> function add_one(data)

julia> @code_sass add_one(a)

Function : add_one
    S2R R0, SR_CTAID.X;
    ...
    ST.E [R4], R0;
    EXIT;
```

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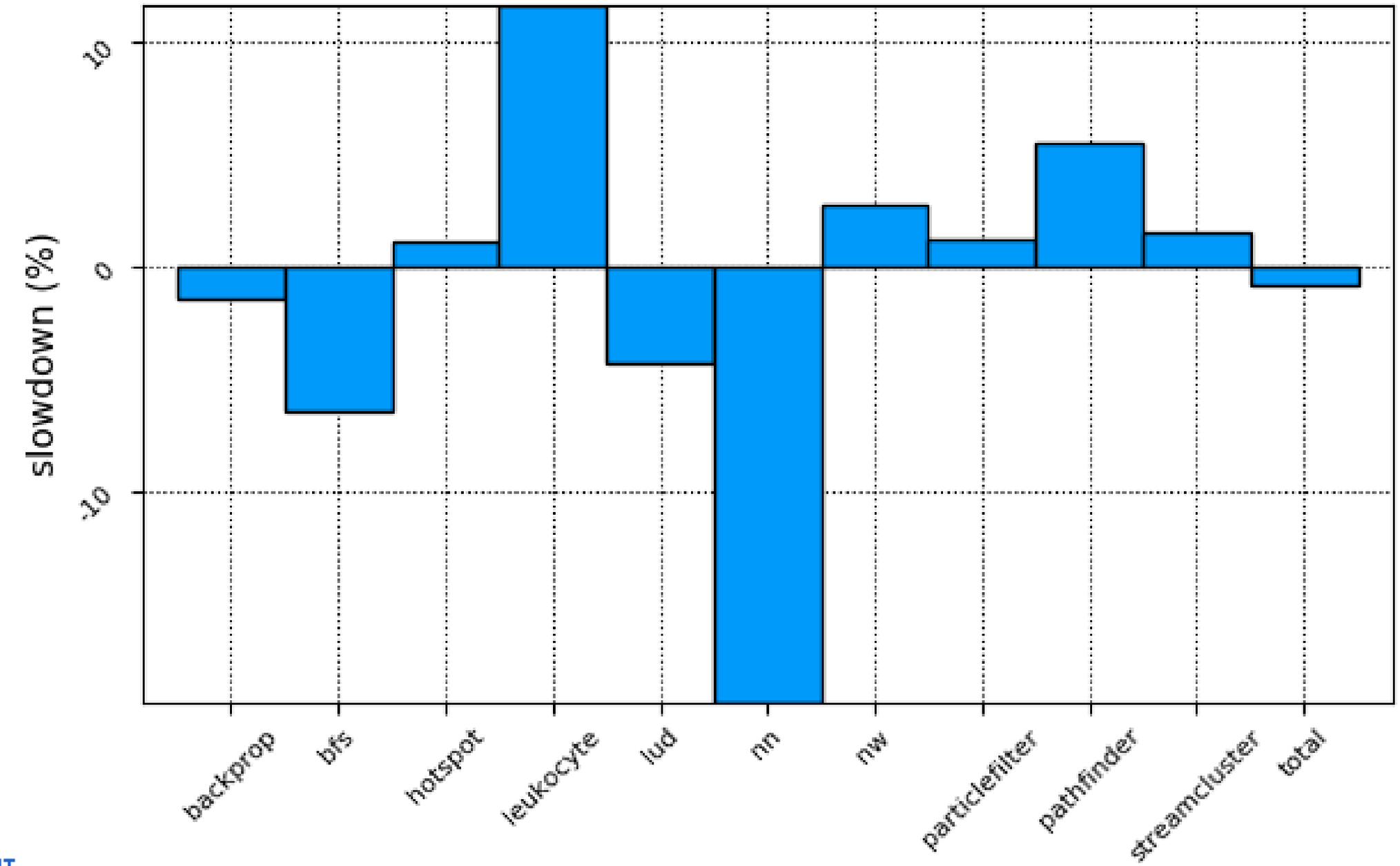
PERFORMANCE

KERNEL PERFORMANCE

Now 0.77% faster!

https://github.com/JuliaParallel/rodinia



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LAUNCH PERFORMANCE

CUDA CPU: 12.8 µs GPU: 6.8 µs

```
void kernel_dummy(float *ptr)
{
    ptr[0] = 0;
}
```

```
gettimeofday

cuEventRecord
cuLaunchKernel
cuEventRecord

cuEventSynchronize

gettimeofday
```

CUDAdrv.jl CPU: 12.4 µs GPU: 6.9 µs

```
cuModuleLoad

cuModuleGetFunction
```

```
Base.@elapsed begin
    CUDAdrv.@elapsed begin
        cudacall
    end
end
```

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LAUNCH PERFORMANCE

CUDA

CPU: 12.8 µs
GPU: 6.8 µs

```
void kernel_dummy(float *ptr)
{
    ptr[0] = 0;
}
```

```
gettimeofday

cuEventRecord
cuLaunchKernel
cuEventRecord

cuEventSynchronize

gettimeofday
```

CUDAnative.jl

CPU: 12.6 µs
GPU: 7.0 µs

```
function kernel(ptr)
    unsafe_store(ptr, 0f0, 0)
    return
end
```

```
Base.@elapsed begin
    CUDAdrv.@elapsed begin
        @cuda
    end
end
```

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FUTURE WORK

- ❑ Usability
- ❑ Julia support
- ❑ CUDA support
- ❑ Better compiler integration

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PROGRAMMING NVIDIA GPUS WITH CUDANATIVE.JL

https://github.com/JuliaGPU/CUDAnative.jl

https://github.com/JuliaGPU/CUDAdrv.jl

https://github.com/maleadt/LLVM.jl

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