AMD
Smarter Choice

Introduction to Compute Abstraction Layer (CAL)

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Module Overview

- CAL Overview
- CAL Runtime API
- CAL Compiler API
- CAL Kernel Execution

Learning Objectives

- Understand CAL architecture from a high-level

- Understand the flow of a typical CAL application

- Review and understand various components involved in a CAL application and their characteristics

- Used a simple example to see how to write a simple CAL application

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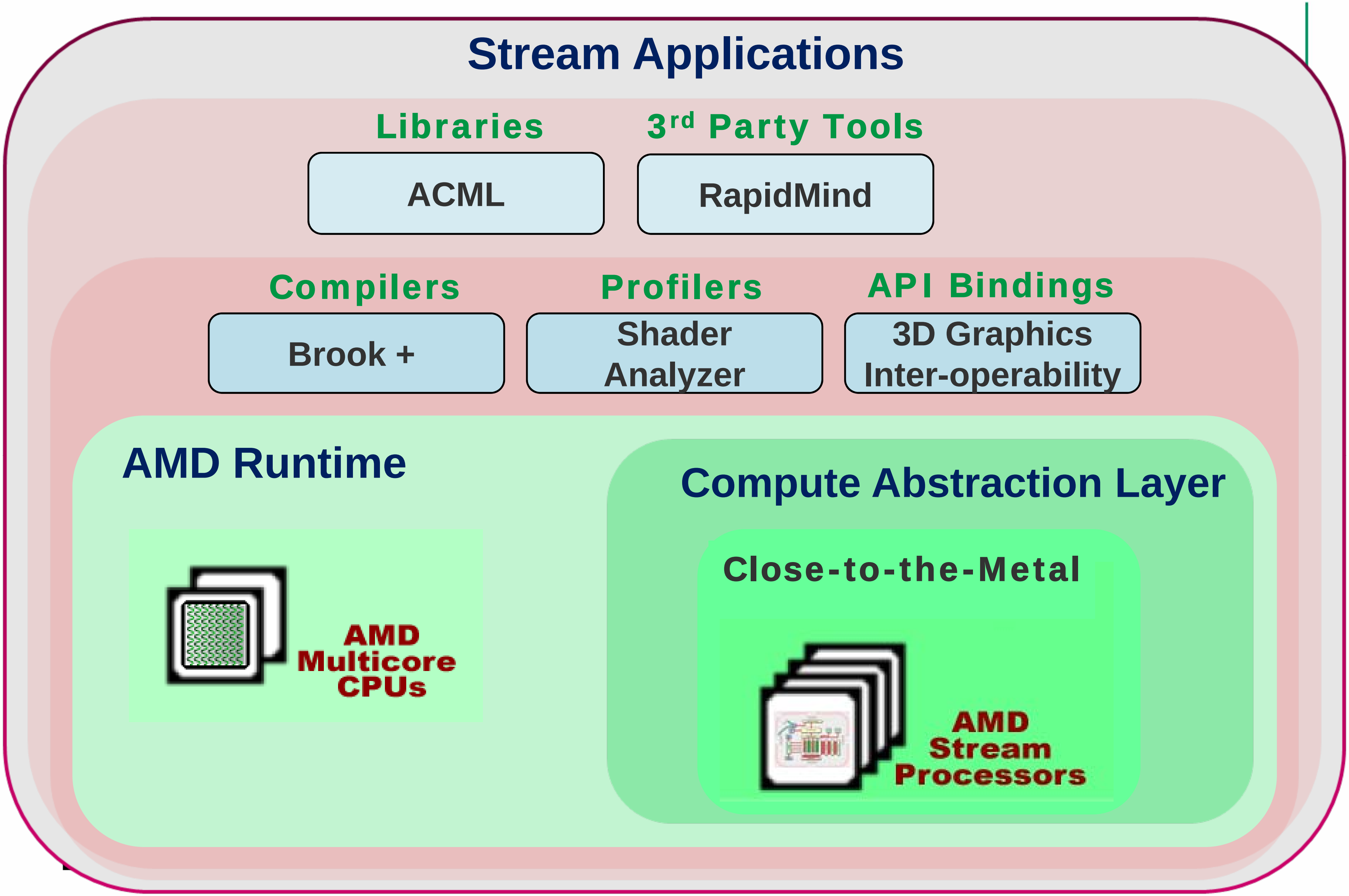
CAL Overview

FireStream SDK



Stream Applications

Libraries

ACML

3rd Party Tools

RapidMind

Compilers

Brook +

Profilers

Shader Analyzer

API Bindings

3D Graphics Inter-operability

AMD Runtime

AMD Multicore CPUs

Compute Abstraction Layer

Close-to-the-Metal

AMD Stream Processors

CAL Overview

- Device driver library for AMD Stream Processors
- Programming Model (similar to Brook+, just lower-level)
  - Decouples program compilation from execution completely
    - Programs can be compiled off-line and binaries can later be loaded on the GPU
  - Binary is GPU architecture dependent
- Consists of two main components
  - `amdcalcl` – Compiler to generate machine binary
  - `amdcalrt` – Runtime infrastructure for executing GPU programs

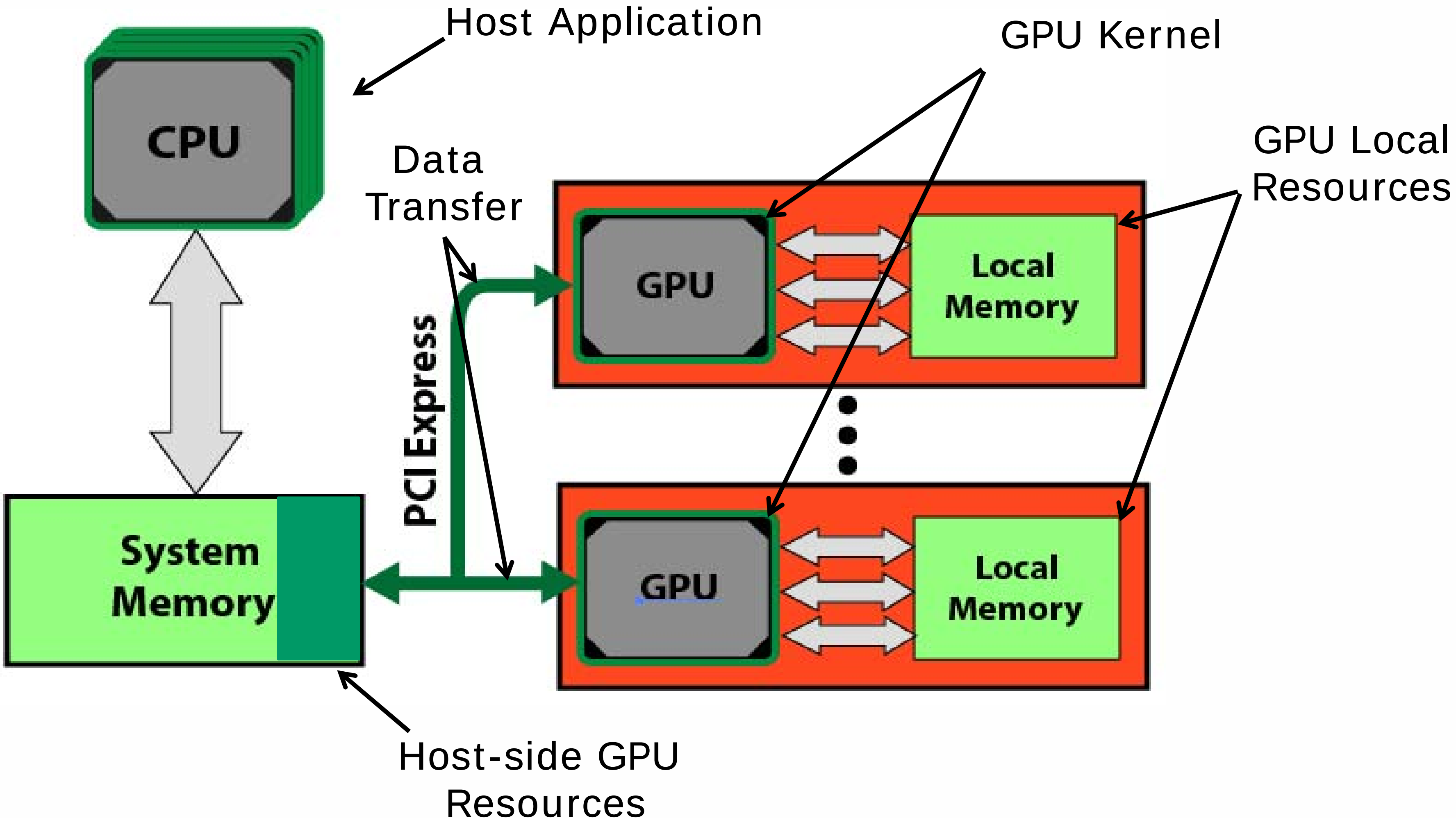
CAL Overview

- Provides interface for
  - Compiling GPU kernels
  - Running kernels on the GPU
  - Transferring data between the host and the GPU
  - Managing GPU Local resources
  - Managing Host-side GPU resources

`amdcalcl` Compiler Library

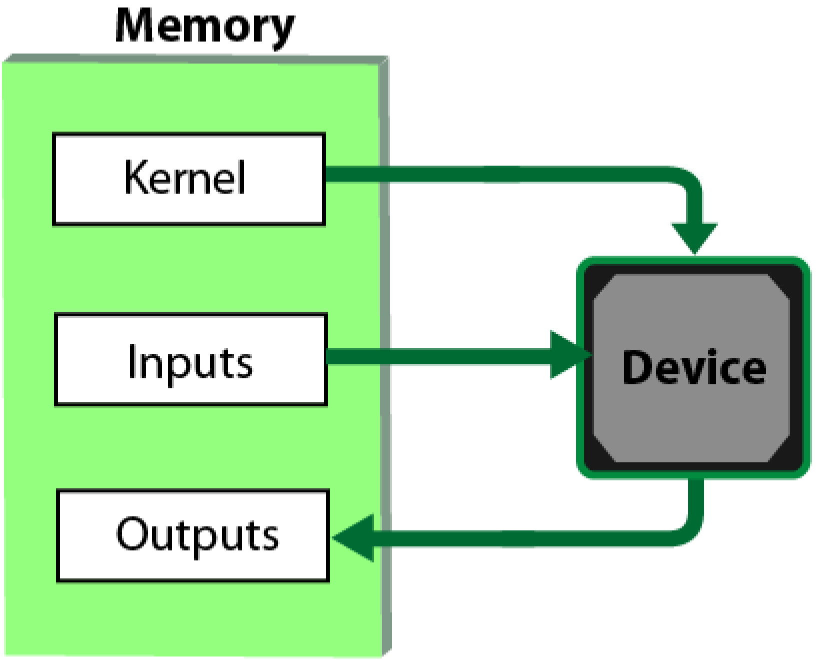
`amdcalrt` Runtime Library

CAL System Architecture



CAL Application Architecture

- Consists of two distinct components
  - Host Application
    - Performs application work
    - Sends commands to the GPU using CAL API
    - Manages GPU and Host-side resources
  - GPU Kernel
    - Reads input data
    - Performs parallel computation
    - Writes output data



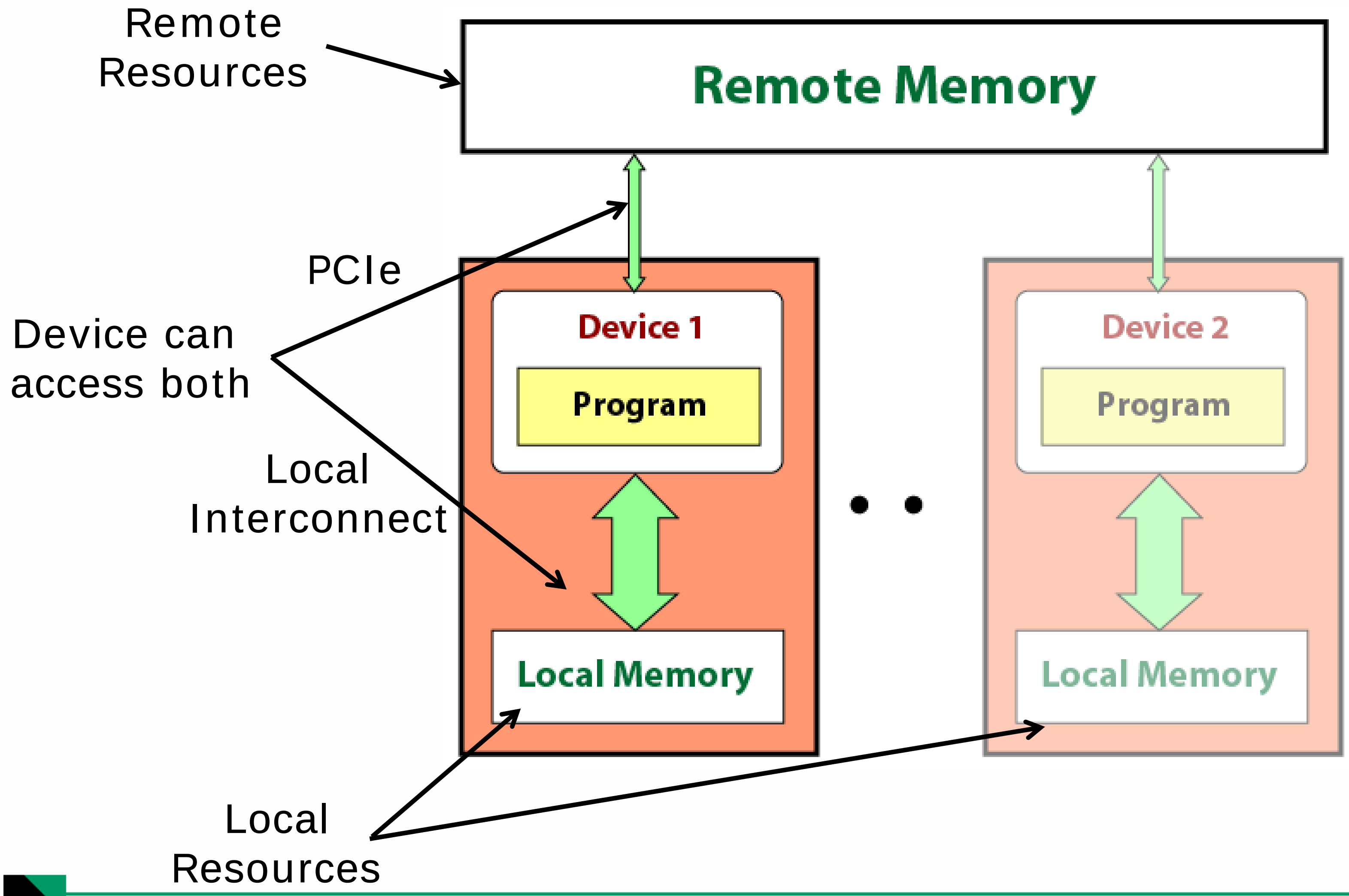
CALDevice

- Abstraction for a Stream Processor
- Initialized *explicitly* by application
- Attributes can be queried via API
- Executes a GPU Kernel
- Reads inputs and writes to outputs
- Accesses both GPU-local as well as Host-side GPU resources

CALResource

- Abstraction for memory buffer accessible by GPU
  - Local resource – resident on GPU Local memory
  - Remote resource – resident in Host-side GPU memory (PCIe memory)
- Allocated *explicitly* by application
- Can be specific to a device or shared between multiple devices
- Can be 1D or 2D
- Can be used as inputs, outputs or constants
- Total available and maximum size are fixed and can be queried
- Attributes include dimensions, data format and data type

CALResource



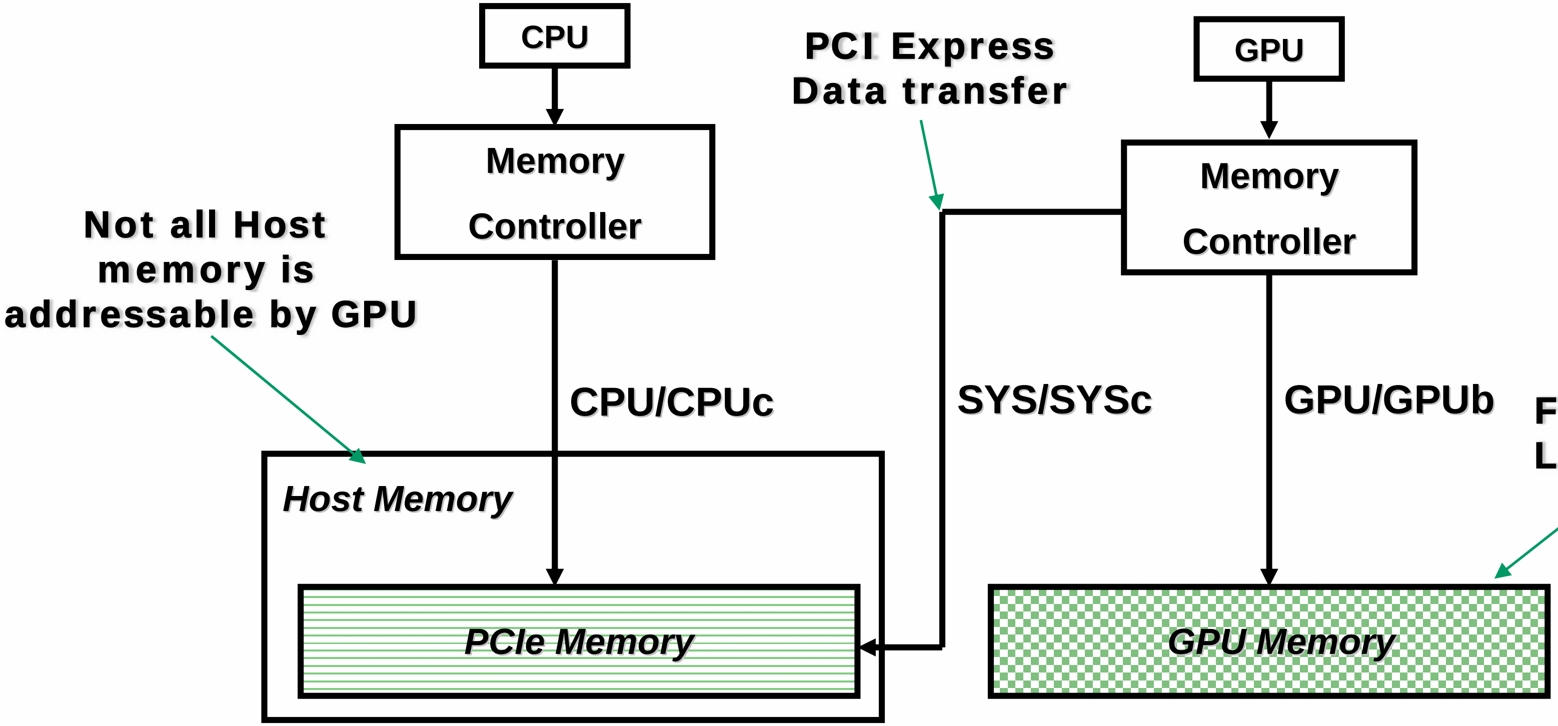
Remote Resources

- GPU can address and access system memory directly
  - Not all of system memory is accessible from GPU
- Driver allocates dedicated system memory for GPU buffers
  - Can be accessed directly from *GPU kernel* for reading and writing
  - Available in GPU's address space
  - Application can request allocation from this *pool*
  - Remote resources can be mapped to application's address space but the reverse is not possible

⇒ If your data is in application's address space, it needs to be copied to GPU accessible memory first

⇒ It is more efficient to allocate from remote resource directly to avoid the extra copies to and from application address space

Local vs Remote Resources



CALImage

- Abstraction for GPU binary
- Created by compiling and linking multiple GPU-specific CAL objects
- Loaded on GPU using CAL API
- Can be stored for subsequent loading

Recap

- *CALDevice* – Abstraction for a GPU
- *CALResource* – Abstraction for GPU memory
  - *Inputs* – Read-only resources accessed by kernel
  - *Outputs* – Write-only resources written by kernel
  - *Constants* – Read-only constant values used by kernel
- *CALImage* – Binary image for the GPU kernel
- Others…

CAL vs Brook+

Brook+	CAL
CALDevice	No API construct – Hidden in Runtime Backend
CALResource – Local – Remote	Stream
CALImage	Kernel

CAL Advantages

- Low-level control over GPU resources and operations
  - Potentially higher performance
    - Hand-tuned kernels
    - Low-level data management
  - Access to features not exposed by higher-level Brook+
  - Explicit platform specific optimizations

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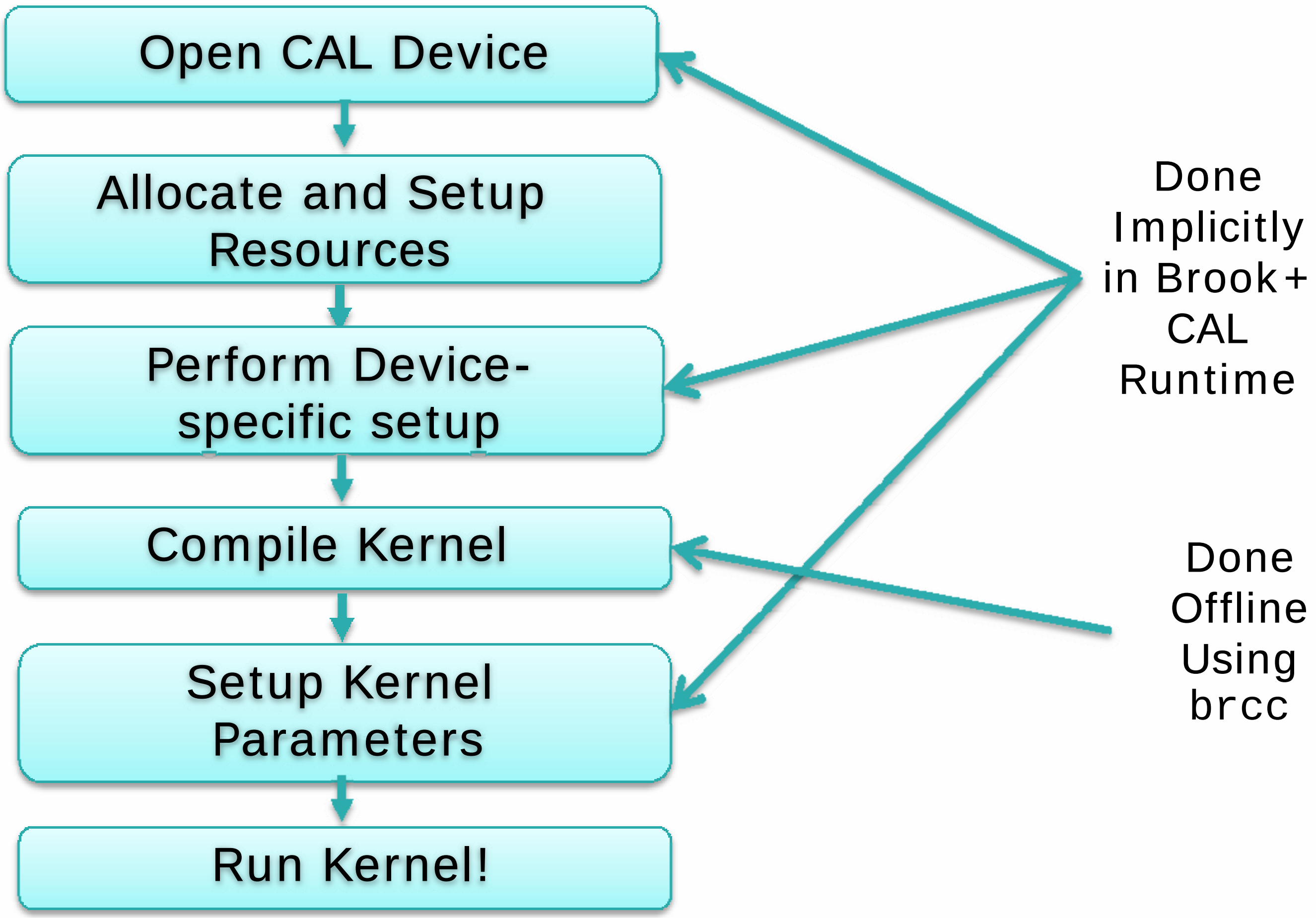
CAL Runtime API

CAL Runtime API - Conventions

- ‘C’ Library
- Routines
  - Runtime prefixed `cal`, e.g. `calInit`
  - Return an error code of type `CALresult`
- Types prefixed `CAL`, e.g. `CALfloat`
- Enums prefixed `CAL_`, e.g. `CAL_FORMAT_FLOAT_1`
- Opaque handles to internal data structures prefixed `CAL`, e.g. `CALdevice`

CAL Application – High-Level Flow



Open CAL Device

Allocate and Setup Resources

Perform Device-specific setup

Compile Kernel

Setup Kernel Parameters

Run Kernel!

Done Implicitly in Brook+ CAL Runtime

Done Offline Using brcc

CAL System Initialization

`calInit`

```
CALresult calInit(CALvoid);
```

- Initializes the CAL system, detect GPUs, etc
- Needs to be the first _CAL routine_ in an application
- Returns CAL_RESULT_ERROR otherwise
- Needs to be called only once

`calShutdown`

```
CALresult calShutdown(CALvoid);
```

- Last CAL routine in an application

CAL System Query

`calGetVersion`

```
CALresult calGetVersion(CALuint* major, CALuint* minor,
   CALuint* imp);
```

- Query the version of the CAL runtime

`calDeviceGetCount`

```
CALresult calDeviceGetCount(CALuint* count);
```

- Query the number of GPUs on the system
- Each GPU is identified by a unique integer ID `[0..N-1]`
- See/Run `FindNumDevices` tutorial program

CAL Error Handling

- All CAL routines return `CAL_RESULT_OK` on success and an error code on failure
- `calGetErrorString` can be used to get further information about the error

`calGetErrorString`

```
const CALchar* calGetErrorString(void);
```

- Returns a NULL-terminated string on the last error that occurred

CAL Device Query

`calDeviceGetInfo`

```
CALAPI CALresult CALAPIENTRY calDeviceGetInfo(
       CALdeviceinfo* info, // struct to be filled by the runtime
       CALuint ordinal);    // Which device ? [0.. N-1]
```

- Get information on a given device

```
struct {
    CALtarget target;
    CALuint   maxResource1DWidth;
    CALuint   maxResource2DWidth;
    CALuint   maxResource2DHeight;
} CALdeviceinfo;
```

GPU ASIC Type e.g. CAL_TARGET_770

Maximum legal dimensions of 1D and 2D resources, e.g. 8096 for 770

CAL Device Query

- E.g. querying the type of GPU on the system

```
// Get the information on the 0th device
CALdeviceinfo info;
if(calDeviceGetInfo(&info, 0) != CAL_RESULT_OK)
   ERROR_OCCURRED();

switch(info.target)
{
    case CAL_TARGET_670:
        fprintf(stdout, "Device Type = GPU R6V70\n");
        break;
    case CAL_TARGET_770:
        fprintf(stdout, "Device Type = GPU RV770\n");
        break;
}
```

CAL Device Query

```
calDeviceGetAttribs
CALresult calDeviceGetAttribs(
        CALdeviceattribs* attribs, // filled by the runtime
        CALuint ordinal);          // Which device? [0.. N-1]
```

- Get detailed device attributes on a given device

```
struct {
    CALuint   struct_size;       // Size of struct
    CALtarget target;            // ASIC identifier, e.g. R670
    CALuint   localRAM;          // Local GPU RAM in MB, e.g. 800MB
    CALuint   uncachedRemoteRAM; // Uncached remote memory in MB
    CALuint   cachedRemoteRAM;   // Cached remote memory in MB
    CALuint   engineClock;       // GPU device clock rate in MHz
    CALuint   memoryClock;       // GPU memory clock rate in MHz
    ……
} CALdeviceattribs;
```

CAL Device Status Query

```
calDeviceGetStatus
CALresult calDeviceGetStatus(
  CALdevicestatus* status, // filled by the runtime
  CALdevice device);        // Which device? [0.. N-1]
```

- Get the current status of the given device

```
struct {
    CALuint   struct_size;  // Size of struct
    CALuint   availLocalRAM; // Available local memory
    CALuint   availUncachedRemoteRAM; // Available uncached
                                     // resource
    CALuint   availCachedRemoteRAM; // Available cached resource
} CALdevicestatus;
```

CAL Device Management

`calDeviceOpen`

```
CALresult calDeviceOpen(CALdevice* dev, CALuint ordinal);
```

- Initialize the device
- Initializes dev on success with handle to device
- Returns CAL_RESULT_ERROR otherwise

`calDeviceClose`

```
CALresult calDeviceClose(CALdevice dev);
```

- Un-initialize the device
- See/Run `OpenCloseDevice` tutorial program

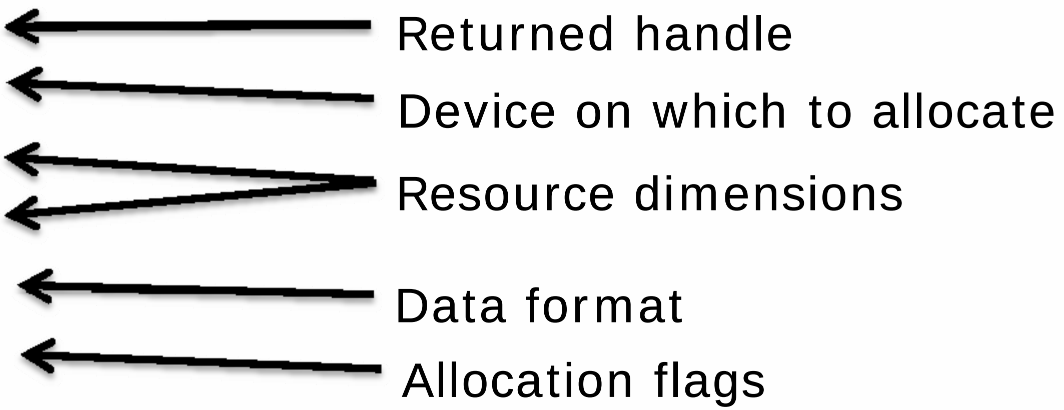
CAL Resource Allocation

`calResAlloc{∊ Local Remote}{∊ 1 2}D([args]);`

- CAL Resource Allocation routines, e.g.

`calResAllocLocal2D`

```
CALresult calResAllocLocal2D(
        CALresource* res,
        CALdevice dev,
        CALuint width,
        CALuint height,
        CALformat format,
        CALuint flags);
```



Returned handle

Device on which to allocate

Resource dimensions

Data format

Allocation flags

- Allocates 2D resource from GPU local memory
- Returns opaque handle to resource `CALResource`
- Can be de-allocated using `calResFree`

CAL Resource Allocation

- Both Local and Remote resources are limited
  - Maximum size of a buffer is given by `calDeviceGetInfo`
  - Total size is given by `calDeviceGetAttribs`
- Always check the returned error code and handle value before using the resource

CAL Resource Format

- Resources can be of different data types
- Resources can have 1, 2 or 4 components per element
- Formats specified using enum `CALformat`
- Components are arranged in interleaved order
- E.g. following allocates 1024x1024 size resource with 4 32-bit floating point values per element

```
CALresource resLocal = 0;
calResAllocLocal2D(&resLocal, device,
                   1024, 1024,
                   CAL_FORMAT_FLOAT_4, 0);
```

CAL Resource Format

- `CALformat` syntax

  `CAL_FORMAT_{∊ UBYTE BYTE USHORT SHORT UINT INT FLOAT DOUBLE}_{∊ 1 2 4}`

- E.g. `CAL_FORMAT_FLOAT_1, CAL_FORMAT_BYTE_4`

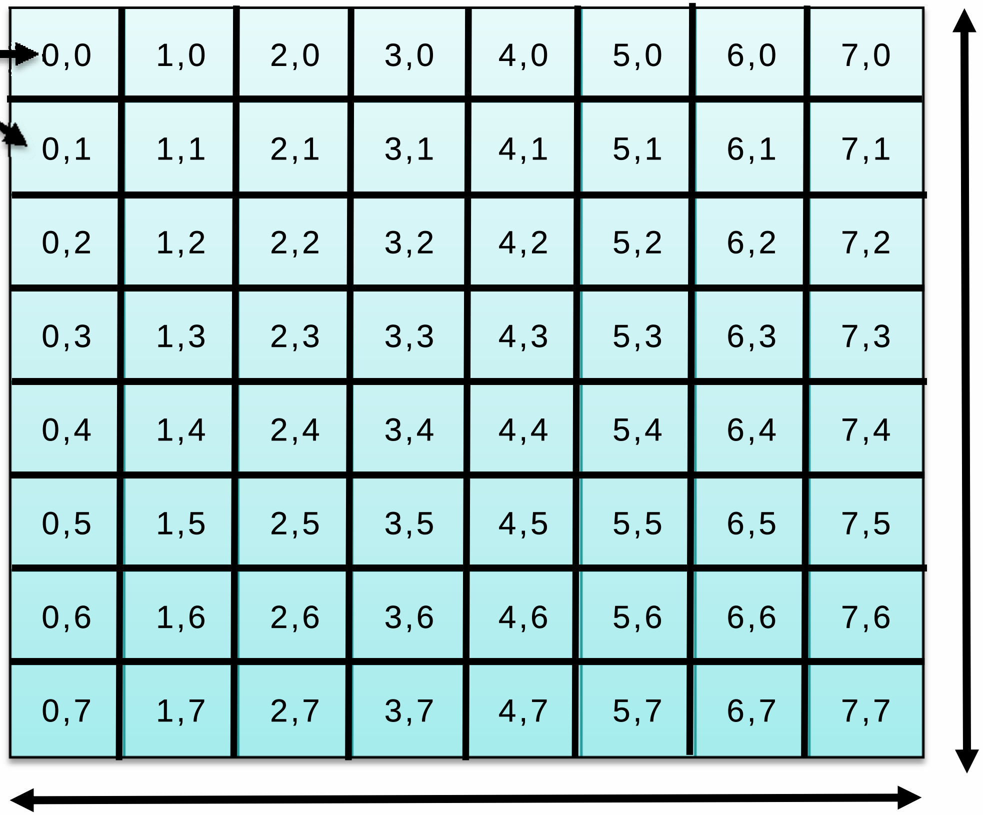
Data Type	**Description**
UBYTE, BYTE	Signed/unsigned 8-bit integer
USHORT, SHORT	Signed/unsigned 16-bit integer
UINT, INT	Signed/unsigned 32-bit integer
FLOAT	Single precision 32-bit floating point
DOUBLE	Double precision 64-bit floating point

- Note: `CAL_FORMAT_DOUBLE_4` is not supported

CAL Resource Format

FLOAT_1
Each element
has 1 float value

C-Style LINEAR memory arrangement in row-major order



0,0	1,0	2,0	3,0	4,0	5,0	6,0	7,0
0,1	1,1	2,1	3,1	4,1	5,1	6,1	7,1
0,2	1,2	2,2	3,2	4,2	5,2	6,2	7,2
0,3	1,3	2,3	3,3	4,3	5,3	6,3	7,3
0,4	1,4	2,4	3,4	4,4	5,4	6,4	7,4
0,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5
0,6	1,6	2,6	3,6	4,6	5,6	6,6	7,6
0,7	1,7	2,7	3,7	4,7	5,7	6,7	7,7

Height = 8

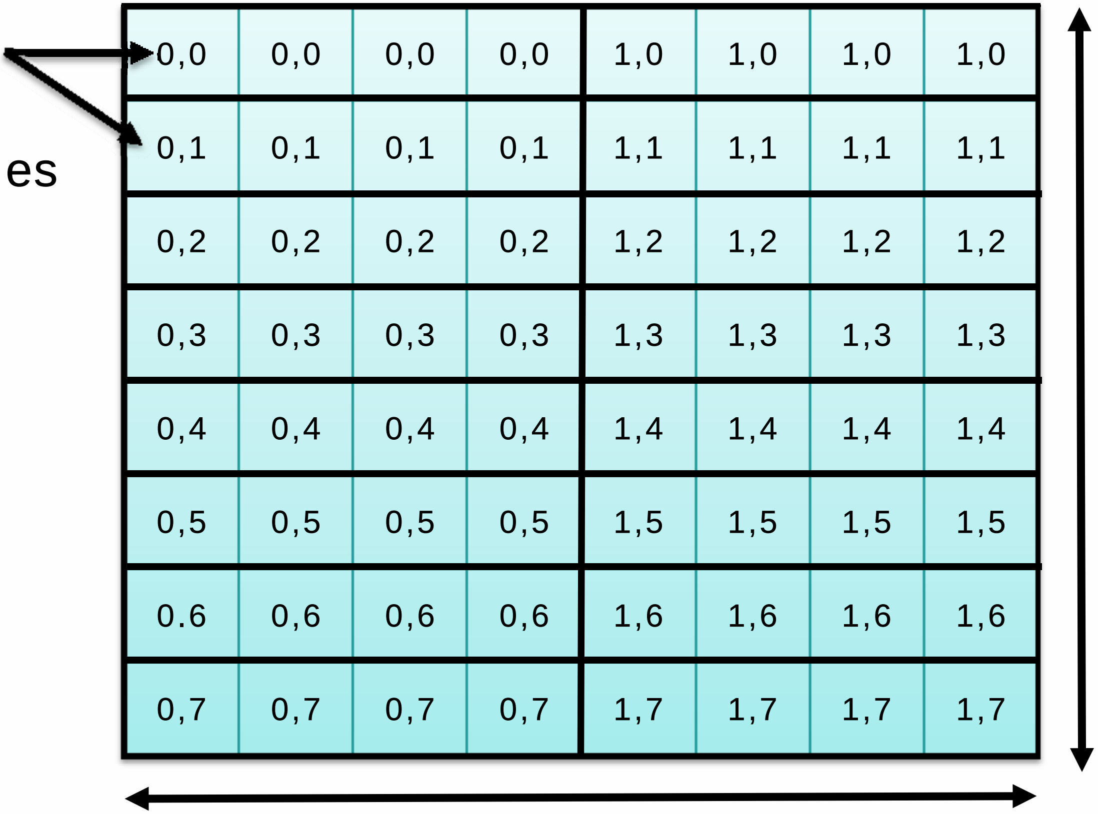
Width = 8

```
calResAllocLocal2D(&resLocal, device, 8, 8,
                         CAL_FORMAT_FLOAT_1, 0);
```

CAL Resource Format

FLOAT_4
Each element
has 4 float values

C-Style LINEAR memory arrangement in row-major order



0,0	0,0	0,0	0,0	1,0	1,0	1,0	1,0
0,1	0,1	0,1	0,1	1,1	1,1	1,1	1,1
0,2	0,2	0,2	0,2	1,2	1,2	1,2	1,2
0,3	0,3	0,3	0,3	1,3	1,3	1,3	1,3
0,4	0,4	0,4	0,4	1,4	1,4	1,4	1,4
0,5	0,5	0,5	0,5	1,5	1,5	1,5	1,5
0.6	0,6	0,6	0,6	1,6	1,6	1,6	1,6
0,7	0,7	0,7	0,7	1,7	1,7	1,7	1,7

Height = 8

Width = 2

```
calResAllocLocal2D(&resLocal, device, 2, 8,
                   CAL_FORMAT_FLOAT_4, 0);
```

Remote Resource Allocation

`calResAllocRemote2D`

- Allocates 2D resource from GPU remote memory
- Resource can be shared by more than 1 device

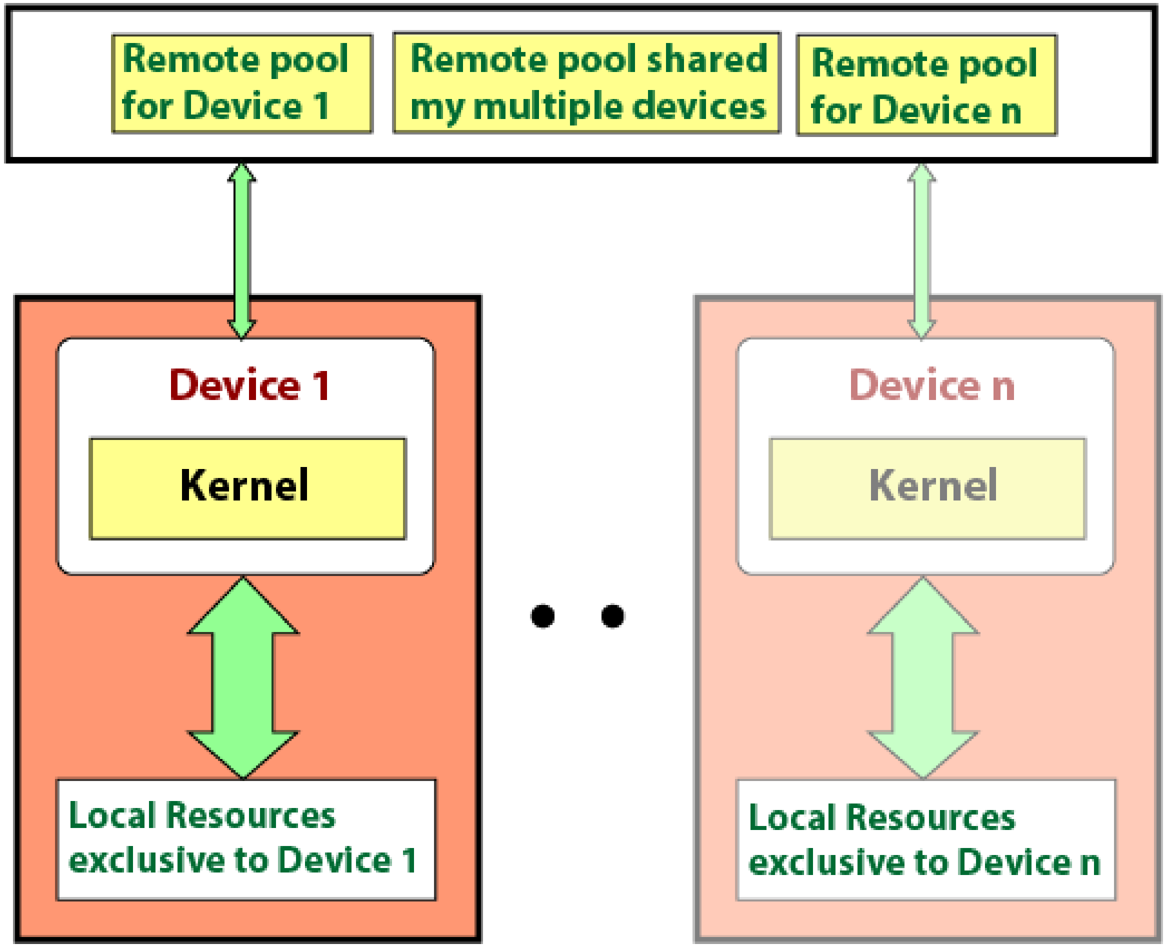
```
CALresult calResAllocRemote2D(
   CALresource* res,
   CALdevice *dev,
   CALuint deviceCount,
   CALuint width,
   CALuint height,
   CALformat format,
   CALuint flags);
```

`*dev` ← List of devices which can share the resource

`deviceCount` ← Number of devices in dev

e.g. `calResAllocRemote2D(&resRemote, &device, 1, 1024, 1024, CAL_FORMAT_FLOAT_1, 0);`

Remote vs Local Resources



Resource Initialization

- Initialization requires accessing resource from CPU
- Done using `calResMap` that maps `CALResource` to the application's address space

```
CALresult calResMap(
            CALvoid** pPtr,
            CALuint* pitch,
            CALresource res,
            CALuint flags);
```

Returned CPU pointer

Number of elements in each row of mapped buffer

Input resource to be mapped

Flags (placeholder for future use)

e.g.

```
float *dataPtr = NULL;
CALuint pitch = 0;
calResMap((CALVoid **)&dataPtr, &pitch, resLocal, 0);
```

Resource Initialization

- Pitch is the number of elements in a row
  - Number of elements not necessarily equal to requested resource width
  - Actual size of buffer allocated for a 2D resource is given by

```
Allocated Buffer Size = Pitch * Height *
                        Number of components *
                        Size of data type
```

Resource Initialization

- Important when dereferencing and addressing the returned pointer, e.g.

```
for(int i = 0; i < height; i++) {
  // Use the pitch to properly offset into the memory pointer
  float* tmp = &dataPtr[i * pitch];
  for (int j = 0; j < width; j++) {
      // For FLOAT_1, we should initialize temp[j] only
      tmp[j] = (float)(i * width + j);
  }
}
```

- Need to unmap the resource once done with initialization
  - Mapped resource cannot be used in a kernel
  - Use `calResUnmap`

CAL Context

- CAL allows multiple connections to a device
- Each connection is associated with local settings
  - Collectively termed as the device state
  - Abstracted in CAL using `CALContext`
- All device operations need to be specific to a `CALContext`
- Can be thought of as a separate process on the device
  - Each context has it’s own address space
  - Only a single context can be active on the device at a time

All context-specific routines are prefixed `calCtx`, e.g. `calCtxCreate`

CAL Context

`calCtxCreate`

```
CALresult calCtxCreate(CALcontext* ctx, CALdevice dev);
```

- Create a context on the given device

`calCtxDestroy`

```
CALresult calCtxDestroy(CALcontext ctx);
```

- Destroy the specified context
- See/Run `CreateContext` tutorial program

Context-specific Resource Mapping

- GPU kernels need a valid CALContext to run
- Resources are accessed by kernels using a context-specific address
  - Represented using an opaque handle CALMem
  - Mapping done using `calCtxGetMem` that returns a context-specific handle to a resource

`calCtxGetMem`

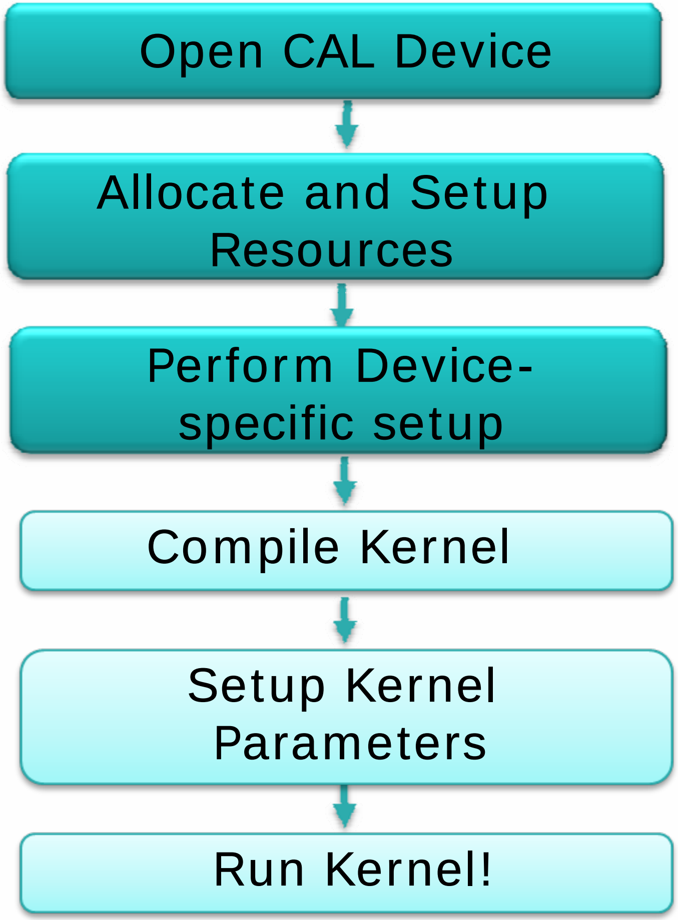
```
CALresult calCtxGetMem(CALmem* mem, CALcontext ctx,
   CALresource res);
```

e.g.

```
CALmem memLocal = 0;

calCtxGetMem(&memLocal, ctx, resLocal);
```

CAL Application – High-Level Flow



Open CAL Device

Allocate and Setup Resources

Perform Device-specific setup

Compile Kernel

Setup Kernel Parameters

Run Kernel!

`CALdevice`

`CALresource`

`CALcontext,`
`CALmem`

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CAL Compiler API

CAL Compiler API - Conventions

- ‘C’ Library
- Routines
  - Compiler prefixed `calcl`, e.g. `calclCompile`
  - Return an error code of type `CALresult`
- Enums prefixed `CAL_`, e.g. `CAL_LANGUAGE_ISA`
- Opaque handles to internal data structures prefixed `CAL`, e.g. `CALobject`

CAL Compiler API

- Compiler allows offline as well as runtime compilation
  - Compiler API used to compile kernels at runtime
  - Compiled binary can be stored as a file and loaded later at runtime
- Typically,
  - Runtime compilation used for development
  - Pre-compiled binaries shipped during deployment
    - Prevents overhead of kernel compilation at runtime
    - Prevents exposing proprietary kernels

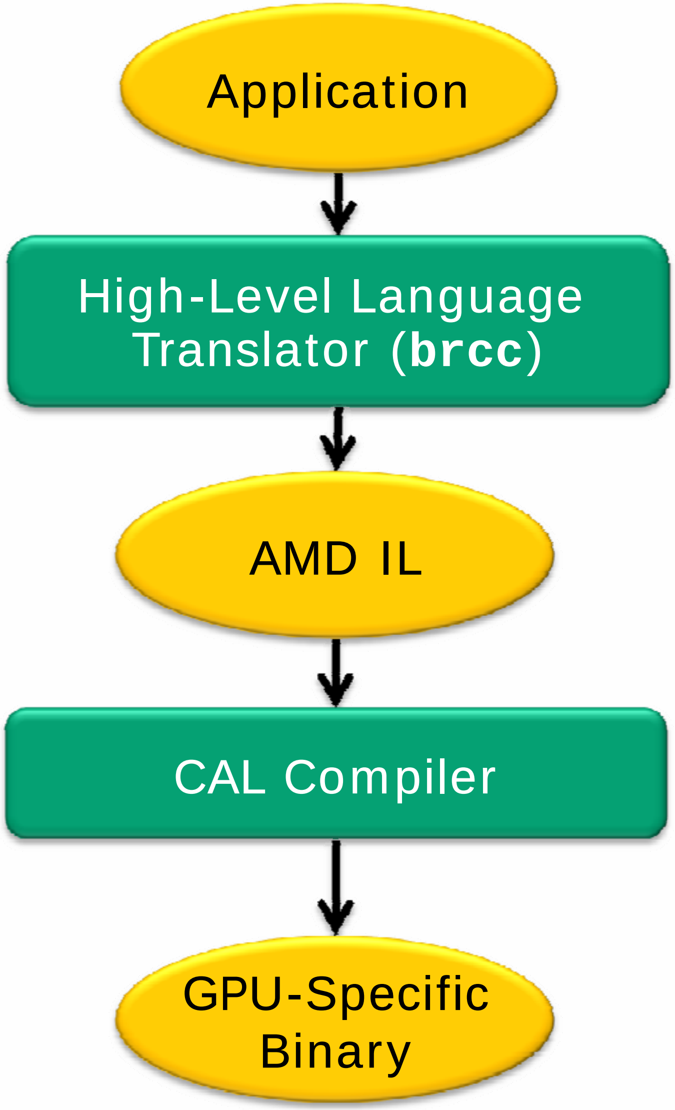
Kernel Programming

- CAL supports two interfaces directly
  - Portable psuedo assembly – AMD Intermediate Language (IL)

    `$(CALROOT)\doc\il.pdf`
  - GPU-specific Instruction Set Architecture (ISA)

    `$(CALROOT)\doc\r600isa.pdf`
- Higher level languages can be used with external tools/compilers
  - Brook+
  - AMD High Level Shading Language (HLSL)

Kernel Compilation Steps



Application

High-Level Language Translator (**brcc**)

AMD IL

CAL Compiler

GPU-Specific Binary

CAL Compiler Query and Error Handling

`calclGetVersion`

```
CALresult calclGetVersion(CALuint* major, CALuint* minor,
   CALuint* imp);
```

- Query the CAL Compiler version

`calclGetErrorString`

```
const CALchar* calclGetErrorString(void);
```

- Returns NULL terminated string with information about the last error

Kernel Compilation

`calclCompile`

- Compile a given kernel to a GPU-specific binary object
  - Returns an opaque handle `CALObject`

```
CALresult calclCompile(
   CALobject* obj,        // Generated binary object
   CALlanguage language, // Kernel language, e.g. CAL_LANGUAGE_IL
   const CALchar* source,// String for kernel source
   CALtarget target);    // Target GPU, e.g. CAL_TARGET_R770
```

- The AMD IL is parsed and optimized for the given GPU architecture

- The GPU ISA generated is internally assembled into the returned `CALobject`

Kernel Specification

- Need to specify as a C String
- Lines of code separated using new line characters

```
// IL kernel  to implement Output = Input * Constant
std::string programIL =
    "il_ps_2_0                        \n"
    "dcl_input_interp(linear) v0.xy__\n"
    "dcl_output_generic o0            \n"
    "dcl_cb cb0[1]                    \n"

"dcl_resource_id(0)_type(2d,unnorm)_fmtx(float)_fmty(float)_fmtz(float)
_fmtw(float)                         \n"
    "sample_resource(0)_sampler(0) r0, v0.xyxx  \n"
    "mul o0, r0, cb0[0]               \n"
    "ret_dyn                          \n"
    "end                              \n";
```

Using GPU ISA

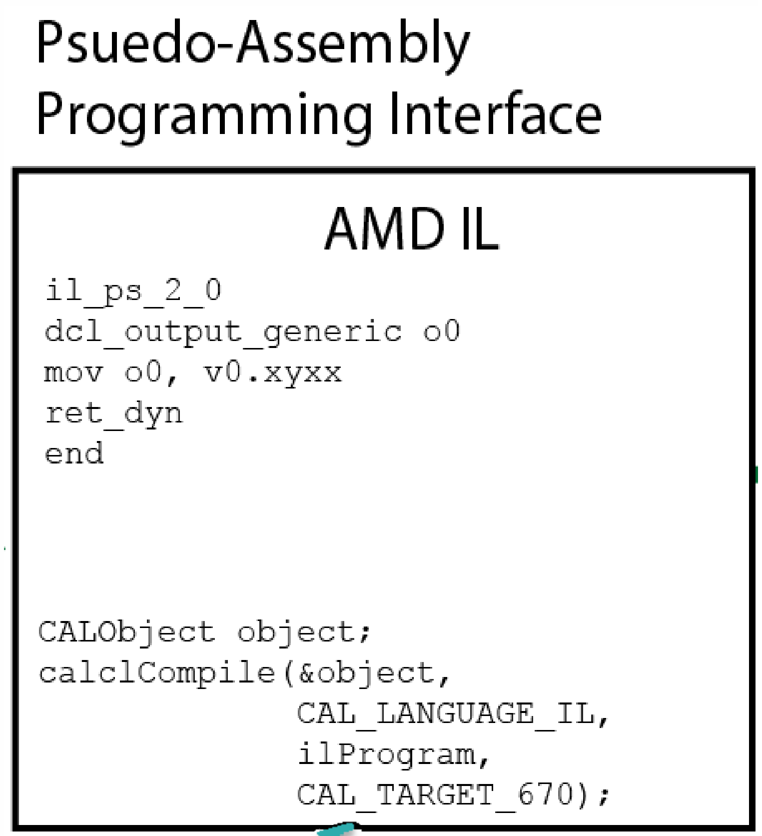
`calclAssembleObject`

- Assemble the given GPU ISA into a binary object

```
CALresult calclAssembleObject(
   CALobject* obj,          // Generated binary object
   CALCLprogramType type, // Program type - CAL_PROGRAM_TYPE_PS
   const CALchar* source, // String for kernel source
   CALtarget target);      // Target GPU, e.g. CAL_TARGET_R670
```

- The GPU ISA is simply assembled into the CALobject – no optimizations are done

Kernel Compilation Steps



Psuedo-Assembly
Programming Interface

AMD IL

```
il_ps_2_0
dcl_output_generic o0
mov o0, v0.xyxx
ret_dyn
end
```

```
CALObject object;
calclCompile(&object,
             CAL_LANGUAGE_IL,
             ilProgram,
             CAL_TARGET_670);
```

Application can specify
IL or ISA directly

Binary Image Generation

`calclLink`

- Link the specified `CALobjects` into a binary image
- Returns an opaque handle `CALImage`

```
CALresult calclLink(
   CALimage* image, // Returned binary image
   CALobject* obj,  // Array of objects to be linked
   CALuint objCount); // Number of objects in above array
```

- E.g. `calclLink(&image, &object, 1);`
- Allows linking-in multiple objects compiled for different GPU ASICs

Binary Image Management

- The generated `CALimage` can be stored for subsequent use
  - Need to copy the contents of `CALimage` to a regular C buffer and then stored

`calclImageWrite`

```
CALresult calclImageWrite(CALvoid* buffer, CALuint size,
CALimage image);
```

- Serialize the content of `CALimage` to the supplied buffer
- buffer needs to be allocated by application
- size can be queried using `calclImageGetSize`

Binary Image Management

- Need to initialize the given C buffer to a CALimage

  `calImageRead`

```
CALresult calImageRead(
    CALimage *image,          // Returned CALimage handle
    const CALvoid* buffer, // Buffer from which to
                              // initialize the CALimage
    CALuint size);            // Size of buffer
```

- Create a new CALimage and serialize into it from the supplied buffer

Compiler Memory Management

- Memory for CALobject and CALimage are allocated internally by the compiler
  - Need to be free'ed once the memory is not needed

```
CALresult calclFreeObject(CALobject obj);
CALresult calclFreeImage(CALimage image);
```

Free the object and image respectively

CAL Application – High-Level Flow

Open CAL Device	`CALdevice`
Allocate and Setup Resources	`CALresource`
Perform Device-specific setup	`CALcontext`, `CALmem`
Compile Kernel	`CALobject`, `CALimage`
Setup Kernel Parameters	
Run Kernel!	

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CAL Kernel Execution

Kernel Loading

- The compiled CALimage is not bound to a CALcontext

  `calModuleLoad`

- Loads a given CALimage as a context-specific CALmodule

```
CALresult calModuleLoad(
 CALmodule* module, // Returned handle to CALmodule
 CALcontext ctx,    // Context in which to load the CALimage
 CALimage image);   // Pre-linked CALimage
```

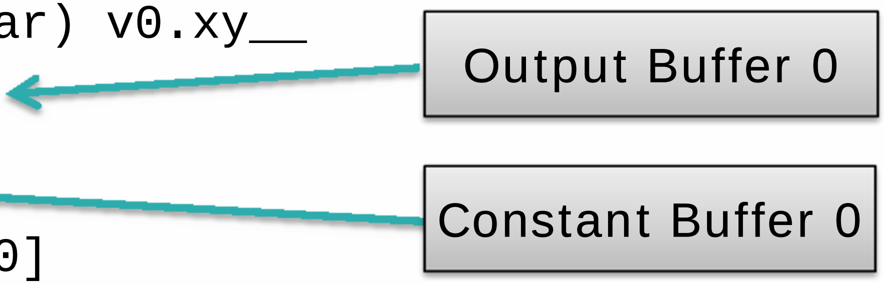
- E.g.

```
CALmodule module = 0;
calModuleLoad(&module, ctx, image);
```

Kernel Parameter Binding

- Need to link various CALmem handles to corresponding variable names in the kernel

```
il_ps_2_0
dcl_input_interp(linear) v0.xy__
dcl_output_generic o0
dcl_cb cb0[1]
mul o0, v0.xyxx, cb0[0]
ret_dyn
end
```



Output Buffer 0

Constant Buffer 0

- Steps
  - Get handle to parameter names from module
  - Associate locations with memory handles

Kernel Parameter Binding

`calModuleGetName`

- Get handle to a given kernel parameter from the module
- Returns an opaque handle CALname given the parameter string

```
CALresult calModuleGetName(
      CALname* name,      // Returned handle to the parameter
      CALcontext ctx,     // CAL Context
      CALmodule module,   // CAL module loaded in the context
      const CALchar* varName); // string for parameter name
```

- E.g.

```
CALname output;
calModuleGetName(&output, ctx, module, "o0");
```

Kernel Parameter Binding

Parameter Type	Name	Example
Input Resource	`i#`	`i0, i1, i2, … i127`
Output Resource	`o#`	`o0, o1, o2, … o7`
Constant Resource	`cb#`	`cb0, cb1, … cb15`

Constant Buffers

- Read-only resources, similar to Inputs
  - Used for small arrays of up to 4096 elements
  - Legal to have 1, 2 or 4 components per element.
  - All `CALformats` mentioned in `cal.h` header file are supported except for 8-bit (`BYTE`, `UBYTE`) and 16-bit (`SHORT`, `USHORT`) types.
  - Can declare and use upto 16 1D resources as constant buffers. 2D constant buffers are not allowed.
  - Typically allocated using remote resources.
- Copied to a special cache on the GPU

⇒ Reading is more efficient than reading regular inputs.

⇒ For small input arrays, it is preferable to use constant buffers

Kernel Parameter Binding

`calCtxSetMem`

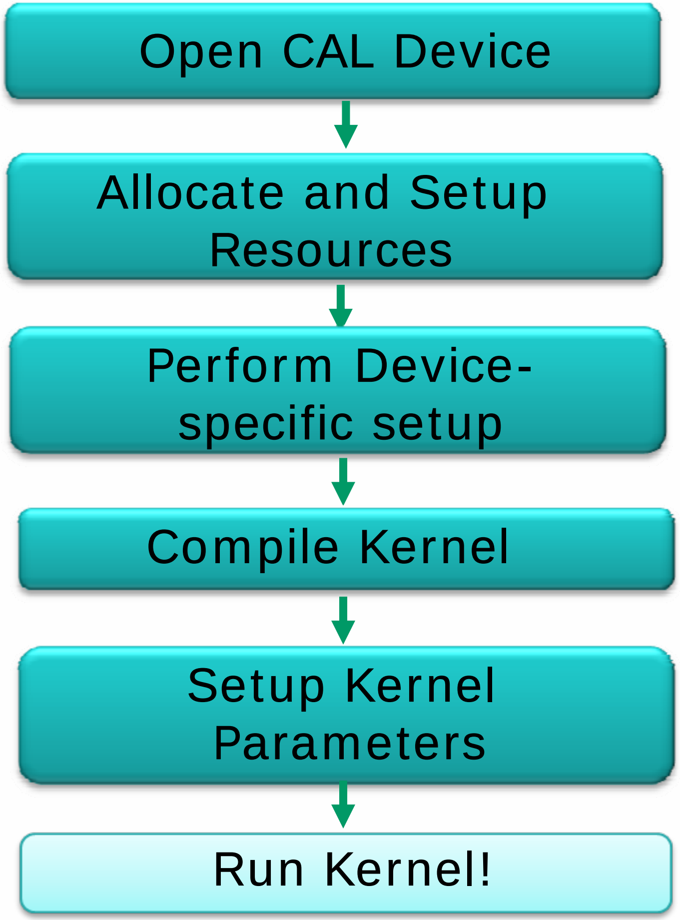
- Associate the given CALmem with the given CALname

```
CALresult calCtxSetMem(
    CALcontext ctx, // CAL context
    CALname name,    // Parameter name from calModuleGetName
    CALmem mem);    // Memory handle for the parameter
```

- E.g.

```
calCtxSetMem(ctx, input, inputMem);
```

CAL Application – High-Level Flow



Open CAL Device	`CALdevice`
Allocate and Setup Resources	`CALresource`
Perform Device-specific setup	`CALcontext,` `CALmem`
Compile Kernel	`CALobject,` `CALimage`
Setup Kernel Parameters	`CALname,` `CALmem binding`
Run Kernel!	

Kernel Execution – Domain

- Kernel is executed over a given range of elements in the output buffer
  - Elements are processed in parallel on the GPU
  - Also referred to as the *domain of execution*
  - Represented in CAL using `CALdomain`

```
struct {
    CALuint x;                  // x origin of domain
    CALuint y;                  // y origin of domain
    CALuint width;              // width of domain
    CALuint height;             // height of domain
} CALdomain;
```

Kernel Execution - Asynchronous

- CAL kernels run on the GPU in a separate thread of execution
  - CPU is free to perform other operations in parallel
- Routine used to launch kernel on the GPU is non-blocking
  - The routine does not wait for the GPU to finish
  - Application needs to synchronize the kernel completion explicitly
  - The above routine returns an event that the application can wait on using CALevent

Kernel Execution - Module Entry Point

- CAL runtime requires the entry point in the CALmodule for the kernel

- Represented using CALfunc

  `calModuleGetEntry`

- Returns the entry point for a given function in the binary module

```
CALresult calModuleGetEntry(
     CALfunc* func,             // Returned handle to function
     CALcontext ctx,            // CAL context
     CALmodule module,          // CAL module
     const CALchar* procName); // Function name – “main”
```

- E.g.

```
CALfunc entry = 0;
calModuleGetEntry(&entry, ctx, module, "main");
```

Kernel Execution – Launching

calCtxRunProgram

```
CALresult calCtxRunProgram(
       CALevent* event, // Returned event for this command
       CALcontext ctx,  // CALcontext
       CALfunc func,    // Entry point in the module
       const CALdomain* domain); // Execution domain
```

- Launch the kernel on the GPU associated with the specified context
- The routine returns almost immediately with the CALevent for synchronizing with the application thread

Kernel Execution – Synchronization

`calCtxIsEventDone`

```
CALresult calCtxIsEventDone(CALcontext ctx, CALevent event);
```

- Poll the CALevent for completion
- Returns CAL_RESULT_PENDING if the event is not complete
- Typical execution:

```
while(calCtxIsEventDone(ctx, event) == CAL_RESULT_PENDING);
```

- Note: the above is a busy wait that wastes CPU cycles
  - It might be better to perform some CPU work before polling for the event

Kernel Execution – Synchronization

- Important note
  - CAL implements a lazy evaluation scheme

⇒ Tries to queue up commands before dispatching them to the GPU

⇒ `calCtxIsEventDone` performs an *implicit flush* to force the dispatch of commands to the GPU

⇒ Calling `calCtxIsEventDone` once after the `calCtxRunProgram` guarantees that the command is sent to the GPU

```
calCtxRunProgram(&event, ctx, entry, &domain);
// Flush commands
calCtxIsEventDone(ctx, event);
// Do other CPU work
….
// Wait for completion
while(calCtxIsEventDone(ctx, event) == CAL_RESULT_PENDING);
```

CAL Application – High-Level Flow

Open CAL Device	`CALdevice`
Allocate and Setup Resources	`CALresource`
Perform Device-specific setup	`CALcontext,` `CALmem`
Compile Kernel	`CALobject,` `CALimage`
Setup Kernel Parameters	`CALname,` `CALmem binding`
Run Kernel!	`CALfunc,` `CALevent`

AMD

Smarter Choice

End of Module 5