Developing an efficient Maya plug-in using CUDA & GLinterop.

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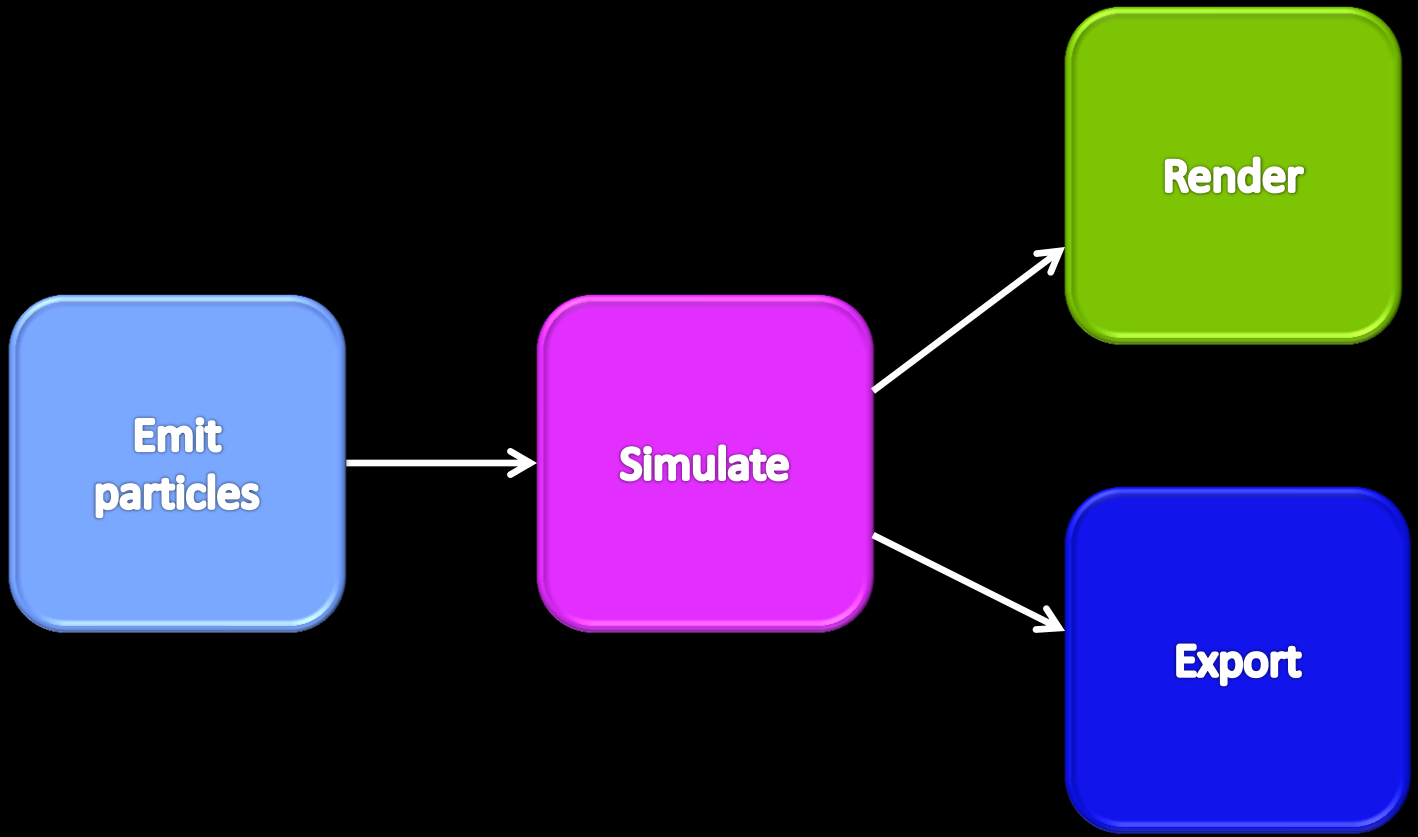
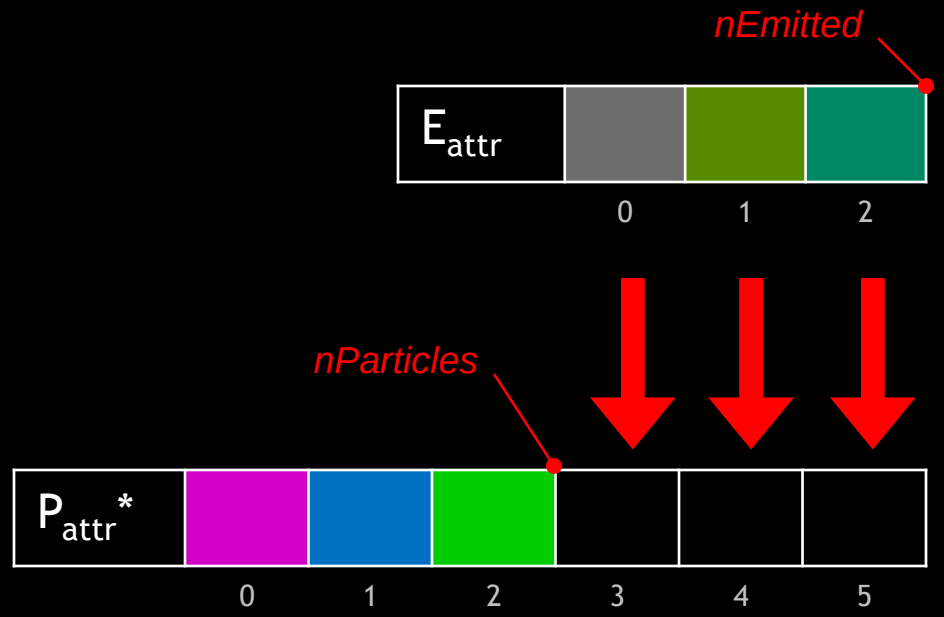
Our Particle pipeline



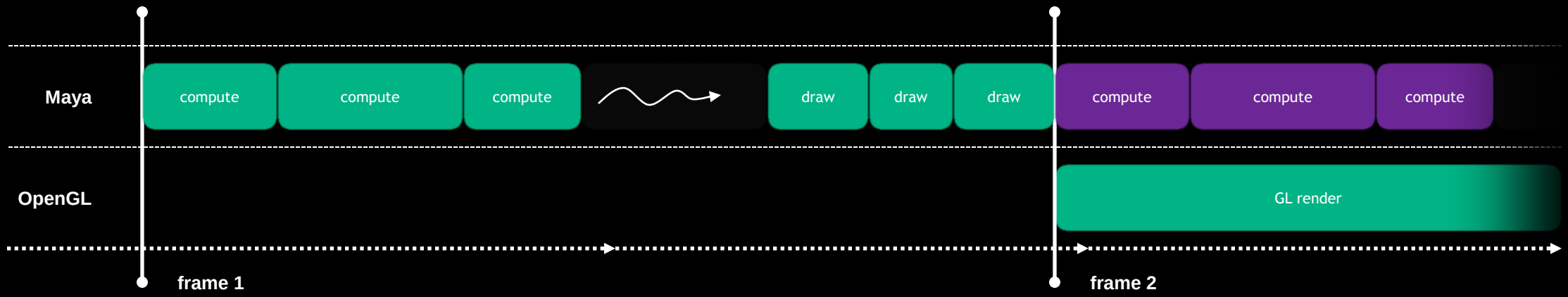
Particle Emission

- Upload emitted data using nParticles as offset.
- nParticles += nEmitted
- We use fast host-to-device transfer for emission data.
  - i.e. page-locked & write-combined host memory.
- For large emissions we can double-buffer and use Async API.



The App Pipeline - (Autodesk Maya)

- Maya plug-in callbacks:
  - Plugin::compute(...) (called during data computation)
    - Upload & Simulate the particles using CUDA.
    - Blit simulated data to VBO.
  - Plugin::draw(...) (called during Maya's scene-graph traversal)
    - Render particle VBO.



CUDA contexts in Maya

- CUDA context
  - We must create one. Where?
  - Other plug-ins (or “future” Maya) might change CUDA “state”.
- Choices:
  - Push and pop any previous CUDA context (using driver API).
  - Or create our own “persistent” thread with dedicated CUDA context.

- If we want GL interoperability, Maya’s GL context must be passed into our persistent thread via context sharing.

Code: persistent CUDA context thread

```
// Initialize from within Maya thread ...
void Plugin::_initializeThread()
{
     HDC display = getDisplay();
     HGLRC mayaGlCxt = getGlContext();

     HGLRC glCxt = wglCreateContext(display);
     wglShareLists(mayaGlCxt, glCxt);

     _hdl = runThread(_threadFunc, display, glCxt);

     launchJob(jobInit);

     wglMakeCurrent(display, mayaGlCxt);
}

// Clean-up from within Maya thread ...
void Plugin::_destroyThread ()
{
     launchJob(jobExit);

     killThread(_hdl);
}
```

```
// Our persistent thread function...
void _threadFunc(HDC display, HGLRC glCxt)
{
     wglMakeCurrent(display, glCxt);
     CUdevice dev;
     cuDeviceGet(&dev, 0);
     CUcontext cuCxt;
     cuGLCtxCreate(&cuCxt, 0, dev);

     while (isRunning)
     {
          // pop & run job from thread-safe queue...
     }

     wglMakeCurrent(0, 0);
     wglDeleteContext(glCxt);
     cuCtxDestroy(cuCxt);
}

void jobInit(Data* ) { // initialize CUDA things... }

void jobExit(Data*) { // clean-up CUDA things... }
```

Particle Initialization

- Simulation & Rendering initialization

```
struct Data
{
    int nParticles;                  // number of particles
    GLuint glVboPositions;           // OpenGL VBO of particle positions
    cudaGraphicsResource* cuGlRes;   // CUDA registered VBO
    cudaStream_t cuStream;           // CUDA stream
    float4* cuPositions;             // CUDA buffer of particle positions
};

void jobInit(Data* d)
{
    cudaStreamCreate(&d->cuStream);
    cudaMalloc(d->cuPositions, d->nParticles * sizeof(float4));
    glGenBuffers(1, &d->glVboPositions)
    glBindBuffer(GL_ARRAY_BUFFER, d->glVboPositions);
    glBufferData(GL_ARRAY_BUFFER, d->nParticles * sizeof(float4), 0, GL_DYNAMIC_DRAW);
    glBindBuffer(GL_ARRAY_BUFFER, 0);
    cudaGraphicsGLRegisterBuffer(&d->cuGlRes, d->glVboPositions, cudaGraphicsMapFlagsWriteDiscard);
}
```

Particle Simulation

- CUDA kernel operates on CUDA buffers.

```
void jobSim(Data* d)
{
     // ...
     somethingCrazyKernel<<<dimGrid, dimBlock, 0, d->cuStream>>>(d->nParticles, d->cuPositions);
}
```

Particle Render Blit

- Blit into VBOs
  - copy the CUDA simulated data into the GL buffers.

```
void jobBlit(Data* d)
{
     void* glVboPositionsPtr = 0;
     size_t nBytes = 0;
     cudaGraphicsMapResources(1, &d->cuGlRes, d->cuStream);
     cudaGraphicsResourceGetMappedPointer(&glVboPositionsPtr, (size_t*)&nBytes, d->cuGlRes);

     cudaMemcpyAsync(glVboPositionsPtr, d->cuPositions, nBytes, cudaMemcpyDeviceToDevice, d->cuStream);

     cudaGraphicsUnmapResources(1, &d->cuGlRes, d->cuStream);
}
```

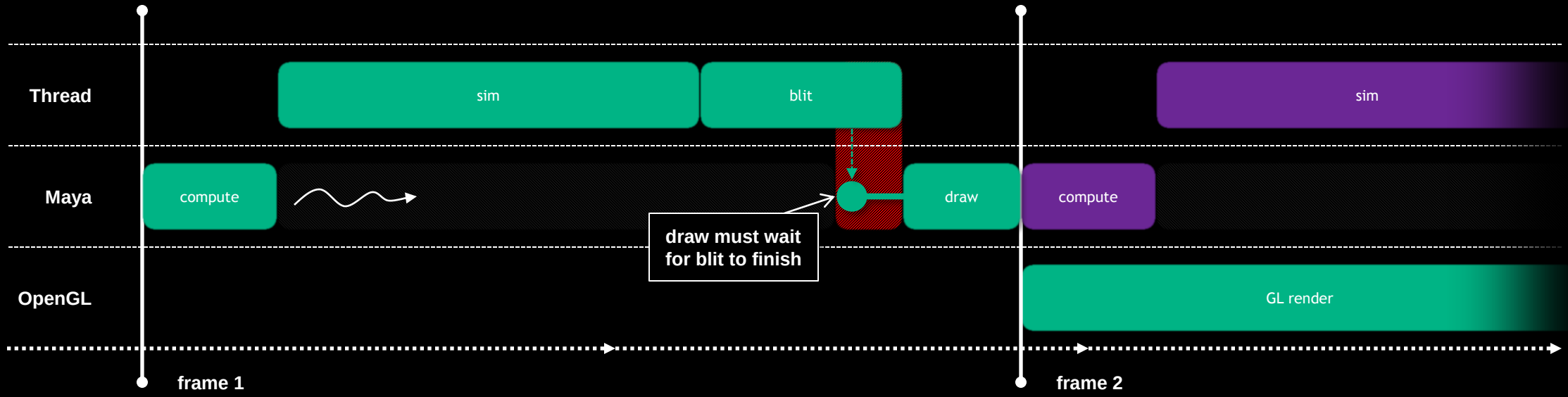
```
void jobSync(Data* d)
{
     cudaStreamSynchronize(d->cuStream);
}
```

Particle Render

```
void Plugin::draw()
{
     launchJob(jobSync);

     Data* d = &_data;

     glBindBuffer(GL_ARRAY_BUFFER, d->glVboPositions);
     glVertexPointer(4, GL_FLOAT, 0, 0);
     glEnableClientState(GL_VERTEX_ARRAY);
     glDrawArrays(GL_POINTS, 0, d->nParticles);
     glBindBuffer(GL_ARRAY_BUFFER, 0);
     glDisableClientState(GL_VERTEX_ARRAY);
}
```

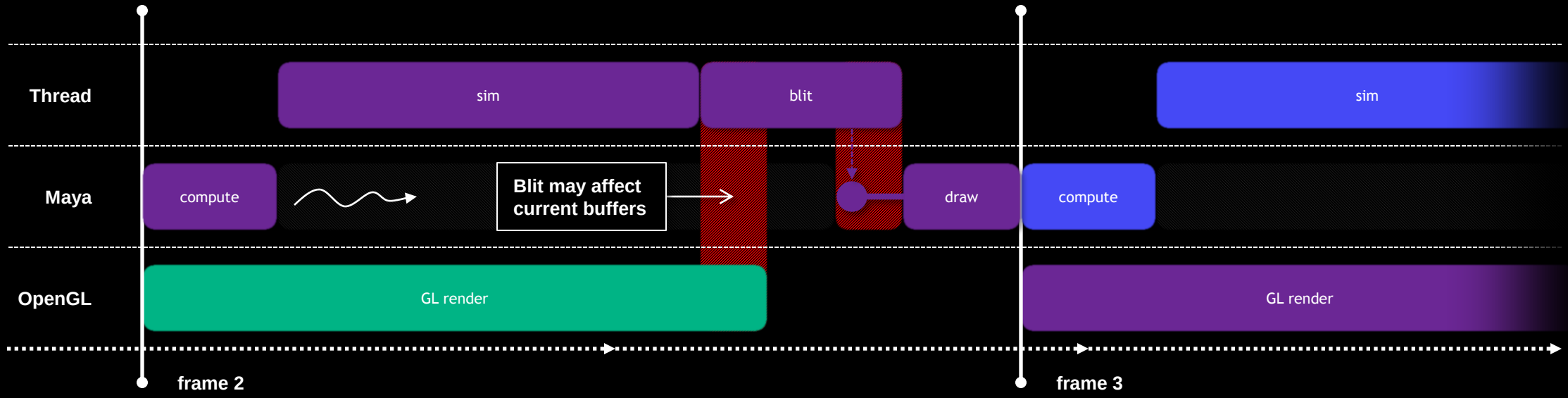
Example 1: Synchronous CUDA thread

- Sync with CUDA thread before we draw the buffers.
  - use a semaphore.
  - or... simply synchronize the CUDA thread: jobSync()



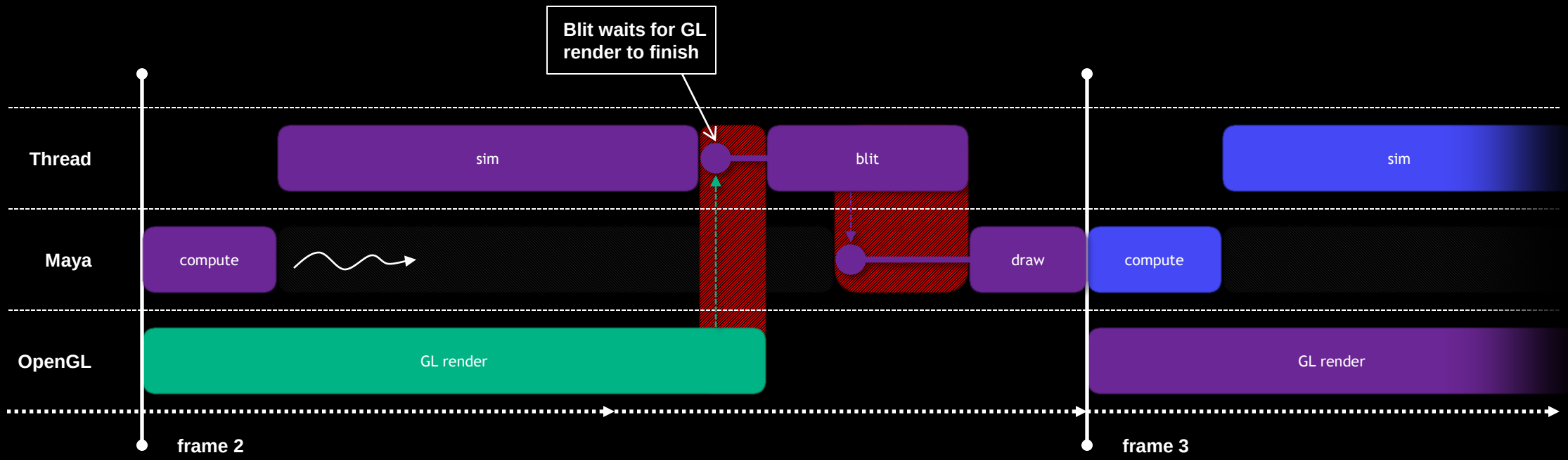
Example 1: Synchronous CUDA thread

- Sync with CUDA thread before we draw the buffers.
- We must synchronize our blit with the GL render.



Example 1: Synchronous CUDA thread

- Sync with CUDA thread before we draw the buffers.
- Sync with OpenGL before we blit to the buffers.



Particle Render

```
void Plugin::draw()
{
     Data* d = &_data;
     d->blitMutex.claim();

     glBindBuffer(GL_ARRAY_BUFFER, d->glVboPositions);
     glVertexPointer(4, GL_FLOAT, 0, 0);
     glEnableClientState(GL_VERTEX_ARRAY);
     glDrawArrays(GL_POINTS, 0, d->nParticles);
     glBindBuffer(GL_ARRAY_BUFFER, 0);
     glDisableClientState(GL_VERTEX_ARRAY);

     d->glVboSync = glFenceSync(GL_SYNC_GPU_COMMANDS_COMPLETE, 0);

     d->blitMutex.release();
}
```

Particle Render Blit v2

- Wait for GL to finish rendering from the vbo.

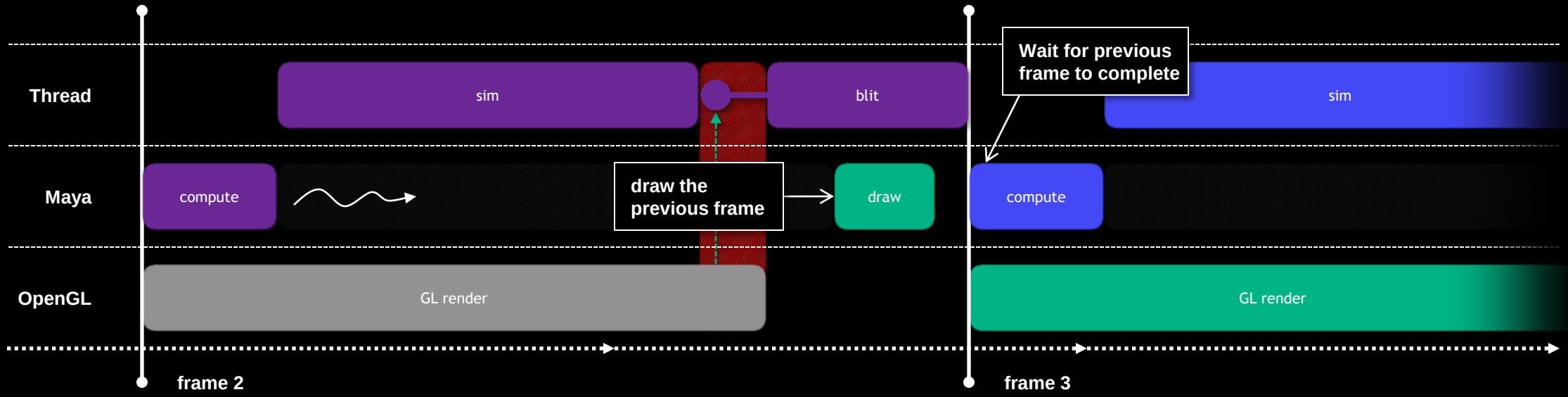
```
void jobBlit(Data* d)
{
     d->blitMutex.claim();

     if (glIsSync(d->glVboSync))
     {
          glClientWaitSync(d->glVboSync, GL_SYNC_FLUSH_COMMANDS_BIT, GL_FOREVER);
          glDeleteSync(d->glVboSync);
          d->glVboSync = 0;
     }

     void* glVboPositionsPtr = 0;
     size_t nBytes = 0;
     cudaGraphicsMapResources(1, &d->cuGlRes, d->cuStream);
     cudaGraphicsResourceGetMappedPointer(&glVboPositionsPtr, (size_t*)&nBytes, d->cuGlRes);
     cudaMemcpyAsync(glVboPositionsPtr, d->cuPositions, nBytes, cudaMemcpyDeviceToDevice, d->cuStream);
     cudaGraphicsUnmapResources(1, &d->cuGlRes, d->cuStream);

     d->blitMutex.release();
}
```

Example 1: Synchronous CUDA thread

- Advantages:
  - Simple to implement.
  - Multi-threading protects our plug-in / host app.
- Disadvantages:
  - We are relying on Maya calling our update at the start, and our render at the end!

Example 2: Double-buffered CUDA thread

- Allow latency and overlap sim with host app.
- Ping-pong into double-buffered VBOs.
  - (We still require sync objects if draw[readIndex] overlaps with blit[writeIndex].)



Particle Render Blit - doublebuffered

```
void jobBlit(Data* d)
{
     d->blitMutex.claim();

     if (glIsSync(d->glVboSync[d->current]))
     {
          glClientWaitSync(d->glVboSync[d->current], GL_SYNC_FLUSH_COMMANDS_BIT, GL_FOREVER);
          glDeleteSync(d->glVboSync[d->current]);
          d->glVboSync[d->current] = 0;
     }

     void* glVboPositionsPtr = 0;
     size_t nBytes = 0;
     cudaGraphicsMapResources(1, &d->cuGlRes[d->current], d->cuStream);
     cudaGraphicsResourceGetMappedPointer(&glVboPositionsPtr, (size_t*)&nBytes, d->cuGlRes[d->current]);
     cudaMemcpyAsync(glVboPositionsPtr, d->cuPositions, nBytes, cudaMemcpyDeviceToDevice, d->cuStream);
     cudaGraphicsUnmapResources(1, &d->cuGlRes[d->current], d->cuStream);
     d->current = (++d->current)%2; // ping-pong

     d->blitMutex.release();
}
```

Particle Render - doublebuffered

```
void Plugin::draw()
{
     Data* d = &_data;
     d->blitMutex.claim();

     glBindBuffer(GL_ARRAY_BUFFER, d->glVboPositions[d->current]);
     glVertexPointer(4, GL_FLOAT, 0, 0);
     glEnableClientState(GL_VERTEX_ARRAY);
     glDrawArrays(GL_POINTS, 0, d->nParticles);
     glBindBuffer(GL_ARRAY_BUFFER, 0);
     glDisableClientState(GL_VERTEX_ARRAY);

     d->glVboSync[d->current] = glFenceSync(GL_SYNC_GPU_COMMANDS_COMPLETE, 0);

     d->blitMutex.release();
}
```

Asynchronous CUDA streams

- Batching the data means…
  - We hide the cost of data transfer between device and host.
  - Extension to Multi-GPU is now trivial.
- NB. Not all algorithms can batch data.
- Each batch's stream requires resource allocation.
  - Be sure to do this up-front, (before OpenGL gets it all!)
  - Number of batches can be chosen based on available resources.

NVIDIA Maximus

- Quadro AND Tesla with 6GB & 448 cores.

- Benefits of Maximus
  - Uses GL-interop for efficient data movement to the Quadro GPU
  - DCC apps like Maya already use many GPU resources.
  - Share the data between two cards allowing for larger simulations.
  - Multi-GPU is scalability for the future.
  - “batch” simulation on your workstation.

Demo

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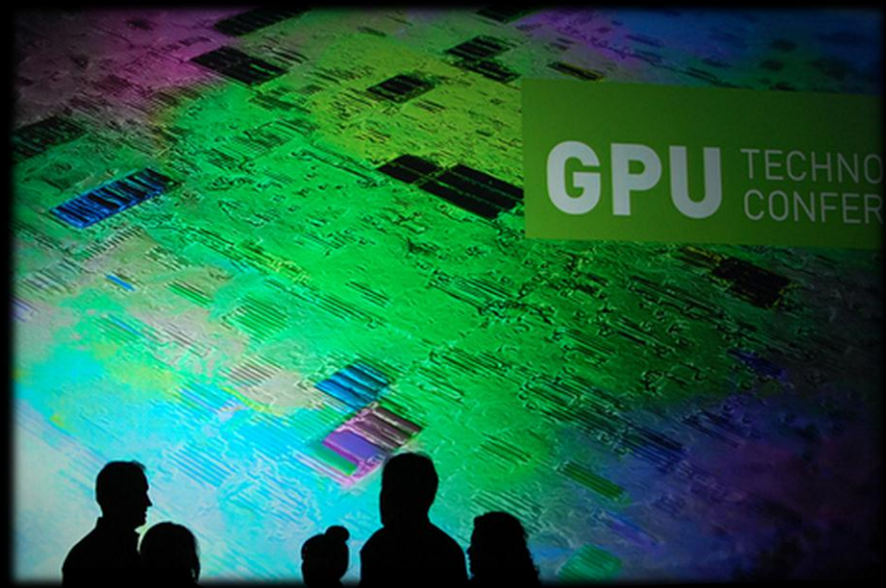

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