GPU TECHNOLOGY CONFERENCE

April 4-7, 2016 | Silicon Valley

OPENGL BLUEPRINT RENDERING

Christoph Kubisch, 4/7/2016

PRESENTED BY NVIDIA

MOTIVATION

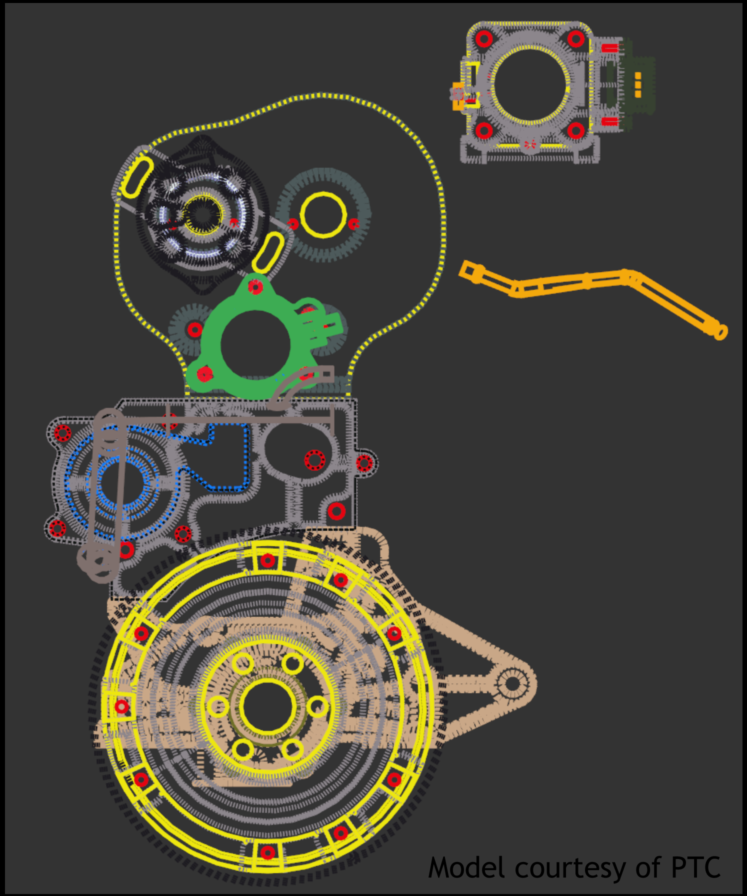
Blueprints / drawings in CAD/graph viewer applications

Documents can contain many LINES and LINE_STRIPS

Various line styles can be used (world-space widths, stippling, joints, caps...)

Potential CPU bottlenecks

- Generating geometry for complex styles
- Collecting and rendering geometry



MOTIVATION

Not targeting full vector graphics

NV_path_rendering covers high fidelity vector graphics rendering

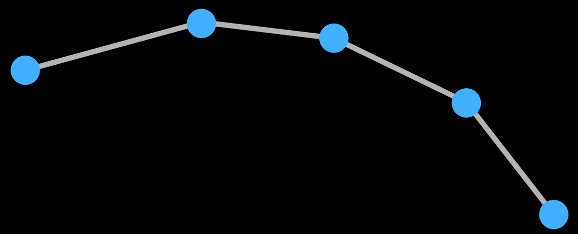
Per-pixel quadratic Bézier evaluation

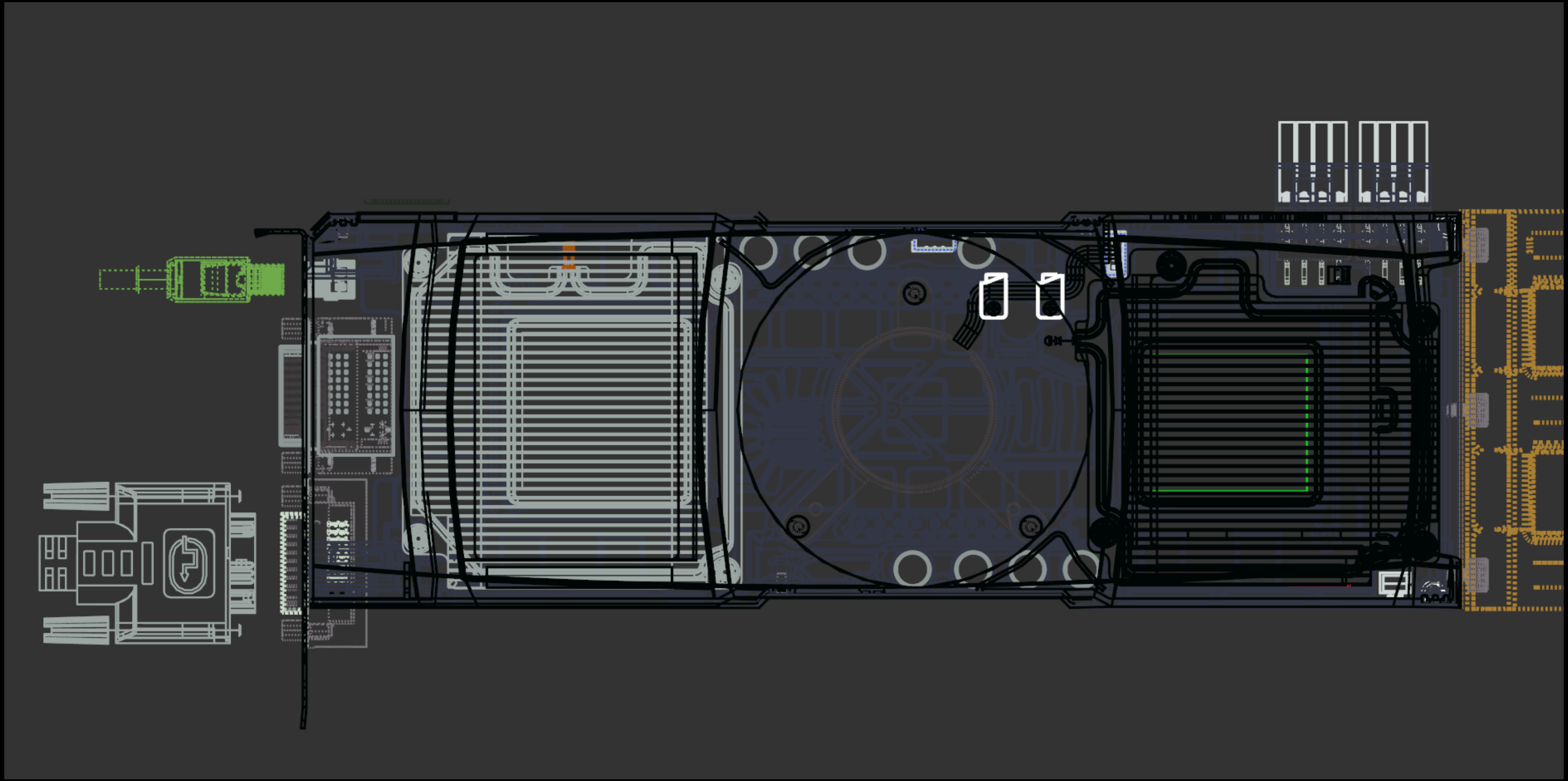
Stencil & Cover pass to allow sophisticated blending

Focus of this talk is rendering lines defined by traditional vertices

Rendering data from OpenGL buffer objects

Single-pass, but does mean not safe for blending (does self-overlap)





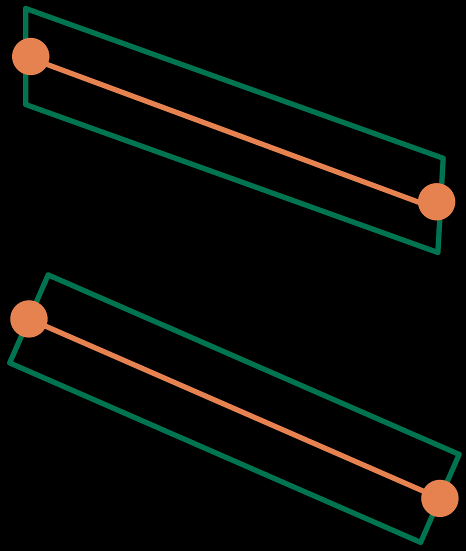
DEMO: BASIC DEMONSTRATION

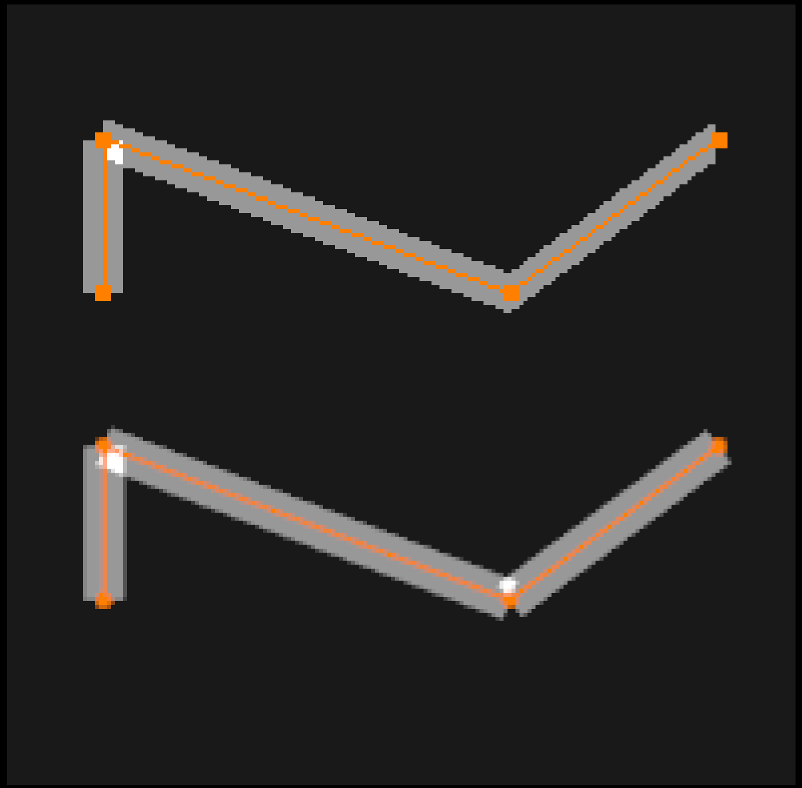
LINE RASTERIZATION

Representation

Standard:
skewed rectangle
pixel snapped lines

Multisampling:
aligned rectangle
smooth lines





Both suffer from visible gaps and overlaps on increasing line width

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LINE RASTERIZATION

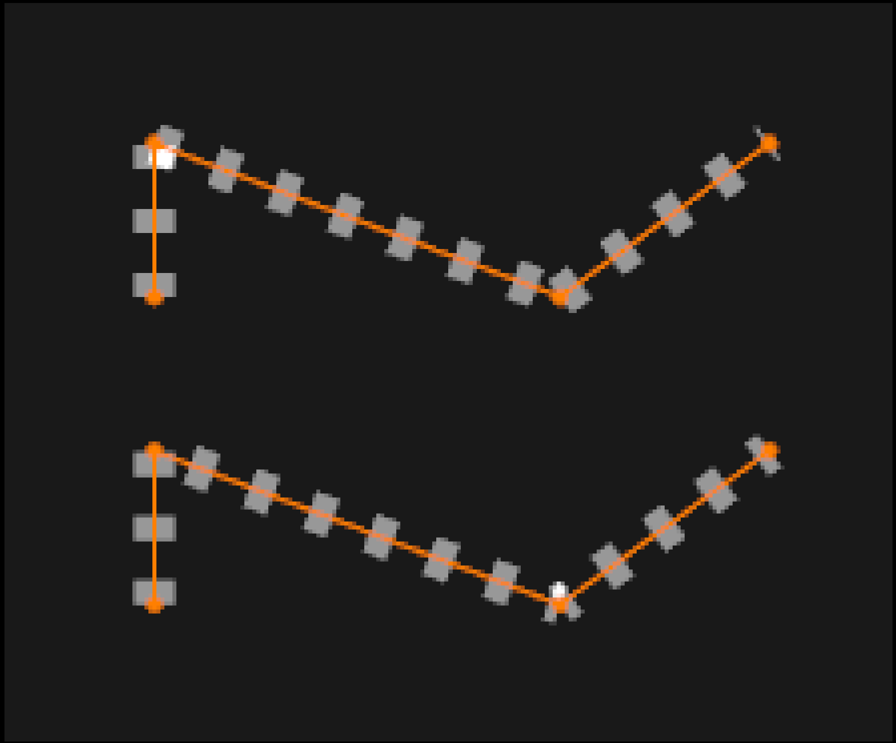
Stippling

Stippling only in screenspace

Patterns must be expressable with 16 bits

LINES re-start pattern every segment

LINE_STRIPS have continous distance



SHADER-DRIVEN LINES

TECH

Create TRIANGLES/QUADS for line segments

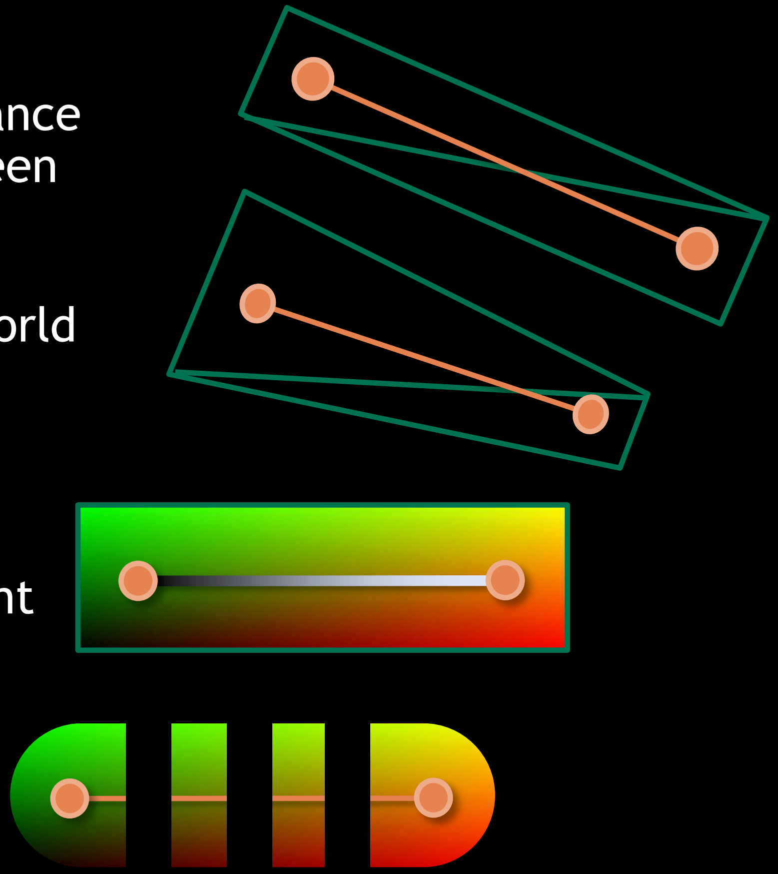
Project extruded vertices to keep line width consistent

Clip and color in fragment shader based on UV coordinates and line distance

Appearance on screen

Geometry in world coordinates

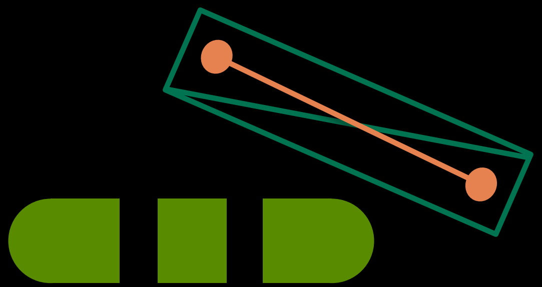
Shapes via fragment shader discard



SHADER-DRIVEN LINES

TECH

Create TRIANGLES for line segments, project extrusion to world/screen, discard fragments



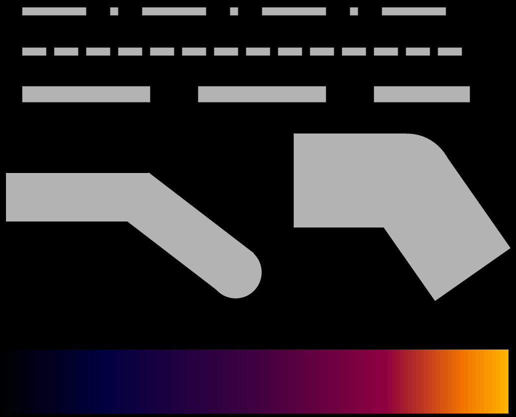
FLEXIBILITY

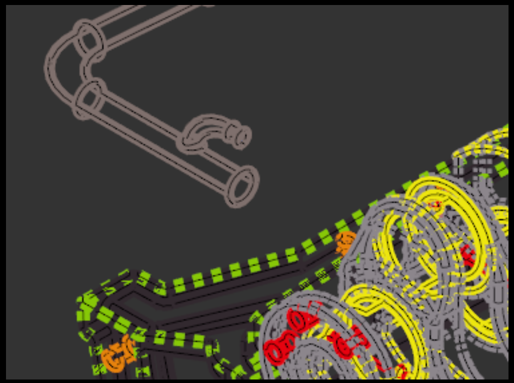
Arbitrary stippling patterns and line widths

Joint- and cap-styles

Different distance metrics

New coloring/animation possibilities via shaders



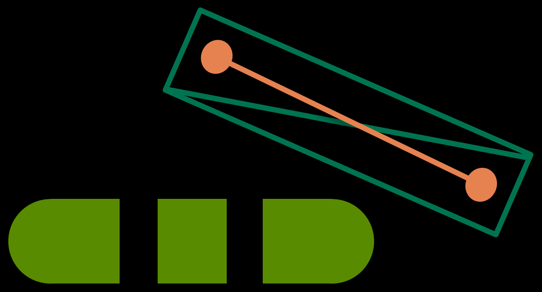


Thin center line as effect

SHADER-DRIVEN LINES

TECH

Create TRIANGLES for line segments, project extrusion to world/screen, discard fragments



FLEXIBILITY

Arbitrary stippling patterns and line widths

Joint- and cap-styles

Different distance metrics

New coloring/animation possibilities via shaders

CAVEATS

Cannot be as fast as basic line rasterization

Not all data local at rendering time (line strip distances need extra calculation)

Geometry still self-overlaps

SHADER-DRIVEN LINES

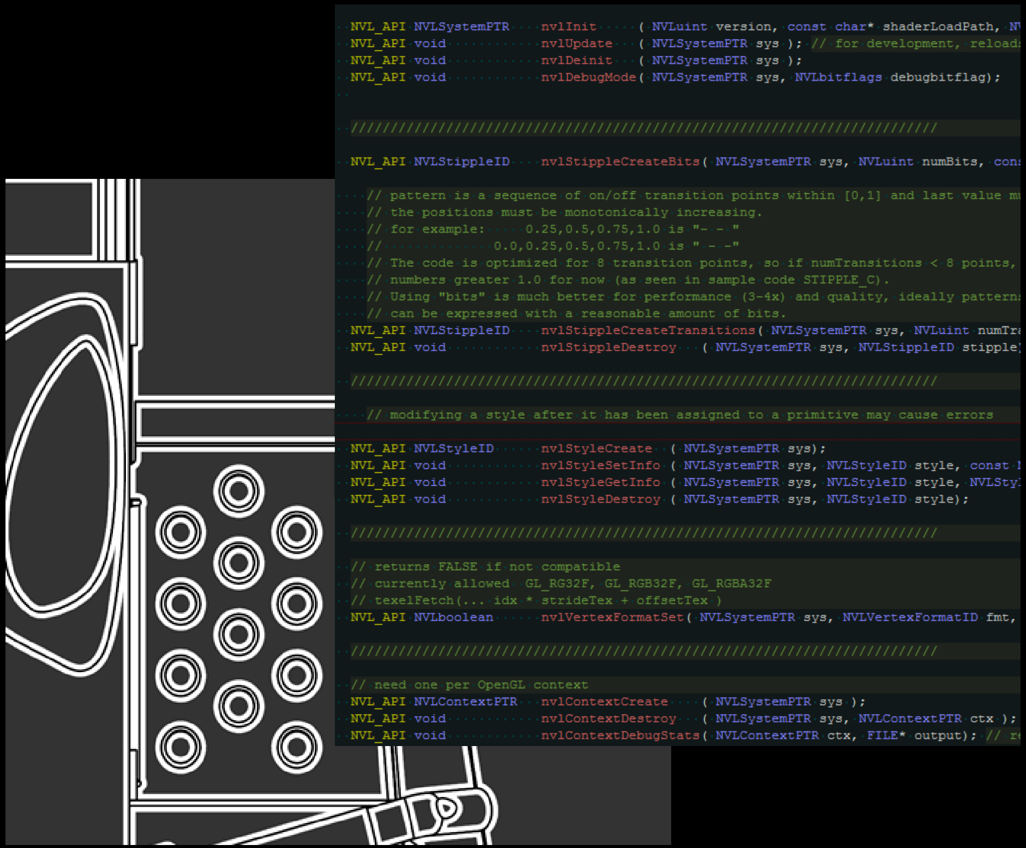
Sample implementation/library

C interface library to render different line primitives (LINES, LINE_STRIPS, ARCS) provided as flexible framework rather than black-box

Two different render-modes:
render as extruded triangles,
or one pixel wide lines

Uses NVIDIA and ARB OpenGL extensions if available

NVIDIA. DESIGNWORKS™

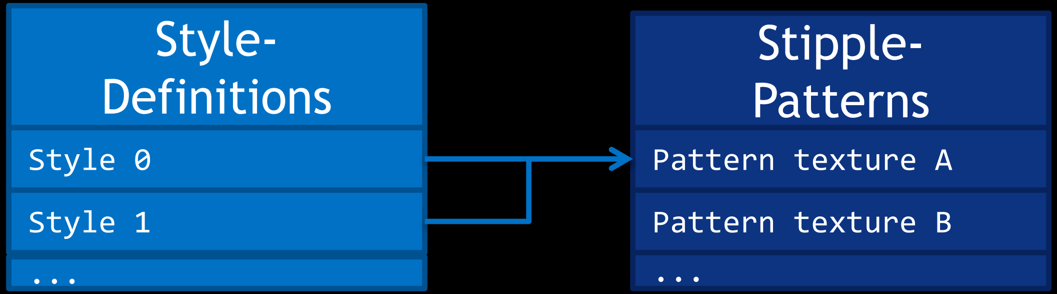


SHADER-DRIVEN LINES

Sample implementation/library

Global style and stipple definitions

Stipple from arbitrary bit-pattern, or float values




```
typedef struct NVLStyleInfo_s {
  NVLSpaceType          projectionSpace;
  NVLJoinType           join;
  NVLCapsType           capsBegin;
  NVLCapsType           capsEnd;
  float                 thickness;
  NVLStippleID          stipplePattern;
  float                 stippleLength;
  float                 stippleOffsetBegin;
  float                 stippleOffsetEnd;
  NVLAnchorType         stippleAnchor;
  NVLboolean            stippleClamp;
} NVLStyleInfo;
```

```
typedef enum NVLSpaceType_e {
  NVL_SPACE_SCREEN,
  NVL_SPACE_SCREENDIST3D,
  NVL_SPACE_CUSTOM,
  NVL_SPACE_CUSTOMDIST3D,
  NVL_NUM_SPACES,
}NVLSpaceType;
```

```
typedef enum NVLCapsType_e {
  NVL_CAPS_NONE,
  NVL_CAPS_ROUND,
  NVL_CAPS_BOX,
  NVL_NUM_CAPS,
}NVLCapsType;
```

```
typedef enum NVLAnchorType_e {
  NVL_ANCHOR_BEGIN,
  NVL_ANCHOR_END,
  NVL_ANCHOR_BOTH,
  NVL_NUM_ANCHORS,
}NVLAnchorType;
```

```
typedef enum NVLJoinType_e {
  NVL_JOIN_NONE,
  NVL_JOIN_ROUND,
  NVL_JOIN_MITER,
  NVL_NUM_JOINS,
}NVLJoinType;
```

SHADER-DRIVEN LINES

Sample implementation/library

Uses GPU friendly collection mechanism:
Record many primitives then render
Optionally render sub-sections

Raw Primitives pass vertex data directly

Geometry Primitives reference existing Vertex Buffers

Collections have usage-style flags:

- filled new per-frame
- recorded once, re-used many frames

Geometry/Raw Recording

Geometry Primitives | VBO reference

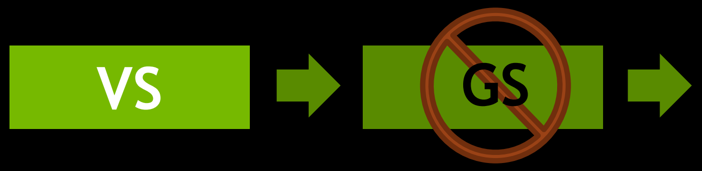
Raw Primitives | Vertex values

Matrix | Color

Style reference

SHADER-DRIVEN LINES

Quad extrusion



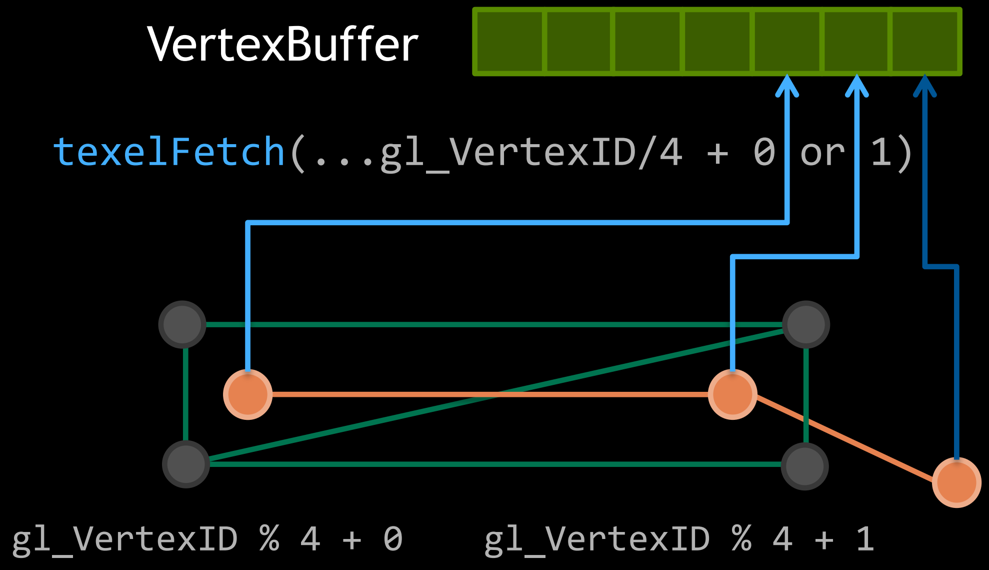
Faster geometry creation by just using Vertex-Shader, avoiding extra Geometry-Shader stage

Render GL_QUADS (4 vertices each segment)

Use gl_VertexID to fetch line points

Use it for the offsets as well

Using custom vertex-fetch generally not recommended, but useful for special situations

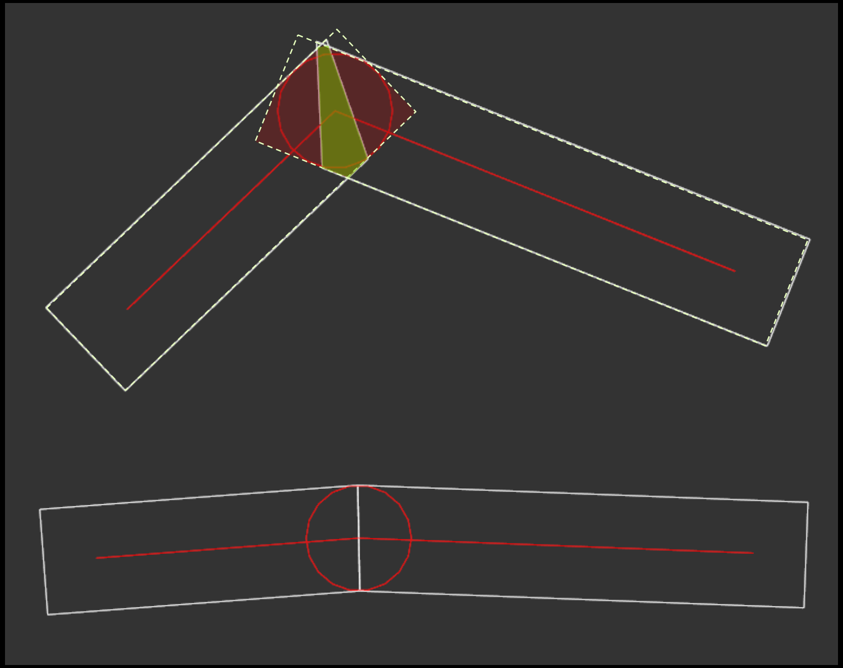


SHADER-DRIVEN LINES

Minimize Overdraw

No naive rectangles but adjacency in LINE_STRIP is used to tighten the geometry

Reduces overdraw and minimizes potential artifacts resulting from that



SHADER-DRIVEN LINES

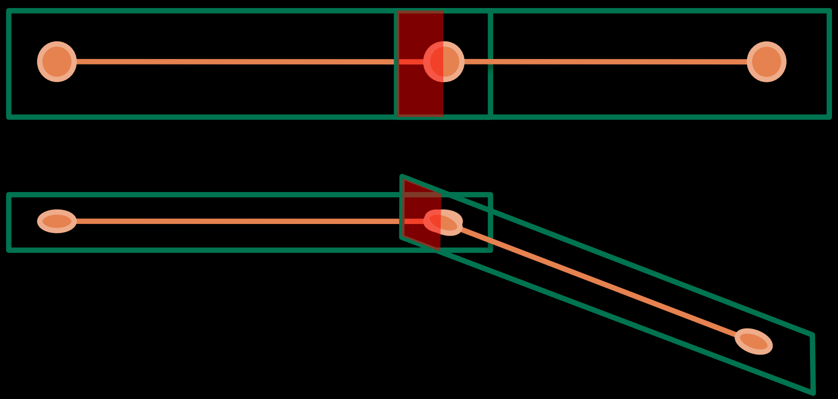
Depth clamping

Joints and caps exceed original line definition

Can cause depth-buffer artifacts

Prevent depth over-shooting by passing closest depth to fragment shader and clamp there

Can use ARB_conservative_depth or just min/max to keep hardware z-cull active

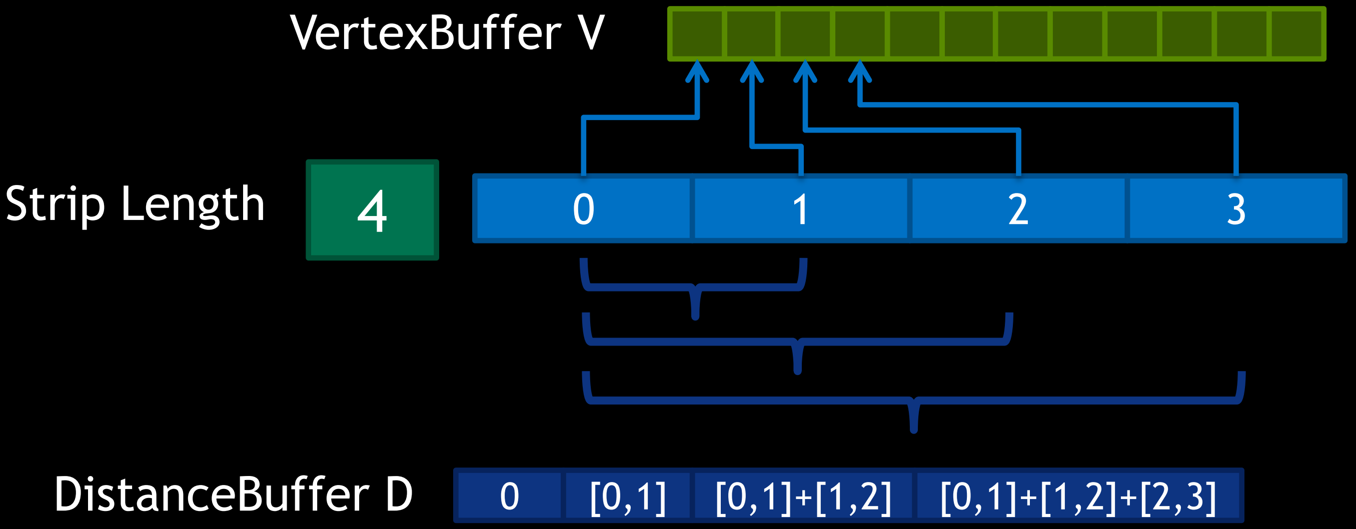


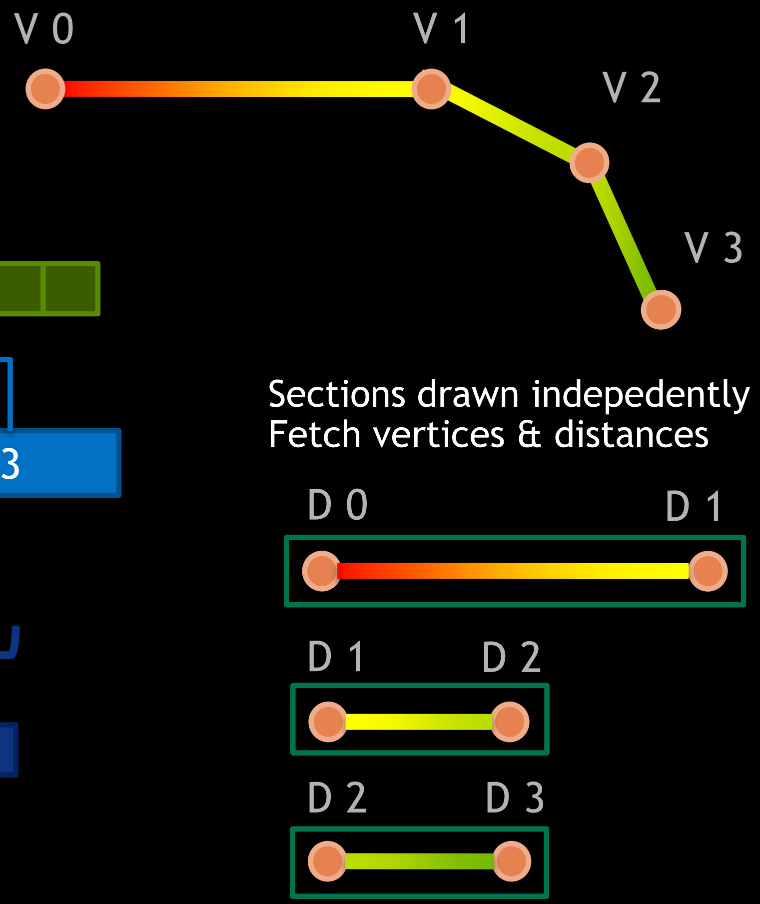
```
#extension GL_ARB_conservative_depth : require
layout (depth_greater) out float gl_FragDepth;

in flat float closestPointDepth;
...

gl_FragDepth = max(gl_FragCoord.z,
                   closestPointDepth);
```

DISTANCE COMPUTATION

LINE_STRIPS need dedicated calculation phase

Read vertices and calculate distances along the strip





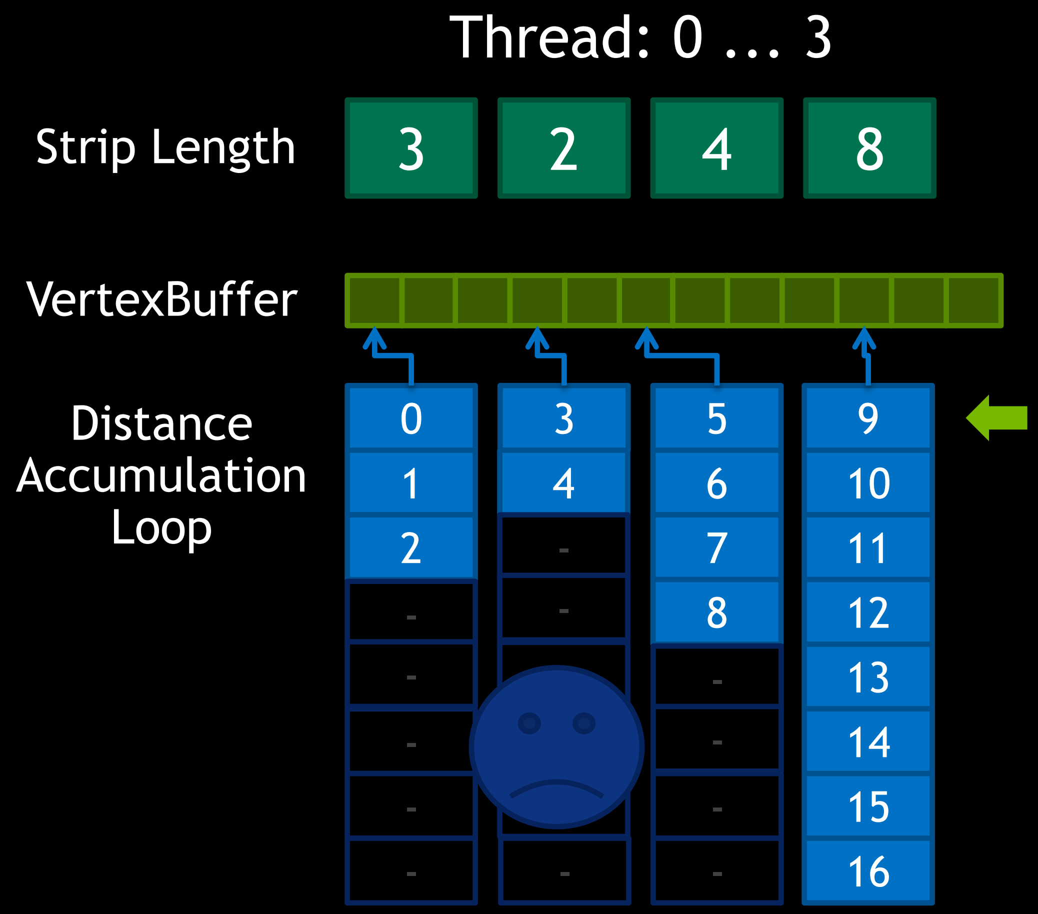
Distances are fetched at render-time

DISTANCE COMPUTATION

Shader Tips

One LINE_STRIP per thread can lead to under utilization and non ideal memory access due to divergence

SIMT hardware processes threads together in lock-step, common instruction pointer (masks out inactive threads).
NVIDIA: 1 warp = 32 threads



DISTANCE COMPUTATION

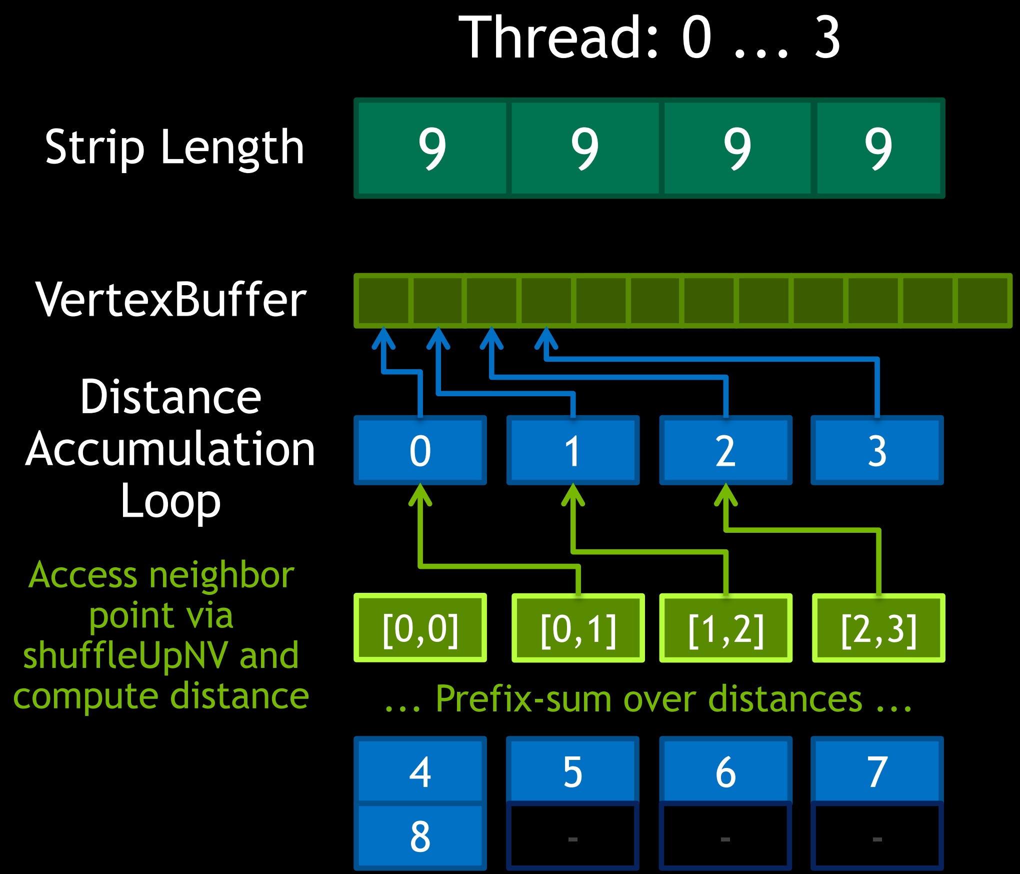
Shader Tips

Compute one LINE_STRIP at a time across warp, gives nice memory fetch

NV_shader_thread_shuffle to access neighbors and do prefix-sum calculation

```
vec3 posA = getPosition ( gl_ThreadInWarpNV + …)
vec3 posB = shuffleUpNV (posA, 1, gl_WarpSizeNV);
... Handle first thread point differently
float dist = distance(posA, posB);
```

Short strips may still under-utilize warp, but are taking only one iteration



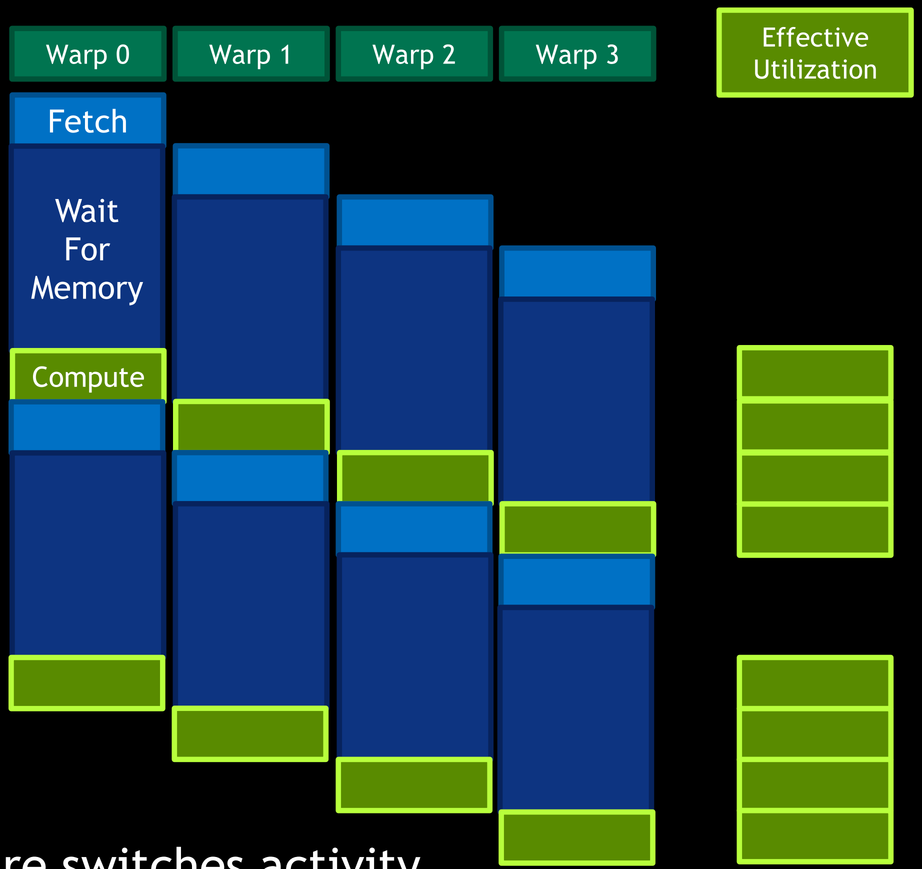
DISTANCE COMPUTATION

Batching & Latency hiding

Memory intensive operations prefer many threads to hide latency of fetch

Would not „compute“ distance for a single strip, but need many strips to work on

Use one warp per strip if total amount of threads is low



Hardware switches activity between entire warps

DISTANCE COMPUTATION

Batching & Latency hiding

Launch overhead of compute dispatch not negligable for < 10 000 threads

Use glEnable(GL_RASTERIZER_DISCARD); and Vertex-Shader to do compute work

No shared memory but warp data sharing as seen before (ARB_shader_ballot or NV_shader_thread_shuffle)

```
... "Compute" alternative for few threads
if (numThreads < FEW_THREADS){
  glUseProgram( vs );
  glEnable    ( GL_RASTERIZER_DISCARD );
  glDrawArrays( GL_POINTS, 0, numThreads );
  glDisable   ( GL_RASTERIZER_DISCARD );
}
else {
  glUseProgram( cs );
  numGroups = (numThreads+GroupSize-1)/GroupSize;
  glUniformi1 (0, numThreads);
  glDispatchCompute ( numGroups, 1, 1 );
}

... Shader
#if USE_COMPUTE
  layout (local_size_x=GROUP_SIZE) in;
  layout (location=0)  uniform int numThreads;
  int threadID = int( gl_GlobalInvocationID.x );
#else
  int threadID = int( gl_VertexID );
#endif
```

SMOOTH TRANSITIONS

Anti-aliasing edges within shader

Fragment shader effects cause outlines of visible shapes to be within geometry

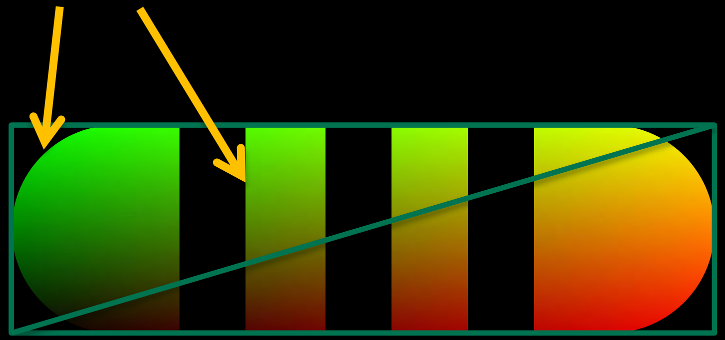
MSAA will not add quality „within triangle“

Need to compute coverage accurately (sample-shading) or approximate

Use of gl_SampleID (e.g. with interpolateAtSample) automatically makes shader run per-sample, „discard“ will affect coverage mask properly

Cheaper: GL_SAMPLE_ALPHA_TO_COVERAGE or clear bits in gl_SampleMask

No geometric edges → No MSAA benefit



```
in float stippleCoord;
...

sc = interpolateAtSample (stippleCoord, gl_SampleID);
stippleResult = computeStippling( sc );
if (stippleResult < 0) discard;
```

SMOOTH TRANSITIONS

Using Pixel Derivatives

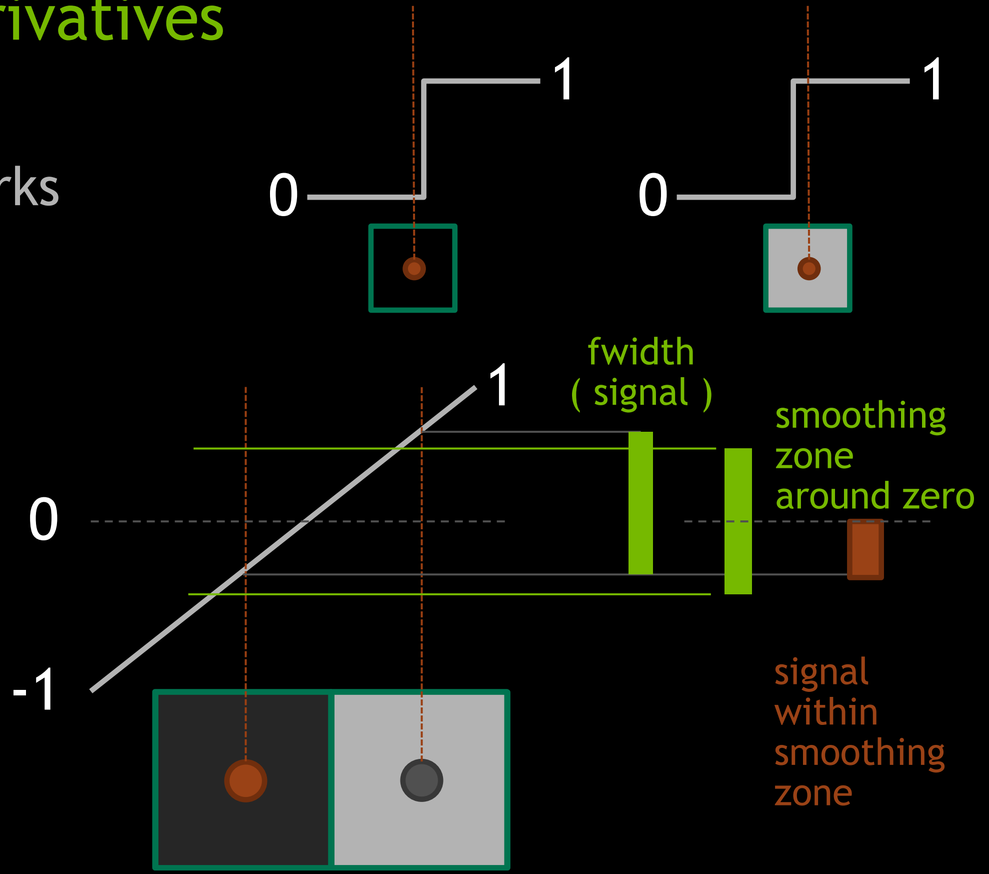
Simple trick to get smooth transitions, also works well on surface contour lines

Use a signed distance field, instead of step function

Find if sample is close to transition (zero crossing) via fwidth

Compute smooth weight if required

```
float weight = signal < 0 ? -1 : 1;
float zone = fwidth ( signal ) * 0.5;
if (abs (signal) < zone){
  weight = signal / zone;
}
```



RECORDING RAW DATA

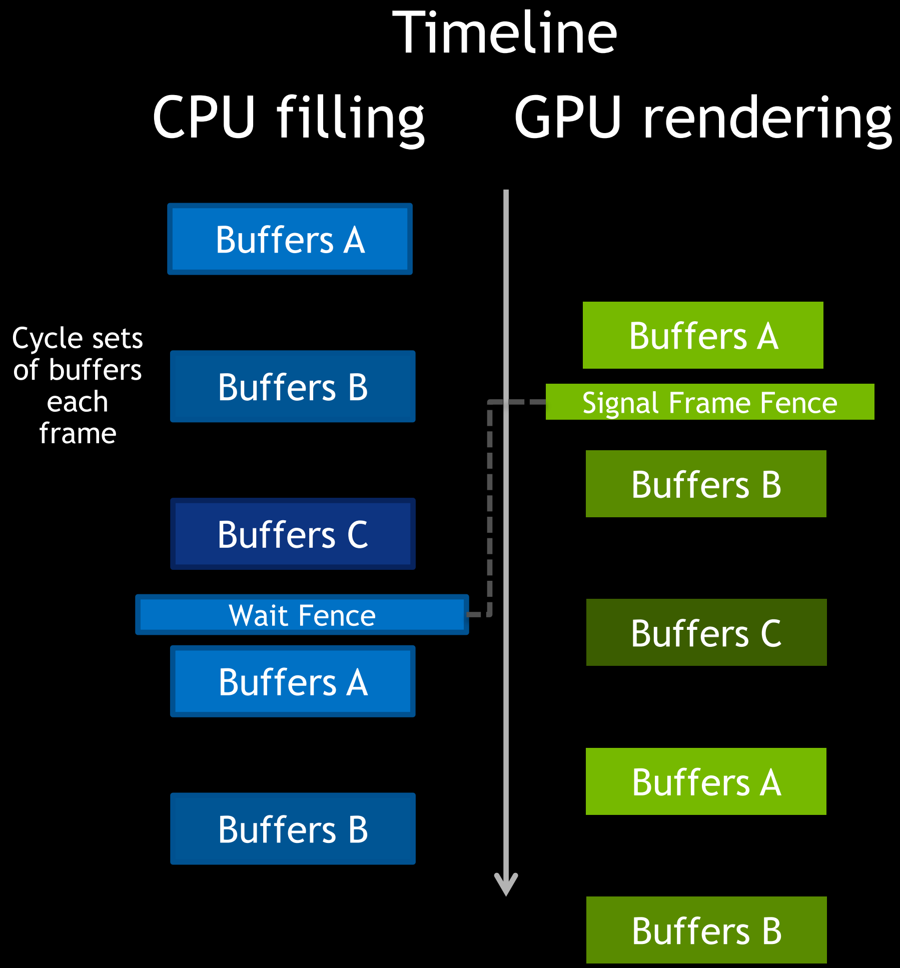
Using persistent mapped buffers

When primitives & vertices are not re-used, but regenerated by CPU, we want a fast way to get them to GPU

Use ARB_buffer_storage/OpenGL 4.3 to have buffers in CPU memory for fast copying

Need fences to avoid overwriting data still used by GPU, 3 frames typically enough to avoid synchronization

CPU memory access „okayish“ if data only read rarely (once for stipple-compute, once for render)



RENDERING ARCS

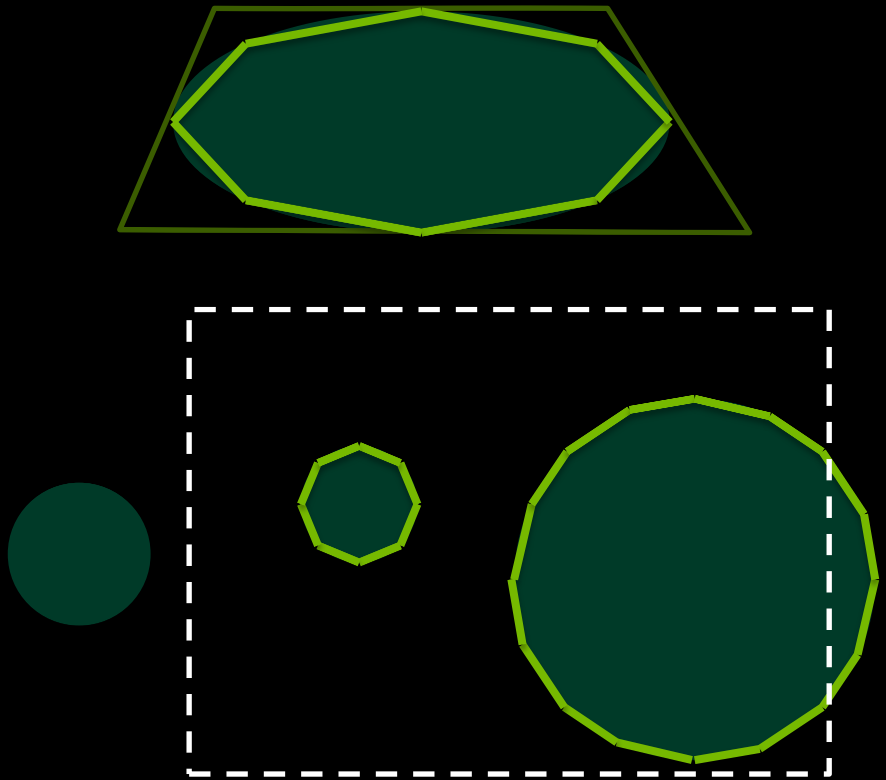
Not trivial to compute distance along an arbitrary projected arc/circle

Approximate circle as line strip

Allocate maximum subdivision

Compute adaptively based on screen-space size (or frustum cull)

Rendering only needs to fetch distance values, can still compute position on the fly



OUTLOOK & CONCLUSION

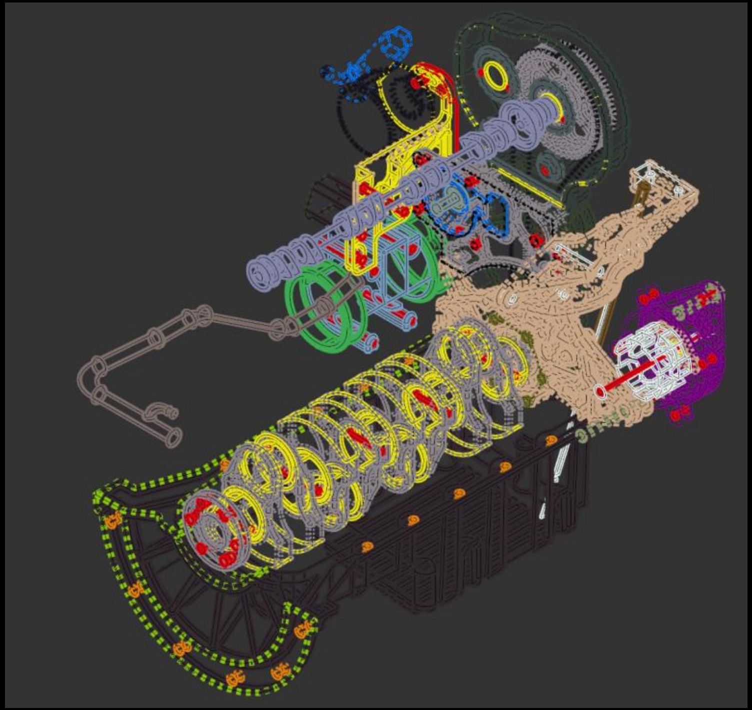
Preserving all primitive order not optimal for performance, ideally application can operate in layers.

Code your own special primitives for annotations (arrows...)

Use of shaders can increase visual quality beyond „fancy surface shading“

Do not need actual geometry for everything (distance fields are great)

GPU programmable enough to move more effects from CPU to GPU



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