Visual Computing Group

Part 4.5

Scalable Mobile Visualization: Smart precomputation for complex lighting

Pere-Pau Vázquez, UPC

High quality illumination

- **Consistent illumination for AR**
- **Soft shadows**
- **Deferred shading**
- **Ambient Occlusion**

Consistent illumination for AR

- **High-Quality Consistent Illumination in Mobile Augmented Reality by Radiance Convolution on the GPU [Kán, Unterguggenberger & Kaufmann, 2015]**

- **Goal**
  - Achieve realistic (and consistent) illumination for synthetic objects in Augmented Reality environments

Consistent illumination for AR

- **Overview**
  - Capture the environment with the mobile
  - Create an HDR environment map
  - Convolve the HDR with the BRDF's of the materials
  - Calculate radiance in realtime
  - Add AO from an offline rendering as lightmaps
  - Multiply with the AO from the synthetic object

Consistent illumination for AR

- **Capture the environment with the mobile**
  - Rotational motion of the mobile
    - In yaw and pitch angles to cover all sphere directions
  - Images accumulated to a spherical environment map
- **HDR environment map constructed while scanning**
  - Projecting each camera image
    - According to the orientation and inertial measurement of the mobile
  - Low dynamic range imaging is transformed to HDR
    - Camera uses auto-exposure
      - Two overlapping images will have slightly different exposure
  - Alignment correction based on feature matching
  - All in the device

Consistent illumination for AR

- **Convolve the HDR with the BRDF's of the materials**
  - Use MRT to support several convolutions at once
  - Assume distant light
  - One single light reflection on the surface
  - Scene materials assumed non-emissive
  - Use a simplified rendering equation
- **Weight with AO (obtained offline)**
  - Built for real and synthetic objects
  - Use the geometry of the scene
    - Use a proxy geometry for the objects of the real world
    - Cannot be simply done on the fly

Consistent illumination for AR

- **Results**

Without AO

With AO

Images courtesy of Peter Kán

Consistent illumination for AR

- **Performance**

3D model	# triangles	Framerate
Reflective cup	25.6K	29 fps
Teapot	15.7K	30 fps
Dragon	229K	13 fps

- **Limitations**
  - Materials represented by Phong BRDF
  - AO and most shading (e.g. reflection maps) is baked

Soft shadows using cubemaps

- **Efficient Soft Shadows Based on Static Local Cubemap [Bala & Lopez Mendez, 2016]**
- **Goal**
  - Soft shadows in realtime

Taken from https://community.arm.com/graphics/b/blog/posts/dynamic-soft-shadows-based-on-local-cubemap

Soft shadows using cubemaps

- **Overview**
  - Create a local cube map
    - Offline recommended
    - Stores color and transparency of the environment
    - Position and bounding box
      - ***Approximates the geometry***
    - Local correction
      - Using proxy geometry
  - Apply shadows in the fragment shader

Soft shadows using cubemaps

- **Generating shadows**
  - Fetch texel from cubemap
    - Using the fragment-to-light vector
    - Correct the vector before fetching
      - Using the scene geometry (bbox) and cubemap creation position
        - » To provide the equivalent shadow rays
  - Apply shadow based on the alpha value
  - Soften shadow
    - Using mipmapping and addressing according to the distance

Soft shadows using cubemaps

- **Conclusions**
  - Does not need to render to texture
    - Cubemaps must be pre-calculated
  - Requires reading multiple times from textures
  - Stable
    - Because cubemap does not change

- **Limitations**
  - Static, since info is precomputed

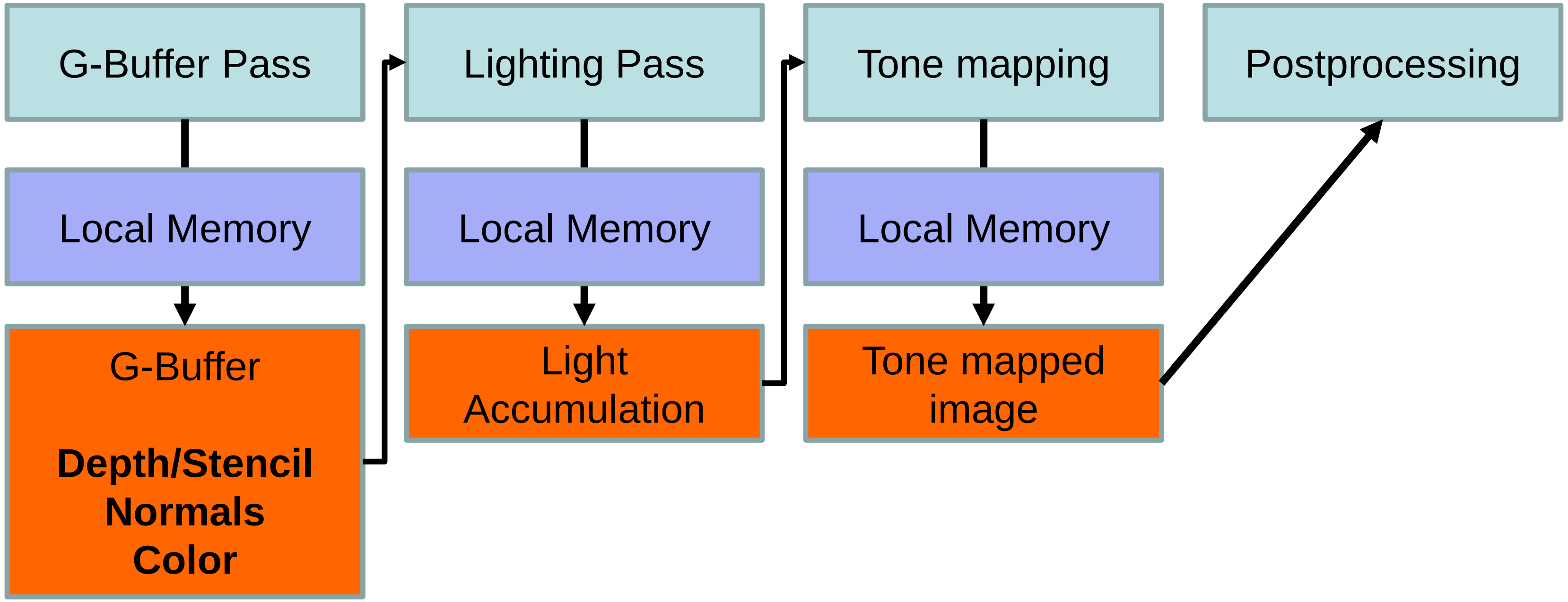
Physically-based Deferred Rendering

- **Physically Based Deferred Shading on Mobile [Vaughan Smith & Einig, 2016]**

- **Goal:**
  - Adapt deferred shading pipeline to mobile
  - Bandwidth friendly
  - Using Framebuffer Fetch extension
    - Avoids copying to main memory in OpenGL ES

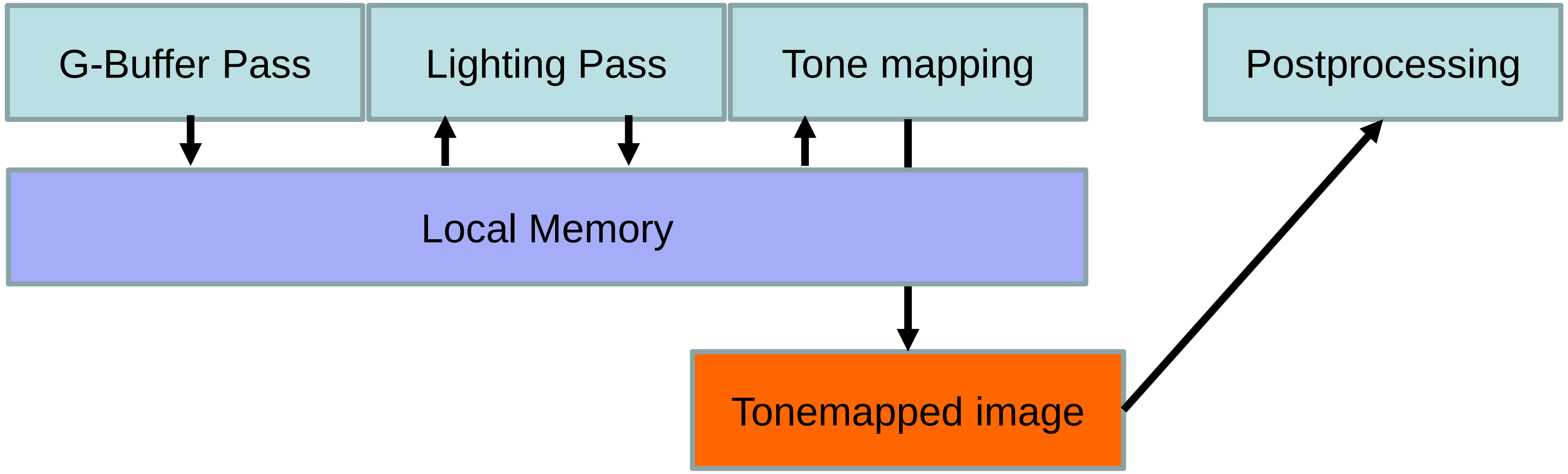
Physically-based Deferred Rendering

- **Overview**
  - Typical deferred shading pipeline



Physically-based Deferred Rendering

- **Main idea: group G-buffer, lighting & tone mapping into one step**
  - Further improve by using Pixel Local Storage extension
    - G-buffer data is not written to main memory
    - Usable when multiple shader invocations cover the same pixel
  - Resulting pipeline reduces bandwidth



Physically-based Deferred Rendering

- **Two G-buffer layouts proposed**
  - Specular G-buffer setup (160 bits)
    - Rgb10a2 highp vec4 light accumulation
    - R32f highp float depth
    - 3 x rgba8 highp vec4: normal, base color & specular color
  - Metallicness G-buffer setup (128 bits, more bandwidth efficient)
    - Rgb10a2 highp vec4 light accumulation
    - R32f highp float depth
    - 2 x rgba8 highp vec4: normal & roughness, albedo or reflectance metallicness

Physically-based Deferred Rendering

- **Lighting**
  - Use precomputed HDR lightmaps to represent static diffuse lighting
    - Shadows & radiosity
  - Can be compressed with ASTC (supports HDR data)
    - PVRTC, RGBM can also be used for non HDR formats
  - Geometry pass calculates diffuse lighting
  - Specular is calculated using Schlick’s approximation of Fresnel factor

Physically-based Deferred Rendering

- **Results (PowerVR SDK)**
  - Fewer rendering tasks
    - meaning that the G-buffer generation, lighting, and tonemapping stages are properly merged into one task.
    - reduction in memory bandwidth
      - 53% decrease in reads and a 54% decrease in writes
- **Limitations**
  - Still not big frame rates

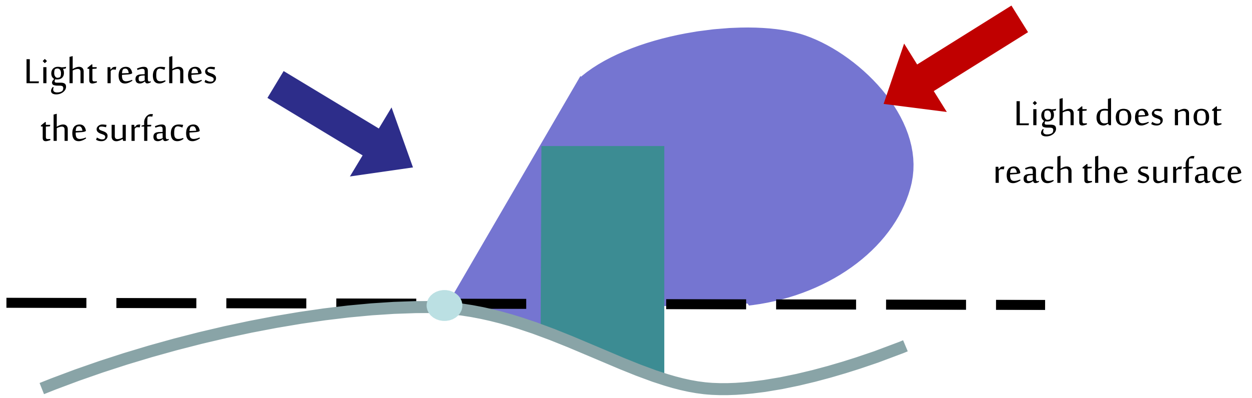
Ambient Occlusion in mobile

- **Optimized Screen-Space Ambient Occlusion in Mobile Devices [Sunet & Vázquez, Web3D 2016]**

- **Goal: Study feasibility of real time AO in mobile**
  - Analyze most popular AO algorithms: Crytek's, Alchemy's, Nvidia's Horizon-Based AO (HBAO), and Starcraft II (SC2)
  - Evaluate their AO pipelines step by step
  - Design architectural improvements
  - Implement and compare

Ambient Occlusion in mobile

- **Ambient Occlusion. Simplification of rendering equation**
  - The surface is a perfect diffuse surface (BRDF constant)
  - Light potentially reaches a point *p* equally in all directions
    - But takes into account point's visibility



$$L_o(p,\omega_o) = \frac{1}{\pi}\int_\Omega \rho(d(p,\omega_i))\,\cos\theta_i\,\mathrm{d}\omega_i$$

$$\rho(d) = \begin{cases} f(d) \in [0,1] & d < \text{threshold} \\ 0 & \text{otherwise} \end{cases}$$

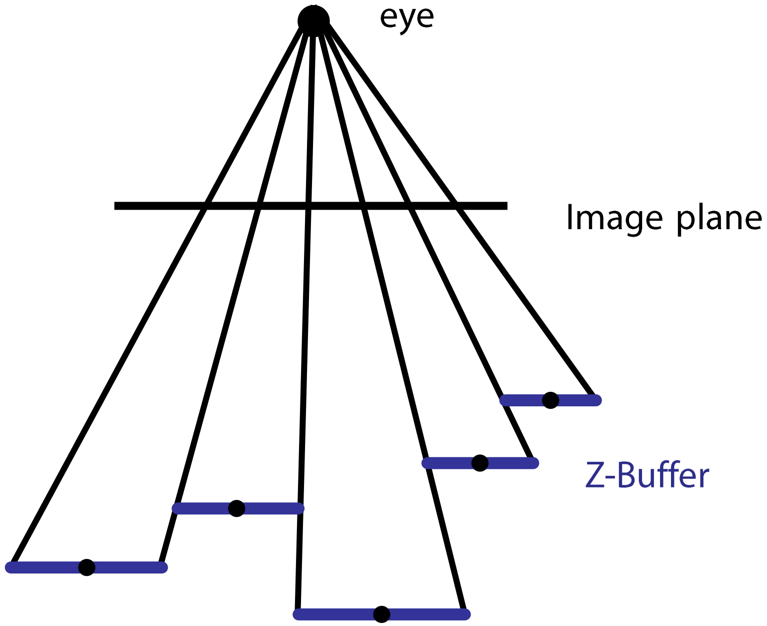
Ambient Occlusion in mobile

- **AO typical implementations**
  - Precomputed AO: Fast & high quality, but static, memory hungry
  - Ray-based: High quality, but costly, visible patterns…
  - Geometry-based: Fast w/ proxy structures, but lower quality, artifacts/noise…
  - Volume-based: High quality, view independent, but costly

  - Screen-space:
    - Extremely fast
    - View-dependent
    - [mostly] requires blurring for noise reduction
    - Very popular in video games (e.g. Crysis, Starcraft 2, Battlefield 3…)

Ambient Occlusion in mobile

- **Screen-space AO:**
  - Approximation to AO implemented as a screen-space post-processing
    - ND-buffer provides coarse approximation of scene's geometry
    - Sample ND-buffer to approximate (estimate) ambient occlusion instead of shooting rays



Assassin's Creed Syndicate

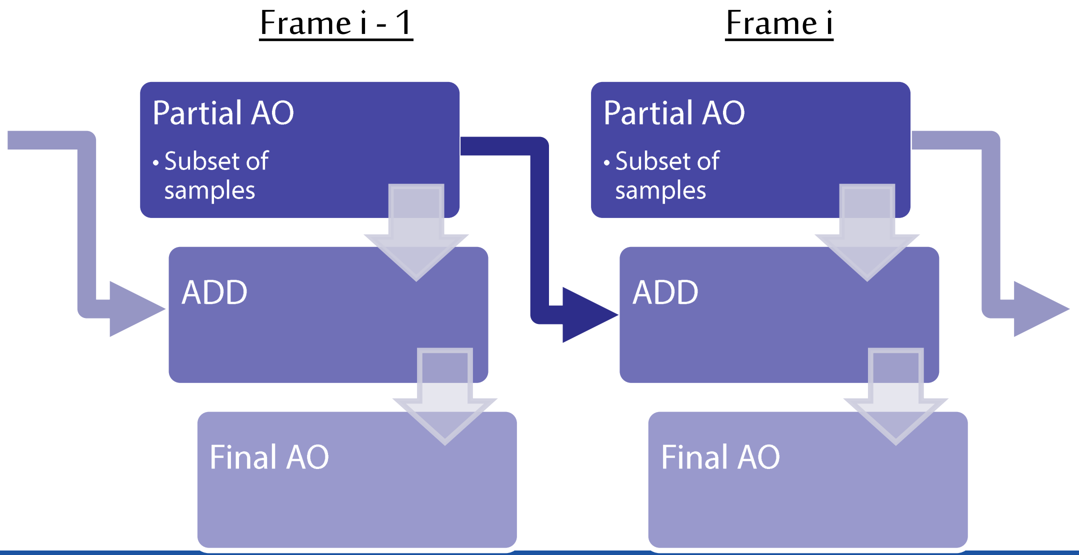
Ambient Occlusion in mobile

- **SSAO pipeline**
  1. Generate ND (normal + depth, OpenGL ES 2) or G-Buffer (ND + RGB…, OpenGL ES 3.+)
  2. Calculate AO factor for visible pixels
     a. Generate a set of samples of positions/vectors around the pixel to shade.
     b. Get the geometry shape (position/normal…)
     c. Calculate AO factor by analyzing shape…
  3. Blur the AO texture to remove noise artifacts
  4. Final compositing

Ambient Occlusion in mobile

- **Optimizations.**
  - G-Buffer storage (less precision)
    - 8 not enough
    - 16 and 32 similar quality
  - Normal storage (RGB vs RG)
    - RGB normals are faster
  - Samples generation (offline)
    - Poisson disc (2D) and 8-point cosine-weighted hemisphere (3D)
  - Geometry recovery
    - Similar triangles instead of inverse tf
  - Geometry storage
    - Store depth instead of 3D positions
      - Trades bandwidth for memory

- **Optimizations (cont)**
  - Banding and noise
    - Reduce noise using bilateral (separable) filter instead of Gaussian
  - Progressive improvement
    - Amortize AO through multiple frames



Ambient Occlusion in mobile

- **Optimizations**
  - Naïve improvement: Reduce the calculation to a portion of the screen
    - Mobile devices have a high PPI resolution
    - Reduction improves timings dramatically while keeping high quality
  - Typical reduction:
    - Offscreen render to 1/4th of the screen
    - Scale-up to fill the screen

- **Results**

Algorithm	Optimized (not progressive)	Optimized + progressive
Starcraft 2	17.8%	38.5%
HBAO	25.6%	39.2%
Crytek	23.4%	35.0%
Alchemy	24.8%	38.2%

Visual Computing Group

Part 4.5

Scalable Mobile Visualization: Volumetric Data

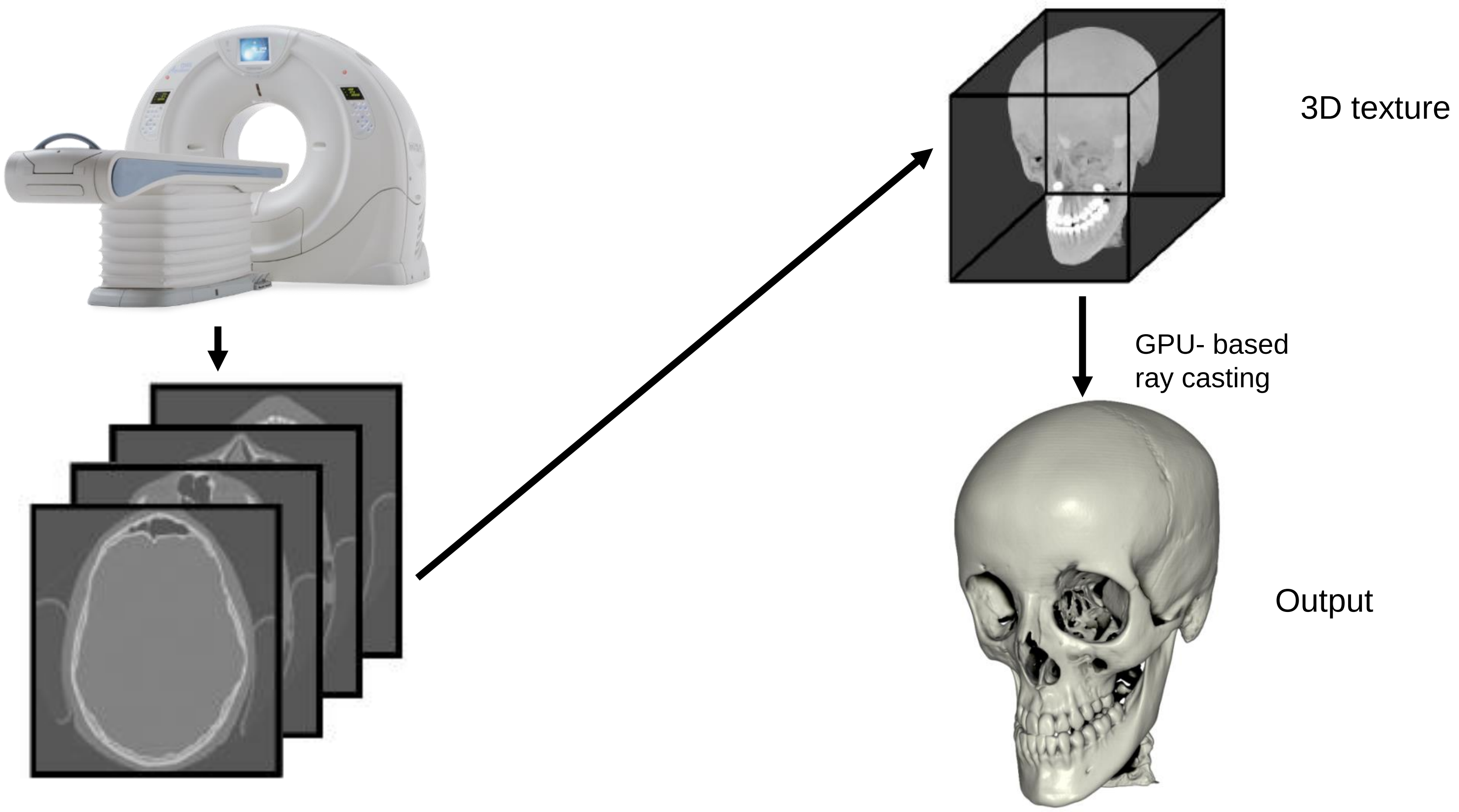
Pere-Pau Vázquez, UPC

Rendering Volumetric Datasets

- **Introduction**
- **Challenges**
- **Architectures**
- **GPU-based ray casting on mobile**
- **Conclusions**

Rendering Volumetric Datasets

Capturing **Rendering**



Rendering Volumetric Datasets

- **Introduction**
  - Volume datasets
    - Sizes continuously growing (e.g. >1024^3)
      - Complex data (e.g. 4D)
  - Rendering algorithms
    - GPU intensive
    - State-of-the-art is ray casting on the fragment shader
  - Interaction
    - Edition, inspection, analysis, require a set of complex manipulation techniques

Rendering Volumetric Datasets

- **Desktop vs mobile**
  - Desktop rendering
    - Large models on the fly
    - Huge models with the aid of compression/multiresolution schemes
  - Mobile rendering
    - Standard sizes (e.g. 512^3) still too much for the mobile GPUs
    - Rendering algorithms GPU intensive
      - State-of-the-art is GPU-based ray casting
    - Interaction is difficult on a small screen
      - Changing TF, inspecting the model…

Rendering Volumetric Datasets

- **Challenges on mobile:**
  - Memory:
    - Model does not fit into memory
      - Use client server approach / compress data
  - GPU capabilities:
    - Cannot use state of the art algorithm (e.g. no 3D textures)
      - Texture arrays
  - GPU horsepower:
    - GPU unable to perform interactively
      - Progressive rendering methods
  - Small screen
    - Not enough details, difficult interaction

Rendering Volumetric Datasets

- **Mobile architectures**
  - Server-based rendering
  - Hybrid approaches
  - Pure mobile rendering

  - Server-based and hybrid rely on high bandwidth communication

Rendering Volumetric Datasets

- **Pure mobile rendering**
  - Move all the work to the mobile
  - Nowadays feasible

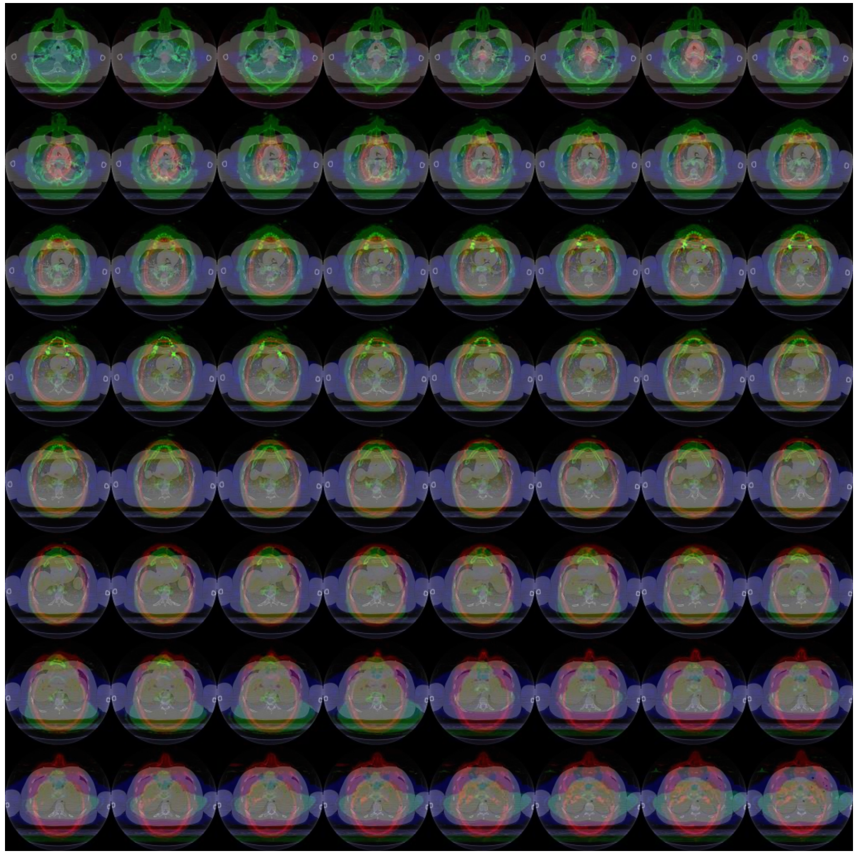
- **Direct Volume Rendering on mobile. Algorithms**
  - Slices
  - 2D texture arrays
  - **3D textures**

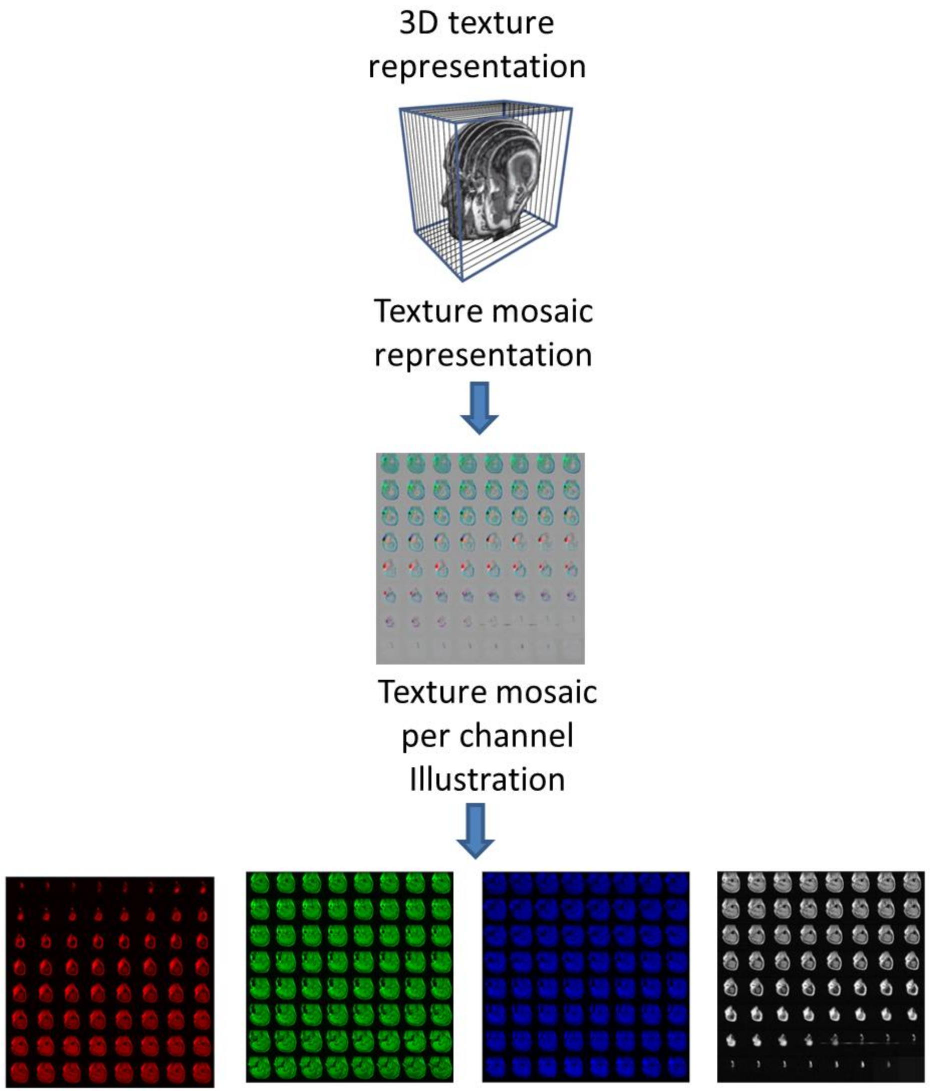
Rendering Volumetric Datasets

- **2D texture arrays + texture atlas [Noguera et al. 2012]**
  - Simulate a 3D texture using an array of 2D textures
  - Implement GPU-based ray casting
    - High quality
    - Relatively large models
    - Costly
    - Cannot use hardware trilinear interpolation

Rendering Volumetric Datasets

- **2D texture arrays + texture atlas**

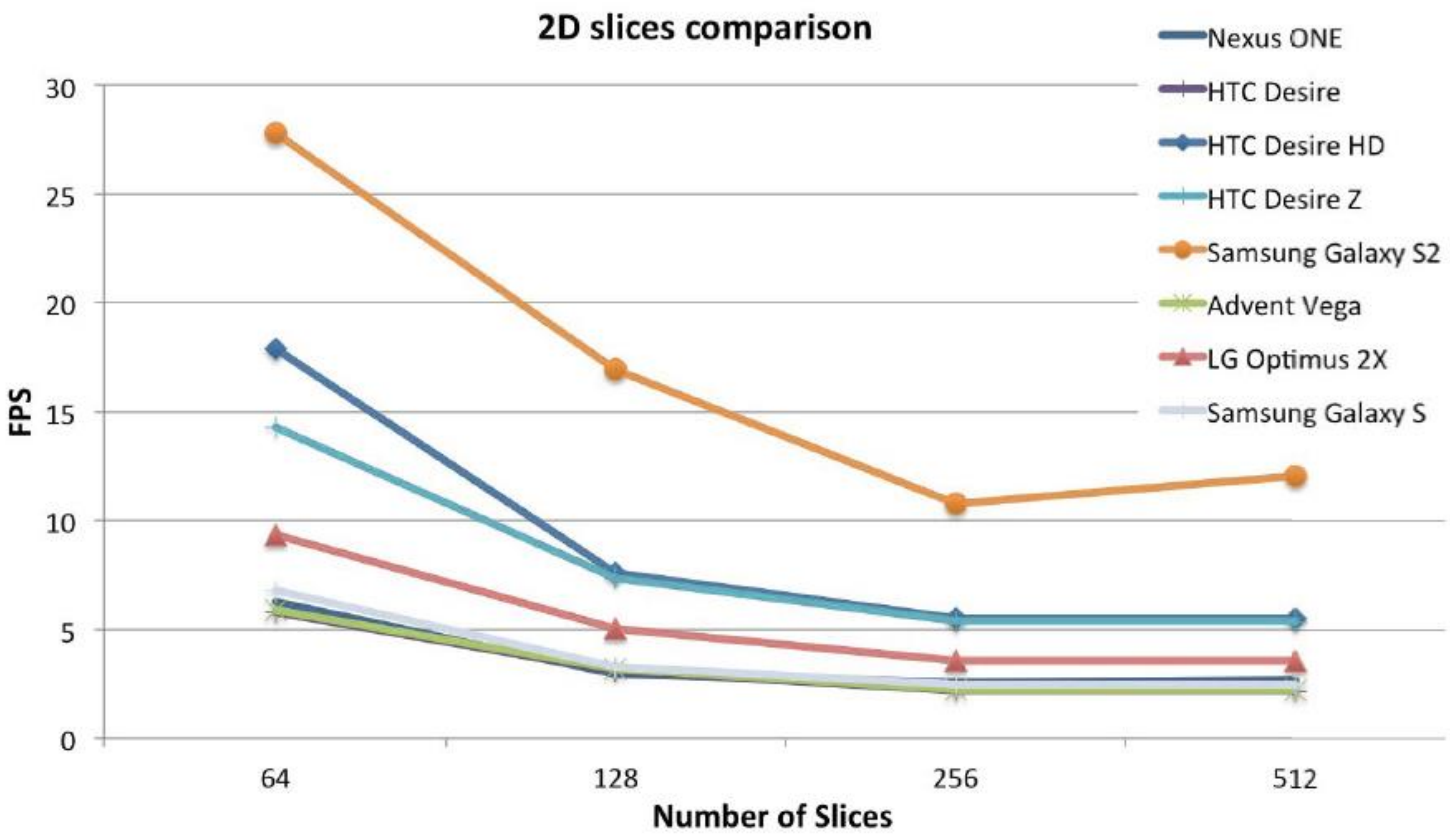




Rendering Volumetric Datasets

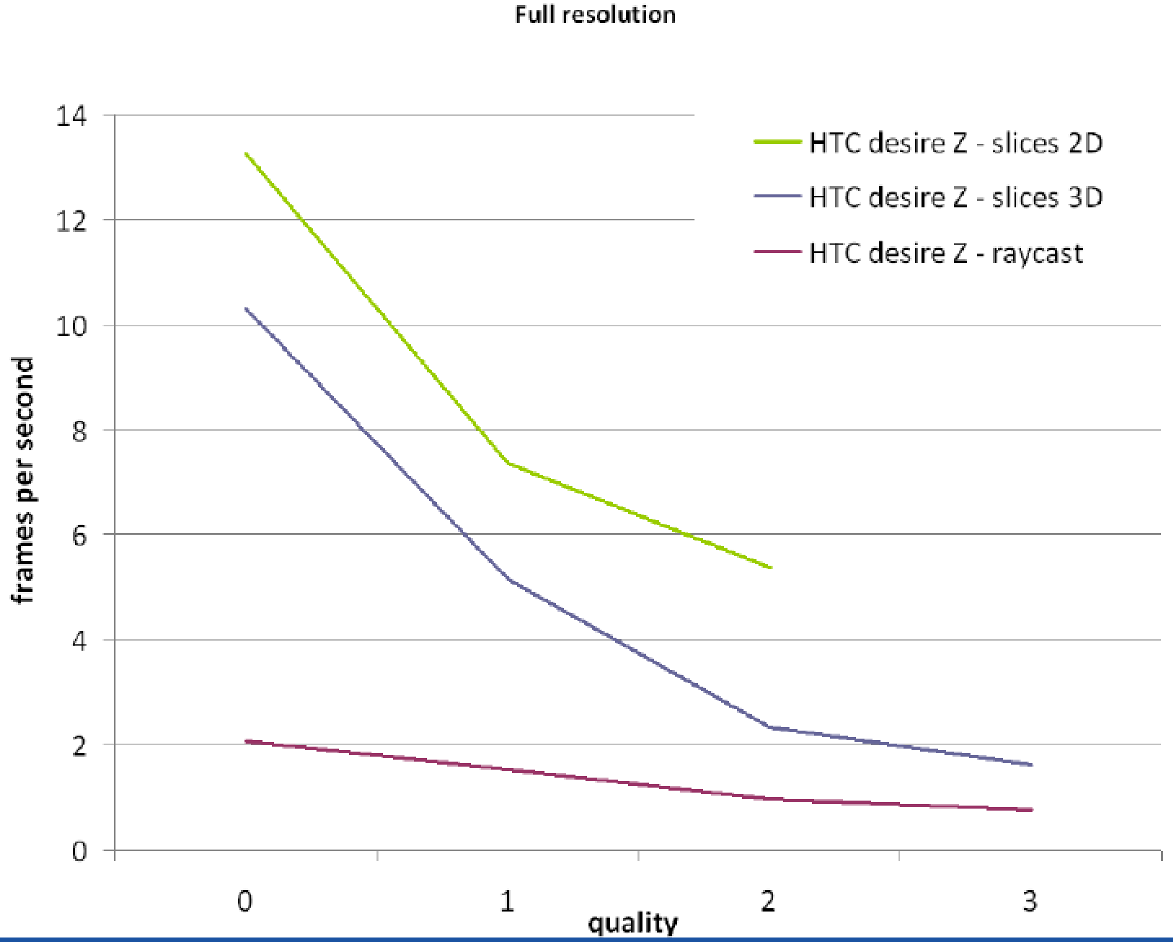
- **3D textures [Balsa & Vázquez, 2012]**
  - Allow either 3D slices or GPU-based ray casting
  - Initially, only a bunch of GPUs sporting 3D textures (Qualcomm's Adreno series >= 200)
  - Performance limitations (data: 256^3 – screen resol. 480x800)
    - 1.63 for 3D slices
    - 0.77 fps for ray casting

Rendering Volumetric Datasets



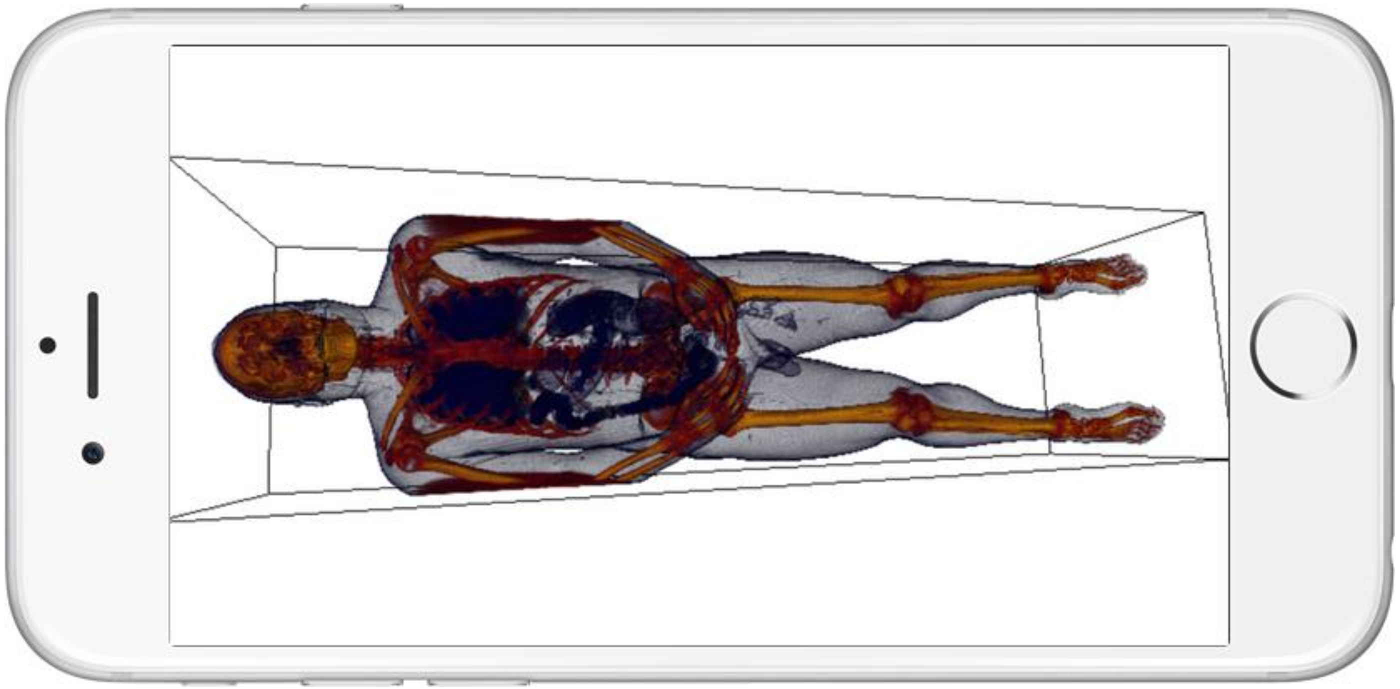
Rendering Volumetric Datasets

- **2D slices vs 3D slices vs raycasting**



Rendering Volumetric Datasets

- **Using Metal on an iOS device [Schiewe et al., 2015]**



Taken from [Schiewe et al., 2015]

Volume data. GPU ray casting on mobile

- **Using Metal on an iOS device [Schiewe et al., 2015]**
  - Standard GPU-based ray casting
  - Provides low level control
  - Improved framerate (2x, to a maximum of 5-7 fps) over slice-based rendering
  - Models noticeably smaller than available memory (max. size was 256^2x942)

Volume data. GPU ray casting on mobile

- **Progressive Ray Casting for Volumetric Models on Mobile Devices [Díaz et al., 2018]**
  - Two algorithms for progressive ray casting adapted to smartphones
  - Tested on Android
  - Using OpenGL

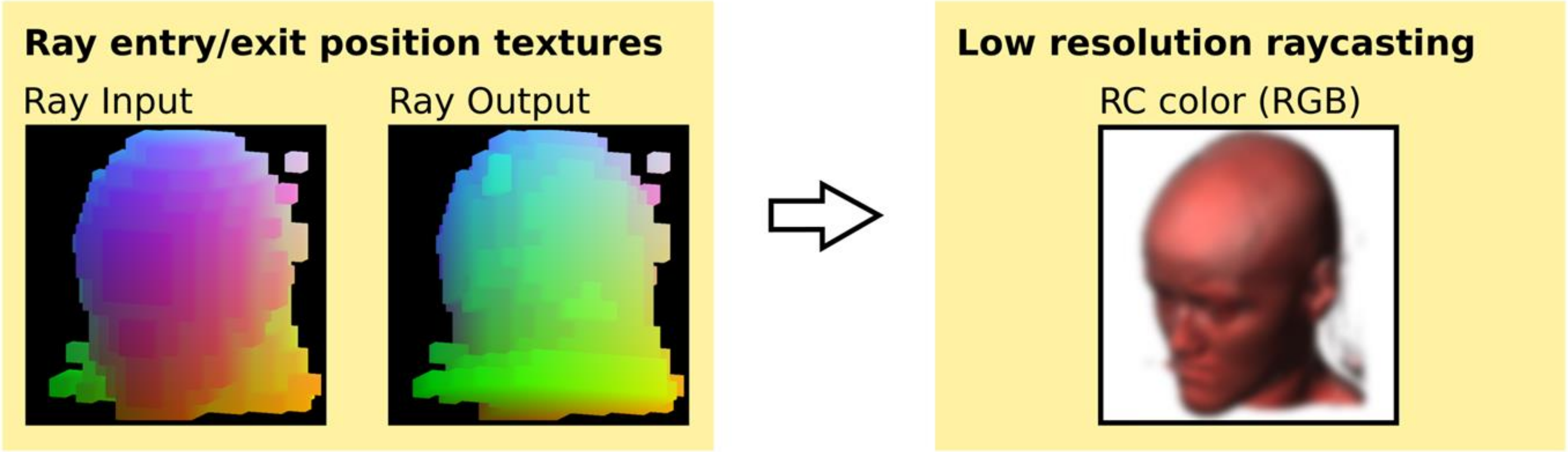
Volume data. GPU ray casting on mobile

- **Overview**
  - Common core: Progressive ray-casting
    - Low-level resolution
  - Two methods for progressive refinement
    - FBSlabs: Refine front to back
      - Budget-based rendering (slab sizes)
      - Requires lower level OpenGL ES/WebGL (3.0 [or lower], no compute shaders)
      - Progressive refinement more noticeable
    - STiles: Refine tile-based
      - Budget-based rendering (number/size of tiles)
      - Less visible update changes
      - Requires higher level OpenGL (3.1 or higher, compute shaders to sort tiles)

Volume data. GPU ray casting on mobile

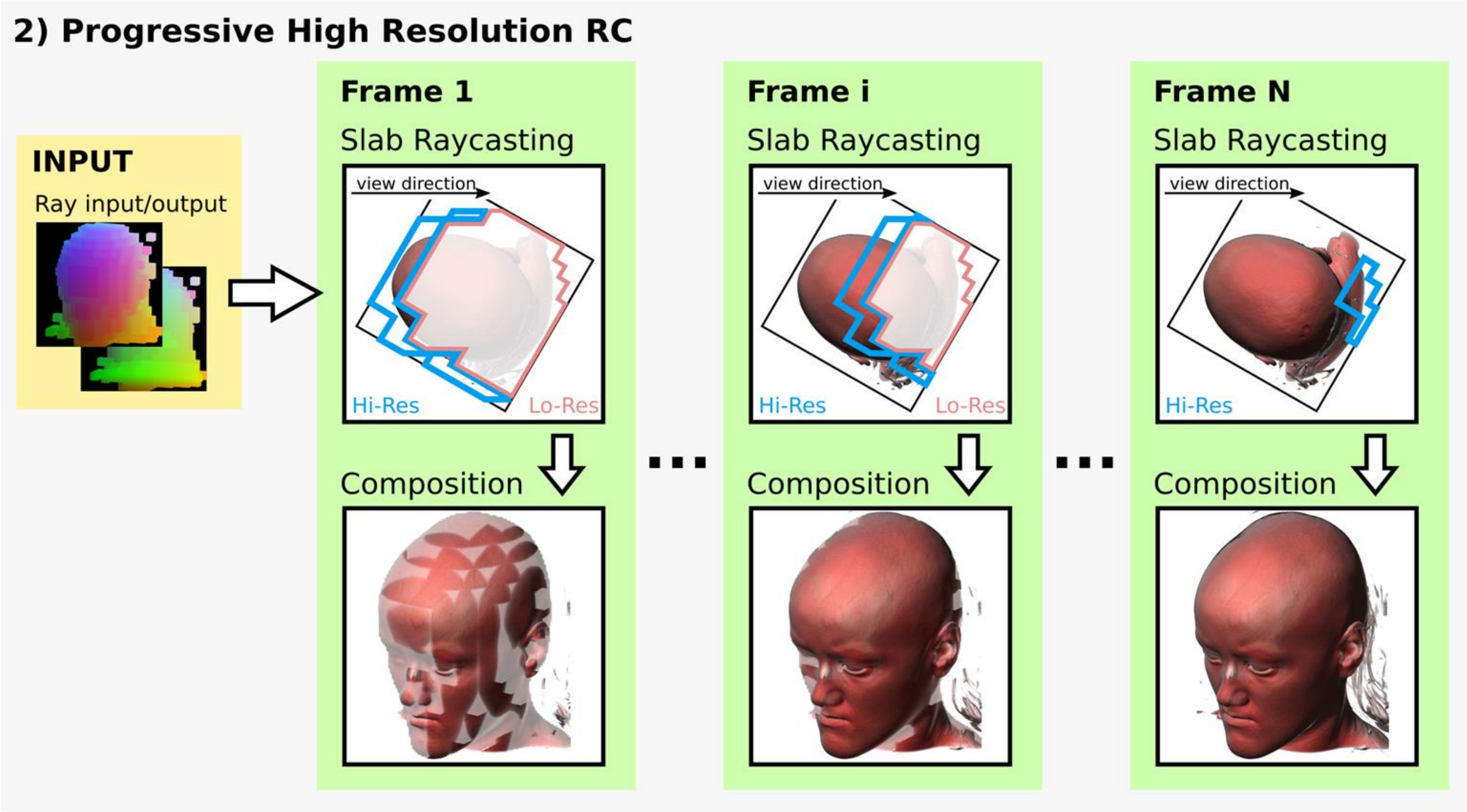
- **FBSlabs**

1) Low Resolution RC (during interaction)



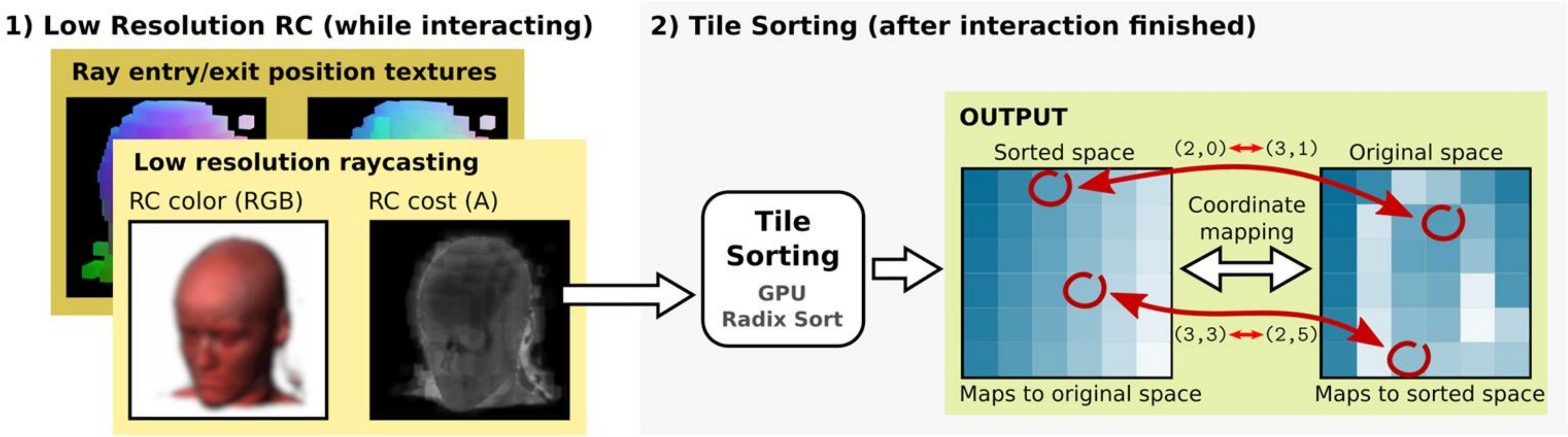
Volume data. GPU ray casting on mobile

- **FBSlabs**



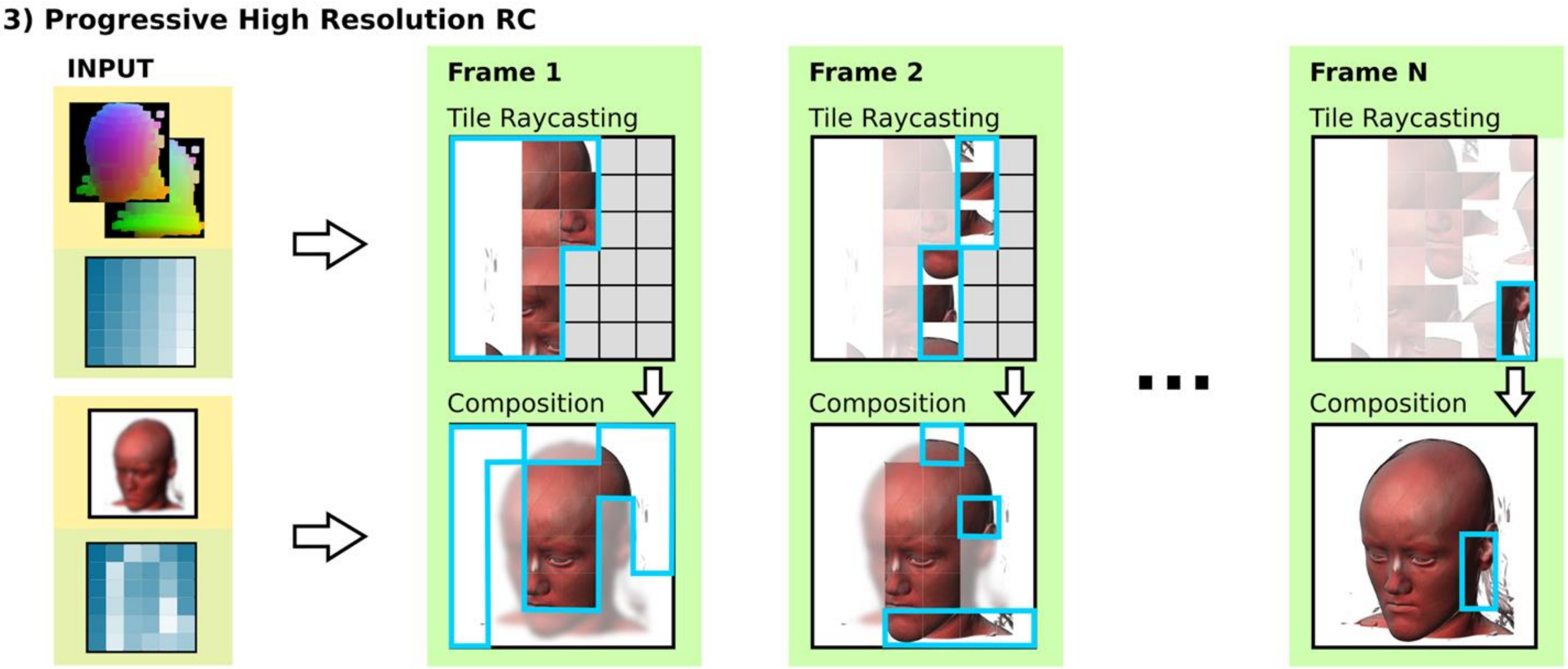
Volume data. GPU ray casting on mobile

- **STiles**



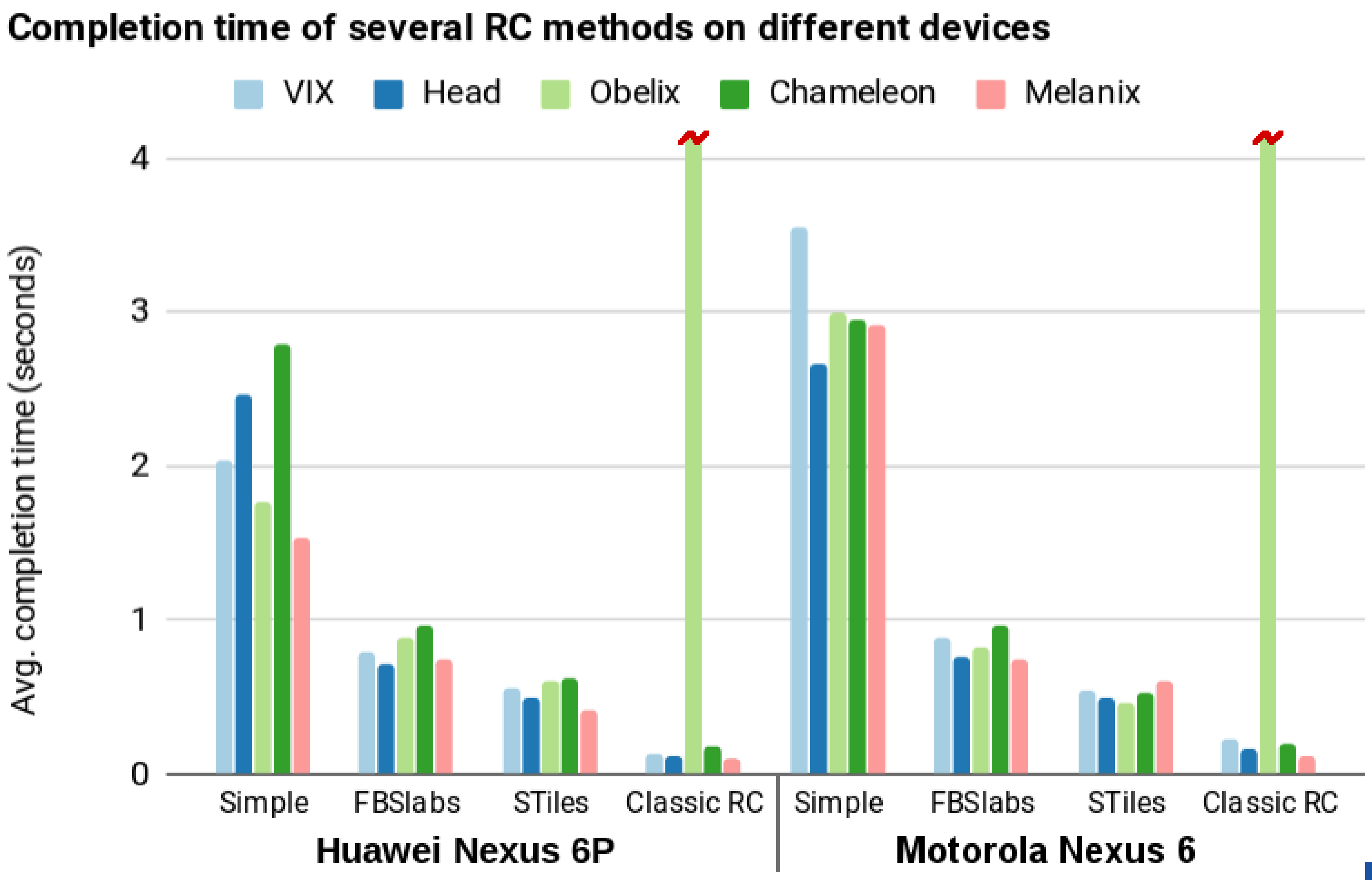
Volume data. GPU ray casting on mobile

- **STiles**



Volume data. GPU ray casting on mobile

- **Results. Completion time**



Volume data. GPU ray casting on mobile

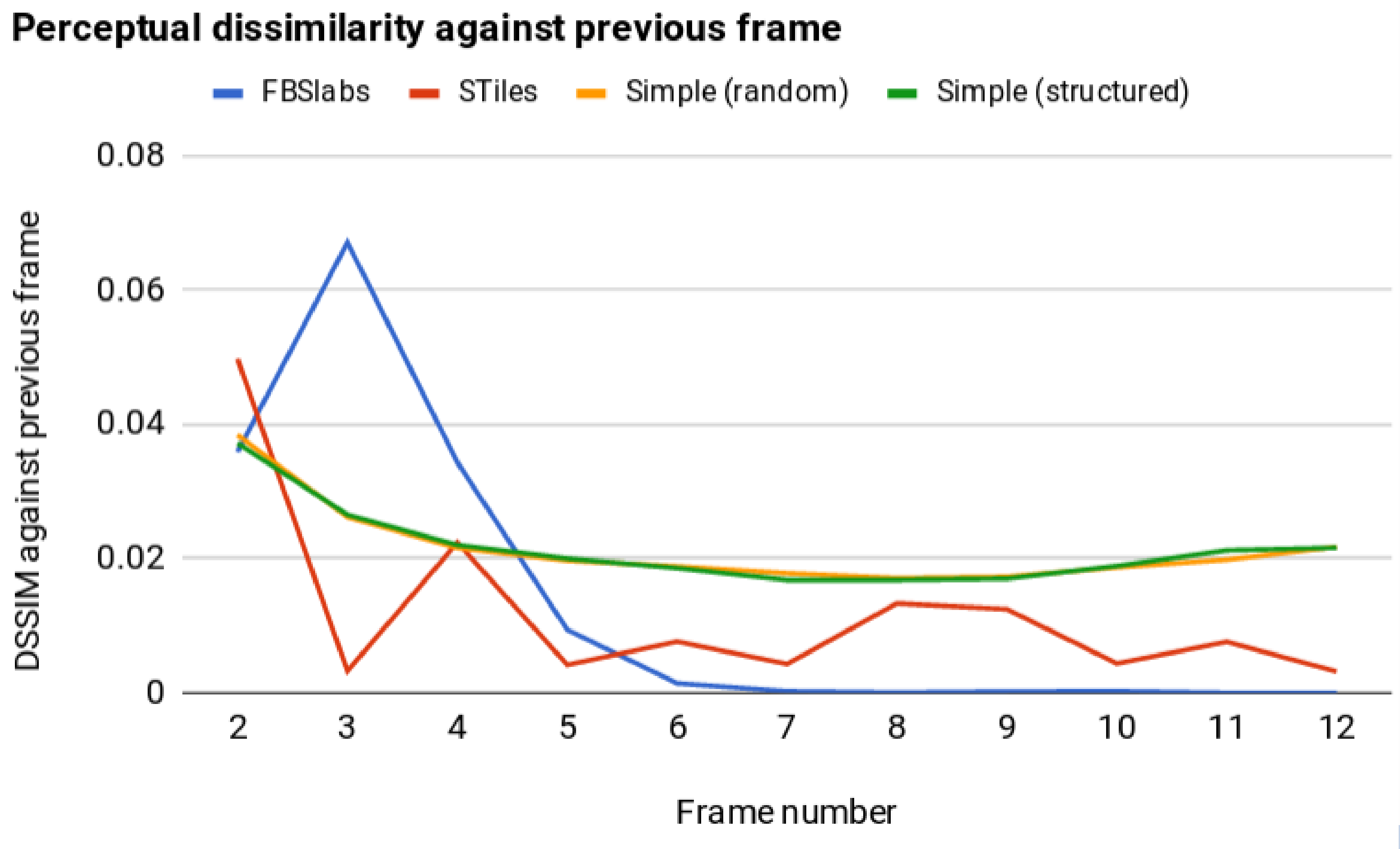
- **Results. Framerate**

	Nexus 6								
	Simple			FBSlabs			STiles		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Vix	8.03635	11.6122	8.84522	10.7524	32.6419	20.6254	12.5105	23.0776	16.5257
Head	8.16621	11.1880	9.73117	17.5999	37.4925	25.4241	11.0722	23.2729	16.2087
Obelix	7.85773	10.2932	8.83859	13.8662	40.3193	23.9071	9.29148	26.8632	17.0683
Chamaleon	7.90516	10.8366	9.75879	17.1355	37.2815	25.3579	13.5114	23.7053	16.8985
Melanix	7.92802	10.2918	8.65489	15.1961	42.8415	25.5537	13.0587	28.4416	19.7347

	Nexus 6P								
	Simple			FBSlabs			STiles		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Vix	9.04296	10.8118	9.65829	18.3297	47.705	28.8664	13.4198	24.1418	16.6214
Head	7.8058	10.5197	9.65324	23.0565	51.6828	31.5486	13.7861	24.4392	17.263
Obelix	8.65025	12.5418	9.68395	17.7137	48.3289	26.762	9.68402	26.2899	16.4421
Chamaleon	8.82493	12.9486	9.59793	17.1363	47.9752	26.1988	12.1175	21.7779	15.7702
Melanix	9.18801	13.3794	10.1308	18.5456	54.088	26.9182	13.1736	32.586	20.3036

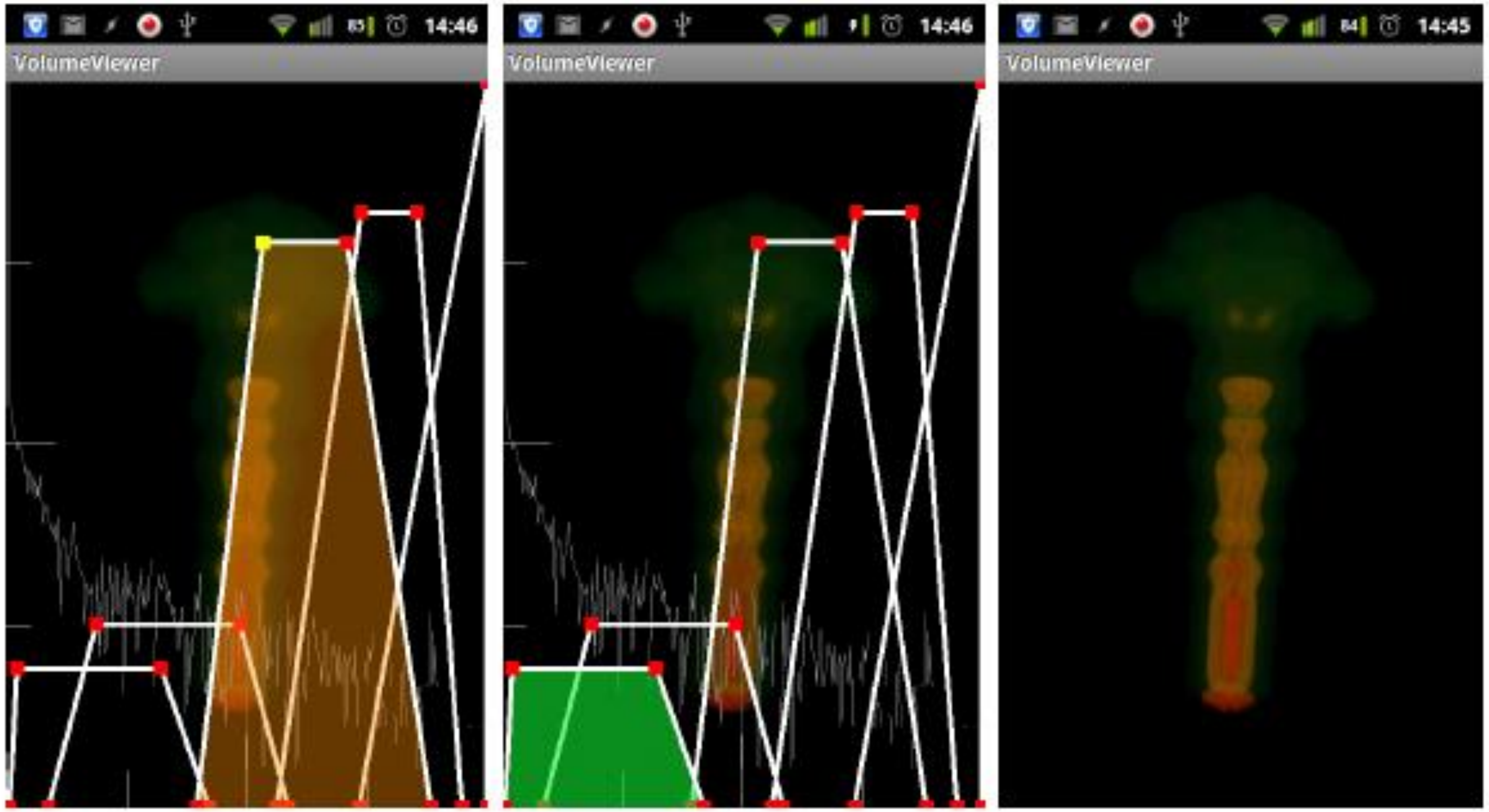
Volume data. GPU ray casting on mobile

- **Results. Perceptual differences vs previous frame**



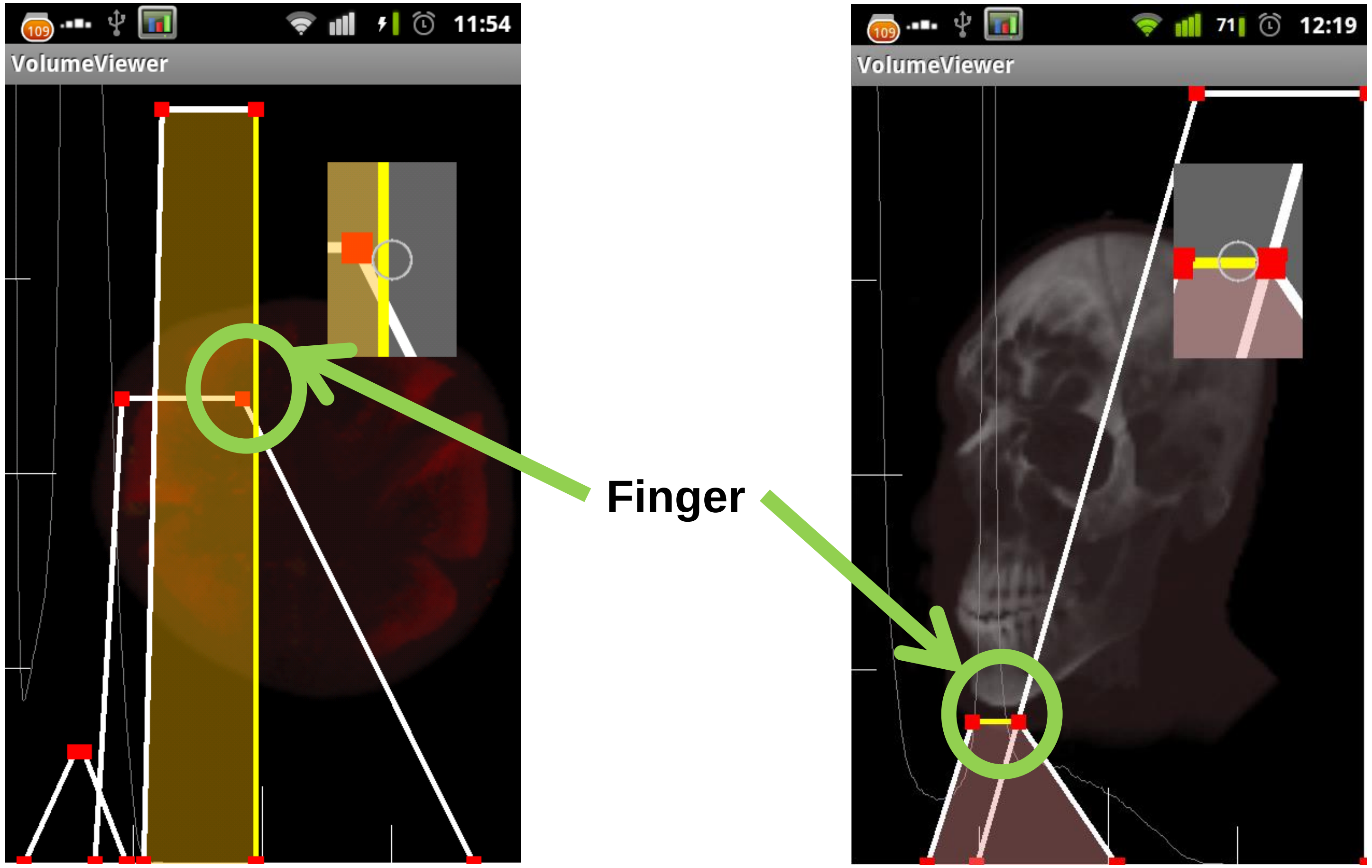
Rendering Volumetric Datasets

- **Challenges: Transfer Function edition**



Rendering Volumetric Datasets

- **Challenges: Transfer Function edition**



Rendering Volumetric Datasets

- **Conclusion**
  - Volume rendering on mobile devices possible but limited
    - Can use daptive rendering (half resolution when interacting)
  - 3D textures in core GLES 3.0
    - Requires progressive raytracing for not so large models
  - Interaction still difficult
  - Client-server architecture still alive
    - Can overcome data privacy/safety & storage issues
    - Better 4G-5G connections
    - …

Next Session

MOBILE METRIC CAPTURE AND RECONSTRUCTION