Oct 2018

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Qualcomm

Making immersive virtual reality possible in mobile

Qualcomm Technologies, Inc.

Agenda

1. Virtual reality will provide the ultimate level of immersion
2. Technologies and ecosystem are aligning for VR
3. VR has extreme requirements for visual quality, sound quality, and intuitive interactions
4. Qualcomm Technologies, Inc. (QTI) is uniquely positioned to support superior mobile VR experiences

Qualcomm

Virtual reality will provide the ultimate level of immersion

Offering unprecedented experiences and unlimited possibilities

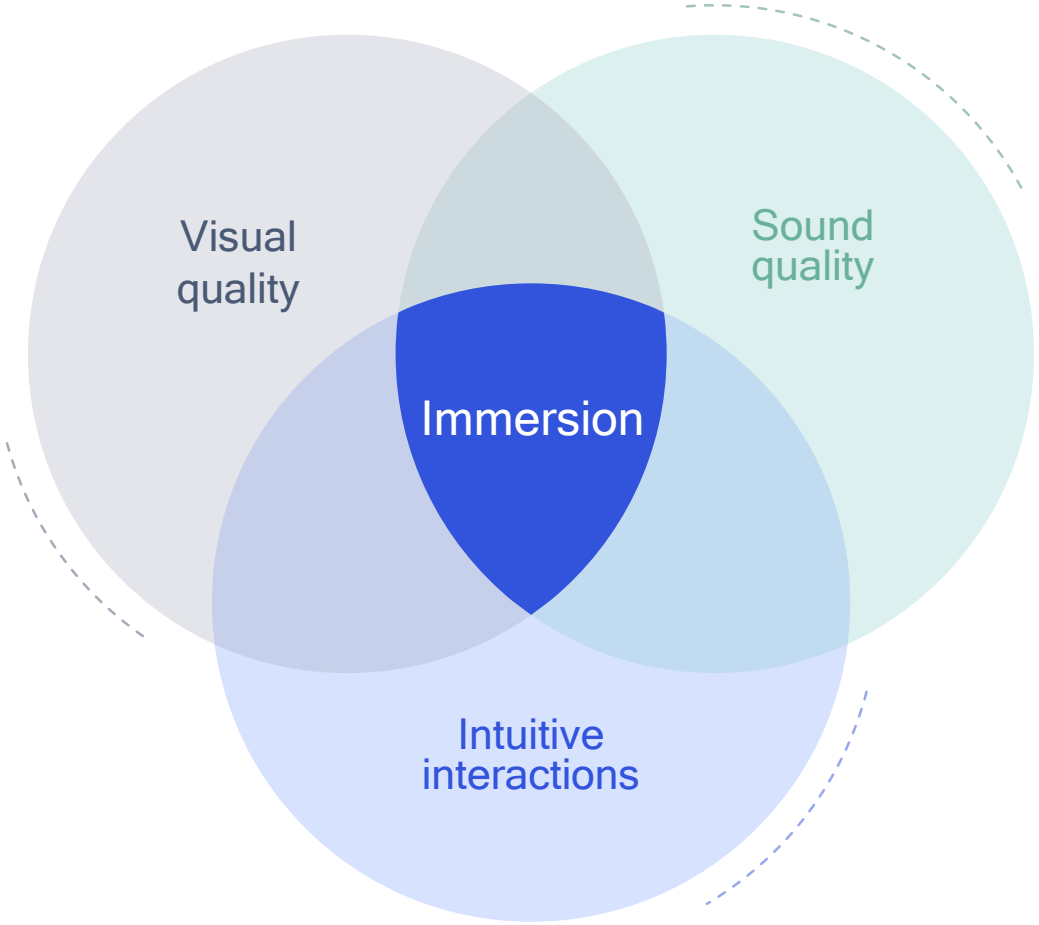
Immersive Experiences

Experiences worth having, remembering, and reliving

- Draw you in…
- Take you to another place…
- Keep you present in the moment…

Achieving full immersion

Simultaneously focusing on three key pillars



VR will provide the ultimate level of immersion

Creating physical presence in real or imagined worlds

Visuals

So vibrant that they are eventually indistinguishable from the real world

Interactions

So intuitive that they become second nature

Sounds

So accurate that they are true to life

VR will be the new paradigm for how we interact with the world

Offering unprecedented experiences and unlimited possibilities

Experiences in VR

Play

Immersive movies and shows

Live concerts, sports, and other events

Interactive gaming and entertainment

Learn

Immersive education

Training and demos

3D design and art

Communicate

Social interactions

Shared personal moments

Empathetic storytelling


Play
Live sports
experience


Learn
Doctor training experience


Communicate
Recital experience

Virtual reality is not augmented reality

Similar underlying technologies but distinct experiences

Virtual reality

Simulates physical presence in real or imagined worlds, and enables the user to interact in that world

Augmented reality

Superimposes content over the real world such that the content appears to a viewer to be part of the real-world scene

Technologies and ecosystem are aligning for VR

Mobile technologies are accelerating VR adoption

The time is right for VR

Technologies and ecosystem are now aligning

Ecosystem drivers

- Device availability
- Software infrastructure
- Content creation and deployment

Technology advancements

- Multimedia & AI technologies
- Display and sensor technologies
- Power and thermal efficiency

VR headsets are becoming available

Mobile VR headsets will drive mass adoption and provide the freedom to enjoy VR anywhere

Mobile VR headsets

Smartphone powered

- Smartphone plugs into or connects to the headset
- Mobile SoC powers VR experience

Standalone

- Dedicated headset optimized for VR
- Mobile SoC powers VR experience

Tethered VR headsets

PC or game console controlled

- Headset connects by wire to a PC or game console
- Desktop-class CPU and GPU power the VR experience

Continuum of VR experiences

The software infrastructure and tools are ready

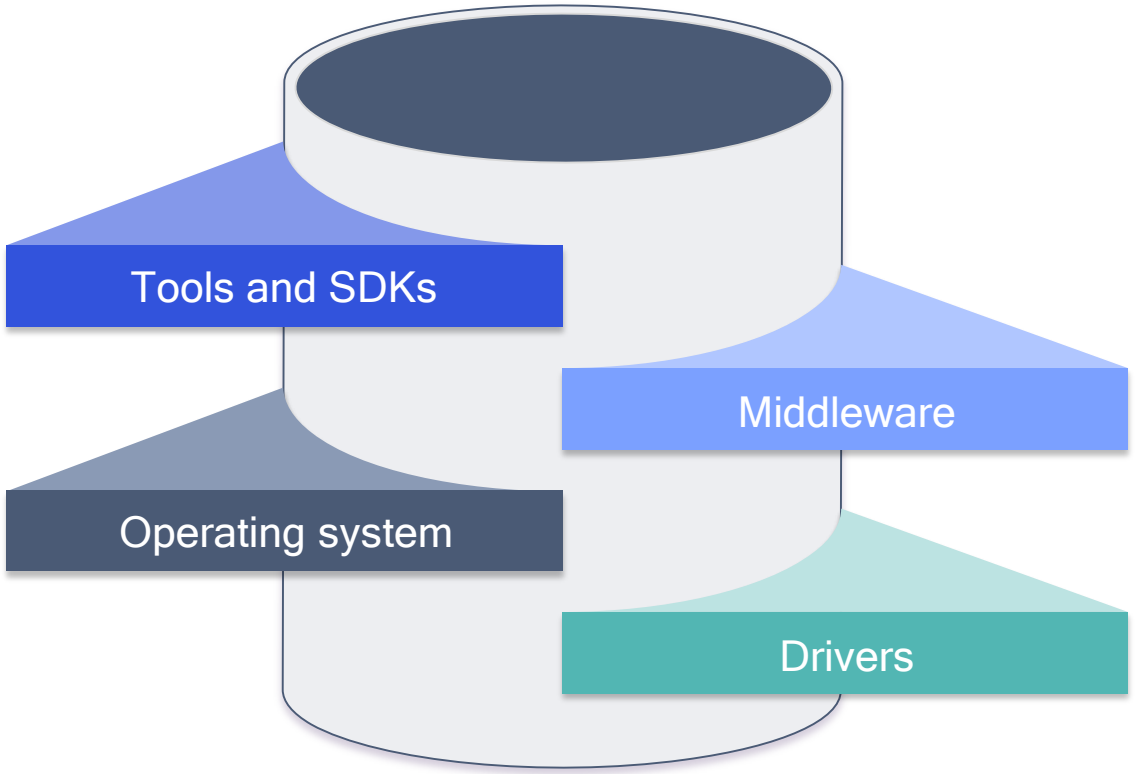
A solid foundation exists and momentum is building

Tools and SDKs to generate, debug, and optimize content, such as:

- Google Cardboard SDK, Oculus Mobile SDK, Qualcomm® Snapdragon™ VR SDK
- 360° video processing tools

OS optimizations to better manage device resources

- Hardware, software, and peripherals



Software stack optimized for VR

Optimized middleware

- Gaming engines like Unity and Unreal Engine
- Audio engines and libraries
- 360° video players

Optimized low-level drivers for VR requirements

- System-level latency reduction
- Peripheral tuning
- API acceleration

Content is being generated and deployed

Content developers are experimenting with VR and see its potential as a new medium

Content generation

Games and apps

- Finding the killer apps through experimentation
- A variety of compelling experiences already exist, from first person shooters to virtual chat rooms, education, and 3D sculpting

Video

- Cinematic VR, such as the life of a refugee or a concert
- Broadcast TV, such as the presidential debate, sports events, and comedy shows
- User generated content
- Premium streaming video providers, such as Netflix and Hulu

Content distribution

App stores

- App aggregation and distribution through stores, such as:
  - Google Play Store with Google Cardboard apps
  - Oculus Store and Oculus Share
  - HTC Viveport app store

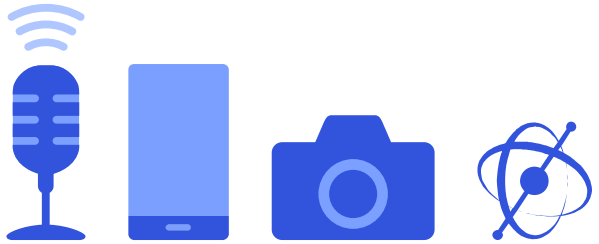
Video distribution

- Upload and stream video from places, such as:
  - YouTube 360
  - 360 video on Facebook

Exponential technology advancements are making VR possible

Multimedia technologies

- Graphics processing
- Audio processing
- Video processing



Display and sensor technologies

- Displays with increased pixel density, power efficiency, and visual quality
- Smaller, lower power, and lower cost sensors without sacrificing accuracy

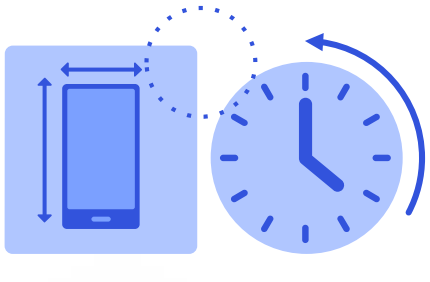
Power and thermal efficiency

- Architecture innovations, such as heterogeneous computing
- Optimized algorithms
- Integration efficiency, including better transistors

The mobile industry is accelerating VR adoption

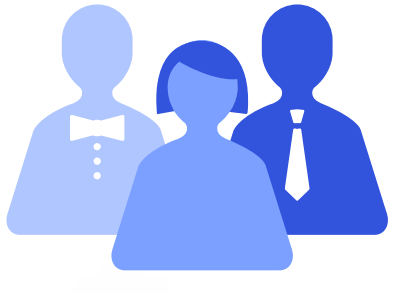
Scale

Innovation at scale and cost advantage



Rapid design cycles

Fast adoption of cutting edge technologies



Mass adoption

Broad appeal for mainstream consumers

Immersive virtual reality has extreme requirements

Qualcomm® Snapdragon™ 845 processor is ideal for mobile VR

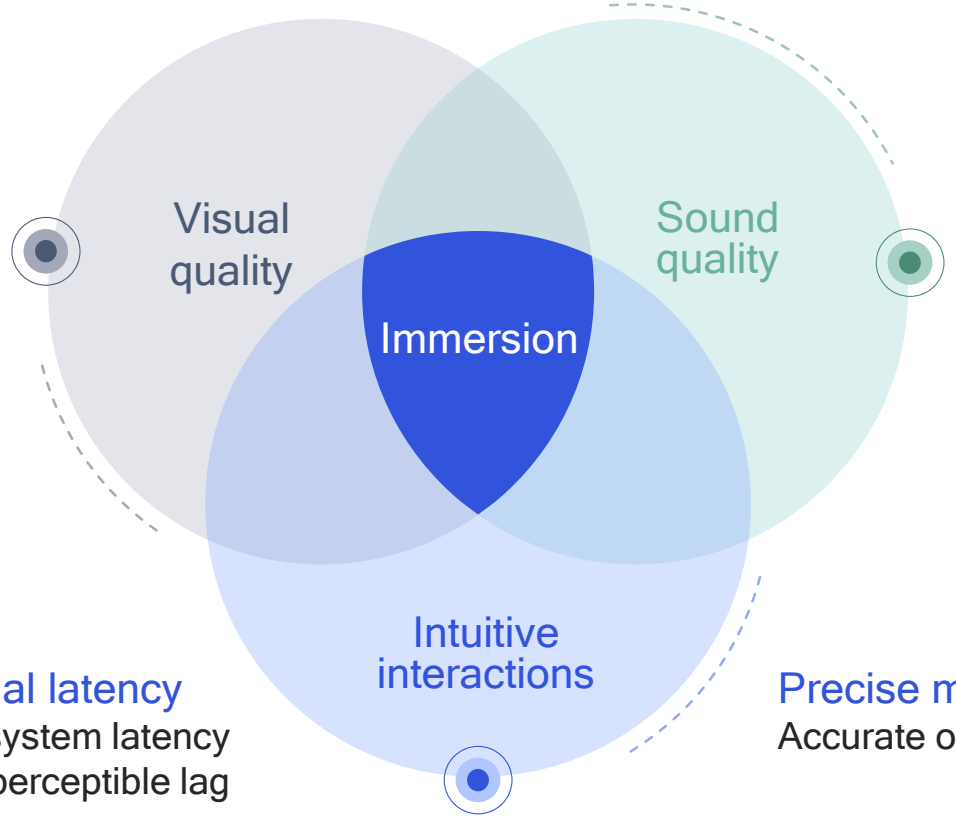
Immersive virtual reality has extreme requirements

Achieving full immersion at low power to enable a comfortable, sleek form factor

Extreme pixel quantity and quality
Screen is very close to the eyes

Spherical view
Look anywhere with a full 360° spherical view

Stereoscopic display
Humans see in 3D



High resolution audio
Up to human hearing capabilities

3D audio
Realistic 3D, positional, surround audio that is accurate to the real world

Minimal latency
Minimized system latency to remove perceptible lag

Precise motion tracking
Accurate on-device motion tracking

Natural user interfaces
Seamlessly interact with VR using natural movements, free from wires

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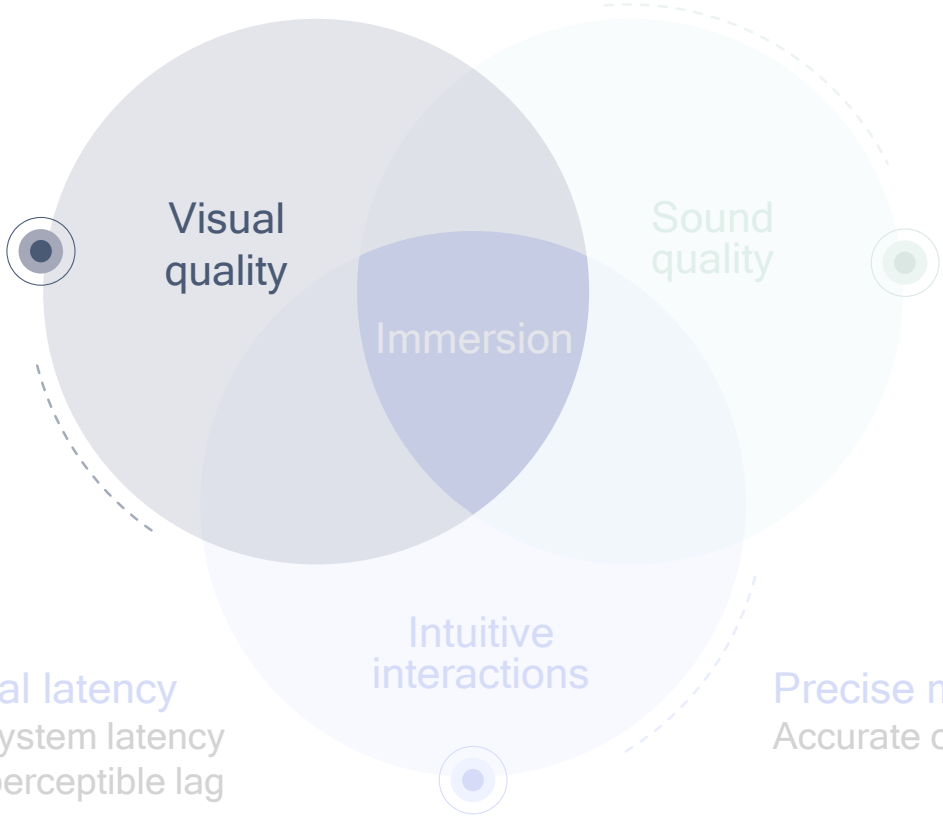

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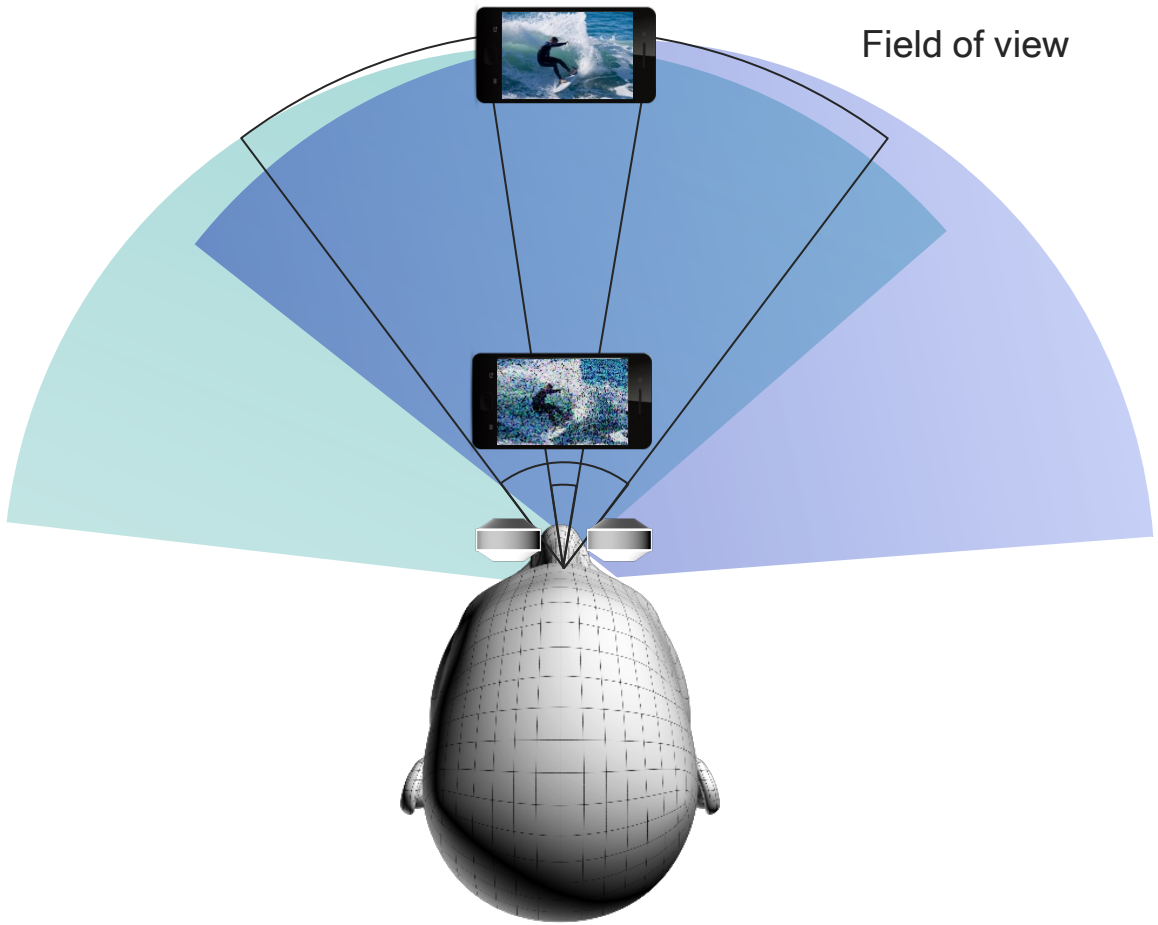
Natural user interfaces
Seamlessly interact with VR using natural movements, free from wires

Extreme pixel quantity and quality are required

The screen is very close to the eyes and a 360° spherical view is necessary



Field of view (FOV)

- For immersive VR, our entire FOV needs to be the virtual world
- Each human eye has ~145° horizontal FOV
- The fovea of the eye can see ~60 pixels per degree (PPD) but comprises less than 1% of the retinal size
- To look anywhere in the virtual world, VR needs to provide full 360° spherical view

Screen-door effect

- As the device is brought closer to your eyes, the screen takes up more of your FOV
- Biconvex lenses magnify the screen further and make the virtual world your entire FOV
- As the screen takes up more of your FOV, pixel density must increase
- Otherwise, you will see individual pixels – the screen door effect

Foveated rendering significantly reduces pixel processing

The human eye can only see high resolution where the fovea is focused

- Rather than rendering with high resolution throughout an image, just render high where the eye is fixated.
- The GPU renders a small rectangle at a high resolution and the rest of the FOV at a lower resolution.
- Foveated rendering will help minimize power, while improving performance and visual quality.

High resolution everywhere

High resolution throughout the image

High resolution

Low resolution

High resolution selectively

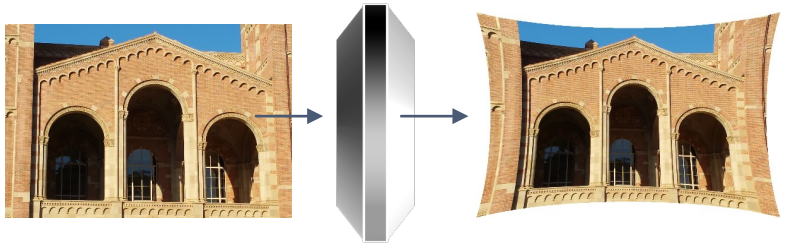
Foveated rendering based on the eyes being fixated on the paraglider

Lens correction for improved visual quality

Fixing lens distortion and chromatic aberration

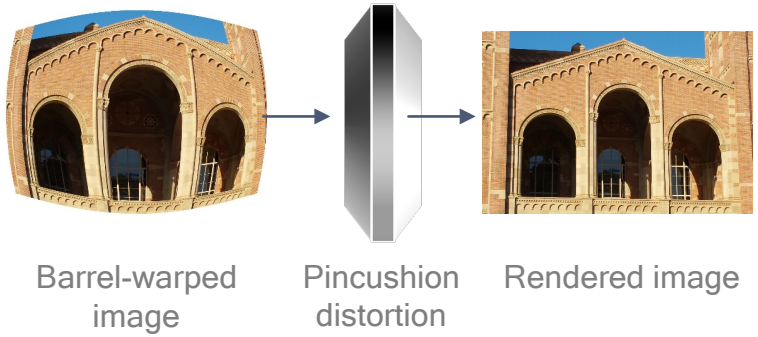
Lens distortion

Problem:
A wide-angle biconvex lens creates a pincushion distortion



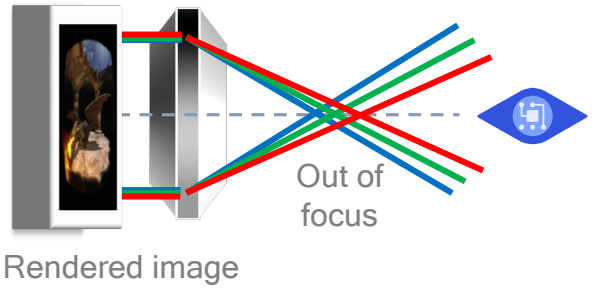
Barrel warp

Solution:
Barrel warp compensates for pincushion distortion



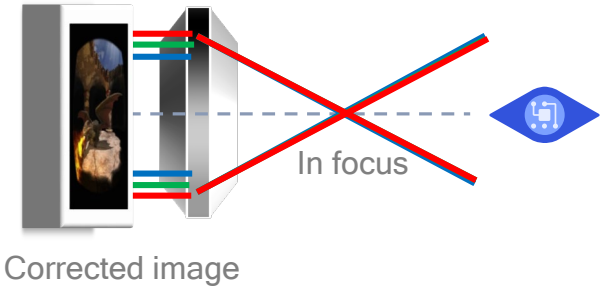
Chromatic aberration

Problem: After passing through the lens, colors are focused at different positions in the focal plane.



Chromatic correction

Solution: Image processing compensates for chromatic aberration. The GPU parameters are determined through lens characterization.



360° spherical view: Look anywhere

Generating and consuming 360° spherical video

VR headsets need to support multiple 360° spherical video formats

Generate video

- Simultaneously capture video with multiple cameras from different views to generate 360° spherical video. Stereoscopic video doubles the number of cameras
- Undistort, stitch together, and map the discrete images to a equirectangular or cube map format
- Encode video

Playback video

- Decode video
- Based on format, apply an equirectangular or cube map UV projection
- Determine pose and show appropriate view of 360° spherical video

Discrete unstitched camera images for 360° spherical view

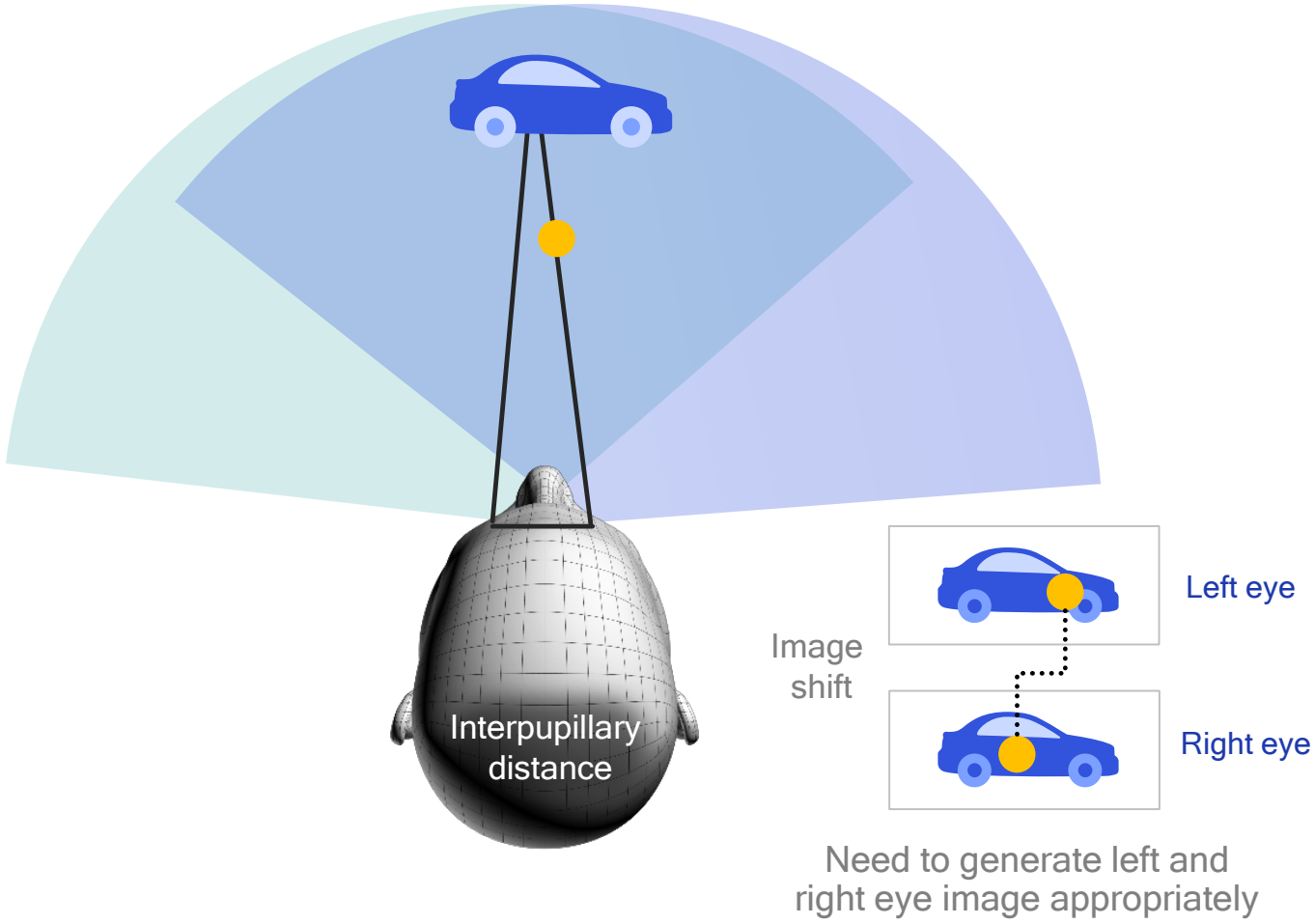
Equirectangular image

Cube map image

Left eye VR headset view

Stereoscopic display to see the world in 3D

Binocular vision helps the brain determine depth



Stereoscopic visuals

- Each eye rotates and focuses to see an object clearly, resulting in slightly different viewpoints.
- Based on the different viewpoints and by knowing the interpupillary distance, the brain determines depth.
- This stereoscopic effect makes the VR experience more immersive.
- For VR, we need to generate the appropriate view for each eye

Accurate and efficient stereoscopy for realistic visuals

Left eye

Right eye

Graphics

- OpenGL ES multiview extension support
- A single draw call generates triangles for both eyes
- Driver and app overhead is reduced

Video

- For stereoscopic video, support of the multiview extension of HEVC codec
- Approximately 2X the decode work since there is a video stream per eye
- For monoscopic video, the same image is shown to both eyes, shifted for binocular disparity

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Achieving full immersion at low power to enable a comfortable, sleek form factor

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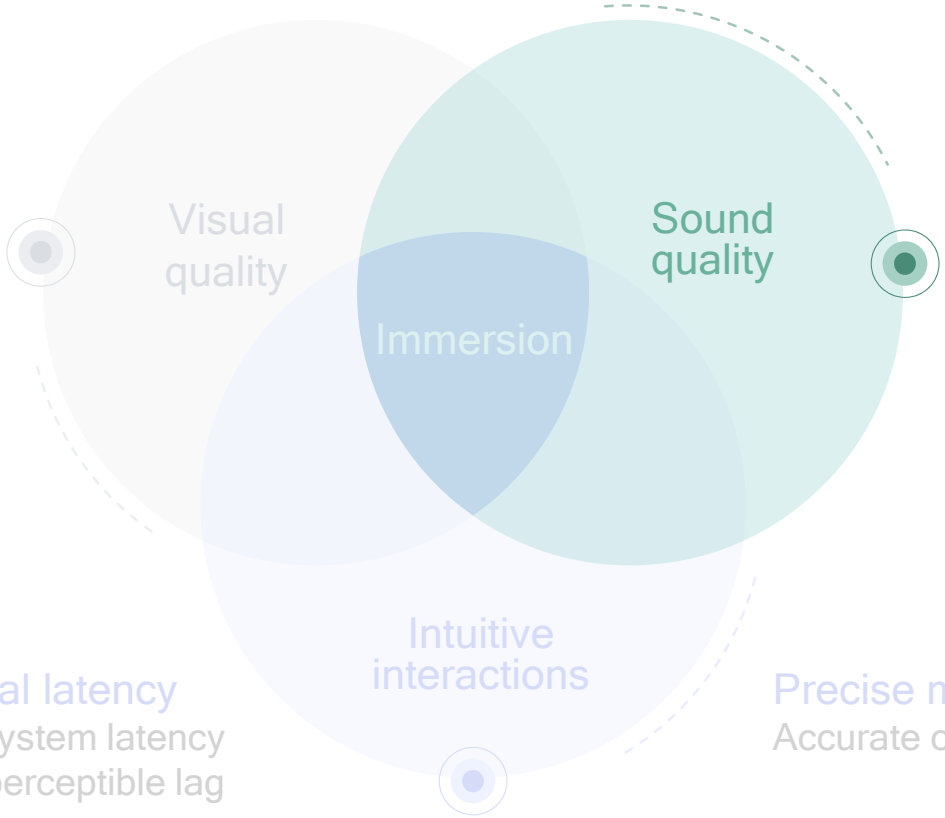

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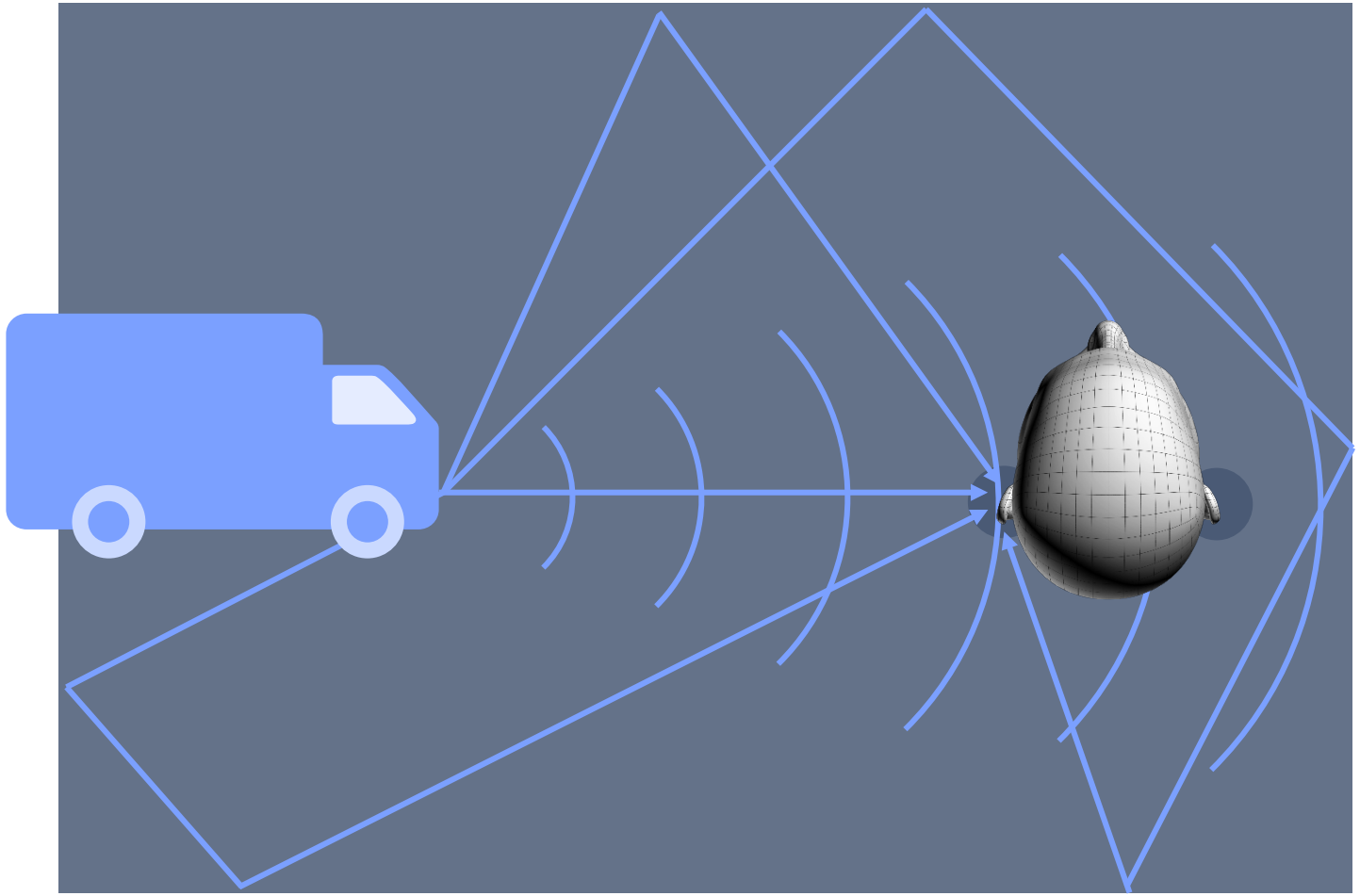
3D positional audio for realistic sound

Accurate 3D surround sound based on your head’s position relative to various sound sources

- Sound arrives to each ear at the accurate time and with the correct intensity
- HRTF (head related transfer function):
  - Takes into account typical human facial and body characteristics, like location, shape, and size of ears.
  - Is a function of frequency and three spatial variables.
- Sound appropriately adjusts dynamically as your head and the sound sources move

Reverberation for realistic sound

Sound reflections spread and interact with the environment appropriately



- Reverberation is function of sound frequency, material absorption, room volume, and room surface area.
- Different rooms reflect and absorb sound differently, such as a hallway or cave versus an open space.
- Accurate reverberation makes the experience more immersive.

Qualcomm® Snapdragon™ 845 processor provides realistic sound quality for VR

Processing performance at low power and low latency

High fidelity audio

- 24-bit at 192 kHz
- Real-time convolutional reverb
- 18 ms playback

3D positional audio

- Support next-gen codecs, like MPEG-H 3D Audio and Dolby Atmos
- HRTF support

Noise filtering

- Fluence™ noise filtering
- Active noise cancellation

Qualcomm® Hexagon™ DSP

- High performance at low power
- Low latency
- CPU offload
- Customer algorithms

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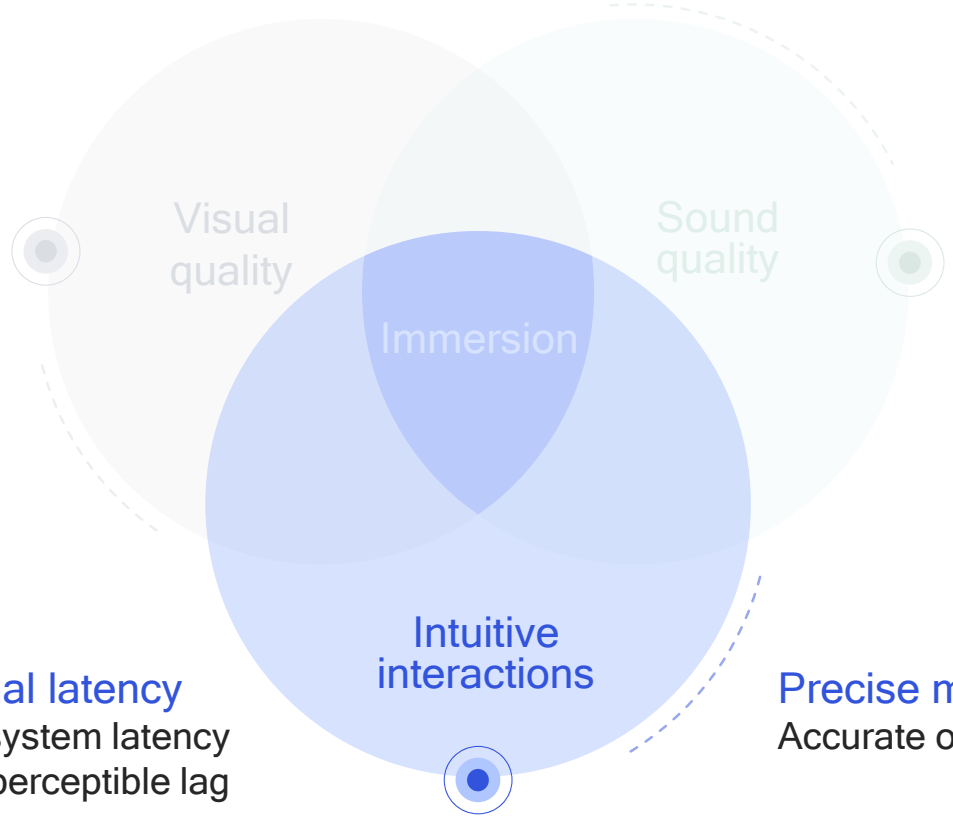

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Precise motion tracking of head movements

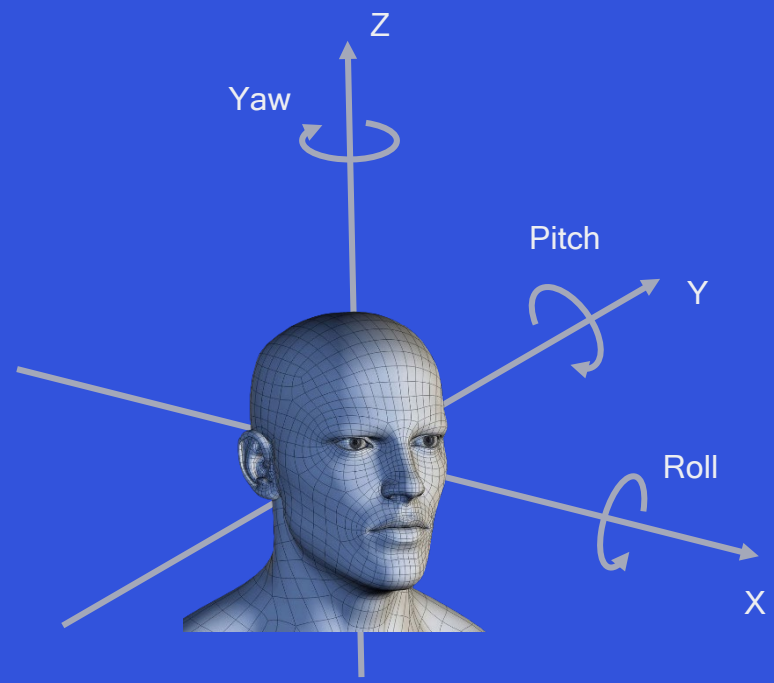
For accurate and intuitive interactions with the virtual world

3 degrees of freedom (3-DOF)

- “In which direction am I looking”
- Detect rotational movement
- Main benefit: look around the virtual world from a fixed point

6 degrees of freedom (6-DOF)

- “Where am I and in which direction am I looking”
- Detect rotational movement and translational movement
- Main benefit: move freely in the virtual world and look around corners



Achieving precise head motion tracking on the device

Visual inertial odometry (VIO) for rapid and accurate 6-DOF pose

Monocular camera data

Captured from tracking camera image sensor at ~30 fps

Accelerometer and gyroscope data

Sampled from external sensors at 800 / 1000 Hz

Snapdragon “VIO” subsystem

Camera feature processing

Inertial data processing

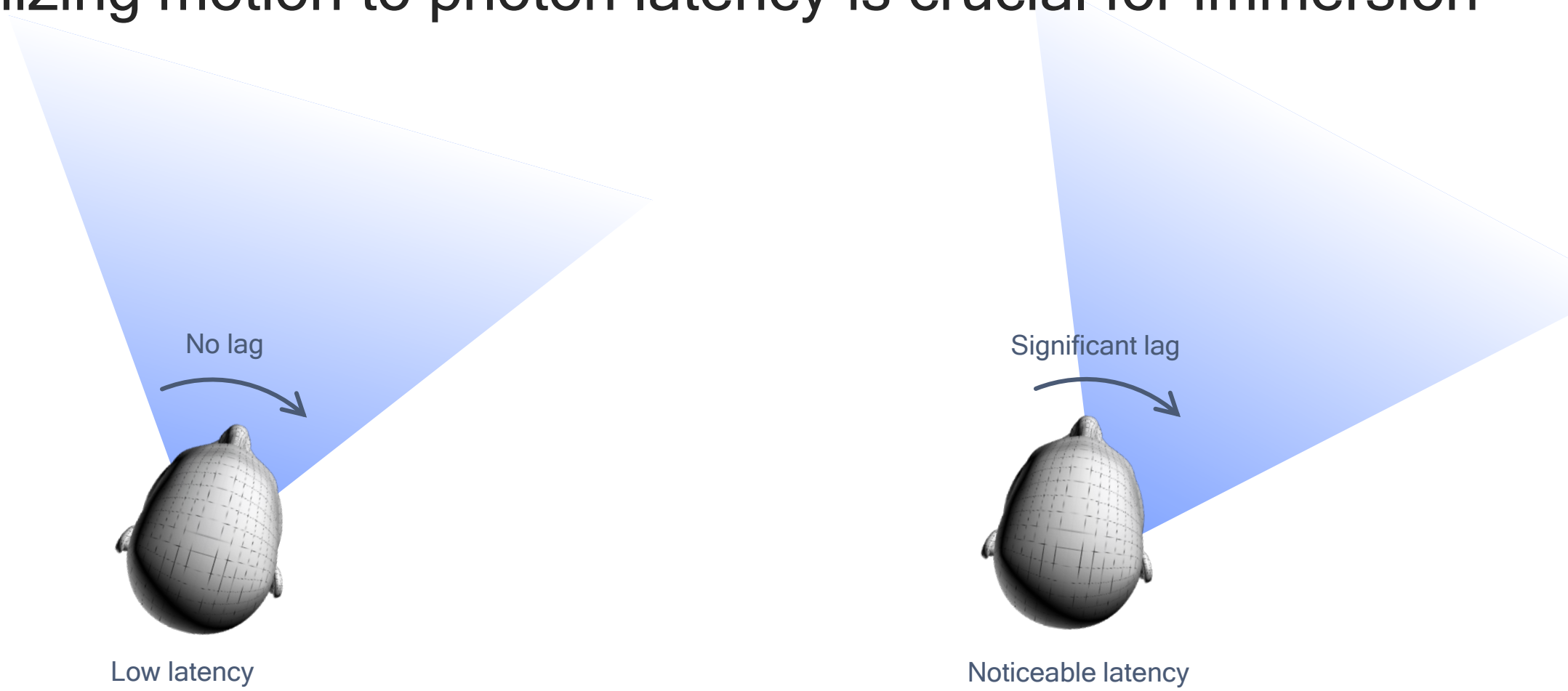
Hexagon DSP algorithms

- Camera and inertial sensor data fusion
- Continuous localization
- Accurate, high-rate “pose” generation & prediction

6-DOF position and orientation

(aka “6-DOF pose”)

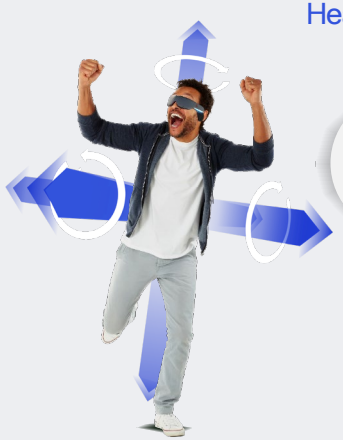
Minimizing motion to photon latency is crucial for immersion



Lag prevents immersion and can cause discomfort

An end-to-end approach is required to minimize latency

Many workloads must run efficiently for an immersive VR experience



Motion detection

Sensor sampling and fusion
Head pose generation

Visual processing

View generation
Render / decode

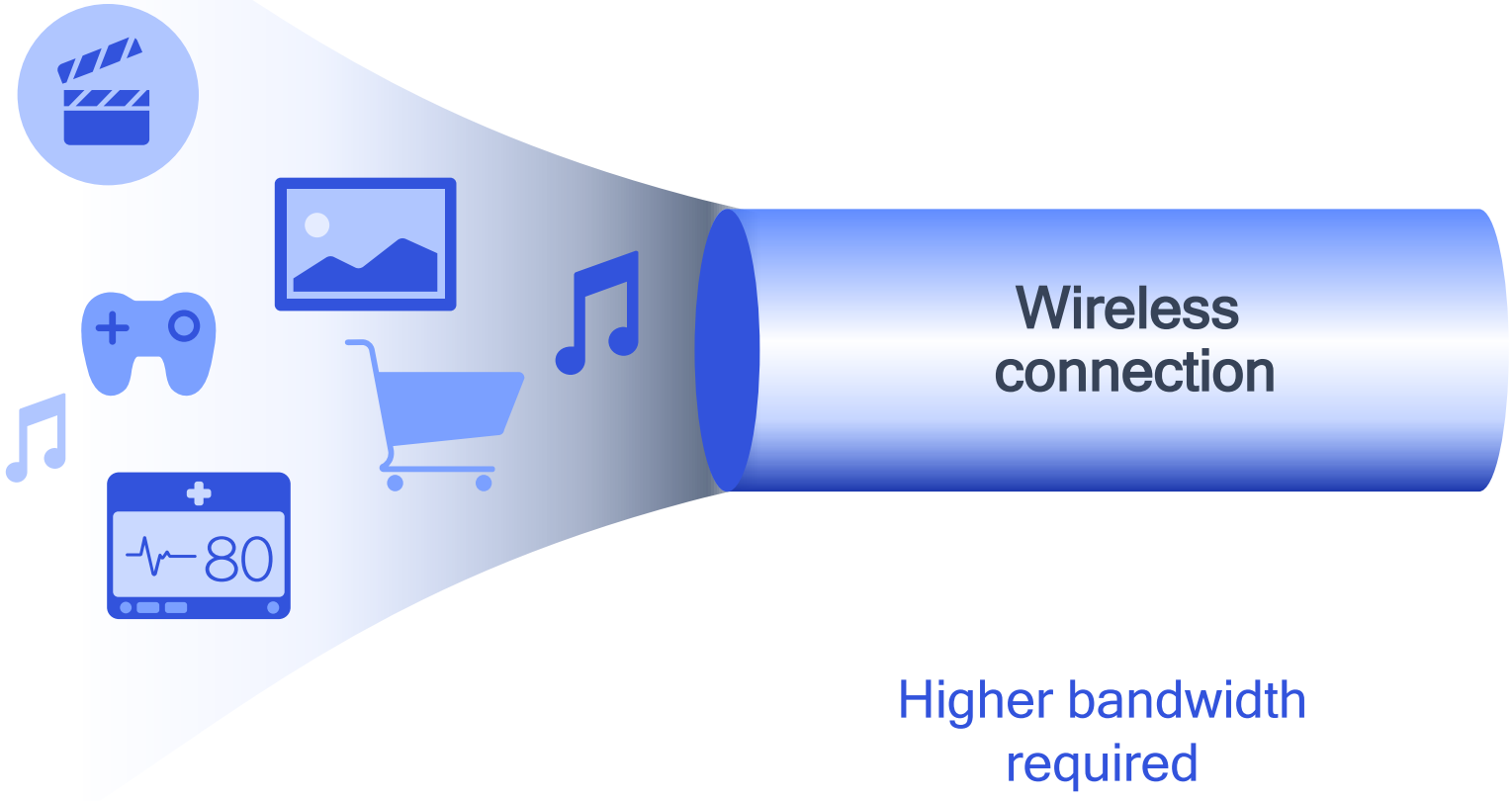
Display

Adjustment to latest pose (time warp)
Quality enhancement and display

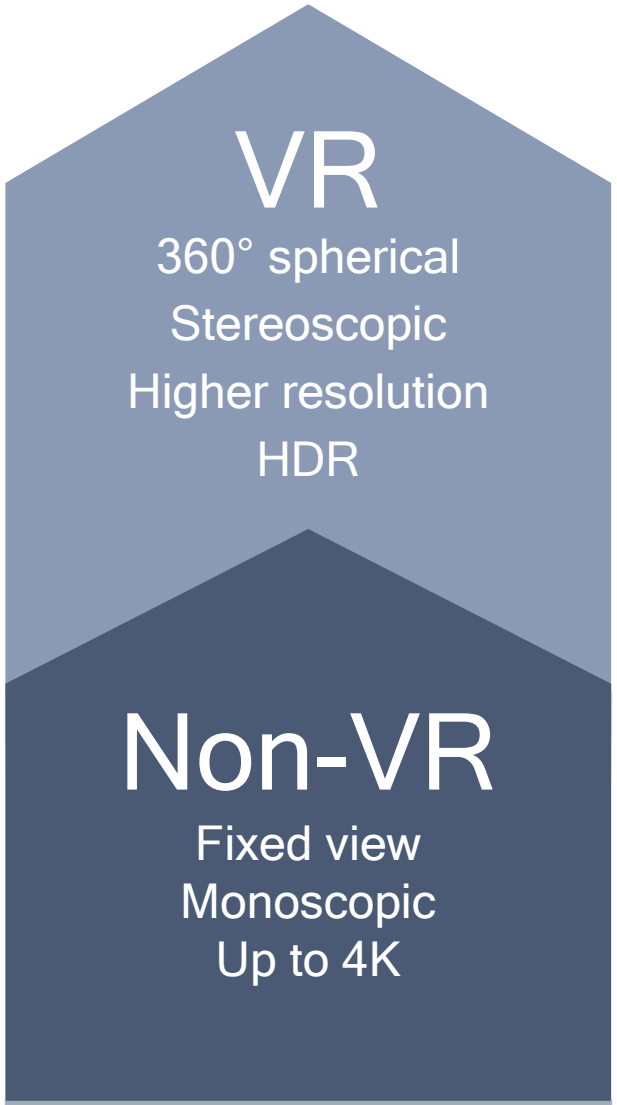
"Motion" Total time (motion to photon latency) for steps must be less than 20 milliseconds "Photon" (new pixels' light emitted from the screen)

VR content requires an enhanced wireless connection

High bandwidth connectivity to share and consume VR content



Higher bandwidth required



Great connectivity is the foundation of mobile experiences

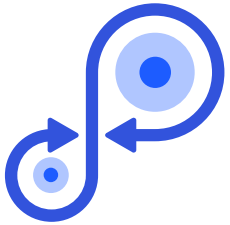
The Qualcomm® Snapdragon™ 845 processor provides connectivity at high bandwidth and low latency

Advanced 4G LTE

- Up to 1.2 Gbps downlink
- Up to 150 Mbps uplink
- Support for LAA

Advanced Wi-Fi

- 11ac MU-MIMO
- 11ad Wi-Fi
- Seamless access across bands



Advanced LTE/Wi-Fi convergence

- LTE + Wi-Fi aggregation
- Antenna sharing
- Advanced antenna design

Taking VR experiences to the next level with 5G

Continued 4G LTE advancements on the path to a more capable 5G platform

Enjoy VR experiences everywhere

At home, at work,
at school,
in the car,
at the airport, …

Share real-time, interactive experiences

Events,
meetings,
telepresence, …

Extreme throughput
multi-gigabits per second

Ultra-low latency
down to 1ms latency

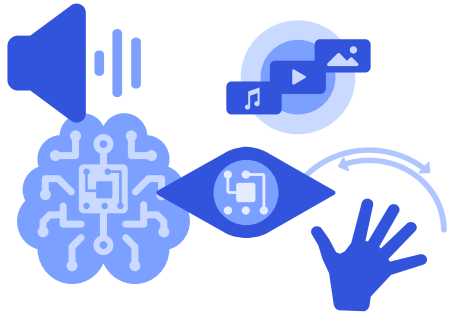
Uniform experience
with much more capacity

All while supporting new levels of cost and energy efficiency

Learn more about our vision for the future of mobile networks: www.qualcomm.com/5G

Power and thermal efficiency for VR tasks is essential

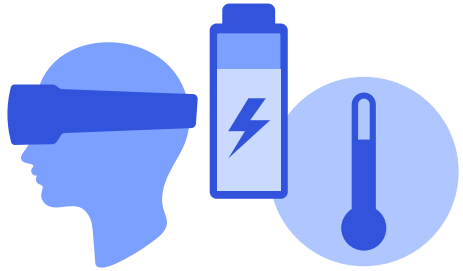
The VR headset needs to be comfortable to wear for extended periods



VR workloads

Compute intensive

Diverse characteristics



Constrained mobile wearable environment

Sleek, ultra-light

Long battery life

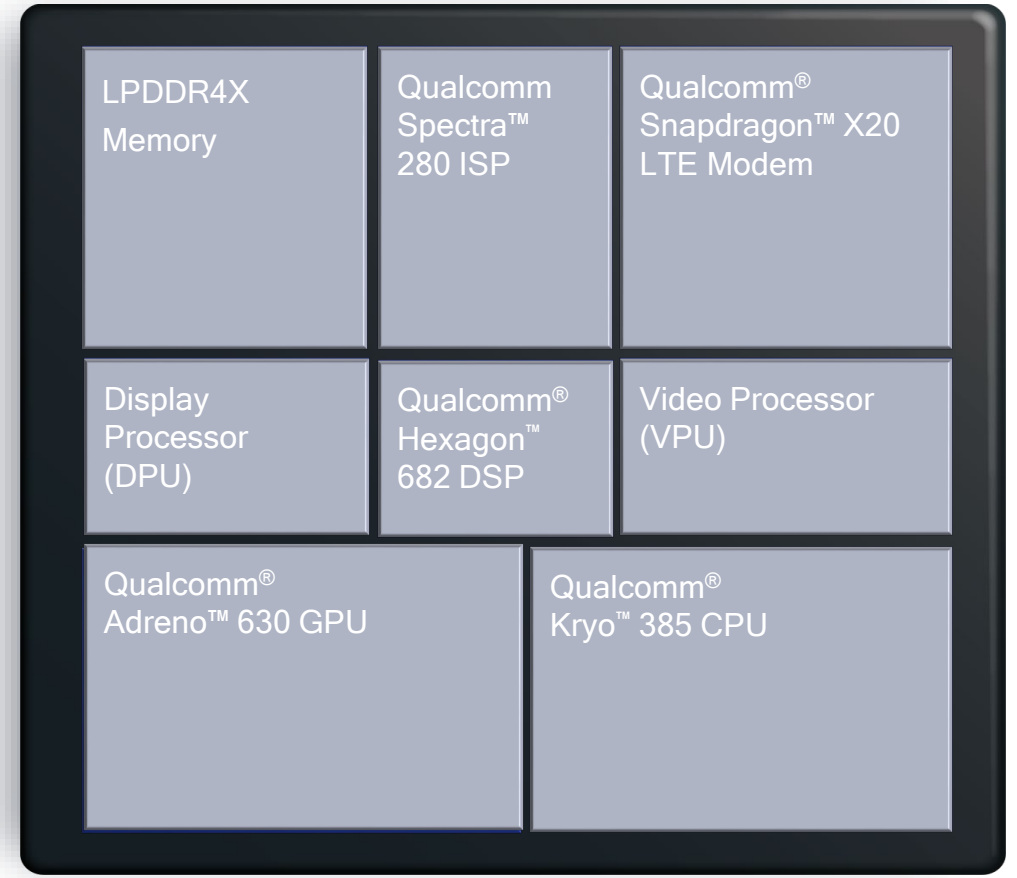
Thermal efficiency

A heterogeneous computing approach is needed for VR

Snapdragon 845 utilizes specialized engines across the SoC for efficient processing

Virtual reality

Computer vision, image processing, sensor processing, graphics, video processing, location, and cloud interaction



Entire SoC is used!

■ High-utilization

* Not to scale

Qualcomm® Snapdragon™ 845 processor is ideal for mobile VR

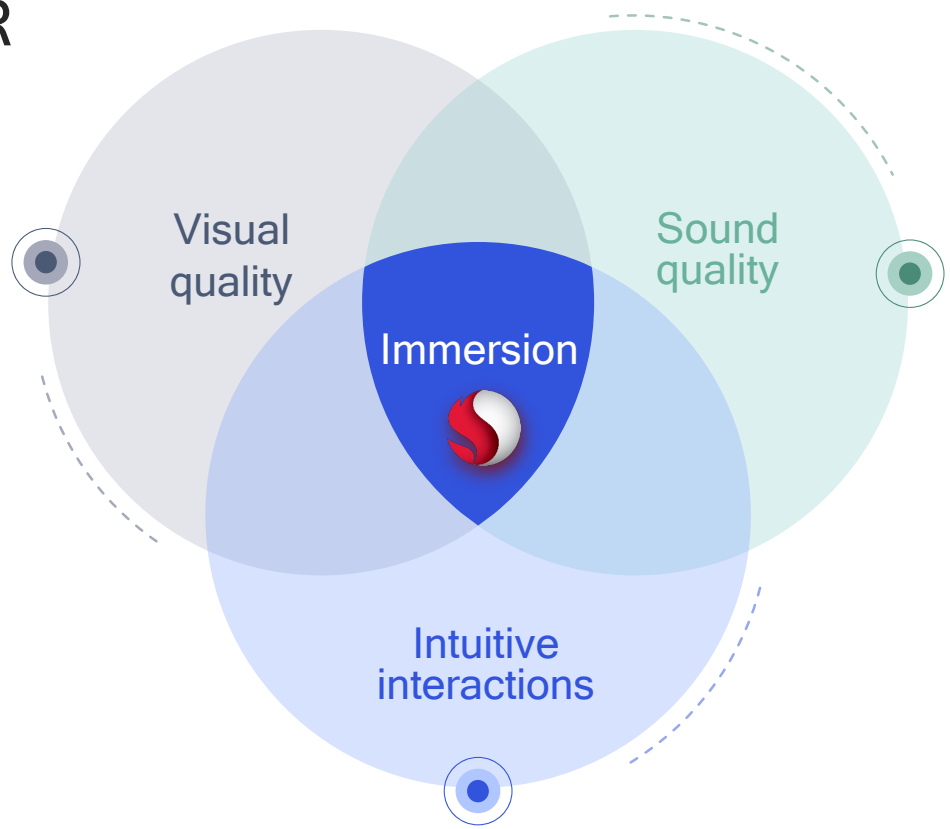
Designed to meet the VR processing demands within the thermal and power constraints

Smooth, 3D stereoscopic, foveated rendering, & support for the latest GPU APIs

Low power 360° 4K HEVC video decoding & display

Qualcomm® TruPalette™ display gamut mapping, color enhancement, etc.

Qualcomm Low-Power Picture Enhancement compression, variable refresh, etc.



Positional audio & 3D surround sound

Fluence™ noise filtering & active noise cancellation

Low level DSP access & tools for custom audio development

Integrated dual-camera ISP + DSP for low power 3D reconstruction & predictive 6-DOF motion tracking

Ultra-fast sensing for minimal motion to photon latency

Qualcomm® Adreno™ Visual Processing | Qualcomm Spectra™ ISP | Qualcomm® Hexagon™ DSP

Qualcomm Artificial Intelligence Engine | Qualcomm Aqstic™ audio | Qualcomm Snapdragon VR SDK | Snapdragon tools

Qualcomm® Snapdragon™ VR SDK

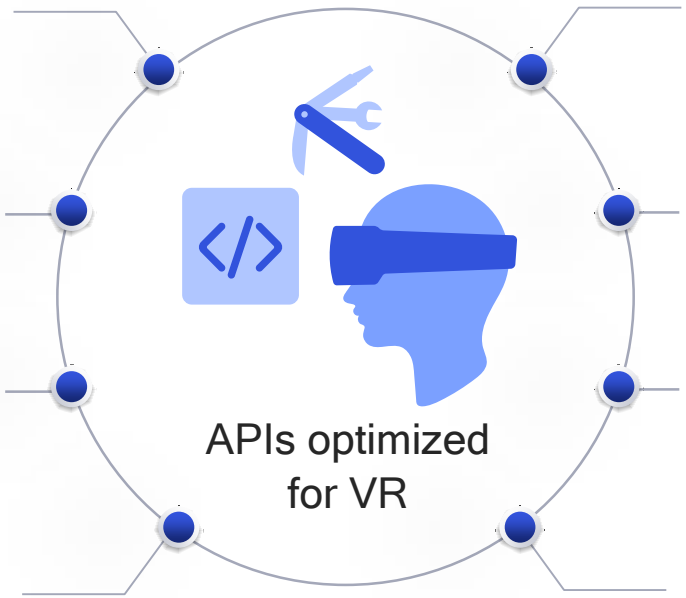
Access to advanced VR features to optimize applications and simplify development

DSP sensor fusion
Access to the latest and predictive head pose

Asynchronous time warp
Warp image based on the latest head pose just prior to scan out

Chromatic aberration correction
Correct color distortion based on lens characteristics

Lens distortion correction
Barrel warp image based on lens characteristics



Stereoscopic rendering
Generate left and right eye view

Single buffer rendering
Render directly to the display buffer for immediate display scan out

Power & thermal management
Qualcomm® Symphony System Manager provides CPU, GPU, and DSP power, thermal, and performance management

VR layering
Generate UI menus and text so that they render correctly in a virtual world

Benefits: Simplified development | Optimized VR performance | Power and thermal efficiency

Offering superior VR development and optimization tools

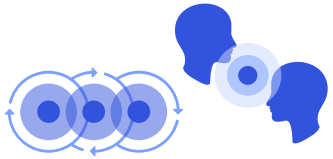
Enabling content creation and tuned devices

Content creation tools

- Specialized solutions for VR development
  - Qualcomm® Snapdragon™ VR SDK
- Other relevant solutions
  - Qualcomm® Adreno™ SDK: Graphics/Compute SDK
  - Qualcomm® Hexagon™ SDK: DSP SDK
  - Qualcomm® Symphony System Manager SDK: Heterogeneous compute SDK
- Optimization and tuning
  - Snapdragon Profiler
- Optimal third-party middleware engines
  - Unity & Unreal Engine

Device optimization tools

- Calibration and tuning
  - Qualcomm® Display Color Management
  - Qualcomm® Audio Calibration Tool
- Analysis and debugging
  - Qualcomm® Commercial Analysis Toolkit
  - Qualcomm® eXtensible Diagnostic Monitor



Other ecosystem enablement

- Development devices
  - Commercial devices
- Customer support
  - Customer engineering support

QTI is uniquely positioned to support superior VR experiences

Custom designed SoCs
and investments in the core
VR technologies

Mobile VR evolution

Devices will become sleeker, lighter, and more fashionable

Google Cardboard

Slot-in

HMD

Sleek HMD

Imperceptible device?

Continued improvements in…

- Power efficiency
- Pixel density & quality
- Sound quality
- Intuitive interactions
- Cost efficiency

QTI is uniquely positioned to support superior VR experiences

Providing efficient, comprehensive solutions

Immersive VR experiences

Visual quality
- Consistent, accurate color
- High resolution and frame rate
- Stereoscopic and spherical display

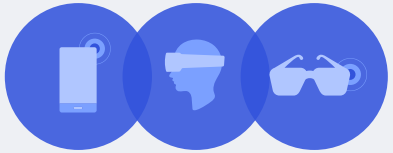
Sound quality
- Positional audio
- 3D surround sound
- Noise filtering

Intuitive interactions
- Minimized system latency
- Precise motion tracking
- Intelligent, contextual interactions

Within device constraints

Development time

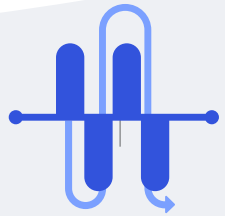
Sleek form factor



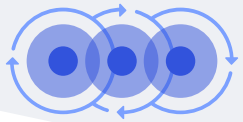
Power and thermal efficiency

Cost

Commercialization



Via Snapdragon™ solutions
- Efficient heterogeneous computing architecture
- Custom designed processing engines
- Comprehensive solutions across tiers



Via ecosystem enablement
- Snapdragon development platforms
- App developer tools
- Ecosystem collaboration

VR is here today

The mobile industry is accelerating VR adoption

Qualcomm® Snapdragon™ 845 processor is ideal for immersive mobile VR

Qualcomm Technologies will continue to drive VR technologies

Start developing
https://developer.qualcomm.com

Learn more
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Thank you

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