



Graphics Engineering on Mobile Platforms

A look into the past, present & future

David Sena
Principal Graphics Engineer
NaturalMotion Games

Contents

- Introduction
- Gaming on Mobile: What, Why and How?
- Hardware Differences: Mobile vs Desktops
 - Mobile GPUs
 - Performance Tips
- A look into the future & Conclusions

Contents

- Introduction
- Gaming on Mobile: What, Why and How?
- Hardware Differences: Mobile vs Desktops
 - Mobile GPUs
 - Performance Tips
- A look into the future & Conclusions

Introduction

- Graduated in 2012 from Instituto Superior Tecnico
- Got my break into the industry working for an indie company - Remode
- Great learning experience working on a team under tight deadlines and on a variety of projects
- Company closed 1 year after I joined



Introduction

- Spent 4 years working at Samsung R&D
 - Learned a lot about mobile devices and graphics
- Worked on a number of topics
 - Hardware ray tracing
 - Global illumination
 - Several VR and AR projects
 - Dev tech support of multiple games such as Need for Speed: No Limits
- Now working as a Principal Graphics Engineer at NaturalMotion
 - On the CSR Racing team



About NaturalMotion



- NaturalMotion is a British software company with development offices in London, Brighton, Birmingham, Austin and San Francisco
- NaturalMotion is a Zynga Studio (parent company)



CSR Racing 2



Dawn of Titans

About NaturalMotion



- NaturalMotion is a British software company with development offices in London, Brighton, Birmingham, Austin and San Francisco
- NaturalMotion is a Zynga Studio (parent company)



What is CSR Racing 2?

- Follow up title of the #1 drag racing game of all time (CSR Classics)
- Launched in 2016 for Android and iOS and currently in live ops
- Some review quotes:
 - “So real it hurts” – CULT OF MAC
 - “Obliterates the line between console and mobile graphics” – POLYGON
 - “CSR Racing 2 is visually stunning” – GAMEZEBO









What does it mean to be a graphics engineer?

- A graphics engineer is usually responsible for making games look their best while staying in budget
 - Budget can be frame time, RAM usage, VRAM usage, power consumption, etc
- We work with art teams to make sure that our technology is able to show their work in the best possible light
- You have to be constantly learning
 - Computer graphics is a relatively new field
 - Groundbreaking research being published every year
 - New platforms and hardware being released every year

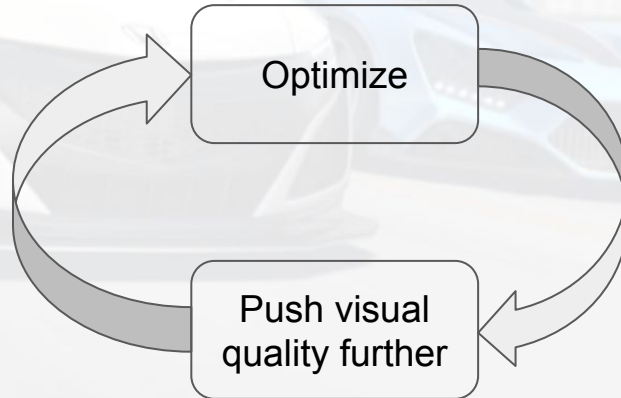
Why is it exciting to be a graphics engineer?

- This implies tackling a lot of different challenges during development!
- Sometimes we need to do R&D on a problem to bring a new feature into the game
 - Here creativity plays a very important role to find the best solution to the problem (not necessarily the most complex or sophisticated)
- Other times we get weird bugs that are only reproducible on a certain device
 - Here we put our forensic jackets on and try to understand where things go wrong



Why is it exciting to be a graphics engineer?

- The graphics engineer also has to optimize the game to ensure a good gameplay experience
 - There's always a trade-off between finding solutions to problems which are optimized and good looking
- The more we optimize the game, the more we can to push the overall quality further



Contents

- Introduction
- Gaming on Mobile: What, Why and How?
- Hardware Differences: Mobile vs Desktops
 - Mobile GPUs
 - Performance Tips
- A look into the future & Conclusions

Gaming on Mobile: What, Why and How?

“The smartphone is the defining technology of the age”

The Economist, March 2015

Gaming on Mobile: What, Why and How?

Mobile devices are everywhere and most people have one



SUBSCRIBE NOW

LOGIN

NEWS POLITICS VOICES SPORT CULTURE **INDY/LIFE** INDYBEST VIDEO DAILY EDITION



THERE ARE OFFICIALLY MORE MOBILE DEVICES THAN PEOPLE IN THE WORLD

The world is home to 7.2 billion gadgets, and they're multiplying five times faster than we are

Zachary Davies Boren | @zdboren | Tuesday 7 October 2014 16:30 |

Gaming on Mobile: What, Why and How?

Mobile devices are everywhere and most people have one



SUBSCRIBE NOW

LOGIN



NEWS POLITICS VOICES SPORT CULTURE **INDY/LIFE** INDYBEST VIDEO DAILY EDITION

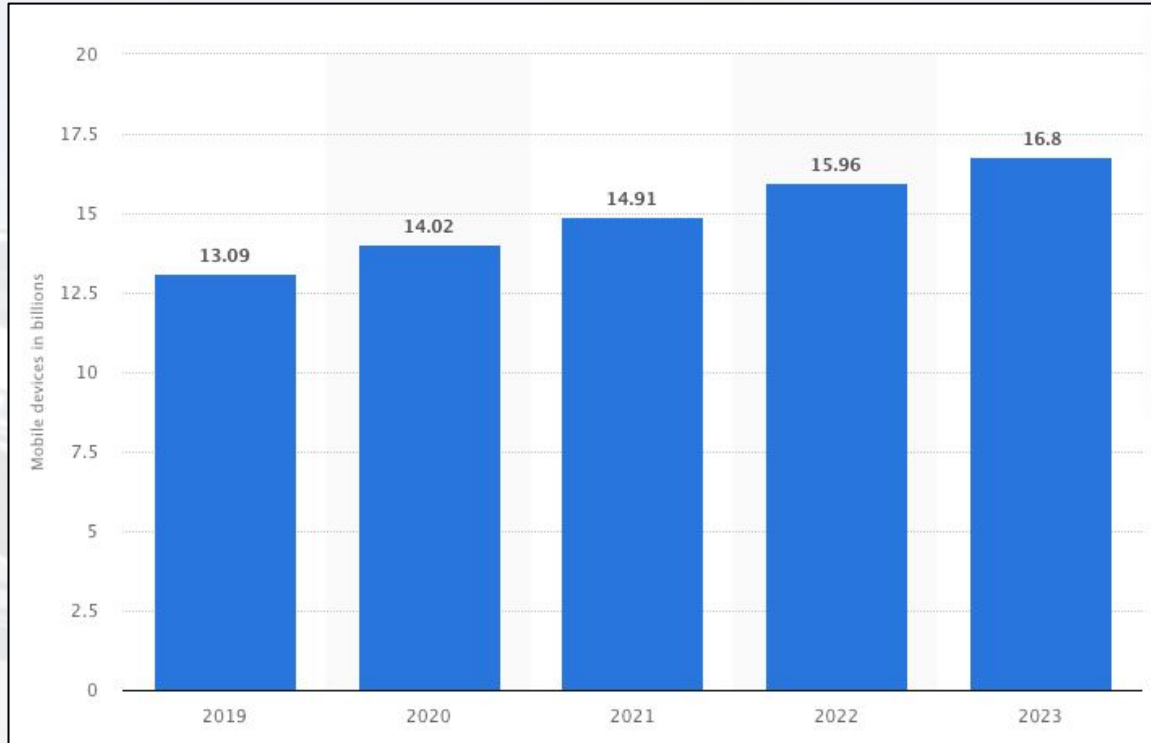


THERE ARE OFFICIALLY MORE MOBILE DEVICES THAN PEOPLE IN THE WORLD

The world is home to 7.2 billion gadgets, and they're multiplying five times faster than we are

Zachary Davies Boren | @zdboren | Tuesday 7 October 2014 16:30 |

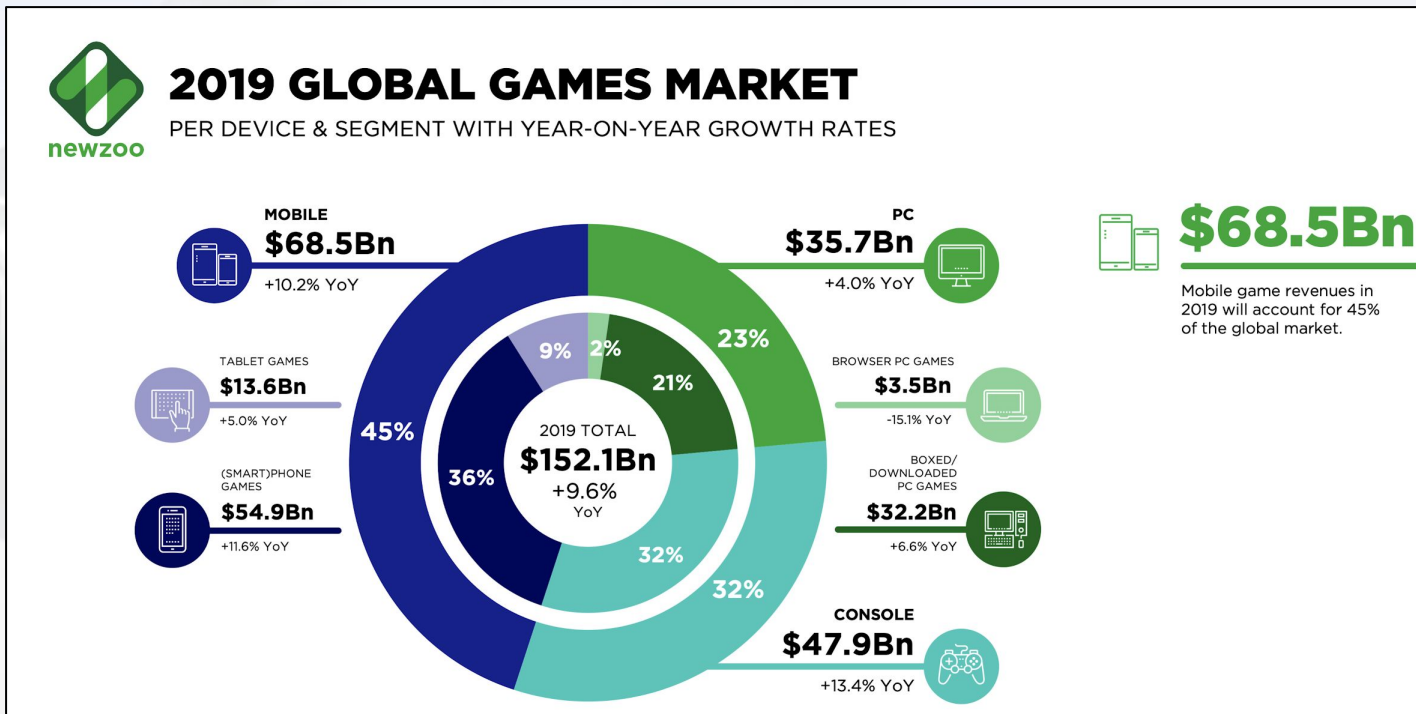
Gaming on Mobile: What, Why and How?



Forecast number of mobile devices(in billions) from 2019 to 2023

Gaming on Mobile: What, Why and How?

Mobiles account for the largest slice of the world's game revenue







9

N



Scarabara







Amber



▶ Auto



Paimon

That's a Statue of The Seven!





Tap Paimon's portrait to summon Paimon



35 ms

Press and drag in the desired direction to aim.
Try attacking the floating Anemo Slime.

Use Amber to defeat the airborne slimes

Higher 13m



Press the Attack Button to shoot



Lv. 1 793 / 793

UID: 715664319





74
91

TARGET:100

03:12

LOC_RANDOMNAME 222
LOC_RANDOMNAME 106
LOC_RANDOMNAME 191
LOC_RANDOMNAME 209
LOC_RANDOMNAME 106
LOC_RANDOMNAME 191
LOC_RANDOMNAME 222

LOSING

B 4m

CAPTURE

A 42m

CALL OF DUTY
MOBILE

47/0

15/128

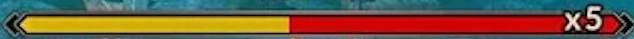
275

HP





Red Nose



Difficulty: 18 2447



Mission Objective
Defeat Red Nose



2801



30

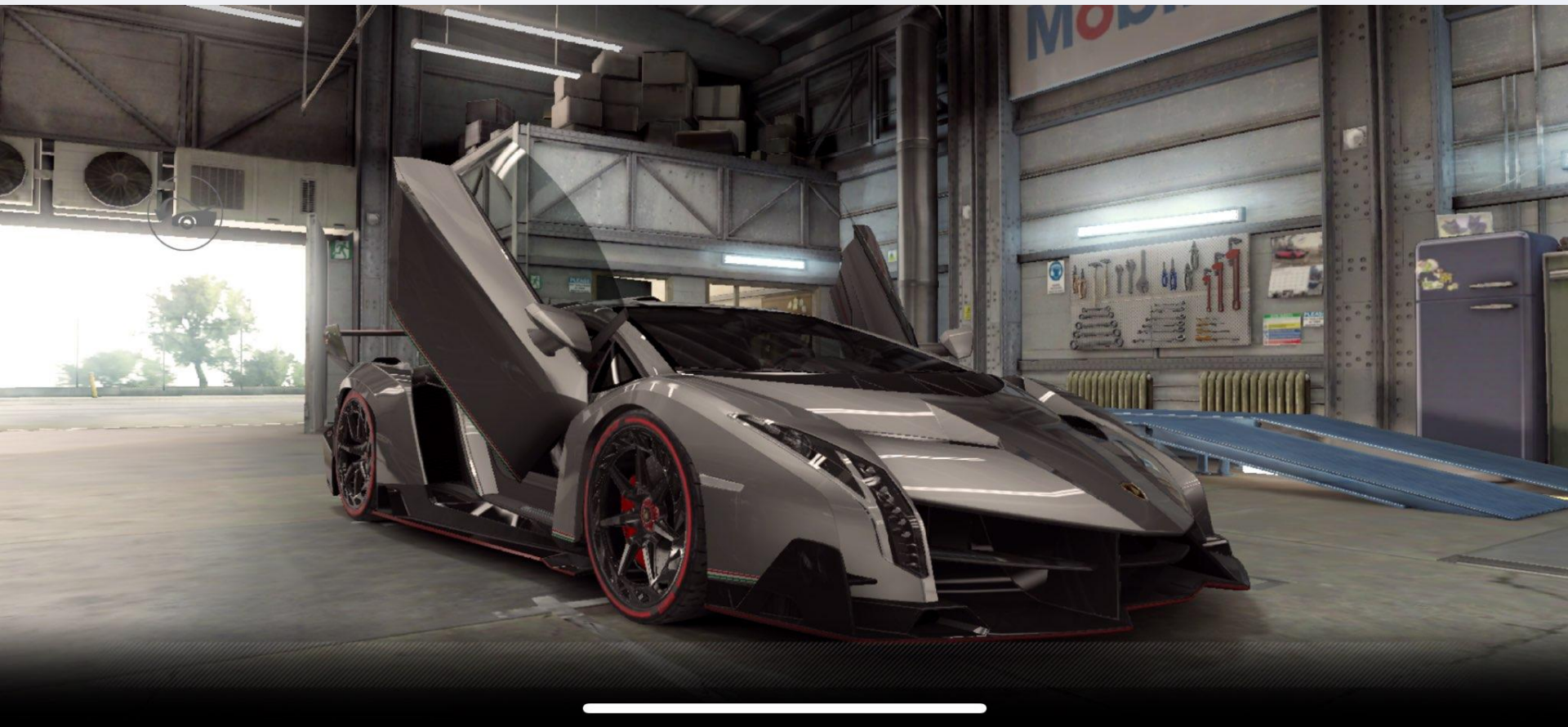


Lv 46 EXP 37.5% 06:22

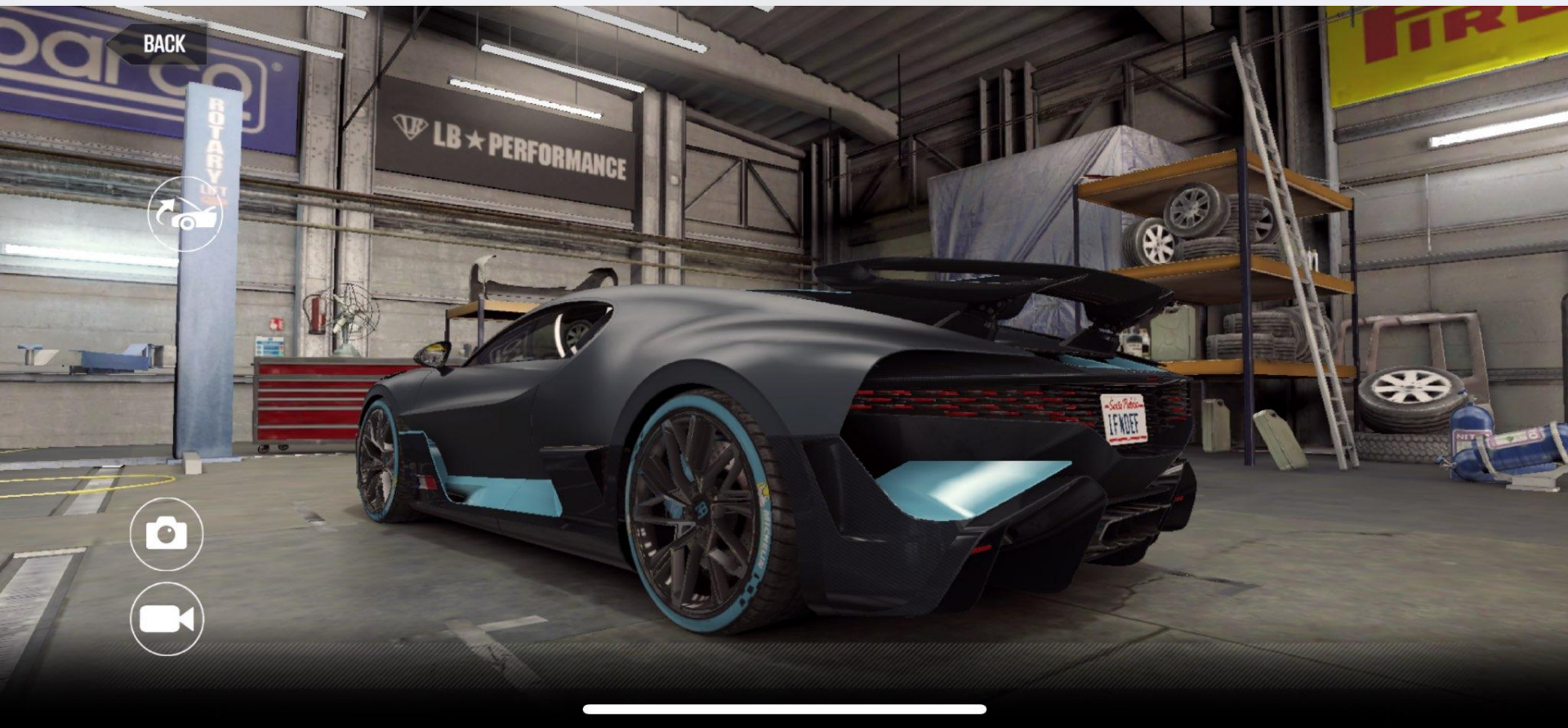


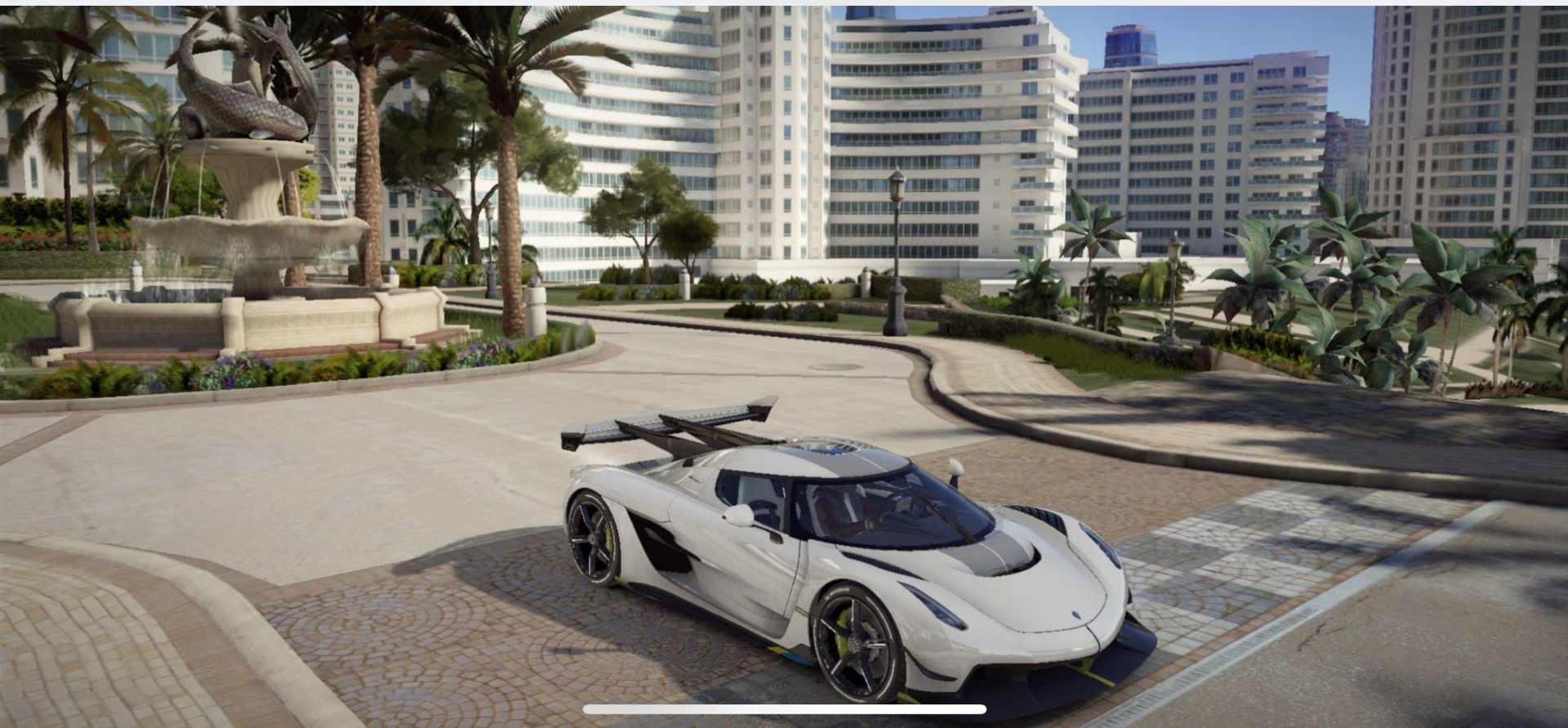
AUTO

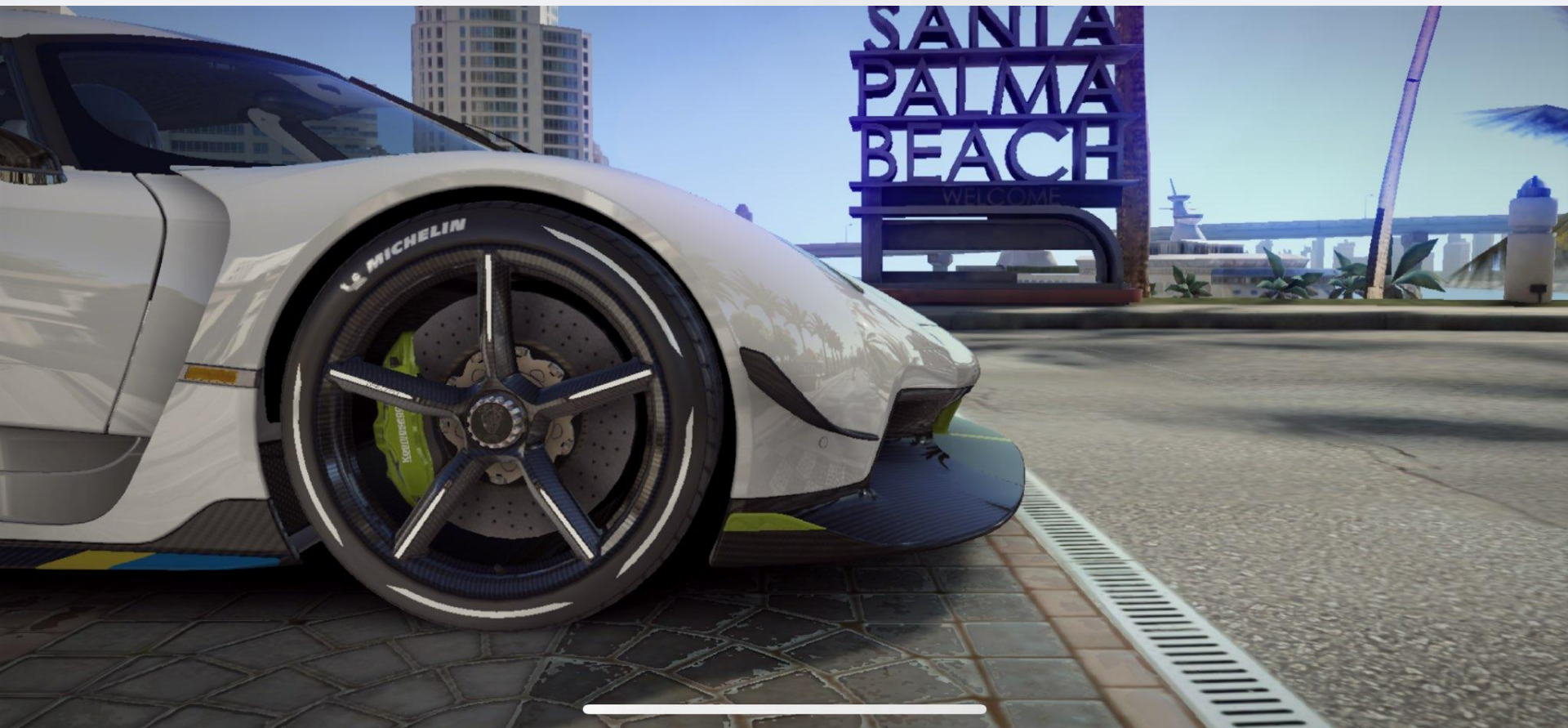












BACK

Face Ring

COMPLETE
AUTO REPAIR

CAR



0.00



5.667



BACK



0.00

Contents

- Introduction
- Gaming on Mobile: What, Why and How?
- **Hardware Differences: Mobile vs Desktops**
 - Mobile GPUs
 - Performance Tips
- A look into the future & Conclusions

Hardware Differences: Mobile vs Desktop

- Mobile devices have evolved a lot in the past 20 years
 - Devices have got a lot faster
 - Most have better displays with higher resolutions than desktop monitors
- ...but why hasn't my desktop machine reduced in size though?
 - It's all about trade-offs!
- The optimization required in mobile devices is hard to achieve
 - Normally you can't just make something smaller & faster without other compromises
- Larger size means better thermal dissipation and less thermal throttling
 - You can have a lot more raw power in a larger sized piece of hardware
 - No need to try and be efficient or too clever about it

Is mobile like hardware only used on phones?



Laptops



Smart TVs



Tablets



Virtual Reality



Augmented Reality



Game Consoles*



Contents

- Introduction
- Gaming on Mobile: What, Why and How?
- **Hardware Differences: Mobile vs Desktops**
 - Mobile GPUs
 - Performance Tips
- A look into the future & Conclusions

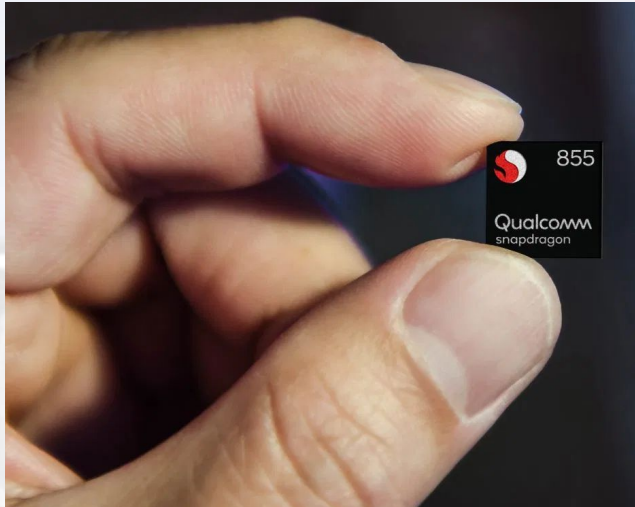
System on Chip (SoC)

- An SoC contains multiple components, most commonly
 - Central Processing Unit (CPU) and Graphics Processing Unit (GPU)
 - Memory
 - Input/output ports
- Today we'll be thinking about an SoC as:



System on Chip (SoC)

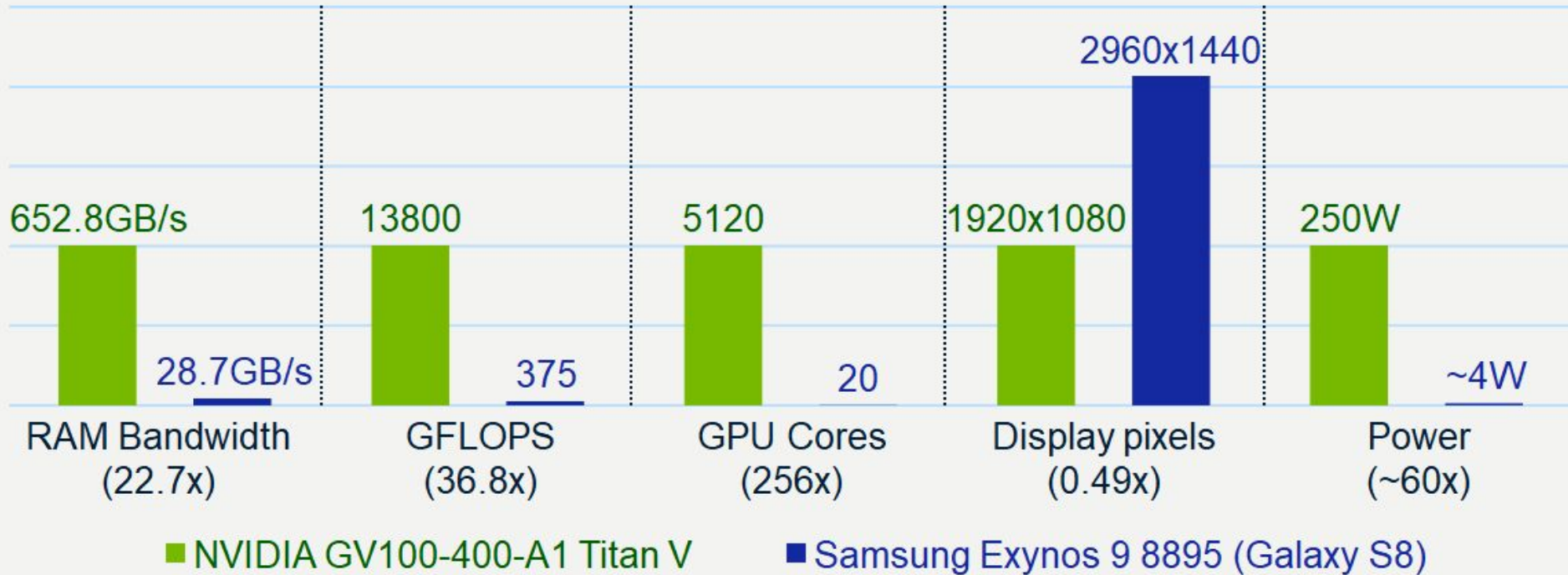
Mobile GPU vs Desktop GPU



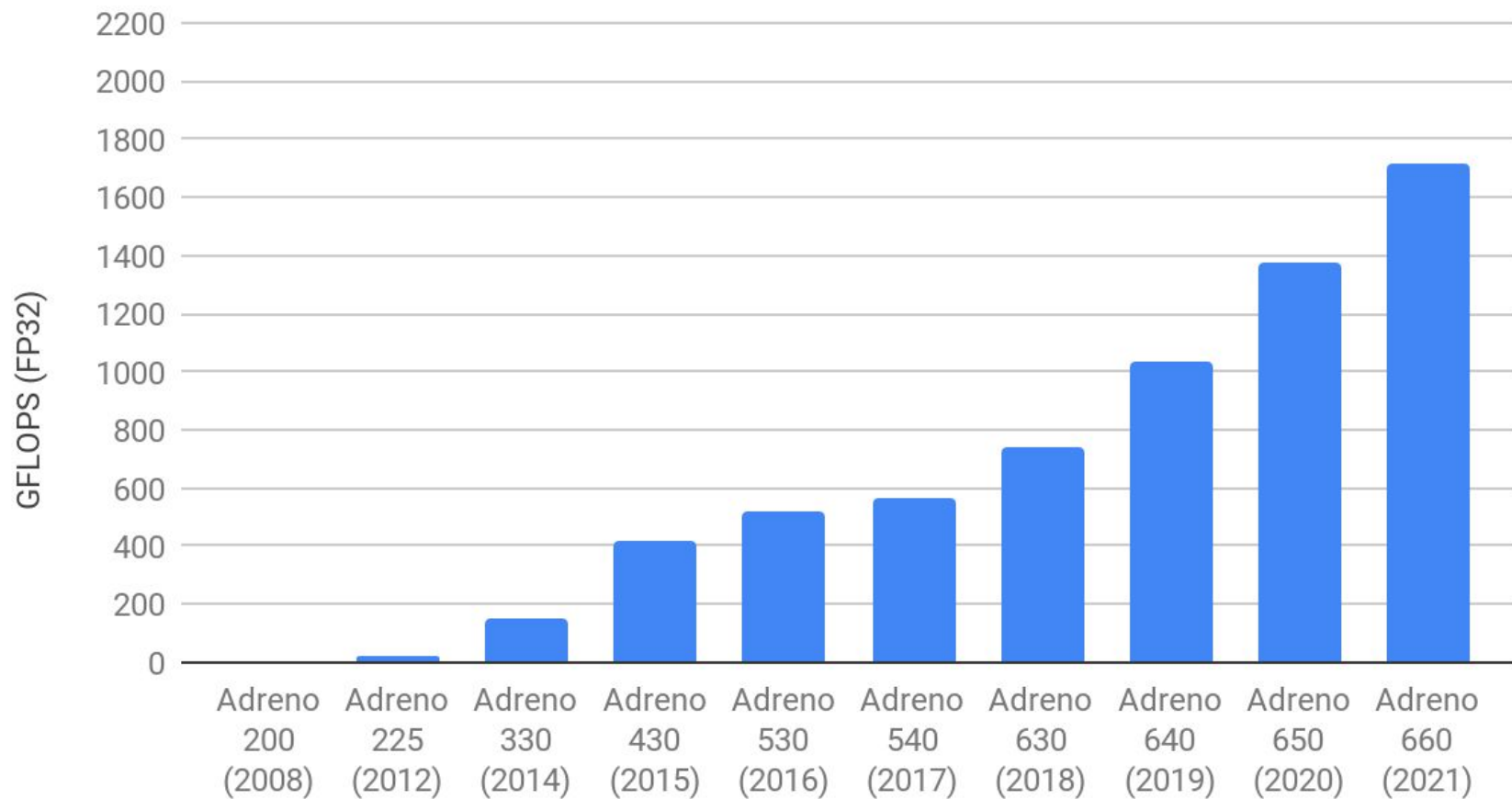
- Power limited by a battery
- Passive cooling
- Shared/Unified memory architecture
- Small form factor

- Unlimited power budget
- Active cooling
- Dedicated memory interface
- Large form factor

Mobile GPU vs Desktop GPU (circa 2017)

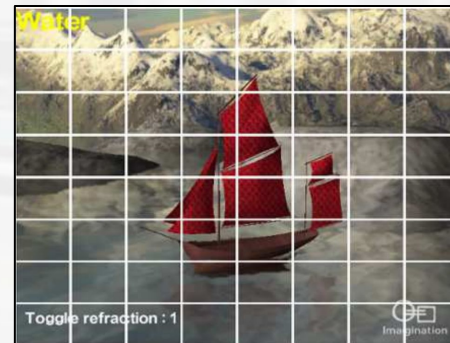


FP32 Performance of Adreno GPUs



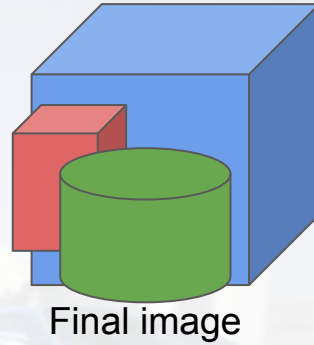
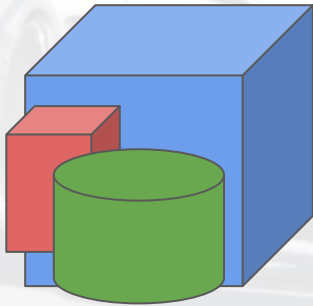
Immediate Mode vs Tiled Based Architectures

- Desktop GPUs are classified as “Immediate mode rendering”
 - Triangles are processed in the order submitted
 - Dedicated GPU memory
 - Less power efficient
- Most mobile GPUs can be classified as having a “Tile based architecture”
 - This means that rendering is processed in “bins”
 - They have a dedicated fast tile buffer

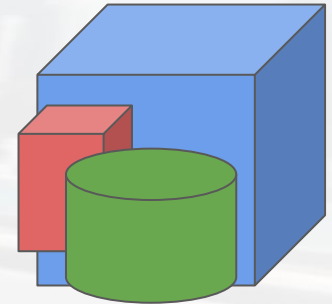


Immediate Mode vs Tiled Based Architectures

Immediate Mode Rendering

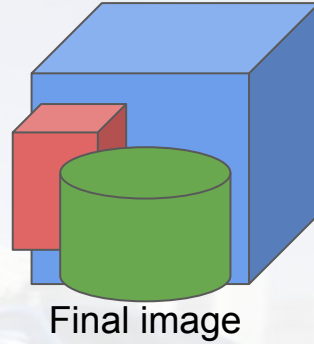
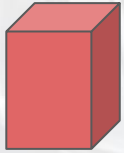


Tiled Based Architectures



Immediate Mode vs Tiled Based Architectures

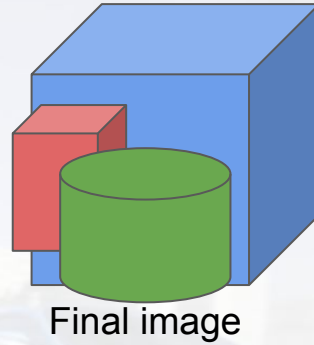
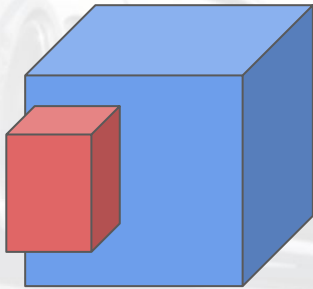
Immediate Mode Rendering



Tiled Based Architectures

Immediate Mode vs Tiled Based Architectures

Immediate Mode Rendering

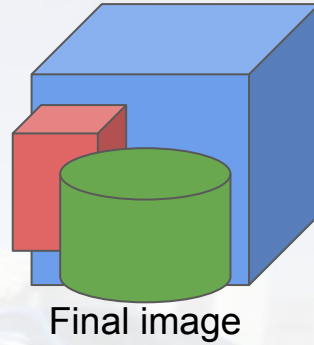
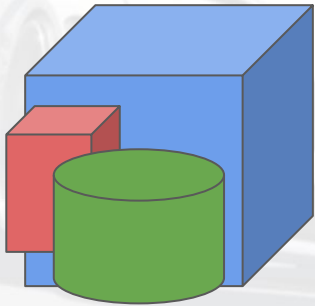


Final image

Tiled Based Architectures

Immediate Mode vs Tiled Based Architectures

Immediate Mode Rendering

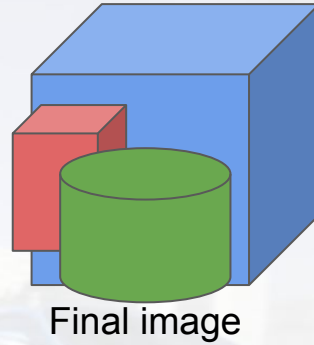
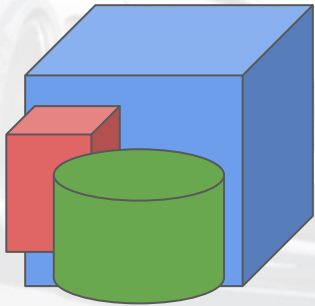


Final image

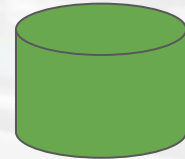
Tiled Based Architectures

Immediate Mode vs Tiled Based Architectures

Immediate Mode Rendering

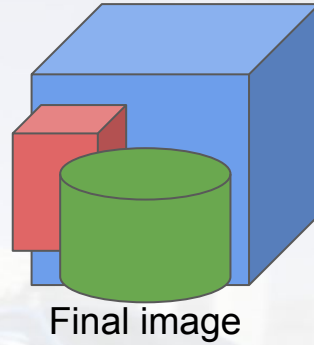
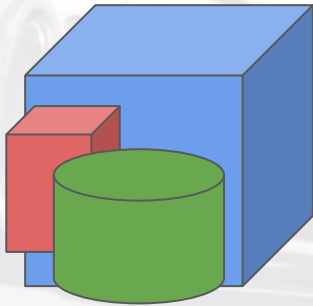


Tiled Based Architectures

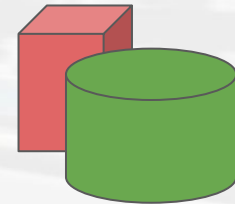


Immediate Mode vs Tiled Based Architectures

Immediate Mode Rendering

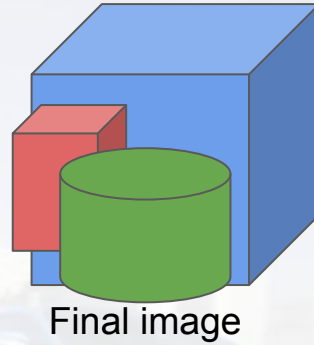
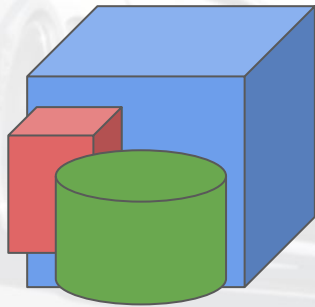


Tiled Based Architectures

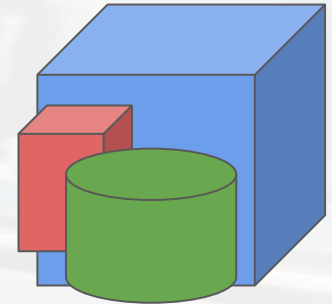


Immediate Mode vs Tiled Based Architectures

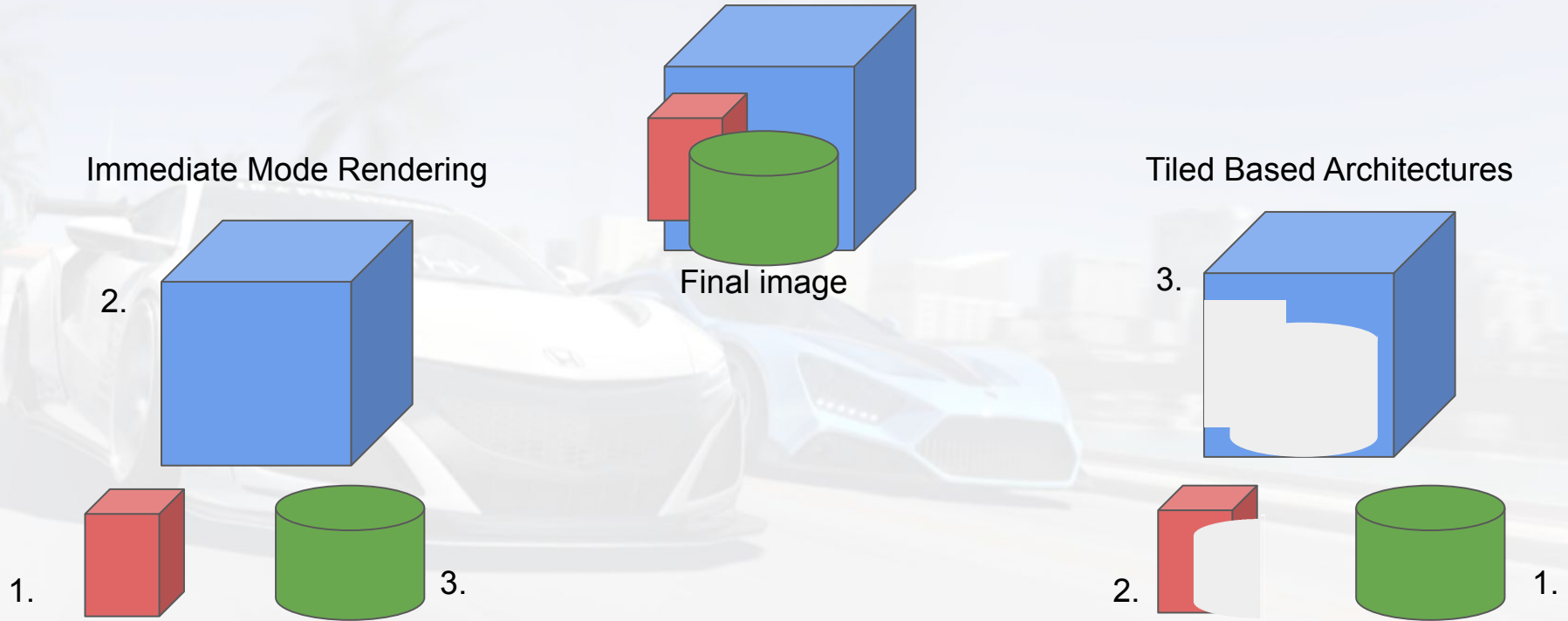
Immediate Mode Rendering



Tiled Based Architectures



Immediate Mode vs Tiled Based Architectures



Contents

- Introduction
- Gaming on Mobile: What, Why and How?
- **Hardware Differences: Mobile vs Desktops**
 - Mobile GPUs
 - Performance Tips
- A look into the future & Conclusions

Performance Tips

- I would like to take some time to walk you through some common performance pitfalls
- These are all pretty much platform agnostic
- Most of them are very easy wins which will help you in your projects



Performance Tips

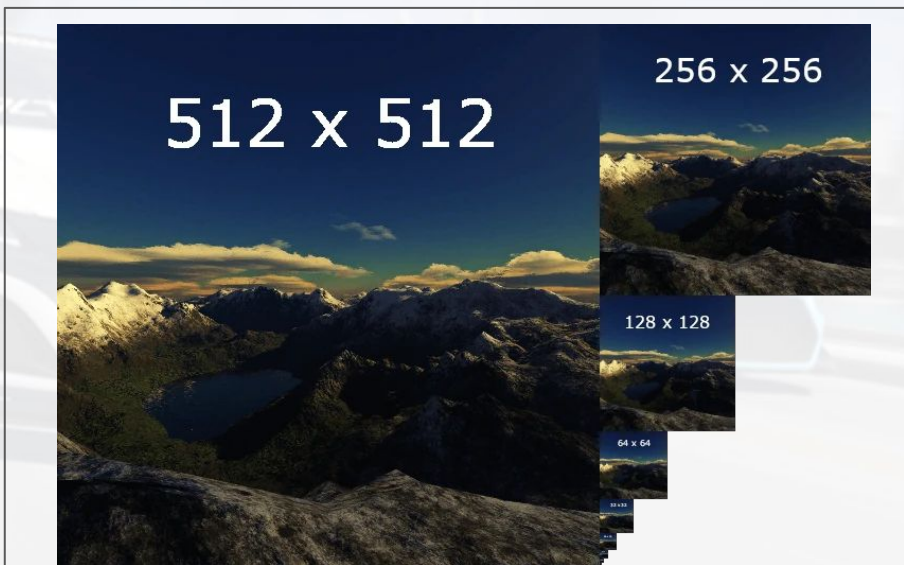
- Compress your textures!
 - There's multiple compression formats available
 - Most modern mobile devices support ASTC
 - Desktop PCs support BCn/DXT
 - With ASTC: use the highest viable block size
- PNG is NOT a compression format
 - ASTC keeps your texture compressed in memory, loading an uncompressed PNG as a texture doesn't
- You can easily 2x the performance of a project by compressing textures alone

Performance Tips

- Limit the number of render passes
 - Trade-off between flexibility and performance
- Limit dimensions, format and channels of textures & render textures
 - Don't make all your textures RGBA16F just because you can
 - Always use the smallest format you can get away with
- Keep texture reads to a minimum

Performance Tips

- Mipmapping should be on virtually everything except 2D screen UI
 - Can also help you save bandwidth
 - Results in better quality & performance

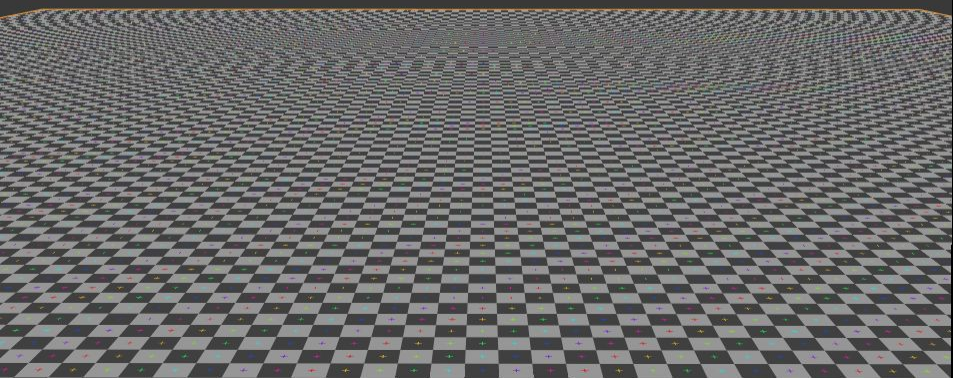


A texture is composed of multiple images

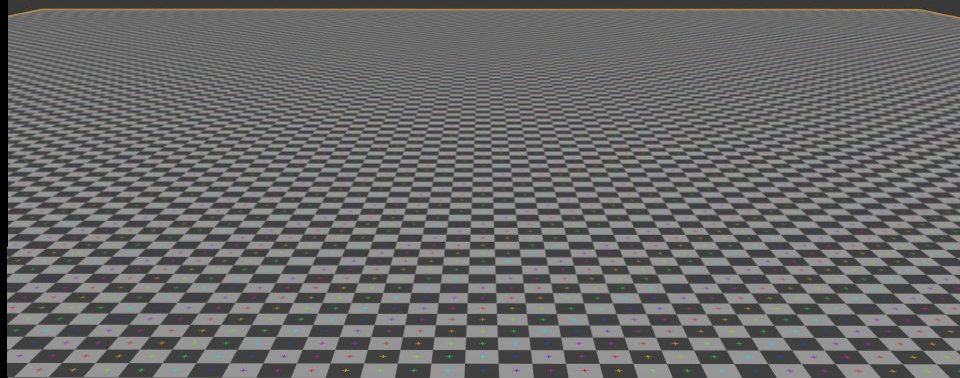
Performance Tips

- Mipmapping should be on virtually everything except 2D screen UI
 - Can also help you save bandwidth
 - Results in better quality & performance

No MipMapping



With MipMapping



Performance Tips

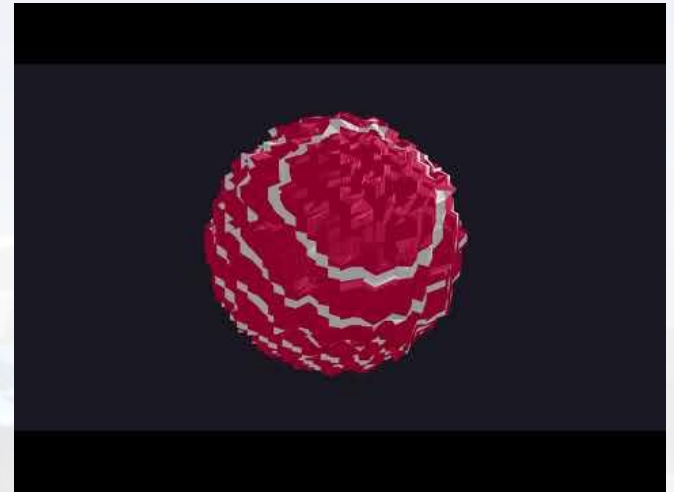
- Keep the number of textures per shader down by channel packing
 - Don't fill 3 channels of a 24 bit RGB texture and then have a separate texture with a single 8 bit channel separately - consider merging the 2 textures into a single 32 bit RGBA texture
- Rendering transparents cost a lot (overdraw)
 - Alpha testing is cheaper and opaques are even cheaper still
 - Keep their coverage down (small in screen space)
 - Avoid layering them - bake layers offline where possible
- On mobile: avoid geometry, tessellation and compute shaders where possible
- On desktop: geometry & tessellation shaders can quickly become bottlenecks

Performance Tips

- All shader languages allow for different levels of floating point precision
 - Usually called FP32, FP16 and FP8
- In GLSL it is part of a float qualifier: lowp, mediump and highp
 - highp - usually 32-bit, floating point range
 - mediump - usually 16 bits, floating point range
 - lowp - usually 11 bits, floating point range
- Note: on most platforms lowp simply maps to mediump

Performance Tips

- In HLSL/Cg floating point precision types are:
 - fixed, half and float
- Most GPUs can execute 16 bit float computations at twice the execution rate of 32 bit float
- Use medump/half precision variables when you can
 - Think about what type of precision your operations need
 - You have 16 bit of floating point precision to use
 - Get extra precision by using (-X to X) instead of (0 - 2X)



Performance Tips - Unity Specific

- On Assets: Read/Write Enabled should almost always be disabled
- Be aware of renderers with multiple materials
 - Multiple materials translate to multiple draw calls
- Minimise using multi-pass shaders
 - Multi-pass shaders also translate to multiple draw calls
- GameObjects which do not move should usually be flagged as 'Static'
 - But be aware that static batching is not always better!
 - Meshes with huge bounding box can result in them being rendered even outside of the frame
 - Instancing might be a better option for duplicate meshes over the frame

Contents

- Introduction
- Gaming on Mobile: What, Why and How?
- Hardware Differences: Mobile vs Desktops
 - Mobile GPUs
 - Performance Tips
- A look into the future & Conclusions

More laptops using mobile like SoCs



VR is only getting started



 **oculus**
from FACEBOOK

**INTRODUCING
QUEST 2**

VR is only getting started

Oculus Quest 2 sales figures prove VR has finally gone mainstream

By Hamish Hector about 1 month ago

Better than all the rest



(Image credit: Future)

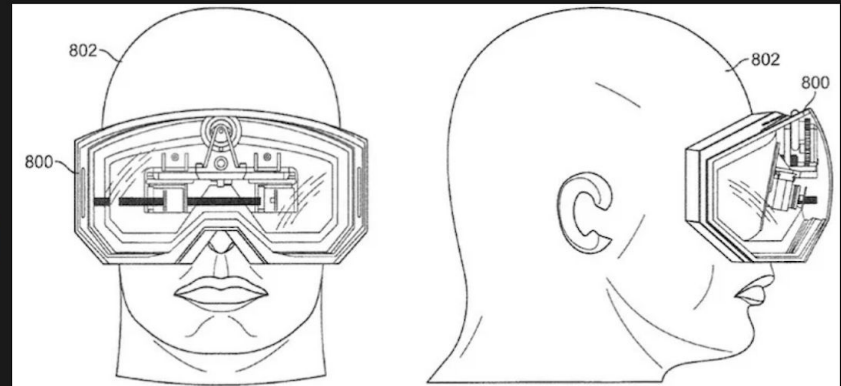
The Oculus Quest 2 has sold more total units than all other Oculus headsets combined. The milestone was recently announced by the VP of Facebook Reality Labs, Andrew Bosworth, and shows that VR is finally starting to hit the mainstream.

AR is only getting started

Apple Glasses

Apple is rumored to have a secret team of hundreds of employees working on virtual and augmented reality projects.

By MacRumors Staff on April 6, 2020



Hardware Accelerated Ray Tracing



Apple's Imagination Technologies deal is all about ray tracing and AR

JEREMY HORWITZ @HORWITZ JANUARY 2, 2020 9:28 AM



The realistic lighting and shadowing capabilities of advanced ray tracing are demonstrated in Cyberpunk 2077.

Image Credit: CD Projekt Red

Apple sent Imagination Technologies' stock into a tailspin when it decided in 2017 to end its licensing contract with the storied British graphics chip maker, a process that was expected to cut Imagination intellectual property out of Apple products by 2019. As A-series CPUs and GPUs have grown to rival Intel's mobile

VB TRANSFORM

The AI event for business leaders

Hosted Online
July 15 - 17

[Learn More](#)

VB

**Transform
2020**

Portable Consoles

The Nintendo Switch can't be stopped

Console sales and games combine for blowout year

By [Thomas Ricker](#) | [@Trixy](#) | May 6, 2021, 3:32am EDT

[f](#) [t](#) [SHARE](#)



Nintendo Switch sales fuel full year profits. | Photo by James Bareham / The Verge

Nintendo Switch sales were up 44 percent percent from January to March compared to the same pandemic-impaired quarter from a year earlier. [Today's numbers](#) bring total Switch sales to 28.83 million for the fiscal year, up 37 percent compared to the 21 million Switch consoles the company shipped the year prior, and beating the company's own revised forecast.

Conclusions


- The future is ubiquitous and is mobile
- The mobile market makes more money than any other gaming market
 - This translates in further investment, opportunities and interesting challenges to solve
- GPUs are 4x faster at ALU calculations when compared with 5 years ago
 - Imagine how much faster will they be by the time you graduate!
 - New GPU architectures are continuously bringing further flexibility and improvements
- VR/AR/Ray Tracing are just getting started
 - The VR market is still waiting for a “killer app/game” to be created
 - AR is still in its infancy with a lot of possibilities for new games to explore
- There’s a huge opportunity for you to leave a mark in all of these areas

The background image shows two sleek, futuristic cars on a road. The car in the foreground is white with blue accents and has 'F7LHV' written on its windshield. The car behind it is blue. The scene is set in a sunny, urban environment with palm trees and a city skyline in the distance. The text 'Thank you' is centered over the image.

Thank you

5 Minute Break



A man in a black tuxedo and white bowtie sits behind a dark table. On the table are a bottle, a glass, a microphone, and a rotary phone. The background is a dark, textured wall.

And now for something completely different.

Personal Recommendations

- I would like to spent some minutes giving some unwarranted and completely personal advice based on my experience
- Vast majority of you are less than 2 years away from graduation
- Things to remember:
 - Recommendations here are based on several years of interviewing candidates
 - Advising multiple MSc dissertations thanks to Prof. Pereira
 - All in all, this is my personal and subjective view

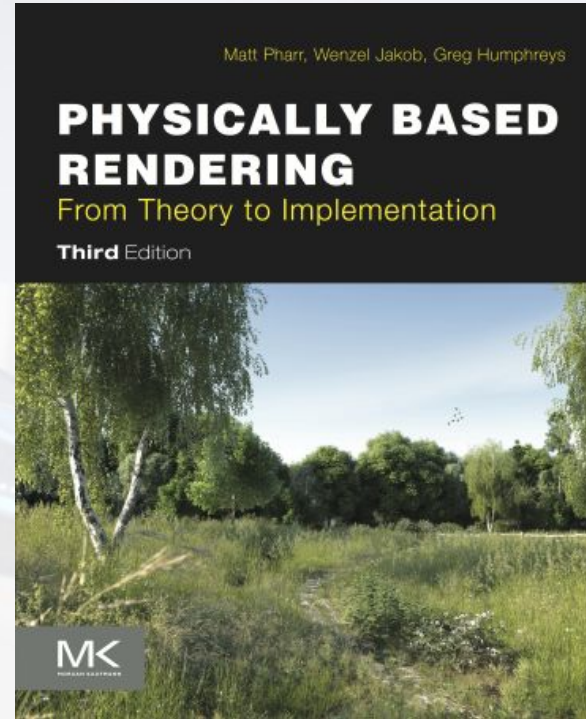
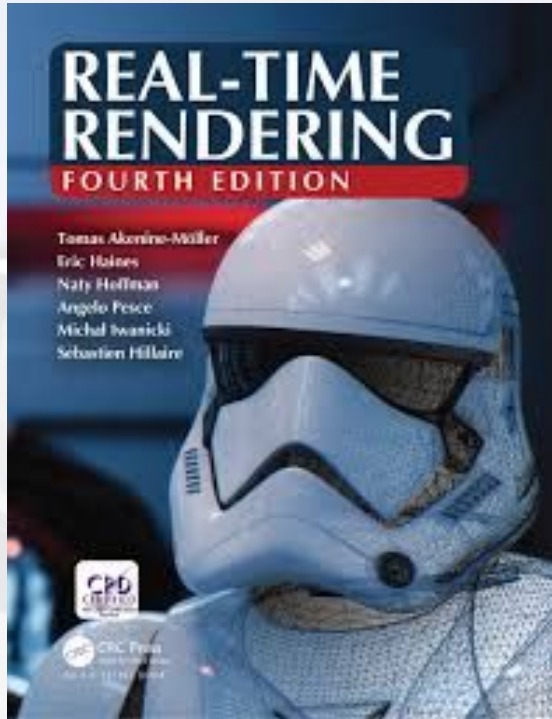
Personal Recommendations

- Make the most of your MSc projects
- For those who want to go into the games/graphics industry:
 - A lot of your MSc projects can and should be used as portfolio pieces
 - You **don't** need a lot of portfolio pieces
 - Have portfolio pieces that are well polished and interesting
 - Before applying for a job, make sure you brush up on the details of each of your projects
- For those who want to continue in academia:
 - Use your projects as a basis to further explore your research interests
 - Try to complement your course projects with techniques/approaches that interest you
 - Develop your own test bed where you can explore and research things further
- Bottomline is
 - You're already investing time in making your coursework projects so make sure you get the most out of them!

Have a Solid Foundation

- **The fundamentals are what will allow you to grow in the future**
 - University is the place where you are introduced to a wide variety of topics
 - A lot of the basics are covered throughout your degree
- Amongst students there's a stigma that basics == "trivial"
- Always keep in mind that there's no shame in saying:
 - "I don't know but I'll look that up and learn"
- I brush up on the different basics of computer graphics every 6 months or so
 - Make sure you do the same before starting sending applications for interviews

Study these (not read, study!)



Available for free online

Study these (not read, study!)

the GRAPHICS CODEx

Programming Projects Syllabus Contents Sample Course

the GRAPHICS CODEx

the GRAPHICS CODEx

The essential reference for computer graphics, now available in both iOS and web editions.

Both readable and solid, the Graphics Codex provides the reader with the essence of 3D computer rendering.
—Eric Haines, Autodesk
coulantor of *Real-Time Rendering*

"I own and use the Graphics Codex. Is it a reference tool, a companion to a textbook, an alternative to a textbook, or a self-study guide? It can work in any of these roles, but I think it is in fact a new thing. It's a thing we'll be seeing a lot of...dollar for dollar, it's the best scholarly information I have ever purchased."
—Peter Shirley, University of Utah
coulantor of *Fundamentals of Computer Graphics*

The Graphics Codex by Morgan McGuire at *Casual Effects* contains:

- 400 cross-referenced equation and diagram entries
- 14 chapters on physically-based shading and rendering
- Multi-platform programming projects
- Links to external DirectX, OpenGL, Unity, Matlab, GSD, and other API documentation
- PDF links and full citations for primary sources and textbooks
- Free updates with new content every month

Download free PDFs of three sample topics: [Chapter 4: A Model of Light](#), [Topic: Ray-Triangle Intersection](#), and [Topic: Fresnel Coefficient](#). For teachers, a sample [syllabus](#) shows how to use the Graphics Codex beside or instead of a conventional textbook.

Topics in the app include: Ray tracing, shallow water equations (2D Navier-Stokes), shadow map shaders, the Rendering Equation, area of a sphere, Fresnel equations, popular BSDFs, CSS selectors, configuring simple web servers, HTML, entities, transformation matrices, quaternion operations, ray intersections, a chart of common resolutions, the EM spectrum, and human photoreceptor frequency response.

Purchase the app once. It will adapt to the native resolution of every device that you use it on. New content and app features will automatically arrive every month as free updates.

The Graphics Codex is written by an expert, always with you, and always up to date. E-mail suggestions and report problems directly to me (Morgan) at morgan@casual-effects.com.

Choose your edition:

- Graphics Codex DLI Edition**
Free Deep Learning Institute edition based by NVIDIA. Requires an internet connection.
- Graphics Codex Web Edition**
Pay \$10 once to use in desktop and mobile browsers through one Amazon account. Requires an internet connection.
- Buy with amazon**
- Graphics Codex iOS Edition**
Pay \$10 once to install on all of your iPad, iPhone, and iPod Touch devices simultaneously. Fast, native, and no internet required.

Download on the App Store

Available for free online at:
<https://graphicscodex.courses.nvidia.com/app.html>

Study these (not read, study!)

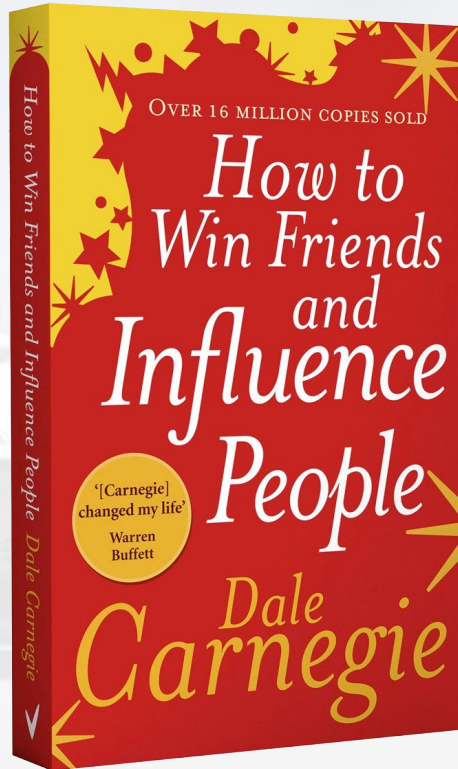


Available for free online at:
<https://gamemath.com/>

Communication Matters

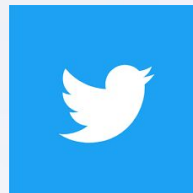
- Take group projects as a way to expand and improve your soft skills
- The image of the “Hollywood” lone wolf multi-millionaire genius is just fiction
 - Even the loneliest of wolves will need a team at some point
- In both the industry and academia you’ll be working as part of a team
- You have to study about how to be more effective when communicating
 - It’s just a skill as any other
 - It’s “not trivial” and no, you’re not great at it yet
- There’s tons of good resources about it

Communication Matters - Starting Points



Be Part of the Community

- The computer graphics community tends to gather on Twitter
 - Probably the best place to keep up with the latest advances and discussions
- A lot of conferences share some/all of their contents online
 - GDC Vault
 - ACM Siggraph is Siggraph's official Youtube channel
 - Digital Dragons on Youtube
 - Many others
- Everyone is on a journey to mastery: share, discuss and learn!





Thank you