Ubiquitous 3D: Graphics Everywhere

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Outline

- History of mobile 3D
- Key enablers and challenges
- Mobile graphics APIs
- Current mobile HW offering
- Mobile gaming
- The way forward

State-of-the-art in 2001: GSM

- What’s the world’s most played electronic game?
  - According to The Guardian (May 2001)

    “it took Nintendo 10 years to sell 100m Game Boys whereas Nokia sold 128m handsets last year alone”

- Communicator demo
  - Assembly 2001
  - Remake of 1994 winning Amiga demo
  - ~10 year from PC to mobile

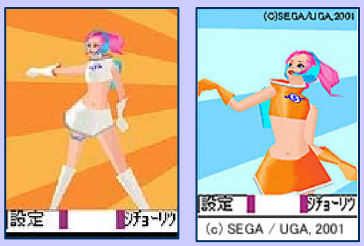
Splatting in 2001

- M-splat
  - Experiment on points as rendering primitives
  - Port of the Q-splat viewer to 9210 Communicator

- Key lesson
  - Floating point operations killed the performance
  - On integer hardware, design the whole system with fixed point maths

State-of-the-art in 2001: Japan

GENKI 3D Characters
(C) 2001 GENKI



ULALA
(c)SEGA/UGA.2001

J-SH07
by SHARP

Space Channel 5
©SEGA/UGA,2001 ©SEGA/UGA,2002

Snowboard Rider
©WOW ENTERTAINMENT INC., 2000-2002all rights reserved.

J-SH51
by SHARP

- High-level API with skinning, flat shading / texturing, orthographic view

GSM world in 2002

- 3410 shipped in May 2002
  - A SW engine implementing a subset of OpenGL
    - full perspective (even with textures)
  - Downloadable 3D screensavers (artist created content)
  - FlyText screensaver (end-user created content)
  - a 3D game

Japan in 2002

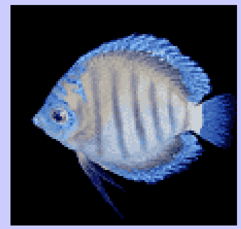
- Gouraud shading, semi-transparency, environment maps


I-3D PolyGame Boxing

@ Hi Vanguard· REZO, BNW

Ulala Channel J

©SEGA/UGA,2001 ©SEGA/UGA,2002



KDDI Au 3D Launcher

©SAN-X+GREEN CAMEL

3d menu

N-GAGE NOKIA

GSM world in 2003

- N-Gage ships
- Lots of proprietary 3D engines on various Series 60 phones
  - Starting already in late 2002

Fathammer's Geopod on XForge

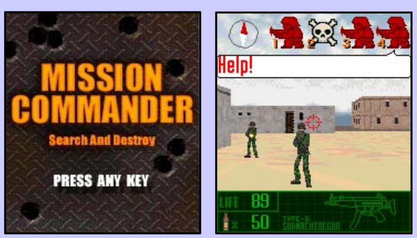
N-GAGE NOKIA

Japan in 2003

- Perspective view, low-level API

Ridge Racer

@ Namco



Mission Commander
Multi-player FPS Game

© IT Telecom

N-GAGE
NOKIA

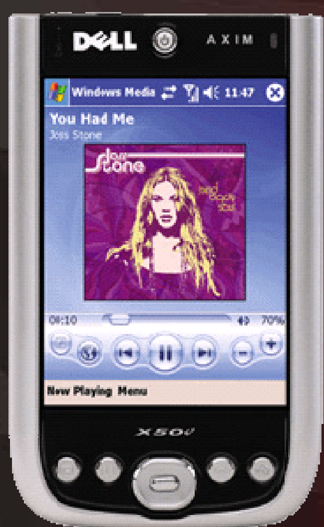
Mobile 3D in 2004

- N-Gage QD
  - better input, hot-swap MMC cards
  - several 3D titles
- 6630 shipped late 2004
  - OpenGL ES 1.0 (for C++)
  - M3G (a.k.a JSR-184, for Java)
- Sharp V602SH in May 2004
  - OpenGL ES 1.0 capable HW
    but API not exposed
  - Java / MascotCapsule API

N·GAGE
NOKIA

Mobile 3D in 2005: With HW

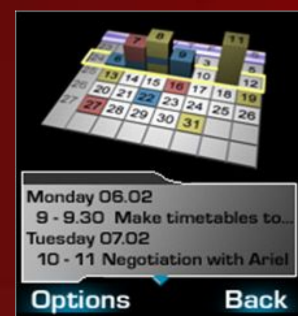
- PSP
- Gaming phones with 3D gfx HW

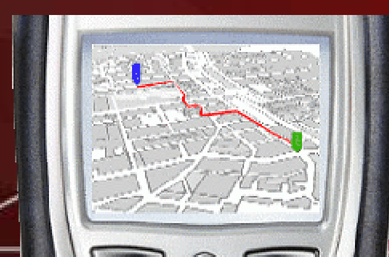


Mobile graphics use cases

- Mostly gaming
  - and other entertainment
    - screensavers, etc.
- The user interface
  - individual applications
  - application launcher
  - …
- Mapping applications



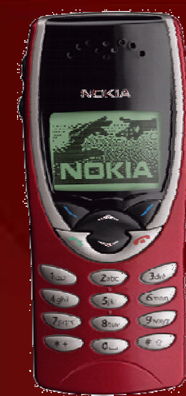





Key enablers and challenges

Changed? Displays!

- Recent improvements
  - Resolution
    - S60: 176 x 208
    - S80: 640 x 200
    - S90: 640 x 320
  - Color depth
    - Not many new B/W phones
    - 12 / 16 / 18 / … bit RGB
- Physical size remains limited
  - Near-eye micro displays in the future?



Changed? Computation!

- 3410
  - ARM 7 @ 26MHz
  - Not much caching, narrow bus
- 7650
  - ARM 9 @ ~100MHz
  - Decent caching, better bus
- 6630
  - ARM 9 @ ~200MHz
  - Faster memories
- Still no FPUs though
  - To high-end soon (at least for graphics), mid-tier later, low-end remains integer longer

Challenge? Power!

- Battery improvement doesn’t follow Moore’s law
  - Only 5-10% per year
- Gene’s law
  - "power consumption of integrated circuits decreases exponentially" over time and because of that the whole system built around chips will get smaller, and batteries will last longer
  - Since 1994, the power required to run an IC has declined 10x every two years
  - But the performance of two years ago is not enough
    - Pump up the speed
    - Use up the power savings

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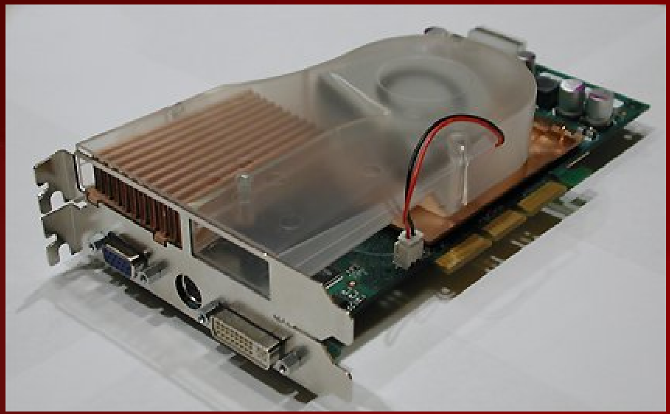
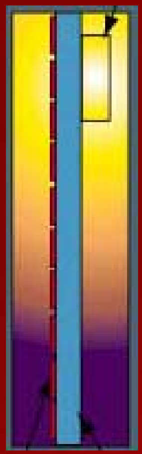
Challenge? Thermal mgt!

- But ridiculously good batteries still won't be the miracle cure
  - The devices are small
  - Generated power must get out
  - No room for fans
- Thermal management must be considered early in the design
  - Hot spot would fry electronics
    - Or at least inconvenience the user…
  - The heat must be conducted through the case walls, and finally removed to the ambient





www.coolingzone.com

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What are phones made of?

- There's an amazing amount of technology in a phone
  - CPU, sometimes more than one
  - DSP, usually several
  - Radio units, many!
  - Memory: ROM, RAM, Flash, MMC, DMA, eDRAM, …
- So how do I access the iron to get most out of it?
  - Thru APIs
    - you really don't want go hacking too close to HW
    - you might get some speed advantage, but that is fleeting
    - HW and products change so much faster than in the old hacking days of 70's and 80's
    - common APIs get you across products of a single manufacturer and also across manufacturers

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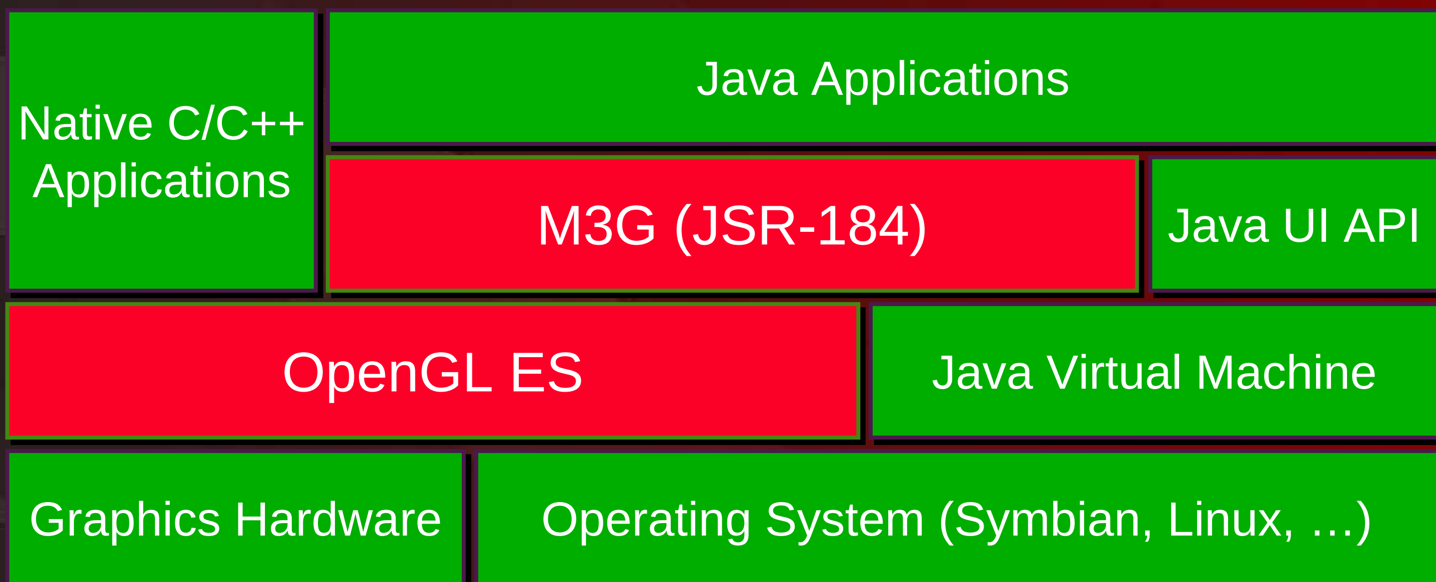
Standard APIs for mobile graphics

Layering for resource reuse

- OpenGL ES and M3G
  - Designed concurrently (and partly by the same people)
  - Influenced each other
  - Layered implementation model (immediate benefit of same HW)



OpenGL ES

- Forum: KHRONOS GROUP
- OpenGL ES 1.0 design targets
  - Compactness: Eliminate un-needed functionality
    - redundant, expensive, unused
    - footprint target 50KB
  - Target both SW and HW implementations
    - don’t mandate FPU support
  - Retain good things of OpenGL
    - basic architecture
    - extensibility
    - conformance tests

OpenGL ES 1.0 in a nutshell

- Retain functionality that apps can’t emulate
  - Full fragment processing of OpenGL 1.3
- Corollary: drop convenience functionality
  - GLU, evaluators, feedback mode, selection, display lists
  - Stippling, polygons / quads, drawpixels, bitmap: all can be emulated
  - Texcoords, user clipping, can be calculated in the application
- Simplify state machine
  - Drop glBegin – glEnd, use arrays instead
  - Only RGBA (no indices), only double-buffering, draw only to back buffer
- Queries
  - Only static ones – Apps can keep track of their own state

Profiles

- OpenGL ES Common
  - Doubles => floats
  - Also support fixed point input (signed 16.16)
  - Require OpenGL (~ float) accuracy with matrix calculations
- OpenGL ES Common Lite
  - Drop floats altogether
    - Only fixed (and integers, of course)
  - Only require 16.16 fixed point accuracy with matrices, allow overflows
- OpenGL ES Safety Critical
  - For aviation, cars, etc. --- anywhere where certification required
  - Still under work

Matrices without FPUs OK!

- What makes the emulation of IEEE floats slow?
  - Special cases (such as NaN, Inf, …) take a lot of processing
  - After every operation you have to do book-keeping
    - Renormalize, i.e., shift the mantissa and update exponent accordingly
- If you know the context, you can make shortcuts
  - Matrix times vector: lots of structure ((4x4, 4x1) => 64 muls, 48 adds)
    - Assume int / fixed-point vertices, matrix elements floats
    - First do the maths on mantissas (effectively integer arithmetics)
    - Book-keeping of exponents at the end
  - Easily 10x speed win compared to emulated IEEE floats
    - Only a modest speed loss w.r.t fixed point-only implementation
    - Floats multiplied with other floats more difficult and slower…

OpenGL ES 1.1 in 2004

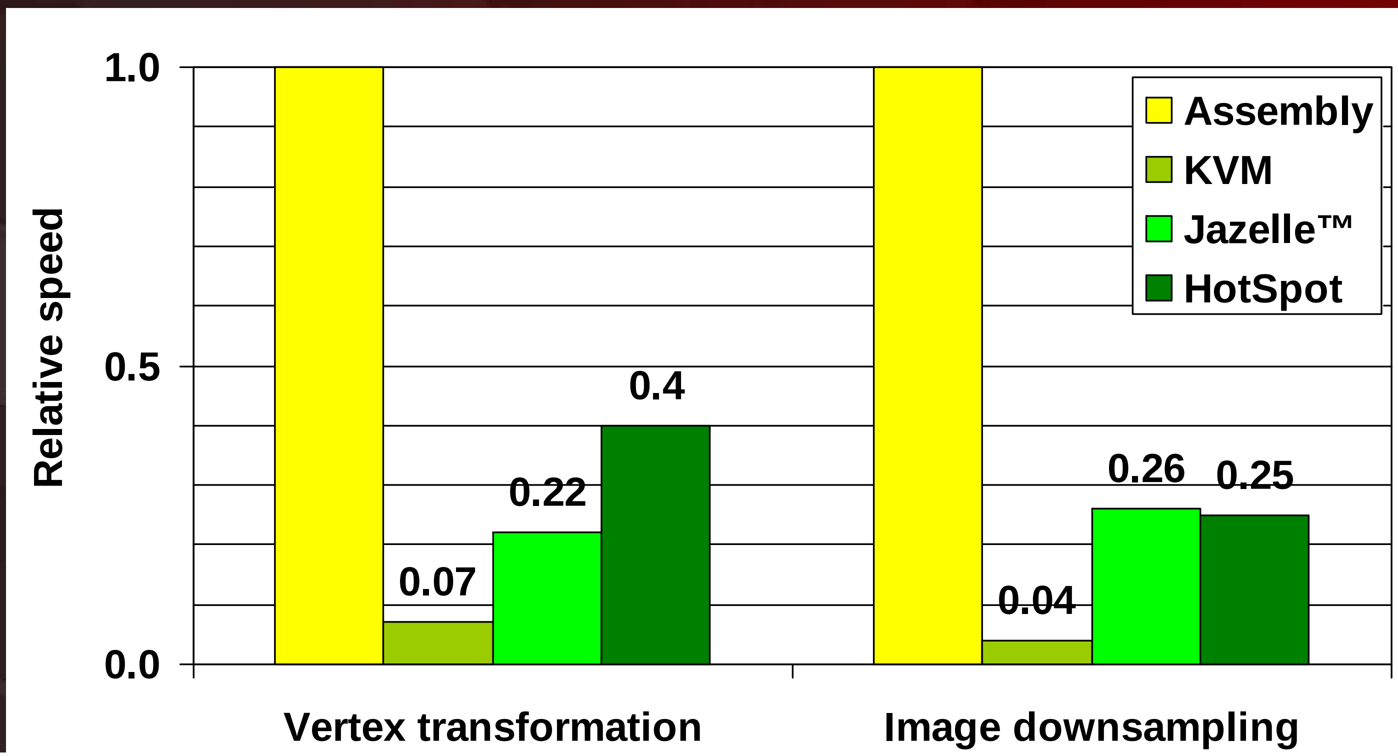
- More HW oriented than 1.0
- Buffer Objects --- allow caching vertex data
- Draw Texture --- pixel rectangles using tex units (data can be cached)
- Better Textures --- >= 2 tex units, combine (+,-,interp), dot3 bumps
- Matrix Palette --- vertex skinning (>= 3 M / vtx, palette >= 9)
- User Clip Planes --- portal culling (>= 1)
- Point Sprites --- particles as points not quads, attenuate size w/ distance
- State Queries --- enables state save / restore, good for middleware

OpenGL ES 2.0 in 2005

- Plan to release at SIGGRAPH
- Features
  - Vertex and fragment shaders
    - GL Shading language
  - Keep it compact
    - no fixed functionality
    - no backwards compatibility
  - Allow compilation both offline and on-device
- Mobile 3D feature set is catching up desktop fast!
  - Sony PS3 chose OpenGL ES 2.0 as the API
    - along with CG, Collada

What about Java?

- On desktop new hotspot compilers are pretty good
  - but on mobiles there's a clear difference between C and Java performance



Benchmarked on an ARM926EJ-S processor with hand-optimized Java and assembly code

M3G (JSR-184)

Need a higher level API

- A game is much more than just 3D rendering
  - Objects, properties, relations (scene graph)
  - Keyframe and other animations
  - Etc. (game logic, sounds, …)
- If everything else but rendering is in Java
  - A very large percentage of the processing is in slow Java
  - Even if rendering was 100% in HW, total acceleration remains limited
- A higher level API could help
  - More of the functionality could be implemented in native (=faster) code
  - Only the game logic must remain in Java

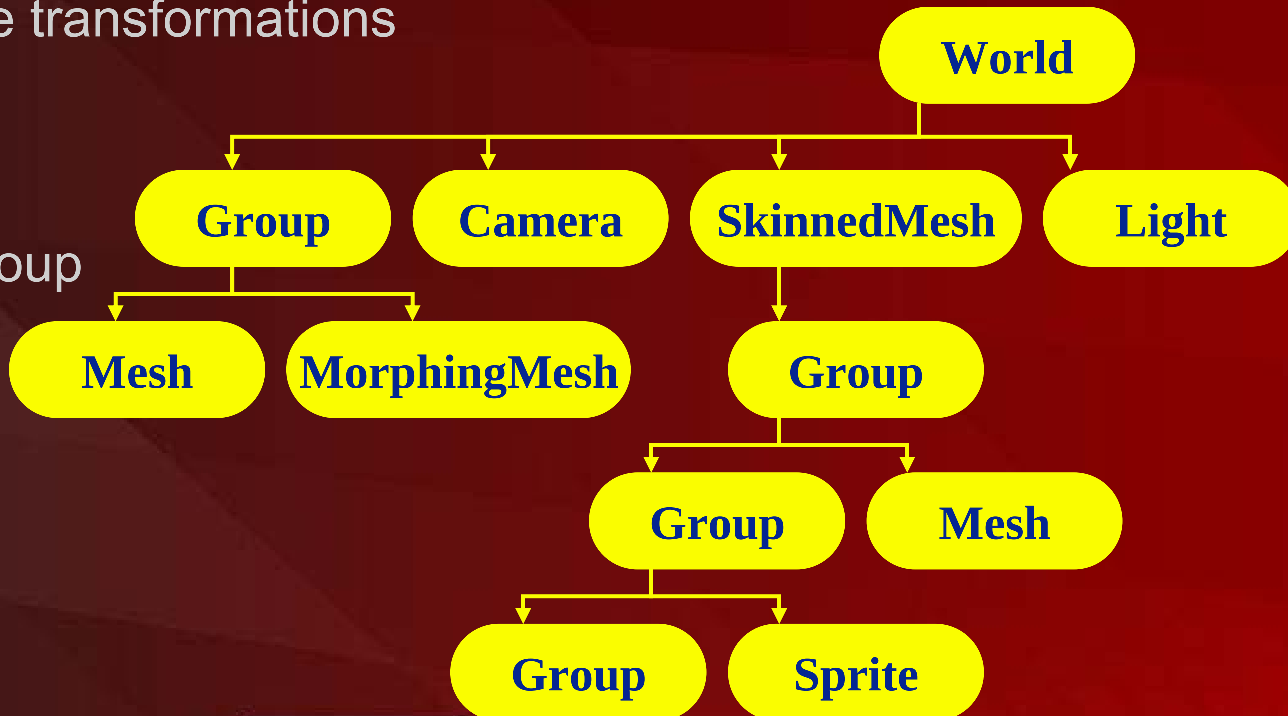
Java3D ES? No, M3G!

- Java3D seemed a good starting point
  - But "Java3D ES" didn't work out
  - Java3D was designed for large-resource systems
    - Java3D distribution is ~40MB (~300x too big for us)
  - Didn't really fit together with MIDP
    - a large redesign necessary
- M3G (JSR-184), a new API
  - Nodes and scene graph
  - Extensive animation support
  - Binary file format and loader

M3G
!=
Java3D

Scene graphs from nodes

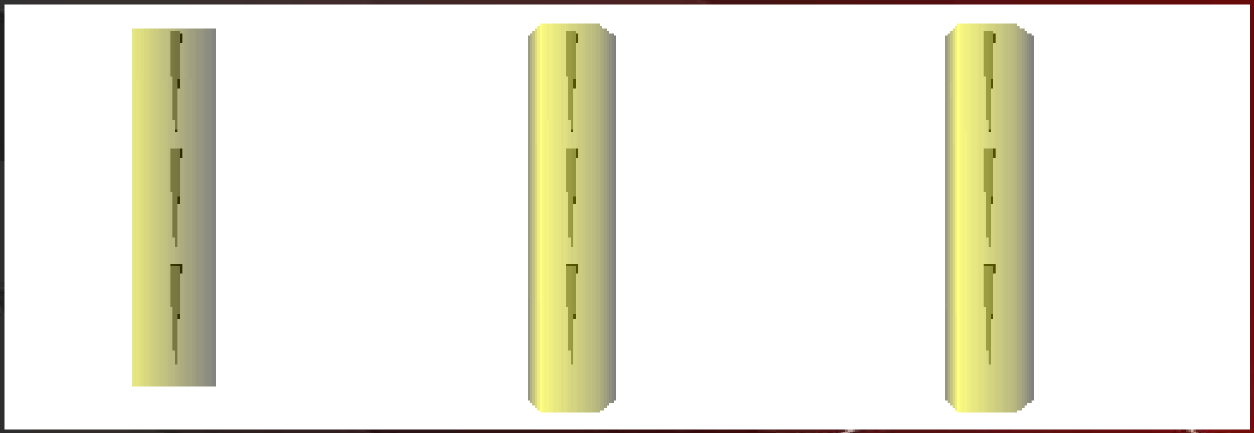
- The tree encodes structure
  - Data (vertices, textures, animation data, …) can be shared
  - Nodes encode relative transformations and inherited alpha
- World is the root
  - A special case of a group
- Other nodes
  - Camera
  - Light
  - Mesh
  - Sprite



M3G (JSR-184)

Special meshes

- SkinnedMesh
  - For articulated motions
  - Bones have weighted associations to vertices
- MorphingMesh
  - For unarticulated animations
  - Base mesh, targets, weighted interpolations towards / away from targets



M3G (JSR-184)

Everything can be keyframed

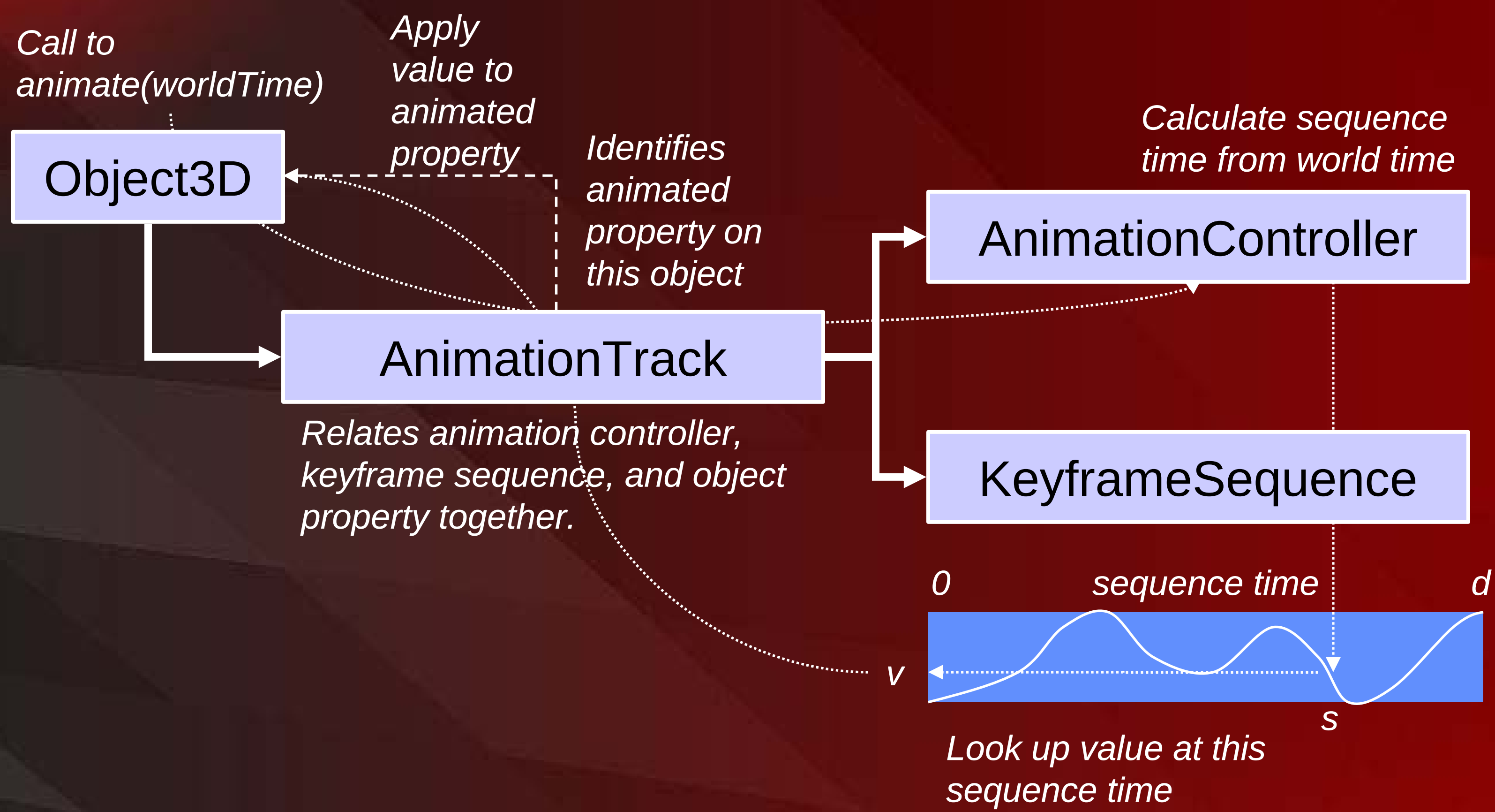


Diagram courtesy of Sean Ellis, Superscape

Layering for resource reuse

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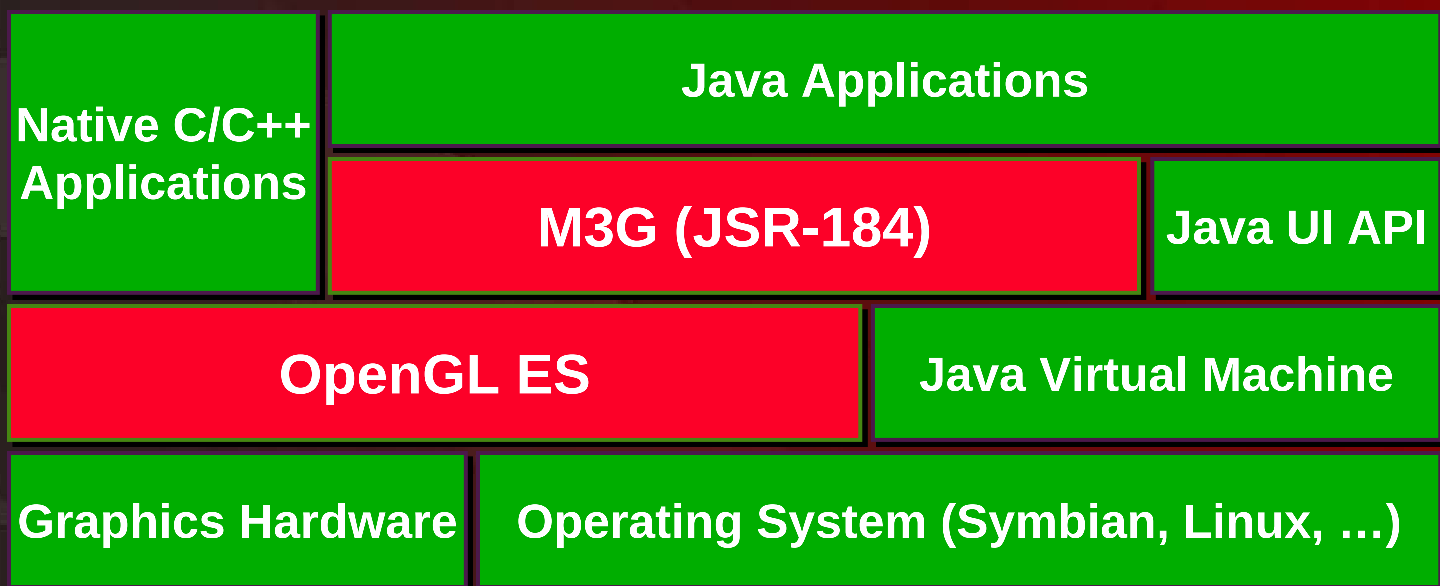
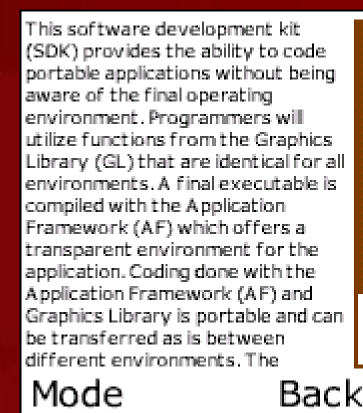


What about 2D vector gfx?

- Need for low-level 2D vector graphics primitives
  - Portable mapping and GPS, E-book readers and text packages
  - Games
  - Advanced user interfaces and screen savers, even GDIs
- Many vector graphics formats in use
  - Flash, SVG, PDF, Postscript, vector fonts, PPT, etc.
- Scalable graphics = Easier to port content



OpenVG fills the need

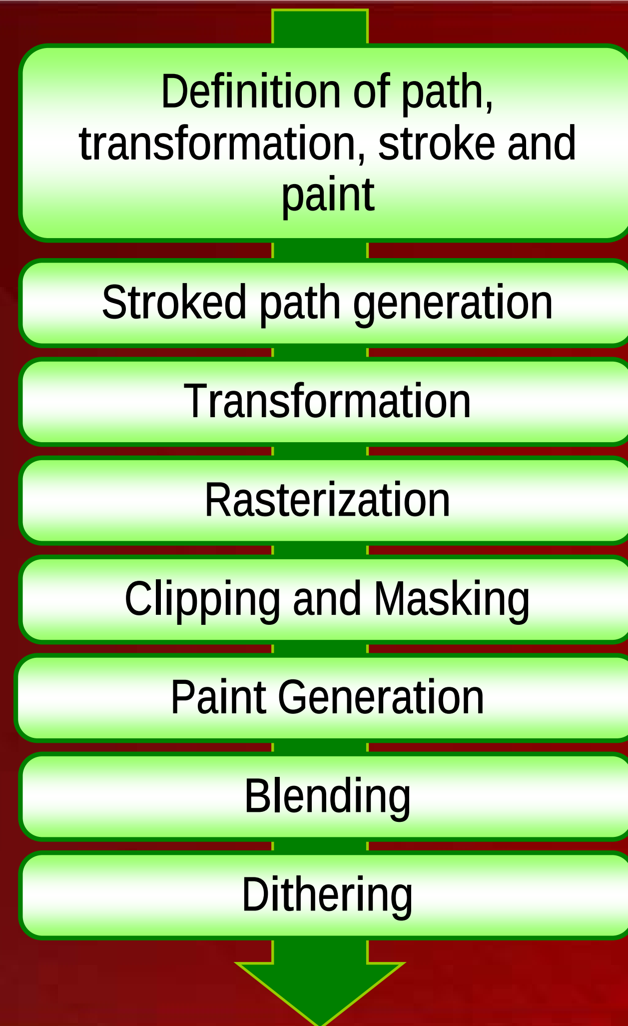
- Need to offload 2D vector graphics operation from the CPU
- Need to save power when running 2D vector graphics
- Need of open standard API

OpenVG™

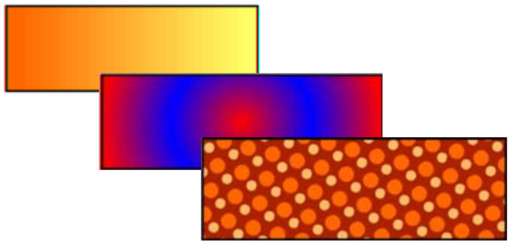
Open Standard for Vector Graphics Hardware Acceleration

OpenVG: Features

- Core API
  - Coordinate systems and transformations
    - image drawing uses a 3x3 perspective transformation matrix)
  - Paths
  - Images
  - Image filters
  - Paint (gradient and pattern)
  - Blending and masking
- The VGU Utility Library
  - Higher-level geometric primitives
  - Image warping



OpenVG: Features



Paints

Mask

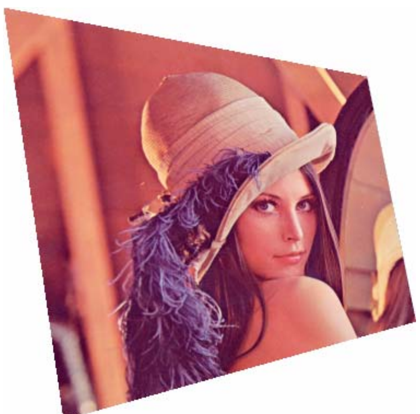
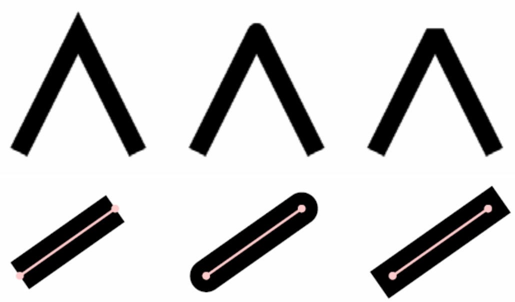
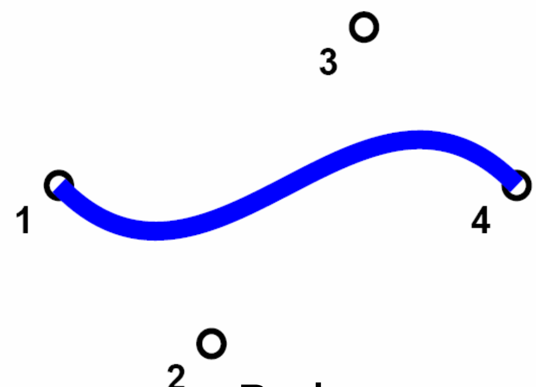


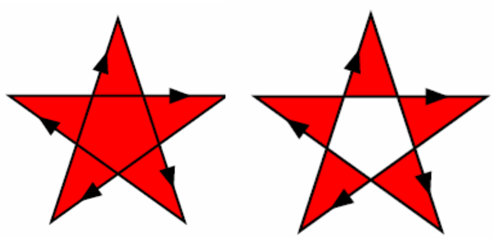
Image transformation



Stroke

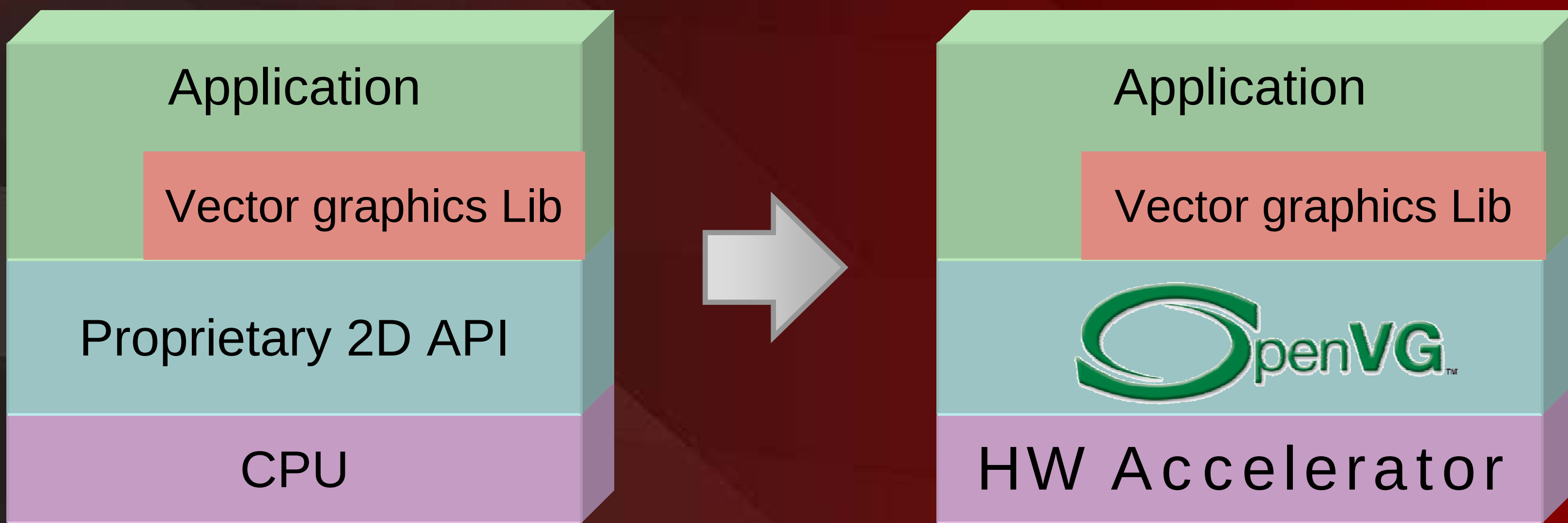


Paths



Fill rule

Where it fits in



2D Vector Graphics Today

2D Vector Graphics with OpenVG

Mobile 3D HW now!

Current HW offering

- There's quite a bit out there available for licensing
  - e.g., ATI, BitBoys, Falanx, Imagination Technologies, Mitsubishi, Nvidia, Toshiba, …
  - … and many others
- Marketing performance figures in the following pages
  - Scaled to 100MHz
  - Usually tri/s means vtx/s, actual number of triangle setups is sometimes taken into account, sometimes not, some numbers estimated some measured, MHz vary, …
  - So don't take the numbers too seriously

ATI

- Imageon 2300
  - OpenGL ES 1.0
  - Vertex and raster HW
    - 32 bit internal pixel pipe
    - 16 bit color and Z buffers
  - 100M pix/s, 1M tri/s @ 100 MHz
  - Integrated QVGA frame buffer
  - Imaging / video codecs
- Qualcomm / Imageon 3D
  - OpenGL ES 1.1
  - Vertex shader, 2x multitex
  - 100M pix/s, 3M tri/s @ 100 MHz
- Imageon 2^{nd} gen. 3D
  - OpenGL ES 1.2
  - Vertex shader (T&L, skinning)
  - Cube map, projective textures, stencils, advanced texture combiners
  - HyperZ
  - 100M pix/s, 4M tri/s @ 100 MHz
  - 3D audio
- Partners / Customers
  - Qualcomm, LG SV360, KV 3600

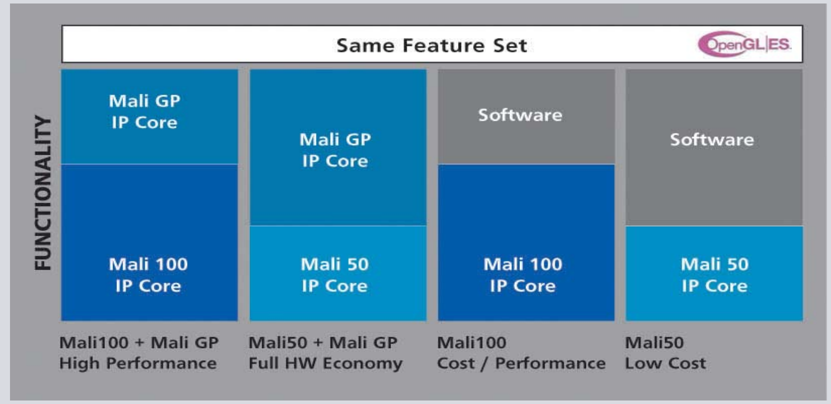
IMAGEON

Bitboys

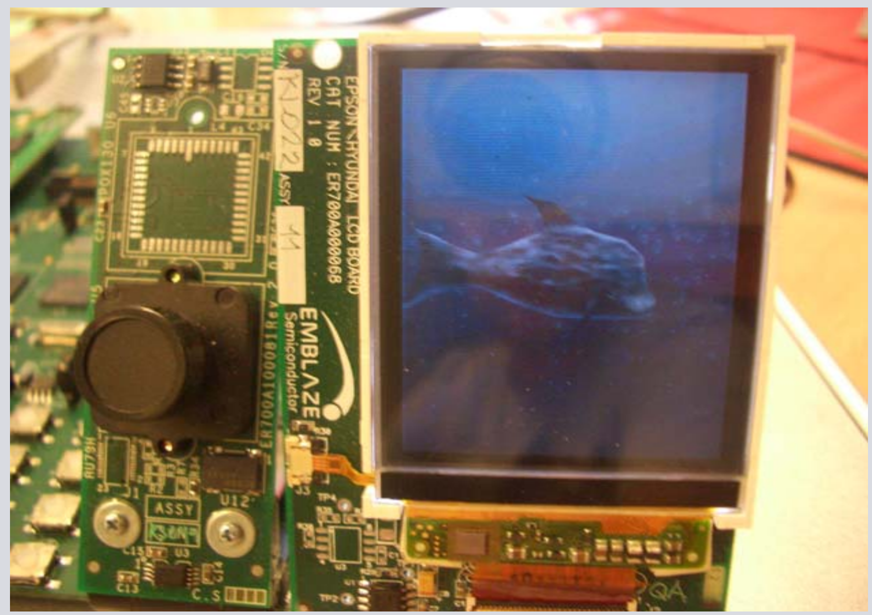
- Graphics processors
  - G12: OpenVG 1.0
  - G34: OpenGL ES 1.1
    programmable geometry processor
  - G40: OpenGL ES 2.0, GLSL
    OpenVG 1.0
    programmable geometry
    and pixel processors
  - Flipquad antialiasing
  - Max clock 200MHz
- Partners / Customers
  - NEC Electronics
  - Hybrid Graphics (drivers)

Falanx

- The Mali Family of IP Cores
  - OpenGL ES 1.1 + Extensions
  - 4X / 16X Full Scene Anti-Aliasing
  - Video Encoding / Decoding (e.g MPEG4)
  - 170 – 400k Logic Gates + SRAM
  - Performance 100MHz Mali100 + Mali Geometry
    - 2.8M tri / s
    - 100M pix / s with 4X FSAA
- Partners / Customers
  - Zoran



Mali Family of IP Cores



Falanx ARM9 / Mali100 rendering
Dot3 bump mapped fish

Imagination Technologies

- MBX
  - OpenGL ES 1.1, raster HW
  - 400M pix / s, 120 mW (@ 100 MHz)
- VGP [Vertex Geometry Processor]
  - Vertex HW, programmable
  - 2.1M tri / s (@ 100 MHz)
- Tile-based architecture
  - Buffer triangles
  - Rasterize a block at a time
    - Deferred everything, hires color, FSAA
- Partners / Customers
  - ARM, Samsung, TI (OMAP 2),
    Renesas (SH-Mobile3), Intel 2700G, …

PowerVR Technologies is a division of Imagination Technologies Ltd.

Mitsubishi

- Z3D family
  - Z3D and Z3D2 out in 2002, 2003
    - Pre-OpenGL ES 1.0
    - Embedded SRAM architecture
  - Current offering Z3D3
    - OpenGL ES 1.0, raster and vertex HW
    - Cache architecture
    - @ 100 MHz: 1.5M vtx / s, 50-60 mW, ~250 kGates
  - Z3D4 in 2005
    - OpenGL ES 1.1
- Partners / Customers
  - Several Japanese manufacturers

Z3D

First mobile 3D HW?

Z3D Graphics Engine

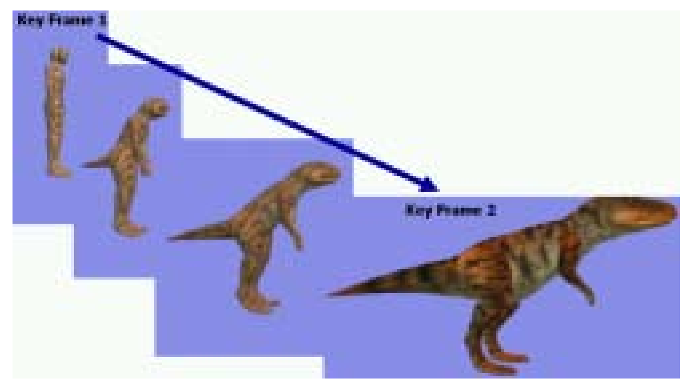
NVidia

- GoForce 3D 4800 multimedia companion chip
  - AR 15 3D IP Core
    - OpenGL ES 1.1 / MD3D, OpenVG 1.0
    - Geometry engine and rasterizer in HW
    - Programmable dot3 pixel shader
    - 40 bit signed non-int (overbright) color pipeline
    - Dedicated 2D engine (bitblt, lines, alpha blend)
    - Supersampled AA, up to 6 textures (8 surfaces)
    - 1.4M vtx|tri / s, 100M pix / s (@ 100 MHz)
    - <50mW avrg. dynamic power cons. for graphics
  - 3MPxl camera support, video
- Partners / Customers
  - ARM

GoForce 4800 Dawn

Sony PSP

- Game processing unit
  - Surface engine
    - tessellation of Beziers and splines
    - skinning (<= 8 matrices), morphing (<= 8 vtx)
    - HW T&L
    - 21 MTri / s (@ 100 MHz)
  - Rendering engine
    - basic OpenGL-style fixed pipeline
    - 400M pix / s (@ 100 MHz)
  - 2MB eDRAM
- Media processing engine
  - 2MB eDRAM
  - H.264 (AVC) video up to 720x480 @ 30fps
  - VME reconfigurable audio/video decoder



Toshiba

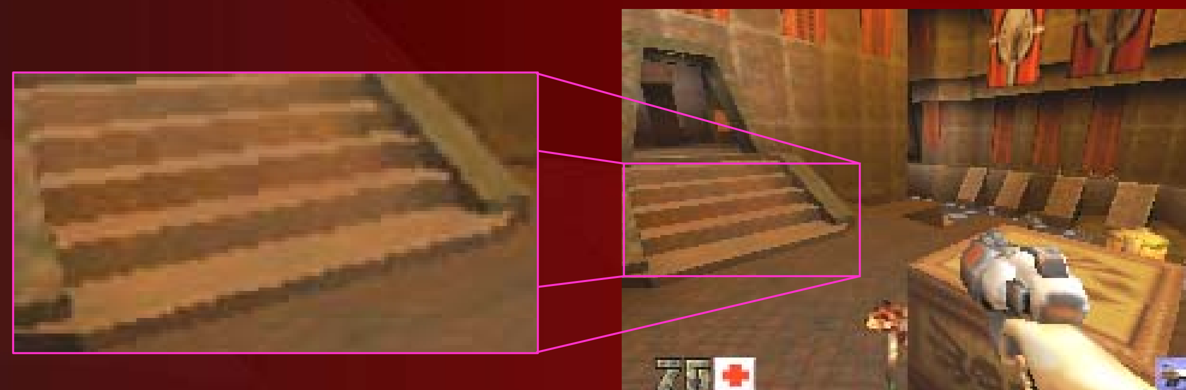
- T5G
  - OpenGL ES 1.1
  - Raster and vertex HW, fixed functionality
  - Large embedded memory for
    - Color and Z buffer
    - Caches for vertex arrays, textures
    - Display lists (command buffer)
  - Cube maps, aniso textures, 2-stage multi tex, …
  - 1.2M vtx / sec (@ 100 MHz)
  - 100M pix / sec (@ 100 MHz)
  - 87 mW @ 100 MHz (incl. eDRAM)
- Partners / Customers
  - Sharp, Toshiba’s own phones, Vodafone

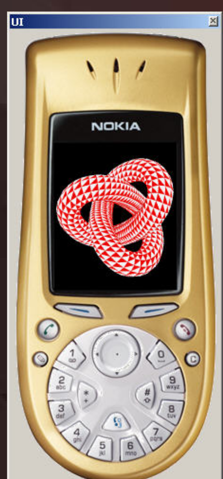
What's different in mobile HW?

- Fewer pixels on the screen
  - Fill rates don't have to be as high
  - Quality matters more
- Power usage
  - Internal bandwidth is the key
- Cost
  - High parallelism => large silicon size => high cost
    - won't work on mobiles
    - at least if we really want to make graphics ubiquitous

Anti-aliasing

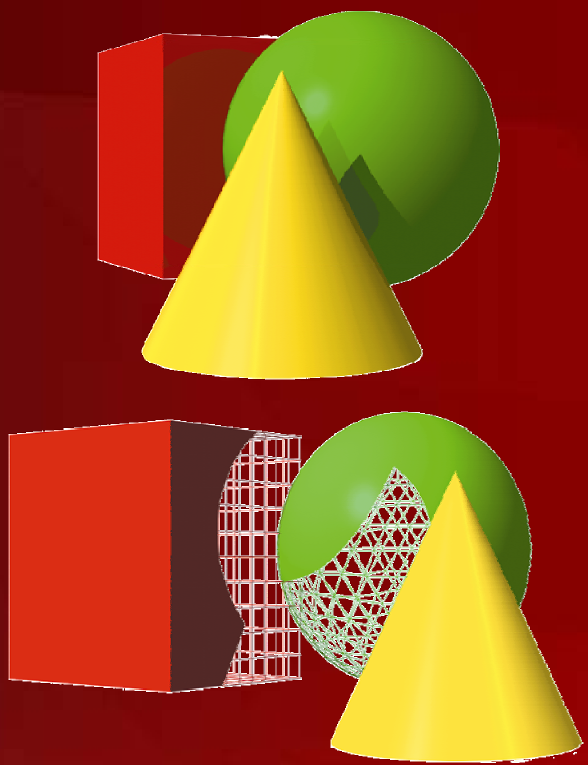
- Even (especially?) on a small screen
  - Few pixels, make the most out of them
  - Even when pixels get small, high frequency noise is annoying
    - especially in animation





Output sensitivity

- Do high-quality and low power mix?
  - Work smart rather than hard
- Work only on visible pixels
  - Avoid read-modify-write
    - Those memory accesses use a lot of power!
    - Especially important with complicated pixel shaders
  - Visibility culling
  - Deferred shading, texturing



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Local read-modify-write

- Tiled rendering
  - Store the triangles into a buffer
  - Process triangles one screen tile at a time in local memory
  - Need auxiliary buffers, extra storage for AA, etc., for only one tile
  - Then block-copy out to display buffer

- Put the whole frame into eDRAM
  - It's also possible to have a tile for the whole frame
    - though screen resolutions are growing…
  - No need to buffer triangles
  - But large embedded memories are expensive

Avoid also other traffic

- Send less data to the engine
  - Caching
    - textures, vertex arrays
  - Texture compression
  - Better pixel processing gives same or better visual quality cheaper
    - Example: bump maps (supported already in OpenGL ES 1.1)

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Avoid traffic, period.

- Procedural everything
  - Ultimate compression!
    - Both for transmission *and* storage in handset *and* btw CPU and GPU
  - Send only seed data, generate rest in the shaders
  - Procedural *textures* in the pixel shader instead of texture lookups
    - Possible with current shaders
  - Procedural *geometry* in the vertex shader from control points
    - Regular tessellation becoming possible, adaptive later
  - Procedural *animation*
    - Natural phenomena (water, smoke, fire, …)
    - Constraints, IK, solved at vertex shader
      - instead of keyframing everything

Example: KKrieger

- A fully procedural FPS (first person shooter)
  - Dynamic lighting, nice textures, monsters, music & effect sounds, …
- This image (800 x 400 gif) takes 160 KB
  - The whole kkrieger exe file is ~96KB!

Avoid any other waste

- Unused HW blocks cost
  - Clock still eats power
    - Even with clock gating there's leakage current from the silicon
    - Voltage islands avoid leakage current, but can't be turned on/off in the middle of pipeline at quick demand
- Efficient use of hardware
  - Example: don't use all of 3D HW for 2D UI
  - Example: dynamically scale voltage & frequency based on loads
  - Example: unified shaders
    - With separate shaders, within the same object, let alone the scene, the bottleneck varies between the vertex and pixel processing
    - Unified shaders are a very efficient use of HW

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Mobile gaming

Gaming still the driving force

- Gaming is the force that moves the PC industry
  - Both the CPUs / systems and graphics cards
  - Lately multimedia has been pretty effective too…
- One of the key technology drivers for mobiles as well
  - But is mobile gaming somehow different?

Always ready

- Many people carry a phone all the time
- Implications of combined phone / gaming device
  - Always on
  - Always ready
  - Always connected
  - Can play when you have time
    - waiting, commuting, …
    - but with good games people actually take time

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Social gaming

- Lots of traditional gaming is exclusive
  - Play alone at home
  - Or with people you can't see
- Sometimes people have game evenings
  - Many players close to each other connected by the net
  - An inclusive, social event
- Short range connectivity
  - Brings the social gaming out of living room

N-Gage QD – Vital Statistics

N-Gage ecosystem

- Growing game portfolio
  - over 45 titles
- Arena provides services
  - find other players
  - post hi-scores
  - etc.

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A bigger picture

“The Gamers’ Phone” devices

Native gaming for Series 60

SNAP Mobile Java

A concept from E3

A concept from E3

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Demo

The way forward:
Where are we going?

Where are we going?

- Performance vs. quality
  - First get performance that is “adequate”
  - Then work on improving quality
- Desktop has often taken brute-force approach
  - Can’t do so on mobiles, must be smarter
  - But many tricks that are must on mobiles are also useful on desktop
    - So mobile graphics can affect desktop
- New features will appear soon also on mobiles
  - See OpenGL ES 2.0
  - Later perhaps at the same time, why not even sooner
  - More active players on mobile than on desktop

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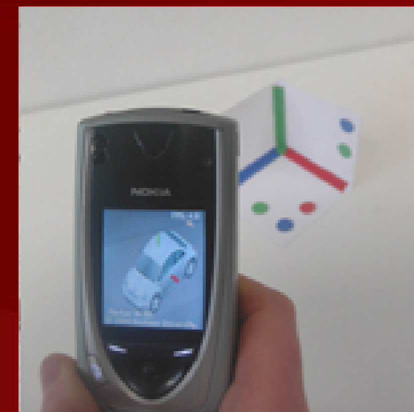
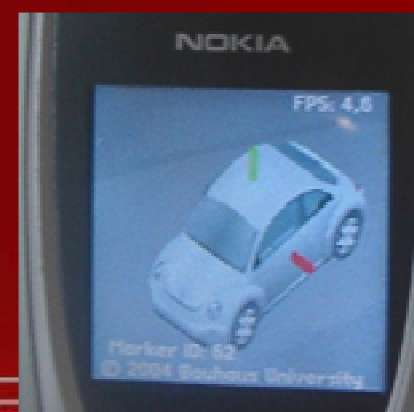
Where are we going?

- Graphics and image processing are merging
  - Life-like models are difficult to create
  - Lots of image/video/etc. papers at SIGGRAPH
- Most new mobile phones have cameras
  - With megapixel class resolutions
  - Real-time video encoding at decent resolution coming
- Add things up
  - Mobile computation
  - Location awareness
  - Connectivity
  - High-quality displays
  - Real-time graphics
  - Real-time image processing



→ AR



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