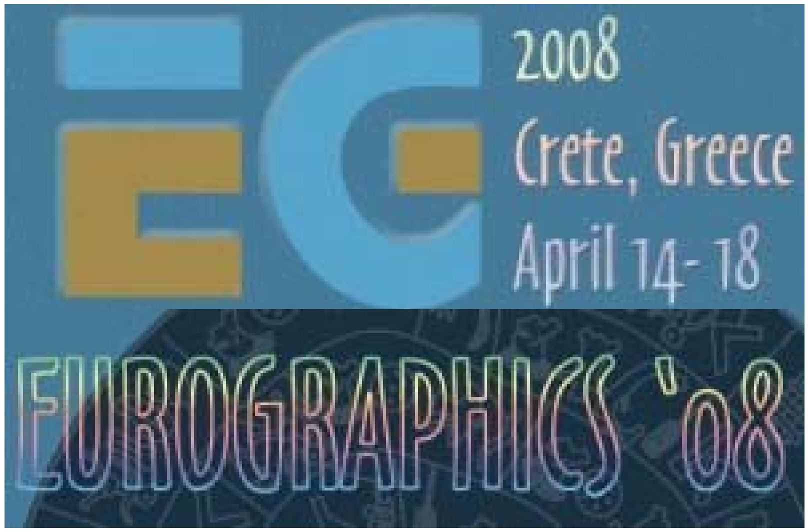
2008
Crete, Greece
April 14- 18

EUROGRAPHICS '08

Mobile 3D Graphics



Kari Pulli	**Nokia Research Center**
Jani Vaarala	**Nokia**
Ville Miettinen	
Robert Simpson	**AMD**
Tomi Aarnio	**Nokia Research Center**
Mark Callow	**HI Corporation**

Today's program: Morning

Start at 9:00

Intro & OpenGL ES overview
40 min, Kari Pulli

Using OpenGL ES 1.x
45 min, Jani Vaarala

OpenGL ES on PyS60
5 min, Kari Pulli

Break 10:30 – 11:00

OpenGL ES performance considerations
40 min, Ville Miettinen

OpenGL ES 2.0
50 min, Robert Simpson

Break 12:30

Today’s program: Afternoon

Start at 14:00

M3G Intro
5 min, Kari Pulli

M3G API overview
60 min, Tomi Aarnio

M3G in the Real World 1
25 min, Mark Callow

Break 15:30 – 16:00

M3G in the Real World 2
55 min, Mark Callow

M3G 2.0
25 min, Tomi Aarnio

Closing & Q&A
10 min, Kari Pulli

Finish at 17:30

Evolution of the Computer

Mainframe computer

Mini computer

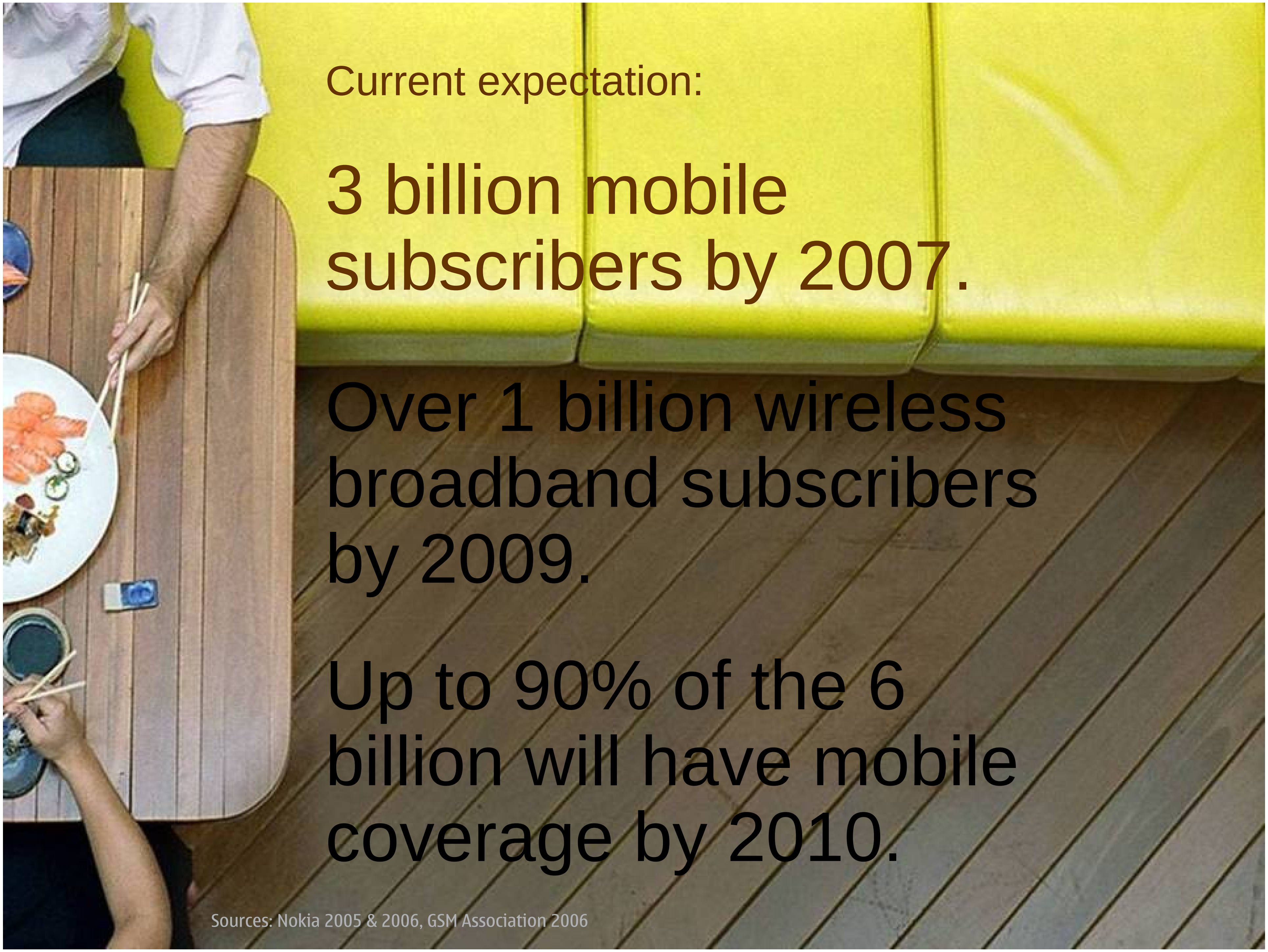
Personal computer

Laptop computer

Multimedia Computer

Pervasive Mobile Computing

- Mobile phones are the largest and fastest growing market - ever
  - The largest ever market opportunity for the graphics industry
- Handsets are becoming personal computing platform
  - Not “just” phones: A real computer in your hand
- Sophisticated media processing is a key
  - Just like it has been on the PC
  - Games are one of the first handheld media applications



Current expectation:

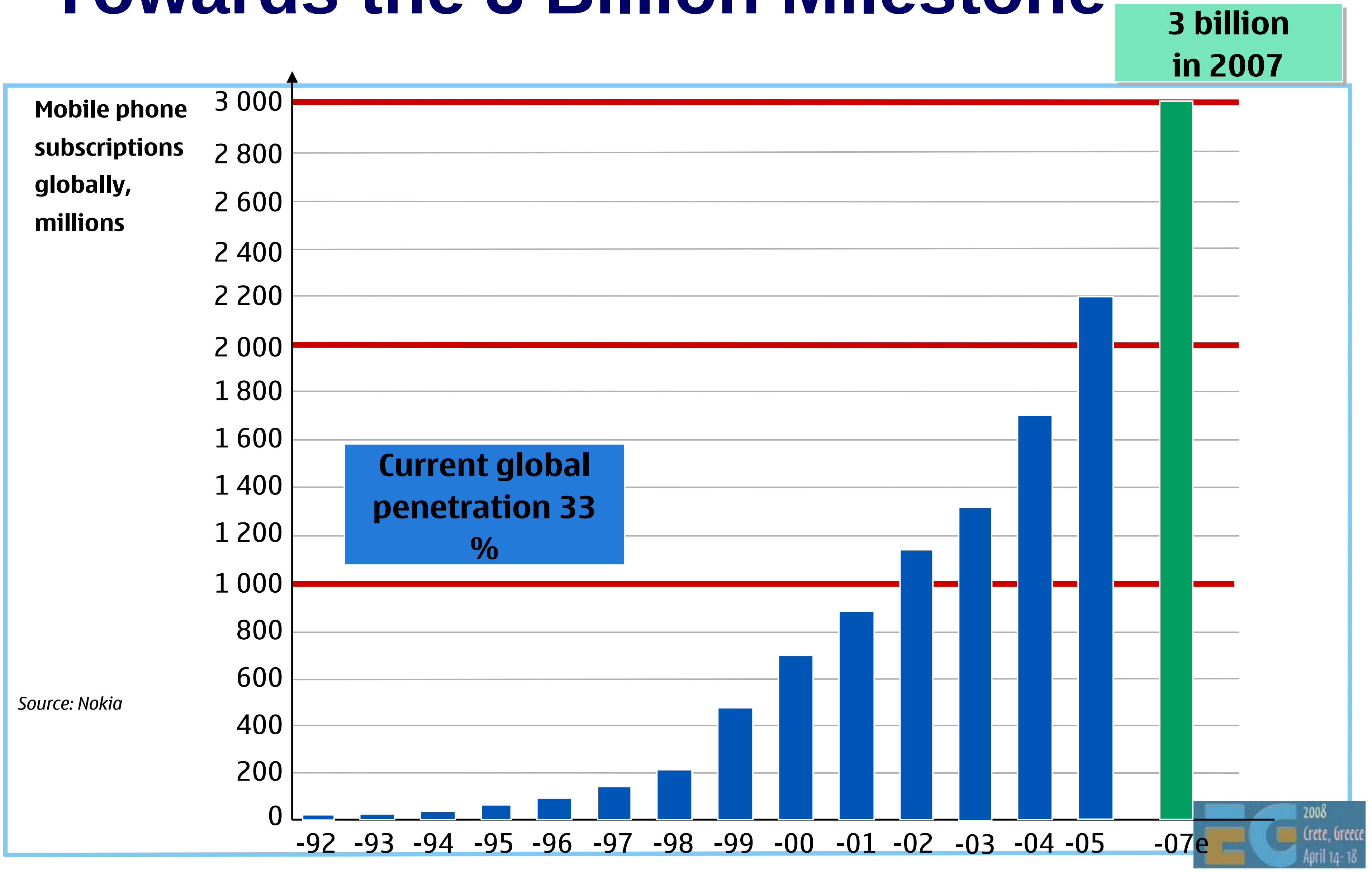
3 billion mobile subscribers by 2007.

Over 1 billion wireless broadband subscribers by 2009.

Up to 90% of the 6 billion will have mobile coverage by 2010.

Sources: Nokia 2005 & 2006, GSM Association 2006

Towards the 3 Billion Milestone



Challenge? Power!

Power is the ultimate bottleneck

- Usually not plugged to wall, just batteries

Batteries don’t follow Moore’s law

- Only 5-10% per year

Challenge? Power!

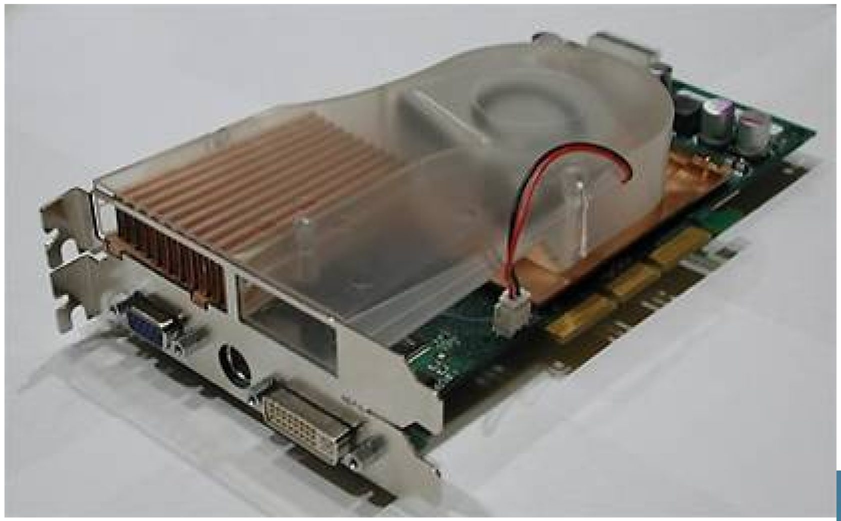
Gene’s law

- "power use of integrated circuits decreases exponentially" over time => batteries will last longer
  - Since 1994, the power required to run an IC has declined 10x every 2 years
- But the performance of 2 years ago is not enough
  - Pump up the speed
  - Use up the power savings

Challenge?   Thermal mgt!

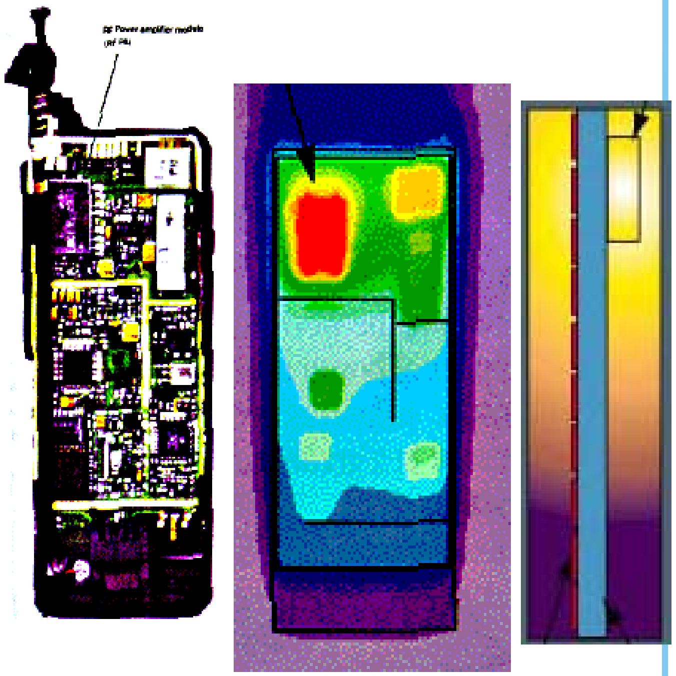
But ridiculously good batteries still won’t be the miracle cure

- The devices are small
- Generated power must get out
- No room for fans



Challenge? Thermal mgt!

- Thermal management must be considered early in the design
  - Hot spot would fry electronics
    - Or at least inconvenience the user…
  - Conduct the heat through the walls, and finally release to the ambient



Changed? Displays!

Resolution

- S60: 320 x 240
- Communicators: 640 x 200
- Internet tablets like N800: 800 x 480

Color depth

- Not many new B/W phones
- 12 / 16 / 18 / … bit RGB

Future? Displays!

Physical size remains limited

- TV-out connection
- Near-eye displays?
- Projectors?
- Roll-up flexible displays?

allaboutsymbian.com

Changed? Computation!

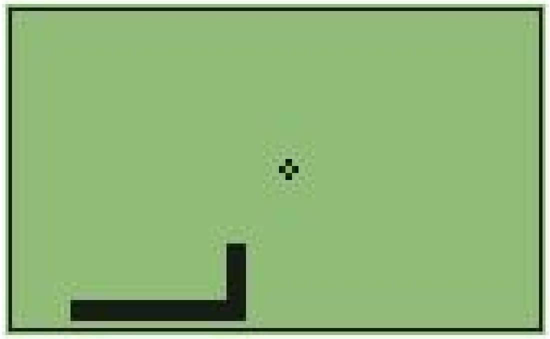
Moore's law in action

- 3410: ARM 7 @ 26MHz
  - Not much caching, narrow bus
- 6600: ARM 9 @ 104MHz
  - Decent caching, better bus
- 6630: ARM 9 @ 220MHz
  - Faster memories
- N93: ARM 11 @ 330MHz
  - HW floating-point unit
  - 3D HW

State-of-the-art in 2001: GSM world

The world's most played electronic game?

According to The Guardian (May 2001)

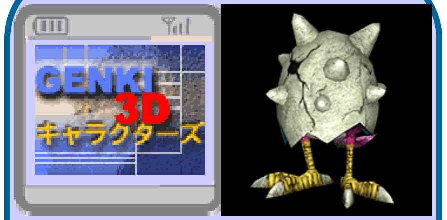


Communicator demo 2001

Remake of a 1994 Amiga demo

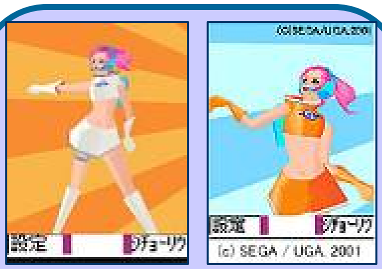
<10 year from PC to mobile

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

State-of-the-art in 2002: GSM world

3410 shipped in May 2002

- A SW engine: a subset of OpenGL including full perspective (even textures)
- 3D screensavers (artist created content)
- FlyText screensaver (end-user content)
- a 3D game

State-of-the-art in 2002: Japan

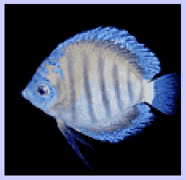
Gouraud shading,
semi-transparency,
environment maps

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

State-of-the-art in 2003: GSM world

N-Gage ships

Lots of proprietary 3D engines on various Series 60 phones

Fathammer's Geopod on XForge

State-of-the-art in 2003: Japan

Perspective view,
low-level API

Ridge Racer

@ Namco

Mission Commander
Multi player Fps Game

© IT Telecom

Mobile 3D in 2004

6630 shipped late 2004

First device to have both OpenGL ES 1.0 (for C++) and M3G (a.k.a JSR-184, for Java) APIs

Sharp V602SH in May 2004

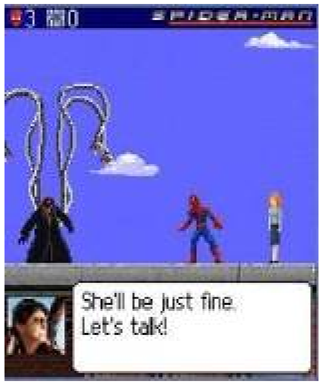
OpenGL ES 1.0 capable HW but API not exposed

Java / MascotCapsule API

2005 and beyond: HW

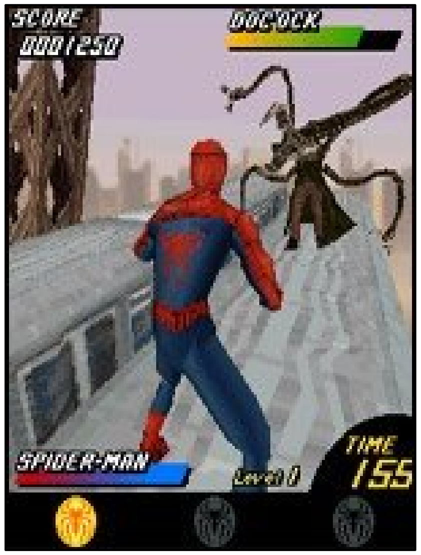
Mobile graphics evolution snapshot

Spider-Man 2: The Hero Returns
Sony Pictures



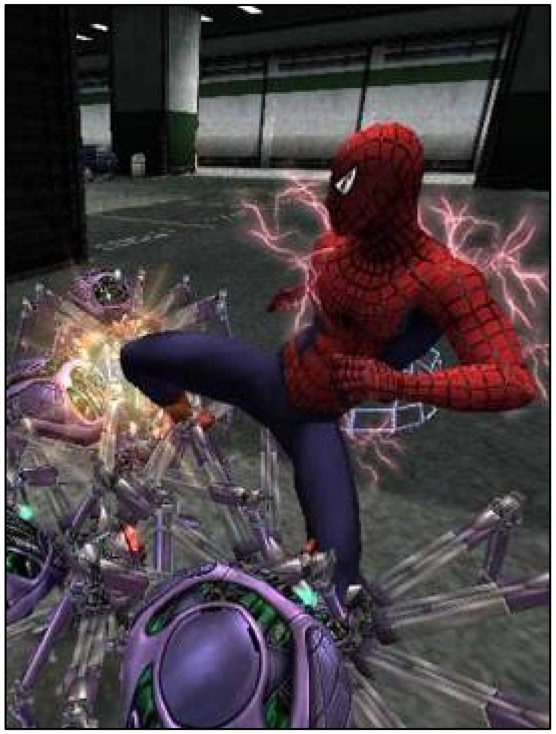
2D

Spider-Man 2 3D: NY Subway
Sony Pictures



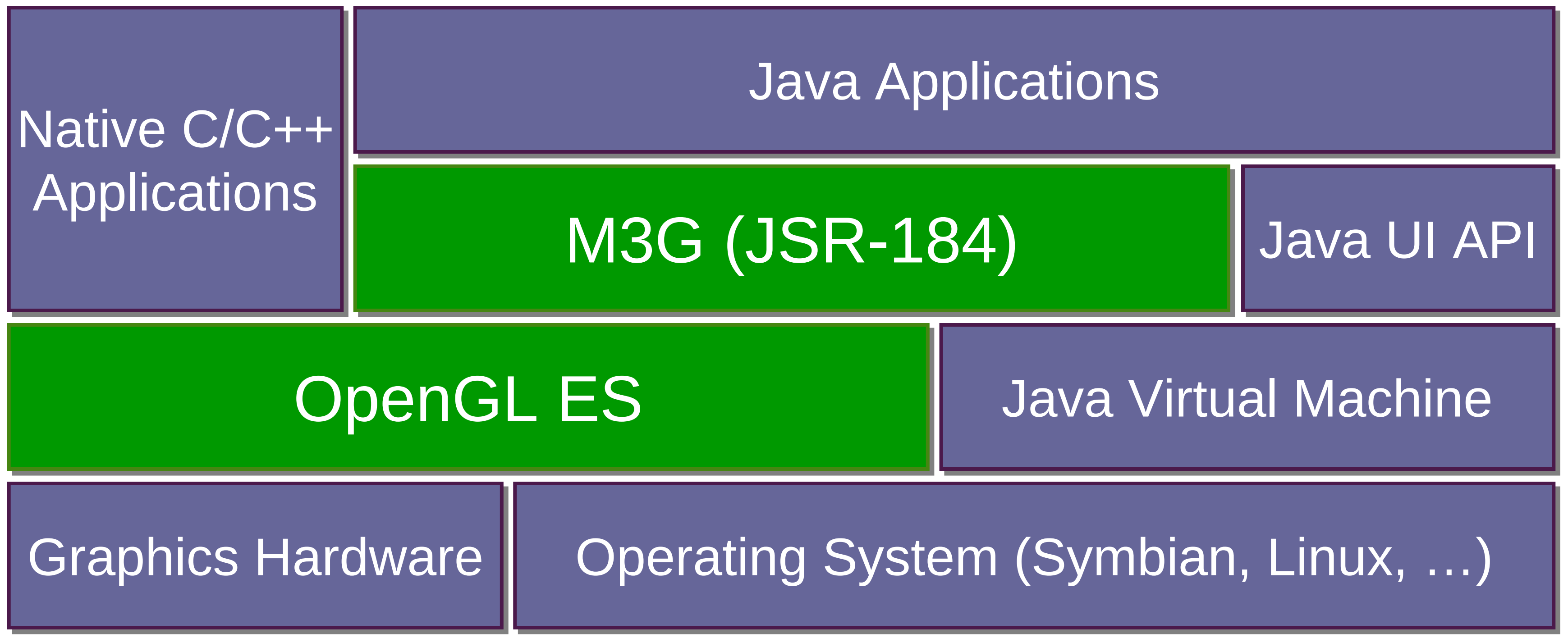
Software 3D

Spider-Man 2
Activision



Accelerated 3D

Mobile 3D APIs



Overview: OpenGL ES

- Background: OpenGL & OpenGL ES
- OpenGL ES 1.0
- OpenGL ES 1.1
- EGL: the glue between OS and OpenGL ES
- How can I get it and learn more?

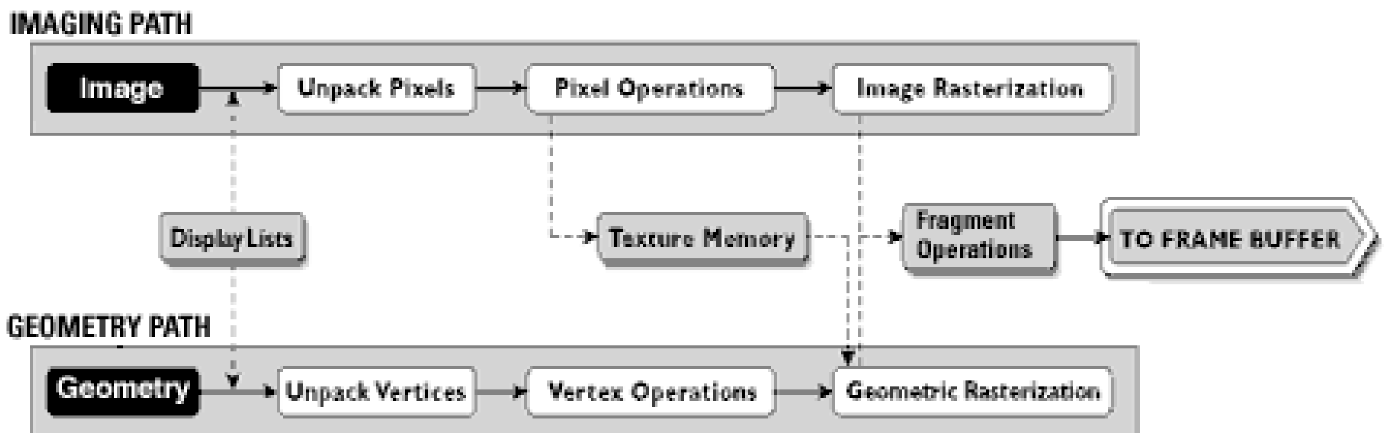
What is OpenGL?

The most widely adopted graphics standard

- most OS's, thousands of applications

Map the graphics process into a pipeline

- matches HW well



modeling
⇩
projecting
⇩
clipping
⇩
lighting & shading
⇩
texturing
⇩
hidden surface
⇩
blending
⇩
pixels to screen

A foundation for higher level APIs

- Open Inventor; VRML / X3D; Java3D; game engines

What is OpenGL ES?

- OpenGL is just too big for Embedded Systems with limited resources
  - memory footprint, floating point HW
- Create a new, compact API
  - mostly a subset of OpenGL
  - that can still do almost all OpenGL can

OpenGL ES 1.0 design targets

- Preserve OpenGL structure
- Eliminate un-needed functionality
  - redundant / expensive / unused
- Keep it compact and efficient
  - <= 50KB footprint possible, without HW FPU
- Enable innovation
  - allow extensions, harmonize them
- Align with other mobile 3D APIs (M3G / JSR-184)

Adoption

Symbian OS, S60

Brew

PS3 / Cell architecture

Sony's arguments: Why ES over OpenGL

- OpenGL drivers contain many features not needed by game developers
- ES designed primarily for interactive 3D app devs
- Smaller memory footprint

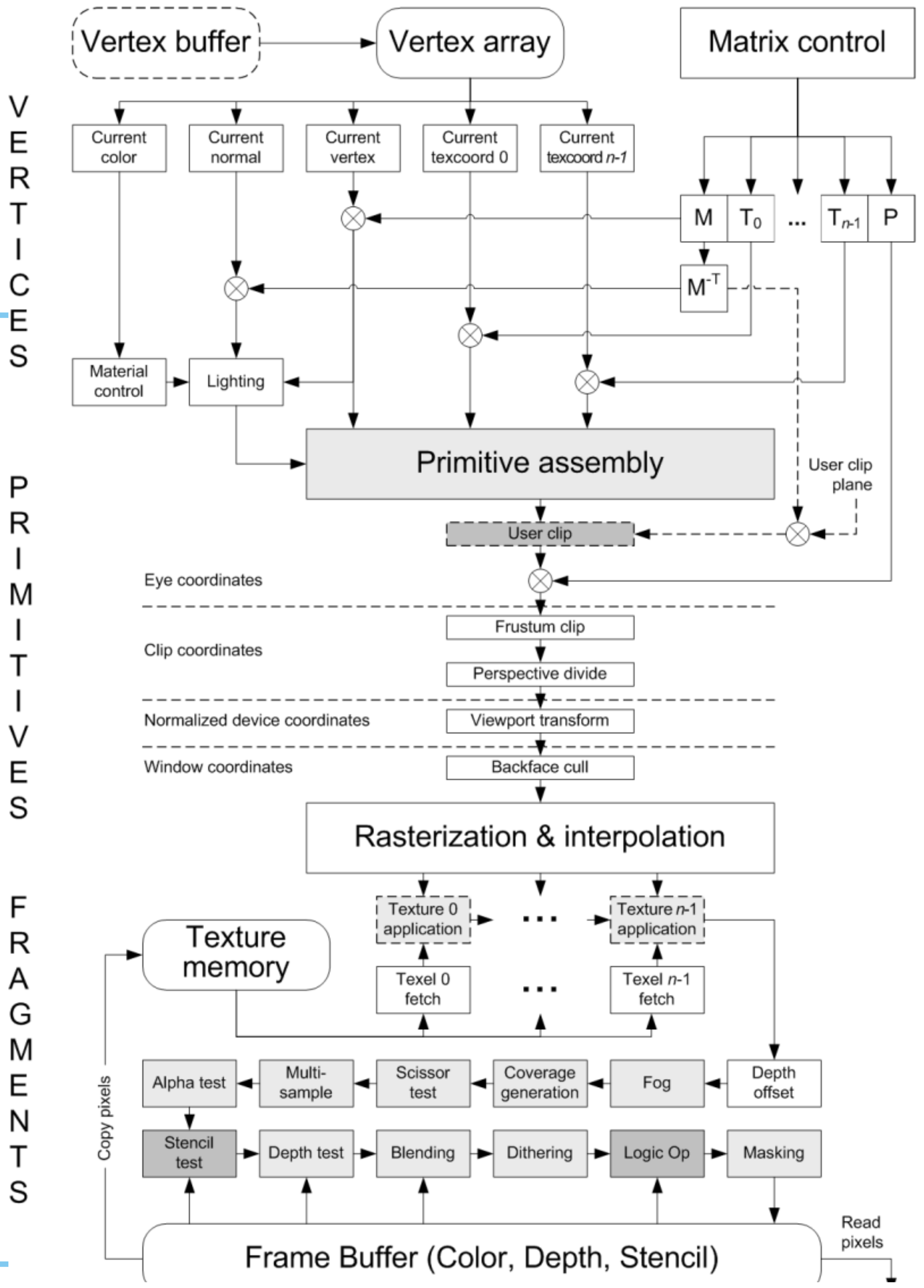
Outline

- Background: OpenGL & OpenGL ES
- OpenGL ES 1.0
- OpenGL ES 1.1
- EGL: the glue between OS and OpenGL ES
- How can I get it and learn more?

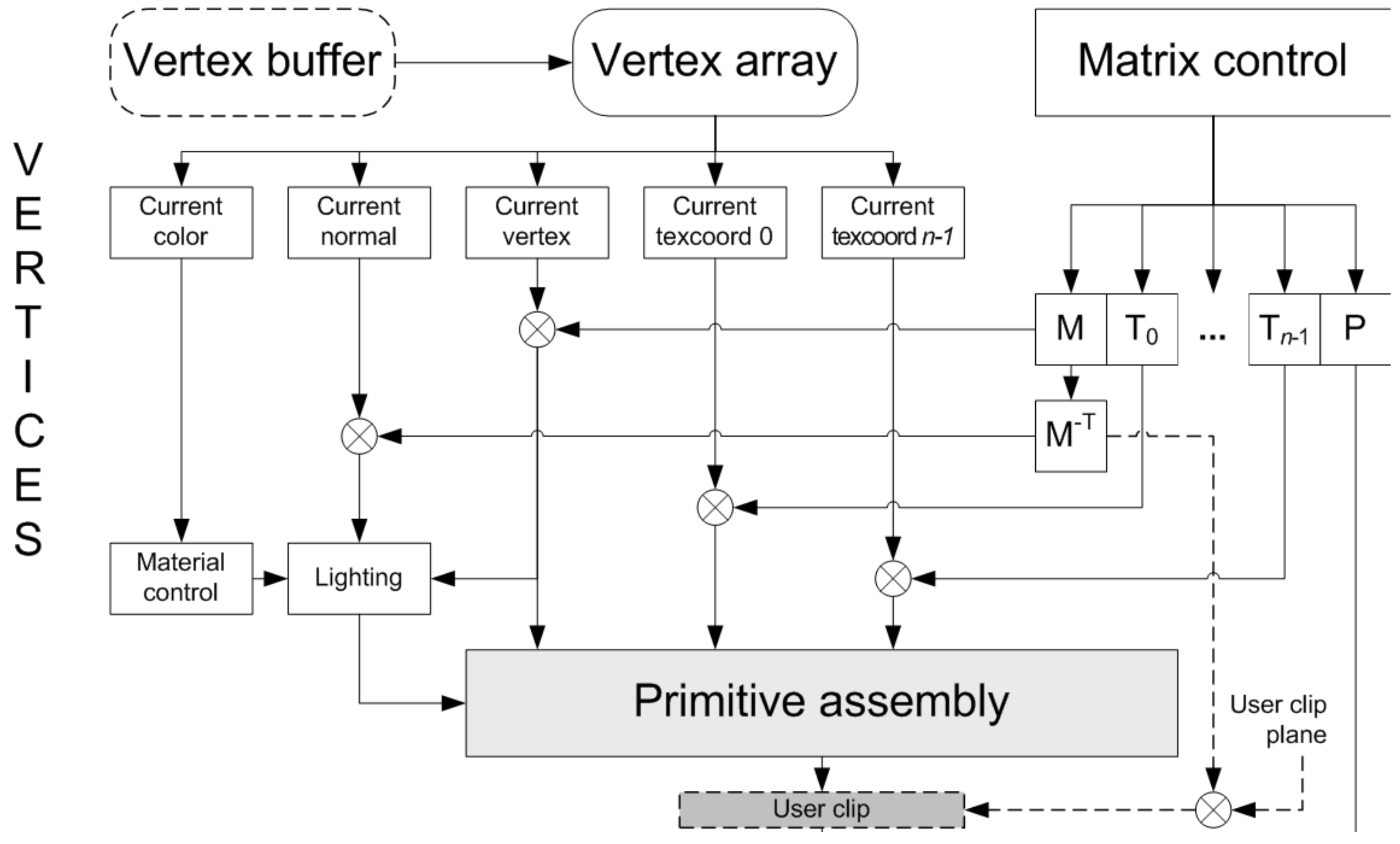
OpenGL ES Pipe

Here's the OpenGL ES pipeline stages

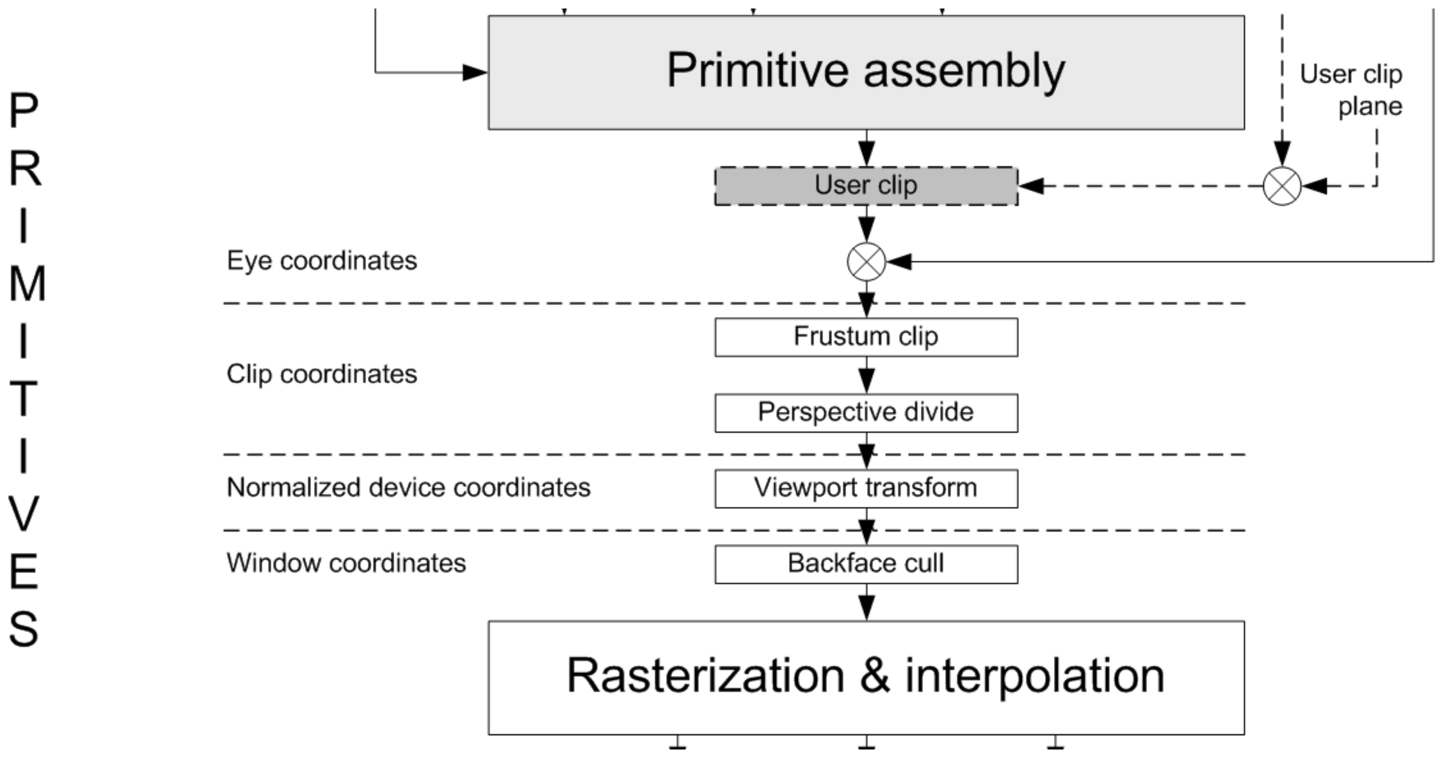
- vertices
- primitives
- fragments



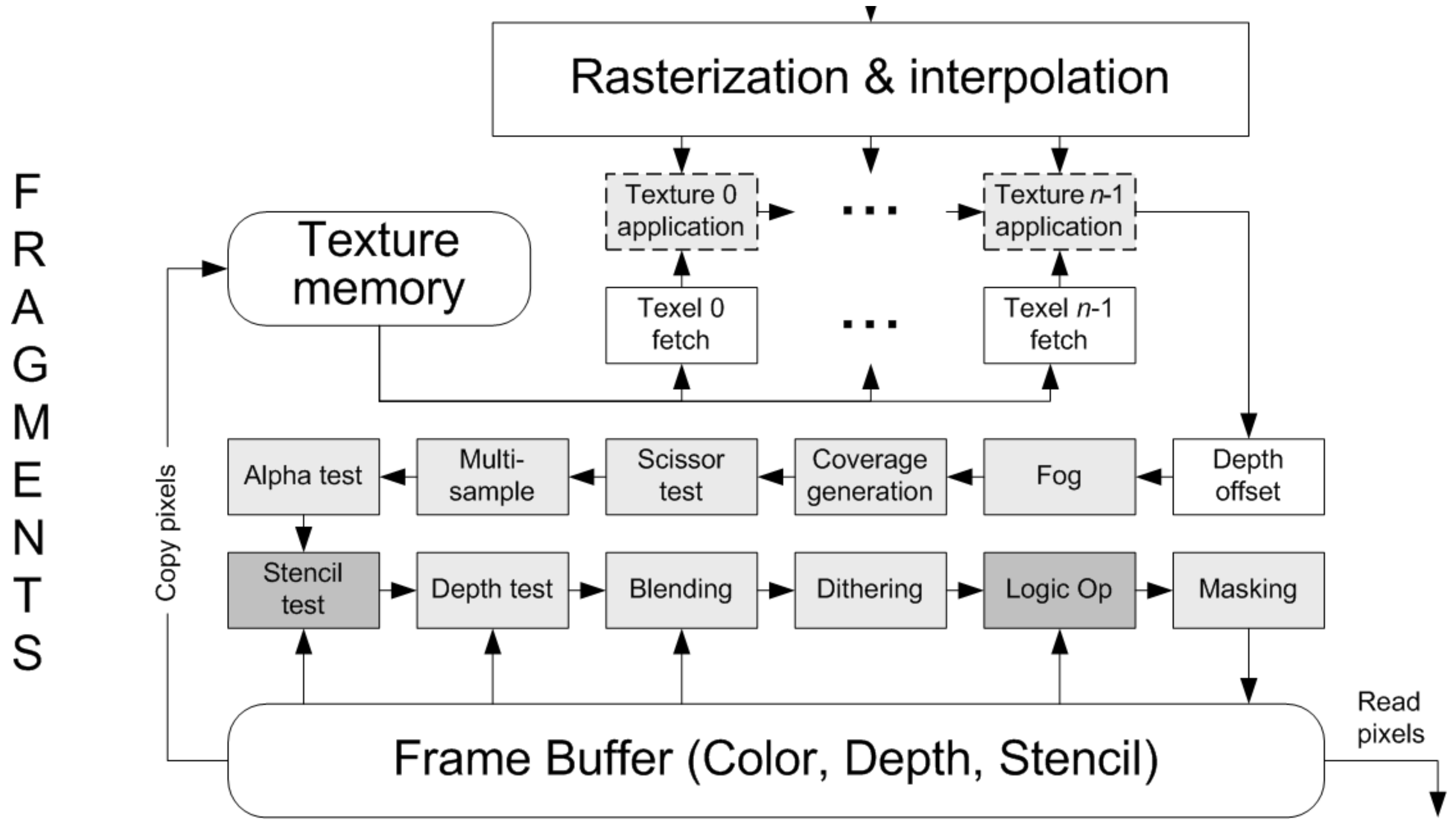
Vertex pipeline



Primitive processing



Fragment pipeline

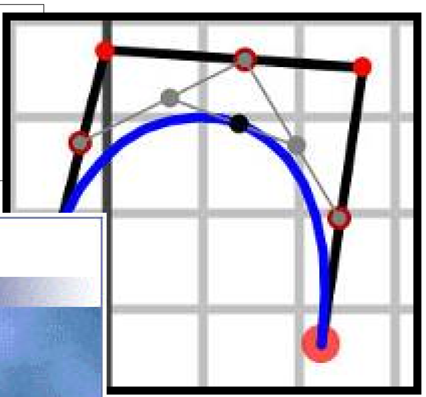


Functionality: in / out? (1/7)

Convenience functionality is OUT

- GLU
  (utility library)
- evaluators
  (for splines)
- feedback mode
  (tell what would draw without drawing)
- selection mode
  (for picking, easily emulated)
- display lists
  (collecting and preprocessing commands)

```
gluOrtho2D(0,1,0,1)
vs.
glOrtho(0,1,0,1,-1,1
```



```
glNewList(1, GL_COMPILE)
myFuncThatCallsOpenGL()
glEndList()
…
glCallList(1)
```

Functionality: in / out? (2/7)

Remove old complex functionality

- glBegin – glEnd (**OUT**); vertex arrays (**IN**)
- new: coordinates can be given as bytes

~~glBegin(GL_POLYGON);~~
~~glColor3f (1, 0, 0);~~
~~glVertex3f(-.5, .5, .5);~~
~~glVertex3f(.5, .5, .5);~~
~~glColor3f (0, 1, 0);~~
~~glVertex3f(.5,-.5, .5);~~
~~glVertex3f(-.5, .5, .5);~~
~~glEnd();~~

```
static const GLbyte verts[4 * 3] =
{    -1,  1,  1,      1,  1,  1,
      1, -1,  1,     -1, -1,  1 };
static const GLubyte colors[4 * 3] =
{   255,  0,  0,    255,  0,  0,
      0,255,  0,      0,255,  0 };
glVertexPointer( 3,GL_BYTE,0, verts );
glColorPointerf( 3,GL_UNSIGNED_BYTE,
                 0, colors );
glDrawArrays( GL_TRIANGLE_STRIP,
              0, 4 );
```

Functionality: in / out? (3/7)

Simplify rendering modes

- double buffering, RGBA, no front buffer access

Emulating back-end missing functionality is expensive or impossible

- full fragment processing is **IN**
    - alpha / depth / scissor / stencil tests,
    - multisampling,
    - dithering, blending, logic ops)

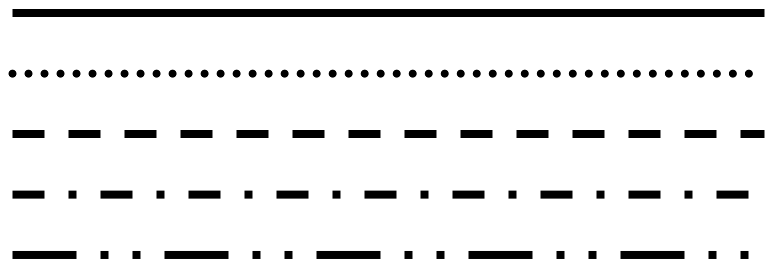
Functionality: in / out? (4/7)

Raster processing

- ReadPixels **IN**, DrawPixels and Bitmap **OUT**

Rasterization

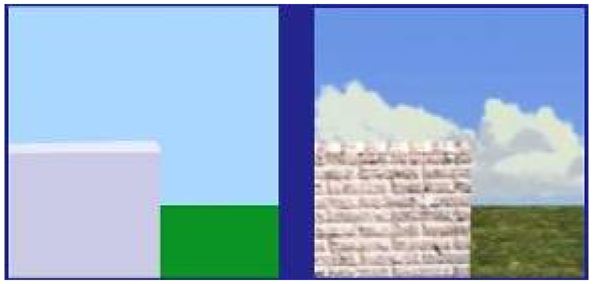
- **OUT:** PolygonMode, PolygonSmooth, Stipple



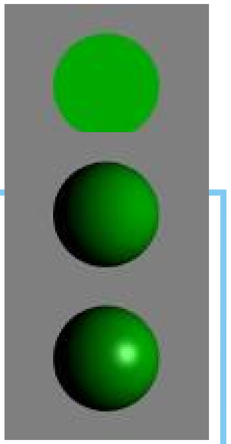
Functionality: in / out? (5/7)

2D texture maps **IN**

- 1D, 3D, cube maps **OUT**
- borders, proxies, priorities, LOD clamps **OUT**
- multitexturing, texture compression **IN** (optional)
- texture filtering (incl. mipmaps) **IN**
- new: paletted textures **IN**

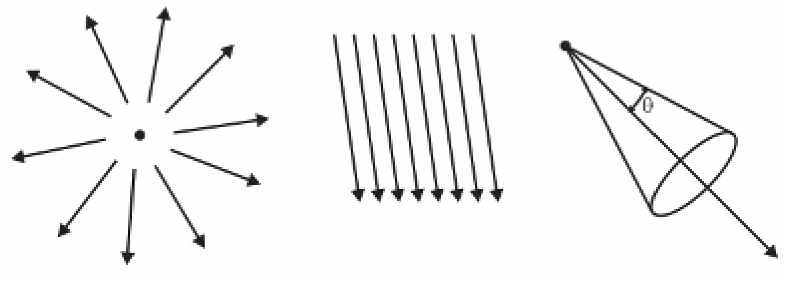


Functionality: in / out? (6/7)



Almost full OpenGL light model **IN**

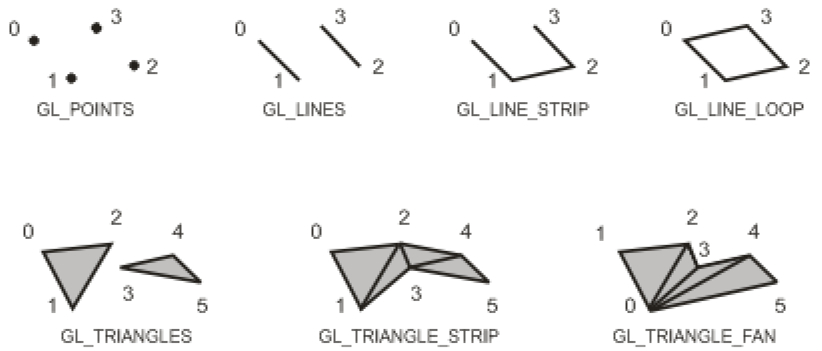
back materials, local viewer, separate specular **OUT**

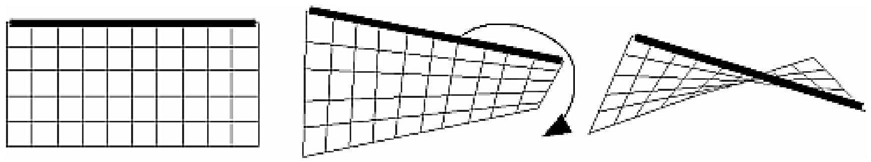


Primitives

IN: points, lines, triangles

OUT: quads & polygons





Functionality: in / out? (7/7)

- Vertex processing
  - **IN:** transformations
  - **OUT:** user clip planes, texcoord generation
- Support only static queries
  - **OUT:** dynamic queries, attribute stacks
    - application can usually keep track of its own state

Floats vs. fixed-point

- Accommodate both
  - integers / fixed-point numbers for efficiency
  - floats for ease-of-use and being future-proof
- Details
  - 16.16 fixed-point: add a decimal point inside an int

```
glRotatef( 0.5f,    0.f   , 1.f,    0.f    );
                    vs.
glRotatex( 1 << 15,    0   , 1 << 16,    0    );
```

  - get rid of doubles

Outline

- Background: OpenGL & OpenGL ES
- OpenGL ES 1.0
- OpenGL ES 1.1
- EGL: the glue between OS and OpenGL ES
- How can I get it and learn more?

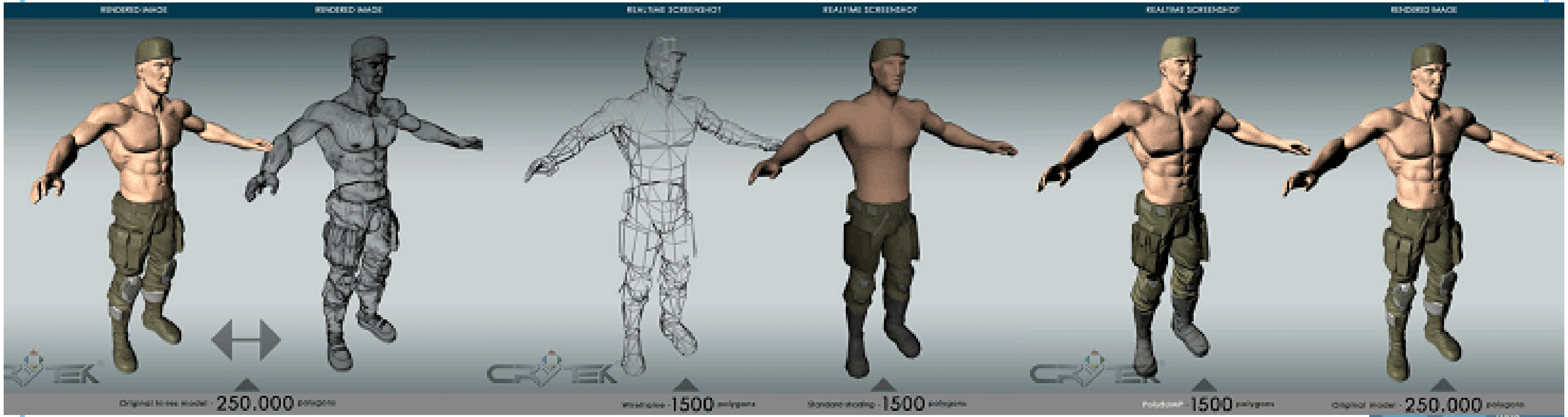
OpenGL ES 1.1: core

- Buffer Objects
  - allow caching vertex data
- Better Textures
  - >= 2 tex units, combine (+,-,interp), dot3 bumps, auto mipmap gen.
- User Clip Planes
  - portal culling (>= 1)
- Point Sprites
  - particles as points not quads, attenuate size with distance
- State Queries
  - enables state save / restore for middleware

Bump maps

Double win

- increase realism
- reduce internal bandwidth -> increase performance



OpenGL ES 1.1: optional

Draw Texture

fast drawing of pixel rectangles
using texturing units
(data can be cached),
constant Z, scaling

Matrix Palette

vertex skinning
(>= 3 matrices / vertex, palette >= 9)

Outline

Background: OpenGL & OpenGL ES

OpenGL ES 1.0

OpenGL ES 1.1

EGL: the glue between OS and OpenGL ES

How can I get it and learn more?

EGL glues OpenGL ES to OS

- EGL is the interface between OpenGL ES and the native platform window system
  - similar to GLX on X-windows, WGL on Windows
  - facilitates portability across OS's (Symbian, Linux, …)
- Division of labor
  - EGL gets the resources (windows, etc.) and displays the images created by OpenGL ES
  - OpenGL ES uses resources for 3D graphics

EGL surfaces

Various drawing surfaces, rendering targets

windows – on-screen rendering
(“graphics” memory)

pbuffers – off-screen rendering
(user memory)

pixmaps – off-screen rendering
(OS native images)

EGL context

A rendering context is an abstract OpenGL ES state machine

- stores the state of the graphics engine
- can be (re)bound to any matching surface
- different contexts can share data
  - texture objects
  - vertex buffer objects
  - even across APIs (OpenGL ES, OpenVG, later others too)

Main EGL 1.0 functions

Getting started

eglInitialize() / eglTerminate(), eglGetDisplay(),
eglGetConfigs() / eglChooseConfig(),
eglCreate**X**Surface() (**X** = Window | Pbuffer | Pixmap),
eglCreateContext()

eglMakeCurrent(display, drawsurf, readsurf, context)

binds context to current thread, surfaces, display

Main EGL 1.0 functions

eglSwapBuffer(display, surface)

posts the color buffer to a window

eglWaitGL( ), eglWaitNative(engine)

provides synchronization between OpenGL ES and native (2D) graphics libraries

eglCopyBuffer(display, surface, target)

copy color buffer to a native color pixmap

EGL 1.1 enhancements

- Swap interval control
  - specify # of video frames between buffer swaps
  - default 1; 0 = unlocked swaps, >1 save power
- Power management events
  - PowerMgmnt event => all Context lost
  - Display & Surf remain, Surf contents unspecified
- Render-to-texture [optional]
  - flexible use of texture memory

Outline

Background: OpenGL & OpenGL ES

OpenGL ES 1.0 functionality

OpenGL ES beyond 1.0

EGL: the glue between OS and OpenGL ES

How can I get it and learn more?

SW Implementations

- Vincent
  - Open-source OpenGL ES library
  - http://www.vincent3d.com/
    http://sourceforge.net/projects/ogl-es
- Reference implementation
  - Wraps on top of OpenGL
  - http://www.khronos.org/opengles/documentation/gles-1.0c.tgz

HW implementations

- There are many designs
- The following slides gives some idea
  - rough rules of thumb
    - from a couple to dozens of MTri / sec (peak)
    - 1 pixel / clock
    - clock speeds 50MHz – 200+MHz
    - power consumption should be ~ 10’s of mW

Bitboys

Graphics processors

G12: OpenVG 1.0

G34: OpenGL ES 1.1
vertex shader

G40: OpenGL ES 2.0, 1.1
OpenVG 1.0
vertex and [illegible] shader

Flipquad antialiasing

Max clock 200MHz

Partners / Customers

NEC Electronics

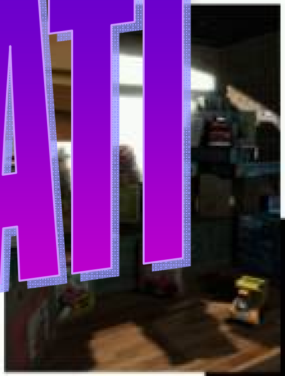
Hybrid Graphics (drivers)

ATI bought BB

ATI

AMD bought ATI

- Imageon 2300
  - OpenGL ES 1.0
  - Vertex and raster HW
    - 32-bit internal pipe
    - 16-bit color and Z buffers
    - [illegible]grate[illegible]QVGA [illegible]ffer
    - [illegible]ing [illegible]
- [illegible] 3D [illegible]
  - [illegible] ES [illegible]
  - [illegible]s,1[illegible]
- [illegible] gen. Imageon 3D adds
  - OpenGL ES 1.1 extension pack
  - Vertex shader
  - HyperZ
  - Audio codecs, 3D audio
- Partners, customers
  - Qualcomm
  - LG SV360, KV3600
  - Zodiac



AMD Graphics IP

3D Processors

- AMD Z430 & Z460
  - Unified Shader architecture derived from the Xbox 360 Xenos core
  - OpenGL ES 2.0
  - OpenGL ES 1.1 backwards compatible
  - OpenVG 1.x

Vector Graphics Processors

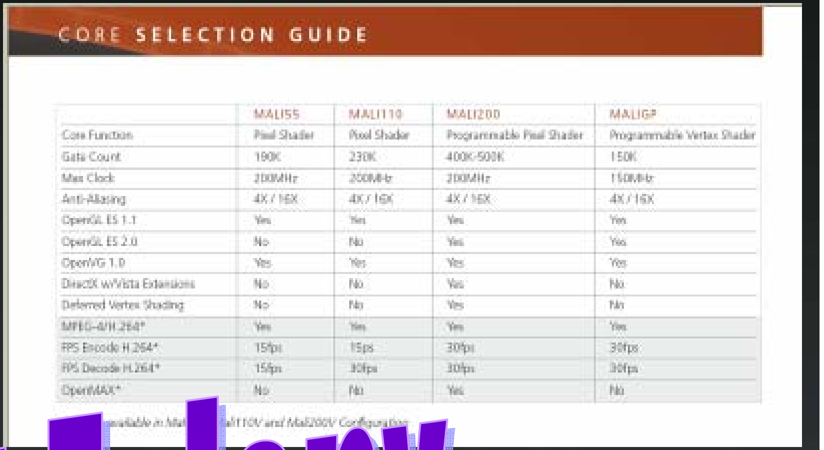
- AMD Z160 & Z180
  - Native, high-performance OpenVG acceleration
  - OpenVG 1.x
  - 16 x antialiasing

All processors are designed to be combined to achieve native HW acceleration of both OpenGL ES 2.0 and OpenVG 1.x for unrivalled performance and image quality.

Falanx

- **Mali 110**
  - OpenGL ES 1.1 + extensions
  - 4x / 16x full screen anti-aliasing
  - Video codecs (e.g., MPEG-4)
  - 170-40 k g at + S
  - 2.8M T / M
- **Mali 20**
  - Open O nVG, D Mob.
  - 5M Tri / s, 100M Pix / s, 11 instr. / cycle
- **Partners / Customer**
  - Zoran

ARM bought Falanx



CORE SELECTION GUIDE

	MALI55	MALI110	MALI200	MALIGP
Core Function	Pixel Shader	Pixel Shader	Programmable Pixel Shader	Programmable Vertex Shader
Gate Count	190K	230K	400K-500K	150K
Max Clock	200MHz	200MHz	200MHz	150MHz
Anti-Aliasing	4X / 16X	4X / 16X	4X / 16X	4X / 16X
OpenGL ES 1.1	Yes	Yes	Yes	Yes
OpenGL ES 2.0	No	No	Yes	Yes
OpenVG 1.0	Yes	Yes	Yes	Yes
DirectX w/Vista Extensions	No	No	Yes	No
Deferred Vertex Shading	No	No	Yes	No
MPEG-4/H.264*	Yes	Yes	Yes	Yes
FPS Encode H.264*	15fps	15fps	30fps	30fps
FPS Decode H.264*	15fps	30fps	30fps	30fps
OpenMAX*	No	No	Yes	No

* available in Mal al110V and Mali200V Configuration

ARM® Mali™ Architecture

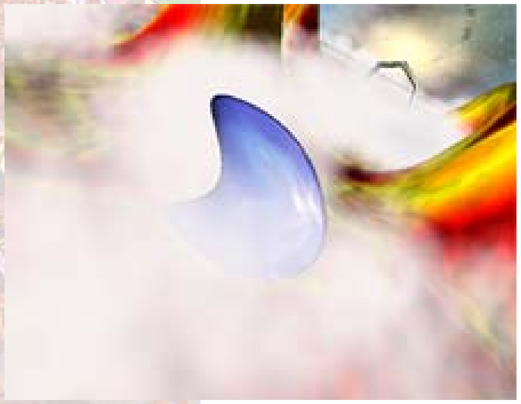
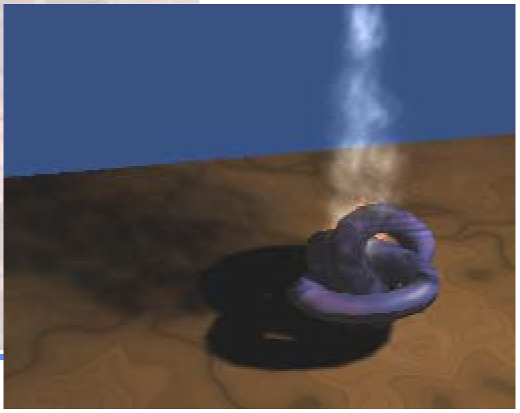
- Compared to traditional immediate mode renderer
  - 80% lower per pixel bandwidth usage, even with 4X FSAA enabled
  - Efficient memory access patterns and data locality: enables performance even in high latency systems
- Compared to traditional tile-based renderer
  - Significantly lower per-vertex bandwidth
  - Impact of scene complexity increases is substantially reduced
- Other architectural advantages
  - Per frame autonomous rendering
  - No renderer state change performance penalty
  - On-chip z / stencil / color buffers
    - minimizes working memory footprint
- Acceleration beyond 3D graphics (OpenVG etc.)

	Mali200	MaliGP2	Mali55
Anti-Aliasing	4X / 16X	4X / 16X	4X / 16X
OpenGL®ES 1.x	YES	YES	YES
OpenGL®ES 2.x	YES	YES	NO
OpenVG 1.x	YES	NA	YES
Max CLK	275MHz	275MHz	200MHz
Fill rate Mpix / s	275	NA	100
Triangles / s	9M	9M	1M

DMP Inc.

Visualize the future

- **PICA graphics core**
  - 3D Features
    - OpenGLES 1.1
    - DMP's proprietary "Maestro" shader extensions
      - **Very high quality graphics with easier programming interface**
      - **Per-fragment lighting,**
      - **Shadow-mapping,**
      - **Procedural texture,**
      - **Polygon subdivision (Geo shader), and**
      - **Gaseous object rendering.**
  - Hardware Features
    - » **Performance: 40Mtri/s, 400Mpixel/s@100MHz**
    - » **Power consumption: 0.5-1mW/MHz**
    - » **Max. clock freq. 400MHz (65nm)**

Fujitsu Graphics Controllers

- **Optimized for automotive environment**
  - Extended temp range (-40...+85degC or -40...+105degC)
  - No external active or passive cooling required
  - Long term availability (devices from 1998 still in full mass production!)
  - Fulfills the latest qualification requirements from automotive industry
  - Automotive network interfaces included on-chip
  - Dedicated competence center in Munich for automotive graphics

- **Used in many major car brands for :**
  - Onboard navigation systems (2D and 3D)
  - Cluster Instrumentation (incl. virtual dashboards)
  - Rear seat entertainment systems
  - Head-up displays
  - Night vision systems

- **Also used today in :**
  - Flight instrumentation
  - Marine displays
  - Medical, etc...

Feature	This generation (in MP)	Next generation (tba)
Bandwidth	**~2 GB/s**	**~6 GB/s**
Performance	**~5MT/s ; 200Mpix/s**	**~10MT/s ; 500Mpix/s**
Graphic processing	**OpenGL ES 1.1**	**OpenGL ES 2.0 ; OpenVG**
# of video inputs	**2 video inputs**	**4 video inputs (up to HD)**
# of display outputs	**2 display outputs**	**2 display outputs with dual view option**

Imagination Technologies POWERVR MBX & SGX 2D/3D Acceleration

Imagination

- **5th Generation Tile Based Deferred Rendering**
  - Market Proven Advanced Tiling Algorithms
  - Order-independent Hidden Surface Removal
  - Lowest silicon area, bandwidth and power
  - Excellent system latency tolerance
- **POWERVR SGX: OpenGL ES 2.0 in Silicon Now**
  - Scalable from 1 to 8 pipelines and beyond
  - Programmable multi-threaded multimedia GPU
  - Optimal load balancing scheduling hardware
  - Vertex, Pixel, Geometry shaders + image processing
- **Partners/Customers**
  - TI, Intel, Renesas, Samsung, NXP, NEC, Freescale, Sunplus, Centrality & others unannounced

POWERVR MBX: The de-facto standard for mobile graphics acceleration, with >50 PowerVR 3D-enabled phones shipping worldwide

www.powervrinsider.com
Market-leading Ecosystem with more than 1650 members

	PowerVR MBX Family	PowerVR SGX Family
OpenGL	ES1.1	2.0, ES1.1 and ES2.0
Direct3D	Mobile	Mobile, 9L and 10.1
OpenVG	1.0	1.0.1 and 1.1
Triangles/Sec	1.7M … 3.7M	1M … 15.5M
Pixels/Sec	135M … 300M	50M … 500M

Performance quoted at 100MHz for MBX, MBX Lite and for SGX510 to SGX545.
Peak SoC achievable performance not quoted, e.g. <50% Shader load for Tri/Sec.
Performance scales with clock speeds up to 200MHz and beyond.
Planned future cores will offer higher performance levels.

Mitsubishi

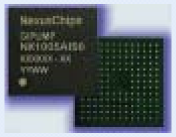
- Z3D family
  - Z3D and Z3D2 out in 2002, 2003
    - Pre-OpenGL ES 1.0
    - Embedded SRAM architecture
  - Z3D3 in 2004
    - OpenGL ES 1.0, raster and vertex HW
    - Cache architecture
    - @ 100 MHz: 1.5M vtx / s, 50-60 mW, ~250 kGates
  - Z3D4 in 2005
    - OpenGL ES 1.1
- Partners / Customers
  - Several Japanese manufacturers

Z3D

First mobile 3D HW?

Z3D Graphics Engine

GiPump™ Series



GiPump™ NX1005
; Mobile 3D graphics acc. with camera control functions
- OpenGL ES 1.1 / GIGA / JSR184
- 5M poly/s, 80M pix/s @ 80MHz, JPEG codec (3M pixel), ~QVGA display
- Cellular phone, smart phone, etc.

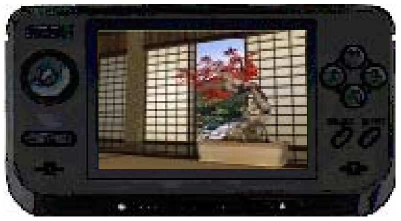
GiPump™ NX1007
; High end 3D graphics acc. for mobile
- OpenGL ES 1.1 + Ext. / GIGA / JSR184
- 12.5M poly/s, 200M pix/s @ 100MHz, ~SVGA display, PIP supports
- PND, PMP, game device, mobile device, etc.

GiPump™ NX1008
; Mobile 3D graphics acc. with stereoscopic display
- OpenGL ES 1.1 / GIGA / JSR184
- 5M poly/s, 80M pix/s @ 80MHz, ~QVGA display, stereoscopic display
- Cellular phone, smart phone, etc.

GiPump™ NX1009
; Economical mobile 3D graphics accelerator
- OpenGL ES 1.1 + Ext. / GIGA / JSR184
- 12.5M poly/s, 200M pix/s @ 100MHz, ~SVGA display, boost mode
- Cellular phone, Smart phone, etc.

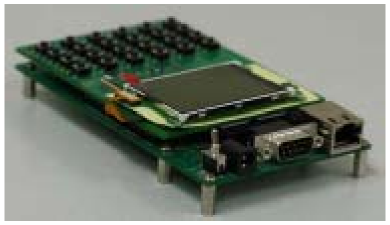
GiPump™ NX2001
; 3D Graphics enhanced multimedia processor
- OpenGL ES 2.0 / 1.1 Ext. / JSR184 / D3DM
- 10M poly/s, 200M pix/s @ 200MHz, ~SVGA display
- PND, PMP, game device, mobile device, etc.

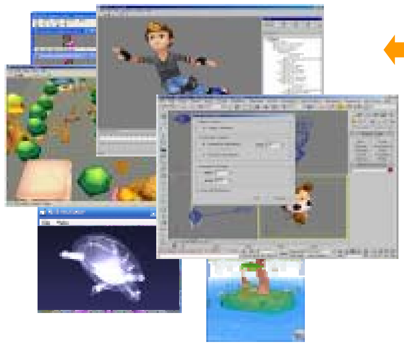
Service Solutions



Nexus Mobile Platform^{TM}
Gaming Device Platform
(OS: WinCE, Linux, RTOS, etc.)
To: Game Device Maker

NX1008TK^{TM}
3D Reference B/D
GiPump™ Integration Platform
To: Device Developer





GiPump™ SDK
NXsdk with Emulator
NXsdk Shader+
NXm3g Engine
NX3D Engine & Tools

GiPump™ Partners : Samsung, SKT, Other Device Manufactures

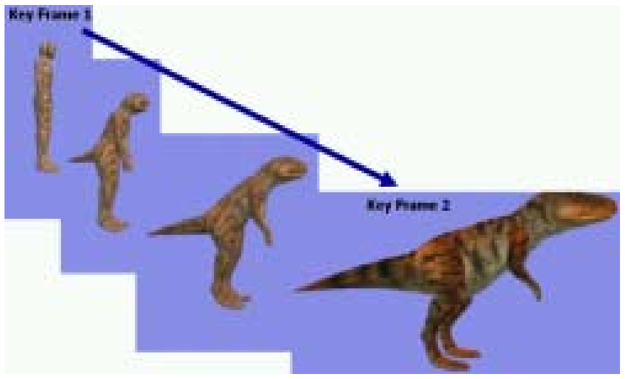
* GiPump™ : Pronounced, "G", "I", "Pump". It means "Graphics / Image Pump".
* GIGA (Giga Instruction Giga Acceleration) : SK Telecom's mobile 3D graphics platform

NVidia

- GoForce 5500 handheld GPU
  - 3D geometry and rasterization HW
  - OpenGL ES 1.1, D3D Mobile, OpenVG 1.0
  - 1.3M tri / s, 100M pix / s (@ 100 MHz)
  - Programmable pixel micro shaders
  - 40 bit signed non-int (overbright) color pipeline
  - Dedicated 2D engine (bitblt, lines, alpha blend)
  - Supersampled anti-aliasing, up to 6 textures
  - <50mW avg. dynamic power cons. for graphics
  - 10MPxl camera support, XGA LCD, MPEG-4 video, audio
- Partners / Customers
  - Motorola, Sony Ericsson, Samsung, LG, Kyocera, O2, HTC, Marvell, Freescale, …

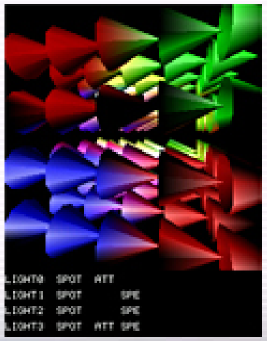
Sony PSP

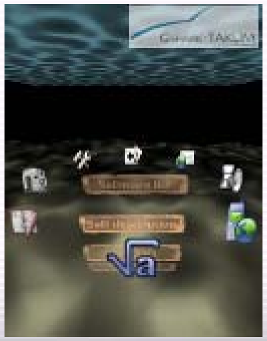
- Game processing unit
  - Surface engine
    - tessellation of Beziers and splines
    - skinning (<= 8 matrices), morphing (<= 8 vtx
    - HW T&L
    - 21 MTri / s (@ 100 MHz)
  - Rendering engine
    - basic OpenGL-style fixed pipeline
    - 400M pix / s (@ 100 MHz)
  - 2MB eDRAM
- Media processing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



TAKUMI

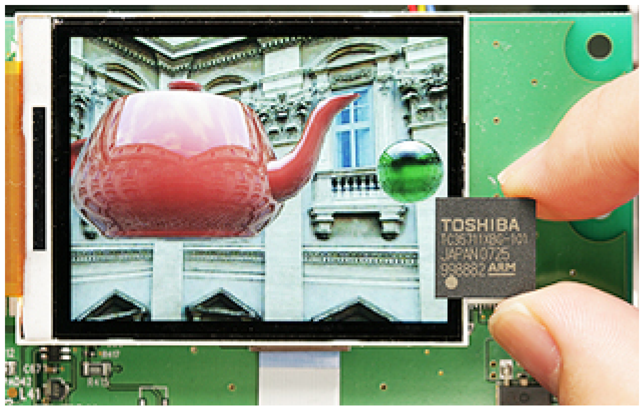
- **GSHARK-TAKUMI Family**
  - **GP**
    - OpenGL ES 1.0
    - 0.5M tri/s @100MHz, 170Kgate
  - **GT**
    - OpenGL ES 1.1
    - 1.4M tri/s @100MHz, < 30mW
  - **G2**
    - OpenGL ES 1.1
    - 5M tri/s @100MHz
- Partners / Customers
  - NEC Electronics
- Concepts & Architecture
  - Small Gate Counts
  - Low Power Consumption
  - Vertex Processor (T&L)
  - Dedicated 2D Sprite Engine
  - Target Application
    - Mobile Phone and Digital AV Equipments such as DTV, STB, DSC, PMP, etc.

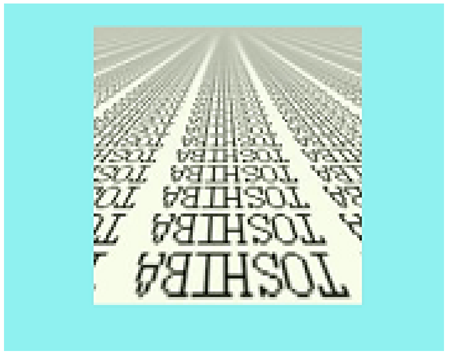


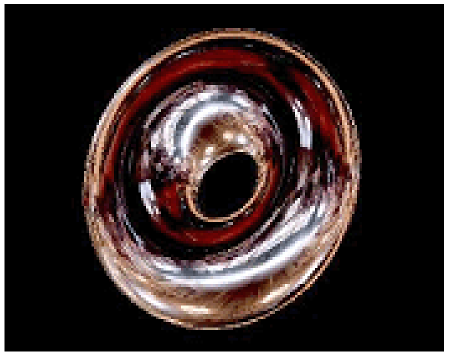


TAKUMI CORPORATION

Toshiba





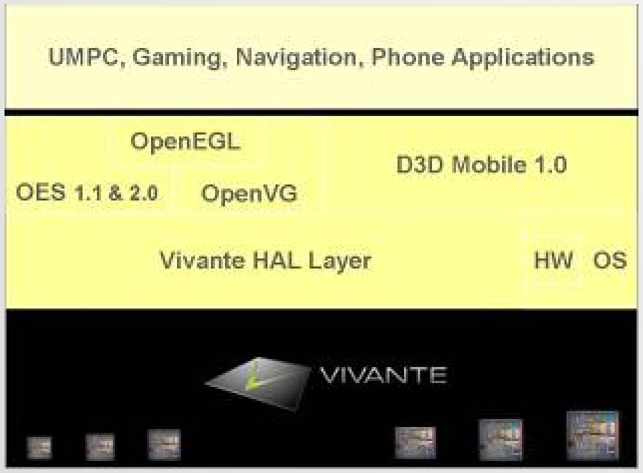


TC35711XBG

- Programmable shader
- Plan to support OpenGL ES2.0
- Large embedded memory for
  - Color and Z buffer
  - Caches for vertex arrays, textures
  - Display lists (command buffer)
- 50M vtx / sec, 400M pix / sec (@ 100 MHz)
  - clocks up to 200MHz
- WVGA LCD controller
- 13mm x 13mm x 1.2mm 449Ball BGA

Vivante GPU for Handheld

- OpenGL ES 1.1 & 2.0 and D3D 9.0
- Unified vertex & pixel shader
- Anti-Aliasing
- AXI/AHB interface
- GC500
  - 3 mm^2 die area in 65nm (1.8mm x 1.2mm)
  - 10 MPolygons/s and 100 MPixel/s at 200 MHz
  - 50mW GPU core power
- Scalable solution to 50 MPolygons/s and 1 GPixels/s (GC1000, GC4000)
- **Silicon proven solution**
- Designed into multiple 65nm SoCs



VIVANTE

SDKs

Nokia S60 SDK (Symbian OS)

http://www.forum.nokia.com

Imagination SDK

http://www.pvrdev.com/Pub/MBX

NVIDIA handheld SDK

http://www.nvidia.com/object/hhsdk_home.html

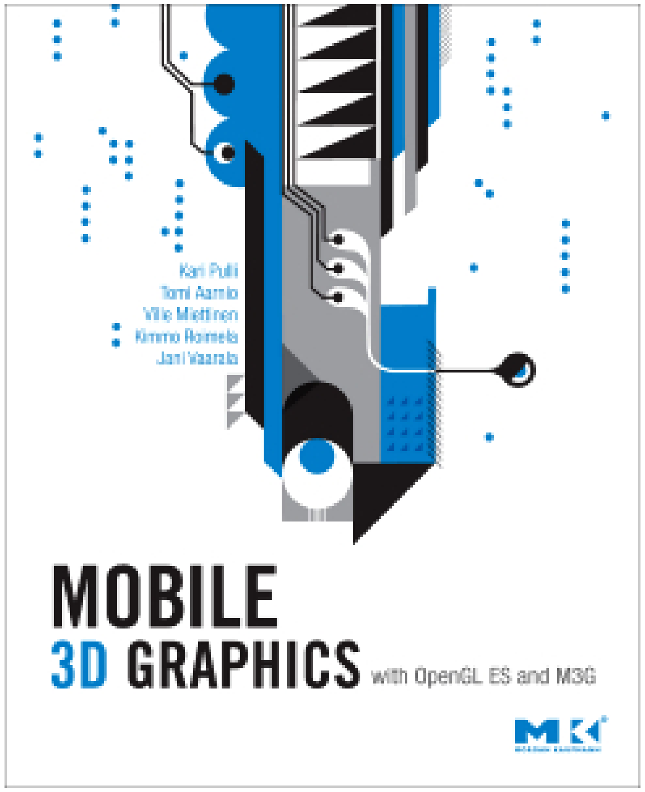
Brew SDK & documentation

http://brew.qualcomm.com

see http://people.csail.mit.edu/kapu/EG_08

Mobile 3D Graphics with OpenGL ES and M3G

Kari Pulli, Tomi Aarnio, Ville Miettinen, Kimmo Roimela, Jani Vaarala



http://www.graphicsformasses.com/

Questions?

Using OpenGL ES

2008
Crete, Greece
April 14-18
EUROGRAPHICS '08

Jani Vaarala

Nokia

Using OpenGL ES

Simple OpenGL ES example

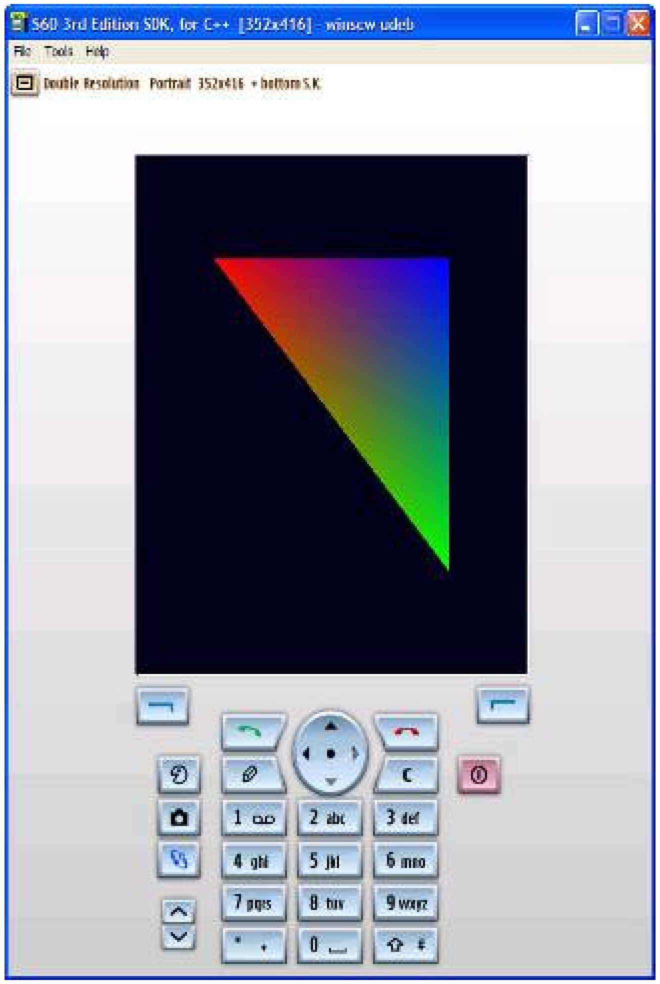
EGL configuration selection

Texture matrix example

Fixed point programming

Converting existing code

"Hello OpenGL ES"


S60 3rd Edition SDK, for C++ [352x416] - winscw udeb
File Tools Help
Double Resolution Portrait 352x416 + bottom S.K.

Hello OpenGL ES, EGL initialization

```
/* ====================================================================
 *  "Hello OpenGL ES" OpenGL ES code.
 *
 *  Eurographics 2008 tutorial.
 *
 *  Copyright: Jani Vaarala
 * ====================================================================
*/

#include <GLES/gl.h>
#include <GLES/egl.h>

EGLDisplay          display;
EGLContext          context;
EGLSurface          surface;
EGLConfig           config;
```

2008
Crete, Greece
April 14- 18

Hello OpenGL ES, EGL initialization

```
EGLint attrib_list[ ] =
{
    EGL_BUFFER_SIZE,   16,
    EGL_DEPTH_SIZE,    15,
    EGL_SURFACE_TYPE,   EGL_WINDOW_BIT,
    EGL_NONE
};

void init_egl(void)
{
    EGLint numOfConfigs;

    display = eglGetDisplay( EGL_DEFAULT_DISPLAY );
    eglInitialize( display, NULL, NULL );
    eglChooseConfig( display, attrib_list, &config, 1 , &numOfConfigs );
    surface = eglCreateWindowSurface( display, config, WINDOW( ), NULL );
    context = eglCreateContext( display, config, EGL_NO_CONTEXT, NULL );
    eglMakeCurrent( display, surface, surface, context );
}
```

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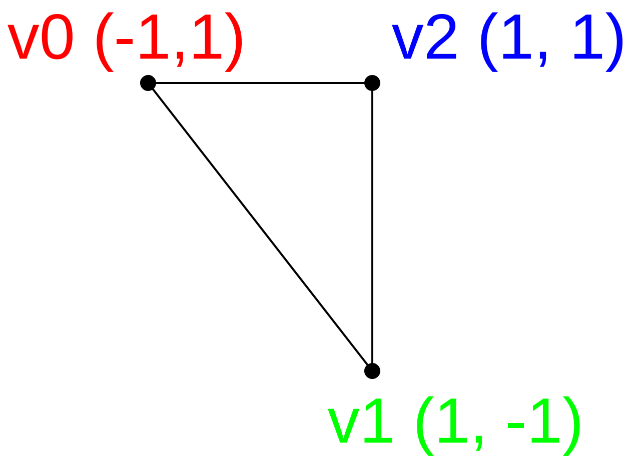
Crete, Greece
April 14- 18

Hello OpenGL ES, OpenGL ES part

```
#include <GLES/gl.h>

static const GLbyte vertices[3 * 3] =
{
    -1,    1,    0,
     1,   -1,    0,
     1,    1,    0
};

static const GLubyte colors[3 * 4] =
{
        255,    0,      0,      255,    🟥
        0,      255,    0,      255,    🟩
        0,      0,      255,    255     🟦
};
```



Hello OpenGL ES, OpenGL ES part

```
void init( )
{
    glClearColor          ( 0.f, 0.f, 0.1f, 1.f );
    glMatrixMode          ( GL_PROJECTION );
    glFrustumf            ( -1.f, 1.f, -1.f, 1.f, 3.f, 1000.f );
    glMatrixMode          ( GL_MODELVIEW );
    glShadeModel          ( GL_SMOOTH );
    glDisable             ( GL_DEPTH_TEST );
    glVertexPointer       ( 3, GL_BYTE, 0, vertices );
    glColorPointer        ( 4, GL_UNSIGNED_BYTE, 0, colors );
    glEnableClientState   ( GL_VERTEX_ARRAY );
    glEnableClientState   ( GL_COLOR_ARRAY );
    glViewport            ( 0, 0, GET_WIDTH(), GET_HEIGHT() );

    INIT_RENDER_CALLBACK(drawcallback);
}
```

Hello OpenGL ES, OpenGL ES part

```
void drawcallback(void)
{
    glClear          ( GL_COLOR_BUFFER_BIT );
    glLoadIdentity   ( );
    glTranslatef     ( 0.f, 0.f, -5.f );
    glDrawArrays     ( GL_TRIANGLES, 0, 3 );

    eglSwapBuffers( display, surface );
}
```

EGL config sorting

ATTRIBUTE	DEFAULT VALUE	SELECTION RULE	SORT PRIORITY	SORT ORDER
EGL_BUFFER_SIZE [16]	0	AtLeast	3	Smaller
EGL_DEPTH_SIZE [15]	0	AtLeast	6	Smaller
…				

Selection rule:	minimum requirement
Sort priority:	which attrib is sorted first
Sort order:	how attrib is sorted

One way of sorting

Not optimal for all applications

Example of sorted list of configs

EGL_CONFIG_ID	EGL_BUFFER_SIZE (Sort priority = 3)	EGL_DEPTH_SIZE (Sort priority = 6)
5	16	15
2	16	32
40	24	15
11	32	15
3	32	32
30	32	32

Sorted first, smaller comes first

Sorted next, smaller comes first

Sorted last (if otherwise no unique order exists), smaller comes first

2008 Crete, Greece April 14-18

Example EGL config selection

```
EGLConfig select_config(int type, int color_bits, int depth_bits, int stencil_bits)
{
    EGLBoolean      err;
    EGLint          amount, attrib_list[5*2];   /* fits 5 attribs */
    EGLConfig       best_config, configs[64]; /* max 64 configs considered */
    EGLint *ptr;

    ptr = &attrib_list[0];

    /* Make sure that the config supports target surface type */
    *ptr++ = EGL_SURFACE_TYPE;
    *ptr++ = type;

    /* For color, we require minimum of <color_bits> bits */
    *ptr++ = EGL_BUFFER_SIZE;
    *ptr++ = color_bits;

    /* For depth, we require minimum of <depth_bits> bits */
    if(depth_bits)
    {
        *ptr++ = EGL_DEPTH_SIZE;
        *ptr++ = depth_bits;
    }
```

Real-world EGL config selection

```
if(stencil_bits)
{
        ptr[0] = EGL_STENCIL_SIZE;
        ptr[1] = stencil_bits;
        ptr[2] = EGL_NONE;
}
else
{
        ptr[0] = EGL_NONE;
}

err = eglChooseConfig( display, &attrib_list[0], &configs[0], 64, &amount );

if(amount == 0)
{
        /* If we didn't have get any configs, try without stencil */
        ptr[0] = EGL_NONE;
        err = eglChooseConfig( display, &attrib_list[0], &configs[0], 64, &amount );
}
```

Real-world EGL config selection

```
    if(amount > 0)
    {
        /* We have either configs w/ or w/o stencil, not both. Find one with best AA */
        int i,best_samples;
        best_samples    = 0;
        best_config     = configs[0];

        for(i=0 ; i<amount ; i++)
        {
                int samp;
                eglGetConfigAttrib( display, configs[i], EGL_SAMPLES, &samp );
                if(samp > best_samples)
                {
                        best_config  = configs[i];
                        best_samples = samp;
                }
        }
    }
    else    best_config = (EGLConfig)0;              /* no suitable configs found */

    return best_config;
}
```

Texture matrix example

```
void appinit_glass(void)
{
    GLint texture_handle;

    /* View parameters */
    glMatrixMode            ( GL_PROJECTION );
    glFrustumf              ( -1.f, 1.f, -1.f, 1.f, 3.f, 1000.f );
    glMatrixMode            ( GL_MODELVIEW );

    /* Reset state */
    glEnable                ( GL_DEPTH_TEST );
    glClearColor            ( 0.f, 0.f, 0.1f, 1.f );

    /* Enable vertex arrays */
    glEnableClientState  ( GL_VERTEX_ARRAY );
    glEnableClientState  ( GL_TEXTURE_COORD_ARRAY );
```

Texture matrix example

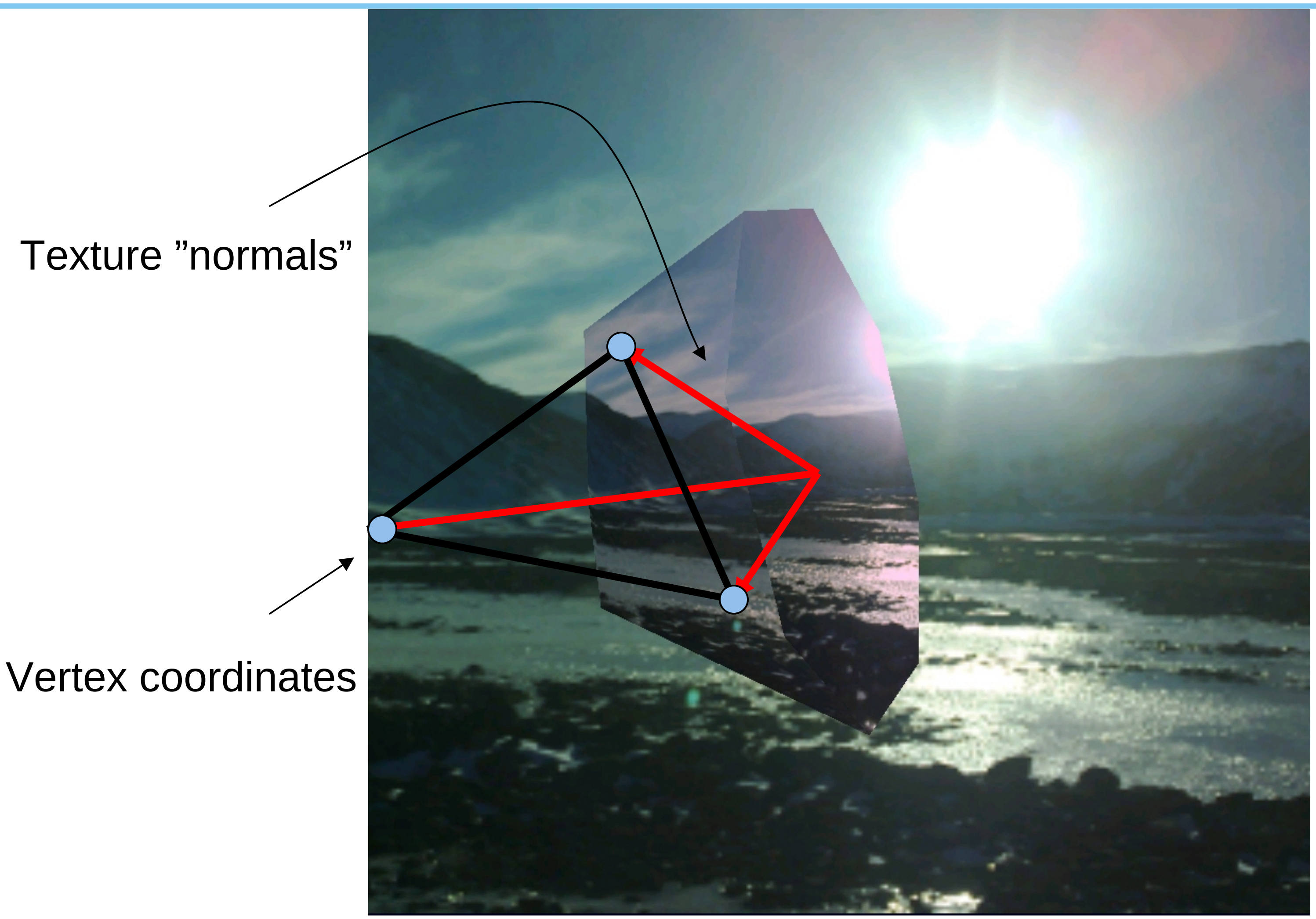
```
    /* Setup texture */
    glEnable              ( GL_TEXTURE_2D );

    glGenTextures         ( 1, texture_handle );
    glBindTexture         ( GL_TEXTURE_2D,  texture_handle );
    glTexImage2D          ( GL_TEXTURE_2D,  0, GL_RGB, 256, 256, 0,
                            GL_RGB, GL_UNSIGNED_BYTE, texture_data );
    glTexEnvi             ( GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE,
                            GL_MODULATE );
    glTexParameteri       ( GL_TEXTURE_2D,  GL_TEXTURE_MIN_FILTER,
                            GL_LINEAR );
    glTexParameteri       ( GL_TEXTURE_2D,  GL_TEXTURE_MAG_FILTER,
                            GL_LINEAR );
    glTexParameteri       ( GL_TEXTURE_2D,  GL_TEXTURE_WRAP_S,
                            GL_CLAMP_TO_EDGE );
    glTexParameteri       ( GL_TEXTURE_2D,  GL_TEXTURE_WRAP_T,
                            GL_CLAMP_TO_EDGE );
}
```

Texture matrix example

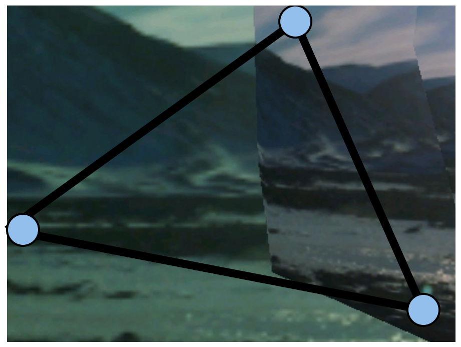
```
int render(float time)
{
    glClear            ( GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT );

    /* draw background with two textured triangles */
    glMatrixMode       ( GL_TEXTURE );
    glLoadIdentity     ( );
    glMatrixMode       ( GL_PROJECTION);
    glLoadIdentity     ( );
    glMatrixMode       ( GL_MODELVIEW);
    glLoadIdentity     ( );
    glColor4ub         ( 255, 255, 255, 255 );
    glScalef           ( 2.f, -2.f, 0.f );
    glTranslatef       ( -0.5f, -0.5f, 0.f );
    glVertexPointer    ( 2, GL_BYTE, 0, back_coords );
    glTexCoordPointer  ( 2, GL_BYTE, 0, back_coords );
    glDrawArrays       ( GL_TRIANGLE_STRIP, 0, 4 );
```

2008
Crete, Greece
April 14- 18

Texture matrix example, coordinates

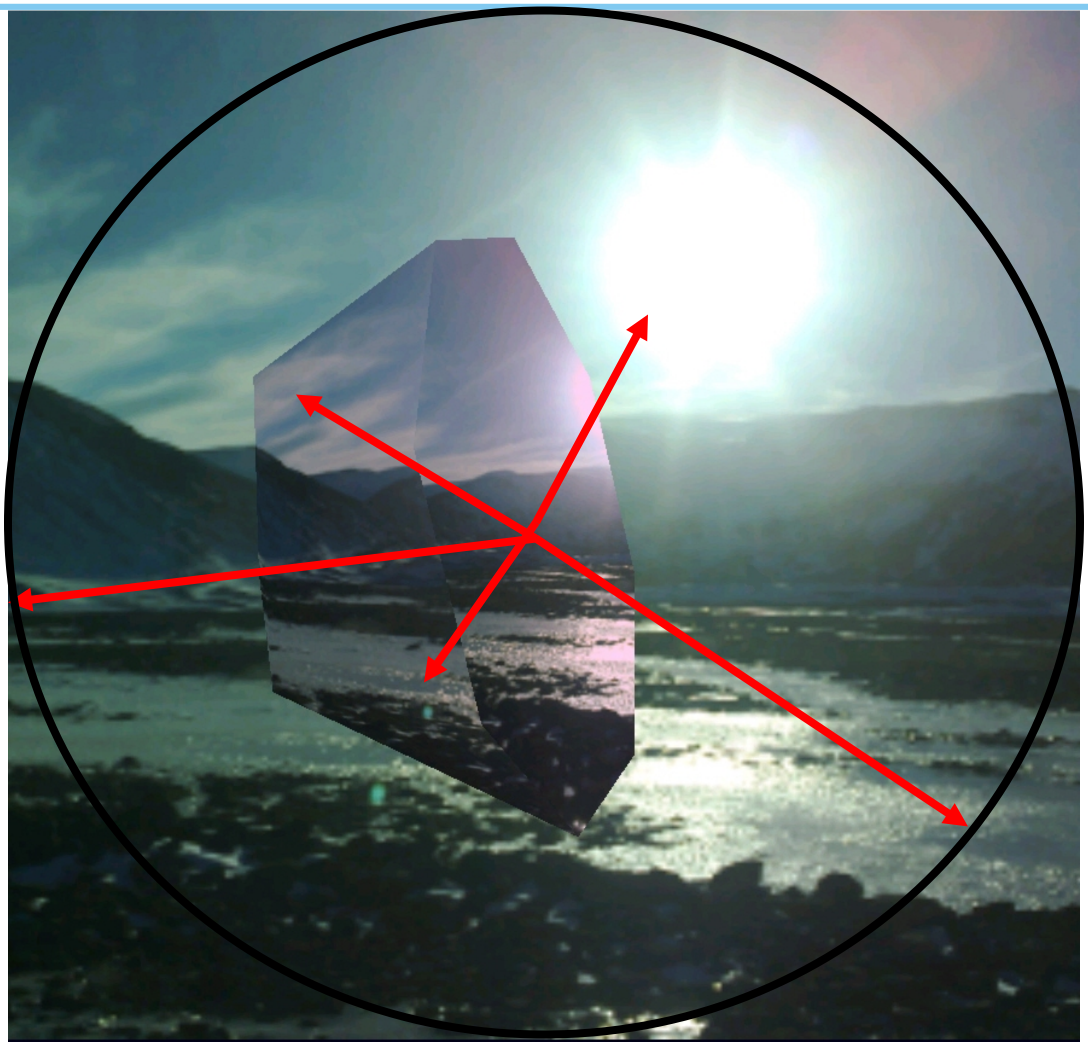


Texture matrix example, coordinates

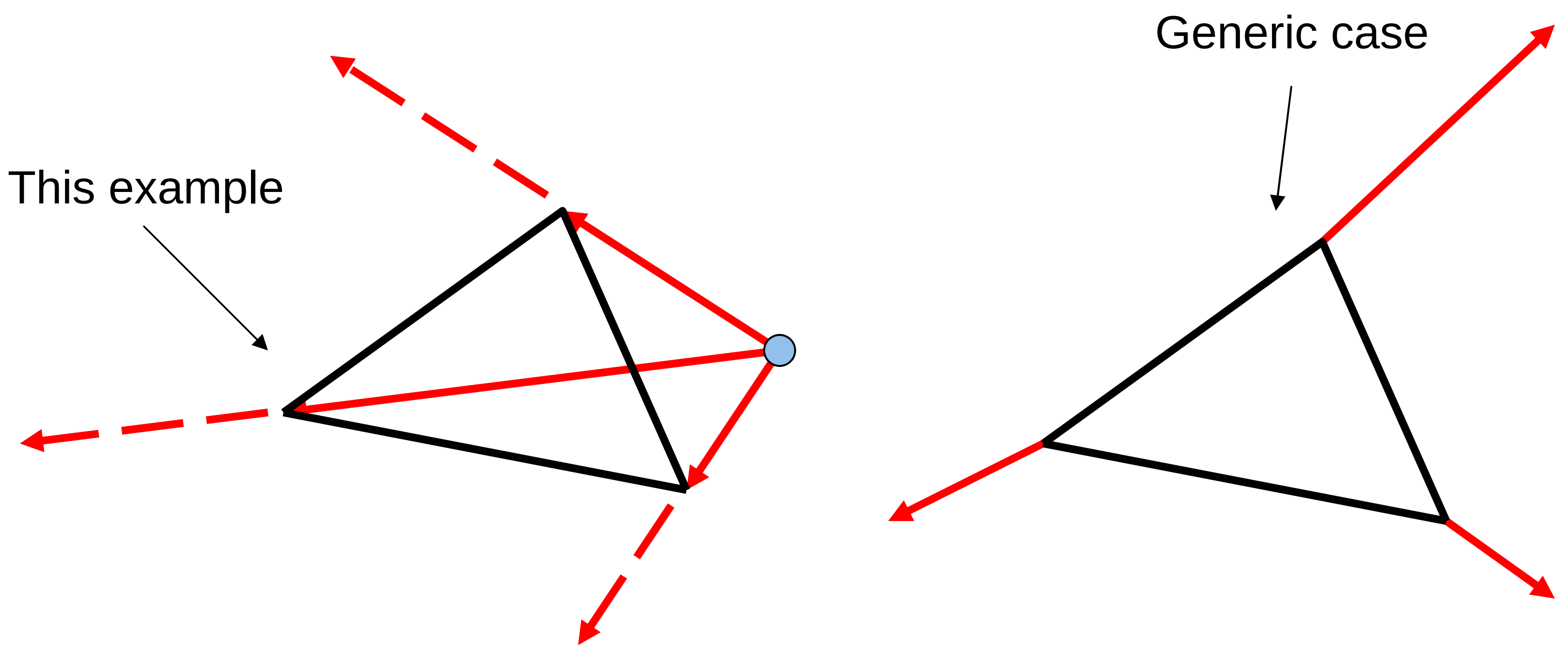


We just take the (x,y) of the texture coordinate output

Texture matrix example, coordinates



Texture matrix example, coordinates



In this example we use the same data for vertex and texture ”normals” as the object is cut away from roughly tessellated sphere (all coordinates unit length)

This is NOT possible for general objects. You should use separate normalized normals for other objects

Texture matrix example

```
glMatrixMode      ( GL_PROJECTION );
glLoadIdentity    ( );
glFrustumf        ( -1.f, 1.f, -1.f, 1.f, 3.f, 1000.f );

glMatrixMode      ( GL_MODELVIEW );
glLoadIdentity    ( );
glTranslatef      ( 0, 0, -5.f );
glRotatef         ( time*25, 1.f, 1.f, 0.f );   /* (1) */
glRotatef         ( time*15, 1.f, 0.f, 1.f );

glMatrixMode      ( GL_TEXTURE );
glLoadIdentity    ( );
glTranslatef      ( 0.5f, 0.5f, 0.f );          /* [-0.5,0.5] -> [0,1]     */
glScalef          ( 0.5f, -0.5f, 0.f );         /* [-1,1]   -> [-0.5,0.5] */
glRotatef         ( time*25, 1.f, 1.f, 0.f );  /* identical rotations! */
glRotatef         ( time*15, 1.f, 0.f, 1.f );  /* see (1) */
```

Texture matrix example

```
    /* use different color for the (glass) object vs. the background */
    glColor4ub              ( 255, 210, 240, 255 );
    glVertexPointer         ( 3,GL_FIXED, 0, vertices );
    glTexCoordPointer       ( 3,GL_FIXED, 0, vertices );
    glDrawArrays            ( GL_TRIANGLES, 0, 16*3 );
}
```

Texture matrix example

Fixed point programming

- Why should you use it?
  - Most mobile handsets don’t have a FPU
- Where does it make sense to use it?
  - Where it makes the most difference
  - For per-vertex processing: morphing, skinning, etc.
  - Per vertex data shouldn’t be floating point
- OpenGL ES API supports 32-bit FP numbers

Fixed point programming

- There are many variants of fixed point:
  - Signed / Unsigned
  - 2’s complement vs. Separate sign
- OpenGL ES uses 2’s complement
- Numbers in the range of [-32768, 32768 [
- 16 bits for decimal bits (precision of 1/65536)
- All the examples here use 16.16 fixed point

Float to fixed and vice versa

Convert from floating point to fixed point

```
#define float_to_fixed(a)  (int)((a)*(1<<16))   or
#define float_to_fixed(a)  (int)((a)*(65536))
```

Convert from fixed point to floating point

```
#define fixed_to_float(a)  (((float)a)/(1<<16)) or
#define fixed_to_float(a)  (((float)a)/(65536))
```

Fixed point programming

Examples:

```
0x0001 0000 =  65536         =     “1.0f”

0x0002 0000 =  2*65536       =     “2.0f”

0x0010 0000 =  16*65536      =     “16.0f”

0x0000 0001 =  1/65536       =     “0.0000152587…”

0xffff ffff = -1/65536(-0x0000 0001)
```

Fixed point operations

Addition

```
#define add_fixed_fixed(a,b) ((a)+(b))
```

Multiply fixed point number with integer

```
#define mul_fixed_int(a,b) ((a)*(b))
```

MUL two FP numbers together

```
 #define mul_fixed_fixed(a,b)                              \
              (int)((((int64)a)*((int64)b)) >> 16)
```

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Fixed point operations and scale

Addition:

a & b	= original float values
S	= fixed point scale (e.g., 65536)

result = (a * **S**) + (b * **S**) = (a + b) * **S**

Scaling term keeps the same

Range of the result is 33 bits

Possible overflow by 1 bit

Fixed point operations and scale

Multiplication:

a & b	= original float values
S	= fixed point scale (e.g., 65536)

result	=	(a * S) * (b * S)	= ((a * b) * S^2)
final	=	((a * b) * S^2) / S	= (a * b) * S

Scaling term is squared (S^2) and takes 32 bits

Also the integer part of the multiplication takes 32 bits

=> need 64 bits for full s16.16 * s16.16 multiply

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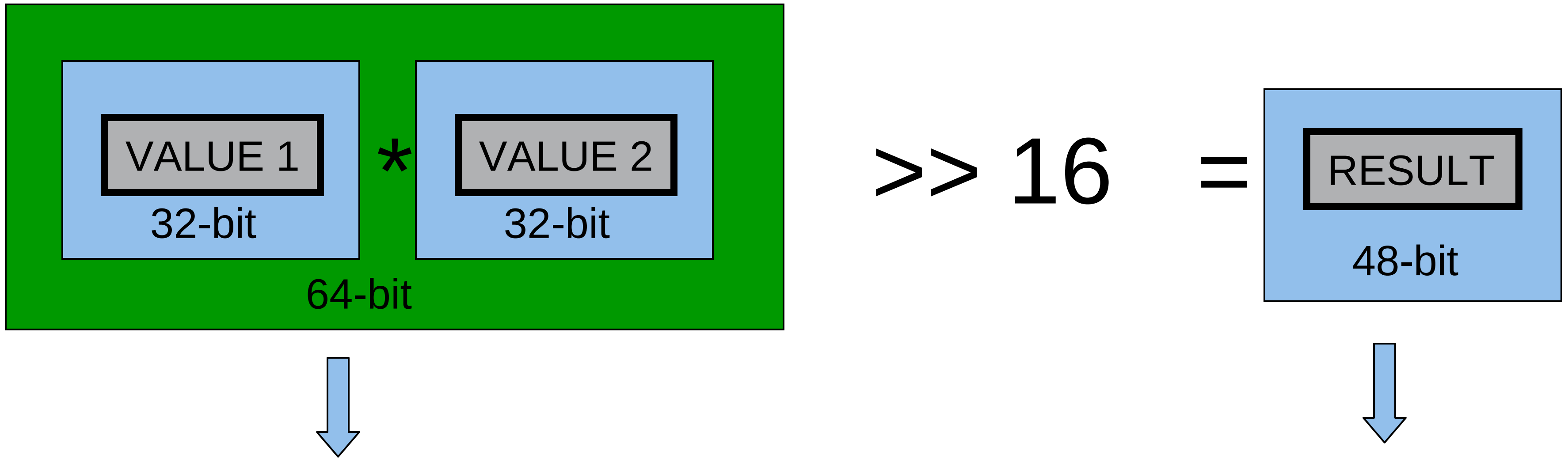
Fixed point programming



Intermediate overflow
- Higher accuracy (64-bit)
- Downscale input
- Redo range analysis

Result overflow (48 bits)
- Redo range analysis
- Detect overflow, clamp

Fixed point programming

Division of integer by integer to a fixed point result

```
#define div_int_int(a,b)                      \
        (int)((((int64)a)*(1<<16))/(b))
```

`(a*S)/ b = (a/b)*S`

Division of fixed point by integer to a fixed point result

```
#define div_fixed_int(a,b) ((a)/(b))
```

Division of fixed point by fixed point

```
#define div_fixed_fixed(a,b)                  \
        (int)((((int64)a)*(1<<16))/(b))
```

`(a*S*S)/(b*S) = (a/b)*S`

Fixed point programming

Power of two MUL & DIV can be done with shifts

a * 65536 = a << 16, a / 256 = a >> 8

Fixed point calculations overflow easily

Careful analysis of the range requirements is required

=>

Always add validation code to your fixed point code

Fixed point programming

```
#if defined(DEBUG)
int add_fix_fix_chk(int a, int b)
{
   int64 bigresult = ((int64)a) + ((int64)b);
   int smallresult = a + b;
   assert(smallresult == bigresult);
   return smallresult;
}
#endif

#if defined(DEBUG)
#  define add_fix_fix(a,b) add_fix_fix_chk(a,b)
#else
#  define add_fix_fix(a,b) ((a)+(b))
#endif
```

Fixed point math functions

- Complex math functions
  - Pre-calculate for the range of interest

- An example: Sin & Cos
  - Sin table between [0, 90°], fixed point angle (S = 2048)
  - Generate other angles and Cos from the table
  - Store in a short table (16-bit) as s0.16 (S = 32768)
  - Range for shorts is [-32768,32767] ([-1.0, 1.0[for s0.16 FP)
  - Equals to [-1.0, +1.0[for s0.16 FP (+1.0 not included !)
  - Negative values stored in the table (can represent -1.0)

Example: Simple morphing (LERP)

Simple fixed point morphing loop (16-bit data, 16-bit coeff)

```
#define DOLERP_16(a,b,t) (short)(((((b)-(a))*(t))>>16)+(a))

void lerpgeometry(short *out, const short *inA, const short *inB,
   int count, int scale)
{
   int i;

   for(i=0; i<count; i++)
   {
       out[i*3+0] = DOLERP_16(inB[i*3+0], inA[i*3+0], scale);
       out[i*3+1] = DOLERP_16(inB[i*3+1], inA[i*3+1], scale);
       out[i*3+2] = DOLERP_16(inB[i*3+2], inA[i*3+2], scale);
   }
}
```

Converting existing code

- OS/device conversions
  - Programming model, C/C++, compiler, CPU
- Windowing API conversion
  - EGL API is mostly cross platform
  - EGL Native types are platform specific
- OpenGL -> OpenGL ES conversion

Example: Symbian porting

- Programming model
  - C++ with some changes (e.g., exceptions)
  - Event based programming (MVC), no main / main loop
  - Three level multitasking: Process, Thread, Active Objects
- ARM CPU
  - Unaligned memory accesses will cause exception (unlike x86)

- OpenC (http://www.forum.nokia.com/openc)

Example: EGL porting

- Native types are OS specific
  - EGLNativeWindowType (RWindow *)
  - EGLNativePixmapType (CFbsBitmap *)
  - Pbuffers are portable
- Config selection
  - Select the color depth to be same as in the display
- Windowing system issues
  - What if render window is clipped by a system dialog?
  - Only full screen windows may be supported

OpenGL porting

- glBegin/glEnd wrappers
  - _glBegin stores the primitive type
  - _glColor changes the current per-vertex data
  - _glVertex stores the current data behind arrays and increments
  - _glEnd calls glDrawArrays with primitive type and length

```
_glBegin(GL_TRIANGLES);
  _glColor4f(1.0,0.0,0.0,1.0);
  _glVertex3f(1.0,0.0,0.0);
  _glVertex3f(0.0,1.0,0.0);
  _glColor4f(0.0,1.0,0.0,1.0);
  _glVertex3f(0.0,0.0,1.0);
_glEnd();
```

OpenGL porting

- Display list wrapper
  - Add the display list functions as wrappers
  - Add all relevant GL functions as wrappers
  - When drawing a list, go through the collected list

OpenGL porting

```
void _glEnable( par1, par2 )
{
  if( GLOBAL()->iSubmittingDisplayList )
  {
    *(GLOBAL()->dlist)++ = DLIST_CMD_GLENABLE;
    *(GLOBAL()->dlist)++ = (GLuint)par1;
    *(GLOBAL()->dlist)++ = (GLuint)par2;
  }
  else
  {
    glEnable(par1,par2);
  }
}
```

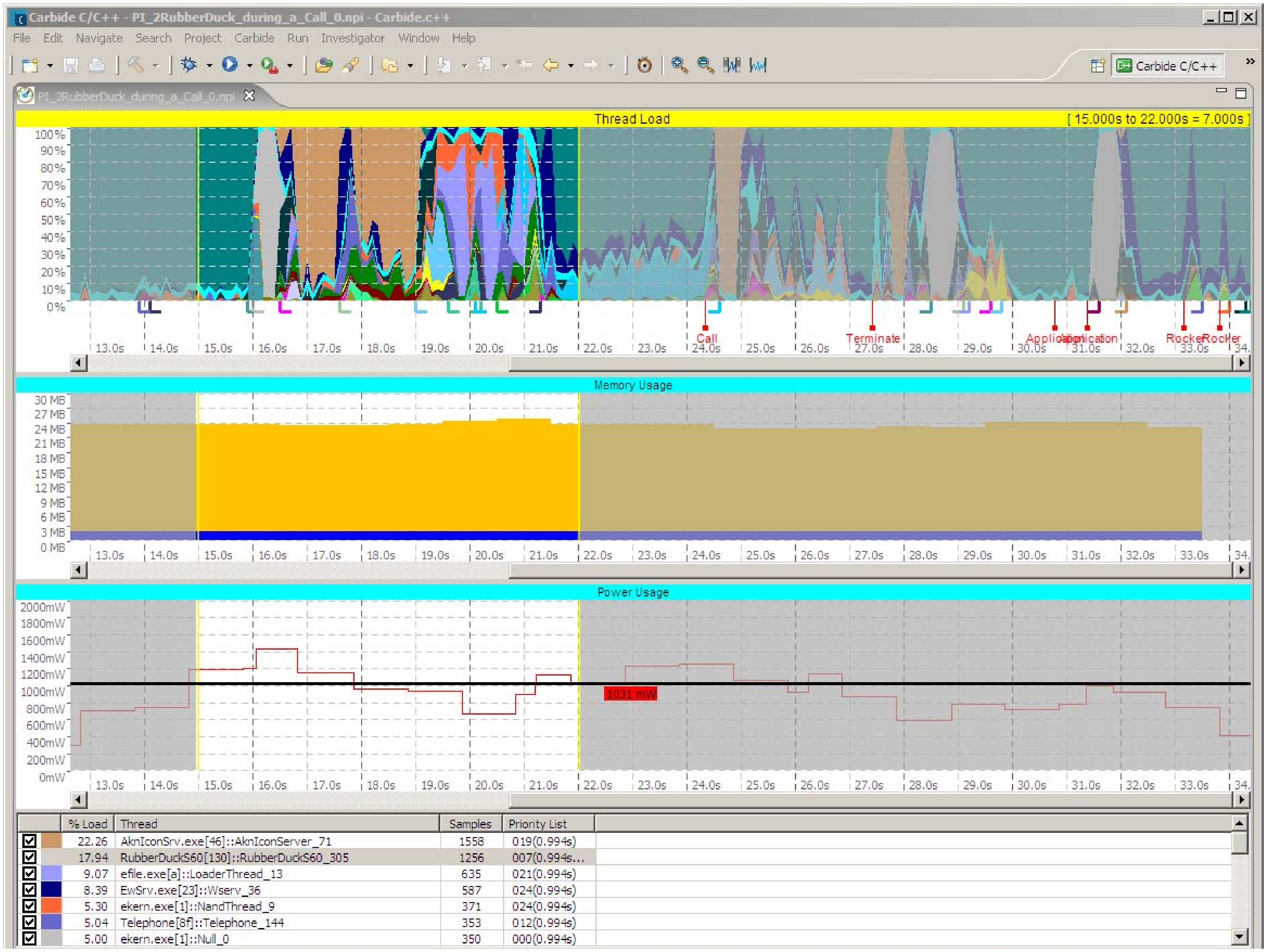
OpenGL porting

Vertex arrays

- OpenGL ES supports only vertex arrays
- SW implementations get penalty from float data
- Use as small types as possible (byte, short)
- For HW it shouldn’t make a difference, mem BW
- With OpenGL ES 1.1 always use VBOs

OpenGL porting

- No quads
  - Convert a quad into 2 triangles
- No real two-sided materials in lighting
  - If you really need it, submit front and back triangles
- OpenGL ES and querying state
  - OpenGL ES 1.0 only supports static getters
  - OpenGL ES 1.1 supports dynamic getters
  - For OpenGL ES 1.0, create own state tracking if needed


Carbide C/C++ - PI_2RubberDuck_during_a_Call_0.npi - Carbide.c++
File Edit Navigate Search Project Carbide Run Investigator Window Help
Carbide C/C++
PI_2RubberDuck_during_a_Call_0.npi
Thread Load
[15.000s to 22.000s = 7.000s]
100% 90% 80% 70% 60% 50% 40% 30% 20% 10% 0%
Call
Terminate
Application
Application
Rocker
Rocker
13.0s 14.0s 15.0s 16.0s 17.0s 18.0s 19.0s 20.0s 21.0s 22.0s 23.0s 24.0s 25.0s 26.0s 27.0s 28.0s 29.0s 30.0s 31.0s 32.0s 33.0s 34.
Memory Usage
30 MB 27 MB 24 MB 21 MB 18 MB 15 MB 12 MB 9 MB 6 MB 3 MB 0 MB
Power Usage
2000mW 1800mW 1600mW 1400mW 1200mW 1000mW 800mW 600mW 400mW 200mW 0mW
1031 mW

		% Load	Thread	Samples	Priority List
☑	🟫	22.26	AknIconSrv.exe[46]::AknIconServer_71	1558	019(0.994s)
☑	⬜	17.94	RubberDuckS60[130]::RubberDuckS60_305	1256	007(0.994s...
☑	🟪	9.07	efile.exe[a]::LoaderThread_13	635	021(0.994s)
☑	🟦	8.39	EwSrv.exe[23]::Wserv_36	587	024(0.994s)
☑	🟧	5.30	ekern.exe[1]::NandThread_9	371	024(0.994s)
☑	🟪	5.04	Telephone[8f]::Telephone_144	353	012(0.994s)
☑	⬜	5.00	ekern.exe[1]::Null_0	350	000(0.994s)

Demo

Sequel to game One (Nokia)

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Questions?

? ? ?

OpenGL ES on PyS60

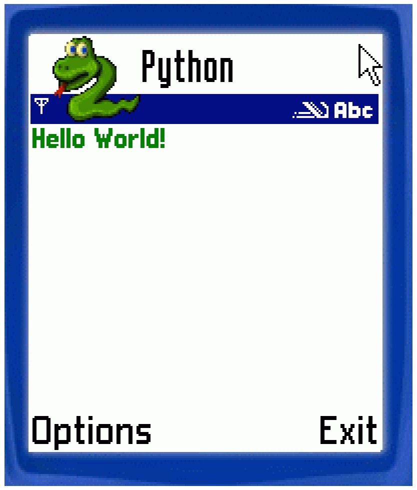
2008
Crete, Greece
April 14-18
EUROGRAPHICS '08

Kari Pulli

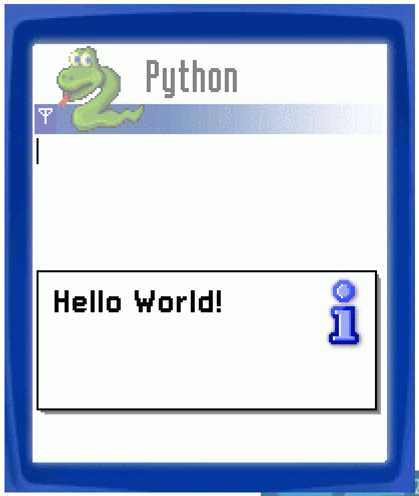
Nokia Research Center

Python: Great for rapid prototyping

- Python
  - designed to be as small, practical, and open as possible
  - easy and fun OO programming
- sourceforge.net/projects/pyS60
  - Python 2.2.2 on Symbian S60
  - wrappers for phone SDK libraries
  - can extend in Symbian C++



Hello World!



Hello World!

Python bindings to OpenGL ES

- Almost direct bindings
- OpenGL ES functions that take in pointers typically take in a Python list
- Next we’ll show a full S60 GUI program with OpenGL ES

Import libraries

```
import appuifw    # S60 ui framework
import sys


from glcanvas  import *
from gles      import *
from key_codes import *
```

Application class, data

```
class Hello:

    vertices = array( GL_BYTE, 3,
                      [-1, 1, 0,
                        1,-1, 0,
                        1, 1, 0] )

    colors = array( GL_UNSIGNED_BYTE, 4,
                    [255, 0,   0,  255,
                     0, 255,   0,  255,
                     0,   0, 255,  255] )
```

Initialize the application

```
def __init__(self):                           # class constructor
    self.exiting = False                       # while !exit, run
    self.frame, self.angle = 0, 0              # set variables
    self.old_body = appuifw.app.body
    try:                                       # create surface
        c = GLCanvas( redraw_callback = self.redraw,
                      resize_callback = self.resize )
        appuifw.app.body = c
        self.canvas = c
    except Exception, e:
        appuifw.note( u"Exception: %s" % (e) )
        self.start_exit()
        return
    appuifw.app.menu = [(u"Exit", self.start_exit)]
    c.bind( EKeyLeftArrow,  lambda:self.left() )
    c.bind( EKeyRightArrow, lambda:self.right() )
    self.initgl()
```

Keyboard and resize callbacks

```
def left(self):
    self.angle -= 10
def right(self):
    self.angle += 10
def resize(self):
    if self.canvas:
        glViewport( 0, 0,
                    self.canvas.size[0],
                    self.canvas.size[1] )
```

Main loop

```
def start_exit(self):
    self.exiting = True

def run(self):
    app = appuifw.app
    app.exit_key_handler = self.start_exit
    while not self.exiting:
        self.canvas.drawNow()
        e32.ao_sleep( 0.01 )
    app.body             = self.old_body
    self.canvas          = None
    app.exit_key_handler = None
```

Initialize OpenGL ES

```
def initgl(self):
    glMatrixMode( GL_PROJECTION )
    glFrustumf  ( -1.0, 1.0, -1.0, 1.0,
                  3.0, 1000.0 )
    glMatrixMode( GL_MODELVIEW )
    glDisable   ( GL_DEPTH_TEST )
    glShadeModel( GL_SMOOTH )
    glClearColor( 0.0, 0.0, 0.1, 1.0 )
    glVertexPointerb( self.vertices )
    glColorPointerub( self.colors )
    glEnableClientState( GL_VERTEX_ARRAY )
    glEnableClientState( GL_COLOR_ARRAY )
```

Draw cycle

```
def redraw(self, frame=None):
    if self.canvas:
        glClear( GL_COLOR_BUFFER_BIT )
        glLoadIdentity()
        glTranslatef( 0.0, 0.0, -5.0 )
        glRotatef   ( self.angle,
                      0.0, 0.0, 1.0 )
        glRotatef   ( self.frame,
                      0.0, 1.0, 0.0 )
        glDrawArrays( GL_TRIANGLES, 0,3 )
        self.frame += 1
```

Using the class

```
appuifw.app.screen = 'full'
try:
    app = Hello()
except Exception, e:
    appuifw.note( u"Cannot start: %s" %
                  (e) )
else:
    app.run()
del app
```

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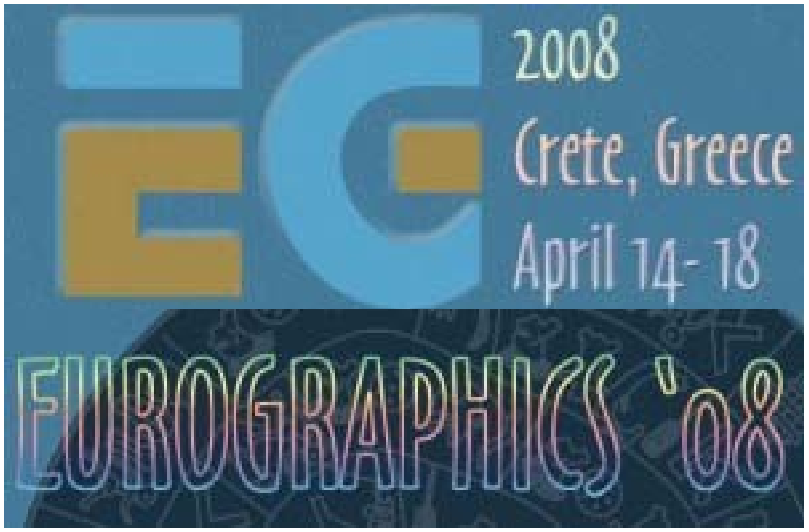
OpenGL ES Performance Considerations



Ville Miettinen

Targeting the ”mobile platform”

- CPU speed and available memory varies
  - Current range ~30Mhz - 600+ MHz, ARM7 to ARM11
  - From no FPUs to SIMD FPUs
- Different resolutions
  - QCIF (176x144) to VGA (640x480) and beyond, antialiasing on higher-end devices
  - Color depths 4-8 bits per channel (12-32 bpp)
- Portability issues
  - Different CPUs, OSes, Java VMs, C compilers, ...
  - OpenKODE from the Khronos Group will help to some extent

Graphics capabilities

- General-purpose multimedia hardware
  - Pure software renderers (all done using CPU & integer ALU)
  - Software + DSP / WMMX / FPU / VFPU
  - Multimedia accelerators
- Dedicated 3D hardware
  - Software T&L + HW tri setup / rasterization
  - Full hardware acceleration
- Performance: 50K – 2M tris, 1M – 100M pixels / sec
- Next gen: 30M+ tris, 1000M pixels / sec

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Standards help somewhat

- Act as hardware abstraction layers
  - Provide programming interface (API)
  - Same feature set for different devices
  - Unified rendering model
- Performance cannot be guaranteed

Scalability

- Successful application has to run on hundreds of different phone models
  - No single platform popular enough
- Same gameplay but can scale video and audio
- Design for lowest-end, add eye candy for high-end
  - Scalability has to be built into the design

3D content is easy to scale

Separate low and high poly count 3D models

Different texture resolutions & compressed formats

Rendering quality can be scaled

- Texture filtering, perspective correction, blend functions, multi-texturing, antialiasing

Special effects

- Identify special effects
  - Bullet holes, skid marks, clouds, ...
  - Cannot have impact on game play
    - Fog both gameplay and visual element
    - Multiplayer games have to be fair
- Users can alter performance by controlling effects

Tuning down the details

- Particle systems
  - Number of particles, complexity, visuals
  - Shared rendering budget for all particle systems
- Background elements
  - Collapse into sky cubes, impostors
- Detail objects
  - Models to have “important” and “detail” parts

Profiling

Performance differences often system integration issues - not HW issues

Measuring is the only effective way to find out how changes in code affect performance

Profile on actual target device if possible

Public benchmark apps provide some idea of graphics performance

gDEBugger ES for gfx driver profiling

Identifying bottlenecks

- Three groups: application code, vertex pipeline, pixel pipeline
  - Further partitioned into pipeline stages
  - Overall pipeline runs as fast as its slowest stage
- Locate bottlenecks by going through each stage and reducing its workload
  - If performance changes, you have a bottleneck
- Apps typically have multiple bottlenecks

Pixel pipeline bottlenecks

- Find out by changing rendering resolution
  - If performance increases, you have a bottleneck
  - Either texturing or frame buffer accesses
- Remedies
  - Smaller screen resolution, render fewer objects, use simpler data formats, smaller texture maps, less complex fragment and texture processing

Vertex pipeline bottlenecks

- Vertex processing or submission bottlenecks
  - Find out by rendering every other triangle but using same vertex arrays
- Remedies
  - Submission: smaller data formats, cache-friendly organization, fewer triangles
  - Vertex processing: simpler T&L (fewer light sources, avoid dynamic lighting and fog, avoid floating-point data formats)

Application code bottlenecks

- Two ways to find out
  - Turn off all application logic
  - Turn off all rendering calls
- Floating-point code #1 culprit
- Use profiler
  - HW profilers on real devices costly and hard to get
  - Carbide IDE from Nokia (S60 and UIQ Symbian)
  - Lauterbach boards
  - Desktop profiling (indicative only)

Changing and querying the state

- Rendering pipes are one-way streets
- Apps should know their own state
  - Avoid dynamic getters if possible!
- Perform state changes in a group at the beginning of a frame
- Avoid API synchronization
  - Do not mix 2D and 3D libraries!

”Shaders”

- Combine state changes into blocks (”shaders”)
  - Minimize number of shaders per frame
  - Typical application needs only 3-10 ”pixel shaders”
    - Different 3-10 shaders in every application
    - Enforce this in artists’ tool chain
- Sort objects by shaders every frame
  - Split objects based on shaders

Complexity of shaders

- Software rendering: everything costs!
  - Important to keep shaders as simple as possible
    - Even if introduces additional state changes
    - Example: turn off fog & depth buffering when rendering overlays
- Hardware rendering: Usually more important to keep number of changes small

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Model data

- Keep vertex and triangle data short and simple!
    - Better cache coherence, less memory used
- Make as few rendering calls as possible
    - Combine strips with degenerate triangles
- Weld vertices using off-line tool
- Order triangle data coherently
- Use hardware-friendly data layouts
    - Buffer objects allow storing data on server

Transformation pipeline

- Minimize matrix changes
  - Changing a matrix may involve many hidden costs
  - Combine simple objects with same transformation
  - Flatten and cache transformation hierarchies
- ES 1.1: Skinning using matrix palettes
  - CPU doesn’t have to touch vertex data
- ES 1.1: Point sprites for particle effects

Rendering pipeline

- Rendering order is important
  - Front-to-back improves depth buffering efficiency
  - Also need to minimize number of state changes!
- Use culling to speed up rendering pipeline
  - Conservative: frustum culling & occlusion culling
    - Portals and Potentially Visible Sets good for mobile
  - Aggressive culling
    - Bring back clipping plane in, drop detail & small objects

Lighting

Fixed-function lighting pipelines are so 1990s

- Drivers implemented badly even in desktop space
- In practice only single directional light fast
- OpenGL’s attenuation model difficult to use
- Spot cutoff and specular model cause aliasing
- No secondary specular color
- Flat shading sucks
- Artifacts unless geometry heavily tessellated

Lighting (if you have to use it)

Single directional light usually accelerated

Pre-normalize vertex normals

Avoid homogeneous vertex positions

Turn off specular illumination

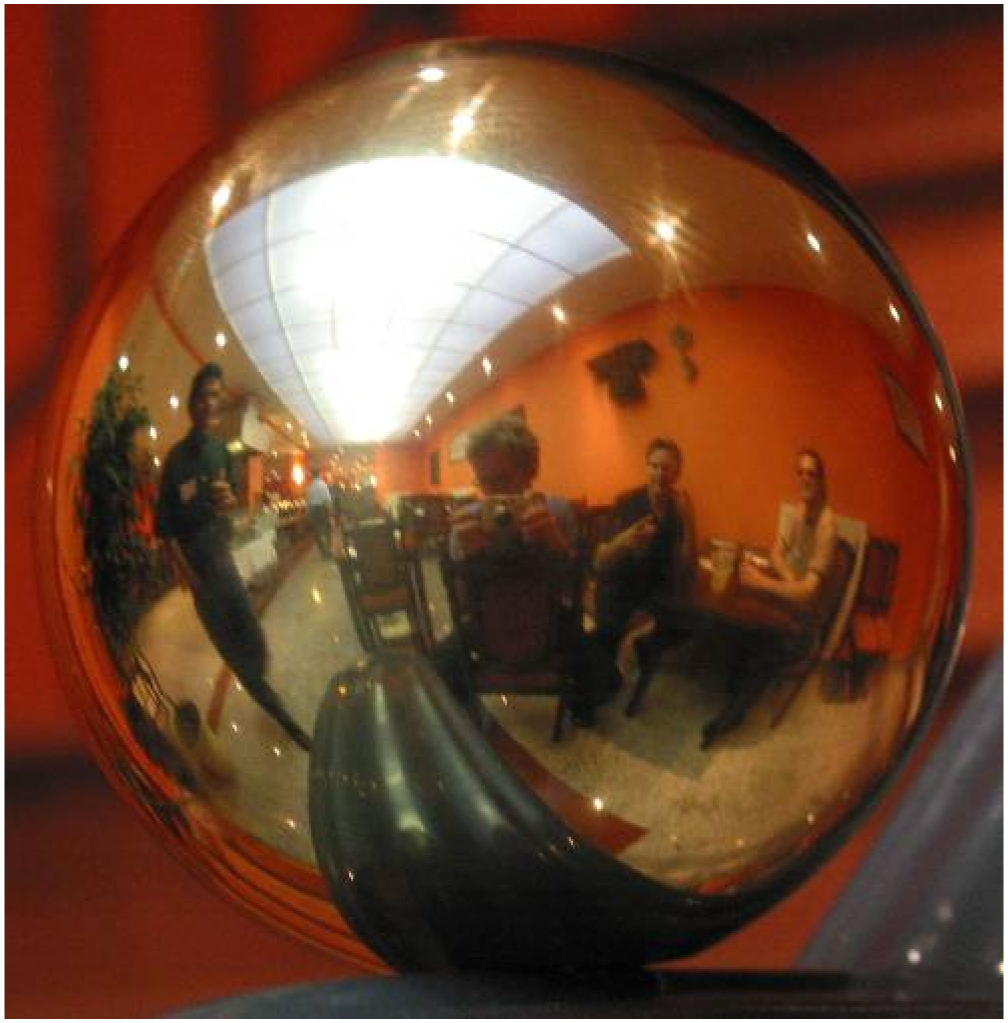
Avoid distance attenuation

Turn off distant non-contributing lights

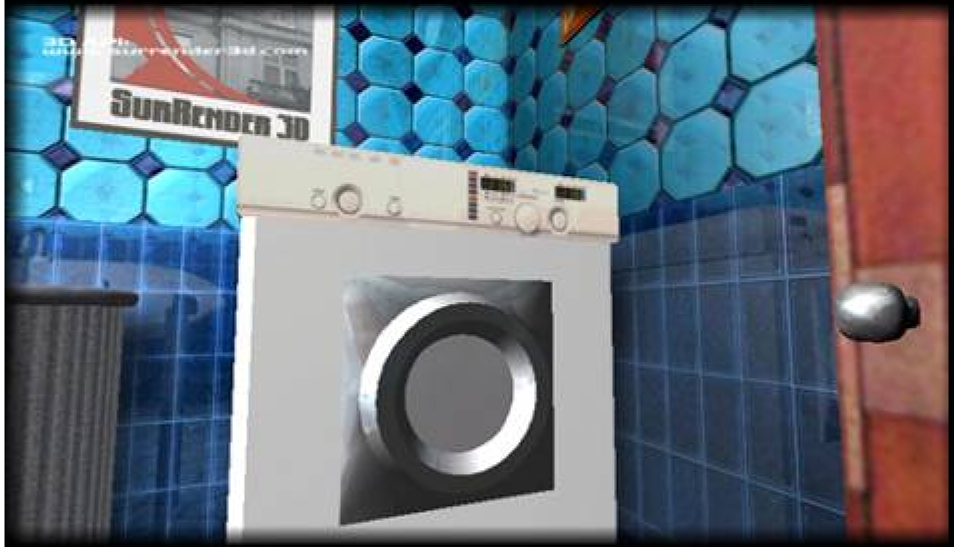
Lighting: the fast way

- While we’re waiting for OpenGL ES 2.0 drivers
  - Pre-computed vertex illumination good if slow T&L
  - Illumination using texturing
    - Light mapping
    - ES 1.1: dot3 bump mapping + texture combine
    - Less tessellation required
  - Combining with dynamic lighting: color material tracking

Environment mapping



MOTH


3D API:
www.surrender3d.com
SurRender 3D

3D API:
www.surrender3d.com

3D API:
www.surrender3d.com

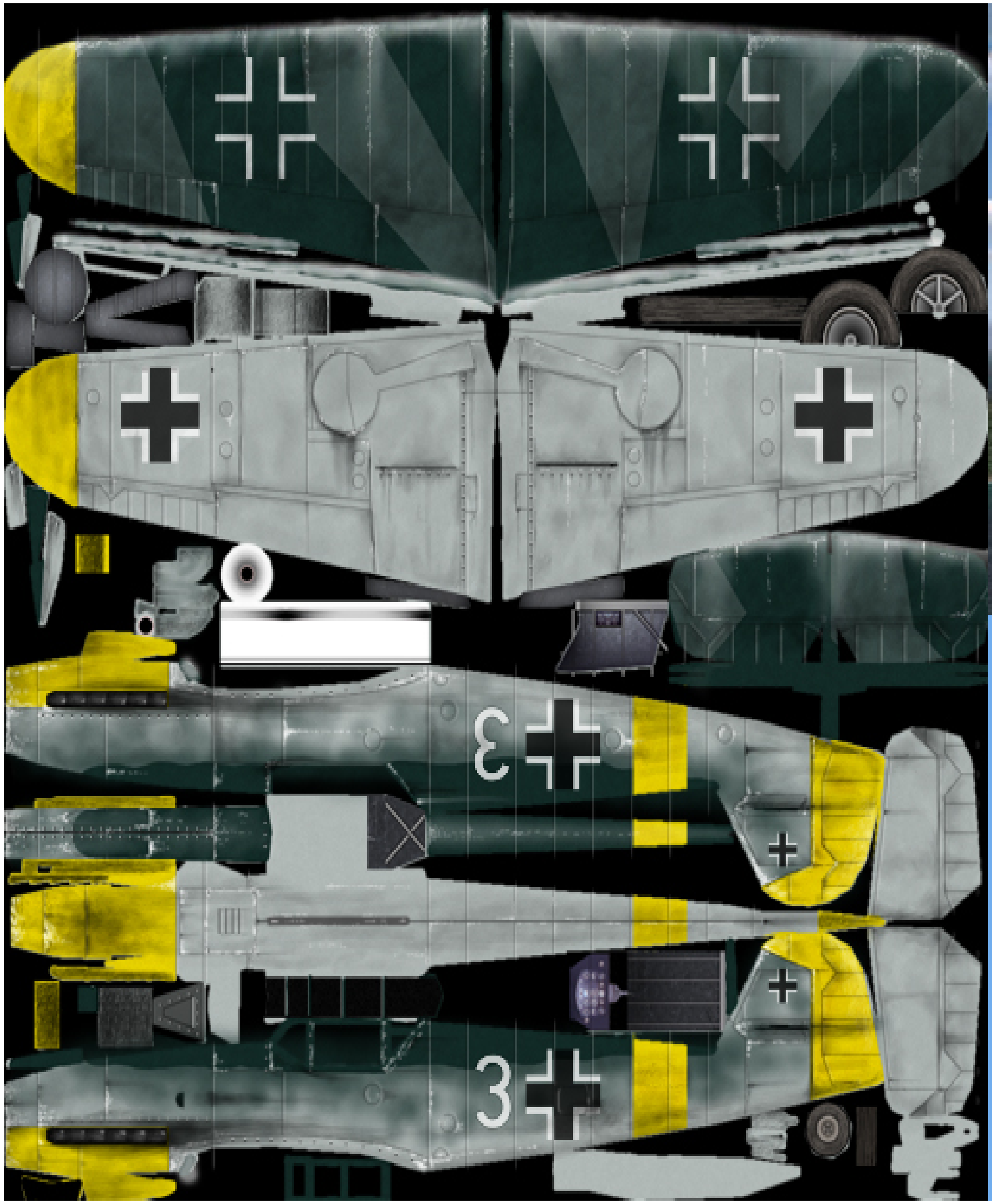
3D API:
www.surrender3d.com
Processor-specific code paths

Textures

- Mipmaps always a Good Thing™
  - Improved cache coherence and visual quality
  - ES 1.1 supports auto mipmap generation
- Avoid modifying texture data
- Keep textures ”right size”, use compressed textures
- Different strategies for texture filtering & perspective correction
  - SW implementations affected

Textures (cont'd)

- Multitexturing
  - Always faster than doing multiple rendering passes
  - ES 1.1: support at least two texturing units
  - ES 1.1: TexEnvCombine neat toy
- Use small & compressed texture formats
- Texture atlases: combining multiple textures
  - Reduces texture state changes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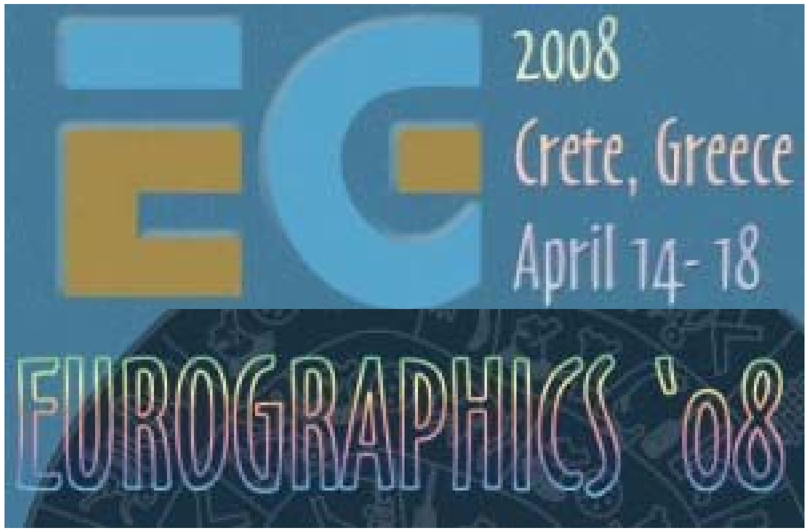
3

ES 2.0 Overview



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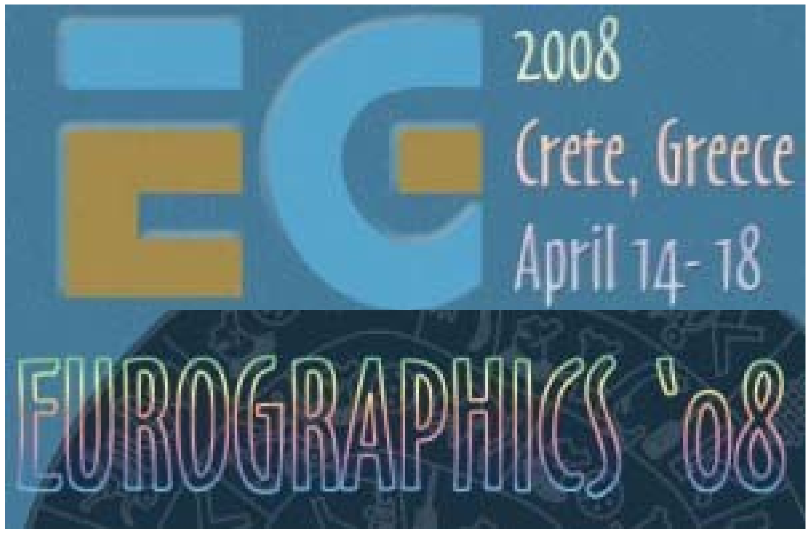
ES 2.0 Pipeline



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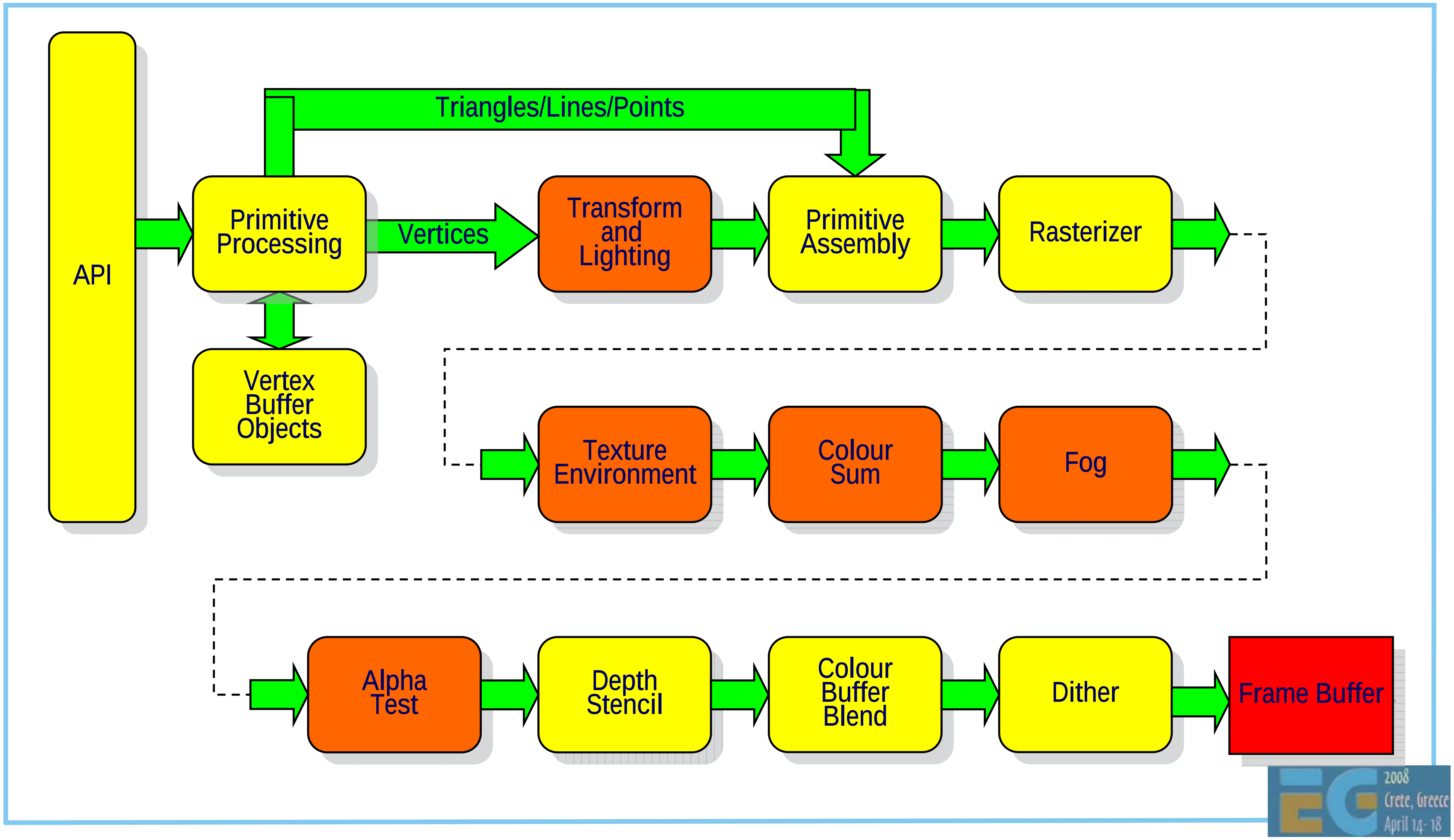
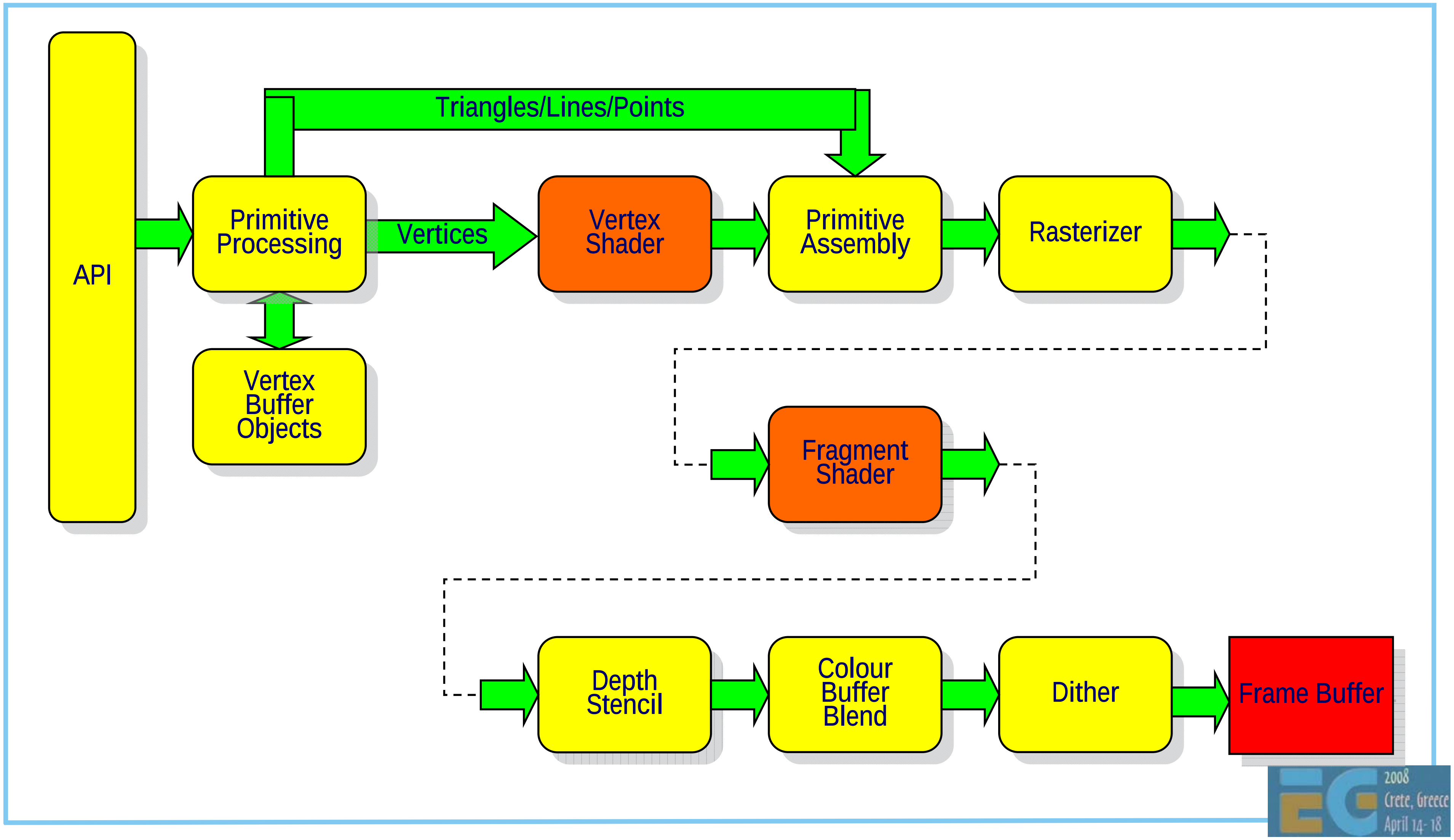
Open GL Fixed Function pipeline



Open GL Programmable pipeline



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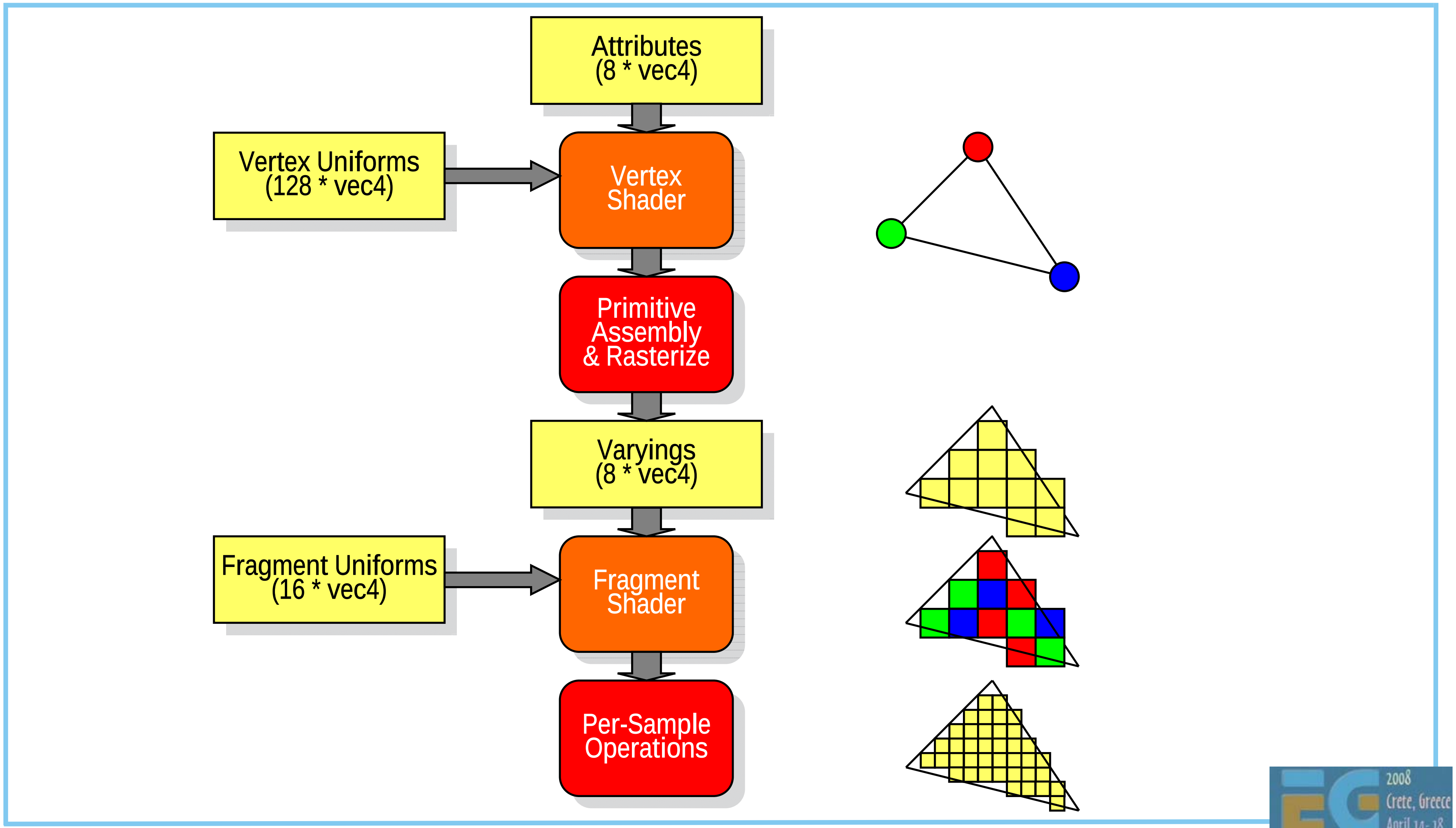
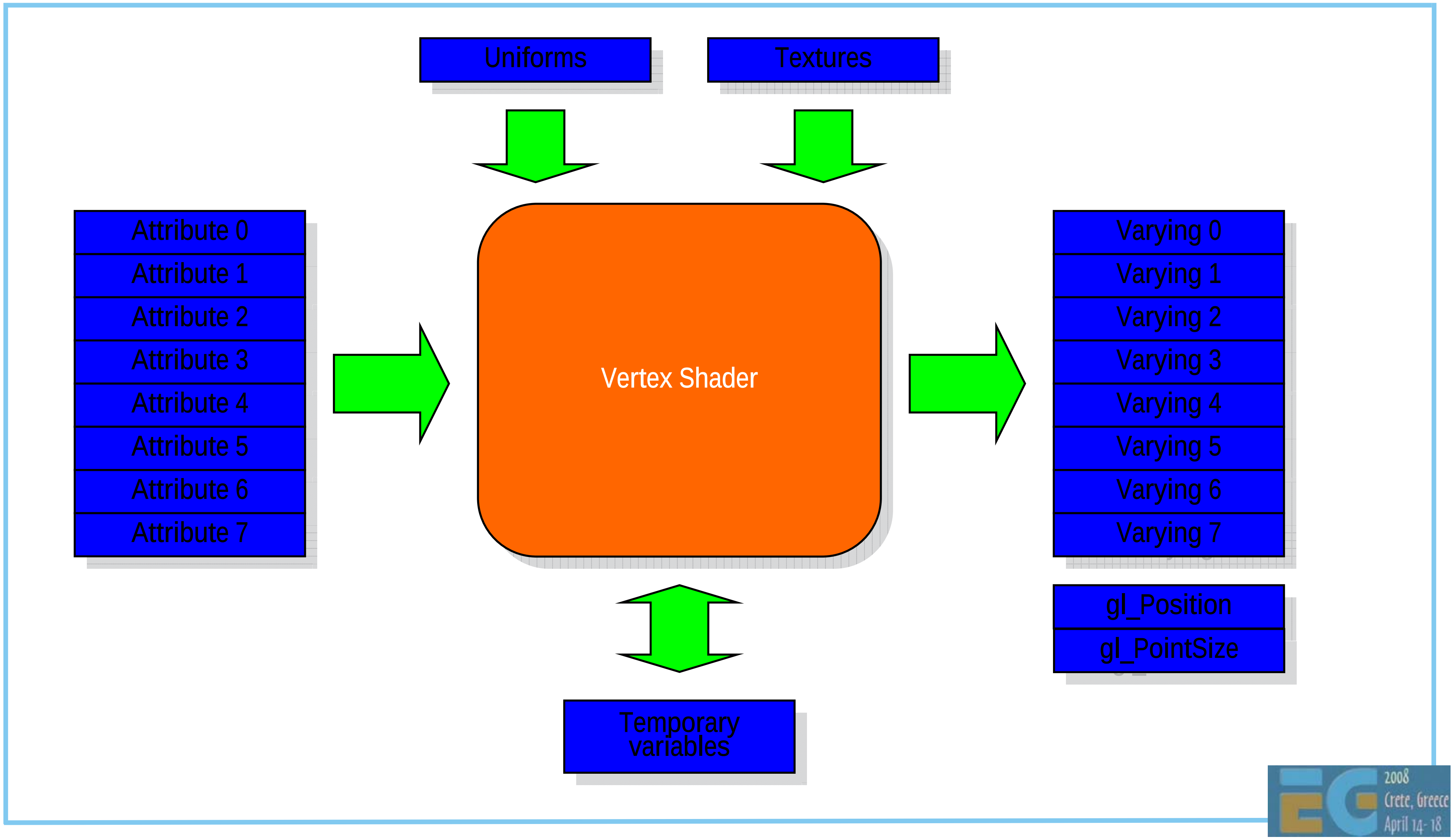
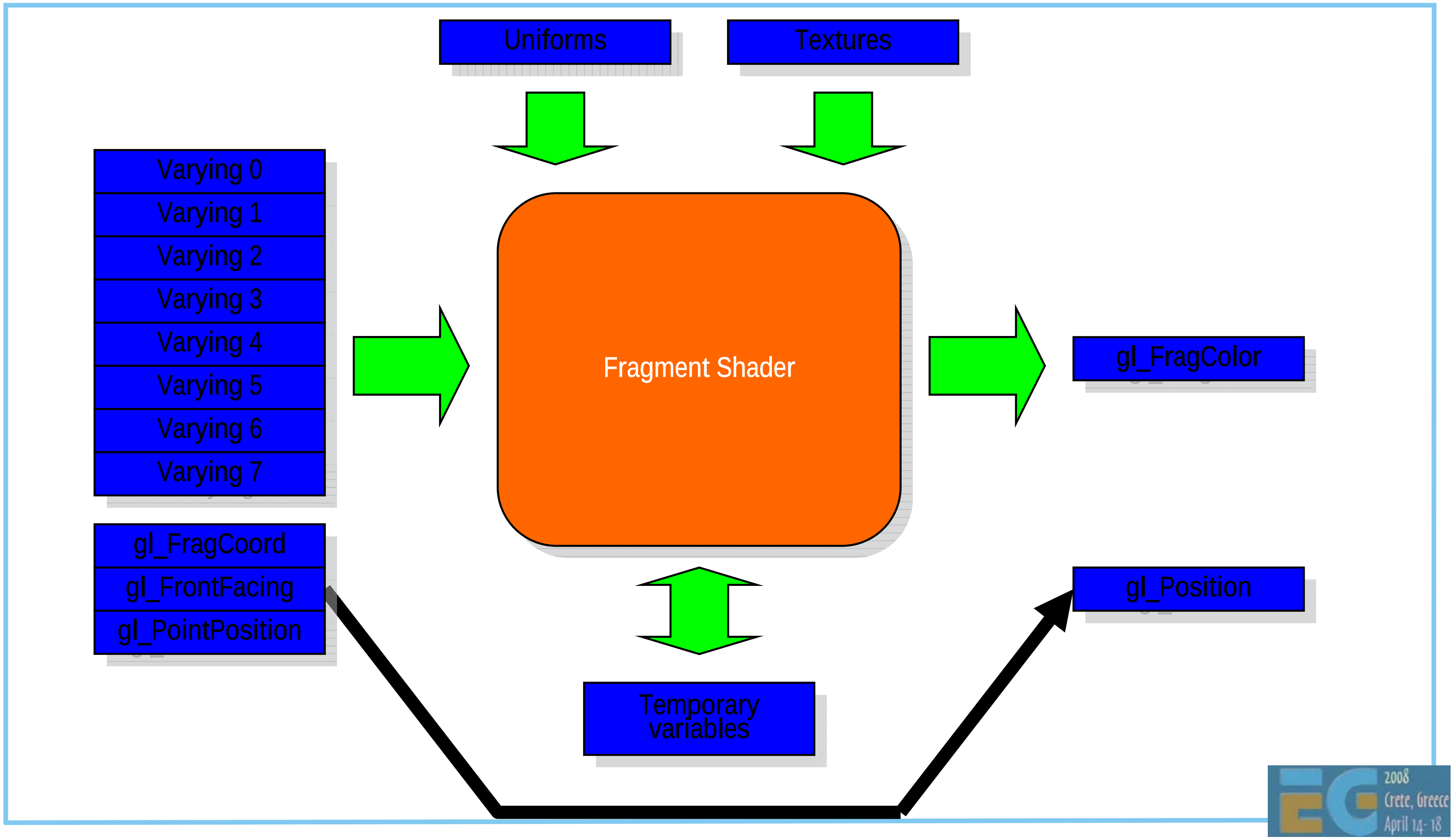
Programmer's model



Vertex Shader



Fragment Shader



The Vertex Shader

The vertex shader can do:

- Transformation of position using model-view and projection matrices
- Transformation of normals, including renormalization
- Texture coordinate generation and transformation
- Per-vertex lighting
- Calculation of values for lighting per pixel

The Vertex Shader

The vertex shader cannot do:

- Anything that requires information from more than one vertex
- Anything that depends on connectivity.
- Any triangle operations (e.g. clipping, culling)
- Access colour buffer

The Fragment Shader

The fragment shader can do:

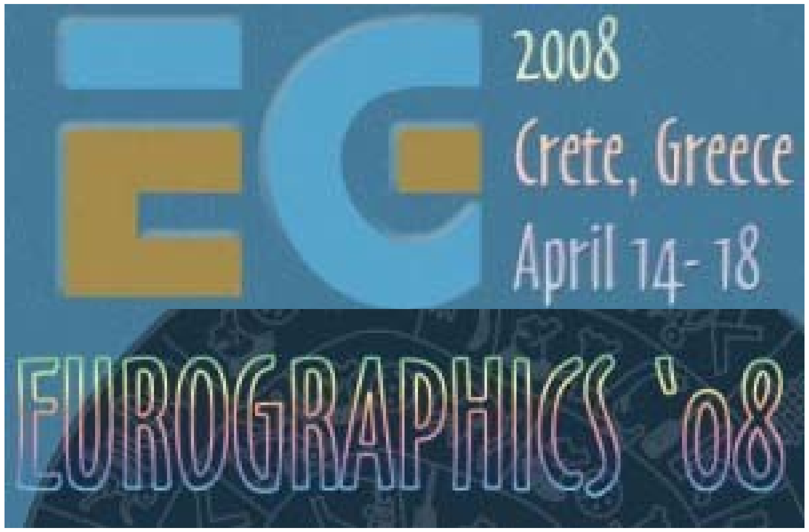
- Texture blending
- Fog
- Alpha testing
- Dependent textures
- Pixel discard
- Bump and environment mapping

The Fragment Shader

The fragment shader cannot do:

- Blending with colour buffer
- ROP operations
- Depth or stencil tests
- Write depth

GLSL ES



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GLSL ES Overview

- Based on GLSL as used in OpenGL 2.0
  - Open standard
- Pure programmable model
  - Most fixed functionality removed.
- Not 100% backward compatible with ES1.x
  - Embedded systems do not have the legacy requirements of the desktop
- No Software Fallback
  - Implementations (usually) hardware or nothing
  - Running graphics routines in software doesn’t make sense on embedded platforms
- Optimized for use in Embedded devices
  - Aim is to reduce silicon cost
  - Reduced shader program sizes
  - Reduced register usage
  - Reduced numeric precision

GLSL ES Overview

- ‘C’ – like language
- Many simplifications
  - No pointers
  - Strongly typed. No implicit type conversion
  - Simplified preprocessor
- Some graphics-specific additions
  - Built-in vector and matrix types
  - Built-in functions
  - Support for mixed precisions
  - Invariance mechanism.
- Differences from Desktop OpenGL
  - Restrictions on shader complexity
  - Fewer sampler modes

GLSL ES Overview

Comments

```
//
/*   */
```

Control

```
#if
#ifdef
#ifndef
#else
#elif
#endif
#error
```

Operators

```
defined
```

Macros

```
#
#define
#undef
```

Extensions

```
#pragma
#extension
```

Misc

```
#version
#line
```

GLSL ES Overview

Scalar				
	`void` `float`	`int`	`bool`	
Vector				
boolean:	`bvec2`	`bvec3`	`bvec4`	
integer:	`ivec2`	`ivec3`	`ivec4`	
floating point:	`vec2`	`vec3`	`vec4`	
Matrix				
floating point	`mat2`	`mat3`	`mat4`	
Sampler				
	`sampler2D`			
Containers				
Structures	`struct`			
Arrays	`[]`			

GLSL ES Storage Qualifiers

`const`

Local constants within a shader.

`uniform`

'Constant shader parameters' (light position/direction, texture units, …)
Do not change per vertex.

`attribute`

Per-vertex values (position, normal,…)

`varying`

Generated by vertex shader
Interpolated by the rasterizer to generate per pixel values
Used as inputs to Fragment Shader
e.g. texture coordinates

Function Parameter Qualifiers

Used to pass values in or out or both e.g.

```
bool f(in vec2 in_v, out float ret_v)
{
        ...
}
```

Qualifiers:

`in`	Input parameter. Variable can be modified
`const in`	Input parameter. Variable cannot be modified.
`out`	Output parameter.
`inout`	Input and output parameter.

Functions can still return a value

- But need to use a parameter if returning an array

Function Parameter Qualifiers

Call by value ‘copy in, copy out’ semantics.

Not quite the same as c++ references:

```
bool f(inout float a, b)
{
        a++;
        b++;
}

void g()
{
        float x = 0.0;
        f(x,x);                 // x = 1.0 not 2.0
}
```

GLSL ES Overview

Order of copy back is undefined

```
bool f(inout float a, b)
{
     a = 1.0;
     b = 2.0;
}

void g()
{
     float x ;
     f(x,x);   // x = 1.0 or 2.0
               // (undefined)
}
```

Precision Qualifiers

`lowp float`

Effectively sign + 1.8 fixed point.

Range is -2.0 < x < 2.0

Resolution 1/256

Use for simple colour blending

`mediump float`

Typically implemented by sign + 5.10 floating point

-16384 < x < 16384

Resolution 1 part in 1024

Use for HDR blending.

Precision Qualifiers

`highp float`

- Typically implemented by 24 bit float (16 bit mantissa)
- range $\pm 2^{62}$
- Resolution 1 part in 2^{16}
- Use of texture coordinate calculation
  - e.g. environment mapping

single precision (float32)

- Not explicit in GLSL ES but usually available in the vertex shader (refer to device documentation)

Precision Qualifiers

Precision depends on the operands:

```
lowp float x;
mediump float y;
highp float z = x * y;
```

(evaluated at medium precision)

Literals do not have any defined precision

```
lowp float x;
highp float z = x * 2.0 + 1.2;
```

(evaluated at low precision)

Constructors

- Replaces type casting
- No implicit conversion: must use constructors
- All named types have constructors available
  - Includes built-in types, structures
  - Excludes arrays
- Integer to Float:

```
int n = 1;
float x,y;
x = float(n);
y = float(2);
```

Constructors

Concatenation:

```
float x = 1.0,y = 2.0;
vec2 v = vec2(x,y);
```

Structure initialization

```
struct S {int a; float b;};
S s = S(2, 3.5);
```

Swizzle operators

Use to select a set of components from a vector

Can be used in L-values

```
vec2 u,v;
v.x = 2.0;          // Assignment to single
                    // component
float a = v.x;      // Component selection
v.xy = u.yx;        // swap components
v = v.xx;           // replicate components
v.xx = u;           // Error
```

Component sets: Use one of

`xyzw` OR `rgba` OR `stpq`

Indexing operator

Indexing operator

```
 vec4 u,v;
 float x = u[0]; // equivalent to u.x
```

Must use indexing operator for matrices

```
mat4 m
vec4 v = m[0];
m.x; // error
```

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GLSL ES Overview

Operators

```
++  --  +  -  ! () []
*  /  +  -
<  <=  >  >=
==  !=
&&  ^^  ||
?:
=  *=  /=  +=  -=
```

Flow control

```
x == y ? a : b
if else
for while do
return break continue
```

`discard` (fragment shader only)

Built-in Variables

Aim of ES is to reduce the amount of fixed functionality

- Ideal would be a totally pure programmable model
- But still need some

Vertex shader

```
vec4    gl_Position;   // Write-only
float   gl_PointSize;  // Write-only
```

Fragment shader

```
vec4    gl_FragCoord;  // Read-only
bool    gl_FrontFacing;// Read-only
vec2    gl_PointCoord; // Read-only
float   gl_FragColor;  // Write only
```

Built-in Functions

General

```
pow, exp2, log2, sqrt, inversesqrt
abs, sign, floor, ceil, fract, mod,
min, max, clamp
```

Trig functions

```
radians, degrees, sin, cos, tan,
asin, acos, atan
```

Geometric

```
length, distance, cross, dot, normalize,
faceForward, reflect, refract
```

GLSL ES Overview

Interpolations

```
mix(x,y,alpha)
    x*( 1.0-alpha) + y*alpha)
step(edge,x)
    x <= edge ? 0.0 : 1.0
smoothstep(edge0,edge1,x)
    t = (x-edge0)/(edge1-edge0);
    t = clamp( t, 0.0, 1.0);
    return t*t*(3.0-2.0*t);
```

Texture

```
texture1D, texture2D, texture3D, textureCube
texture1DProj, texture2DProj, textureCubeProj
```

GLSL ES Overview

Vector comparison (`vecn`, `ivecn`)

```
bvecn lessThan(vecn, vecn)
bvecn lessThanEqual(vecn, vecn)
bvecn greaterThan(vecn, vecn)
bvecn greaterThanEqual(vecn, vecn)
```

Vector comparison (`vecn`, `ivecn`, `bvecn`)

```
bvecn equal(vecn, vecn)
bvecn notEqual(vecn, vecn)
```

Vector (`bvecn`)

```
bvecn any(bvecn)
bvecn all(bvecn)
bvecn not(bvecn)
```

Matrix

```
matrixCompMult (matn, matn)
```

Invariance

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Invariance

Definition:

“An invariant operation is an operation that, given the same set of inputs, always produces the same result.”

So why might this not be true?

Invariance: The Problem

Causes of variance:

- Mathematical operations are not precisely defined.
  - No IEEE arithmetic
- User has limited control over the driver/compiler
  - Compilers ‘cheat’ a bit to get better performance e.g.

```
a + b + c + d  -->  (a+b) + (c+d)
```

Mathematically correct but in floating point can give different a result

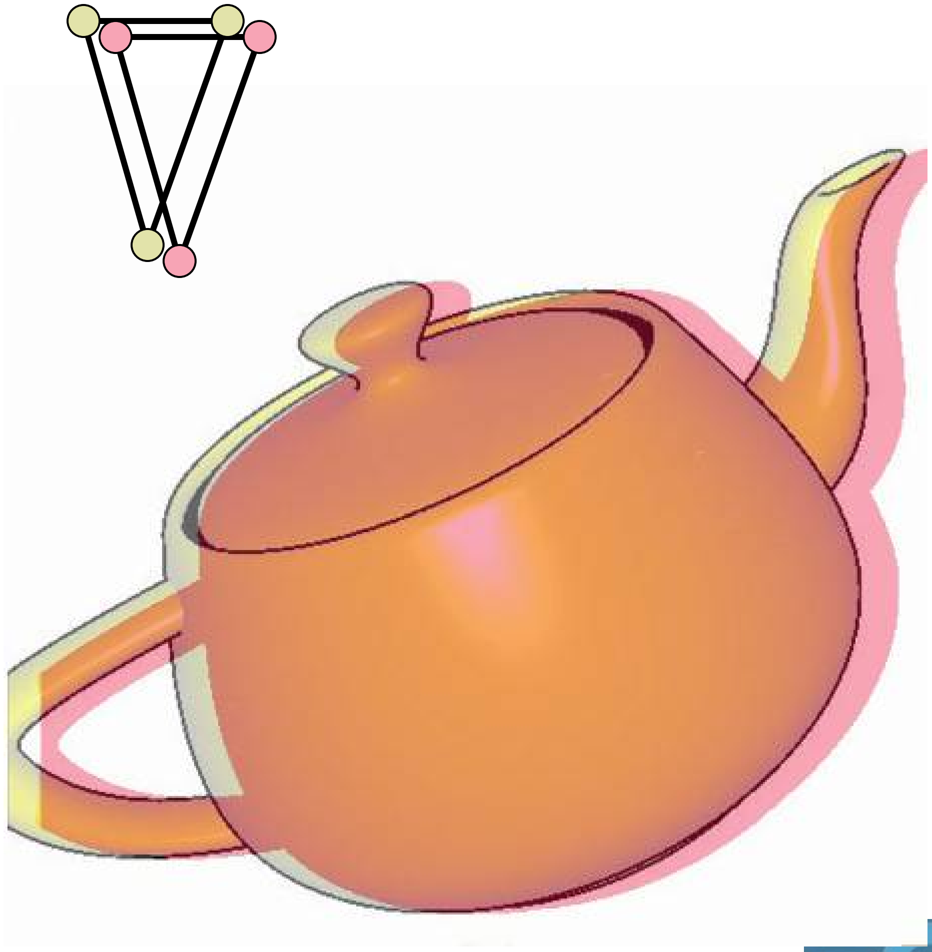
Consequence:

- Same code may produce (slightly) different results

Invariance

Why do you care?

- Multi-pass
- Any algorithm relying on repeatable calculations
- Any algorithm relying on a value remaining constant



Invariance

Consider a simple transform in the vertex shader:

$$\begin{pmatrix} x' \\ y' \\ z' \\ w' \end{pmatrix} = \begin{pmatrix} a & b & c & d \\ e & f & g & h \\ i & j & k & l \\ m & n & o & p \end{pmatrix} \begin{pmatrix} x \\ y \\ z \\ w \end{pmatrix}$$

x' = ax + by + cz + dw

But how is this calculated in practice?

- There may be several possible code sequences

Invariance

e.g.

```
MUL R1, a, x
MUL R2, b, y
MUL R3, c, z
MUL R4, d, w
ADD R1, R1, R2
ADD R3, R3, R4
ADD R1, R1, R3
```

or

```
MUL R1, a, x
MADD R1, b, y
MADD R1, c, z
MADD R1, d, w
```

Invariance

Three reasons the result may differ:

- Use of different instructions
- Instructions executed in a different order
- Different precisions used for intermediate results (only minimum precisions are defined)

But it gets worse...

Invariance

Modern compilers may rearrange your code
- Values may lose precision when written to a register
- Sometimes cheaper to recalculate a value
  - But will it be calculated the same way?

```
const vec2 pos = a + b * c;      // Done once
                                 // or twice?

vec4 col1 = texture2D(tex1, pos);
...
vec4 col2 = texture2D(tex2, pos); // does pos have
                                  // the same value
                                  // as before?

gl_FragColor = col1 – col2;       //
```

Invariance

Solution is in two parts:

- invariant keyword specifies that specific variables are invariant e.g.

```
invariant varying vec3 LightPosition;
```

  Currently can only be used on certain variables

- Global switch to make all variable invariant

```
#pragma STDGL invariant(all)
```

Invariance

Invariance flag controls:

- Invariance within shaders
- Invariance between shaders.

Usage

- Turn on invariance to make programs ‘safe’ and easier to debug
- Turn off invariance to get the maximum optimization from the compiler.

ES2.0 Example:

The Application Framework

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Writing an application – Basic Steps

Set up EGL

Setup shader, pipeline state

Create vertex buffers, textures

Main loop
- Update state (transforms etc.)
- Bind
- Draw

Writing an App – Initialization

- EGL
  - Get EGL display
  - EGL Initialization
  - Choose EGL config options using an attribute list
  - Create window surface
  - Create EGL context and attach to surface
- GL ES
  - Compile and Link shaders
  - Create and bind Textures
  - Bind (or get) attributes
  - Set up uniforms
  - Create Vertex Buffers
  - Map buffer data

Writing an App – EGL Initialization

```
EGLDisplay egl_display =
eglGetDisplay(EGL_DEFAULT_DISPLAY);


int ok = eglInitialize(egl_display,
                  &majorVersion,
             &minorVersion)
```

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EGL Initialization

Set up attributes for EGL context

```
EGLint attr[MAX_EGL_ATTRIBUTES];

attr[nAttrib++] = EGL_RED_SIZE;
attr[nAttrib++] = 5;
...
attrib[nAttrib++] = EGL_DEPTH_SIZE;
attrib[nAttrib++] = 16;
attrib[nAttrib++] = EGL_STENCIL_SIZE;
attrib[nAttrib++] = 0;
...
```

EGL Initialization (cont)

```
eglChooseConfig(egl_display,
          attrib_list,
          &egl_config,  // returned configs
          1,            // max no. of configs
          &num_configs)

eglCreateWindowSurface(egl_display,
                 egl_config,
                 NativeWindowType (hWnd),
                 NULL)
```

EGL Initialization: Creating a context

```
context = eglCreateContext(egl_display,
                           egl_config,
                           EGL_NO_CONTEXT,
                           NULL);

eglMakeCurrent(egl_display,
         egl_surface,  // for  draw
         egl_surface,  // for read
         egl_context);
```

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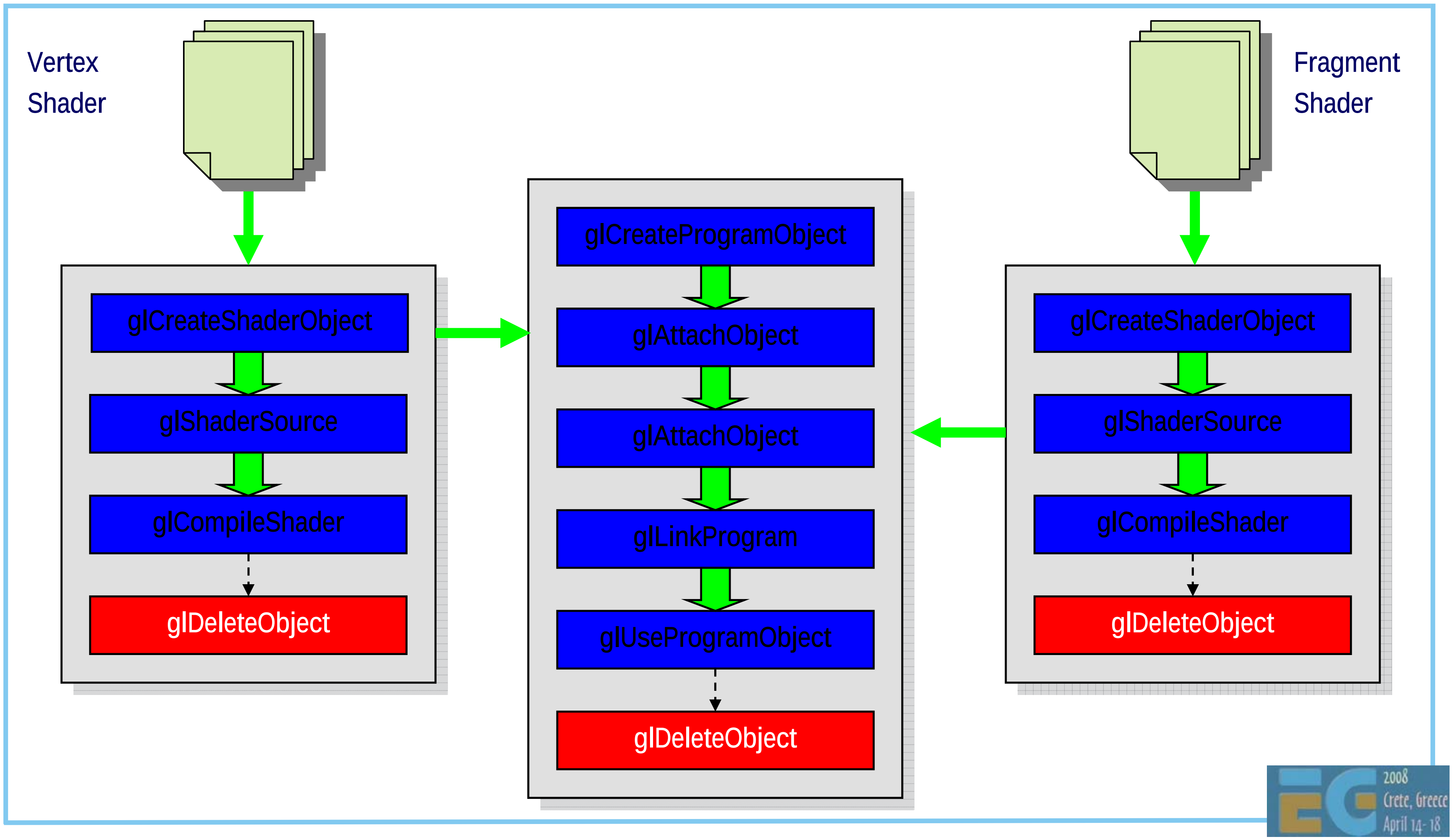
Compiling and using shaders



Compiling and Linking Shaders

Create objects

```
program_handle = glCreateProgram();

// Create one shader of object of each type.

GLuint vertex_shader_handle
      = glCreateShader (GL_VERTEX_SHADER);

GLuint fragment_shader_handle
      = glCreateShader (GL_FRAGMENT_SHADER);
```

Compiling Shaders

Compile vertex shader (and fragment shader)

```
char* vert_source = ...

const char* vert_gls[1] = {vert_source};

glShaderSource(vertex_shader_handle,
               1,                  // no. of strings
               vert_gls,
               NULL );

glCompileShader(vertex_shader_handle);

GLint vertCompilationResult = 0;

glGetShaderiv(vertex_shader_handle,
              GL_COMPILE_STATUS,
              &vertCompilationResult);
```

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Linking Shaders

Attach shaders to program object and link

```
glAttachShader(program_handle,
                   vertex_shader_handle);
glAttachShader(program_handle,
                   fragment_shader_handle);
glLinkProgram (program_handle);
```

Note that many compilers will only report errors at link time.

Setting up Attributes

Can bind attributes before linking e.g.

```
glBindAttribLocation (prog_handle, 0, “pos");
```

Or get attribute location after linking:

```
GLint p;
p = glGetAttribLocation (prog_handle, “pos");
```

Can do a combination.

Setting up Textures

Texture samplers are ***Uniforms*** in GLSL ES

First Generate ID and specify type (cube map)

```
uint32 Id;
glGenTextures(1, &Id);
glActiveTexture (GL_TEXTURE0);
glBindTexture(GL_TEXTURE_CUBE_MAP, Id);
```

Setting up Textures (cont)

```
glTexImage2D(GL_TEXTURE_CUBE_MAP_POSITIVE_X,
             0,
             GL_RGBA,
             width,
             height,
             0,
             GL_RGBA,
             GL_UNSIGNED_BYTE,
             image [0].pixels);

glTexImage2D(GL_TEXTURE_CUBE_MAP_NEGATIVE_X, ...
glTexImage2D(GL_TEXTURE_CUBE_MAP_POSITIVE_Y, ...
glTexImage2D(GL_TEXTURE_CUBE_MAP_NEGATIVE_Y, ...
glTexImage2D(GL_TEXTURE_CUBE_MAP_POSITIVE_Z, ...
glTexImage2D(GL_TEXTURE_CUBE_MAP_NEGATIVE_Z, ...
```

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Setting up Uniforms

Must do this after glUseProgram:

```
glUseProgram(prog_handle);
```

Use glGetUniformLocation e.g.

```
GLint loc_sky_box =
      glGetUniformLocation (prog_handle,"skyBox“);
```

Can then set value e.g.

```
GLint texture_unit = 0;
    glUniform1i (loc_sky_box,texture_unit);
```

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Setting up Attribute Buffers

Create buffer names

```
GLuint bufs[1];
glGenBuffers (1, bufs);
```

Create and initialize buffer

```
glBindBuffer (GL_ARRAY_BUFFER, bufs[0]);
glBufferData (GL_ARRAY_BUFFER,
  size_bytes, p_data, GL_STATIC_DRAW);
```

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Setting up Attribute Buffers (cont)

Specify format:

```
glBindBuffer(GL_ARRAY_BUFFER, bufs[0]);

glVertexAttribPointer(0,        // index
                      4,        // size
                      GL_FLOAT, // type
                      GL_FALSE, // normalize?
                      0,        // (stride)
                      NULL );   // (attribs)
```

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Drawing the frame

Clear frame buffer
Set render state
Enable array
DrawArray

Drawing

Enable array and Draw

```
glEnableVertexAttribArray( 0 );

glBindBuffer (GL_ARRAY_BUFFER,0);

glDrawArrays (GL_TRIANGLE_STRIP,0, n_vertices);
```

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ES2.0 Example

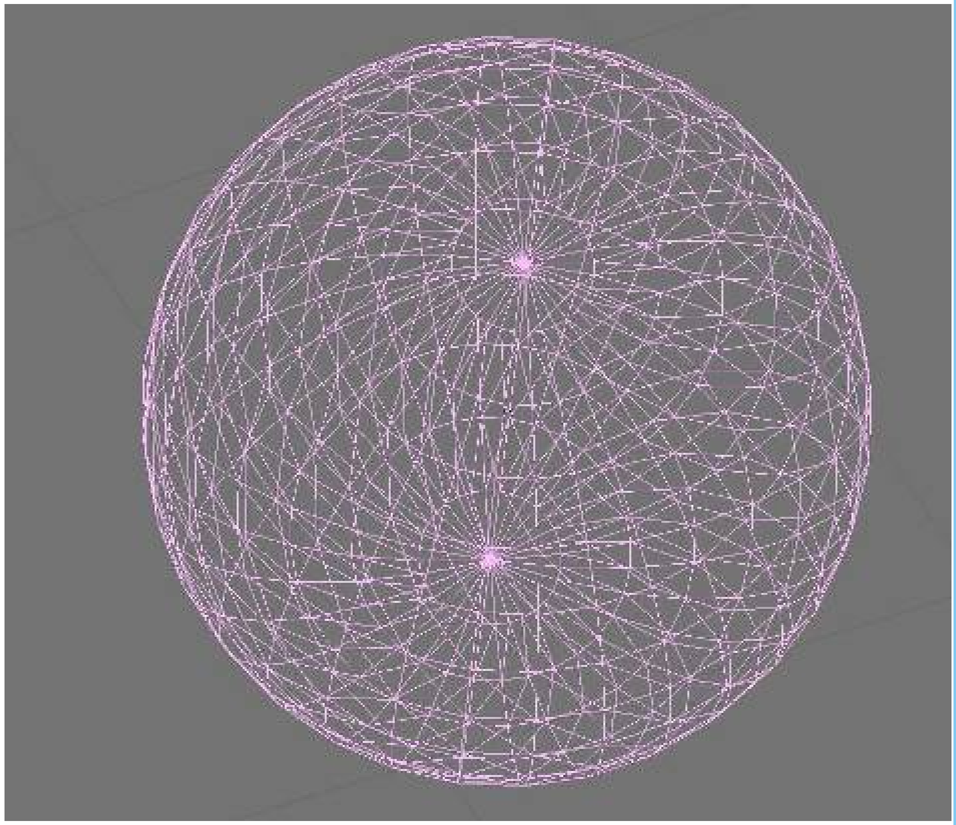
- The shaders

Example: Water demo

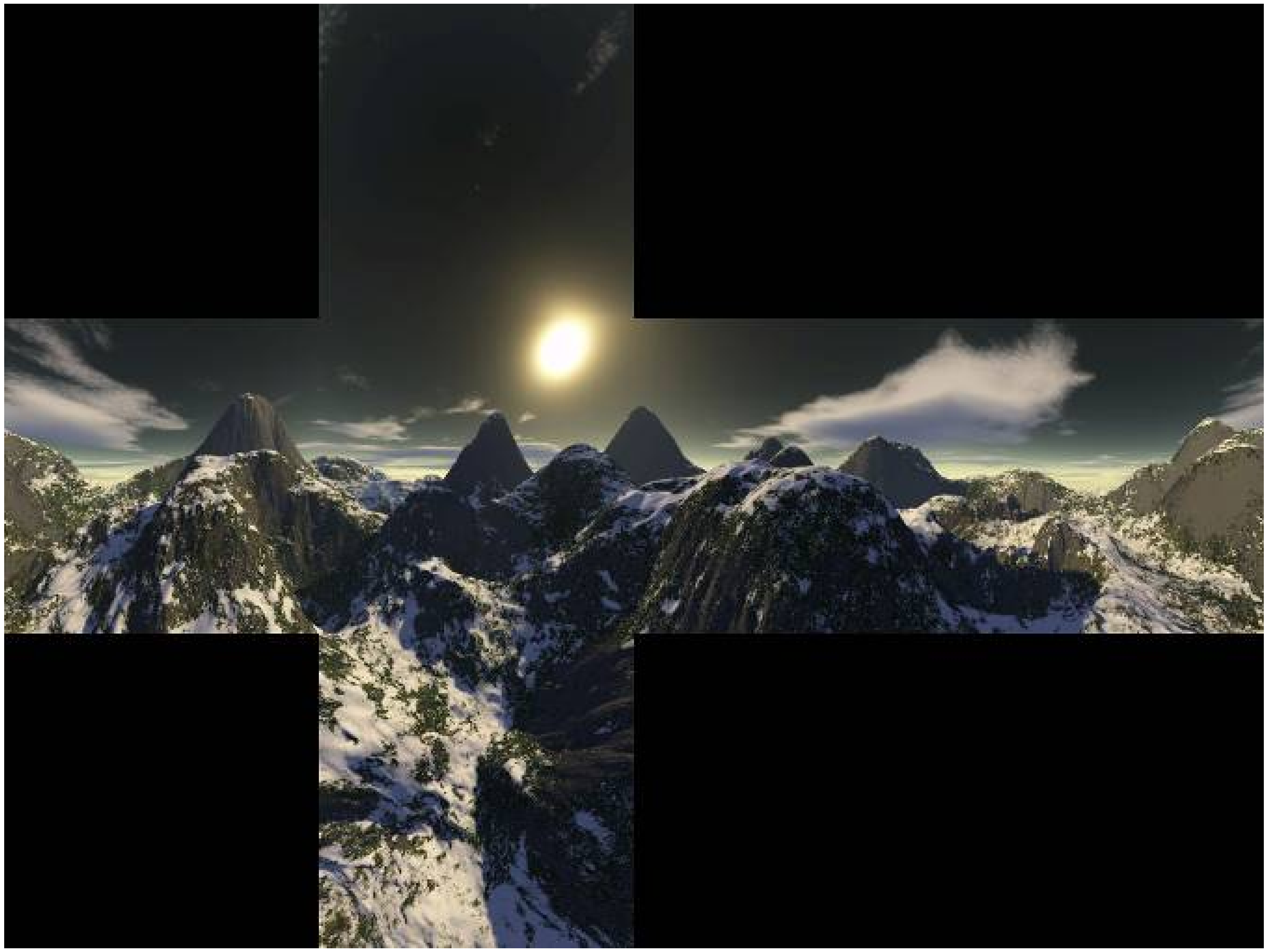
Skybox

Geometry is a sphere

Use position to access a cube map

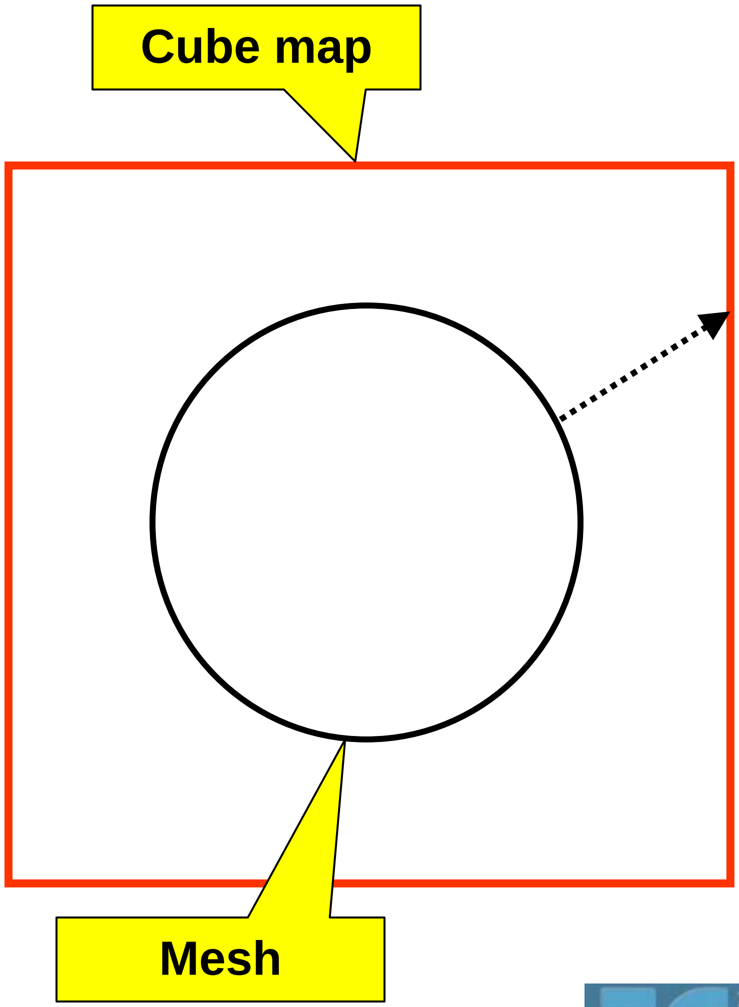


Cube Map



Skybox

Access cube map using the normals of the vertices

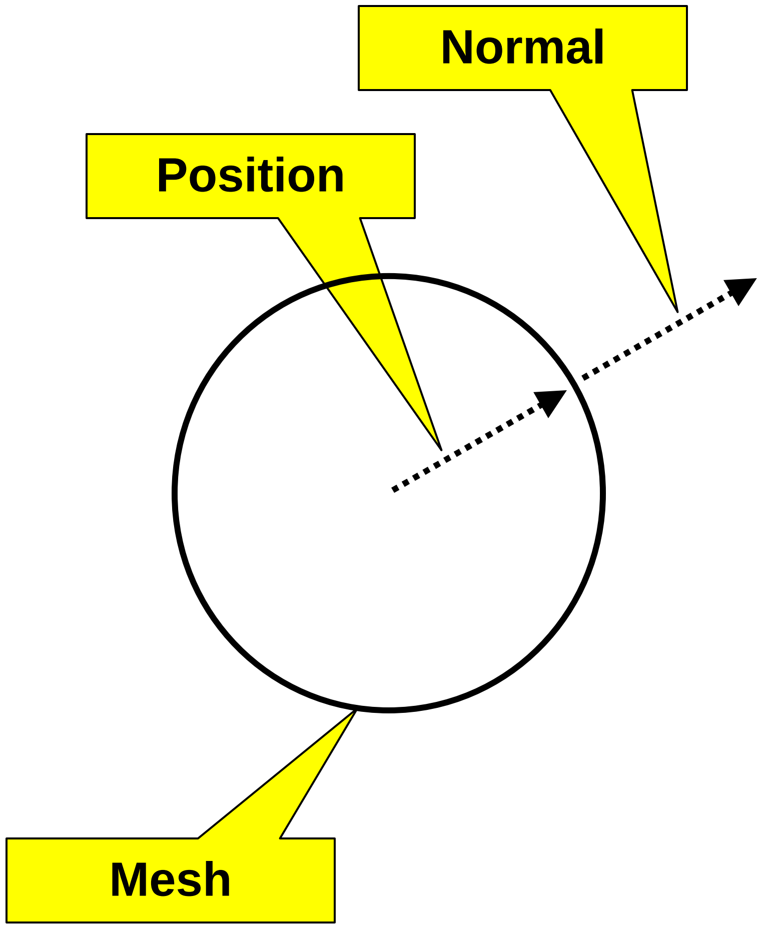


Skybox

But...

Normal = Position

So no need to generate and store separate normals



Sky box: Vertex shader

```
uniform mat4 view_proj_matrix;
uniform vec4 view_position;
attribute vec4 rm_Vertex;
varying vec3 vTexCoord;
void main(void)
{
   vec4 newPos = vec4(1.0);
   newPos.xyz  = rm_Vertex.xyz + view_position.xyz;
   gl_Position = view_proj_matrix * vec4(newPos.xyz,1.0);
   vTexCoord = rm_Vertex.xyz;
}
```

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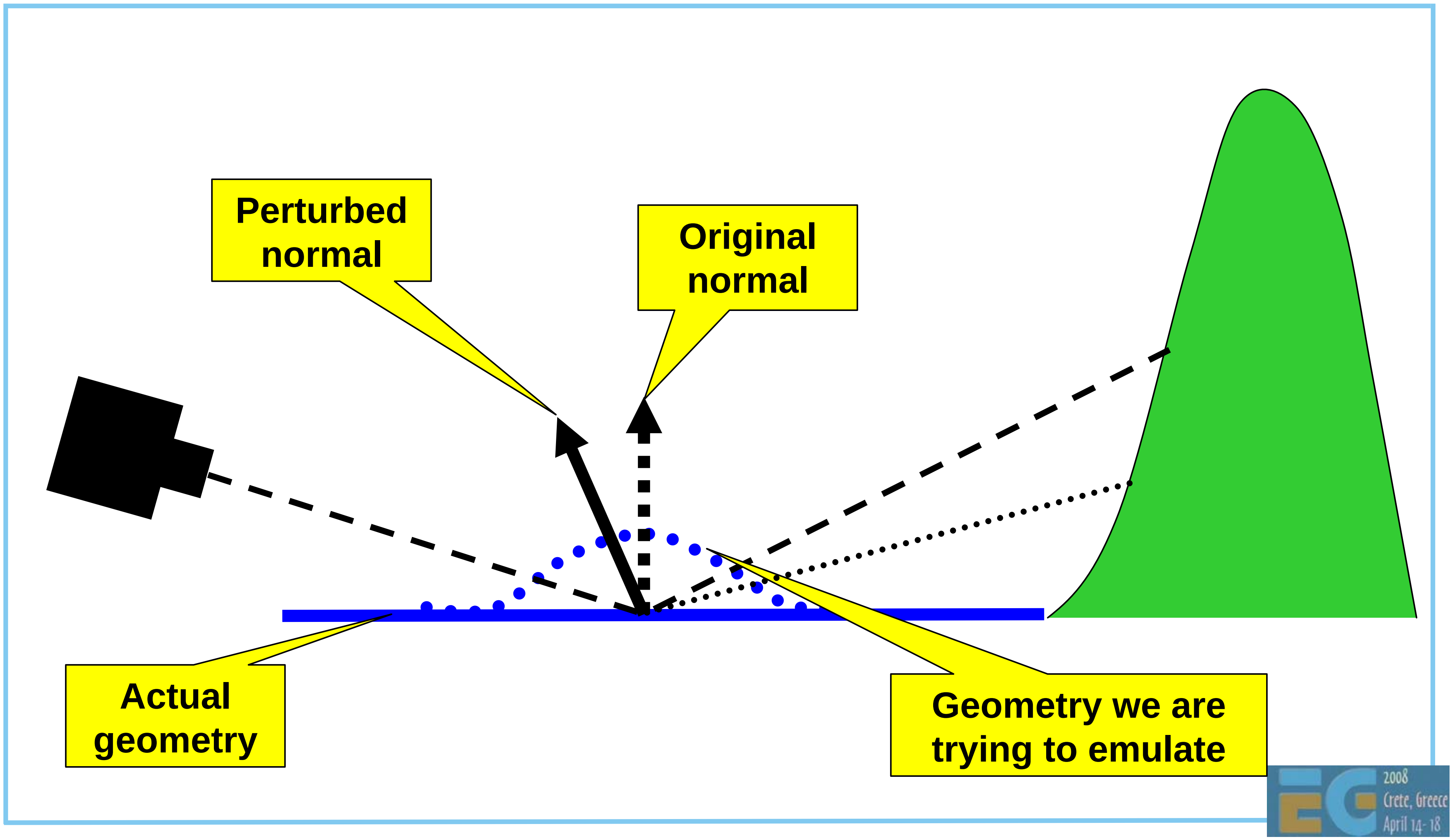
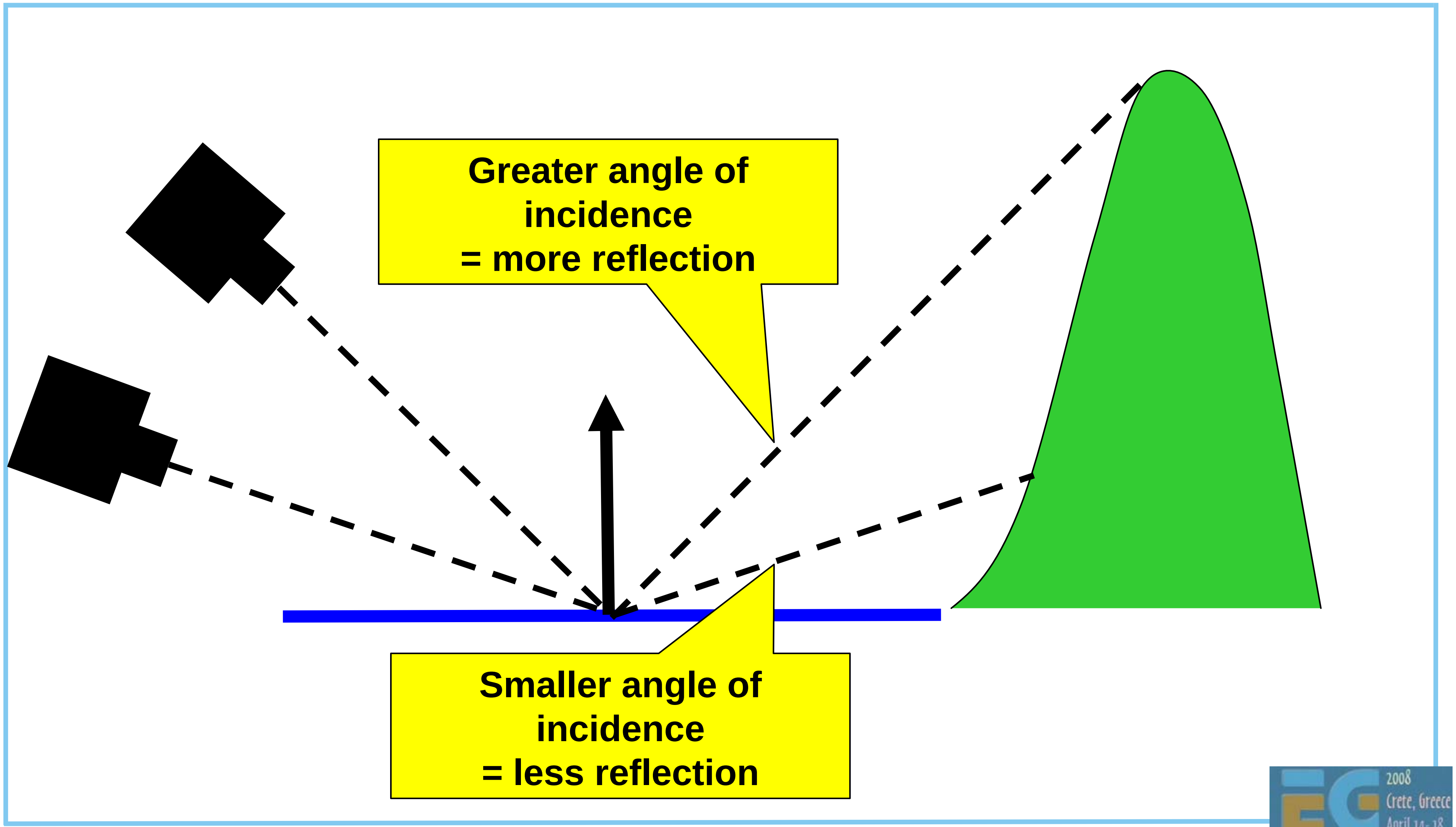
Sky box: Fragment Shader

```
precision highp float;
uniform samplerCube skyBox;
varying vec3 vTexCoord;
void main(void)
{
  gl_FragColor = textureCube(skyBox,vTexCoord);
}
```

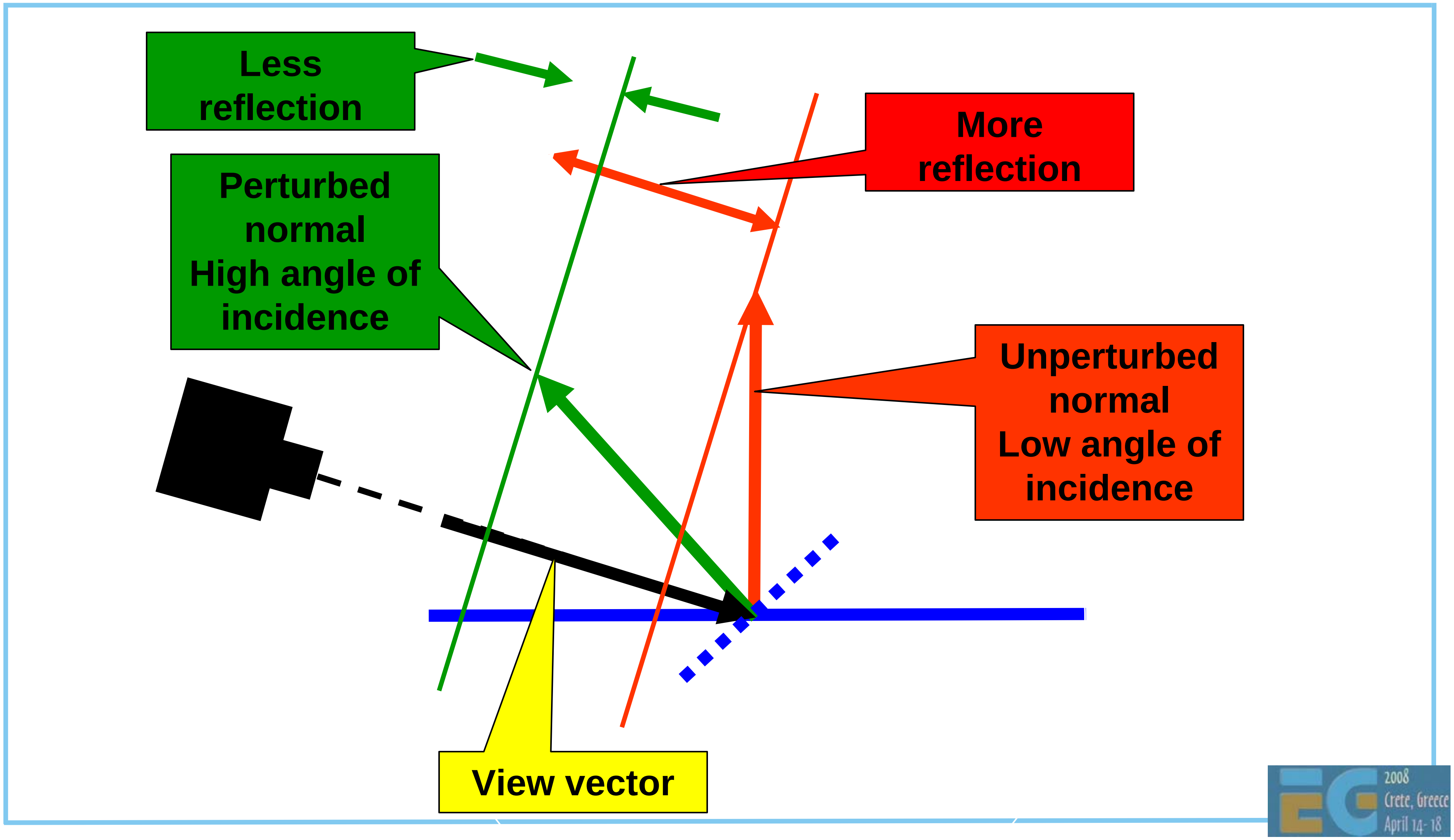
Water: Reflection Mapping



Approximating Fresnel Reflection



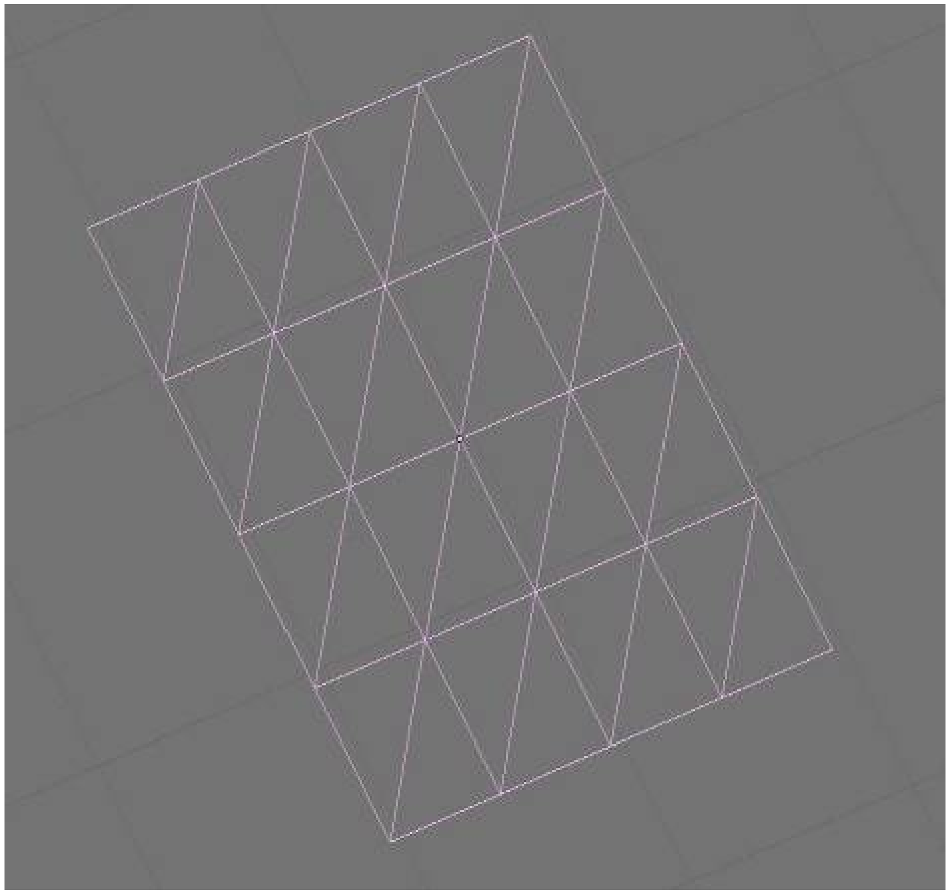
Fresnel Reflection (cont.)


Less reflection
More reflection
Perturbed normal High angle of incidence
Unperturbed normal Low angle of incidence
View vector

Water

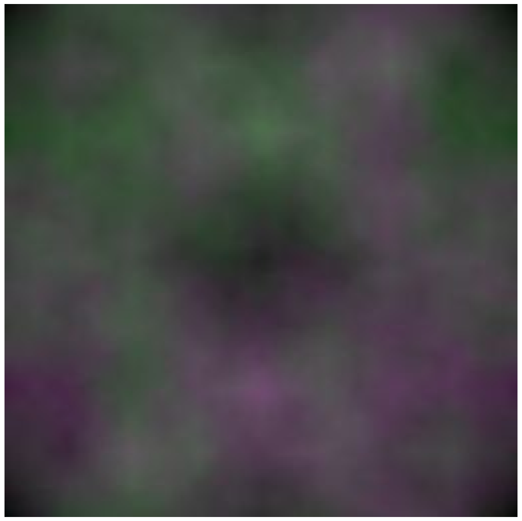
Geometry is a simple grid

Uses the same cubemap as the skybox



Water Ripples

- Use noise texture for bump map.
- Exact texture not important
  - Try experimenting



Water: Vertex Shader

```
uniform vec4 view_position;
uniform vec4 scale;
uniform mat4 view_proj_matrix;
attribute vec4 rm_Vertex;
attribute vec3 rm_Normal;
varying vec2 vTexCoord;
varying vec3 vNormal;
varying vec3 view_vec;
```

Water: Vertex Shader (cont)

```
void main(void)
{
  vec4 Position = rm_Vertex.xyzw;
  Position.xz *= 1000.0;
  vTexCoord   = Position.xz * scale.xz;
  view_vec    = Position.xyz - view_position.xyz;
  vNormal     = rm_Normal;
  gl_Position = view_proj_matrix * Position;
}
```

Water: Fragment Shader

```
uniform sampler2D noise;
uniform samplerCube skyBox;
uniform float time_0_X;
uniform vec4  waterColor;
uniform float fadeExp;
uniform float fadeBias;
uniform vec4  scale;
uniform float waveSpeed;
varying vec2 vTexCoord;
varying vec3 vNormal;
varying vec3 vViewVec;
```

Water Fragment Shader (cont)

```
void main(void)
{
   vec2 tcoord = vTexCoord;
   tcoord.x += waveSpeed  * time_0_X;
   vec4 noisy = texture2D(noise, tcoord.xy);
   // Signed noise
   vec3 bump = 2.0 * noisy.xyz - 1.0;
   bump.xy *= 0.15;

   // Make sure the normal always points upwards
   bump.z = 0.8 * abs(bump.z) + 0.2;
```

Water Fragment Shader (cont)

```
// Offset the surface normal with the bump
bump = normalize(vNormal + bump);

// Find the reflection vector
vec3 reflVec = reflect(vViewVec, bump);
vec4 refl = textureCube(skyBox, reflVec.yzx);
```

Water Fragment Shader (cont)

```
  float lrp = 1.0 - dot(-normalize(vViewVec), bump);


  // Interpolate between the water color and
  // reflection
  float blend = fadeBias + pow(lrp, fadeExp);
  blend = clamp(blend ,0.0, 1.0);
  gl_FragColor = mix(waterColor, refl, blend);
}
```

Programming Tips

Programming Tips

Check for errors regularly

Use e.g.

```
assert(!glError ());
```

But remember glError () gets the last error:

```
... // error here
Glint error = glError ();
...
assert(!glError ()); // No error
```

The coordinate system

Coordinate system is:

Right handed before projection

Increasing z is towards the viewer.

Left handed after projection

Increasing z is away from the viewer.

Matrix Convention

- Matrices are column-major
  - column index varies more slowly
- Vectors are columns
- But this is purely convention
- Only the position in memory is important
  - Translation specified in elements 12,13,14

The projection matrix

You need to provide a projection matrix e.g.

$$\begin{bmatrix} \frac{2.0*near}{right-left} & 0.0 & \frac{right+left}{right-left} & 0.0 \\ 0.0 & \frac{2.0*near}{top-bottom} & \frac{top+bottom}{top-bottom} & 0.0 \\ 0.0 & 0.0 & \frac{-(far+near)}{far-near} & \frac{-2.0*far*near}{far-near} \\ 0.0 & 0.0 & -1.0 & 0.0 \end{bmatrix}$$

near and far are both *positive*

Performance Tips

- Keep fragment shaders simple
  - Fragment shader hardware is expensive.
  - Early implementations will not have good performance with complex shaders.
- Try to avoid using textures for function lookups.
  - Calculation is quite cheap, accessing textures is expensive.
  - This is more important with embedded devices.

Performance Tips (cont)

- Minimize register usage
  - Embedded devices do not support the same number of registers compared with desktop devices. Spilling registers to memory is expensive.
- Minimize the number of shader changes
  - Shaders contain a lot of state
  - May require the pipeline to be flushed
  - Use uniforms to change behaviour in preference to loading a new shader.

ES vs. Desktop

GLSL ES vs. GLSL desktop

- Based on GLSL as used in OpenGL 2.0
  - Open standard
- Pure programmable model
  - Most fixed functionality removed.
- Not 100% backward compatible with ES1.x
  - Embedded systems do not have the legacy requirements of the desktop
- No Software Fallback
  - Implementations (usually) hardware or nothing
  - Running graphics routines in software doesn’t make sense on embedded platforms
- Optimized for use in Embedded devices
  - Aim is to reduce silicon cost
  - Reduced shader program sizes
  - Reduced register usage
  - Reduced numeric precision

Mobile Architecture

CPU, graphics on the same chip.

Unified memory architecture

Cache for CPU

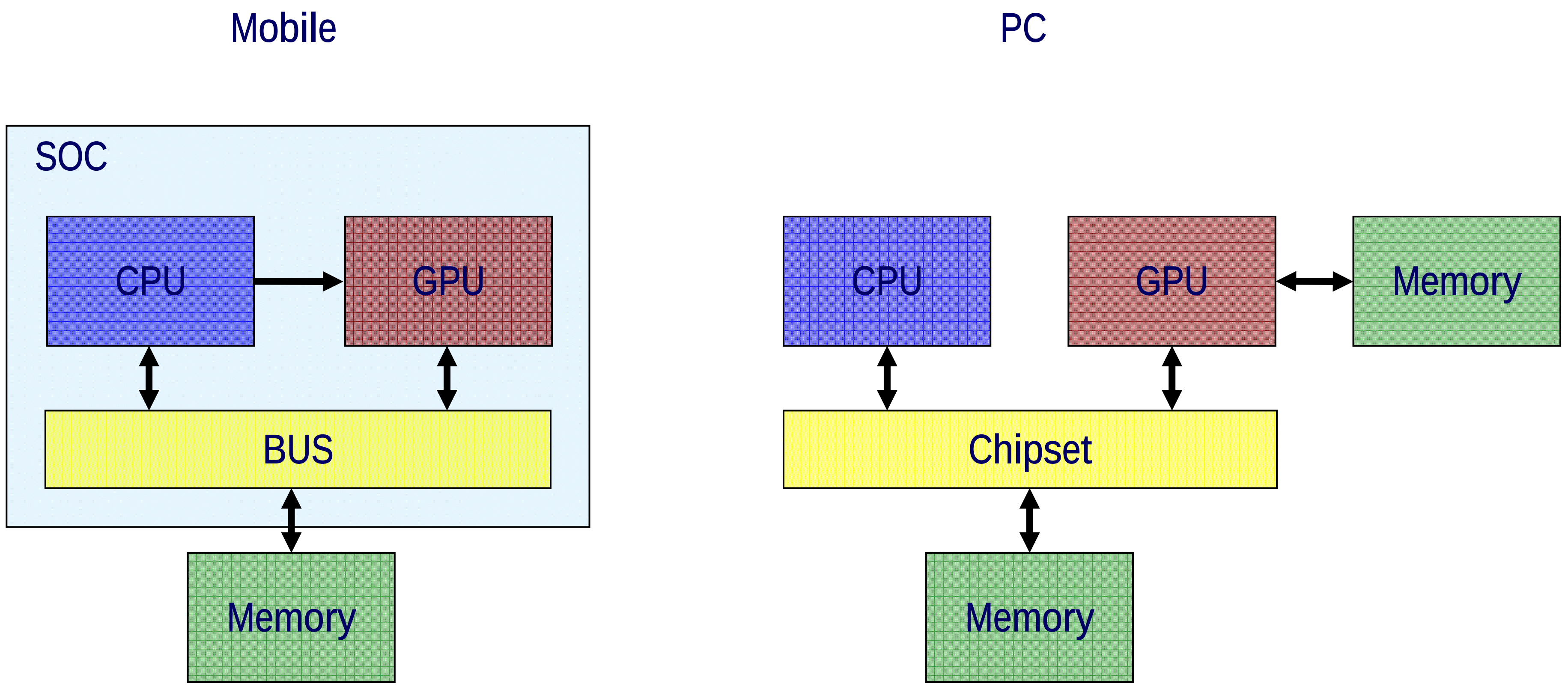
Only limited cache for graphics device

No internal framebuffer

No internal z buffer

Limited texture cache

Mobile vs. PC Architecture



Mobile Architecture – What this means

- Limited memory bandwidth
  - Hardware number crunching is relatively cheap
  - Moving data around is the main problem
  - Frame buffer access (or geometry buffer access for tiled architectures) is a heavy user
  - Texture bandwidth is an issue
- CPU cannot perform floating point
  - Rather different from the PC world
  - Means more rapid move to hardware vertex shaders
- Any advantages?
  - Lower resolution means less data to move around
  - Easier to access frame/depth buffer because of unified memory

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Performance Tips

Tips for Improving Performance

Golden rules:

Don’t do things you don’t need to do

Let the hardware do as much as possible

Don’t interrupt the pipeline

Minimize data transfer to and from the GPU

Don’t do what you don’t need to do

- What frame rate do you actually need?
  - Achieving 100fps on a PC may be a good thing
  - LCD displays have slower response
  - Eats power.
- Not using depth testing? Turn off the z buffer
  - Saves at least one read per pixel
- Not using alpha blending? Turn it off.
  - Saves reading the colour buffer.
- Not using textures? Don’t send texture coordinates to the GPU
  - Reduces geometry bandwidth

Let the hardware do it

Hardware is very good at doing computation

- Transform and lighting is fast
- Will become even more useful with vertex shaders
- Texture blending is ‘free’. Don’t use multi-pass.
- Anti-aliasing is very cheap.
- Hardware is good when streaming data
  - But works best when data is aligned with memory
  - Most efficient when large blocks are transferred
- BUT: Memory bandwidth is still in short supply

Minimize Data Transfer

Use Vertex Buffers

- Driver can optimize storage (alignment, format)

Reduce Vertex Size

- Use byte coordinates e.g. for normals

Reduce size of textures

- Textures cached but limited on-chip memory
- Use mip-mapping. Better quality and lower data transfer
- Use texture compression where available.

Memory Alignment

- Always best to align data
  - Alignment to bus width very important
  - Alignment to DRAM pages gives some benefit
- Embedded devices have different types of memory
  - Bus width may be 32 bit, 64 bit or 128 bit
- Penalty for crossing a DRAM page (typically 1-4KB)
  - Can be several cycles.

Batch Data

Why?

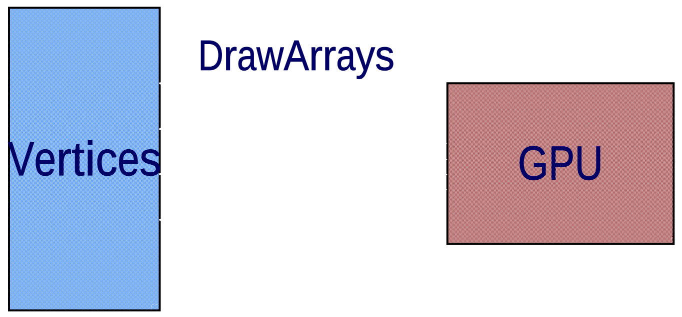
- Big overhead for interpreting the command and setting up a new transfer
- Memory latency large

How?

- Combine geometry into large arrays.
- Use Vertex Buffer Objects

Batch Data

Don’t:

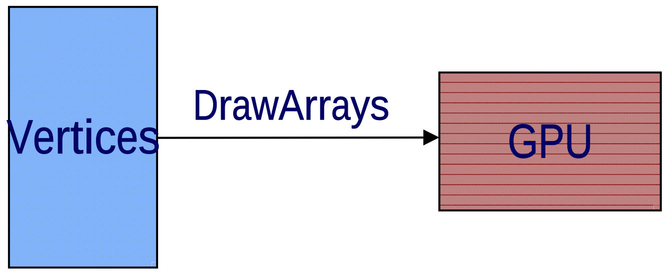


Multiple API calls

Lots of overhead

Slow

Do:



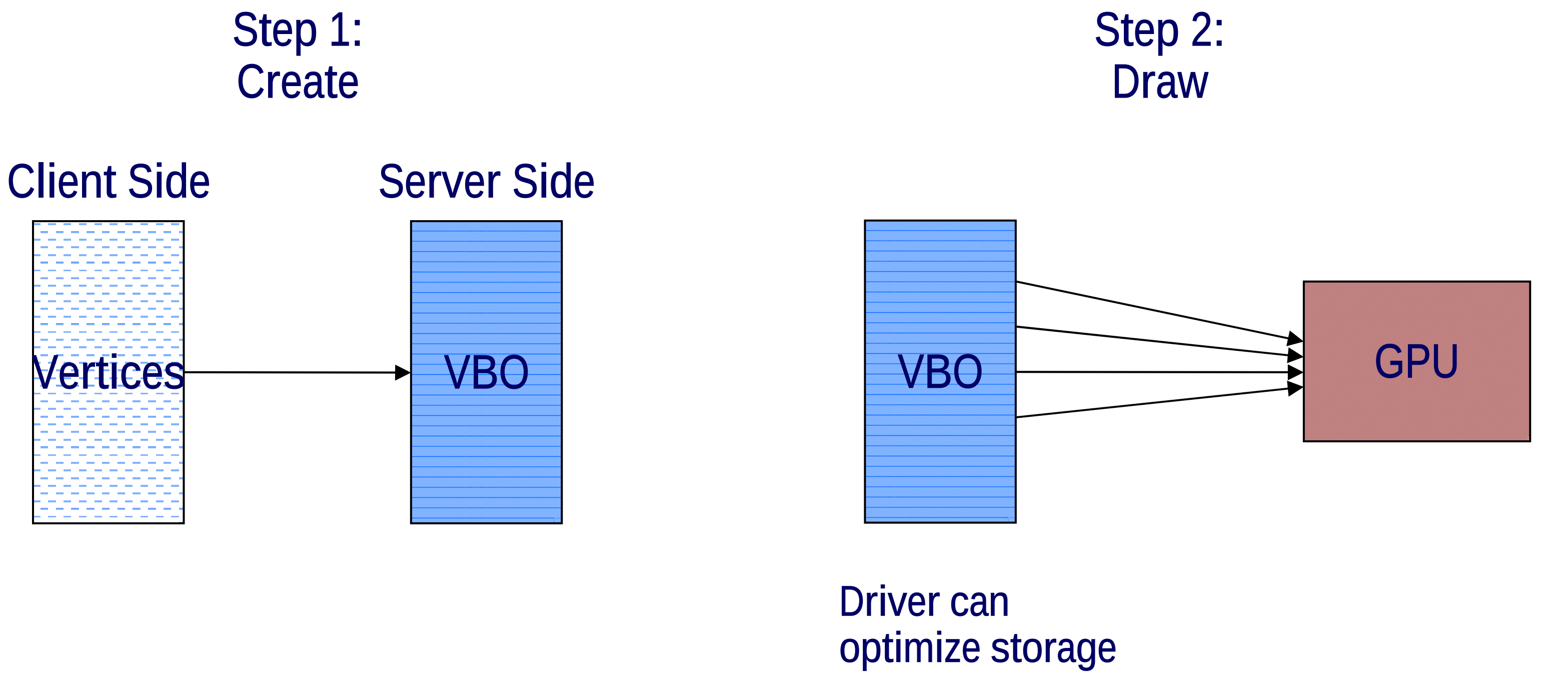
Fewer API calls

Less overhead

Much faster

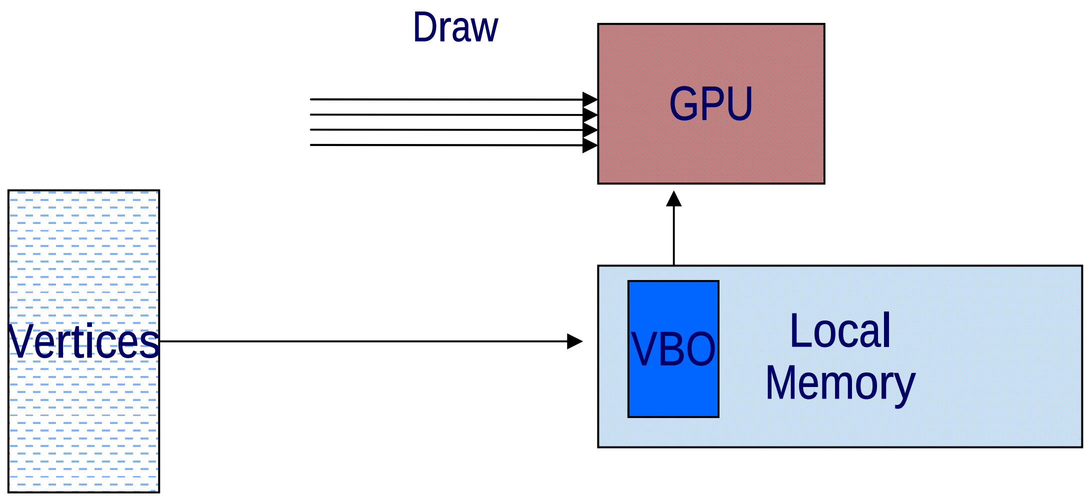
Vertex Buffer Objects

Even better:



Vertex Buffer Objects

Ultimately:



Don’t interrupt the pipeline

- GPUs are streaming architectures.

They have high bandwidth but also long latencies.

- Minimize state changes.
  - Set up state and then render as much as possible.
  - E.g. Don’t mix 2d and 3d operations
- Don’t lock buffers unnecessarily
  - OK at end of scene
- Don’t use GetState unnecessarily
  - Main usage is for 3rd party libraries. App should know what the state is.

All these can cause interruptions to data streaming.

- May even cause the entire pipeline to be flushed.

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More on State Changes

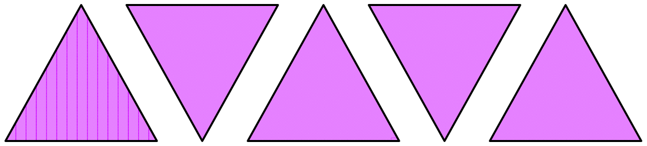
- Major changes of state will always be expensive
  - Changing textures (consider using a texture atlas)
  - Texture environment modes
  - Light types (e.g. turning on specular)
- Some are quite cheap
  - Turning individual lights on and off
  - Enabling/disabling depth buffer
- BUT
  - Varies with the hardware (and driver) implementation

Be nice to the Vertex Cache

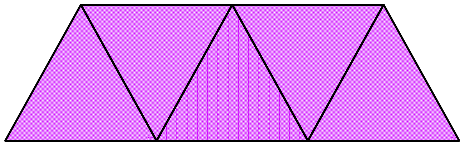
- Hardware typically holds 8-32 vertices.
  - Smaller than in software implementations
  - Likely to vary between implementations
  - Possible to trade no. of vertices against vertex size in some implementations
- Hardware cannot detect when two vertices are the same.
- To make efficient use of the cache use:
  - Vertex Strips
  - Vertex fans
  - Indexed triangles

Vertex Cache

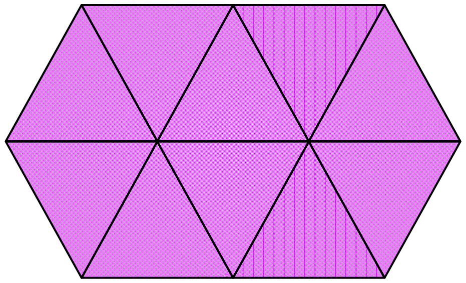
Individual triangles: 3 vertices/triangle



Vertex Strip: 1 vertex triangle (ideal case)



Indexed triangles: 0.5 vertices/triangle (ideal case)



Depth Complexity

- Drawing hidden triangles is expensive.
- Costs:
  - Transferring the geometry
  - Transform & lighting
  - Fetching texels for hidden pixels
  - Reading and writing the colour and depth buffer
  - Storing and reading the geometry (tiled or delay stream architectures)
- Deferred rendering is not a magic solution
  - Can even make matters worse in some situations

Depth Complexity - solutions

- Render scene front to back
  - Eliminates many writes to colour and depth buffer
  - Can reduce texture fetches (early z kill)
- Use standard occlusion culling techniques
  - View frustum culling (don’t draw objects that are out of view)
  - DPVS
  - Portals

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Future Trends

Future Trends

- More local caches for graphics hardware
- Display resolution increasing
  - More pixel pipelines
- Better power management
- Integration of other functionality
  - Video

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Questions?

M3G Intro

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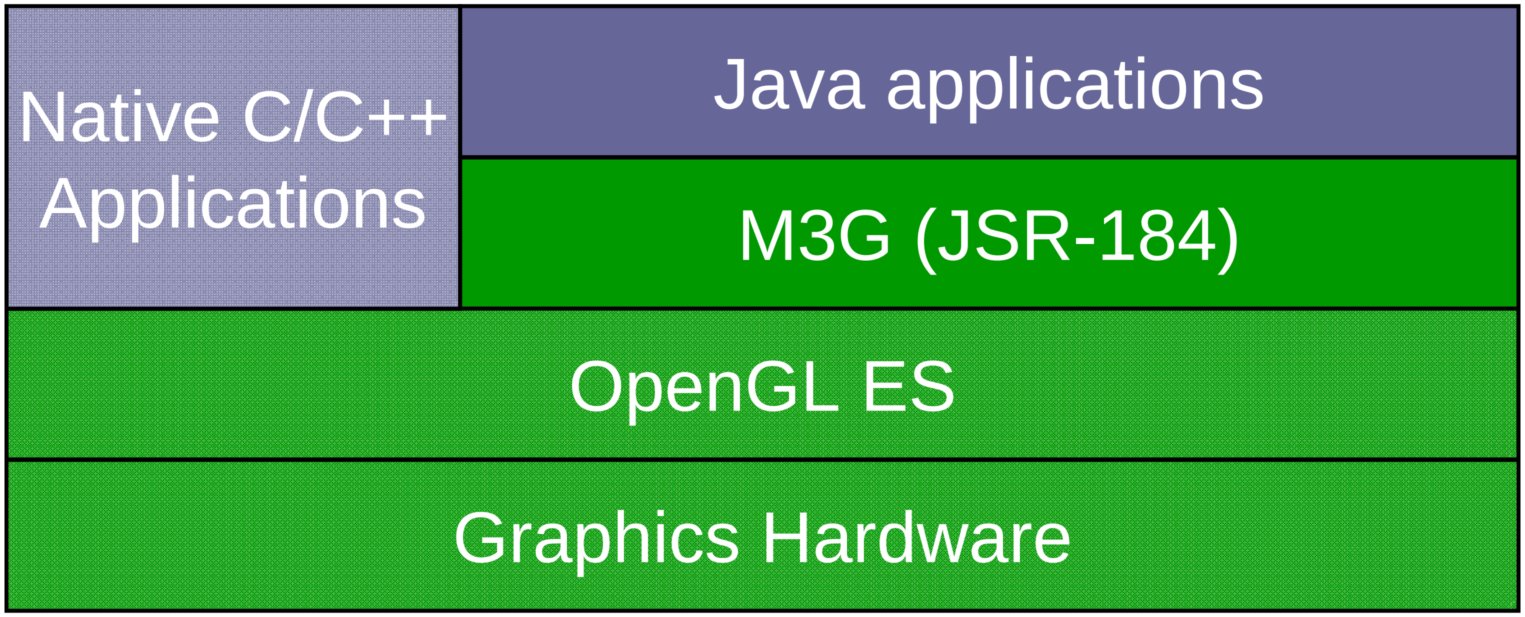
Kari Pulli

Nokia Research Center

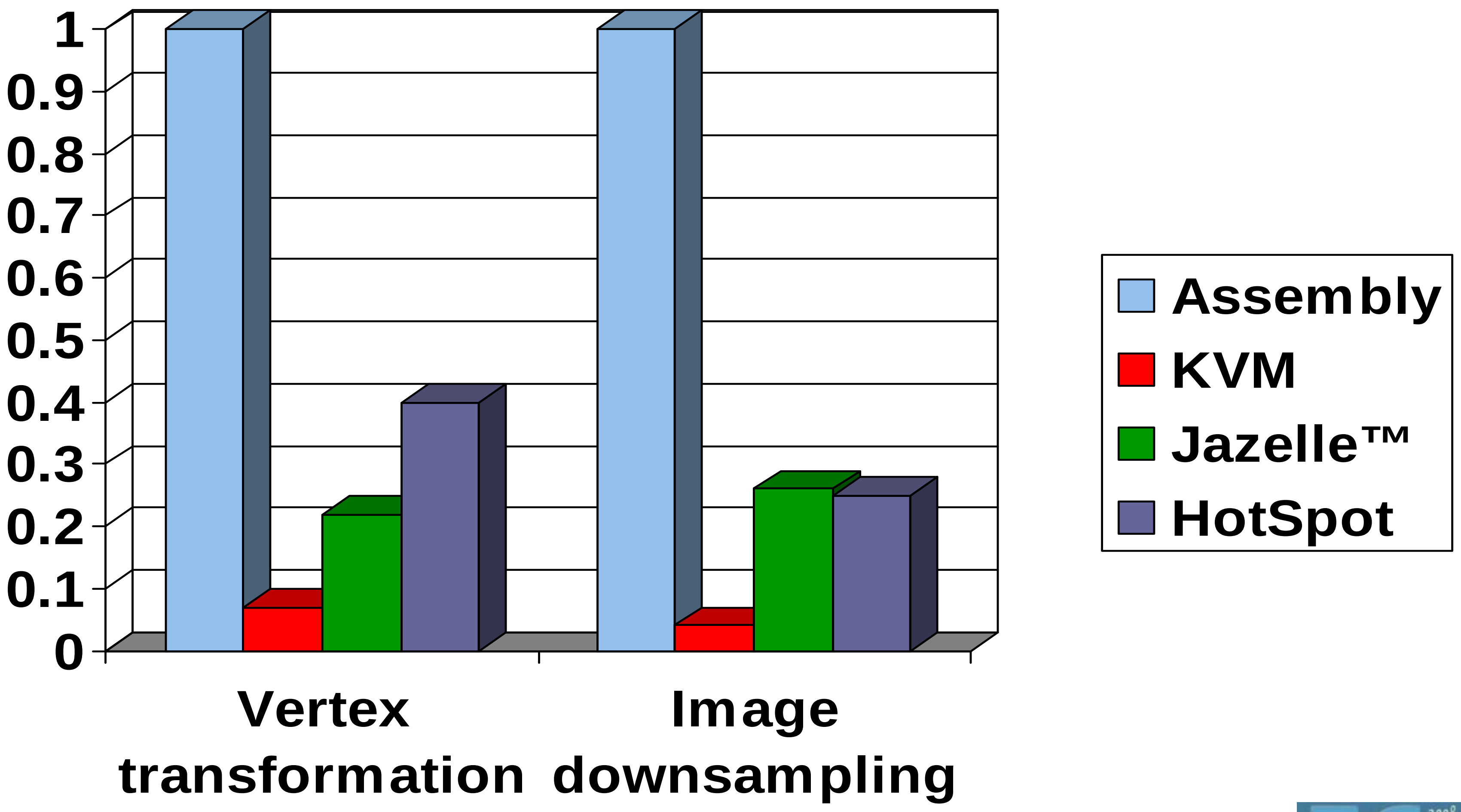
Mobile 3D Graphics APIs



Why Should You Use Java?

- Largest and fastest growing installed base
  - 1200M phones running Java by June 2006
  - The majority of phones sold today support Java
- Better productivity compared to C/C++
  - Much fewer opportunities to introduce bugs
  - Comprehensive, standardized class libraries

Java Will Remain Slower



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

M3G Design Principles

#1 **No Java code along critical paths**

Move all graphics processing to native code

- Not only rasterization and transformations
- Also morphing, skinning, and keyframe animation
- All data on native side to avoid Java-native traffic

M3G Design Principles

#2

Cater for both software and hardware

- Do not mandate hardware-only features
  - Such as per-pixel mipmapping or per-pixel fog
- Do not try to expand the OpenGL pipeline
  - Such as with hardcoded transparency shaders

M3G Design Principles

#3

Maximize developer productivity

- Address content creation and tool chain issues
  - Export art assets into a compressed file (.m3g)
  - Load and manipulate the content at run time
  - Need scene graph and animation support for that
- Minimize the amount of “boilerplate code”

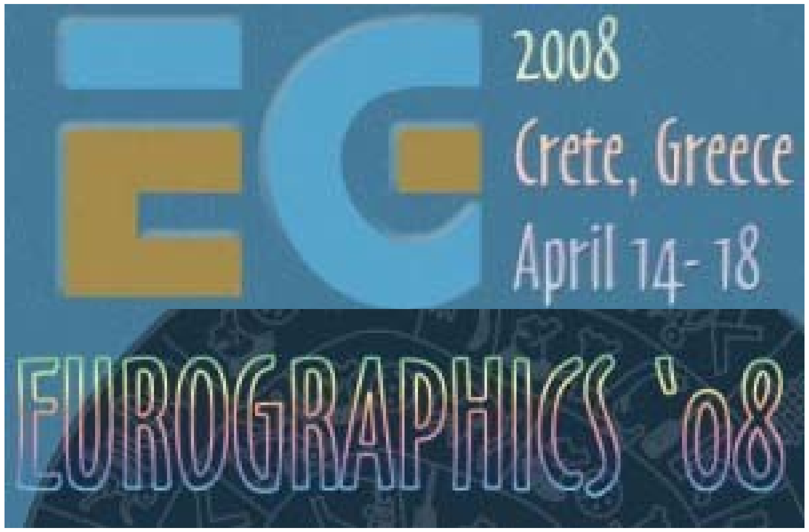
M3G Design Principles

#4	Minimize engine complexity
#5	Minimize fragmentation
#6	Plan for future expansion

Why a New Standard?

- OpenGL ES is too low-level
  - Lots of Java code and function calls needed
  - No support for animation and scene management
- Java 3D is too bloated
  - A hundred times larger (!) than M3G
  - Still lacks a file format, skinning, etc.

M3G API Overview



Tomi Aarnio

Nokia Research Center

Objectives

Get an idea of the API structure and features

Learn practical tricks not found in the spec

Prerequisites

Fundamentals of 3D graphics

Some knowledge of OpenGL ES

Some knowledge of scene graphs

M3G API Overview

Getting started

Rendering

Scene graph

Performance tips

Deformable meshes

Keyframe animation

Demos

Programming Model

M3G is not an “extensible scene graph”

Rather a black box – much like OpenGL

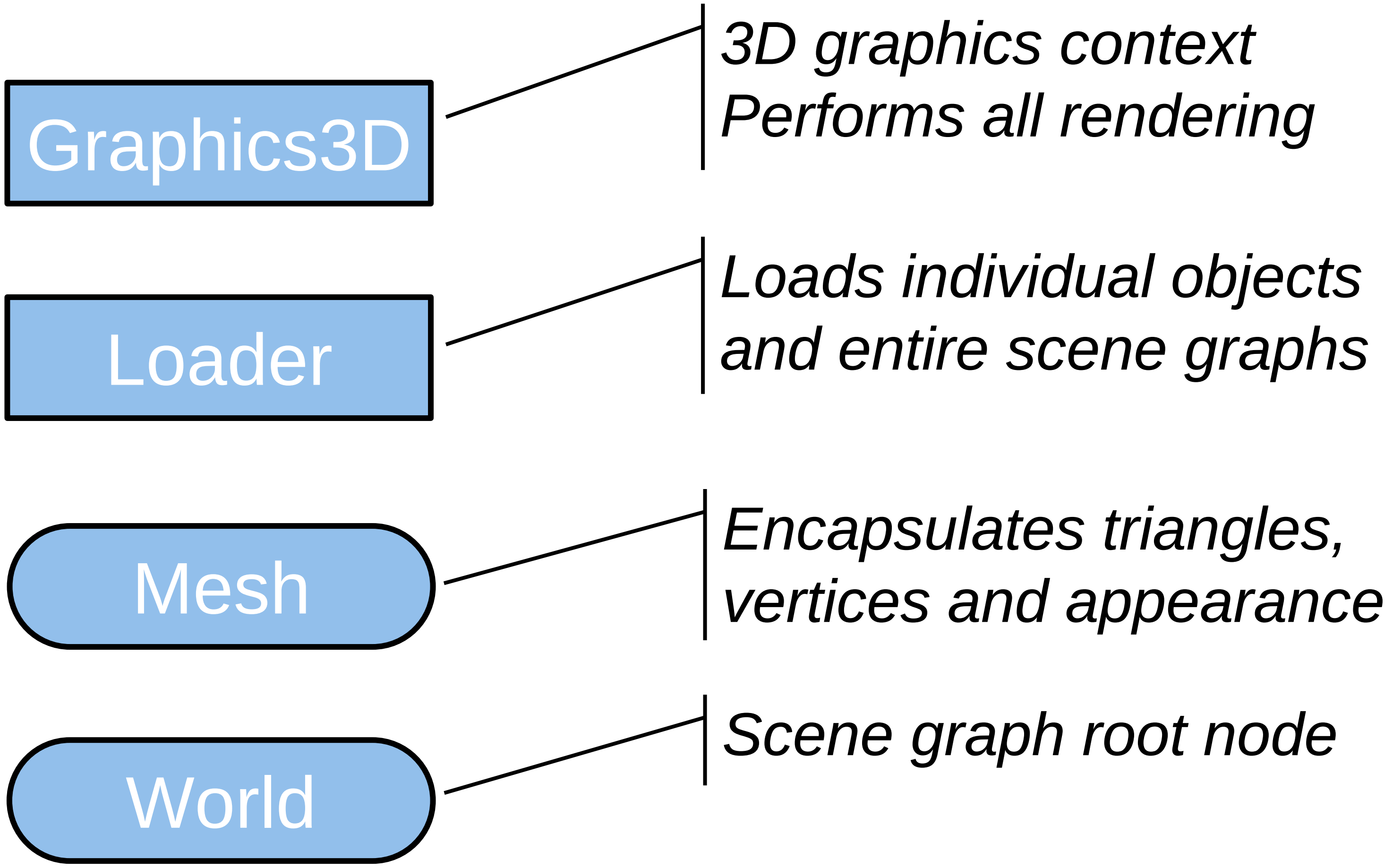
- No interfaces, events, or render callbacks
- No threads; all methods return only when done

Programming Model

Scene update is decoupled from rendering

`render`	➔ Draw the scene, no side-effects
`animate`	➔ Update the scene to the given time
`align`	➔ Re-orient target cameras, billboards

Key Classes



Graphics3D
3D graphics context
Performs all rendering
Loader
Loads individual objects
and entire scene graphs
Mesh
Encapsulates triangles,
vertices and appearance
World
Scene graph root node

Graphics3D: How to Use

Bind a target to it, render, release the target

```
void paint(Graphics g) {
   myGraphics3D.bindTarget(g);
   myGraphics3D.render(world);
   myGraphics3D.releaseTarget();
}
```

Rendering State

- Graphics3D contains global state
  - Frame buffer, depth buffer
  - Viewport, depth range

- Most rendering state is in the scene graph
  - Vertex buffers, textures, matrices, materials, …
  - Packaged into Java objects, referenced by meshes
  - Minimizes Java-native data traffic, enables caching

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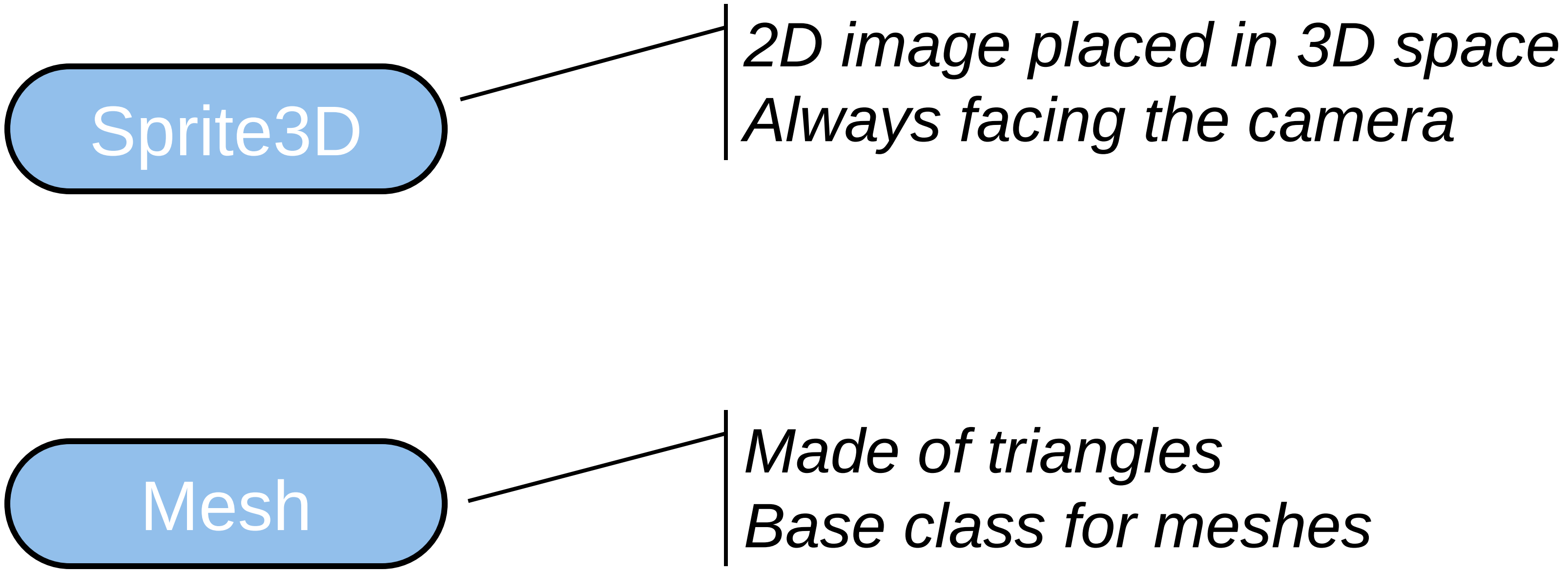
Renderable Objects

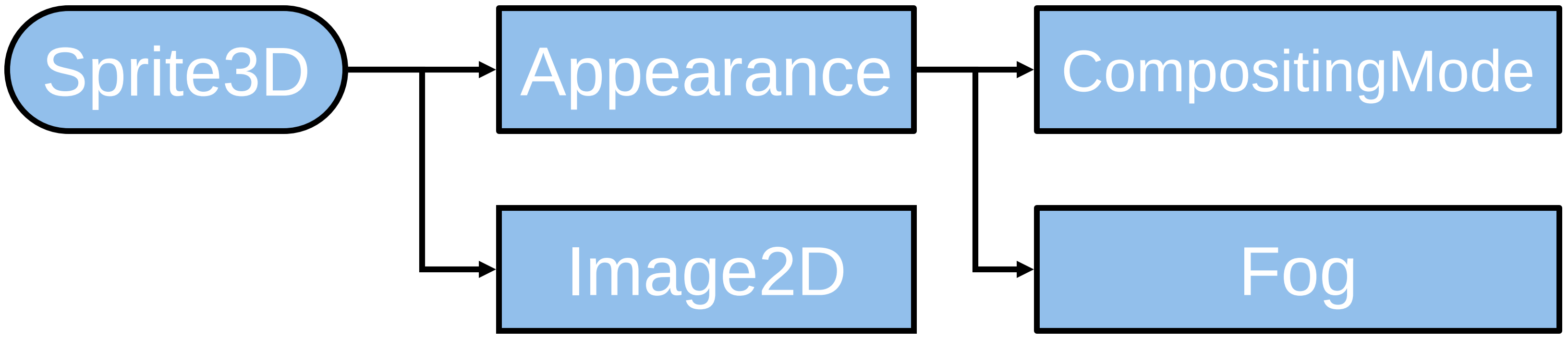


2D image placed in 3D space
Always facing the camera

Made of triangles
Base class for meshes

Sprite3D

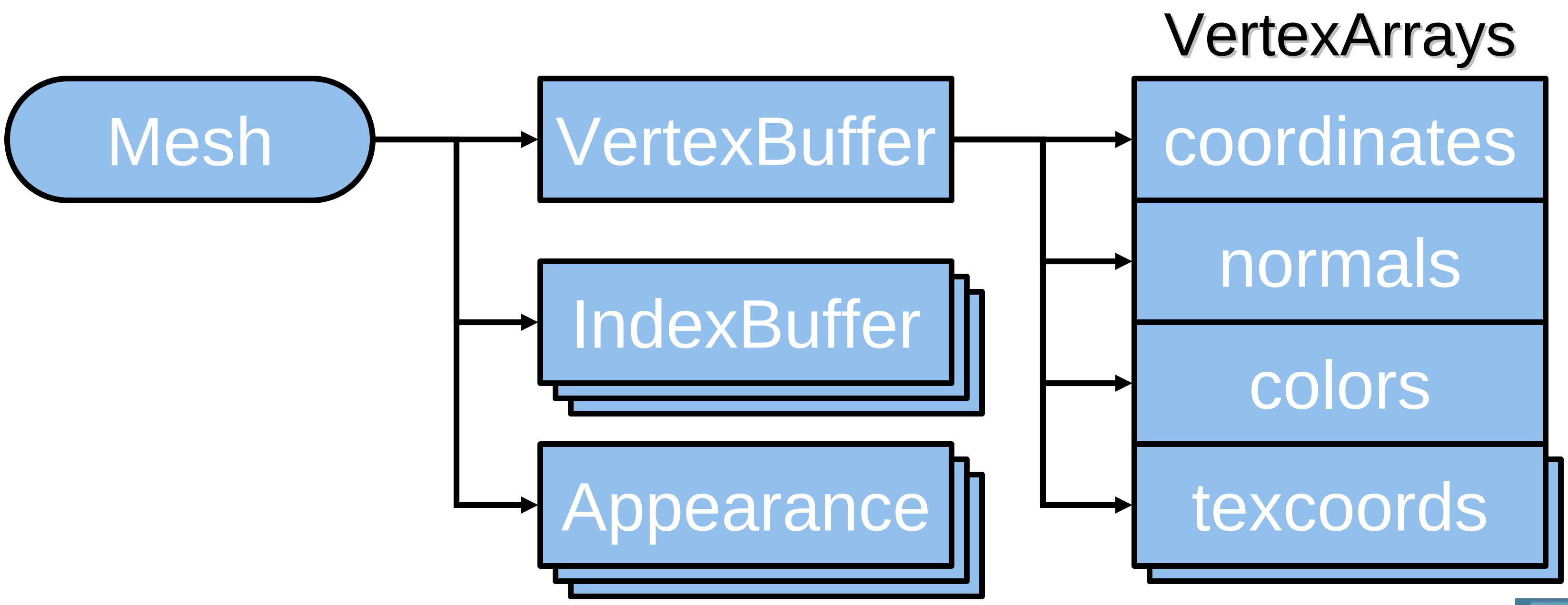
- 2D image with a position in 3D space
  - Scaled mode for billboards, trees, etc.
  - Unscaled mode for text labels, icons, etc.
  - Too much overhead for particle effects



Mesh

One VertexBuffer, containing VertexArrays

1..*N* submeshes (IndexBuffer + Appearance)



IndexBuffer Types

	Byte	Short	Implicit	Strip	Fan	List
Triangles	✓	✓	✓	✓	✗	✗
Lines	✗	✗	✗	✗	✗	✗
Points	✗	✗	✗	▨	▨	✗
Point sprites	✗	✗	✗	▨	▨	✗

Relative to OpenGL ES 1.1

VertexBuffer Types

	Byte	Short	Fixed	Float	2D	3D	4D
Vertices	✓	✓	✗	✗	✗	✓	✗
TexCoords	✓	✓	✗	✗	✓	✓	✗
Normals	✓	✓	✗	✗	▨	✓	▨
Colors	✓	▨	✗	✗	▨	*	✓
PointSizes	▨	▨	✗	✗	▨	▨	▨

* M3G supports RGB color arrays, although OpenGL ES only supports RGBA

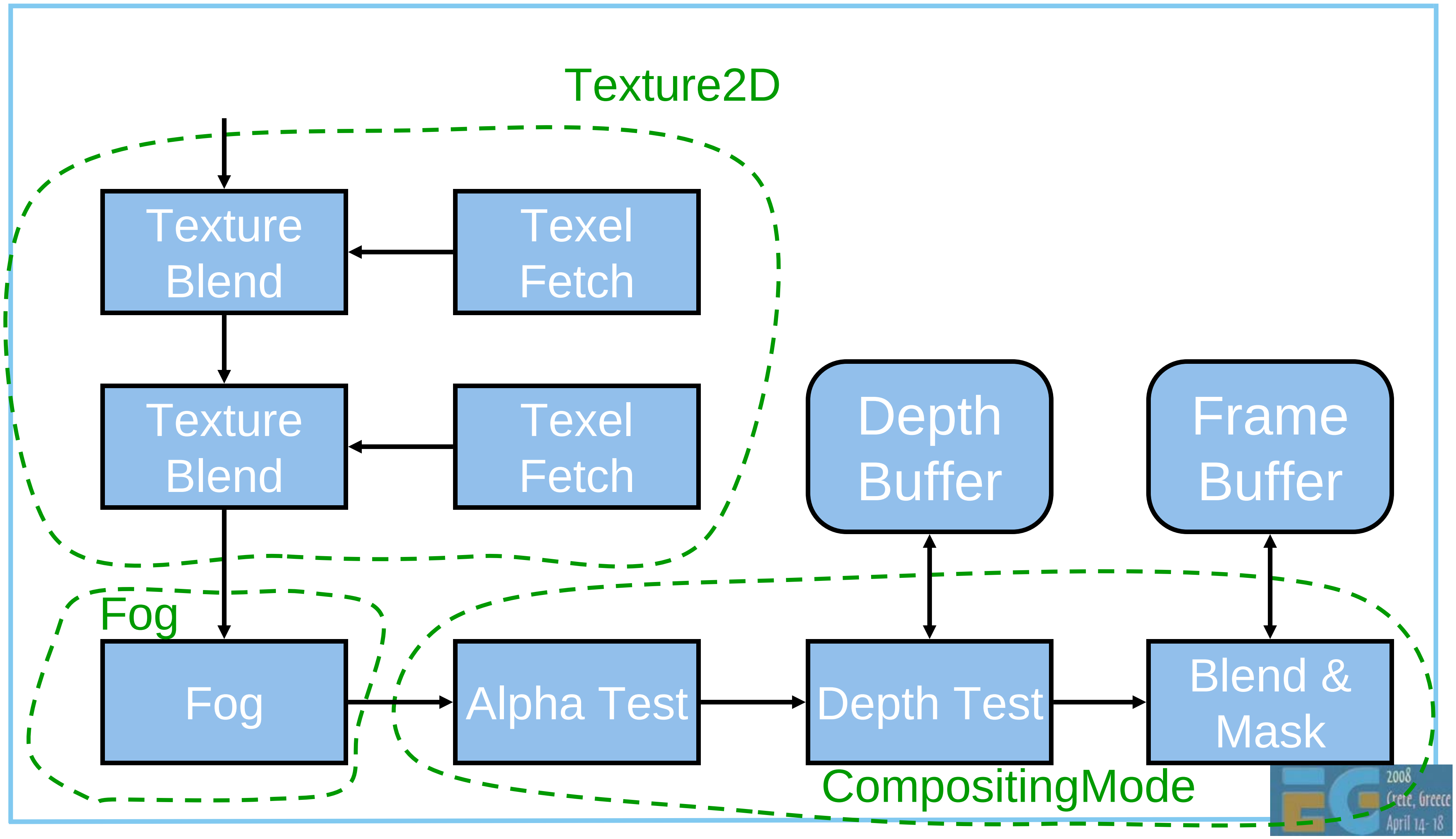
Vertex and Index Buffer Objects

- Vertices and indices are stored on server side
- Similar to OpenGL Buffer Objects
  - Reduces data traffic from Java to native
  - Allows caching, bounding box computation, etc.

Appearance Components

Material	*Material colors for lighting* *Can track per-vertex colors*
CompositingMode	*Blending, depth buffering* *Alpha testing, color masking*
PolygonMode	*Winding, culling, shading* *Perspective correction hint*
Fog	*Fades colors based on distance* *Linear and exponential mode*
Texture2D	*Texture matrix, blending, filtering* *One Texture2D for each unit*

Fragment (Pixel) Pipeline



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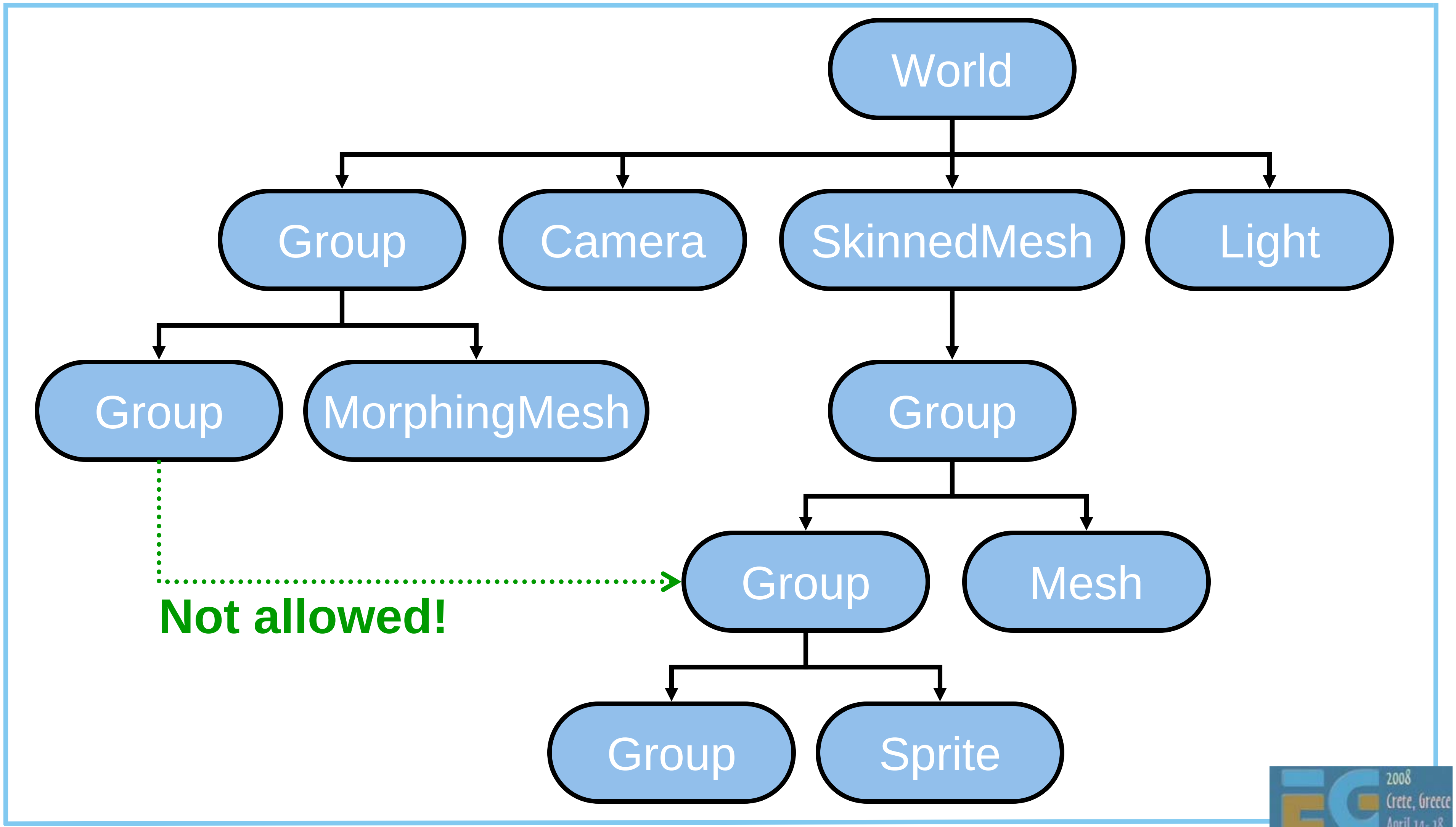
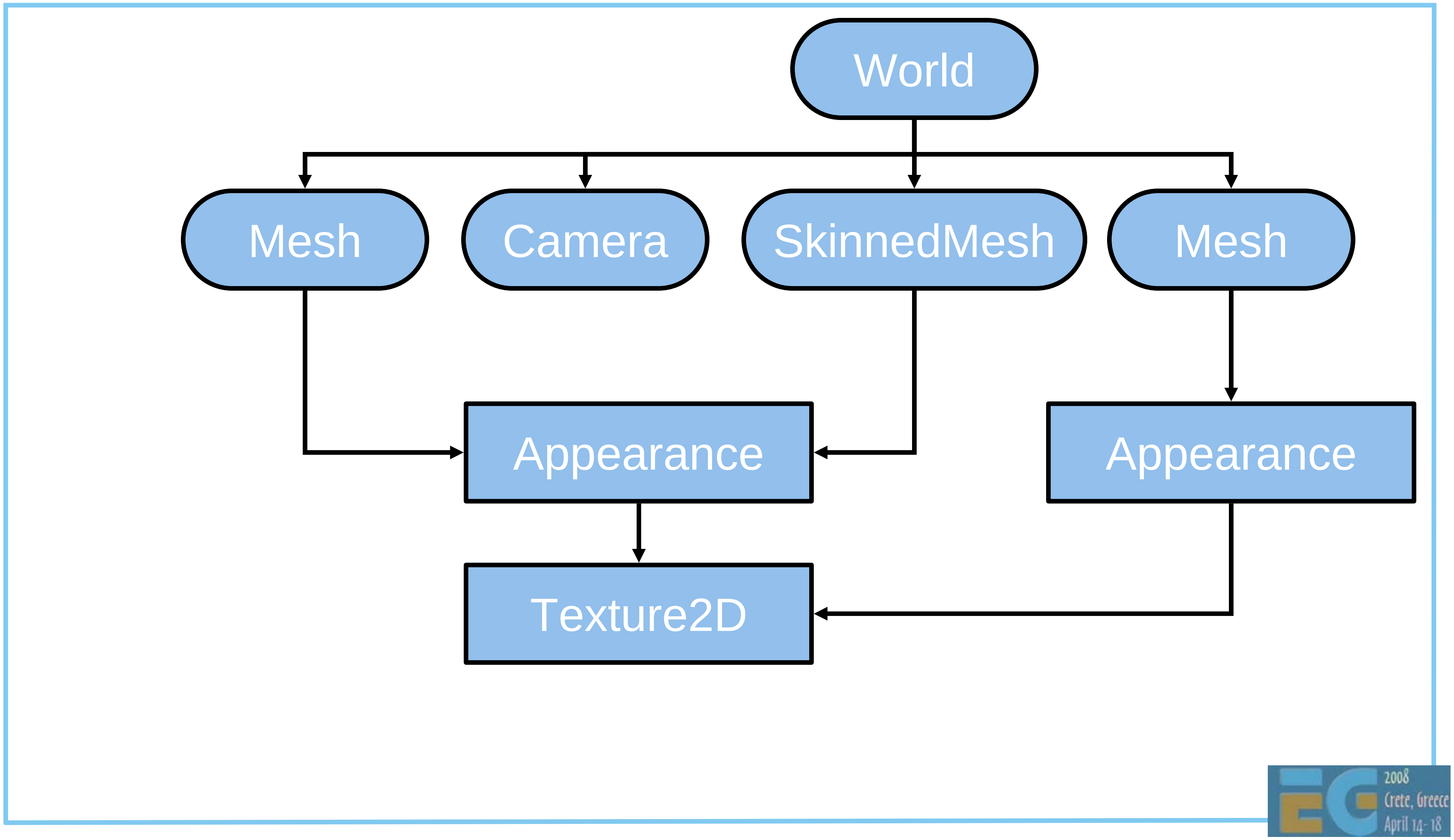
Scene Graph


World
Group
Camera
SkinnedMesh
Light
Group
MorphingMesh
Group
Group
Mesh
Not allowed!
Group
Sprite

Shared Node Components



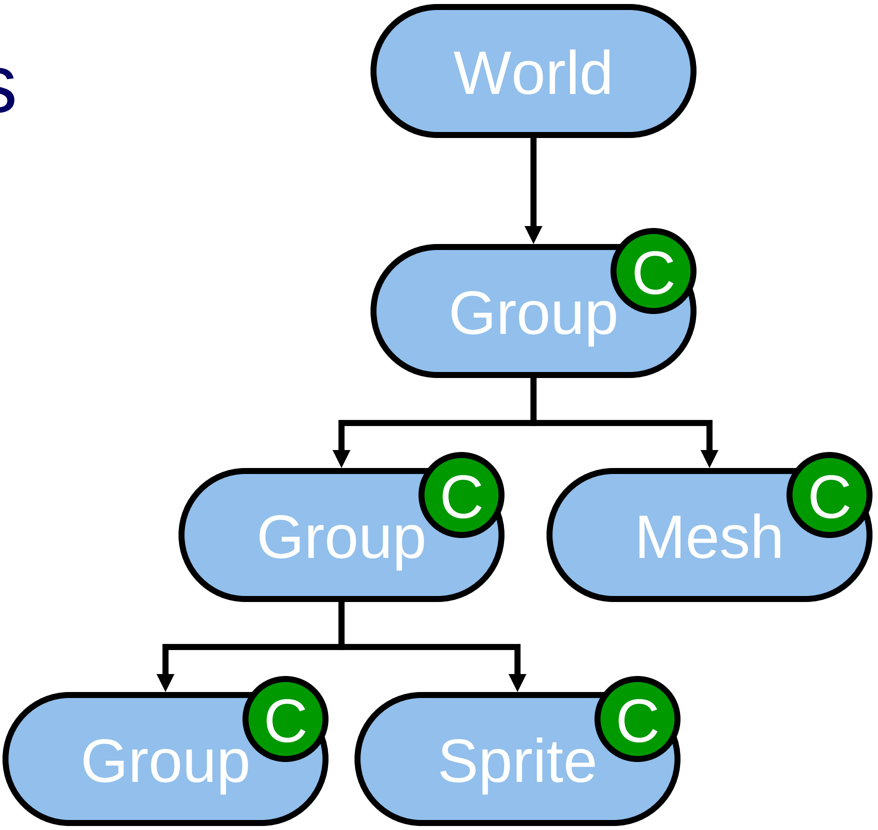
Node Transformation

From this node to the parent node

Composed of four parts

- Translation T
- Orientation R
- Non-uniform scale S
- Generic 3x4 matrix M

C = T R S M



Node Alignment

Reorients a node towards a target node

Recomputes the orientation component (R)

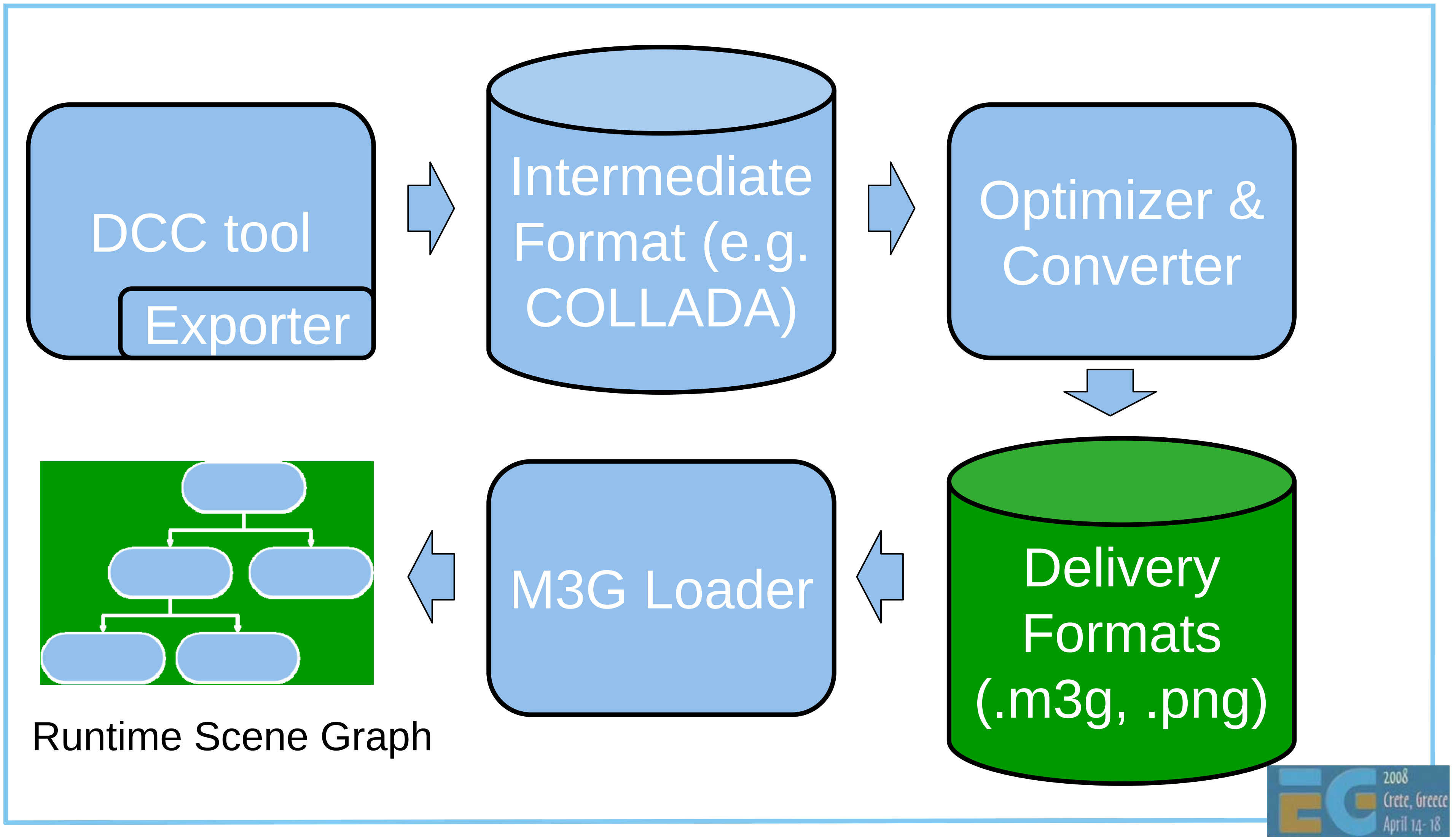
For target cameras & lights, billboards, etc.

Other Node Features

- Inherited properties
  - Alpha factor (for fading in/out)
  - Rendering enable (on/off)
  - Picking enable (on/off)

- Scope mask

Content Production



M3G File Format

Small size, easy to decode

Matches API features 1:1

Stores individual objects, entire scenes

ZLIB compression of selected sections

Can reference external files – e.g. textures

Highly portable – no extensions

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Use the Retained Mode

- Render a World instead of separate objects
  - Minimizes Java code and method calls
  - Allows view frustum culling, etc.
- Put co-located objects into Groups
  - Speeds up hierarchic view frustum culling

Simplify Node Properties

Transformations

- Favor the **T R S** components over **M**
- Avoid non-uniform scales in **S**
- Use auto-alignment sparingly

Keep the alpha factor at 1.0

Optimize Rendering Order

`Appearance.setLayer(int layer)`

- Defines a global ordering for submeshes
- Within each layer, opaque objects come first

Use layers for…

- Making sure that overlays are drawn first
- Making sure that distant objects are drawn last
- Multipass effects (e.g. for lighting)

Optimize Texturing

- Multitexturing is faster than multipass
  - Transformation and setup costs cut by half
- Use mipmaps to save memory bandwidth
  - Tradeoff: 33% extra memory consumption
- Combine small textures into a texture atlas

Use Perspective Correction

Much faster than increasing triangle count

- Nokia: 2% fixed overhead, 20% in the worst case
- No overhead at all on hardware implementations

Pitfall: Quality varies by implementation

- Refer to quality scores at www.jbenchmark.com

Reduce Object Count

Per-Mesh processing overhead is high

Per-submesh overhead is also fairly high

Merge

- Meshes that are close to each other
- submeshes that have a common Appearance

Avoid Dynamic Geometry

`VertexArray.set(…)` can be slow

- Java array contents must be copied in
- May also trigger bounding box updates, etc.
- Replace with morphing or skinning where possible

IndexBuffers have no `set(…)` method at all

- `new IndexBuffer(…)` per frame is <u>not</u> a good idea
- Switch between predefined IndexBuffers instead

Beware of Exporters

- Exported content is often suboptimal
  - Lighting enabled, but overwritten by texture
  - Lighting disabled, normal vectors still included
  - Alpha blending enabled, but alpha always 1.0
  - 16-bit vertices when 8 bits would be enough
  - Perspective correction always enabled
  - …
- Always review the exported scene tree!

Hardware vs. Software

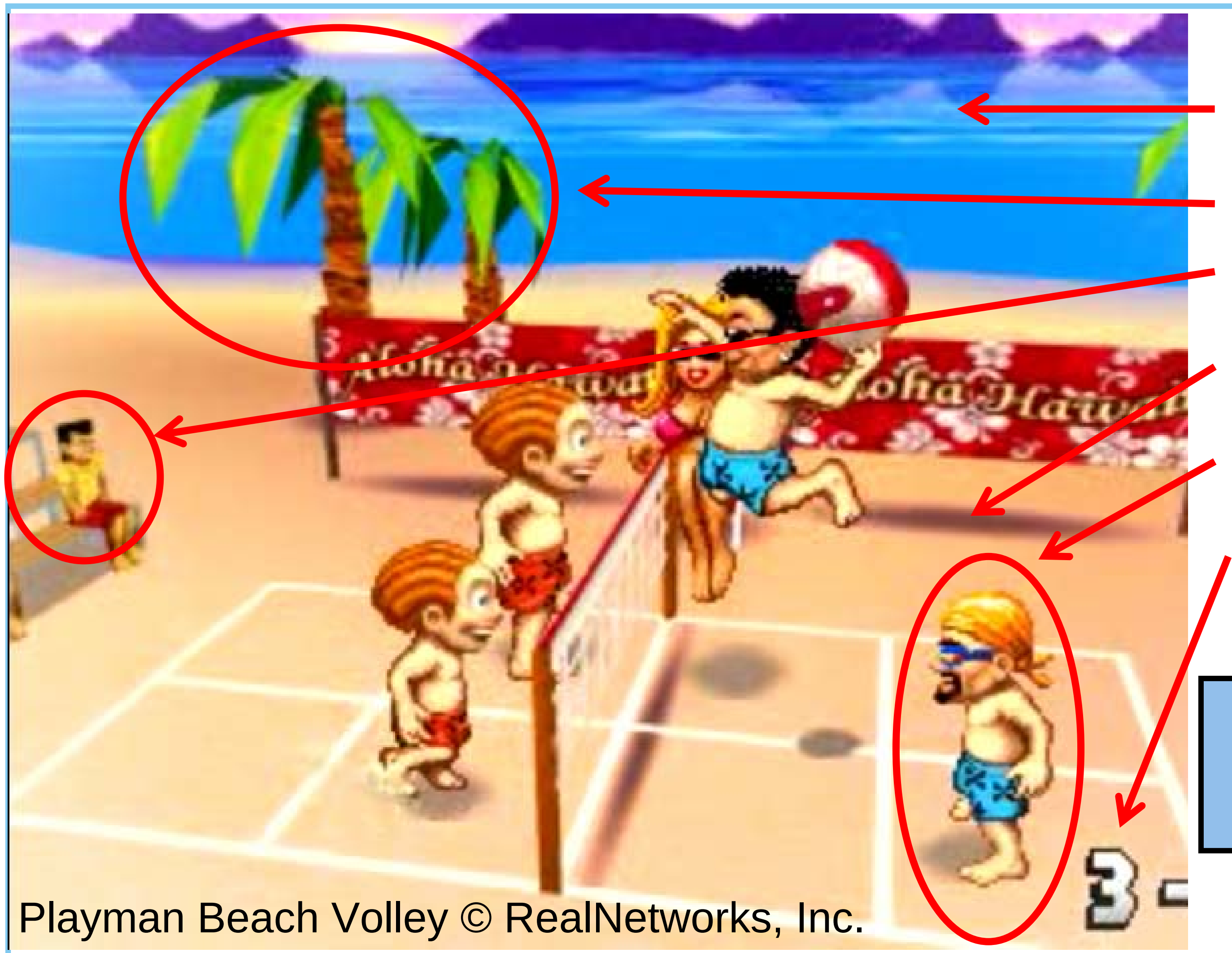
Shading state

- SW: Minimize per-pixel operations
- HW: Minimize shading state changes

Mixing 2D and 3D rendering

- SW: No performance penalty
- HW: Substantial penalty (up to 3x)

Layering 2D and 3D



Playman Beach Volley © RealNetworks, Inc.

~7 layers of 2D and 3D!

Use Picking with Caution

`myWorld.pick(…)` can be <u>very</u> slow

Restrict the pick ray to

- meshes in a specific Group
- meshes with a specific scope mask

Use simplified geometry for picking

- `setPickingEnable(true)`
- `setRenderingEnable(false)`

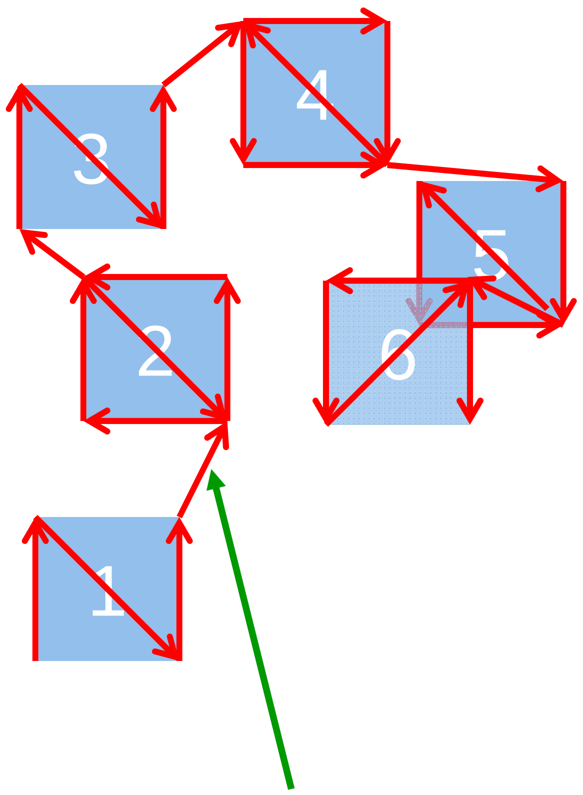
Particle Effects

Point sprites – not available

Sprite3D – much too slow

Put all particles in one Mesh

- One particle == two triangles
- Animate by `VertexArray.set(…)`



Particles glued into a tri-strip

Easy Terrain Rendering

Split the terrain into tiles (Meshes)

Put the meshes into a scene graph

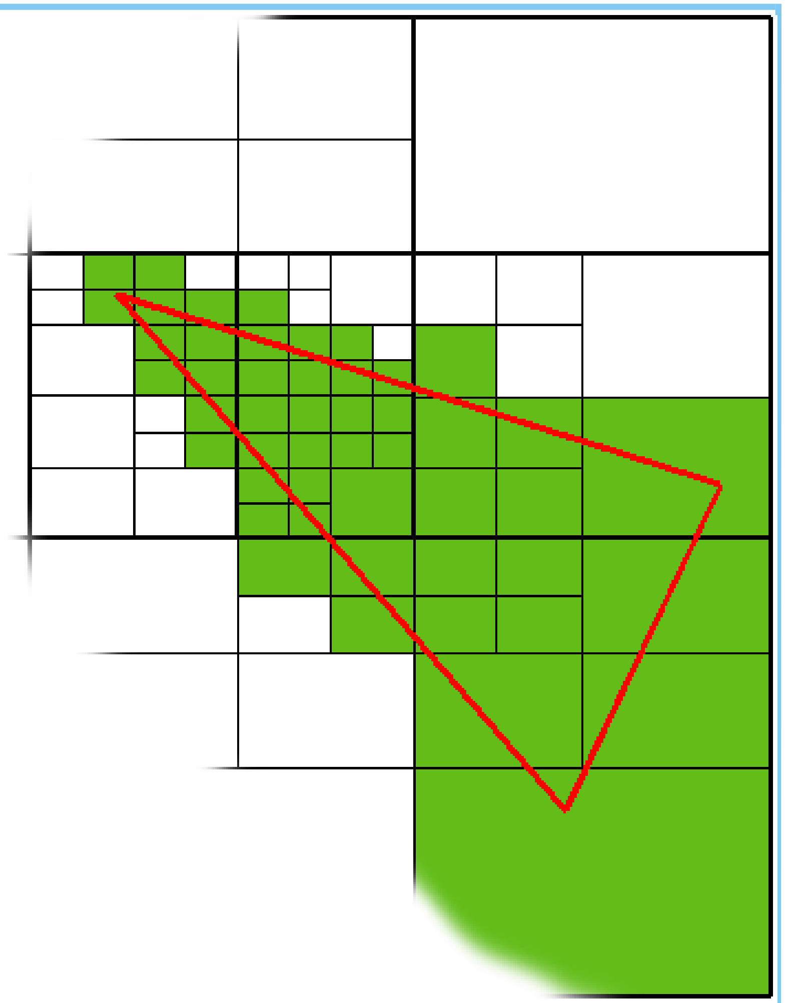
The engine will do view frustum culling

Terrain Rendering with LOD

Preprocess into a quadtree

- leaf node == Mesh
- inner node == Group

Use `setRenderingEnable` based on the view frustum



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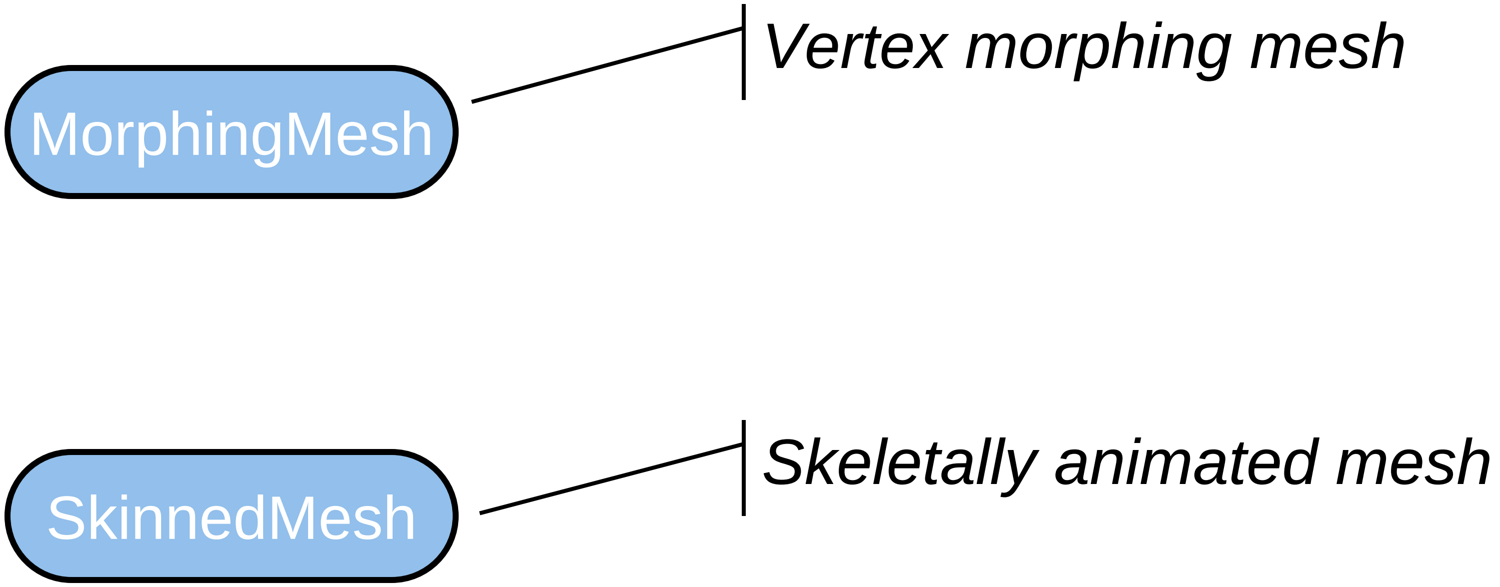
Deforming Meshes



MorphingMesh

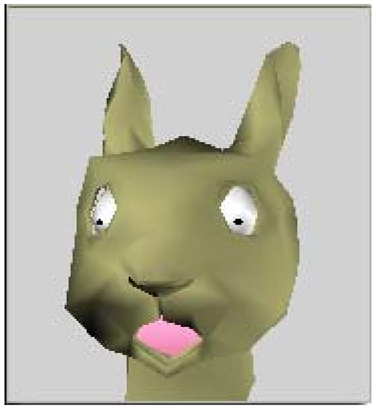
Traditional vertex morphing animation

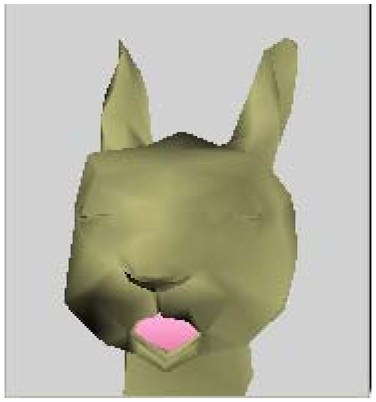
- Can morph any vertex attribute(s)
- A base mesh **B** and any number of morph targets $\mathbf{T}_i$
- Result = weighted sum of morph deltas

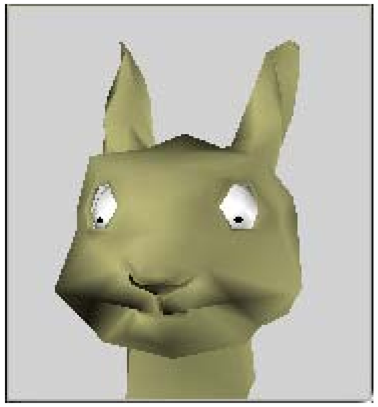
$$\mathbf{R} = \mathbf{B} + \sum_i w_i (\mathbf{T}_i - \mathbf{B})$$

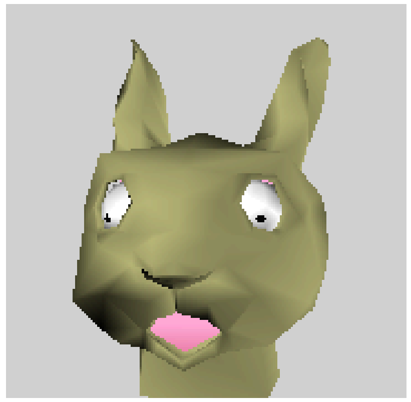
Change the weights $\boldsymbol{w_i}$ to animate

MorphingMesh


Base


Target 1
eyes closed


Target 2
mouth closed


Animate eyes
and mouth
independently

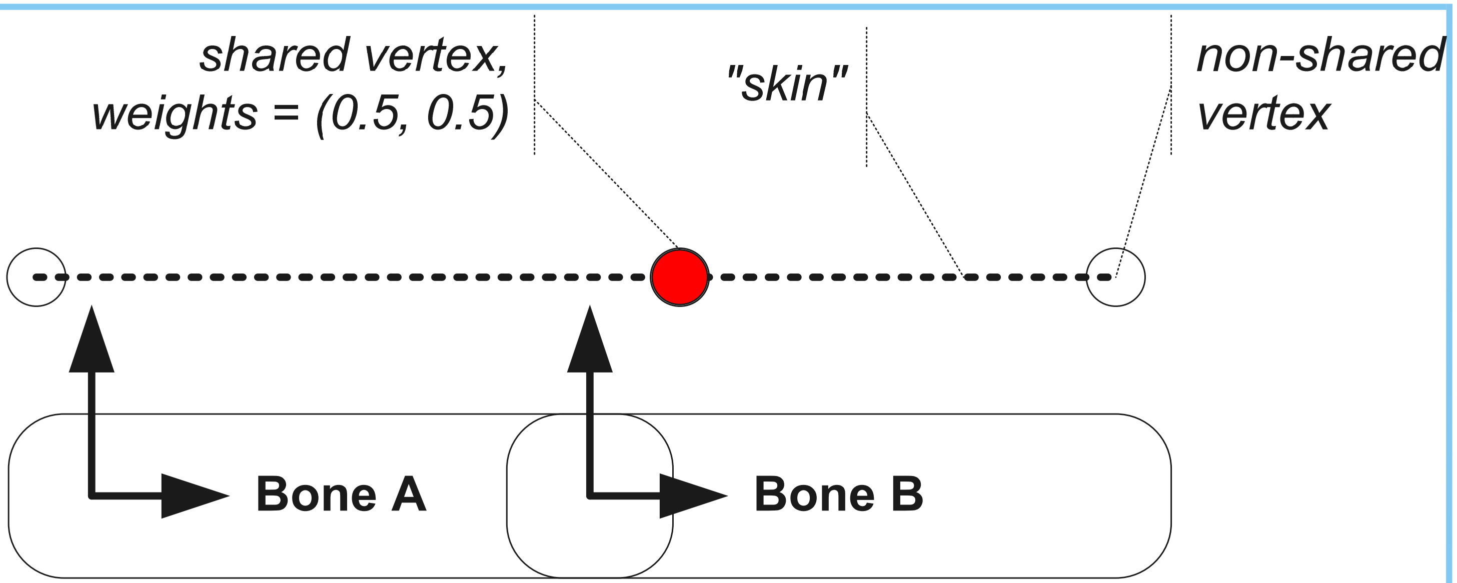
SkinnedMesh

- Articulated characters without cracks at joints
- Stretch a mesh over a hierarchic “skeleton”
  - The skeleton consists of scene graph nodes
  - Each node (“bone”) defines a transformation
  - Each vertex is linked to one or more bones

$$v' = \sum_i w_i \mathbf{M}_i \mathbf{B}_i v$$

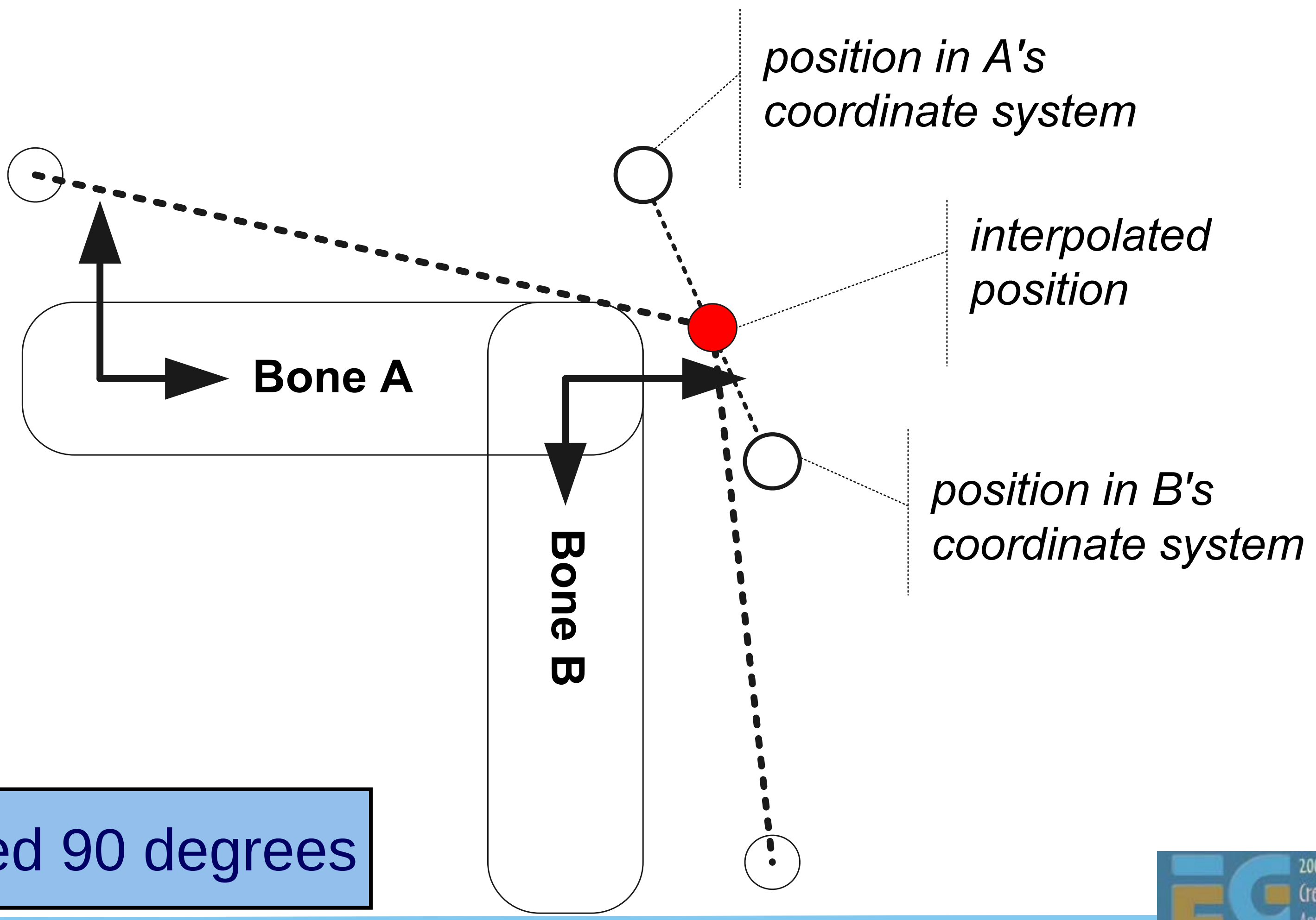
  - $\mathbf{M}_i$ are the node transforms – $\boldsymbol{v}, \boldsymbol{w}, \mathbf{B}$ are constant

SkinnedMesh



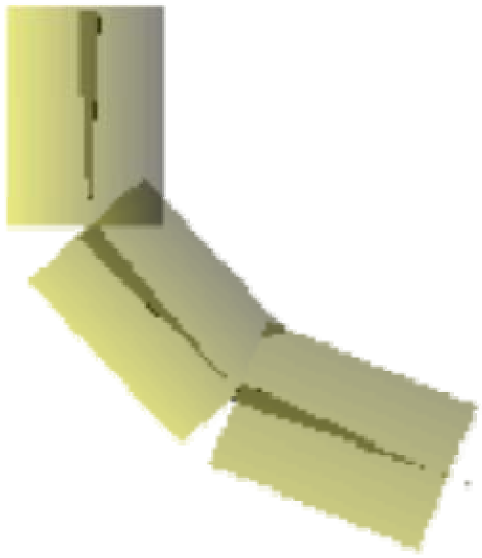
Neutral pose, bones at rest

SkinnedMesh

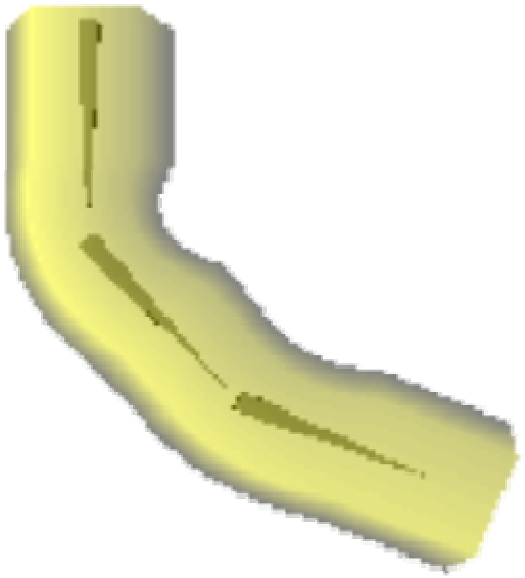

position in A's coordinate system
interpolated position
Bone A
Bone B
position in B's coordinate system

Bone B rotated 90 degrees

SkinnedMesh



Mesh



SkinnedMesh

M3G API Overview

Getting started

Rendering

Scene graph

Performance tips

Deformable meshes

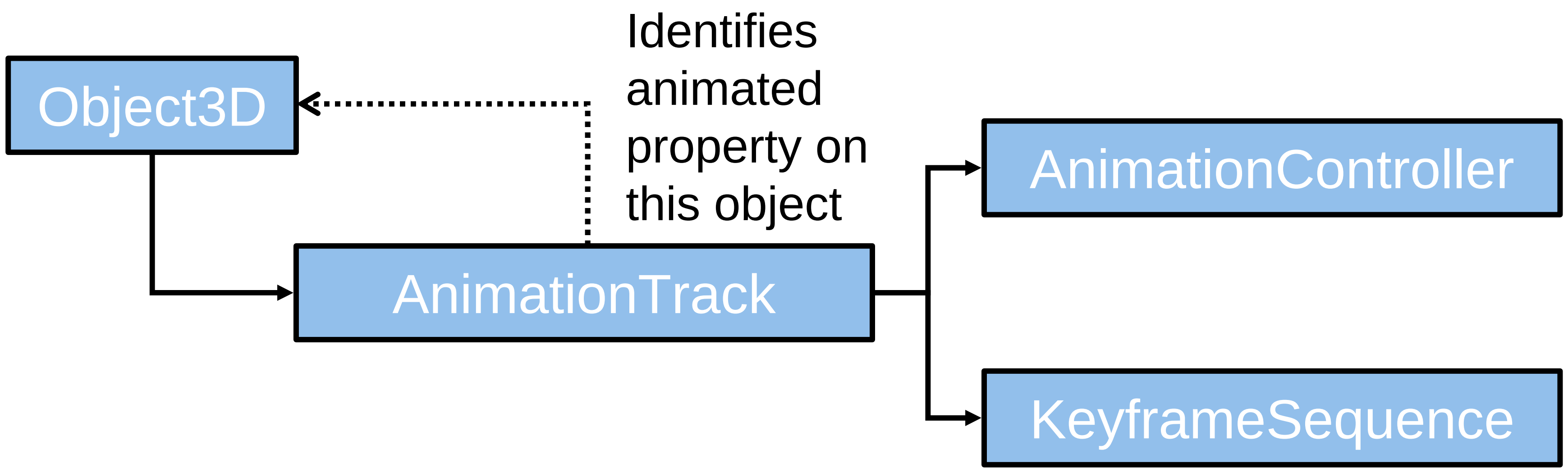
Keyframe animation

Demos

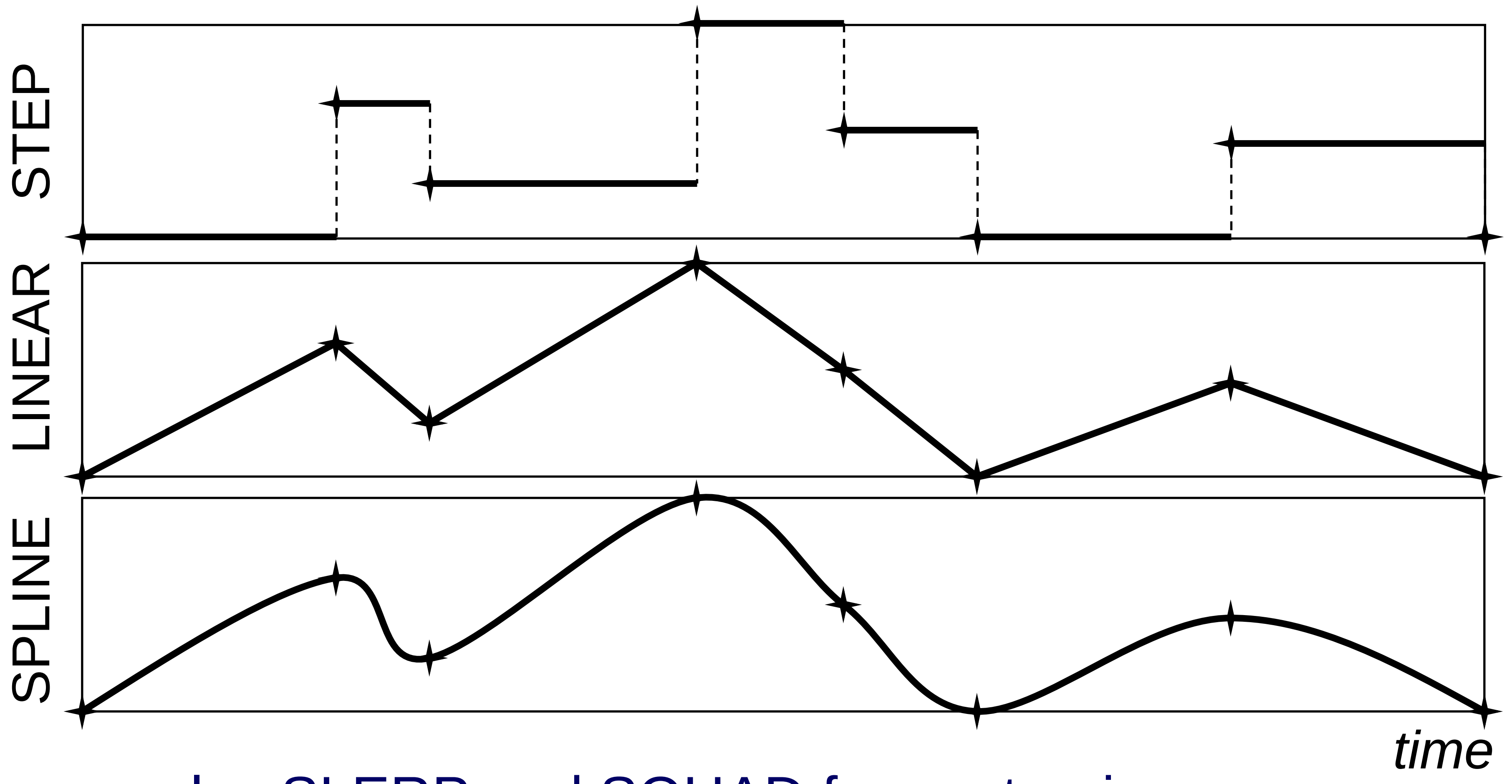
Animation Classes

KeyframeSequence	*Storage for keyframes Defines interpolation, looping*
AnimationController	*Controls the playback of one or more sequences*
AnimationTrack	*A link between sequence, controller and target*
Object3D	*Base class for all objects that can be animated*

Animation Classes



KeyframeSequence: Interpolation Modes



…plus SLERP and SQUAD for quaternions

AnimationController: Timing and Speed

Maps world time into sequence time

Can control any number of sequences

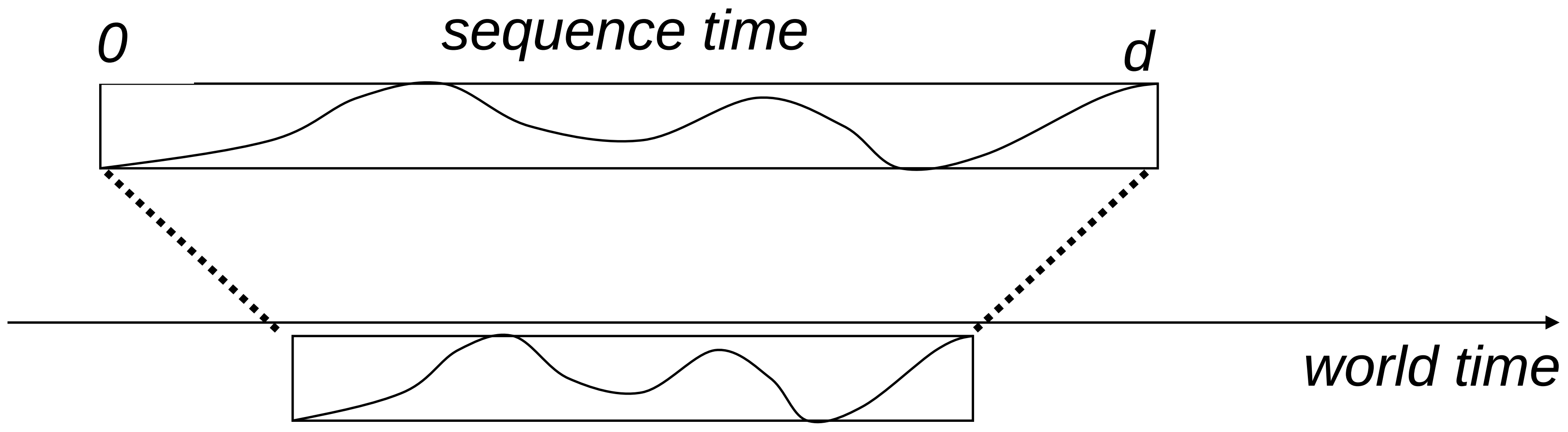


Diagram courtesy of Sean Ellis, ARM

Animation

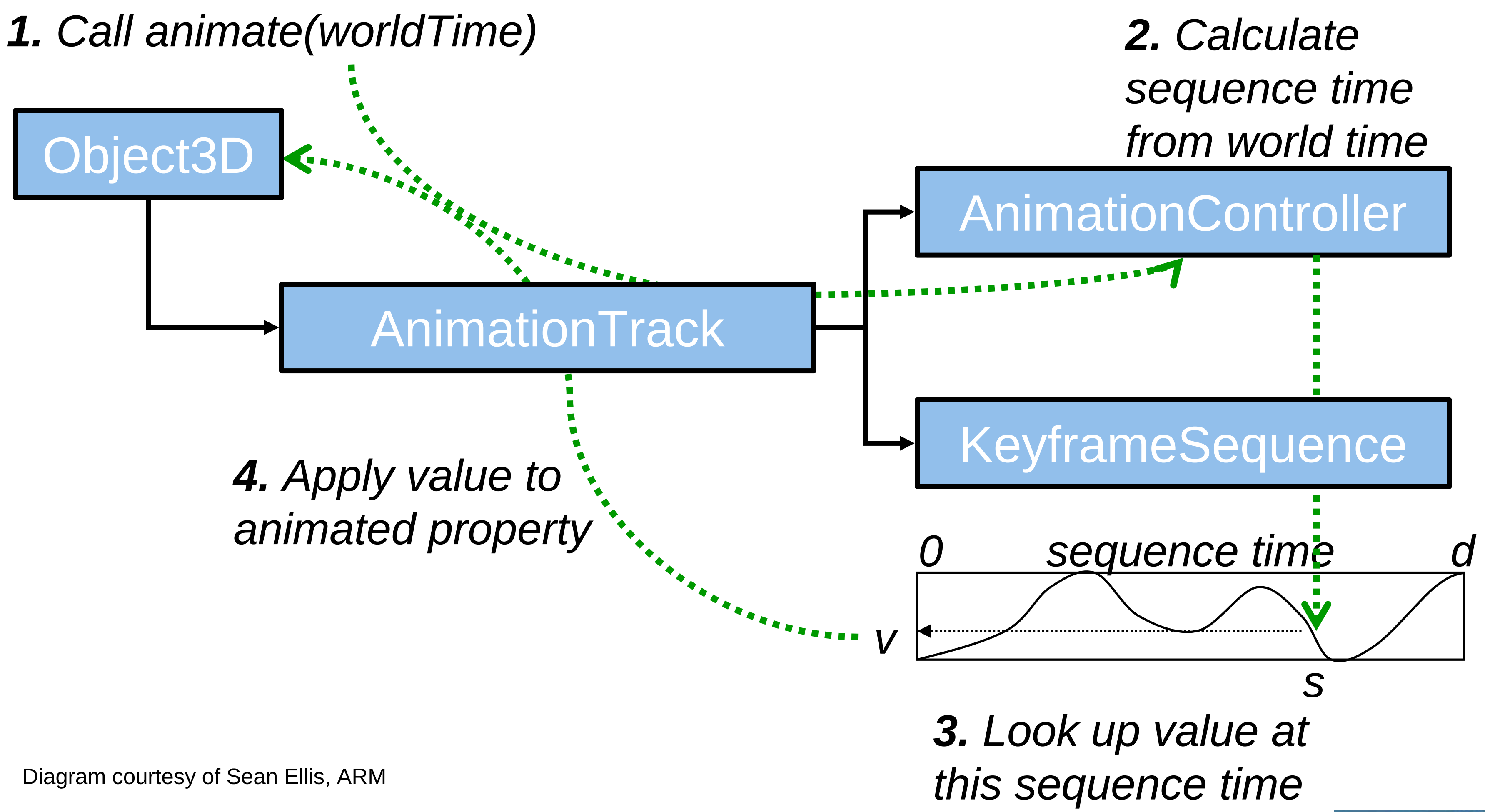

1. Call animate(worldTime)
2. Calculate sequence time from world time
Object3D
AnimationController
AnimationTrack
KeyframeSequence
4. Apply value to animated property
0
sequence time
d
v
s
3. Look up value at this sequence time

Diagram courtesy of Sean Ellis, ARM

Animation

Tip: Interpolate quaternions as ordinary 4-vectors

- Supported in HI Corp's M3G Exporter
- SLERP and SQUAD are slower, but need less keyframes
- Quaternions are automatically normalized before use

M3G API Overview

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Demos

2008 Crete, Greece April 14- 18

Summary

M3G enables real-time 3D on mobile Java

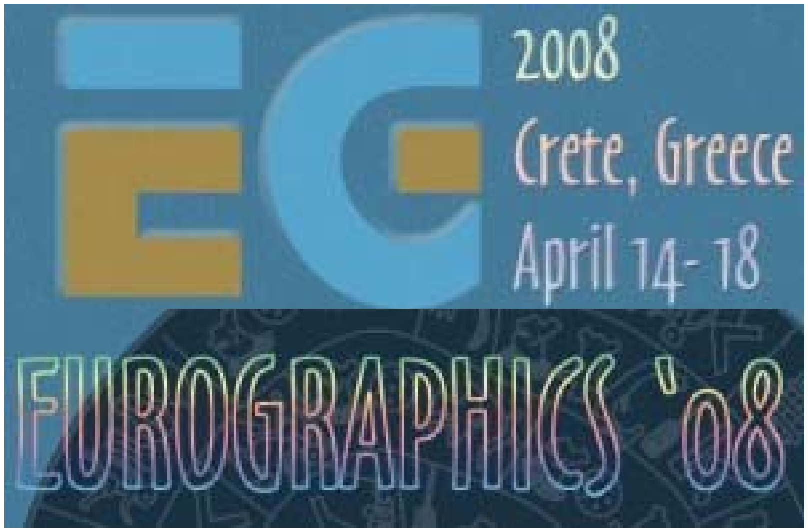
- Minimizes Java code along critical paths
- Designed for both software and hardware

OpenGL ES features at the foundation

Animation & scene graph layered on top

30’000 devices sold during this presentation

Demos



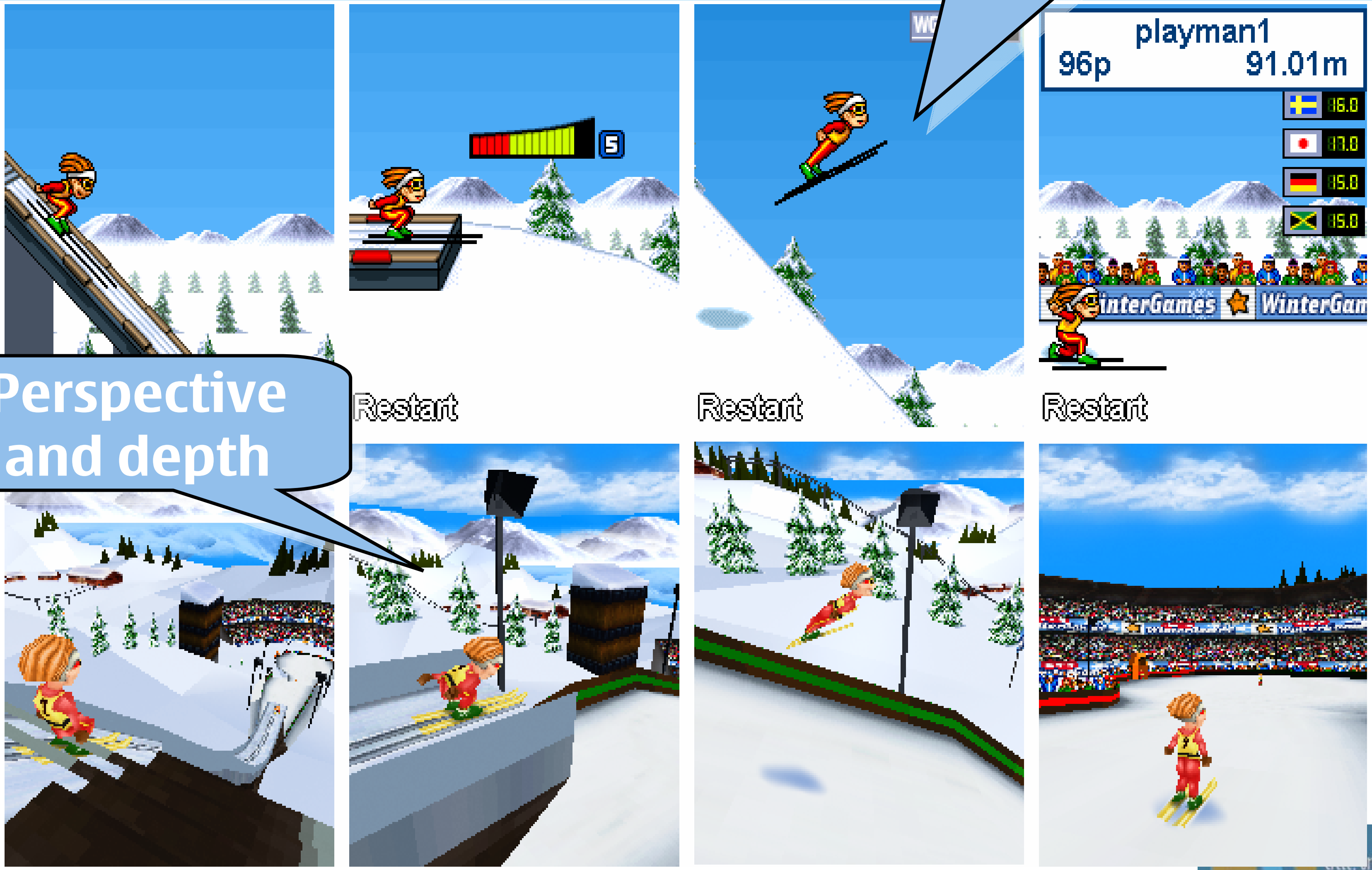
Playman Winter Games – RealNetworks

Side view only

2D

3D

Perspective and depth

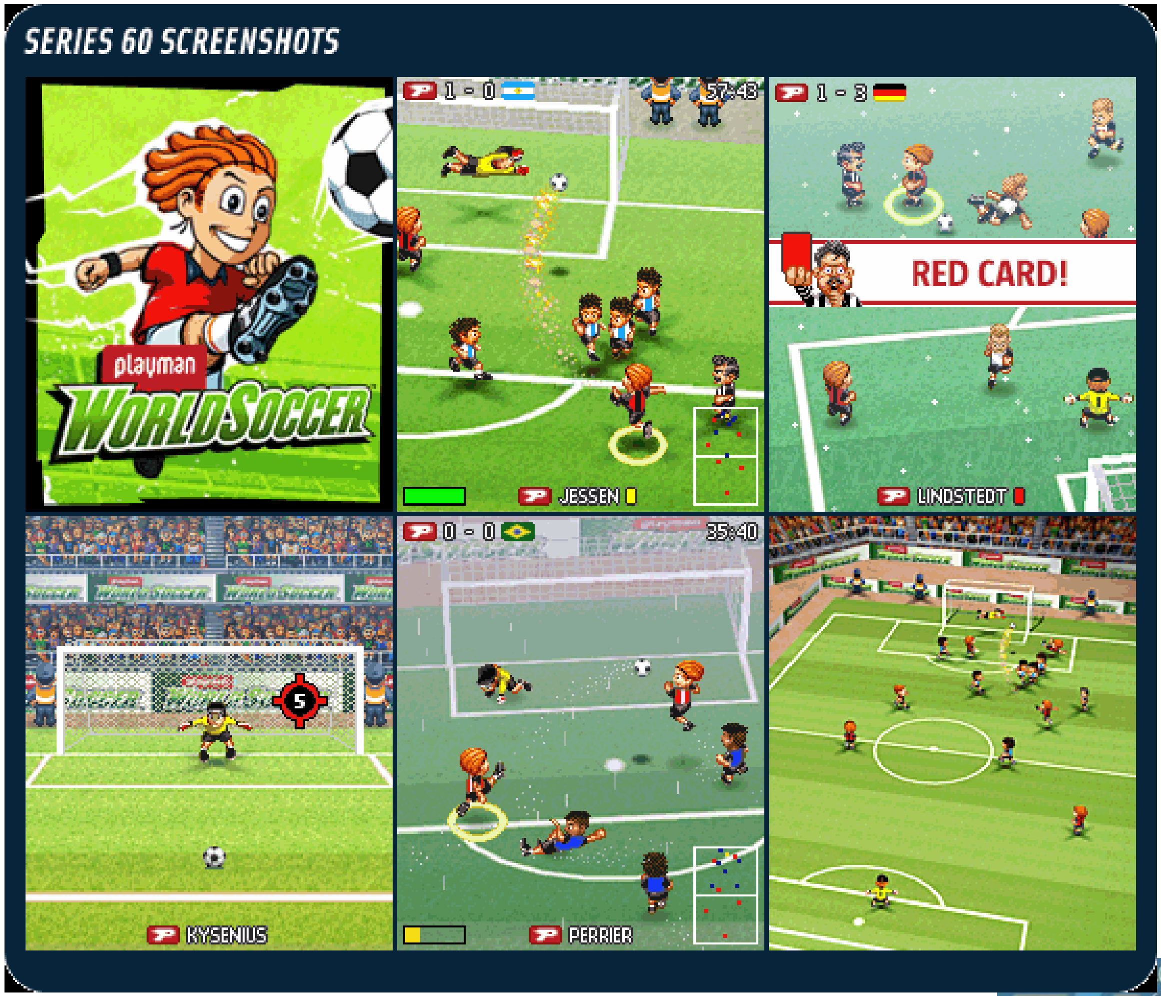


Playman World Soccer – RealNetworks

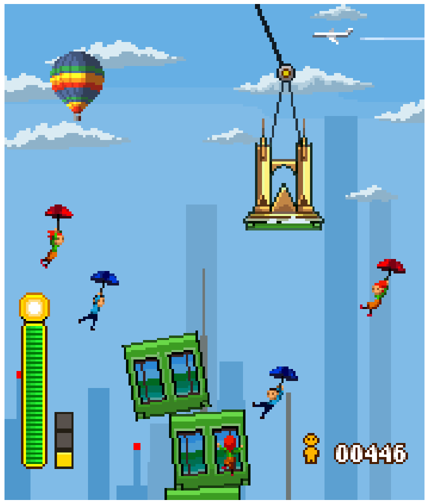
2D/3D hybrid

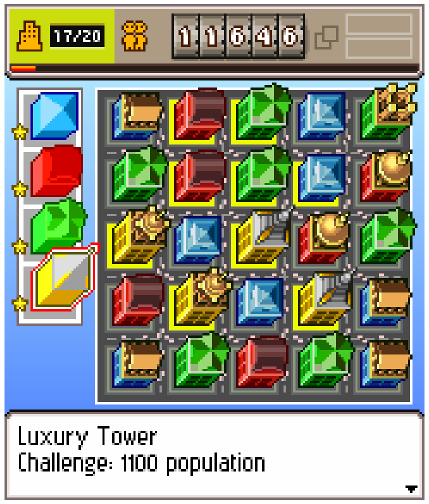
Cartoon-like 2D figures in a 3D scene

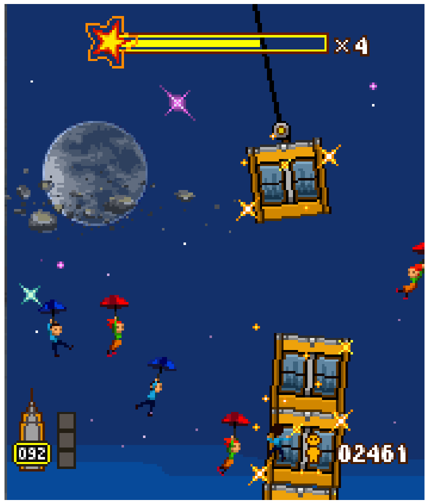
2D particle effects etc.



Tower Bloxx – Digital Chocolate





Luxury Tower
Challenge: 1100 population


Puzzle/arcade mixture

Tower building mode is in 3D, with 2D overlays and backgrounds

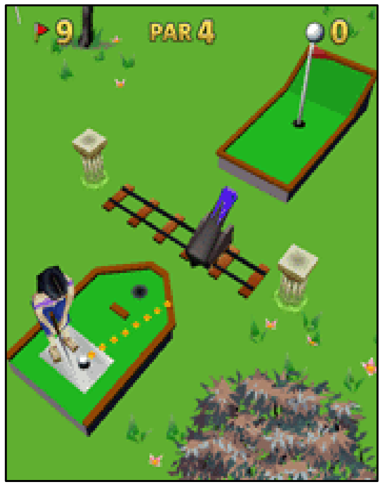
City building mode is in pure 2D

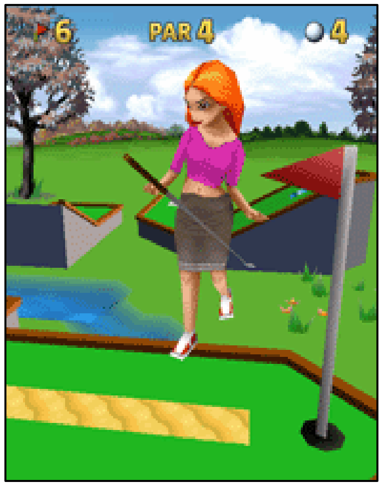
Mini Golf Castles – Digital Chocolate

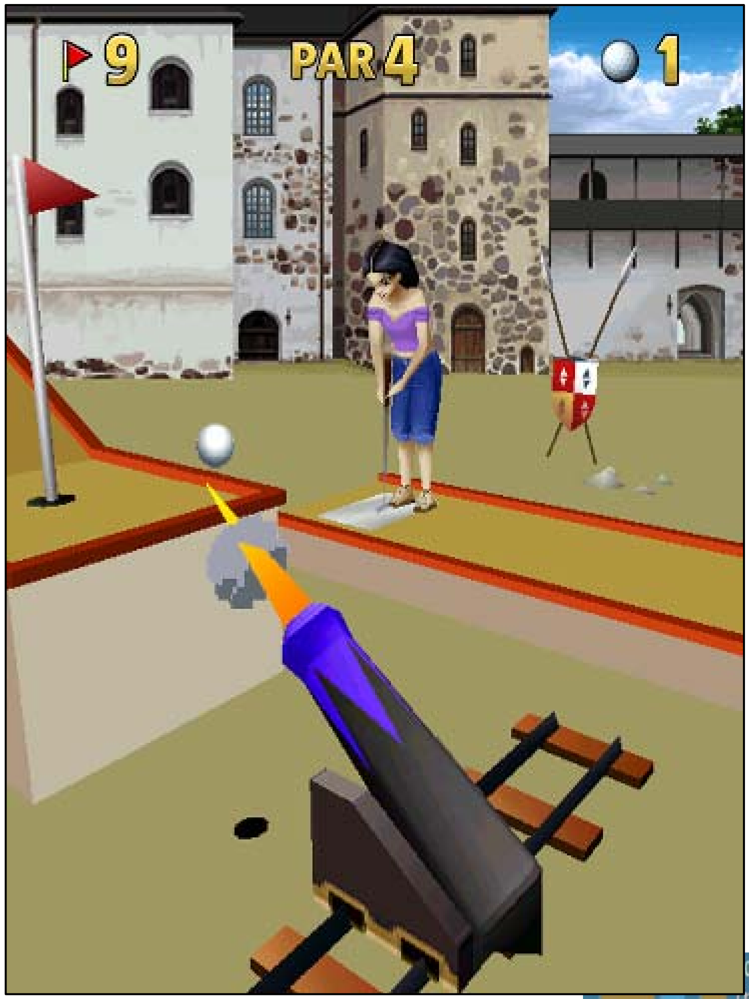
3D with 2D background and overlays

Skinned characters

Realistic ball physics





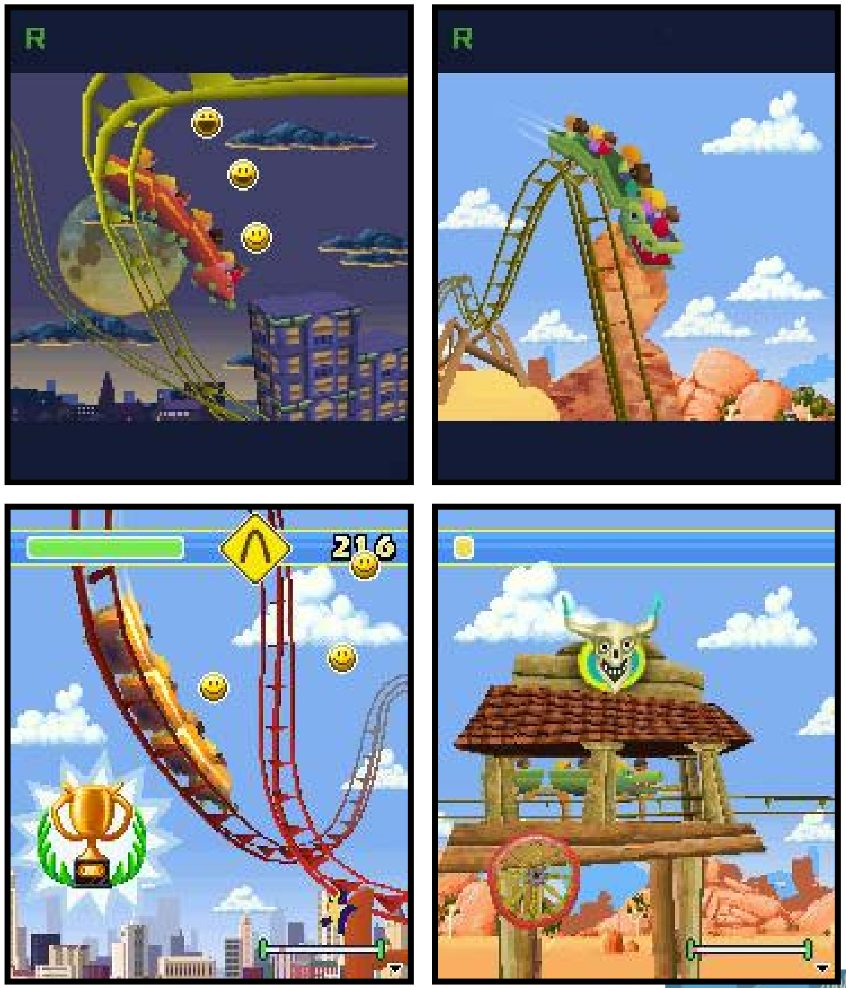


Rollercoaster Rush – Digital Chocolate

2D backgrounds

3D main scene

2D overlays



Q&A

EG 2008 Crete, Greece April 14-18

EUROGRAPHICS '08

Thanks:

Sean Ellis (ARM)

Kimmo Roimela (Nokia)

Markus Pasula (RealNetworks)

Sami Arola (Digital Chocolate)

M3G in the Real World

2008
Crete, Greece
April 14-18
EUROGRAPHICS '08

Mark Callow

Chief Architect

HI CORPORATION

An M3G Game

Copyright 2007, Digital Chocolate Inc.

Rollercoaster Rush 3D™

Agenda

J2ME game development

Tools

COFFEE BREAK

The structure of a MIDlet

A walk through a sample game

Why mobile game development is hard

Publishing your content

Agenda

J2ME game development

- Tools
- COFFEE BREAK
- The structure of a MIDlet
- A walk through a sample game
- Why mobile game development is hard
- Publishing your content

Game Development Process

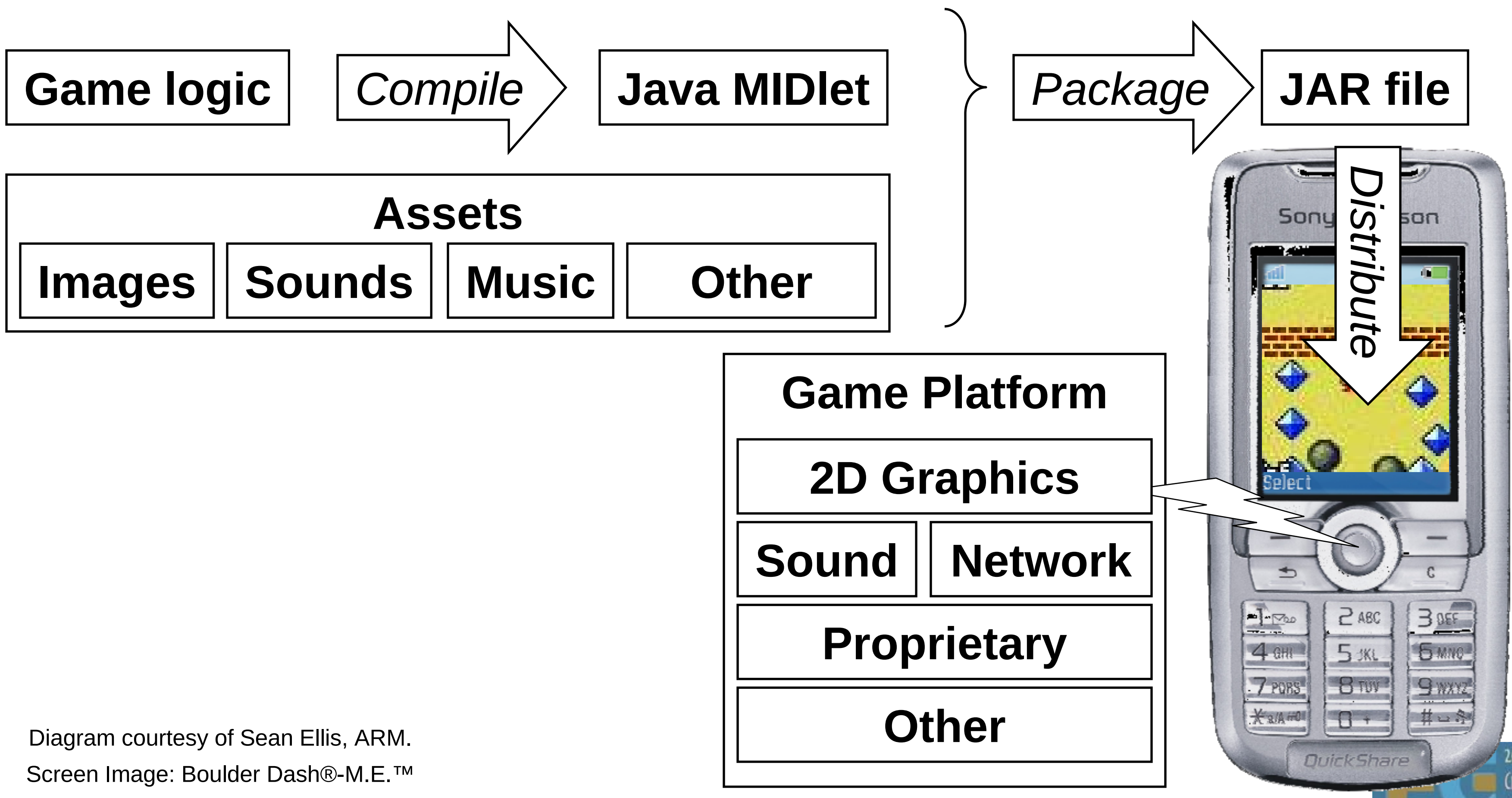


Diagram courtesy of Sean Ellis, ARM.

Screen Image: Boulder Dash®-M.E.™

M3G Game Development Process

How M3G Fits

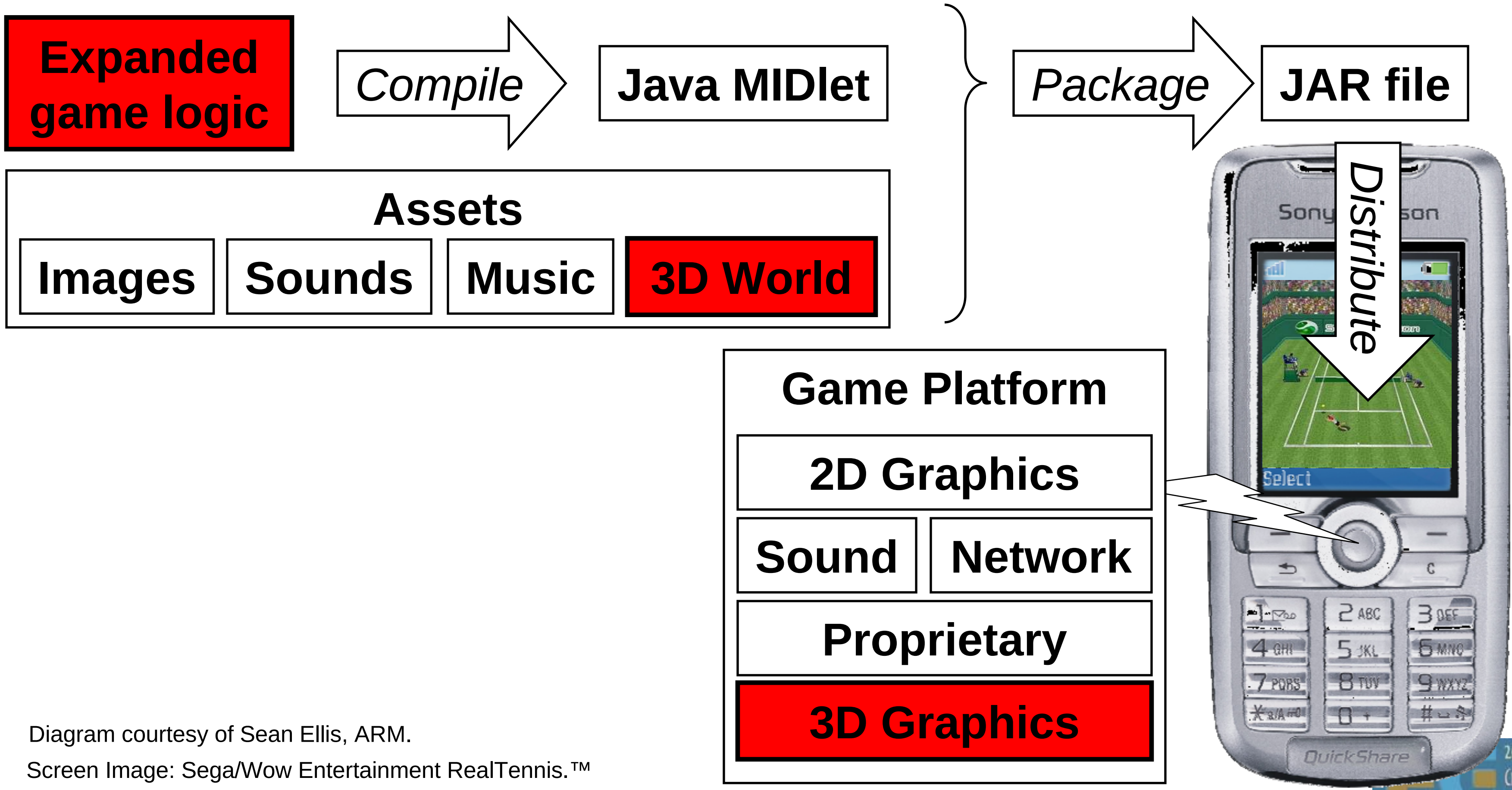
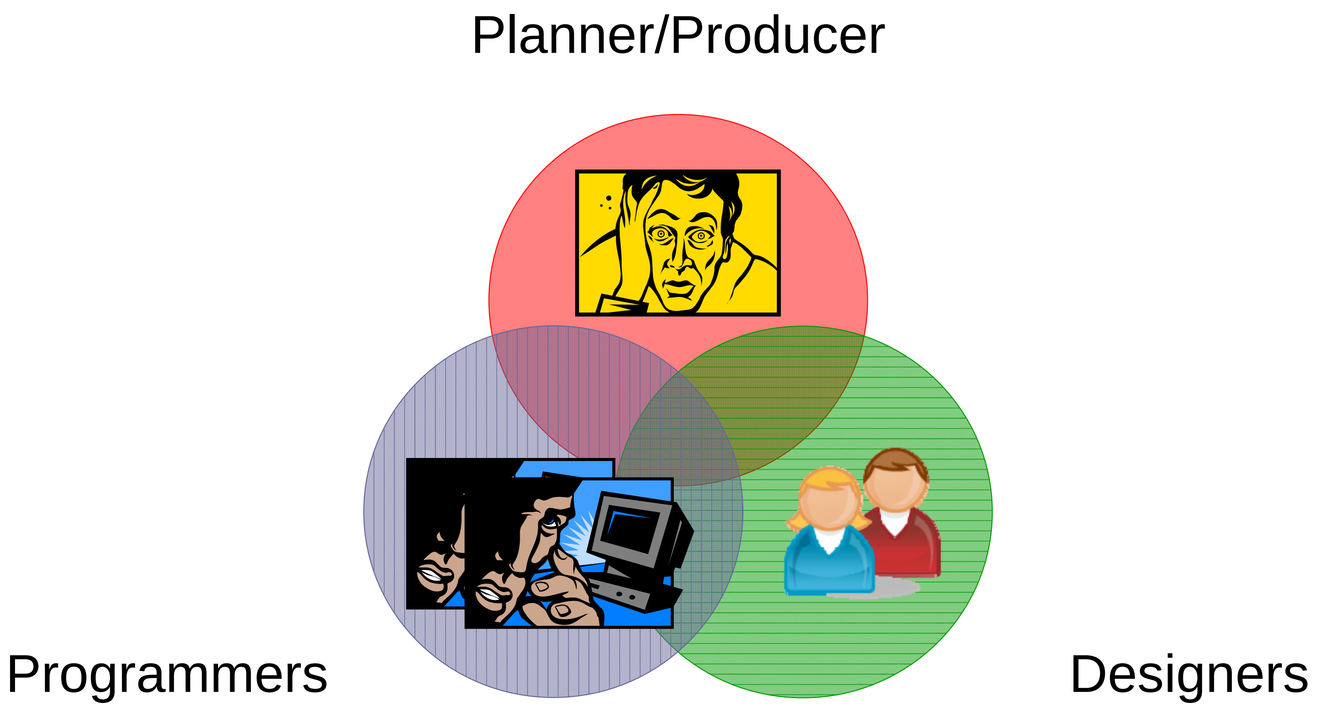


Diagram courtesy of Sean Ellis, ARM.

Screen Image: Sega/Wow Entertainment RealTennis.™

Development Team Structure



Agenda

- J2ME game development
- Tools
- COFFEE BREAK
- The structure of a MIDlet
- A walkthrough a sample game
- Why mobile game development is hard
- Publishing your content

2008 Crete, Greece April 14-18

Tools Agenda

- Tools
  - Creating your assets
  - Programming tools & development platforms

Creating Your Assets: Images

Textures & Backgrounds

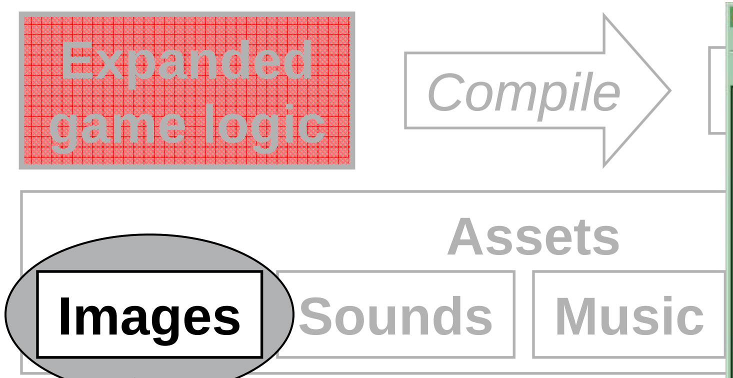
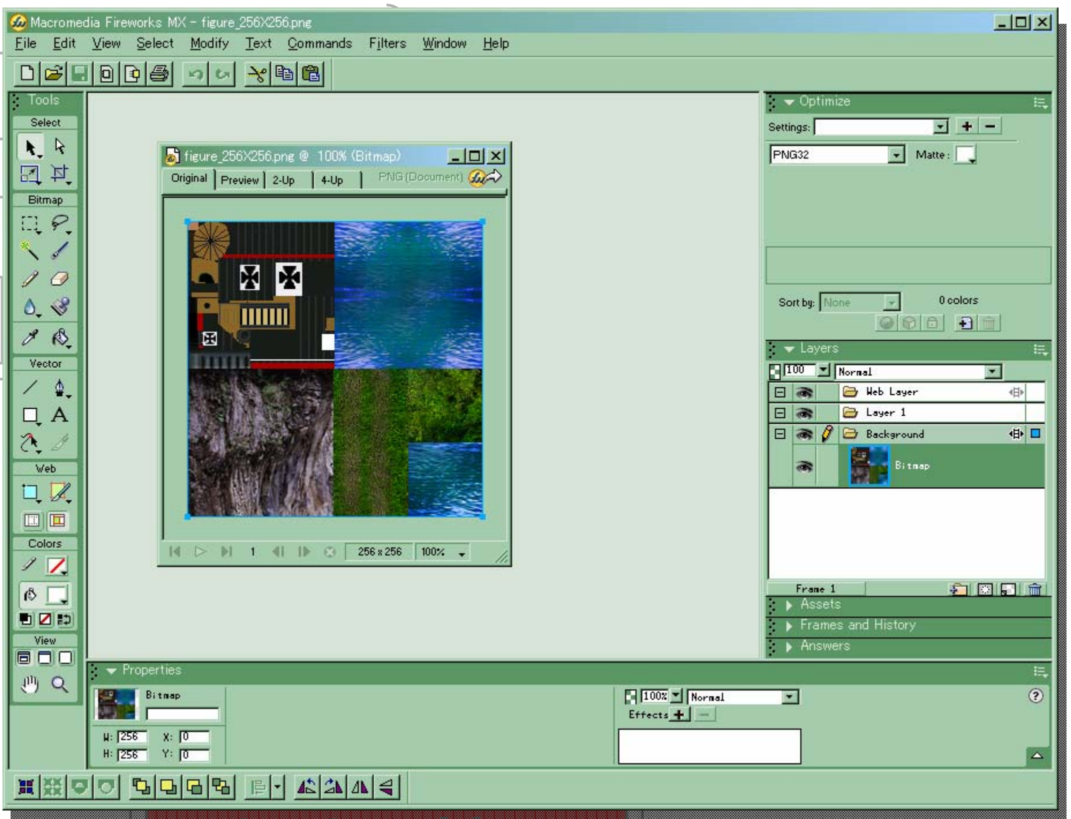


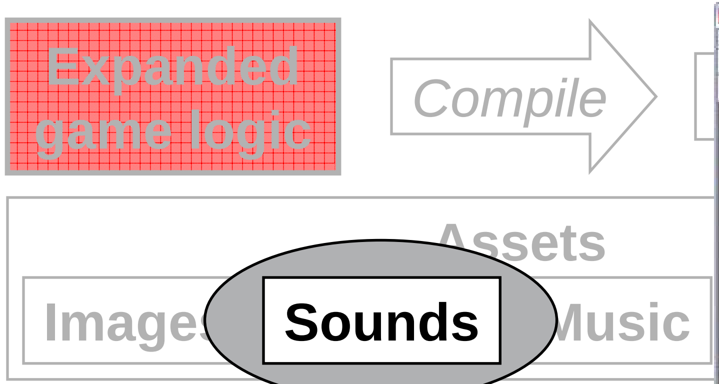
Image Editor with PNG output. E. g:

- •Adobe Fireworks
- •Adobe Photoshop



Creating Your Assets: Sounds

Audio Tools

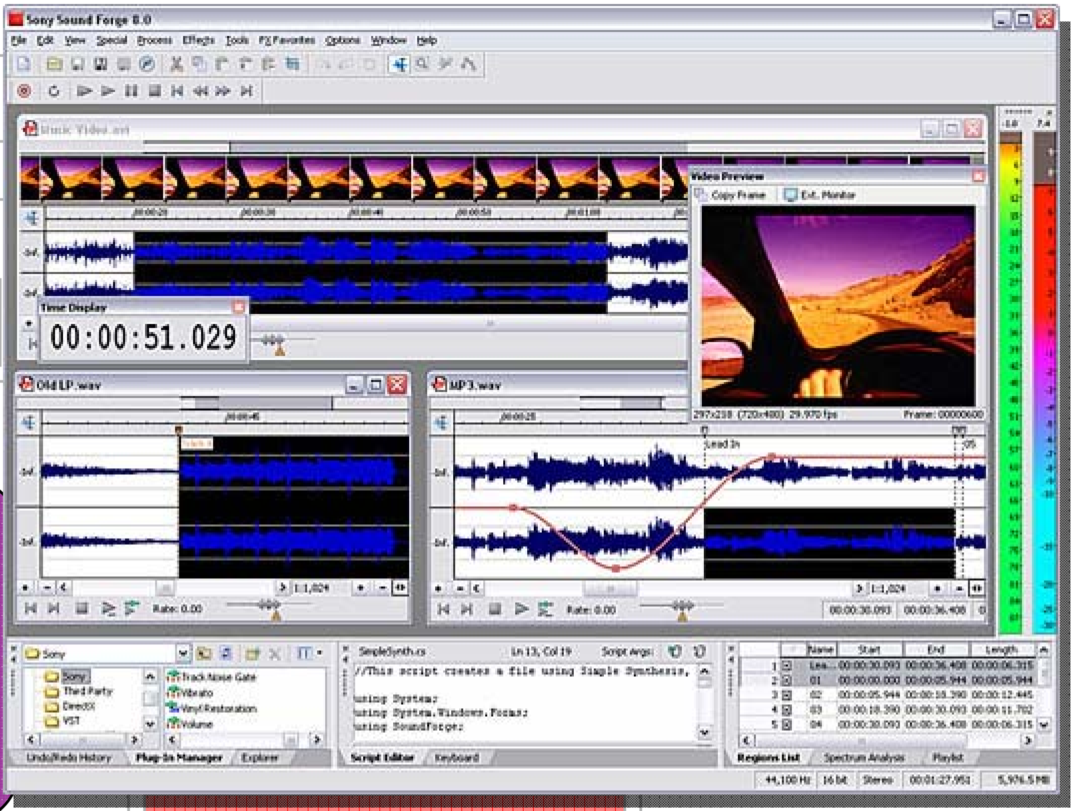


Audio Production Tool; e. g.

- Sony Sound Forge®

Commonly Used Formats:

- WAV, AU, MP3, SMAF

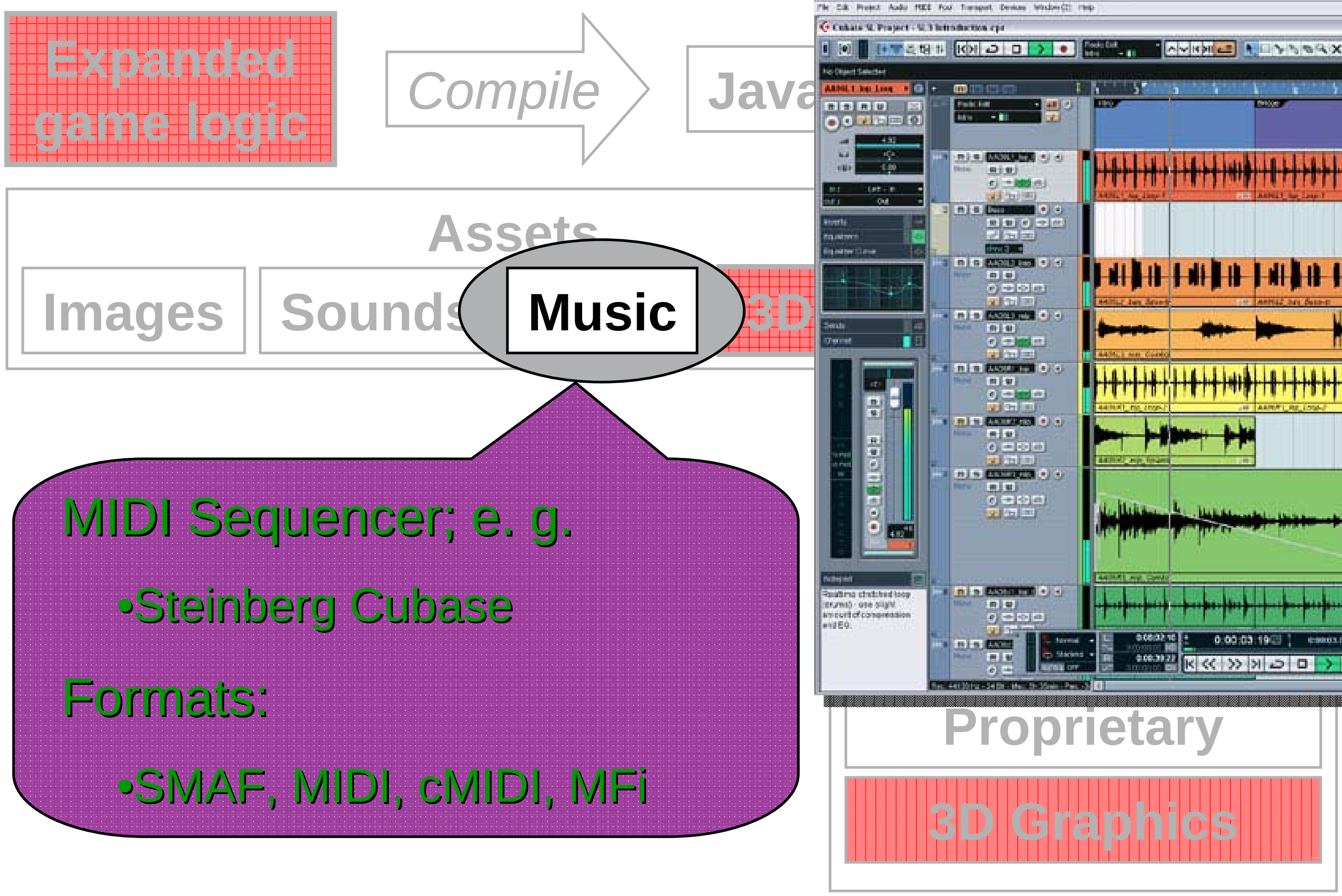


```
//This script creates a file using Simple Synthesis,

using System;
using System.Windows.Forms;
using SoundForge;
```

	Name	Start	End	Length
1	Lea...	00:00:30.093	00:00:36.408	00:00:06.315
2	01	00:00:00.000	00:00:05.944	00:00:05.944
3	02	00:00:05.944	00:00:18.390	00:00:12.445
4	03	00:00:18.390	00:00:30.093	00:00:11.702
5	04	00:00:30.093	00:00:36.408	00:00:06.315

Creating Your Assets: Music

Music Tools



MIDI Sequencer; e. g.

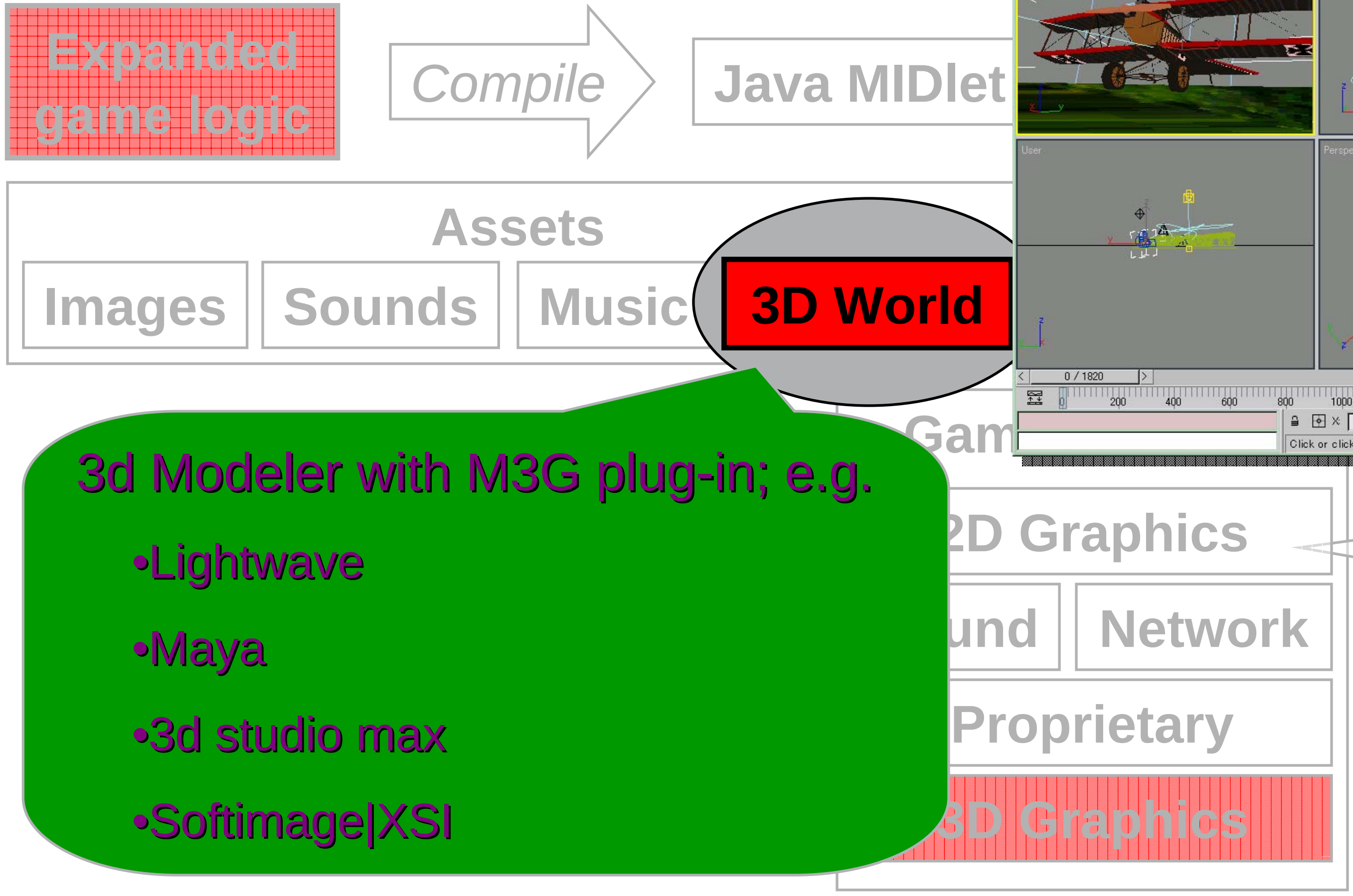
- Steinberg Cubase

Formats:

- SMAF, MIDI, cMIDI, MFi

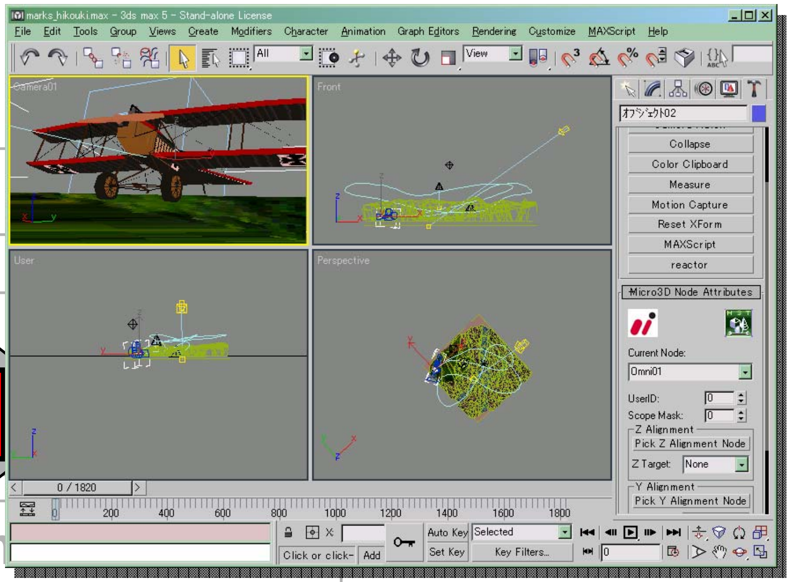
Creating Your Assets: 3d Models

Modeling Tools

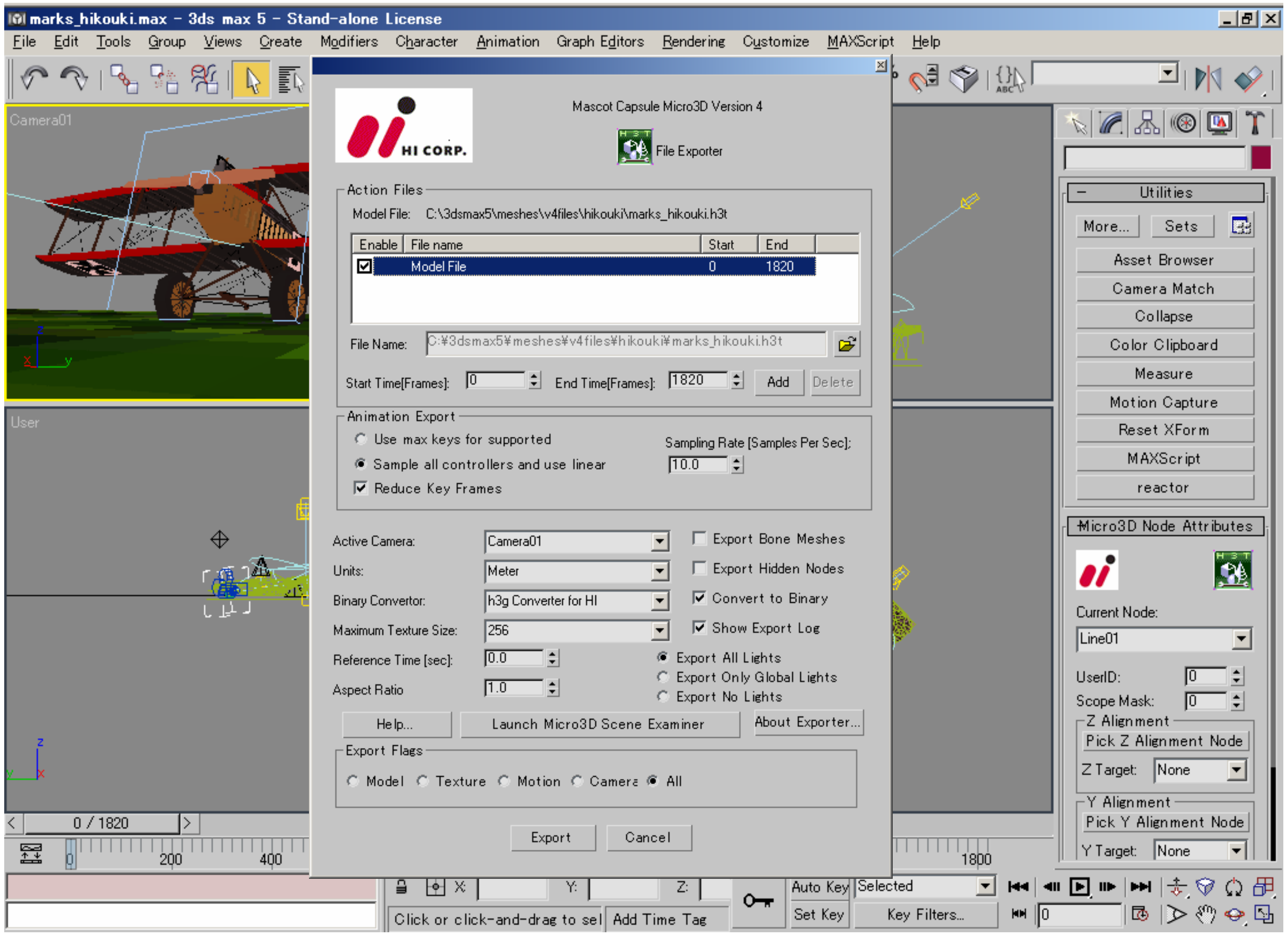


3d Modeler with M3G plug-in; e.g.

- •Lightwave
- •Maya
- •3d studio max
- •Softimage|XSI



Export 3d Model to M3G



Mascot Capsule Micro3D Version 4

File Exporter

Action Files

Model File: C:\3dsmax5\meshes\v4files\hikouki\marks_hikouki.h3t

Enable	File name	Start	End
☑	Model File	0	1820

File Name: C:¥3dsmax5¥meshes¥v4files¥hikouki¥marks_hikouki.h3t

Start Time[Frames]: 0 End Time[Frames]: 1820

Animation Export

- ○ Use max keys for supported
- ● Sample all controllers and use linear
- ☑ Reduce Key Frames

Sampling Rate [Samples Per Sec]: 10.0

Active Camera: Camera01

Units: Meter

Binary Convertor: h3g Converter for HI

Maximum Texture Size: 256

Reference Time [sec]: 0.0

Aspect Ratio 1.0

- ☐ Export Bone Meshes
- ☐ Export Hidden Nodes
- ☑ Convert to Binary
- ☑ Show Export Log
- ● Export All Lights
- ○ Export Only Global Lights
- ○ Export No Lights

Export Flags

○ Model ○ Texture ○ Motion ○ Camera ● All

Current Node: Line01

UserID: 0

Scope Mask: 0

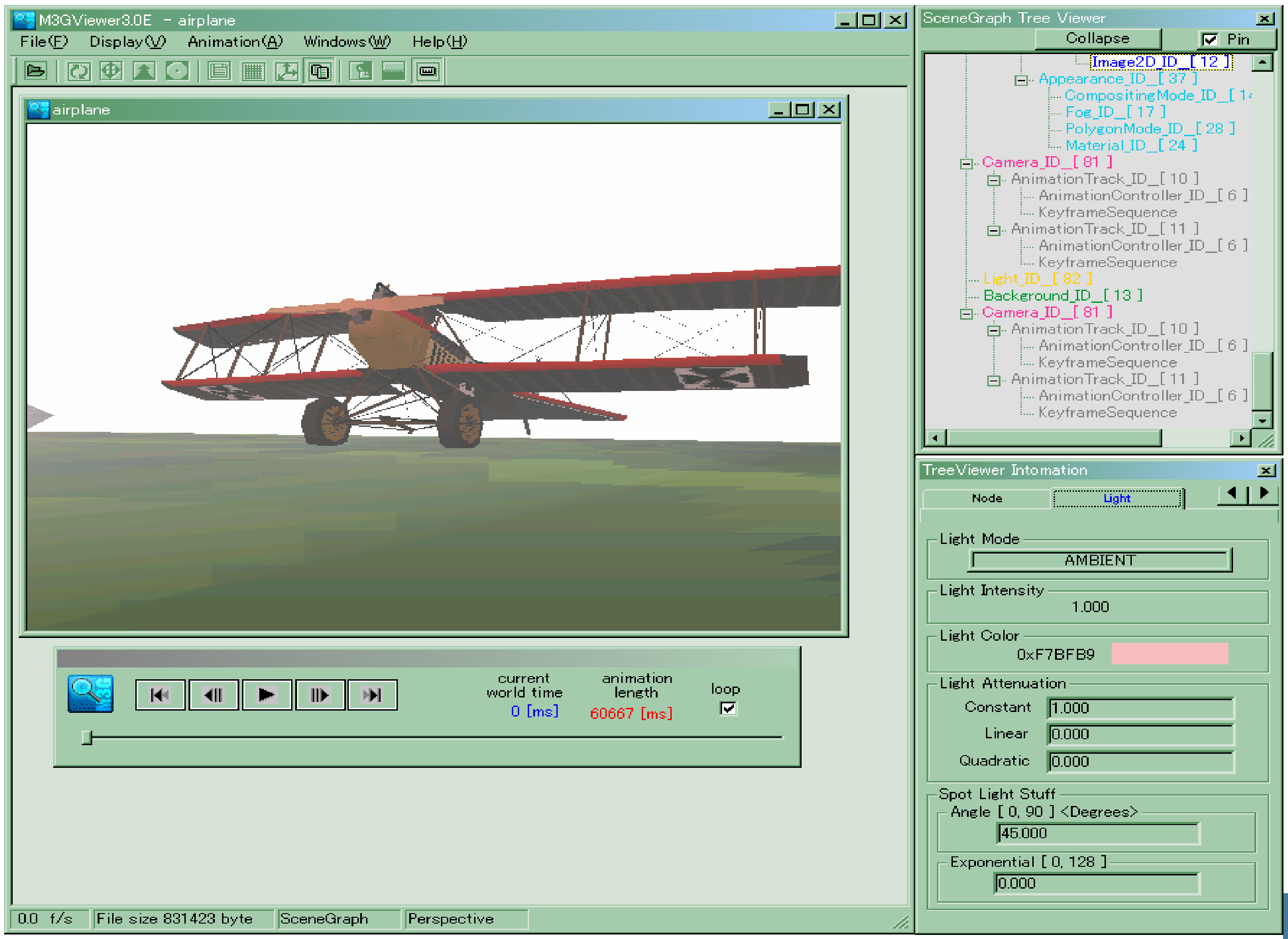
Z Alignment

Z Target: None

Y Alignment

Y Target: None

M3G File Viewer



current world time 0 [ms]
animation length 60667 [ms]
loop ✓

```
Image2D_ID_[ 12 ]
Appearance_ID_[ 37 ]
    CompositingMode_ID_[ 14
    Fog_ID_[ 17 ]
    PolygonMode_ID_[ 28 ]
    Material_ID_[ 24 ]
Camera_ID_[ 81 ]
    AnimationTrack_ID_[ 10 ]
        AnimationController_ID_[ 6 ]
        KeyframeSequence
    AnimationTrack_ID_[ 11 ]
        AnimationController_ID_[ 6 ]
        KeyframeSequence
Light_ID_[ 82 ]
Background_ID_[ 13 ]
Camera_ID_[ 81 ]
    AnimationTrack_ID_[ 10 ]
        AnimationController_ID_[ 6 ]
        KeyframeSequence
    AnimationTrack_ID_[ 11 ]
        AnimationController_ID_[ 6 ]
        KeyframeSequence
```

Light Mode: AMBIENT

Light Intensity: 1.000

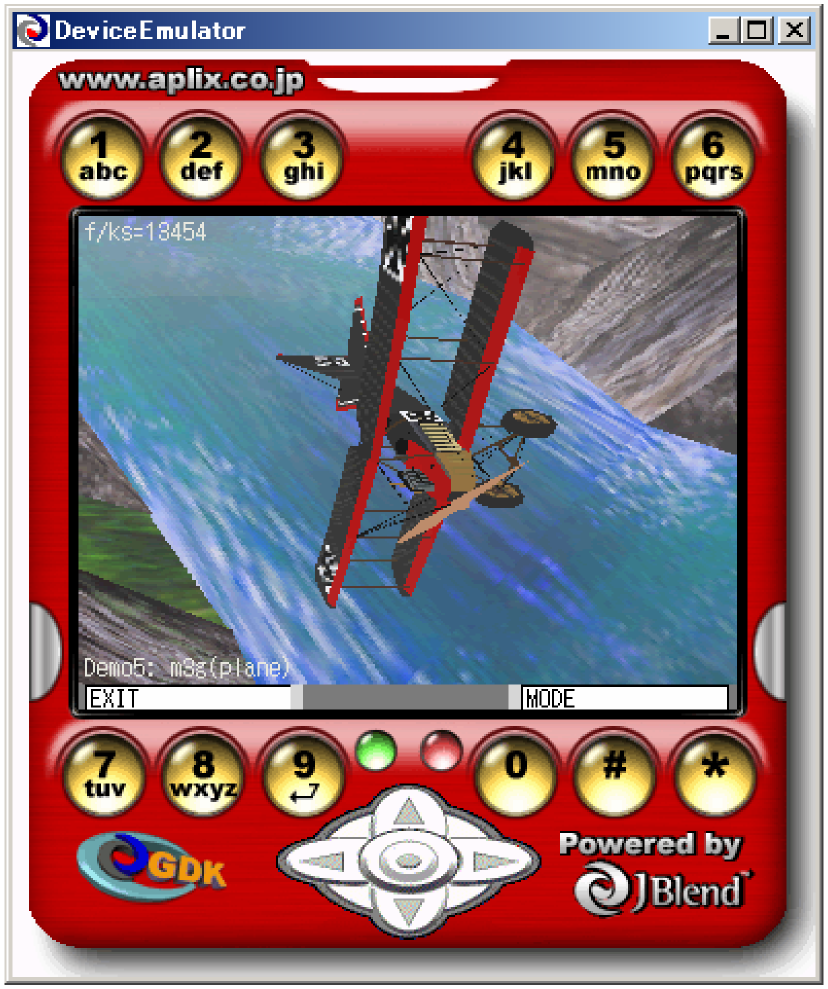
Light Color: 0xF7BFB9

Light Attenuation
- Constant: 1.000
- Linear: 0.000
- Quadratic: 0.000

Spot Light Stuff
- Angle [0, 90] <Degrees>: 45.000
- Exponential [0, 128]: 0.000

0.0 f/s | File size 831423 byte | SceneGraph | Perspective

On an Emulator



Tips for Designers 1

TIP: Don’t use GIF files

- *The specification does not require their support*

TIP: Create the best possible quality audio & music

- It’s much easier to reduce the quality later than increase it

TIP: Polygon reduction tools & polygon counters are your friends

- Use the minimum number of polygons that conveys your vision satisfactorily

Tips for Designers 2

TIP: Use light maps for lighting effects

- Usually faster than per-vertex lighting
- Use luminance textures, not RGB
- Multitexturing is your friend

TIP: Try LINEAR interpolation for Quaternions

- *Faster than SLERP*
- *But less smooth*

Tips for Designers 3

TIP: Favor textured quads over Background & Sprite3D

- Background and Sprite3D will be deprecated in M3G 2.0
- Were intended to speed up software renderers
- but implementation is complex, so not much speed up and no speed up at all with hardware renderers
- Nevertheless Sprite3Ds are convenient to use for 2D overlays and Backgrounds are convenient when background scrolling is required.

LIMITATION: Sprites not useful for particle systems

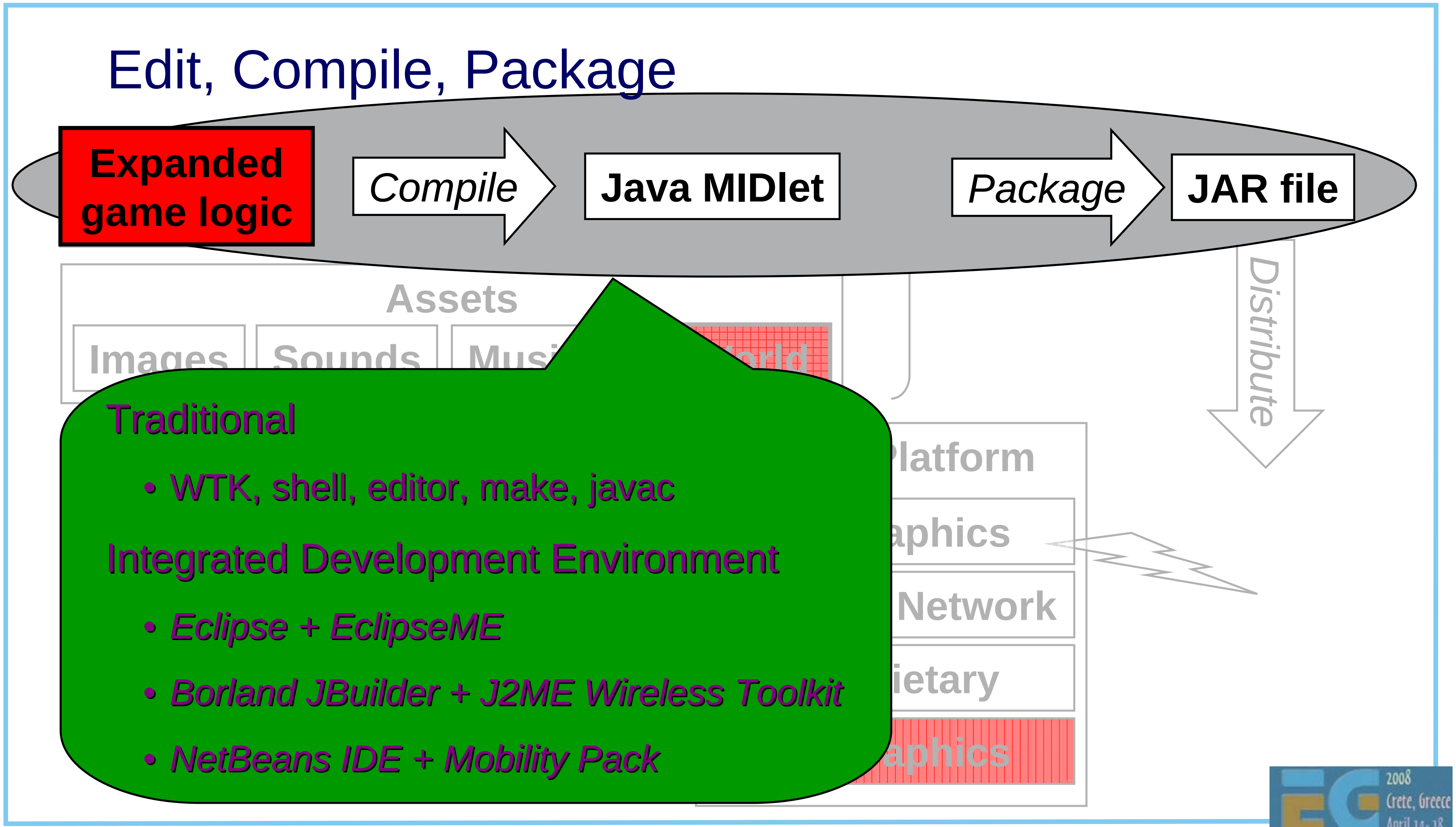
Tools Agenda

Tools

– Creating your assets

Programming tools & development platforms

Program Development



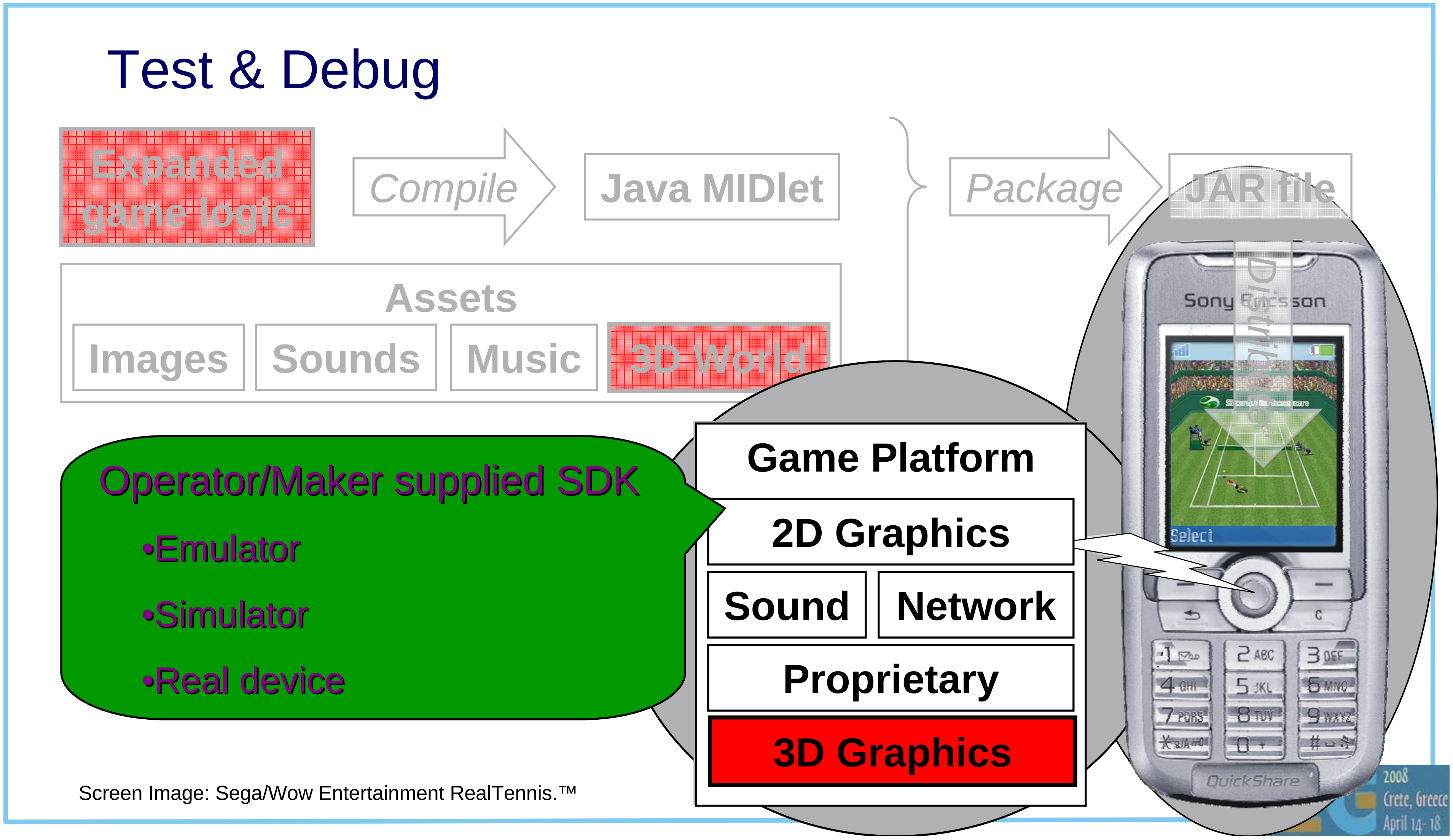
Traditional

- WTK, shell, editor, make, javac

Integrated Development Environment

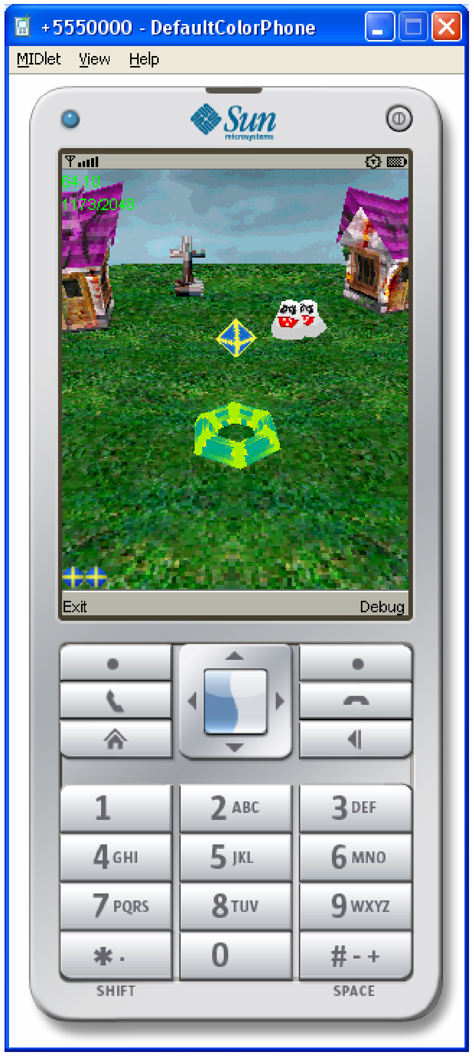
- *Eclipse + EclipseME*
- *Borland JBuilder + J2ME Wireless Toolkit*
- *NetBeans IDE + Mobility Pack*

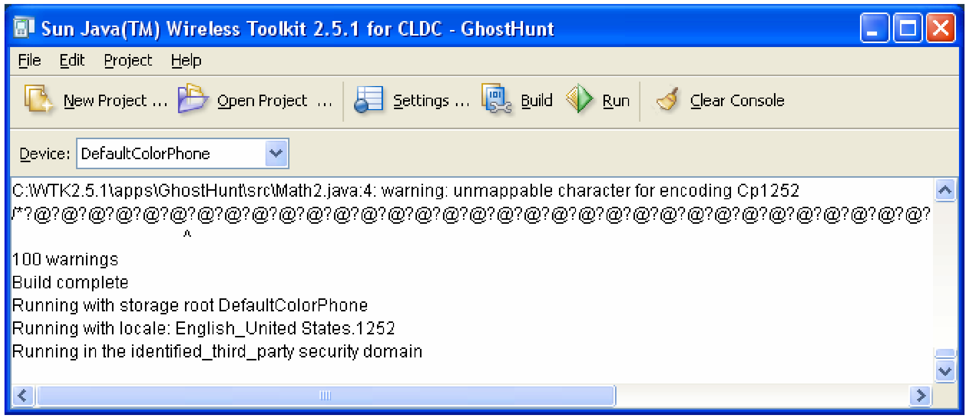
Program Development



Screen Image: Sega/Wow Entertainment RealTennis.™

Java Wireless Toolkit 2.5.1 for CLDC





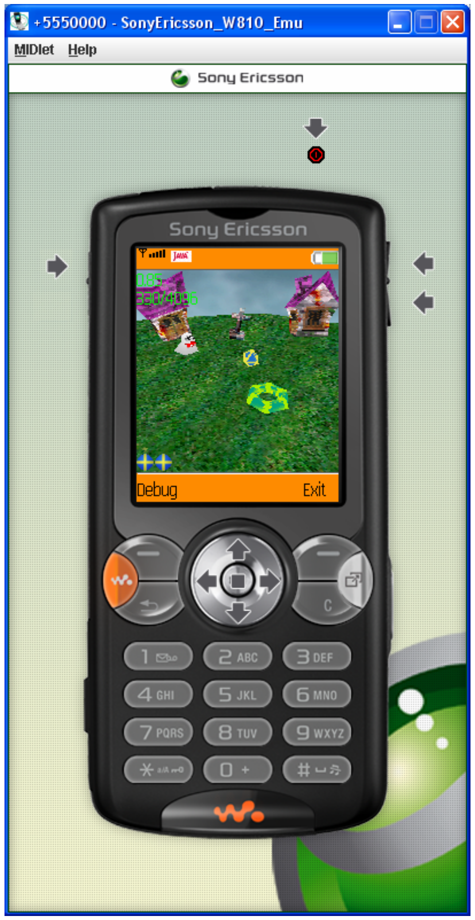
Device: DefaultColorPhone

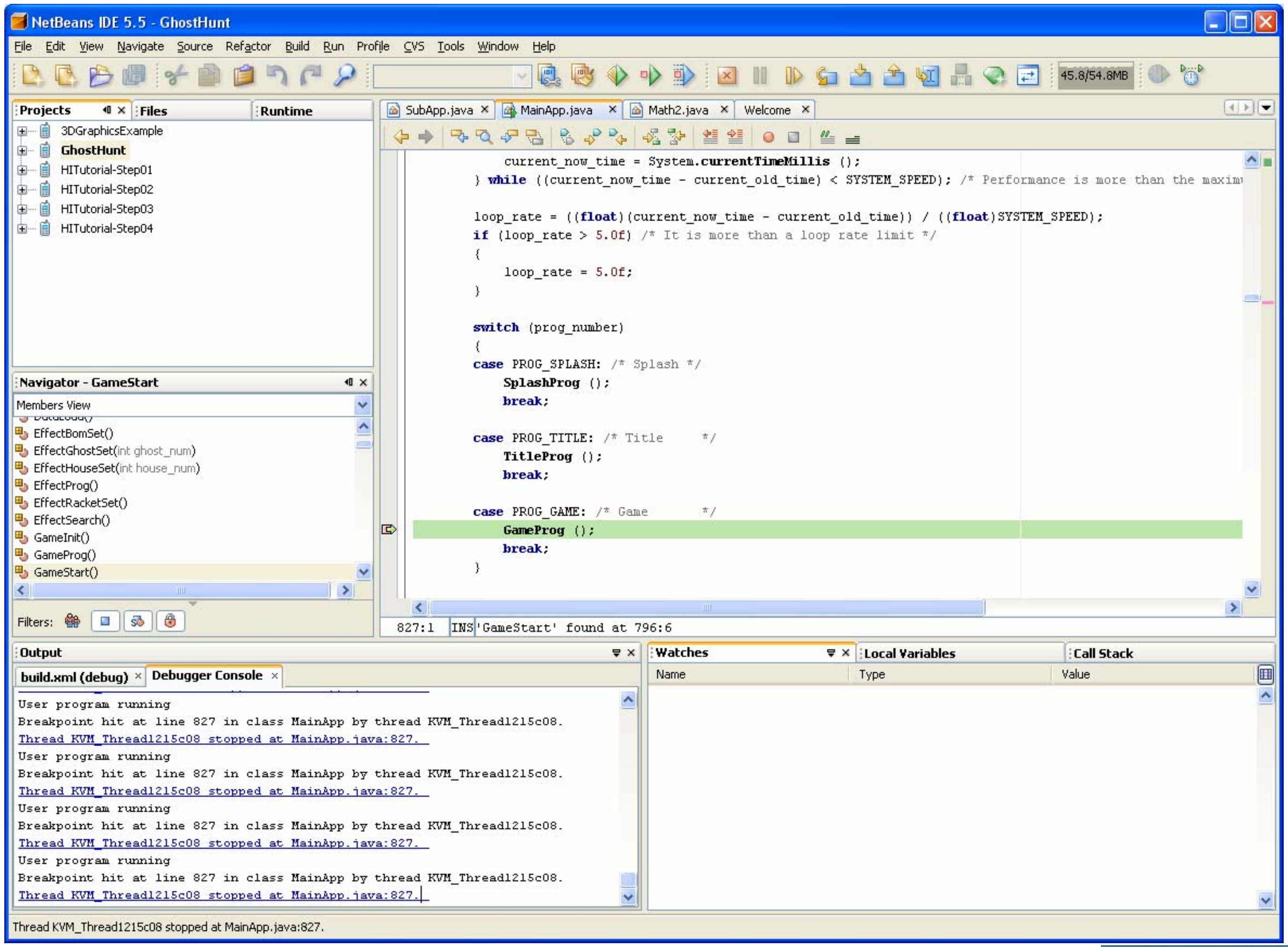
```
C:\WTK2.5.1\apps\GhostHunt\src\Math2.java:4: warning: unmappable character for encoding Cp1252
/*?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?@?
             ^

100 warnings
Build complete
Running with storage root DefaultColorPhone
Running with locale: English_United States.1252
Running in the identified_third_party security domain
```

KToolBar

Handset Emulator

NetBeans + Mobility Pack + SE SDK





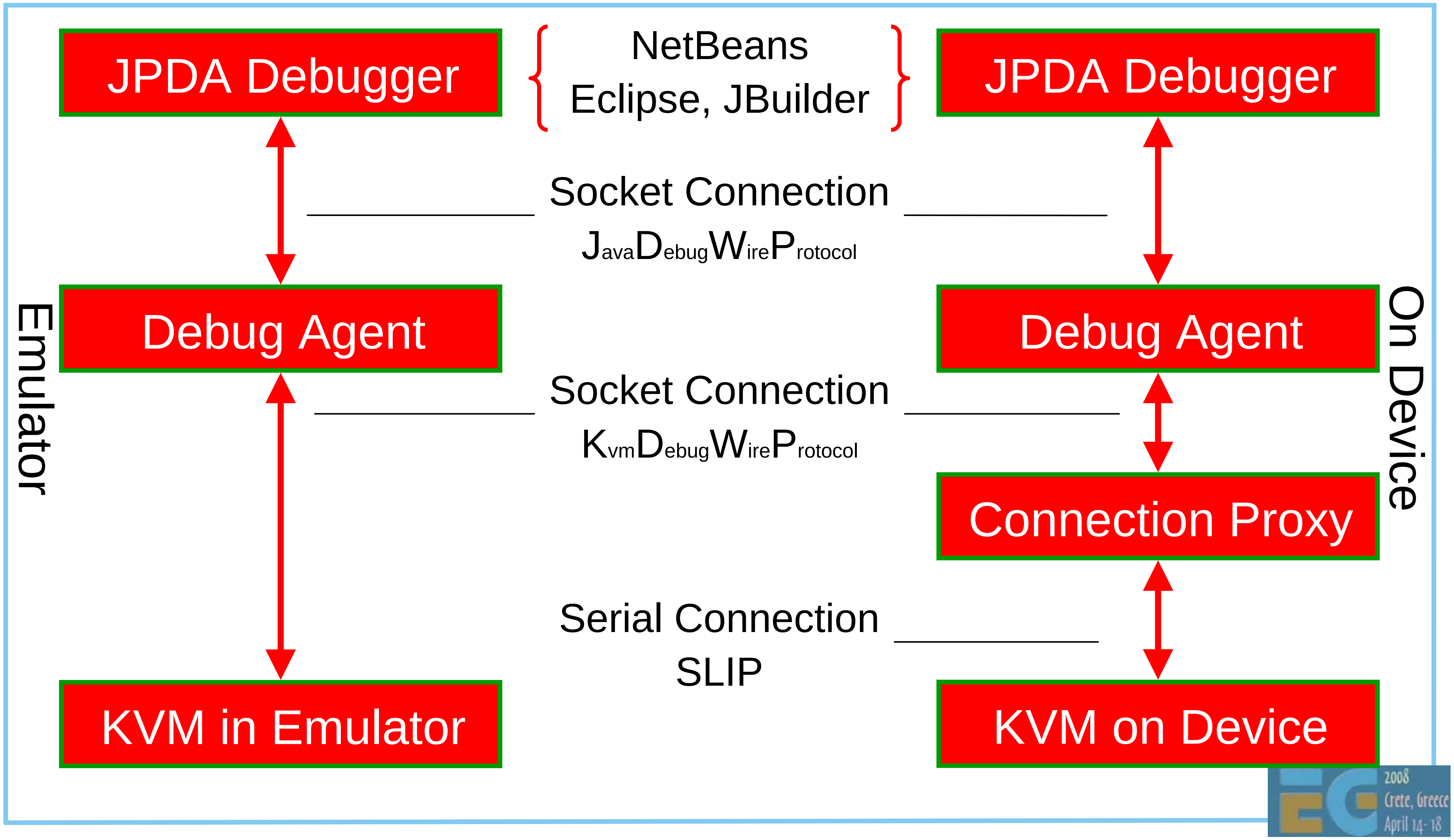
```
            current_now_time = System.currentTimeMillis ();
        } while ((current_now_time - current_old_time) < SYSTEM_SPEED); /* Performance is more than the maxim

        loop_rate = ((float)(current_now_time - current_old_time)) / ((float)SYSTEM_SPEED);
        if (loop_rate > 5.0f) /* It is more than a loop rate limit */
        {
            loop_rate = 5.0f;
        }

        switch (prog_number)
        {
        case PROG_SPLASH: /* Splash */
            SplashProg ();
            break;

        case PROG_TITLE: /* Title     */
            TitleProg ();
            break;

        case PROG_GAME: /* Game       */
            GameProg ();
            break;
        }
```

```
827:1  INS 'GameStart' found at 796:6
```

```
User program running
Breakpoint hit at line 827 in class MainApp by thread KVM_Thread1215c08.
Thread KVM_Thread1215c08 stopped at MainApp.java:827.
User program running
Breakpoint hit at line 827 in class MainApp by thread KVM_Thread1215c08.
Thread KVM_Thread1215c08 stopped at MainApp.java:827.
User program running
Breakpoint hit at line 827 in class MainApp by thread KVM_Thread1215c08.
Thread KVM_Thread1215c08 stopped at MainApp.java:827.
User program running
Breakpoint hit at line 827 in class MainApp by thread KVM_Thread1215c08.
Thread KVM_Thread1215c08 stopped at MainApp.java:827.
```

Thread KVM_Thread1215c08 stopped at MainApp.java:827.

Java Debugging



Agenda

- J2ME game development
- Tools

COFFEE BREAK

- The structure of a M
- A walk through a sa me
- Why mobile game d nt is hard
- Publishing your content

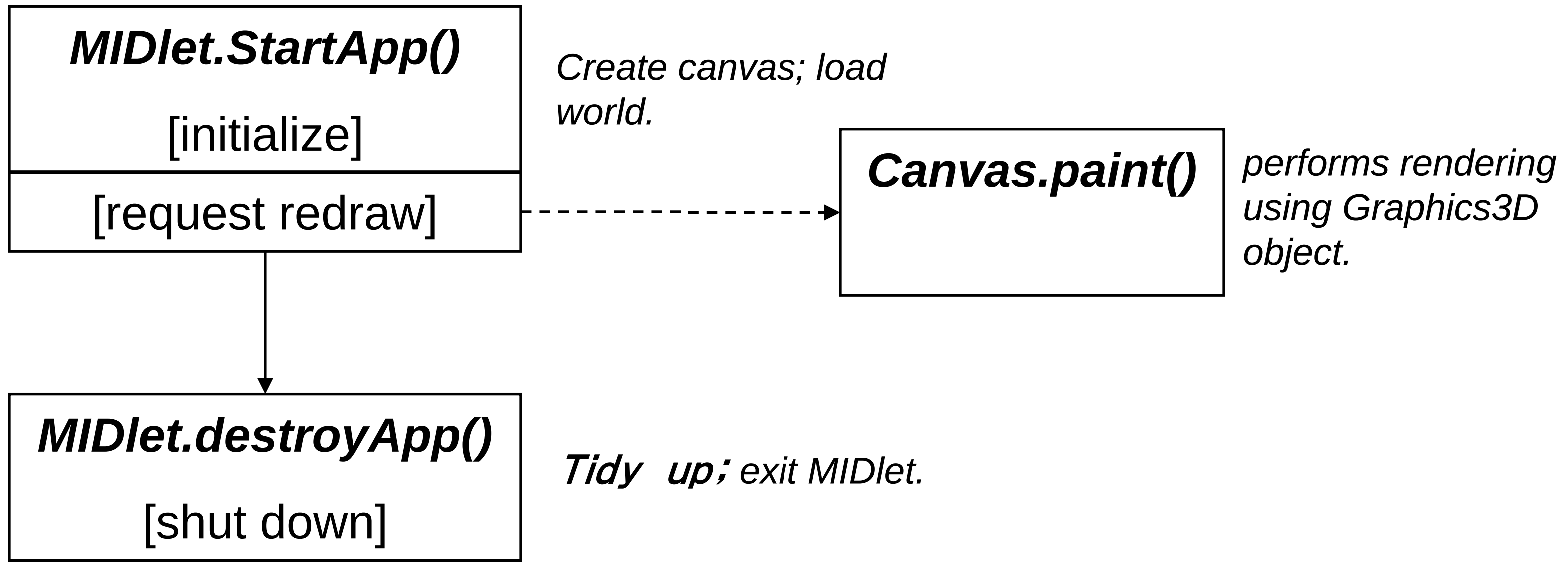
Agenda

- J2ME game development
- Tools
- COFFEE BREAK
- The structure of a MIDlet
- A walk through a sample game
- Why mobile game development is hard
- Publishing your content

The Simplest MIDlet

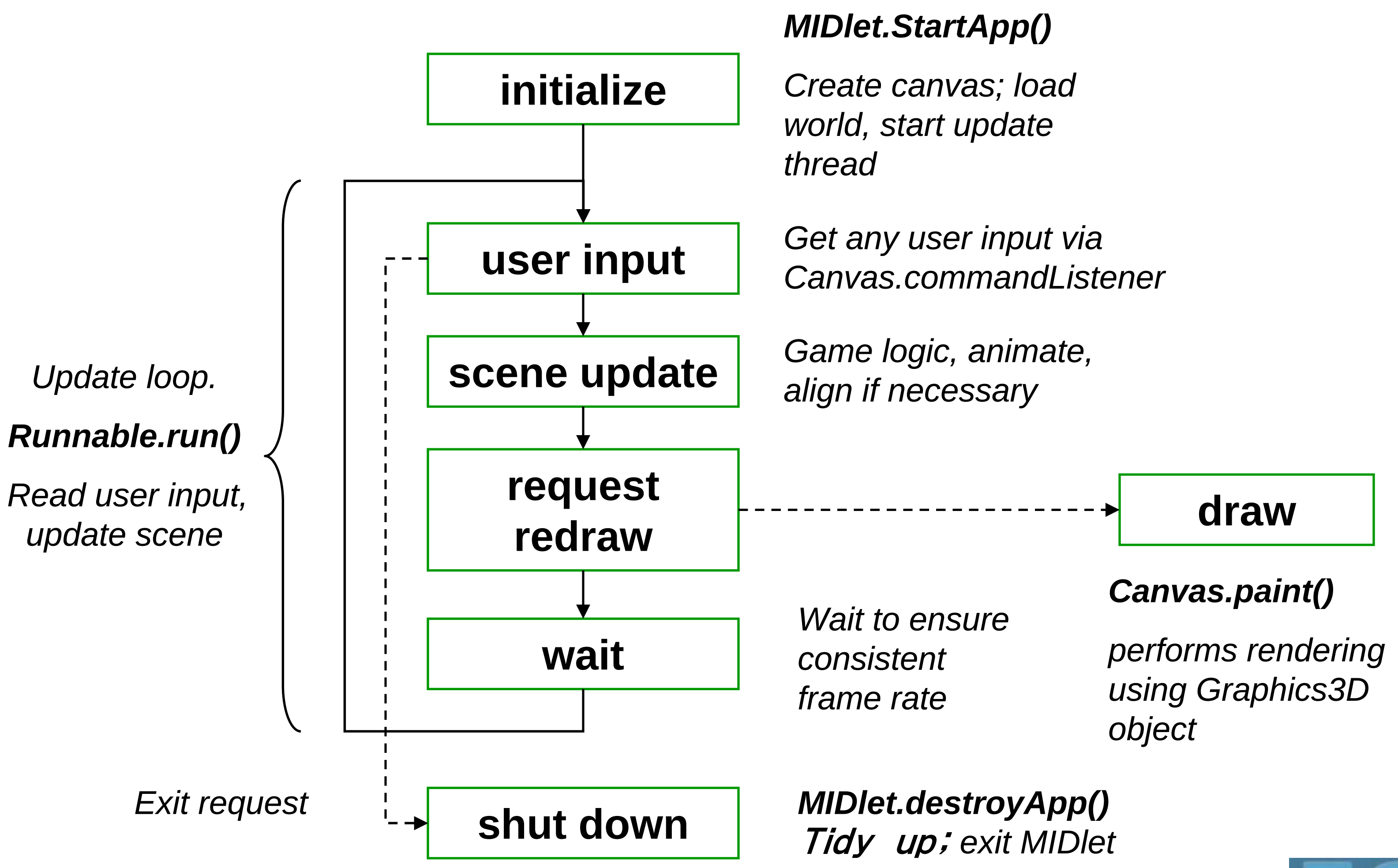
Derived from MIDlet,

Overrides three methods



And that's it.

A More Interesting MIDlet



MIDlet.StartApp()
initialize
Create canvas; load world, start update thread
user input
Get any user input via Canvas.commandListener
scene update
Game logic, animate, align if necessary
Update loop.
Runnable.run()
Read user input, update scene
request redraw
draw
Canvas.paint()
performs rendering using Graphics3D object
wait
Wait to ensure consistent frame rate
Exit request
shut down
MIDlet.destroyApp()
Tidy up; exit MIDlet

Flow-chart courtesy of Sean Ellis, ARM

MIDlet Phases

Initialize

Update

Draw

Shutdown

Initialize

Load assets: world, other 3D objects, sounds, etc.

Find any objects that are frequently used

Perform game logic initialization

Initialize display

Initialize timers to drive main update loop

Update

Usually a thread driven by timer events

Get user input

Get current time

Run game logic based on user input

Game logic updates world objects, if necessary

Animate

Request redraw

Update Tips

TIP: Don’t create or release objects if possible

TIP: Call system.gc() *regularly to avoid long pauses*

TIP: cache any value that does not change every frame; compute only what is absolutely necessary

Draw

Usually on overridden paint method

Bind Graphics3D to screen

Render 3D world or objects

Release Graphics3D

  …whatever happens!

Perform any other drawing (UI, score, etc)

Request next timed update

Draw Tips

TIP: Don’t do 2D drawing while Graphics3D is bound

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Shutdown

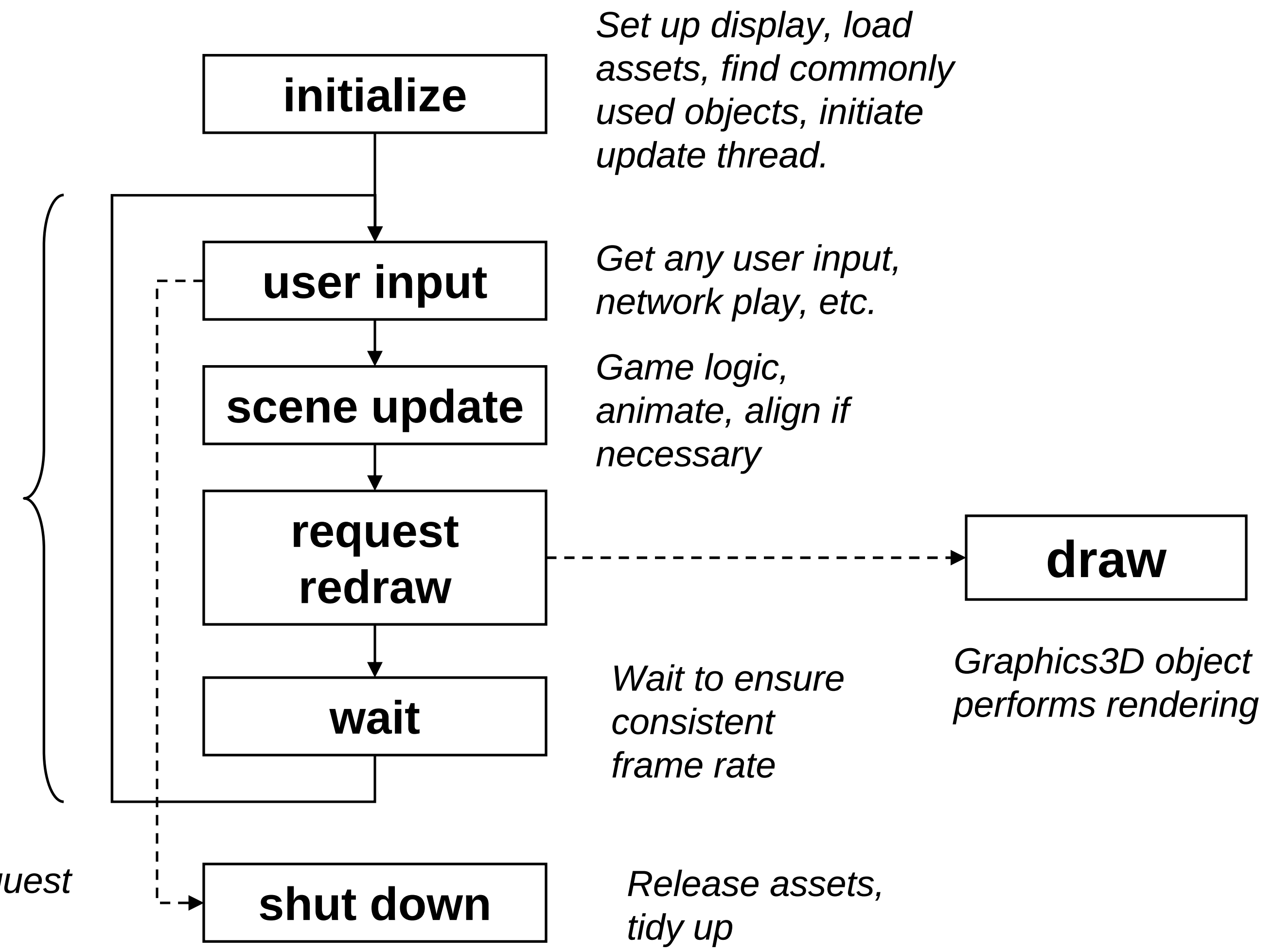
Tidy up all unused objects

Ensure once again that Graphics3D is released

Exit cleanly

Graphics3D should also be released during pauseApp

MIDlet Review



Set up display, load assets, find commonly used objects, initiate update thread.

Update loop.

Don't create/destroy objects if possible

Throttle to consistent frame rate

Keep paint() as simple as possible

Be careful with threads

Get any user input, network play, etc.

Game logic, animate, align if necessary

Wait to ensure consistent frame rate

Graphics3D object performs rendering

Exit request

Release assets, tidy up

Diagram courtesy of Sean Ellis, ARM

Agenda

- J2ME game development
- Tools
- COFFEE BREAK
- The structure of a MIDlet
- A walk through a sample game
- Why mobile game development is hard
- Publishing your content

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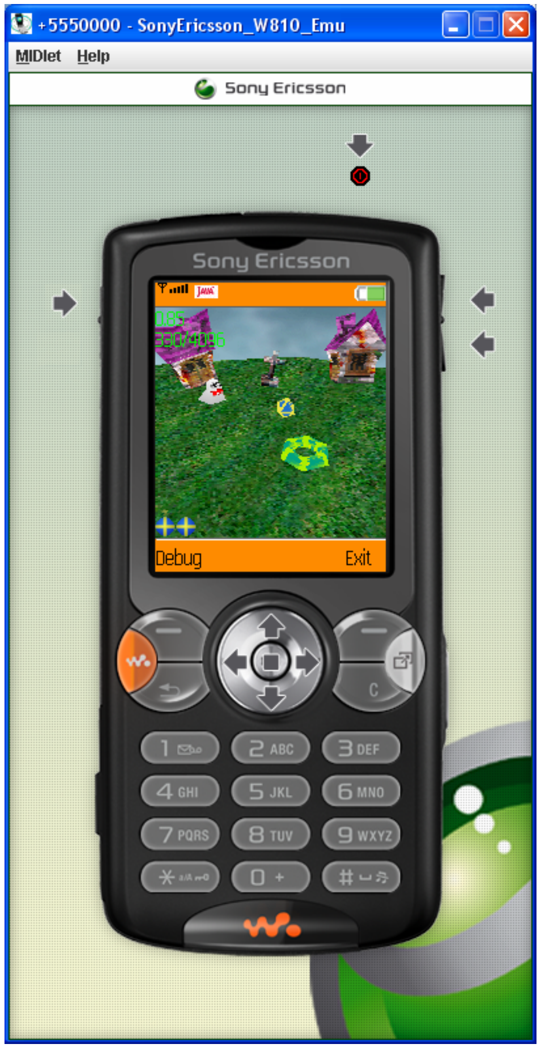
Demo: *GhostHunt*



GhostHunt

Arrow keys move a “plasma” racquet side to side to hit a “plasma” ball

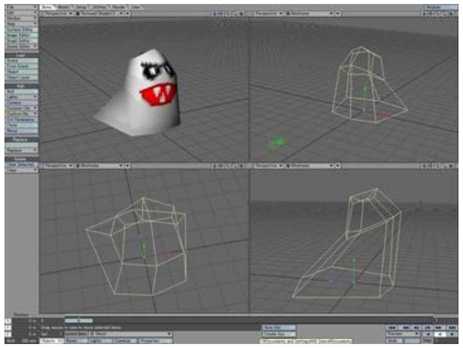
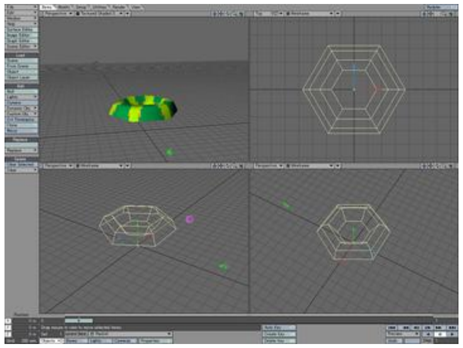
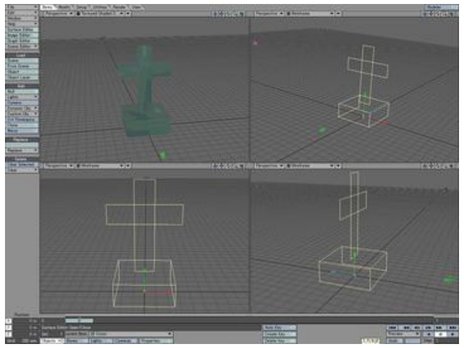
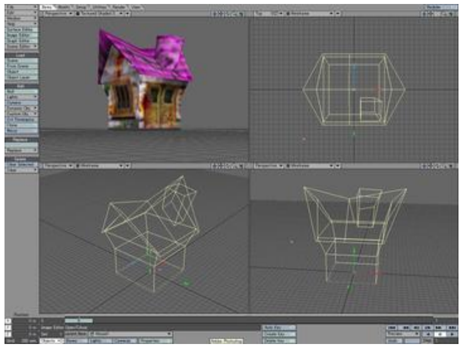
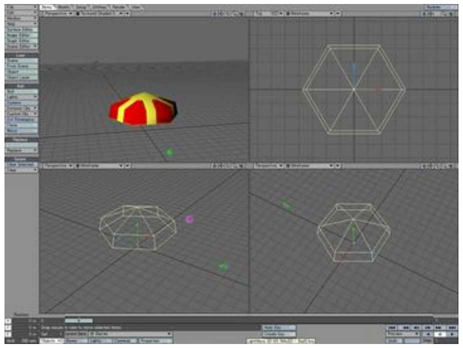
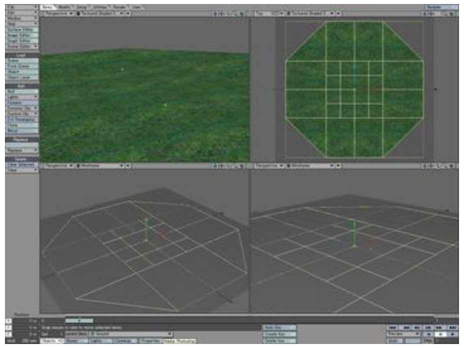
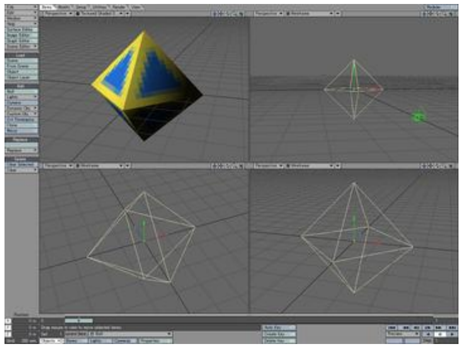
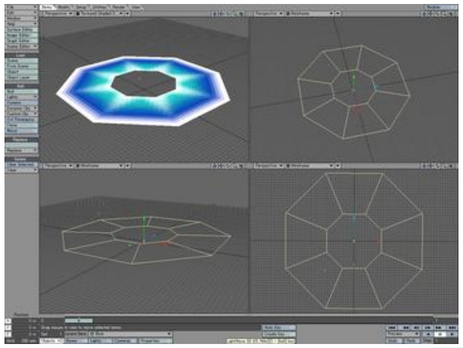
Ball hits deform ghost houses and make the ghosts disappear

Loads data from .m3g and .png files

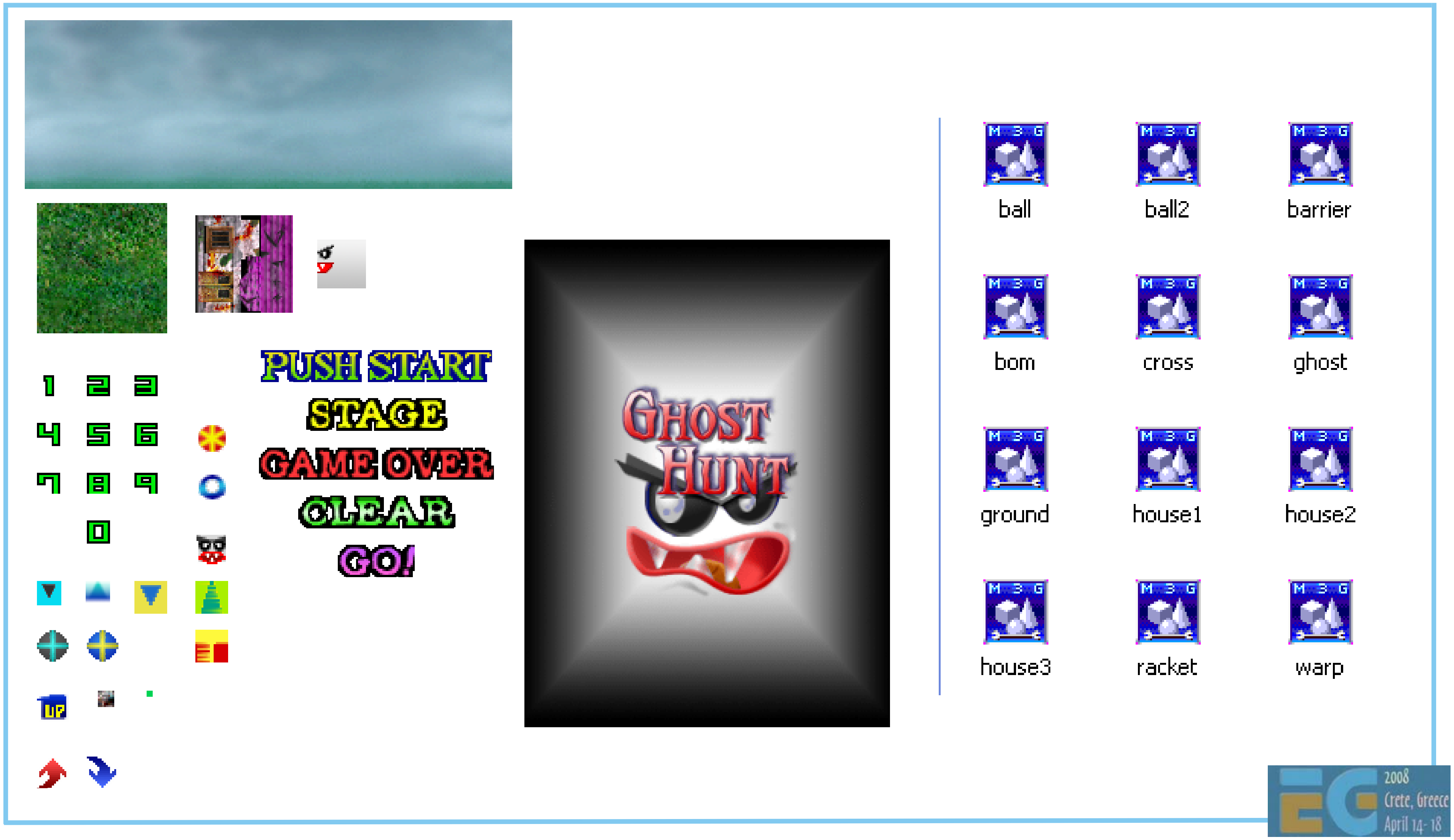
Uses Immediate mode

Uses 2D for sky and scores

GhostHunt Models

GhostHunt Assets



GhostHunt Framework

MainApp.java – MIDlet specialization; handles initialization & data loading; contains run thread

SubApp.java – canvas specialization

Math2.java – math library

GhostHunt: initialization

```
import javax.microedition.midlet.*;
import javax.microedition.lcdui.*;
import javax.microedition.m3g.*;

class MainApp extends MIDlet implements CommandListener {
  MainApp() {
    exit_command   = new Command("Exit" , Command.EXIT  , 0);
    select_command = new Command("Debug", Command.SCREEN, 0);

     /* Create canvas */
    subapp = new SubApp ();
    subapp.addCommand (exit_command);
    subapp.addCommand (select_command);
    subapp.setCommandListener (this);

    SystemInit ();
    prog_number = PROG_SPLASH;
    WorkInit ();
    GameInit ();
    DataLoad ();
 }
```

GhostHunt: loading data

```
DataLoad() {
  try {
    image [TITLE_SP] = Image.createImage ("/title.png");
    …
  } catch (Exception e) {
    System.out.println ("-------------- SP Load");
    ApplicationEnd ();
  }

  try {
    load_data [RACKET_DATA] = Loader.load("/racket.m3g");
  } catch (Exception e) {
    …
  }
  mesh [RACKET_DATA] = (Mesh)load_data [RACKET_DATA][0];
  vbuf [RACKET_DATA] = mesh [RACKET_DATA].getVertexBuffer();
  ibuf [RACKET_DATA] = mesh [RACKET_DATA].getIndexBuffer(0);
  app  [RACKET_DATA] = mesh [RACKET_DATA].getAppearance(0);
  …
}
```

GhostHunt: MIDlet functions

```
public void startApp () {
  thread = new Thread () {
    public void run () {
      GameStart ();
    }
  };
  // Call the new thread’s run method.
  thread.start ();
}

public void pauseApp ()
{
    thread = null;
}

public void destroyApp (boolean unconditional)
{
    ApplicationEnd();
}
```

GhostHunt: GameStart thread

```
void GameStart () {
  Thread thisThread = Thread.currentThread();
  Display.getDisplay (this).setCurrent (subapp);
  while (thread == thisThread) {
    prev_time = now_time;
    do {
      now_time = System.currentTimeMillis ();
    } while ((now_time - prev_time) < SYSTEM_SPEED);
    loop_rate = (now_time - prev_time) / SYSTEM_SPEED;
    if (loop_rate > 5.0f) { /* More than loop rate limit */
      loop_rate = 5.0f;
    }
        /* do game stuff here … */
    try {
      Thread.sleep (1);
    } catch (InterruptedException e) {
      ApplicationEnd ();
    }
  }
}
```

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GhostHunt: “do game stuff here ...”

```
void GameStart () {
  …
  switch (prog_number) {
    case PROG_SPLASH: /* Splash */
      SplashProg ();
     break;
   case PROG_TITLE: /* Title     */
      TitleProg ();
     break;
   case PROG_GAME: /* Game       */
     GameProg ();
     break;
  }
  …
}
```

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GhostHunt: TitleProg

```
void TitleProg ()
{
  key_dat = subapp.sys_key; /* Get keypresses */

  if ((key_dat & KEY_FIRE) != 0) /* it is fire key */
  {
    racket_tx = 0.0f;
    racket_tz = 0.0f; /* for initializing camera */
    WorkInit ();
    GameInit ();
   …
    prog_number = PROG_GAME;
  }

/*------ Updating------*/
  start_loop++;

/*------ Drawing ------*/
  subapp.repaint ();
}
```

SubApp: *GhostHunt's* Canvas

```
public class SubApp extends Canvas {
  int cnt;
  static int keydata [] = { UP, LEFT, RIGHT, DOWN, FIRE };
  int length = keydata.length;

  static int sys_key = 0;

  synchronized public void paint (Graphics graphics) { }

  …

  protected void keyPressed (int key) { }

  protected void keyRepeated (int key) { }

  protected void keyReleased (int key) { }
}
```

GhostHunt: key handling

```
static int keydata [] = { UP, LEFT, RIGHT, DOWN, FIRE };

protected void keyPressed (int key) {
  for (cnt = 0; cnt < length; cnt++) { /* Search key data.
   */
    if (getGameAction (key) == keydata [cnt]) {
      sys_key |= (1 << cnt);
    }
  }
}

protected void keyReleased (int key) {
  for (cnt = 0; cnt < length; cnt++) { /* Search key data.
   */
    if (getGameAction (key) == keydata [cnt]) {
      sys_key &= (~(1 << cnt));
    }
  }
}
```

SubApp *paint* Method

```
synchronized public void paint (Graphics graphics) {
/*------- select drawing process ------*/
   switch (MainApp.prog_number)
   {
   case MainApp.PROG_SPLASH:
        SplashDraw (graphics);  /* Splash */
        break;

   case MainApp.PROG_TITLE:
        TitleDraw (graphics);   /* Title  */
        break;

   case MainApp.PROG_GAME:
        GameDraw (graphics);    /* Game */
        break;
   }

   Math2.Rand ();
}
```

GameDraw

```
void GameDraw (Graphics graphics)
{
    …
   graphics.drawImage (MainApp.image[MainApp.BG_SP], 0, 0,
    Graphics.TOP | Graphics.LEFT); /* 2D background sprite */

   MainApp.g3d.bindTarget (graphics);
   MainApp.g3d.clear (MainApp.background);

   /*------ camera setup ------*/
   …
   /*------ draw 3D objects ------*/
   …

   MainApp.g3d.releaseTarget ();

   /*------ draw score, items etc. in 2D ------*/
   …
}
```

GameDraw: camera set-up

```
MainApp.ctrans.setIdentity();
MainApp.ctrans.postTranslate( MainApp.camera_tx,
                              MainApp.camera_ty,
                              MainApp.camera_tz );
MainApp.ctrans.postRotate( MainApp.camera_ry,
                           0.0f, 1.0f, 0.0f );
MainApp.ctrans.postRotate( MainApp.camera_rx,
                           1.0f, 0.0f, 0.0f );
MainApp.ctrans.postRotate( MainApp.camera_rz,
                           0.0f, 0.0f, 1.0f );

MainApp.g3d.setCamera( MainApp.camera, MainApp.ctrans );
```

GameDraw: draw 3d objects

```
for (count = 0; count != MainApp.GHOST_MAX; count++)
{
  if (MainApp.ghost_draw_flag [count] != 0) {
    data  = count * 2;
    x     = MainApp.ghost_xz [data + 0];
    z     = MainApp.ghost_xz [data + 1];
    r     = MainApp.ghost_r  [count   ];
    trans = MainApp.trans[MainApp.GHOST_M + count];

    trans.setIdentity   ();
    trans.postTranslate (x, 0.0f, z);
    trans.postRotate    (r, 0.0f, 1.0f, 0.0f);
    trans.postScale     (MainApp.ghost_scale [count],
                         MainApp.ghost_scale [count],
                         MainApp.ghost_scale [count]);

    MainApp.g3d.render (MainApp.vbuf [MainApp.GHOST_DATA],
                        MainApp.ibuf [MainApp.GHOST_DATA],
                        MainApp.app  [MainApp.GHOST_DATA],
                        trans);
  }
}
```

GameProg

```
void GameProg() {
  key_dat_old = key_dat; /*---- Get key data ----*/
  key_dat     = subapp.sys_key;

  CameraWorldSet ();
  if (Math2.DistanceCalc2D (0.0f, 0.0f, ball_tx,
   ball_tz) > 1.5f) {
    CameraSet (15.0f * (1.0f / loop_rate));
  }

  if (freeze_time == 0) /* The Game is not frozen */ {
    /*------- do game calculations ------*/
    …
  }
  EffectProg ();
  subapp.repaint ();
  …
}
```

GameProg: do game calculations

```
   RacketProg (key_dat, key_dat_old); /*-- Plasma Racket --*/

   if (racket_break_flag != 1) /*- Racket not destroyed -*/
     BallProg ();

   GhostProg ();

   if (racket_break_flag != 1) /*- Racket not destroyed -*/ {
     BallHit          ();      /*--- Collision Decision ---*/
     RacketBreakCheck ();
   }

   house = HouseCheck (); /*------ Final Check ------*/
   if (house == 0)  /* All ghost houses are destroyed. */ {
     /*------ make all remaining ghosts disappear ------*/
     …
     freeze_time = (int)(MOJI_CLEAR_WAIT * (1.0f/loop_rate));
     moji_number = MOJI_CLEAR;
   }
 }
```

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BallProg: compute new ball position

```
void BallProg () {
  …
  ball_speed_rate = ball_speed * loop_rate;

  dis = Math2.DistanceCalc2D(ball_tx, ball_tz, 0.0f, 0.0f);
  pd = Math2.DistanceCalc2D(ball_tx2, ball_tz2, 0.0f, 0.0f);
  if ((dis > 2.0f) && pd > dis)) /* Homing is necessary */ {
    angle = Math2.AngleCalc (ball_tx, ball_tz, 0.0f, 0.0f);
    if (Math2.DiffAngleCalc (angle, ball_vec) > 0.0f) {
      ball_vec -= (0.6f * loop_rate);
     } else {
      ball_vec += (0.6f * loop_rate);
     }
   }
   Math2.RotatePointCalc (ball_speed_rate, ball_vec);
   ball_tx2 = ball_tx; /* Save the previous coordinates */
   ball_tz2 = ball_tz;
   ball_tx += Math2.calc_x;
   ball_tz += Math2.calc_y;
}
```

BallHit

```
void BallHit () {
  …
  /*------ racket collision detection ------*/
  …
  /*------ ghost house collision detection ------*/
  …
  /*------ ghost collision detection ------*/
  …
  /*------ obstacle (cross) collision detection ------*/
  …
  /*------ warp hole collision detection ------*/
  …
  /*------ check for outside the field ------*/
  …
}
```

BallHit: racket collision detection

```
void BallHit () {
  …   /* final static int Math2.ANGLE = 360 */
  dist = Math2.DistanceCalc2D (racket_tx, racket_tz
                               ball_tx, ball_tz);
  if (dist <= BALL_RACKET_DISTANCE) {
    angle = Math2.AngleCalc (ball_tx, ball_tz, racket_tx,
                             racket_tz);
    diff  = Math2.DiffAngleCalc(angle, ball_vec
                                     + (Math2.ANGLE/2.0f));
    if (Math2.Absf (diff) > (Math2.ANGLE / 4.0f)) {
      /* Feasible angle for collision */
       ball_vec = angle + (diff * -1.0f);

       Math2.RotatePointCalc (ball_speed_rate, ball_vec);
       ball_tx  = ball_tx2 + Math2.calc_x;
       ball_tz  = ball_tz2 + Math2.calc_y;
     }
  }
  …
}
```

Improvement 1: simpler drawing

```
for (count = 0; count != MainApp.GHOST_MAX; count++)
{
  if (MainApp.ghost_draw_flag [count] != 0) {
    …
    ~~MainApp.g3d.render (MainApp.vbuf [MainApp.GHOST_DATA],~~
                        ~~MainApp.ibuf [MainApp.GHOST_DATA],~~
                        ~~MainApp.app  [MainApp.GHOST_DATA],~~
                        ~~trans);~~
    MainApp.g3d.render (MainApp.mesh[MainApp.GHOST_DATA],
                        trans)
  }
}
```

Improvement 2: no busy waiting

```
while (thread == thisThread) {
  prev_time = now_time;
  ~~do {~~
    ~~now_time = System.currentTimeMillis ();~~
  ~~} while ((now_time - prev_time) < SYSTEM_SPEED);~~
  loop_rate = (now_time - prev_time) / SYSTEM_SPEED;
  if (loop_rate > 5.0f) { /* More than loop rate limit */
    loop_rate = 5.0f;
  }
/* do game stuff here … */
  try {
    Thread.sleep (1);
  } catch (InterruptedException e) {
    ApplicationEnd ();
  }
}
```

Improvement 2: no busy waiting

```
while (thread == thisThread) {
  prev_time = now_time;
  ~~do {~~
    ~~now_time = System.currentTimeMillis ();~~
  ~~} while ((now_time - prev_time) < SYSTEM_SPEED);~~
  now_time = System.currentTimeMillis();
  long sleep_time = SYSTEM_SPEED + prev_time - now_time;
  if (sleep_time < 0)
    sleep_time = 1; /* yield anyway so other things can run */
  try {
    Thread.sleep(sleep_time);
  } catch (InterruptedException e) {
    ApplicationEnd ();
  }
  if (thread != thisThread) return;
  now_time = System.currentTimeMillis ();
  loop_rate = (now_time - prev_time) / SYSTEM_SPEED;
  if (loop_rate > 5.0f) { /* More than loop rate limit */
    loop_rate = 5.0f;
  }
/* do game stuff here … */
}
```

Programming Tricks

Use per-object fog to highlight objects

Use black fog for night time

Draw large background objects last

Draw large foreground objects first

Divorce logic from representation

Agenda

- J2ME game development
- Tools
- COFFEE BREAK
- The structure of a MIDlet
- A walkthrough a sample game
- Why mobile game development is hard
- Publishing your content

Why Mobile Game Development is Hard

- Device Fragmentation
- Device Fragmentation
- Device Fragmentation
  - Porting platforms and tools are available:
    - www.tirawireless.com, www.javaground.com
  - Porting and testing services are available:
    - www.tirawireless.com
  - **For some self-help using NetBeans see**
    - J2ME MIDP Device Fragmentation Tutorial with Marv The Miner

Why Mobile Game Development is Hard

- Severe limits on application size
  - Download size limits
  - Small Heap memory
- Small screens
- Poor input devices
- Poor quality sound
- Slow system bus and memory system

Why Mobile Game Development is Hard

- No floating point hardware
- No integer divide hardware
- Many tasks other than application itself
  - Incoming calls or mail
  - Other applications
- Short development period
- Tight $100k – 250k budget

Memory

Problems

- Small application/download size
- Small heap memory size

Solutions

- Compress data ①
- Use single large file ①
- Use separately downloadable levels ①
- Limit contents ②
- Optimize your Java: combine classes, coalesce var’s, eliminate temporary & local variables, … ②

Performance

Problems

- Slow system bus & memory
- No integer divide hardware

Solutions

- Use smaller textures ①
- Use mipmapping ①
- Use byte or short coordinates and key values ①
- Use shifts ②
- Let the compiler do it ②

User-Friendly Operation

- Problems
  - Button layouts differ
  - Diagonal input may be impossible
  - Multiple simultaneous button presses not recognized
- Solutions
  - Plan carefully
  - Different difficulty levels
  - Same features on multiple buttons
  - Key customize feature

Many Other Tasks

- Problem
  - Incoming calls or mail
  - Other applications
- Solution
  - Create library for each handset terminal

Agenda

- J2ME game development
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Publishing Your Content Agenda

- Publishing your content
  - Preparing contents for distribution
  - Getting published and distributed

Preparing for Distribution: Testing

- Testing on actual handsets essential
  - May need contract with operator to obtain tools needed to download test MIDlets to target handset.
  - May need contractor within operator’s region to test over-the-air aspects as handset may not work in your area
- Testing services are available
  - e.g. www.tirawireless.com

Preparing for Distribution: Signing

Java has 4 security domains:

Manufacturer	Operator
3rd Party	Untrusted

Most phones will not install untrusted MIDlets

- If untrusted MIDlets are allowed, there will be limits on access to certain APIs

Operators will not allow untrusted MIDlets in their distribution channels

Preparing for Distribution: Signing

- Your MIDlet must be certified and signed using a 3rd party domain root certificate
- Method varies by operator and country
  - Many makers and operators participate in the Java Verified Program to certify and sign MIDlets for them
- To get certification, MIDlet must meet all criteria defined by JVP and must pass testing

Publishing Your Content Agenda

Publishing your content

– Preparing contents for distribution

Getting published and distributed

Publishing Your Content: Distribution Channels

- Game deck
  - e.g. “More Games button”
- Off deck, in portal
  - e.g. AT&T Wireless’s *Beyond MEdia Net*
- Off portal
  - Independent of operator
  - Premium SMS or web distribution

Distribution Channels: Game Deck

- Customers find you easily
  - but many carriers only allow a few words of text to describe and differentiate the on-deck games
- Operator does billing
  - No credit worries
- Operator may help with marketing
  - or they may not
- Shelf space limited

Distribution Channels: off Deck, in Portal

- Hard to find you. Need viral marketing
  - Customers must enter search terms in operator’s search box
  - or find URL in some other way
- Operator does billing, may help with marketing
- May be able to get here without a publisher

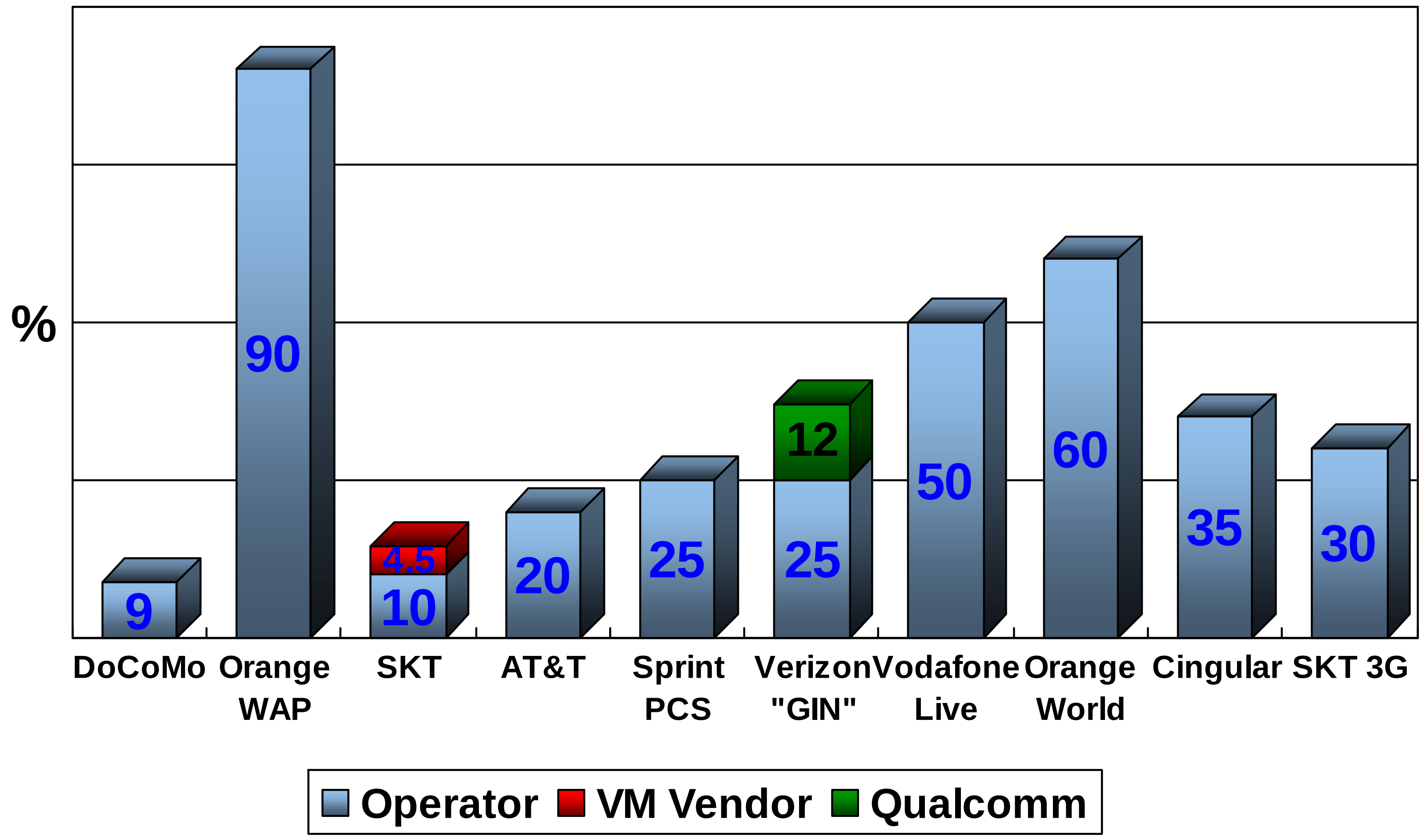
Distribution Channels: off Deck, off Portal

- Very hard for customers to find you
  - Only 4% of customers have managed to buy from the game deck!
- You have to handle billing
  - Typical game prices of $2 - $6 too low for credit cards. Must offer subscription service for CC billing.
  - Nobody is going to enter your url then billing information on a 9-key pad and very few people will use a PC to buy games for their phone.
  - Premium SMS or advertiser funded are about the only ways.
- You take all the risks
- Some handsets/carriers do not permit off-portal downloads

Publishing Your Content
Billing Mechanisms

- One-time purchase via micropayment
  - Flat-rate data? ➔Larger, higher-cost games
- Subscription model via micropayment
  - Episodic games to encourage loyalty
  - Game arcades with new games every month
- Sending Premium SMS
  - Triggers initial download
  - Periodically refills scarce supplies

Operator Revenue Share 1999 - 2004



Source: www.roberttercek.com

Going On-Deck

Find a publisher and build a good relationship with them

Japan: Square Enix, Bandai Networks, Sega WOW, Namco, Infocom, etc.

America: Bandai America, Digital Chocolate, EA Mobile, MForma, Sorrent

Europe: Digital Chocolate, Superscape, Macrospace, Upstart Games

Going Off-Deck

There are off-deck distribution services:

- thumbplay, www.thumbplay.com
- playphone, www.playphone.com
- gamejump, www.gamejump.com free advertiser supported games

These services may be a good way for an individual developer to get started

Other 3D Java Mobile APIs

Mascot Capsule Micro3D Family APIs

- Motorola iDEN, Sony Ericsson, Sprint, etc.
  - com.mascotcapsule.micro3d.v3 (V3)
- Vodafone KK JSCL
  - com.j_phone.amuse.j3d (V2), com.jblend.graphics.j3d (V3)
- Vodafone Global
  - com.vodafone.amuse.j3d (V2)
- NTT Docomo (DoJa)
  - com.nttdocomo.opt.ui.j3d (DoJa2, DoJa 3) (V2, V3)
  - com.nttdocomo.ui.graphics3D (DoJa 4, DoJa 5) (V4)

(Vx) - Mascot Capsule Micro3D Version Number

Mascot Capsule V3 Game Demo

Copyright 2006, by Interactive Brains, Co., Ltd.

Summary

Use standard tools to create assets

Many J2ME SDKs and IDEs are available

Basic M3G MIDlet is relatively easy

Programming 3D Games for mobile is hard

Getting your content marketed, distributed and sold is a huge challenge

Not a typo

Exporters

vaporware?

3ds max

Simple built-in exporter since 7.0

www.digi-element.com/Export184/

www.mascotcapsule.com

www.m3gexporter.com

Maya

www.mascotcapsule.com

www.m3gexport.com

Softimage|XSI

www.mascotcapsule.com

Cinema 4D

www.tetracon.de/public_main_modul.php?bm=&ses=&page_id=453&document_id=286&unit=441299c9be098

Lightwave

www.mascotcapsule.com

Blender

www.nelson-games.de/bl2m3g/

M3GToolkit

www.java4ever.com

SDKs

Motorola iDEN J2ME SDK

idenphones.motorola.com/iden/developer/developer_tools.jsp

Nokia Series 40, Series 60 & J2ME

www.forum.nokia.com/java

Softbank MEXA & JSCL SDKs

developers.softbankmobile.co.jp/dp/tool_dl/java/tech.php

developers.softbankmobile.co.jp/dp/tool_dl/java/emu.php

SDKs

Sony Ericsson

developer.sonyericsson.com/java

Sprint Wireless Toolkit for Java

developer.sprintpcs.com

Sun Java Wireless Toolkit 2.5.1 for CLDC

http://java.sun.com/products/sjwtoolkit/index.html

Vodafone VFX SDK

via.vodafone.com/vodafone/via/Home.do

IDE’s for Java Mobile

- Eclipse Open Source IDE
  - www.eclipse.org & eclipseme.org
- JBuilder 2005 Developer
  - www.borland.com/jbuilder/developer/index.html
- NetBeans
  - www.netbeans.info/downloads/index.php
  - www.netbeans.org/products/
- Comparison of IDE’s for J2ME
  - www.microjava.com/articles/J2ME_IDE_Comparison.pdf

Other Tools

Macromedia Fireworks

www.adobe.com/products/fireworks/

Adobe Photoshop

www.adobe.com/products/photoshop/main.html

Sony SoundForge

www.sonymediasoftware.com/products/showproduct.asp?PID=961

Steinberg Cubase

www.steinberg.de/33_1.html

Yamaha SMAF Tools

smaf-yamaha.com/

Other Tools

Java optimizer - Innaworks mBooster

www.innaworks.com/mBooster.html

Porting Platforms

www.tirawireless.com

www.javaground.com

Services

MIDlet verification & signing

- www.javaverified.com

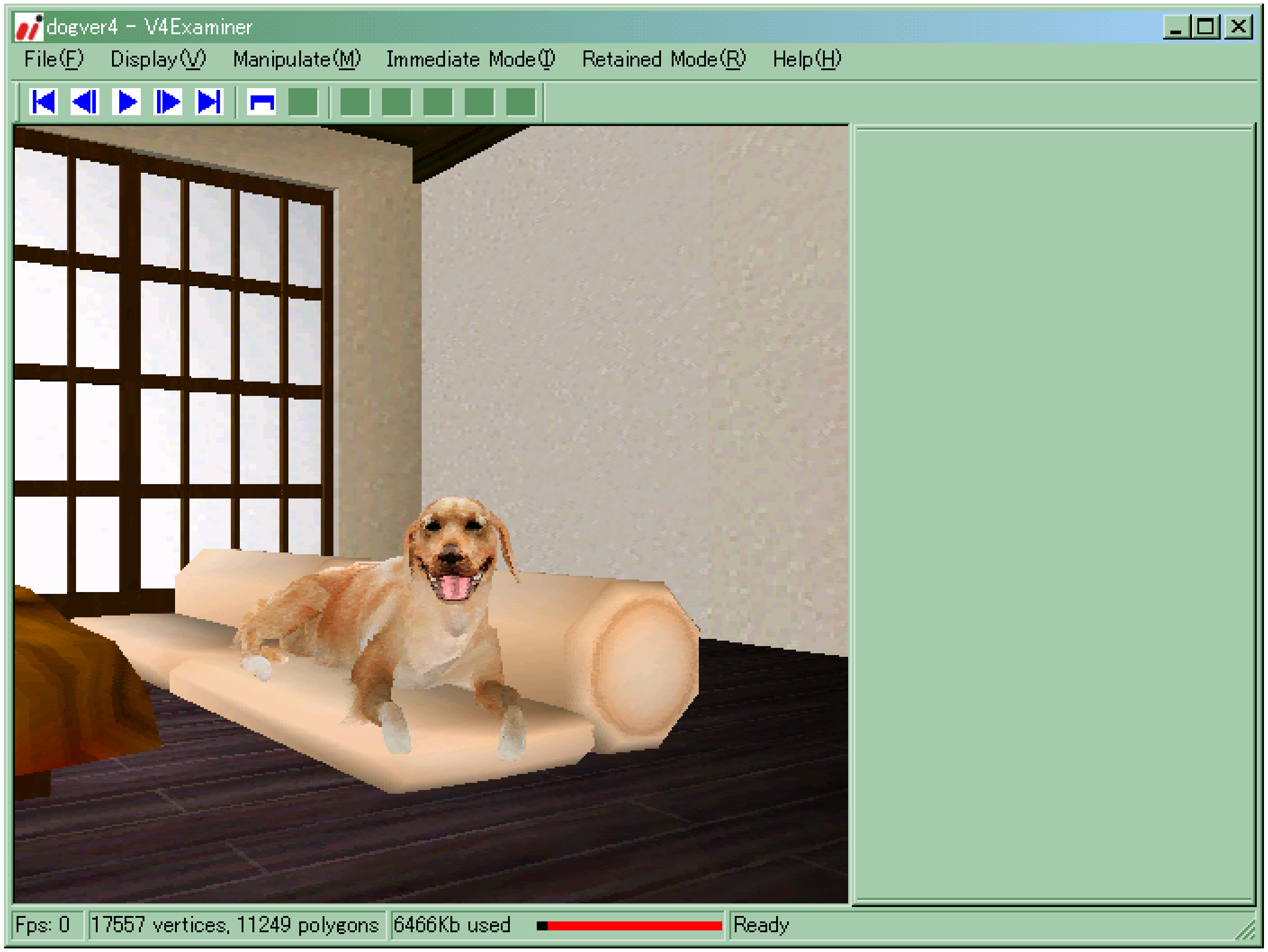
Porting & testing

- www.tirawireless.com

Off deck distribution

- www.thumbplay.com
- www.playphone.com
- www.gamejump.com

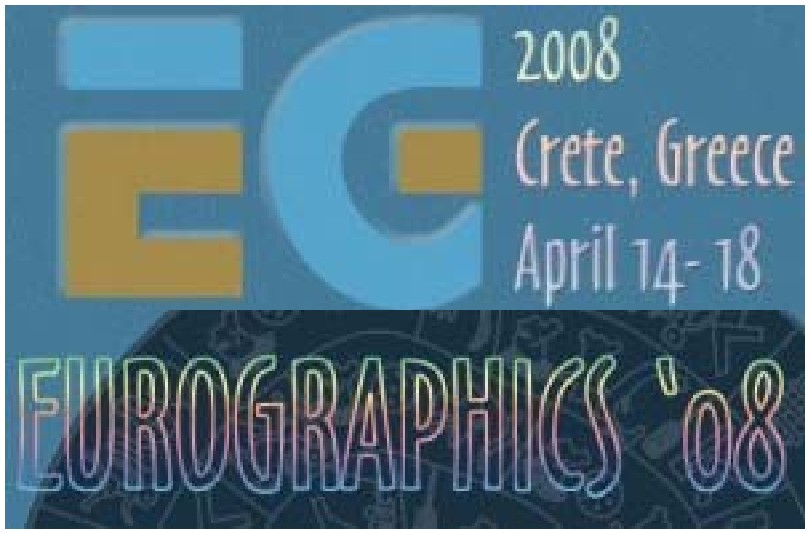
犬友 (Dear Dog) Demo



Fps: 0 | 17557 vertices, 11249 polygons | 6466Kb used | Ready

Thanks to: Koichi Hatakeyama; HI’s MascotCapsule Version 4 Development Team; Sean Ellis; JSR-184 & JSR-297 Expert Groups

M3G 2.0
Sneak Preview



Tomi Aarnio

Nokia Research Center

What is M3G 2.0?

Mobile 3D Graphics API, version 2.0

- Java Specification Request 297
- Successor to M3G 1.1 (JSR 184)

Work in progress

- Public Review Draft is out (www.jcp.org)
- Developer feedback is much appreciated!

Who’s Behind It?

Hardware vendors AMD, ARM NVIDIA, PowerVR	Device makers Nokia, Sony Ericsson Motorola, Samsung
Platform providers Sun, Ericsson HI, Aplix, Acrodea	Developers Digital Chocolate RealNetworks Superscape

M3G 2.0 Preview

Design

Fixed functionality

Programmable shaders

New high-level features

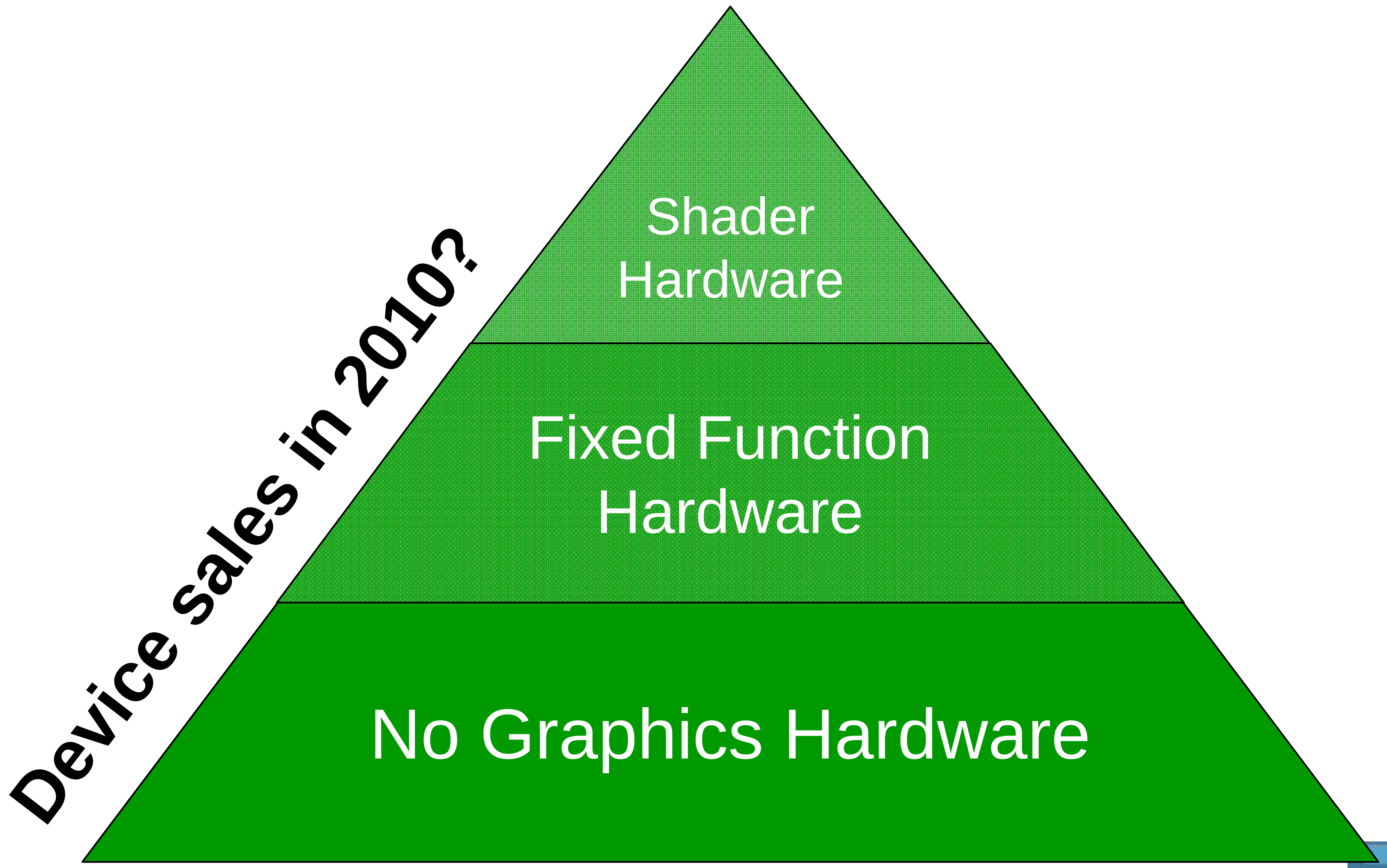
Summary, Q&A

Design Goals & Priorities

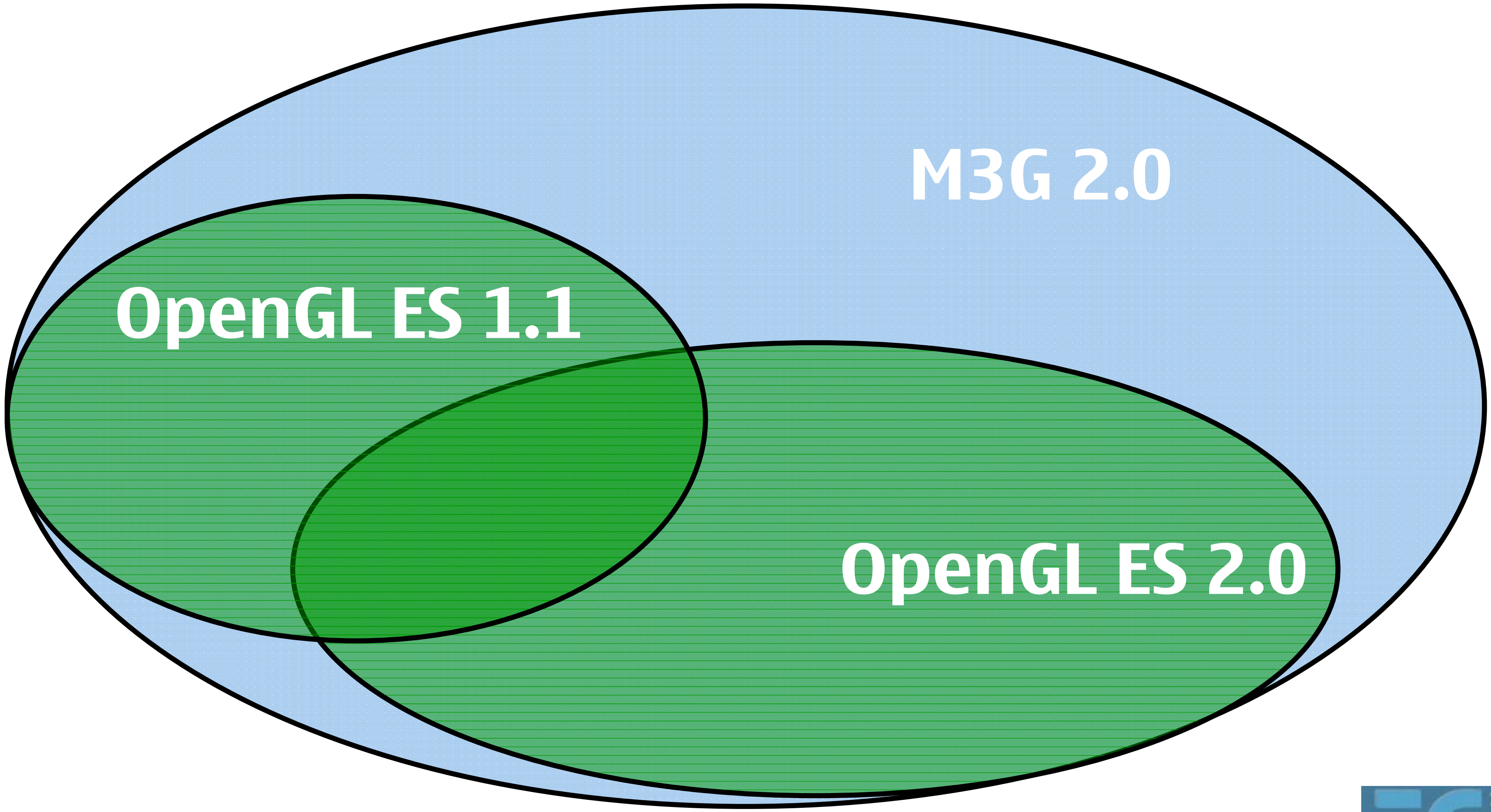
Target <u>all</u> devices

- Programmable HW
- No graphics HW
- Fixed-function HW

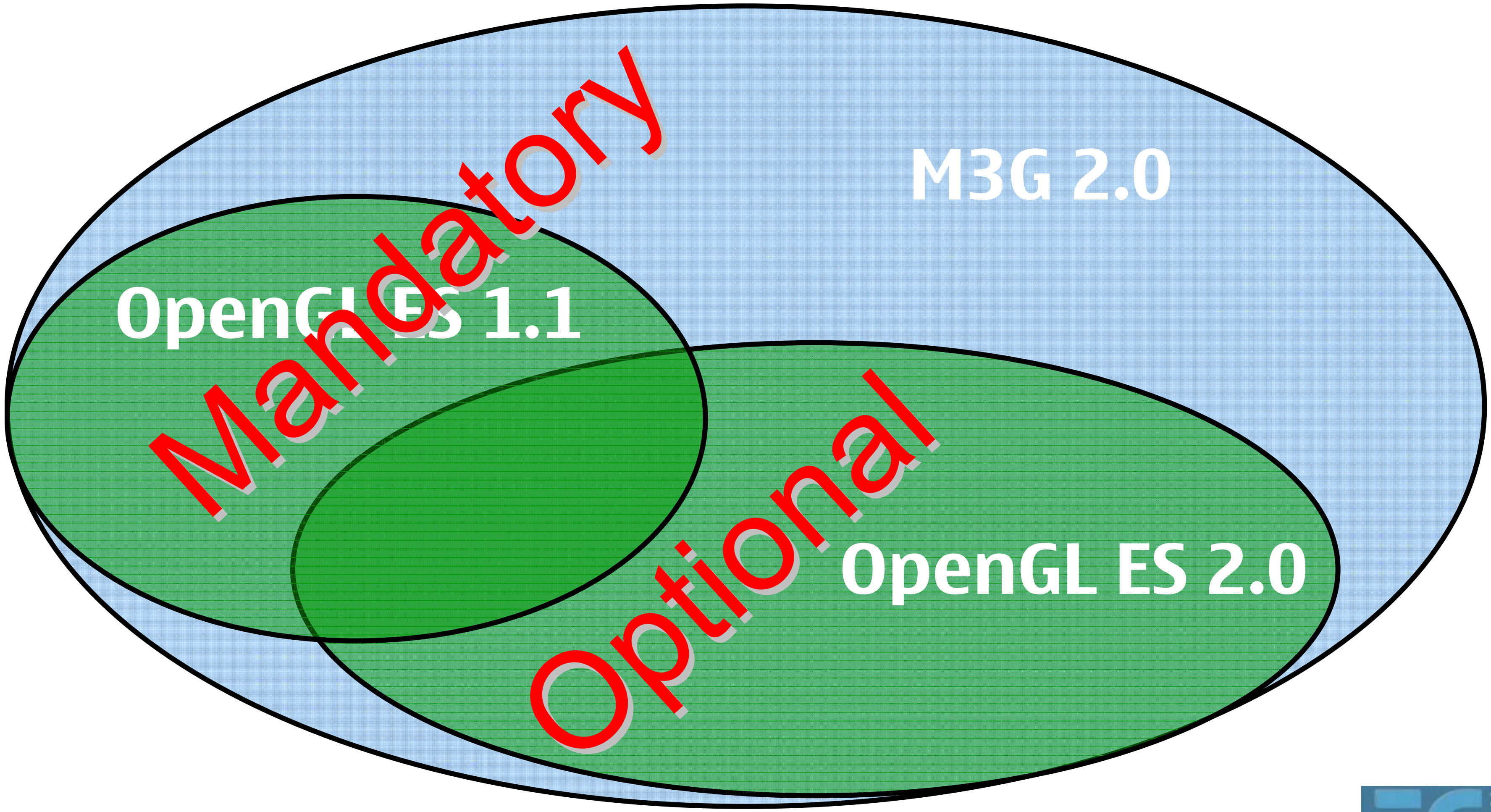
Why Not Shaders Only?



Shaders and Fixed Functionality



Shaders <u>and</u> Fixed Functionality



Design Goals & Priorities

Target <u>all</u> devices

- Programmable HW
- No graphics HW
- Fixed-function HW

Enable reuse of

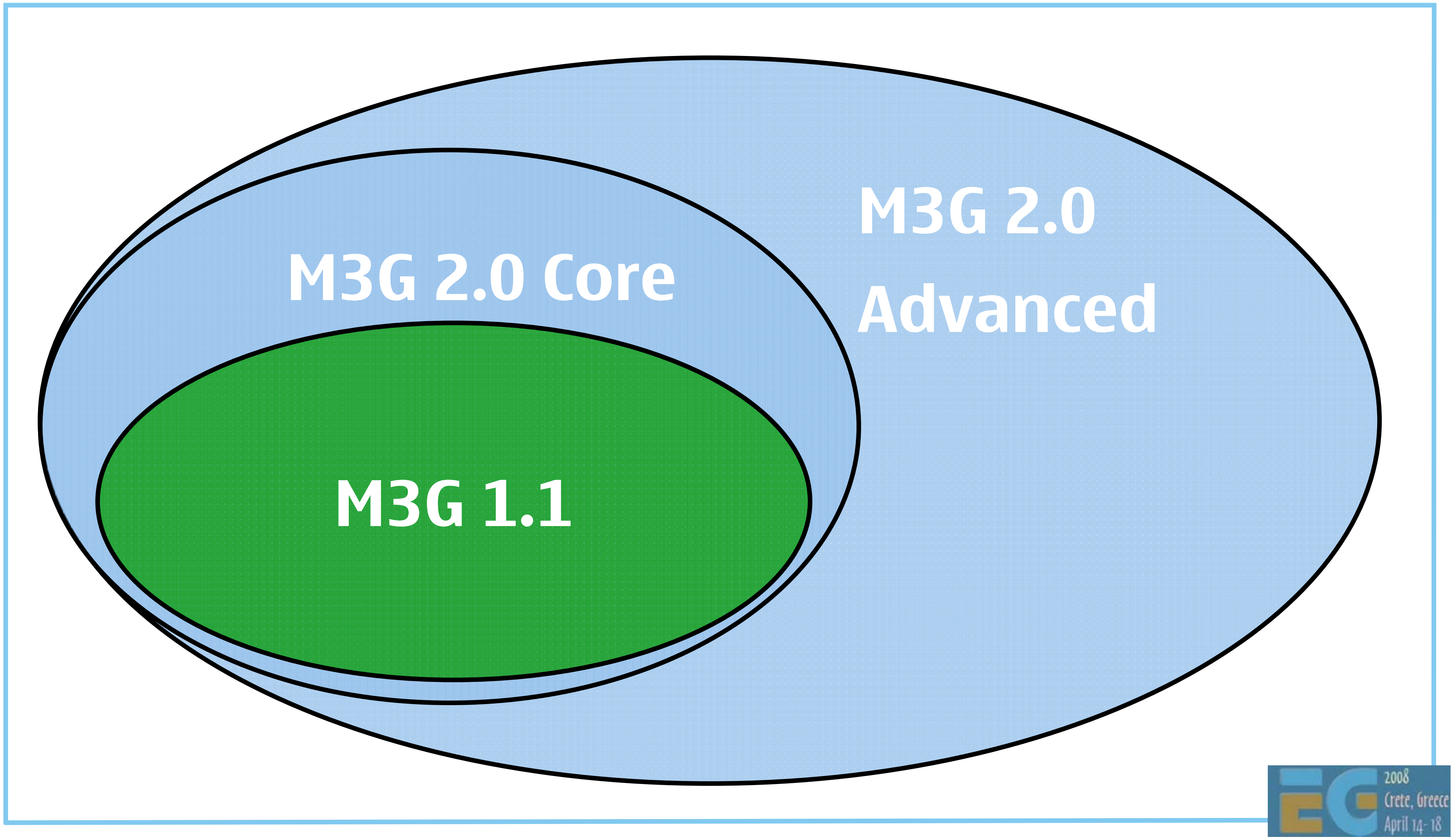
- Assets & tools (.m3g)
- Source code (.java)
- Binary code (.class)

Backwards Compatible – Why?

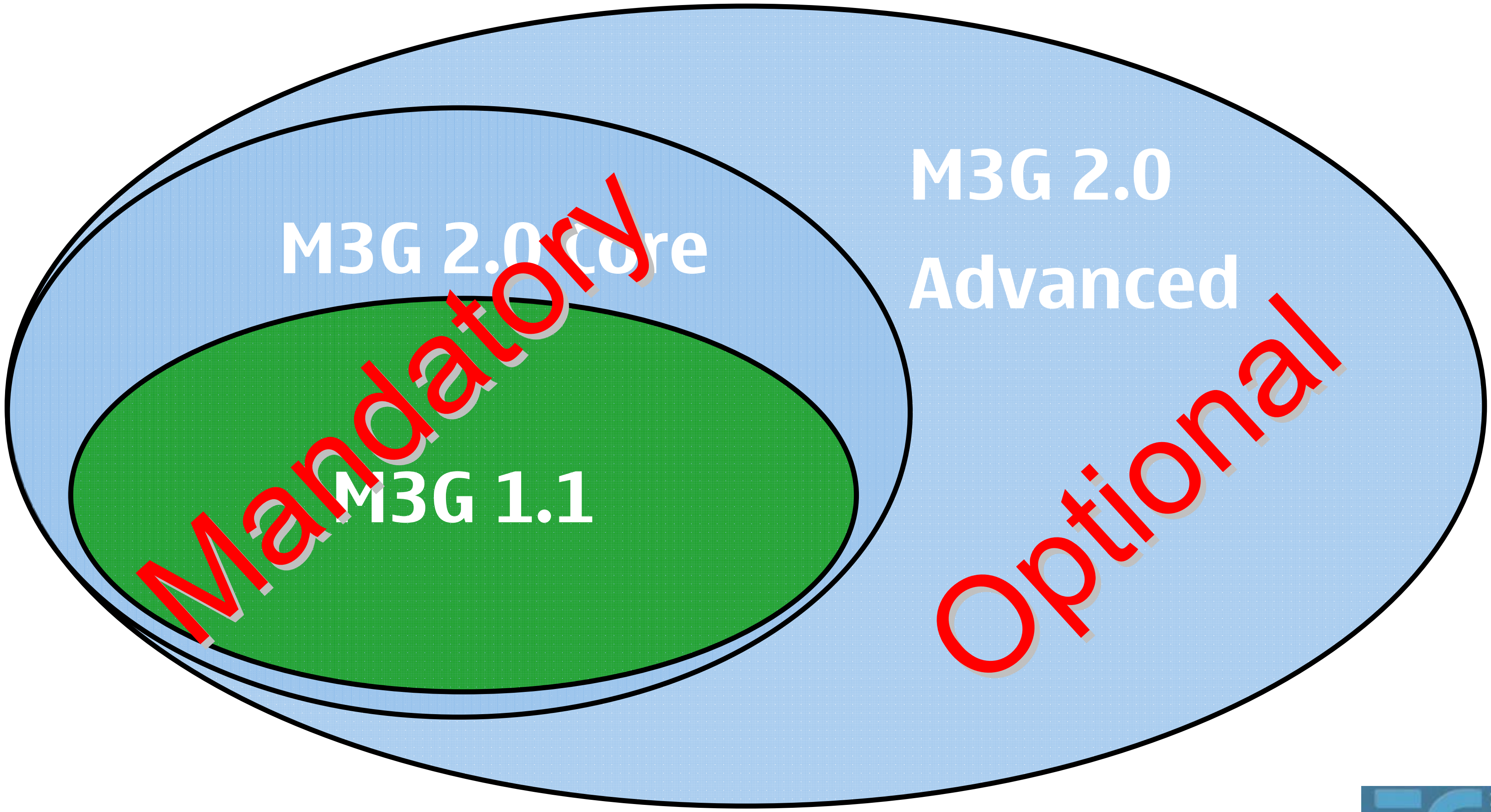
- Device vendors can drop M3G 1.1
  - Rather than supporting both versions (forever)
  - Cuts integration, testing & maintenance into half

- Developers can upgrade gradually
  - Rather than re-doing all code, art, and tools

Backwards Compatible – How?



Backwards Compatible – How?



The Downsides

- Must emulate fixed functionality on shader HW
  - Extra implementation burden
- The API is not as compact as it used to be
  - A pure shader API could have ~20% fewer classes
- Need to drag along obsolete features
  - Flat shading, Sprite3D, Background image
  - Can be deprecated, but not totally removed

Core vs. Advanced

High-level features are common to both

- Scene graph
- Animation

The differences are in rendering

Core	→ OpenGL ES 1.1
Advanced	→ OpenGL ES 2.0

What's in the Core?

Everything that's in M3G 1.1

Everything that's in OpenGL ES 1.1

- Except for useless or badly supported stuff
- Such as points, logic ops, stencil, full blending

A whole bunch of new high-level features

What’s in the Advanced Block?

- Everything that’s in OpenGL ES 2.0
  - Vertex and fragment shaders
  - Cube maps, advanced blending
  - Stencil buffering

What’s not included?

Optional extensions of OpenGL ES

- Floating-point textures
- Multiple render targets
- Depth textures, 3D textures
- Non-power-of-two mipmaps
- Occlusion queries
- Transform feedback

M3G 2.0 Preview

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Summary, Q&A

M3G 2.0 Core vs. M3G 1.1

New capabilities

Better and faster rendering

More convenient to use

Fewer optional features

Point Sprites

- Ideal for particle effects
- Much faster than quads
- Consume less memory
- Easier to set up

Image copyright AMD

Better Texturing

More flexible input

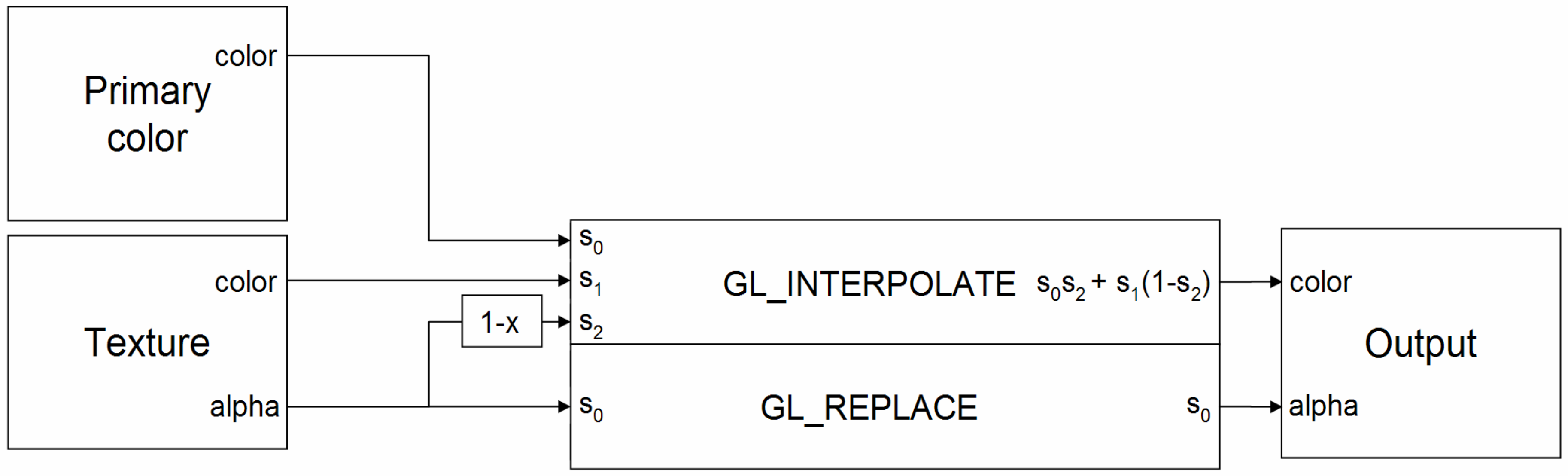
- ETC (Ericsson Texture Compression), JPEG
- RGB565, RGBA5551, RGBA4444
- Can set individual mipmap levels
- Dynamic sources (e.g. video)

Upgraded baseline requirements

- At least two texture units
- At least 1024x1024 size
- Perspective correction
- Mipmapping, bilinear filtering

Texture Combiners

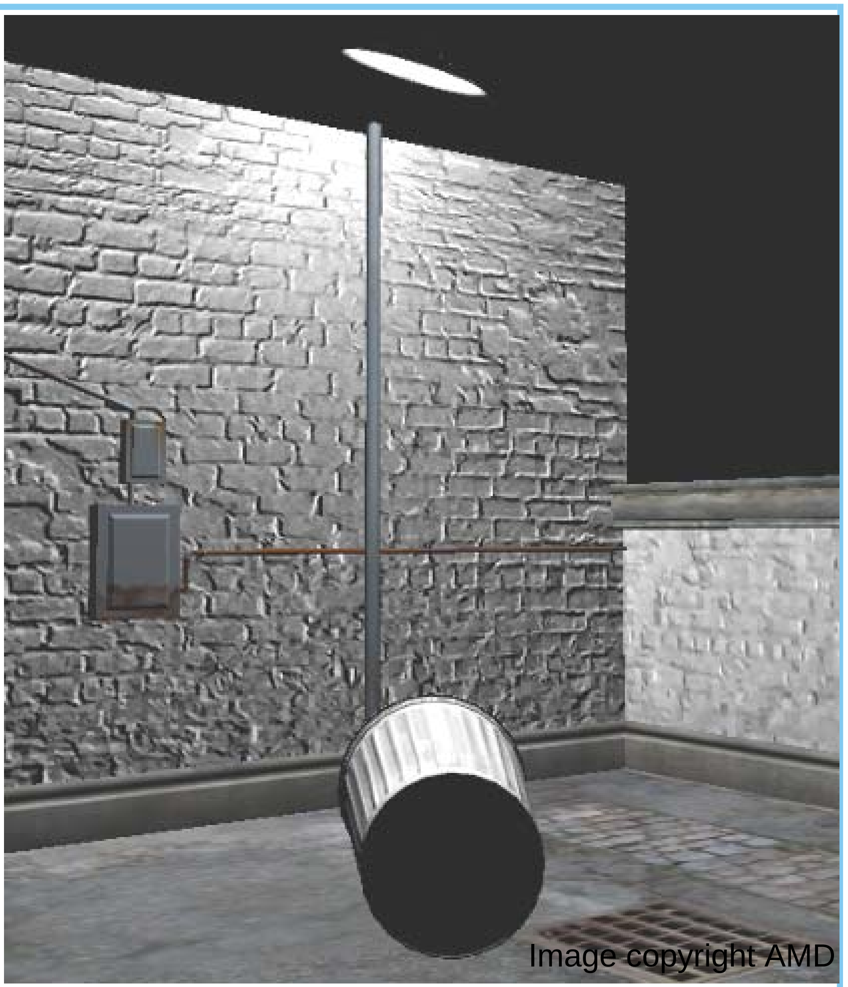
- Precursor to fragment shaders
  - Quite flexible, but not very easy to use



Bump Mapping

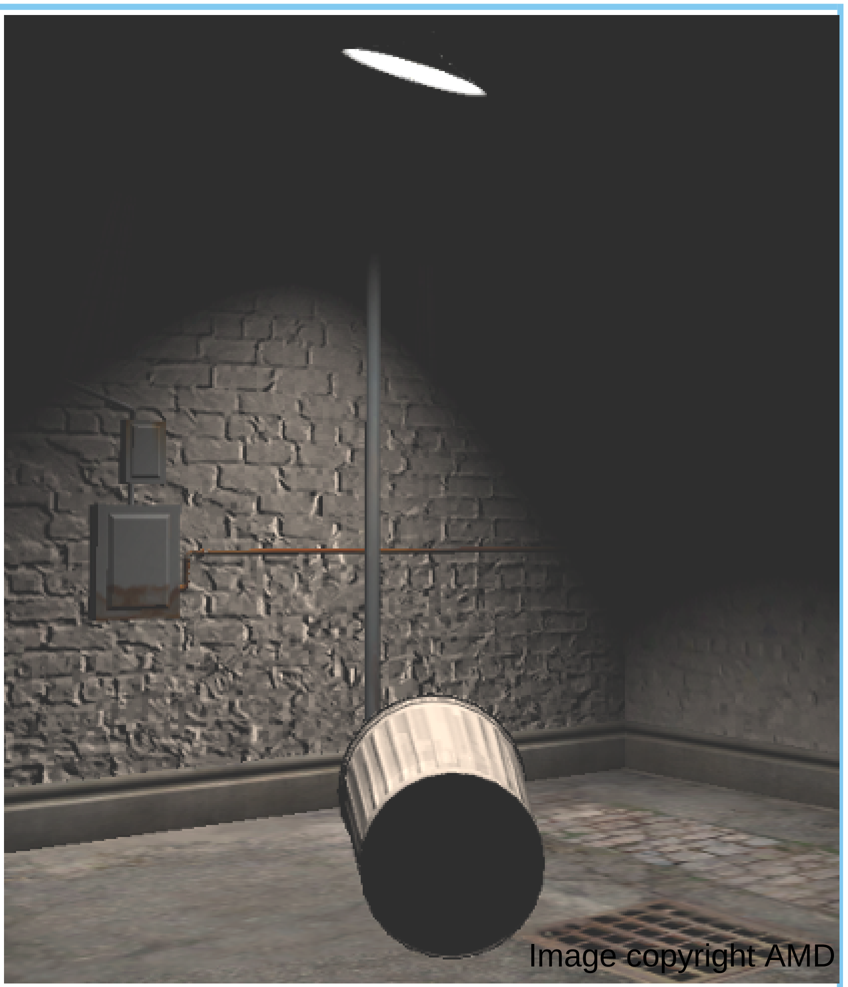
Fake geometric detail

Feasible even w/o HW



Bump Mapping + Light Mapping

Bump map modulated by projective light map



Floating-Point Vertex Arrays

`float (32-bit)`

Easy to use, good for prototyping

Viable with hardware acceleration

`half (16-bit)`

Savings in file size, memory, bandwidth

`byte/short` still likely to be faster

Triangle Lists

- Much easier to set up than strips
  - Good for procedural mesh generation
  - Avoids the expensive stripification
- Sometimes even smaller & faster than strips
  - Especially with a cache-friendly triangle ordering

Primitives – M3G 1.x

	Byte	Short	Implicit	Strip	Fan	List
Triangles	✓	✓	✓	✓	✗	✗
Lines	✗	✗	✗	✗	✗	✗
Points	✗	✗	✗	🟦	🟦	✗
Point sprites	✗	✗	✗	🟦	🟦	✗

Relative to OpenGL ES 1.1

Primitives – M3G 2.0

	Byte	Short	Implicit	Strip	Fan	List
Triangles	✓	✓	✓	✓	✗	✓
Lines	✓	✓	✓	✓	✗	✓
Points	✗	✗	✗	🟦	🟦	✗
Point sprites	✓	✓	✓	🟦	🟦	✓

Relative to OpenGL ES 1.1

VertexBuffer Types – M3G 1.x

	Byte	Short	Fixed	Float	2D	3D	4D
Vertices	✓	✓	✗	✗	✗	✓	✗
TexCoords	✓	✓	✗	✗	✓	✓	✗
Normals	✓	✓	✗	✗	▨	✓	▨
Colors	✓	▨	✗	✗	▨	*	✓
PointSizes	▨	▨	✗	✗	▨	▨	▨

* OpenGL ES 1.1 only supports RGBA colors. M3G also supports RGB

VertexBuffer Types – M3G 2.0

	Byte	Short	Fixed	Float Half	2D	3D	4D
Vertices	✓	✓	✓	✓	✓	✓	✓
TexCoords	✓	✓	✓	✓	✓	✓	✓
Normals	✓	✓	✓	✓		✓	
Colors	✓		✓	✓		*	✓
PointSizes			✓	✓			

* OpenGL ES 1.1 only supports RGBA colors, M3G also supports RGB

Deprecated Features

- Background image
  - Use a sky box instead
- Sprite3D
  - Use textured quads or point sprites instead
- Flat shading
  - Can’t have this on OpenGL ES 2.0!

Deprecated Features Cont'd

- Two-sided lighting
  - Requires duplicated geometry on OpenGL ES 2.0
- Local camera lighting (a.k.a. local viewer)
  - Only a hint that was poorly supported
- Less accurate picking
  - Skinning and morphing not taken into account

M3G 2.0 Preview

Design

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Summary, Q&A

2008
Crete, Greece
April 14- 18

Shading Language

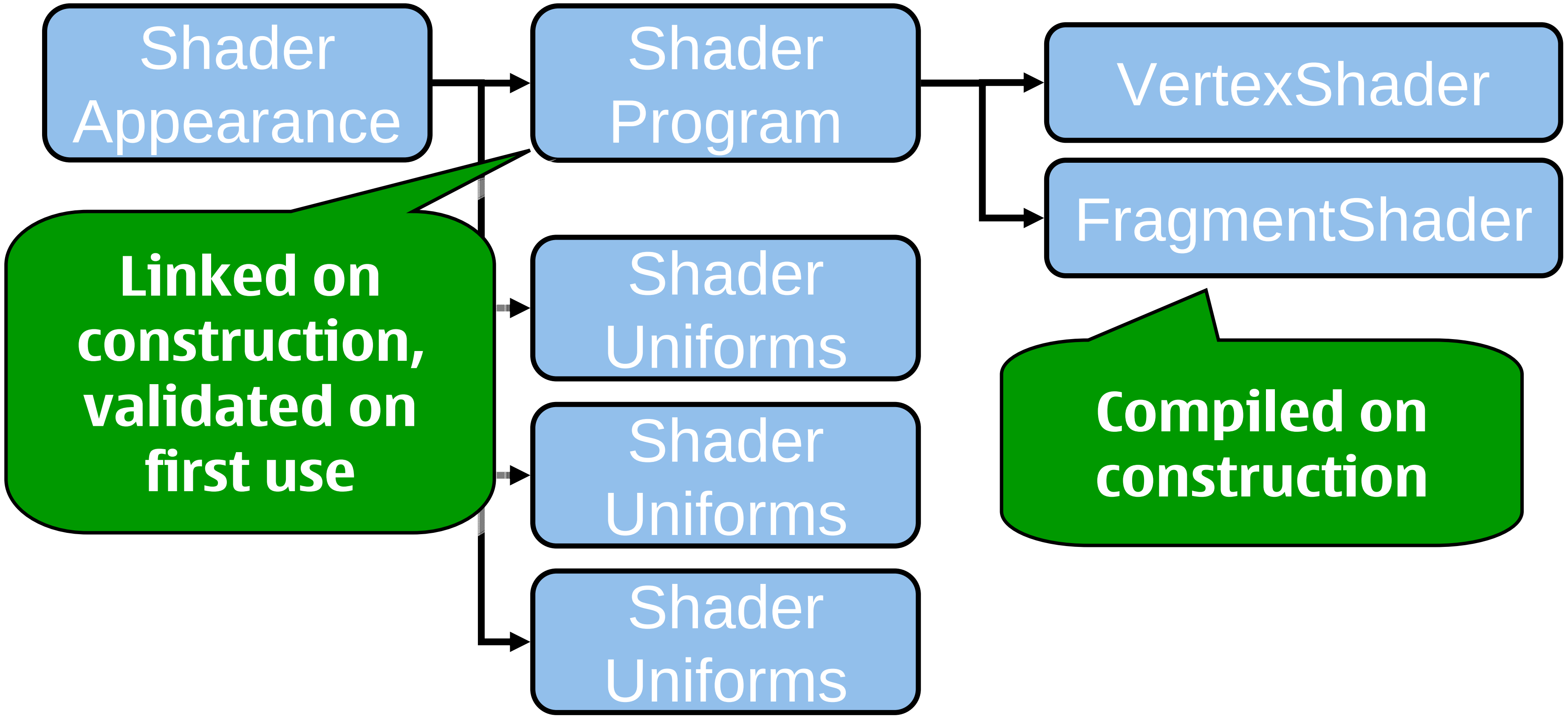
GLSL ES v1.00

- Source code format only
- Binary shaders would break the Java sandbox

Added a few preprocessor `#pragma`'s

- To enable skinning, morphing, etc.
- Apply for vertex shaders only

The Shader Package



Why Multiple ShaderUniforms?

- So that uniforms can be grouped
  - Global constants – e.g. look-up tables
  - Per-mesh constants – e.g. rustiness
  - Per-frame constants – e.g. time of day
  - Dynamic variables – e.g. position, orientation
- Potential benefits of grouping
  - Java object reuse – less memory, less garbage
  - Can be faster to bind a group of variables to GL

2008
Crete, Greece
April 14- 18

A Fixed-Function Vertex Shader

A small example shader

Replicates the fixed-function pipeline using the predefined `#pragma`’s

Necessary Declarations

Names & roles for vertex attributes

```
#pragma M3Gvertex(myVertex)
#pragma M3Gnormal(myNormal)
#pragma M3Gtexcoord0(myTexCo
#pragma M3Gcolor(myColor)


#pragma M3Gvertexstage(clipspace)


varying vec2 texcoord0;
varying vec4 color;
```

Transform all the way to clip space

Variables to pass to the fragment shader

The Shader Code

Applies morphing, scale/bias, skinning, model-view, projection

```
void main() {
    m3g_ffunction();
    gl_Position = myVertex;
    texcoord0 = myTexCoord0.xy;
    color = myColor;
}
```

Results passed to the fragment shader

M3G 2.0 Preview

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Summary, Q&A

RenderPass

- Automated render-to-texture (RTT)
  - First set up RenderTarget, World, Camera
  - Call `myWorld.preRender()` (e.g. every *N*th frame)
  - This updates all dynamic textures in the scene
  - Finally, render the World as usual

- RTT effects can now be authored in DCC tools
  - Advanced FX without programmer intervention
  - Reflection, refraction, HDR bloom, etc.

Transparency Sorting

- Can sort blended submeshes back-to-front
  - Toggled ON/OFF per Appearance and layer
  - Based on the Mesh origin’s depth in eye space
  - Depth = MODELVIEW_MATRIX(3, 4)

- Individual triangles are <u>not</u> sorted

Level of Detail (LOD)

A Group node can select one of its children

Based on their size in screen pixels

Similar to mipmap level selection

Formally

Compute ***s*** = pixels per model-space unit

Select the node whose ideal scale $\boldsymbol{s_i}$ satisfies

$$\max\{s_i \mid s_i \leq s\}$$

Level of Detail (LOD)

Example – from highest detail to lowest:

- SkinnedMesh with 30 bones and 1000 vertices
- SkinnedMesh with 15 bones and 500 vertices
- MorphingMesh with 3 targets and 200 vertices
- Tiny billboard with flip-book animation

Appearance detail scaled in the same way

- E.g. from complex shaders to per-vertex colors

Bounding Volumes (BV)

- To speed up view frustum culling & picking
  - Processed hierarchically to cull entire branches
- Can be specified for each node
  - Bounding sphere = center & radius
  - Bounding box = min & max extents
  - If both are given, use their intersection
  - If neither is given, use an internal BV

Combined Morphing & Skinning

- First morph, then skin the result
- Useful for animated characters
  - Morph targets for facial animation
  - Skinning for the rest of the body

- Can morph and/or skin any vertex attribute
  - Use the result in your own vertex shader
  - `#pragma M3Gvertexstage(skinned)`

Subset Morphing

Can morph an arbitrary subset of vertices

Previously, the whole mesh was morphed

- Now the morph targets are much smaller
- Big memory savings in e.g. facial animation

Multichannel Keyframe Sequences

N channels per KeyframeSequence

- Same number of keyframes in all channels
- Shared interpolation mode
- Shared time stamps

Huge memory savings with skinning

- M3G 1.1: two Java objects per bone (~60 total)
- M3G 2.0: two Java objects <u>per mesh</u>

Other Stuff

- Event tracks associated with animations
  - E.g. play a sound when a foot hits the ground

- Lots of new convenience methods
  - `findAll(Class)` – find e.g. all Appearances
  - Can enable/disable animations hierarchically
  - Can use quaternions instead of axis/angle
  - Easy pixel-exact 2D projection for overlays
  - Easy look-at orientation for camera control
  - Predefined, intuitive blending modes

File Format

- Updated to match the new API
  - File structure remains the same
  - Same parser can handle both old & new
- Better compression for
  - Textures (ETC, JPEG)
  - SkinnedMesh, IndexBuffer

Things Under Consideration

- Simple collision detection
- Fast Matlab-style array arithmetic
  - Based on floating-point VertexArrays
  - Compute the dot product of two arrays, etc.
  - Overcomes the Java Native Interface overhead

M3G 2.0 Preview

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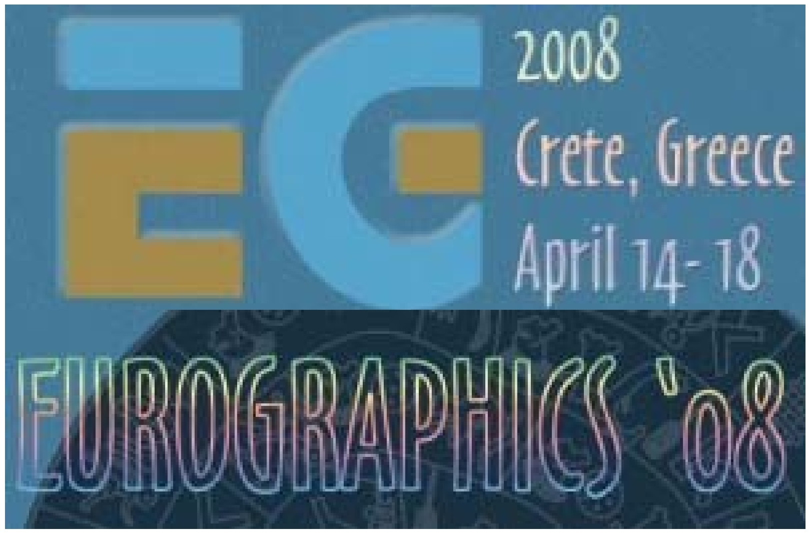
Summary, Q&A

Summary

- M3G 2.0 will replace 1.1, starting next year
  - Existing code & assets will continue to work
- Several key improvements
  - Programmable shaders to the mass market
  - Fully featured traditional rendering pipeline
  - Advanced animation and scene management
  - Better perf across all device categories

Q&A



Thanks:

M3G 2.0 Expert Group

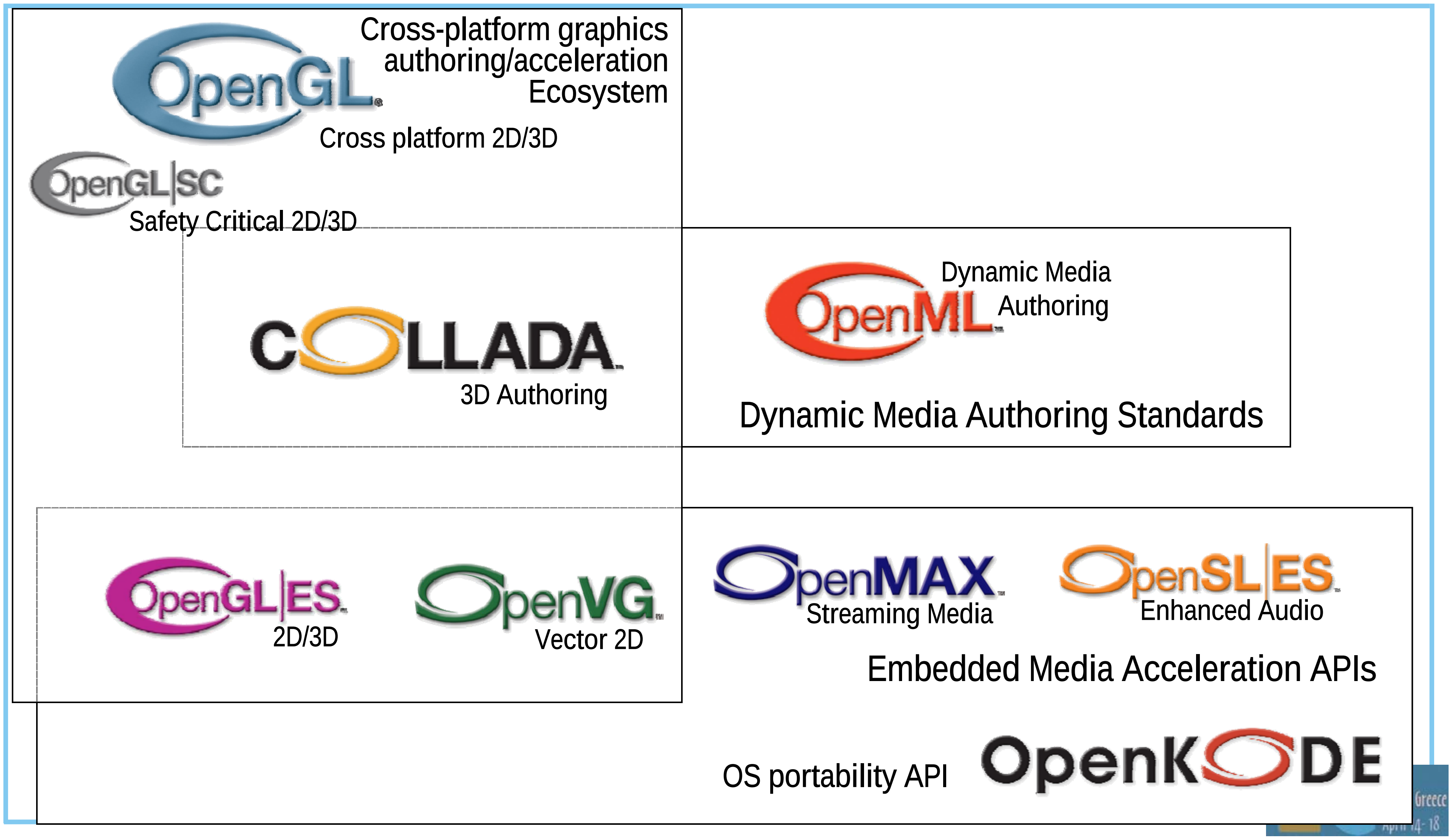
Dan Ginsburg (AMD)

Kimmo Roimela (Nokia)

Closing & Summary

- We have covered
  - OpenGL ES
  - M3G
- Let’s quickly see what else is there
  - COLLADA
  - 2D APIs: OpenVG, JSR 226, JSR 287

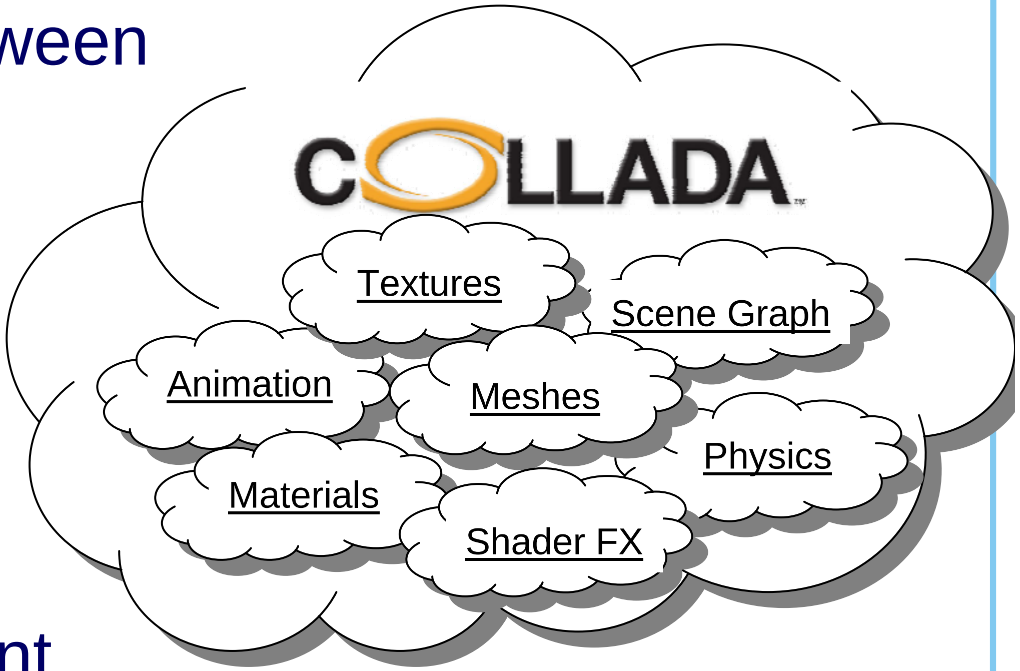
Khronos API family



COLLADA

An open interchange format

- to exchange data between content tools
- allows mixing and matching tools for the same project
- allows using desktop tools for mobile content



Collada conditioning

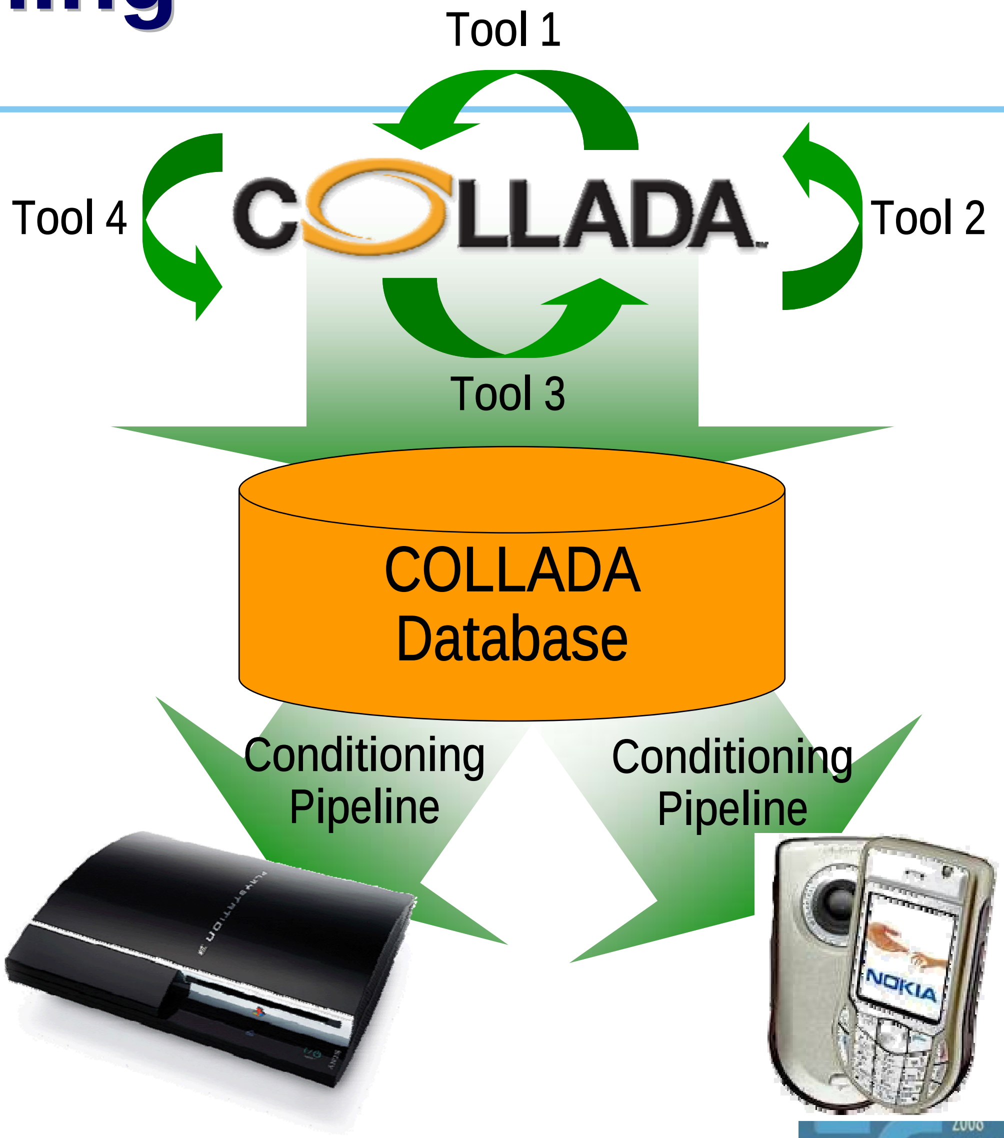
Conditioning pipelines take authored assets and:

1. Strips out authoring-only information

2. Re-sizes to suit the target platform

3. Compresses and formats binary data for the target platform

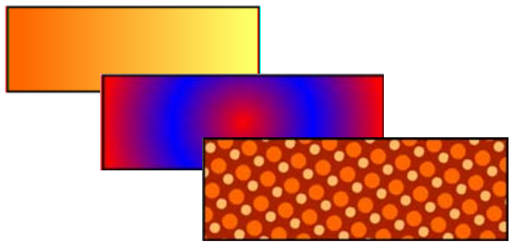
Different target platforms can use the same asset database with the appropriate conditioning pipeline



2D Vector Graphics

- OpenVG
  - low-level API, HW acceleration
  - spec draft at SIGGRAPH 05, conformance tests summer 06
- JSR 226: 2D vector graphics for Java
  - SVG-Tiny compatible features
  - completed Mar 05
- JSR 287: 2D vector graphics for Java 2.0
  - rich media (audio, video) support, streaming
  - may still complete in 07

OpenVG features


Paints

Mask

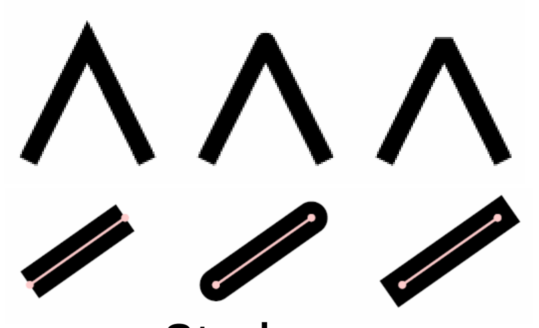
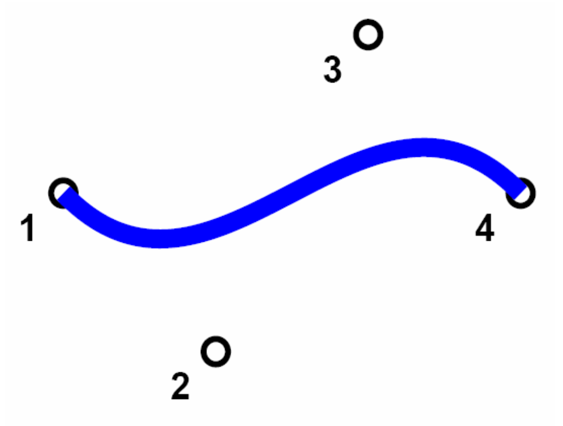
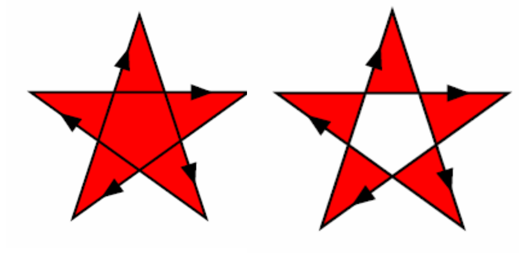

Stroke

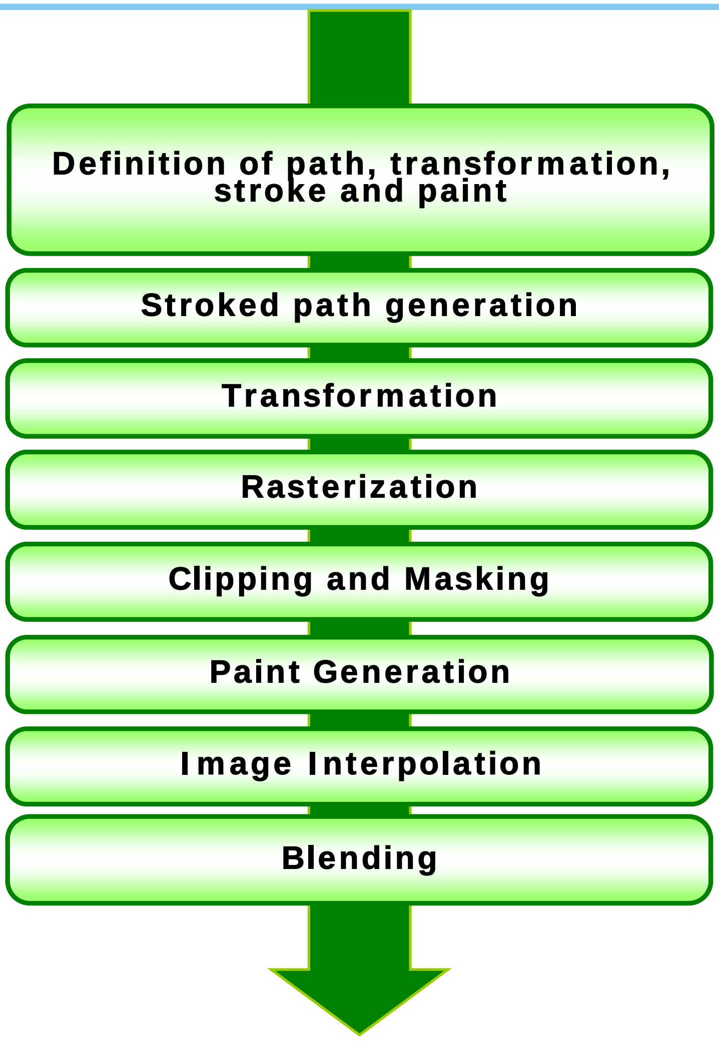
Image transformation

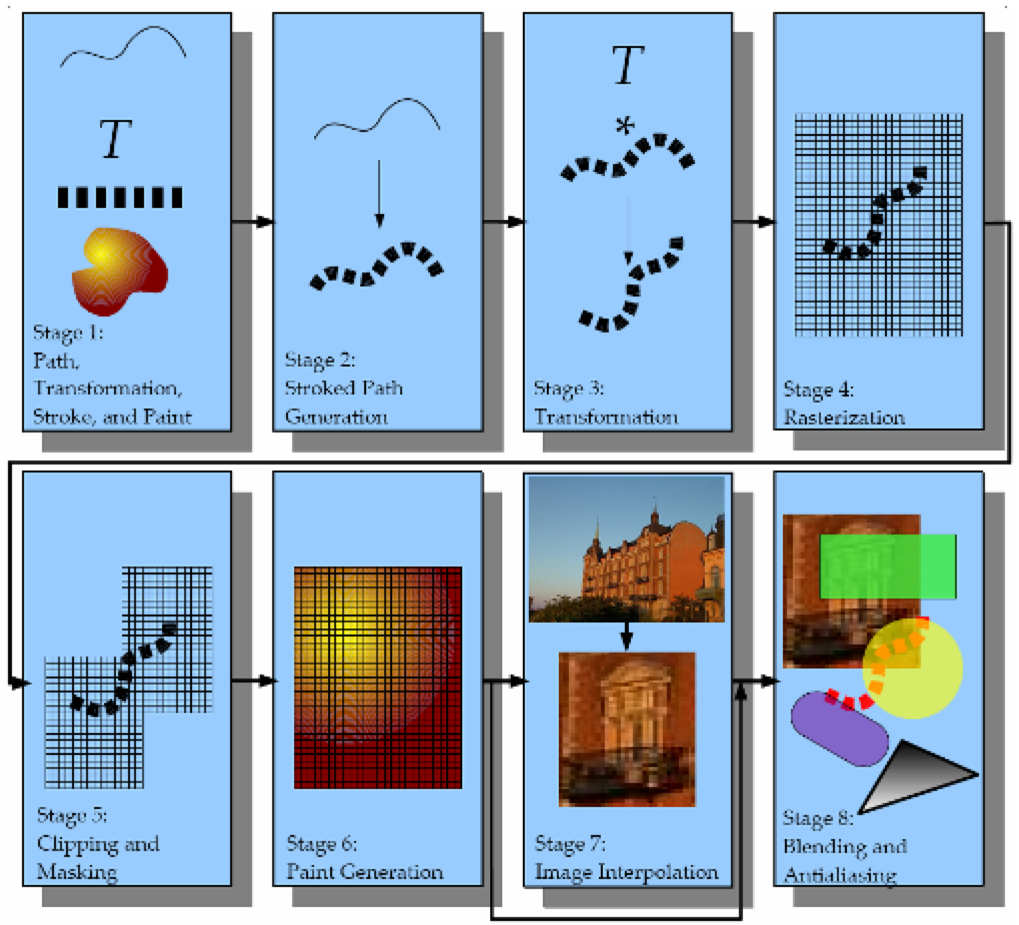


Paths

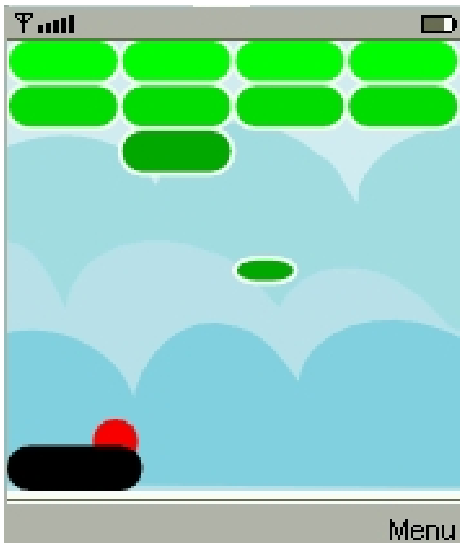

Fill rule

OpenVG pipeline

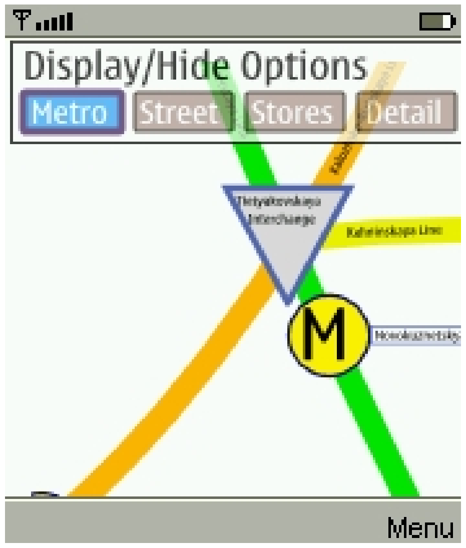



T
Stage 1: Path, Transformation, Stroke, and Paint
Stage 2: Stroked Path Generation
T
*
Stage 3: Transformation
Stage 4: Rasterization
Stage 5: Clipping and Masking
Stage 6: Paint Generation
Stage 7: Image Interpolation
Stage 8: Blending and Antialiasing

JSR-226 examples

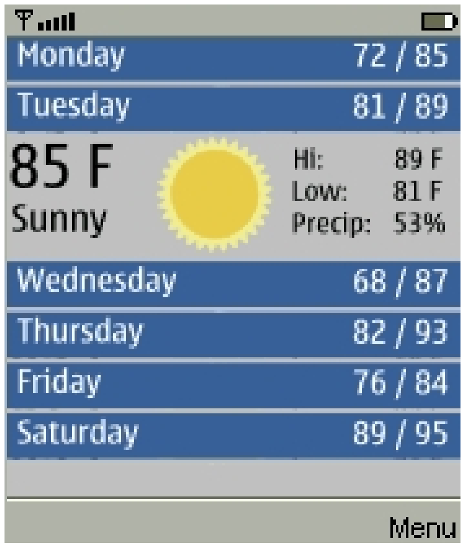


Game, with skins



Scalable maps, variable detail

Cartoon



Monday	72 / 85
Tuesday	81 / 89
85 F Sunny	Hi: 89 F Low: 81 F Precip: 53%
Wednesday	68 / 87
Thursday	82 / 93
Friday	76 / 84
Saturday	89 / 95

Weather info

Combining various APIs

It’s not trivial to efficiently combine use of various multimedia APIs in a single application

EGL is evolving towards simultaneous support of several APIs

- OpenGL ES and OpenVG now
- all Khronos APIs later

OpenGL ES and OpenVG

OpenGL ES
Accurately represents
PERSPECTIVE and
LIGHTING

OpenVG
Accurately represents
SHAPE and
COLOR

OpenVG ideal for advanced compositing user interfaces
OpenGL ES for powerful 3D UI effects

Summary

- Handheld devices are viable 3D platforms
  - OpenGL ES, M3G, COLLADA
- 2D vector graphics is also available
  - JSR 226, Flash, OpenVG, JSR 287
- Download the SDKs
  - and start coding on the smallest (physical size) yet largest (number of units) platform