

MODERN & INTERACTIVE SCIENTIFIC VISUALIZATION

USING SHADER BASED RENDERING

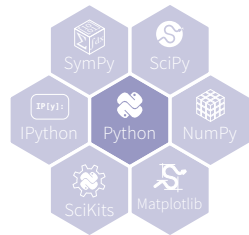


Nicolas P. Rougier
Luke Campagola - Almar Klein - Cyrille Rossant - Eric Larson
X.Org Developer Conference 2014
Bordeaux, October 8-10

A Bit of Context

The Python Scientific Stack

- Python, modern computing script language
- IPython, an advanced Python shell
- Numpy, powerful numerical arrays objects.
- Scipy, high-level data processing routines.
- **Matplotlib**, 2-D visualization plots



Versatile, beautiful but... slow !

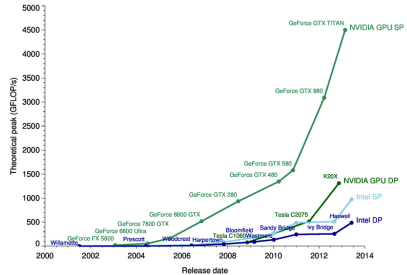
Matplotlib is a python plotting library, primarily for 2-D plotting, but with some 3-D support, which produces publication-quality figures in a variety of hardcopy formats and interactive environments across platforms.

- **Antigrain geometry**, High Fidelity 2D Graphics (www.antigrain.com)
- **Ten Simple Rules for Better Figures**, Nicolas P. Rougier, Michael Droettboom, Philip E. Bourne PLoS Computational Biology, Vol. 10, No. 9.

What about OpenGL ?

Powerful, fast but... **ugly** !

- No decent anti-aliasing
- Only two image filters
- No native text handling
- No markers, no arrows
- No paths, no curves



Proprietary solution

- Mark Kilgard and Jeff Bolz, **GPU-accelerated Path Rendering**, ACM Transactions on Graphics (Proceedings of SIGGRAPH Asia 2012), vol. 31, Num. 6, (2012).
- OpenVG API, Standard for Vector Graphics Acceleration, Khronos group.

But this can also be fixed freely !

Python/OpenGL frameworks

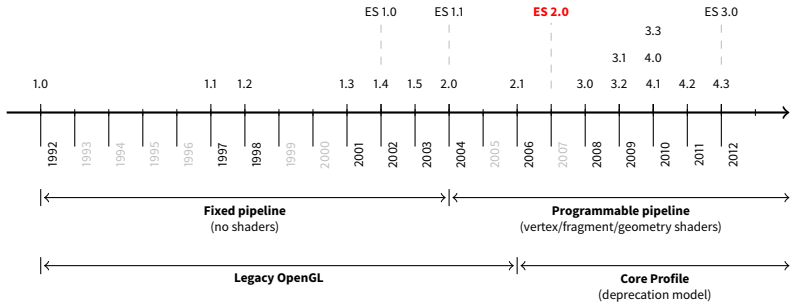
Rendering framework

- **Pyglet**
www.pyglet.org
- **PyOpenGL**
pyopengl.sourceforge.net
- **Nodebox for OpenGL**
www.cityinabottle.org/nodebox
- **PyProcessing**
code.google.com/p/pyprocessing

Visualization framework

- **mayavi 2** (Enthought)
github.com/enthought/mayavi
- **VTK** (Kitware)
www.vtk.org
- **galry** (Cyrille Rossant)
rossant.github.io/galry/
- **visvis** (Almar Klein)
code.google.com/p/visvis/
- **glumpy** (Nicolas Rougier)
code.google.com/p/glumpy/
- **pyqtgraph** (Luke Campagnola)
www.pyqtgraph.org

OpenGL history



Doom (1993)

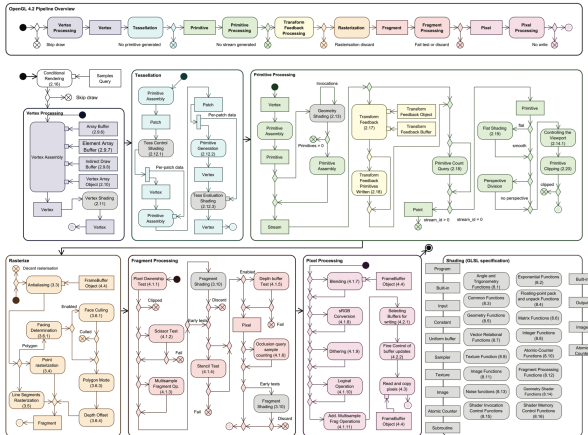


Rage (2011)

OpenGL 4.2 pipeline overview

(could have been worse...)

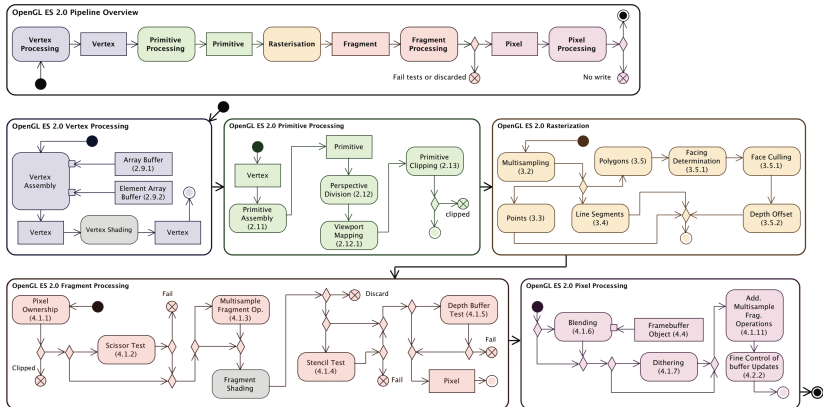
Around 2000 constants and 1000 functions.



OpenGL ES 2.0 pipeline overview

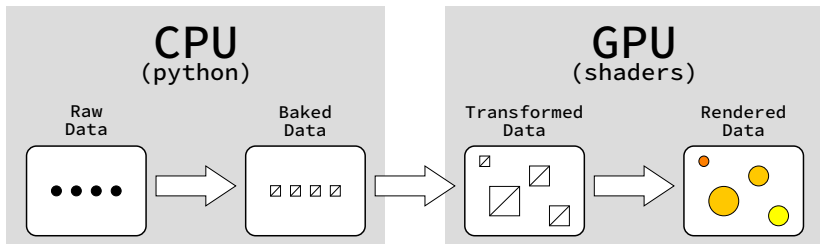
(openglinsights.com)

Around 350 constants and 150 functions.



Pipeline overview

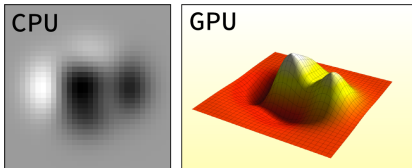
Data centered



Critical parts are the **baking** process and the **transfer** to GPU memory.

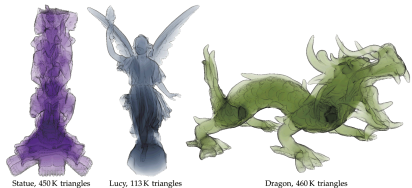
Baking process

Ideal case: no baking



Interpolation, colorization, leveling, gridding, scaling, lighting, aliasing, rendering entirely done on GPU.

Hard case: baking depends on transformation



Transparency implies lot of CPU processing (sorting) or multi-pass rendering.

Where do we start ?

Scalable Vector Graphics (SVG) 2

- ✓ Text
- ✓ Paths
- ✓ Basic shapes
- ✓ Painting: Filling, Stroking and Marker Symbols
- ✓ Clipping, Masking and Compositing
- ✓ Filter Effects

...

Different techniques

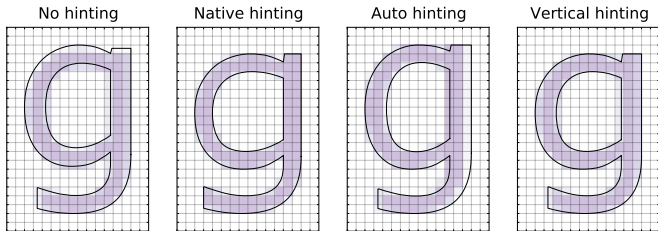
Bitmap, stroke, texture, sdf, vector...



→ Nicolas P. Rougier, **Higher Quality 2D Text Rendering**, Journal of Computer Graphics Techniques (JCGT), vol. 2, no. 1, 50-64, 2013.

Higher quality text rendering

Vertical vs Horizontal hinting



→ Maxim Shemarev, **Texts Rasterization Exposures**, An attempt to improve text rasterization algorithms, 2007

Implementation (github.com/rougier/freetype-gl)

- Subpixel positioning & kerning
- Per pixel gamma correction
- Signed Distance Fields

Dashed stroked polyline

GL line width (fixed pipeline)

- Limited in thickness
- No control over joins and caps
- Deprecated & ugly

GL Stipple (fixed pipeline)

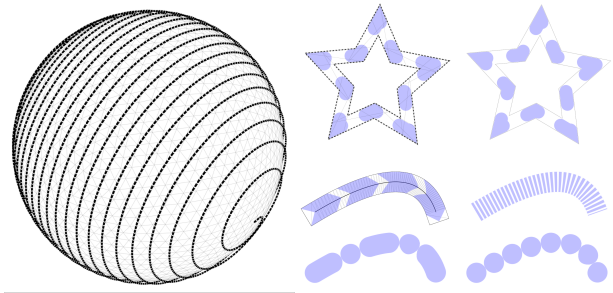
- Limited in pattern
- No control over dash caps
- Deprecated & ugly

PATTERN	FACTOR	
0x00FF	1	_____
0x00FF	2	_____
0x0C0F	1	____ _
0x0C0F	3	_____
0xAAAA	1	- - - - -
0xAAAA	2	- - - - -
0xAAAA	3	- - - - -
0xAAAA	4	- - - - -

Higher quality dashed stroked polyline

Shader based approach

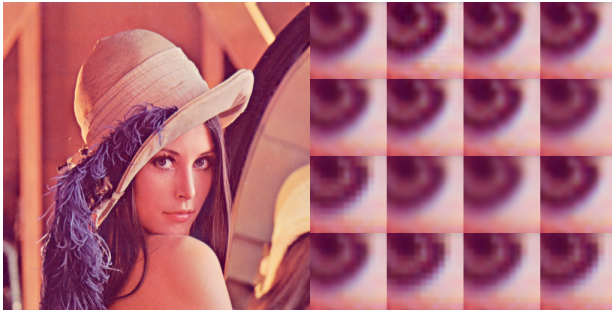
A new method for rendering arbitrary dash patterns along any continuous polyline (smooth or broken). The proposed method does not tessellate individual dash patterns and allows for fast and accurate rendering of any user-defined dash pattern and caps



→ Nicolas P. Rougier, **Shader-Based Antialiased, Dashed, Stroked Polyines**, Journal of Computer Graphics Techniques (JCGT), vol. 2, no. 2, 105–121, 2013.

Image interpolation & filters

OpenGL offers only nearest and linear filters while much more are needed for scientific visualization (Hanning, Hamming, Hermite, Kaiser, Quadric, Bicubic, CatRom, Mitchell, Spline16, Spline36, Gaussian, Bessel, Sinc, Lanczos, Blackman, etc.)

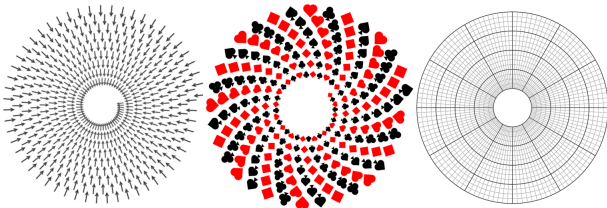


→ Kevin Bjorke, **High-Quality Filtering** in GPU gems 2 : programming techniques for high-performance graphics and general-purpose computation / edited by Matt Pharr ; Randima Fernando (2007).

Grids, markers and arrows

Point based approach

A new method for drawing grids, markers, and arrows using implicit functions such that it is possible draw pixel-perfect antialiased objects with very good performances.



→ Nicolas P. Rougier, **Shader Based Antialiased 2D Grids, Markers, and Arrows**, Journal of Computer Graphics Techniques (JCGT), to appear, 2014.

Still lot of problems ahead...

...but work is in progress

Shader composition

How to define a shader format that allow easy composition/templating ?

Level of details

How to set automatic level of details ?

Very big data

How to render data that doesn't even fit into GPU memory ?

Complex data transformation

How to handle user-supplied exotic transformation ?

From DesktopGL to WebGL

How to render in browser from a python session ?

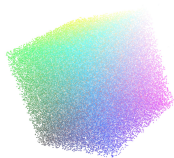
...

Conclusion

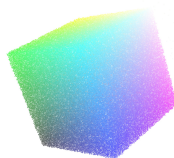
We do not have to (always) trade quality for speed



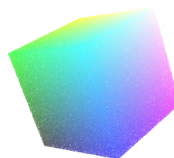
10,000 pts - 403 FPS



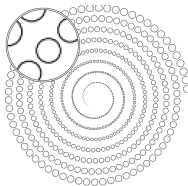
100,000 pts - 140 FPS



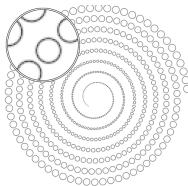
1,000,000 pts - 40 FPS



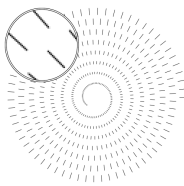
10,000,000 pts - 1.5 FPS



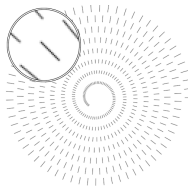
AntiGrain Geometry
(matplotlib agg backend)



OpenGL AntiGrain
(using dedicated shaders)



AntiGrain Geometry
(matplotlib agg backend)



OpenGL AntiGrain
(using dedicated shaders)

Informations & links

The code is spread in several projects but should be soon integrated in the master vispy project.

Projects page

- vispy.org
- vispy.org/gallery.html
- glumpy.github.io
- glumpy.github.io/gallery.html

Code repositories

- github.com/vispy/vispy
- github.com/glumpy/glumpy
- github.com/rougier/gl-agg
- github.com/rougier/freetype-gl

Demo pages

- Markers: <https://www.shadertoy.com/view/XsXXDX>
- Arrows: <https://www.shadertoy.com/view/ldlSWj>
- Transverse Mercator grid: <https://www.shadertoy.com/view/lSXXzm>
- Cartesian grid: <https://www.shadertoy.com/view/MdSXRm>
- Polar grid: <https://www.shadertoy.com/view/MsBSRm>

WHY DO WHALES JUMP
 WHY ARE WITCHES GREEN
 WHY ARE THERE MIRRORS ABOVE BEDS
 WHY DO I SAY UH
 WHY IS SEA SALT BETTER
 WHY ARE THERE TREES IN THE MIDDLE OF FIELDS
 WHY IS THERE NOT A POKEMON MIMO
 WHY IS THERE LAUGHING IN TV SHOWS
 WHY ARE THERE DOORS ON THE FREEWAY
 WHY ARE THERE SO MANY SUICIDEBOMBS RUNNING
 WHY AREN'T THERE ANY COUNTRIES IN PATRICKOTIA
 WHY ARE THERE SCARY SOUNDS IN MINECRAFT
 WHY IS THERE KICKING IN MY STOMACH
 WHY ARE THERE TWO SLASHES AFTER HTTP
 WHY ARE THERE CELEBRITIES
 WHY DO SNAKES EXIST
 WHY DO OYSTERS HAVE PEARLS
 WHY ARE DUCKS CALLED DUCKS
 WHY DO THEY CALL IT THE CLAP
 WHY ARE KYLE AND CHARTMAN FRIENDS
 WHY IS THERE AN ARROW ON AAPNG'S HEAD
 WHY ARE TEXT MESSAGES BLUE
 WHY ARE THERE MUSTACHES ON CLOTHES
 WHY ARE THERE MUSTACHES ON CARS
 WHY ARE THERE MUSTACHES EVERYWHERE
 WHY ARE THERE SO MANY BIRDS IN OHIO
 WHY IS THERE SO MUCH RAIN IN OHIO
 WHY IS OHIO WEATHER SO WEIRD
 WHY ARE THERE MALE AND FEMALE BIKES
 WHY ARE THERE BRIDESMAIDS
 WHY DO DYING PEOPLE RECALL UP
 WHY AREN'T THERE BRIDESMAIDS
 WHY ARE OLD KLUKONS DIFFERENT

WHY DO TESTICLES MOVE
 WHY ARE THERE PSYCHICS
 WHY ARE HATS SO EXPENSIVE
 WHY IS THERE OFFENSE IN MY SHAPPOD
 WHY DO YOUR BOOBS HURT
 WHY DO TWINS HAVE DIFFERENT FINGERPRINTS
 WHY ARE AMERICANS AFRAID OF DRAGONS
 WHY IS HTTPS CROSSED OUT IN RED
 WHY IS THERE A LINE THROUGH HTTPS
 WHY IS THERE A RED LINE THROUGH HTTPS ON FACEBOOK
 WHY IS HTTPS IMPORTANT

WHY ARE THERE SLAVES IN THE BIBLE
 WHY ARE THERE WEEDS
 WHY DO I FEEL DIZZY
 WHY ARE THERE PHLEGT
 WHY ARE THERE SO MANY CROWS IN ROCHESTER, NY
 WHY IS PSYCHIC WEAK TO BUG
 WHY DO CHILDREN GET CANCER
 WHY IS POSEIDON ANGRY WITH ODYSSEUS
 WHY IS THERE ICE IN SPACE
 WHY ARE DOGS AFRAID OF FIREWORKS
 WHY IS THERE NO KING IN ENGLAND
 WHY AREN'T MY ARMS GROWING

QUESTIONS

FOUND IN GOOGLE AUTOCOMPLETE



WHY AREN'T THERE DINOSAUR GHOSTS
 WHY AREN'T ECONOMISTS RICH
 WHY DO AMERICANS CALL IT SOCCER
 WHY ARE MY EARS RINGING
 WHY ARE THERE SO MANY AVENGERS
 WHY ARE THE AVENGERS FIGHTING THE X MEN
 WHY IS WOLVERINE NOT IN THE AVENGERS

WHY AREN'T ECONOMISTS RICH
 WHY DO AMERICANS CALL IT SOCCER
 WHY ARE MY EARS RINGING
 WHY ARE THERE SO MANY AVENGERS
 WHY ARE THE AVENGERS FIGHTING THE X MEN
 WHY IS WOLVERINE NOT IN THE AVENGERS

WHY ARE THERE ANTS IN MY LAPTOP
 WHY IS EARTH TILTED
 WHY IS SPACE BLACK
 WHY IS OUTER SPACE SO COLD
 WHY ARE THERE PYRAMIDS ON THE MOON
 WHY IS NASA SHUTTING DOWN

WHY ARE THERE ANTS IN MY LAPTOP
 WHY IS THERE AN OWL IN MY BACKYARD
 WHY IS THERE AN OWL OUTSIDE MY WINDOW
 WHY IS THERE AN OWL ON THE DOLLAR BILL
 WHY DO OWLS ATTACK PEOPLE
 WHY ARE AK 47s SO EXPENSIVE
 WHY ARE THERE HELICOPTERS CIRCLING MY HOUSE
 WHY ARE THERE GODS
 WHY ARE THERE TWO SPOCKS

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 WHY ARE THERE HELICOPTERS CIRCLING MY HOUSE
 WHY ARE THERE GODS
 WHY ARE THERE TWO SPOCKS

WHY ARE THERE SQUIRRELS

WHY ARE THERE MALE AND FEMALE BIKES
 WHY ARE THERE TINY SPIDERS IN MY HOUSE
 WHY DO SPIDERS COME INSIDE
 WHY ARE THERE HUGE SPIDERS IN MY HOUSE
 WHY ARE THERE LOTS OF SPIDERS IN MY HOUSE
 WHY ARE THERE SPIDERS IN MY ROOM
 WHY ARE THERE SO MANY SPIDERS IN MY ROOM
 WHY DO SPIDER BITES ITCH
 WHY IS DYING SO SCARY

WHY ARE THERE FEMALE MR NINES
 WHY IS MT VESUVIUS THERE
 WHY DO THEY SAY T MINUS
 WHY ARE THERE OBELISKS
 WHY ARE WRESTLERS ALWAYS WET
 WHY ARE OCEANS BECOMING MORE ACIDIC



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 WHY ARE WRESTLERS ALWAYS WET
 WHY ARE OCEANS BECOMING MORE ACIDIC

WHY ARE THERE FEMALE MR NINES
 WHY IS LIFE SO BORING
 WHY AREN'T MY QUAIL LAYING EGGS
 WHY AREN'T MY QUAIL EGGS HATCHING
 WHY AREN'T THERE ANY FOREIGN MILITARY BASES IN AMERICA

WHY IS PROGRAMMING SO HARD
 WHY IS THERE A 0.0% RESISTOR
 WHY DO AMERICANS HATE SOCCER
 WHY DO RAINBOWS SOUND GOOD
 WHY DO TREES DIE
 WHY IS THERE NO SOUND ON CNN
 WHY AREN'T POKEMON REAL
 WHY AREN'T BULLETS SHARP
 WHY DO DREAMS SEEM SO REAL

WHY IS THERE NO GPS IN LAPTOPS
 WHY DO KNEES CLICK
 WHY AREN'T THERE E GRAPDES
 WHY IS ISOLATION BAD
 WHY DO BOYS LIKE ME
 WHY DON'T BOYS LIKE ME
 WHY IS THERE ALWAYS A SNOW UPOBITE
 WHY ARE THESE RED DOTS ON MY BAGHS
 WHY IS LYING GOOD

WHY IS SEX SO IMPORTANT

WHY IS LIFE SO BORING
 WHY AREN'T MY QUAIL LAYING EGGS
 WHY AREN'T MY QUAIL EGGS HATCHING
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 WHY AREN'T MY QUAIL EGGS HATCHING
 WHY AREN'T THERE ANY FOREIGN MILITARY BASES IN AMERICA

WHY AREN'T THERE GUNS IN HARRY POTTER