计算机图形学

发展史及应用

陶钧
taoj23@mail.sysu.edu.cn

中山大学 数据科学与计算机学院
国家超级计算广州中心

课程概要

- 现代计算机图形学
- 计算机图形学发展史
- 计算机图形学应用
- 如何学习计算机图形学

硬件变革:显卡运算性能的爆炸性增长

– 模型处理及图形渲染需要大量运算
– 摩尔定律

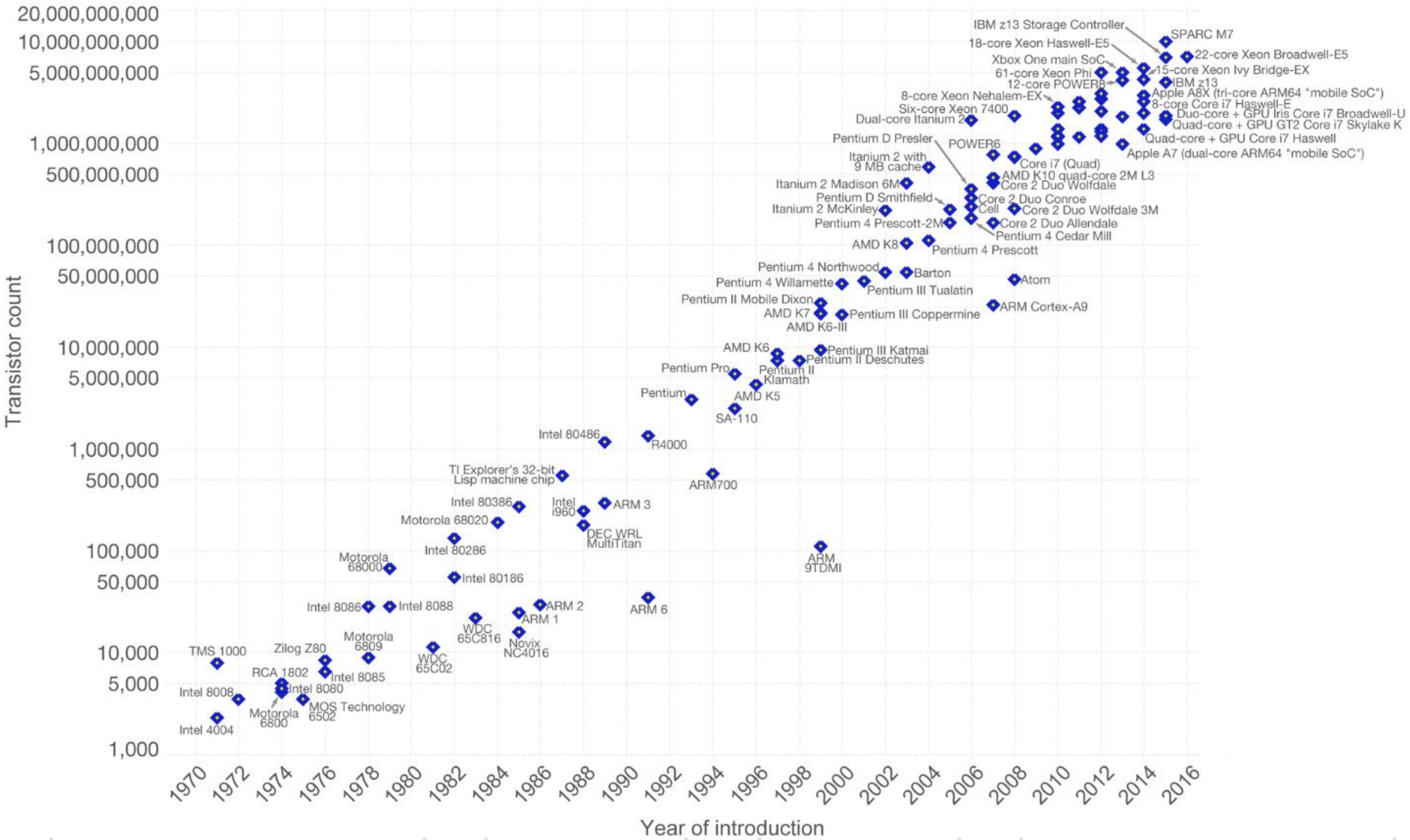
英特尔创始人之一戈登·摩尔提出：

“集成电路上可容纳的晶体管数目，约每隔两年便会增长一倍”

另一版本为18个月（由英特尔首席执行官大卫·豪斯提出）

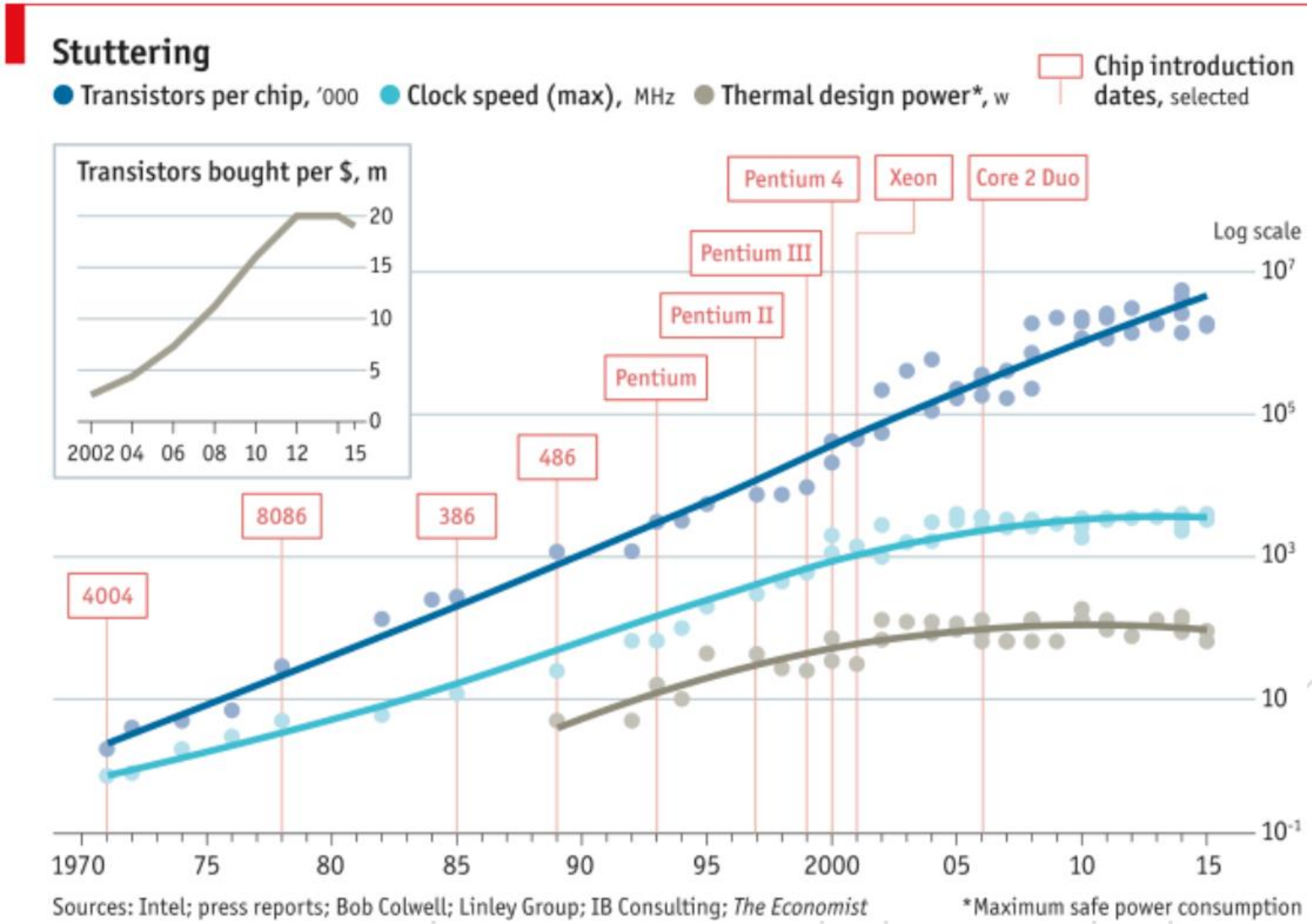
硬件变革:显卡运算性能的爆炸性增长

– 摩尔定律



硬件变革:显卡运算性能的爆炸性增长

– 摩尔定律的瓶颈：晶体管数目≠频率



摩尔定律还能持续多久?

- 2021/2025年假说
- 量子穿隧效应

图片来源：The Economist's Technology Quartlerly

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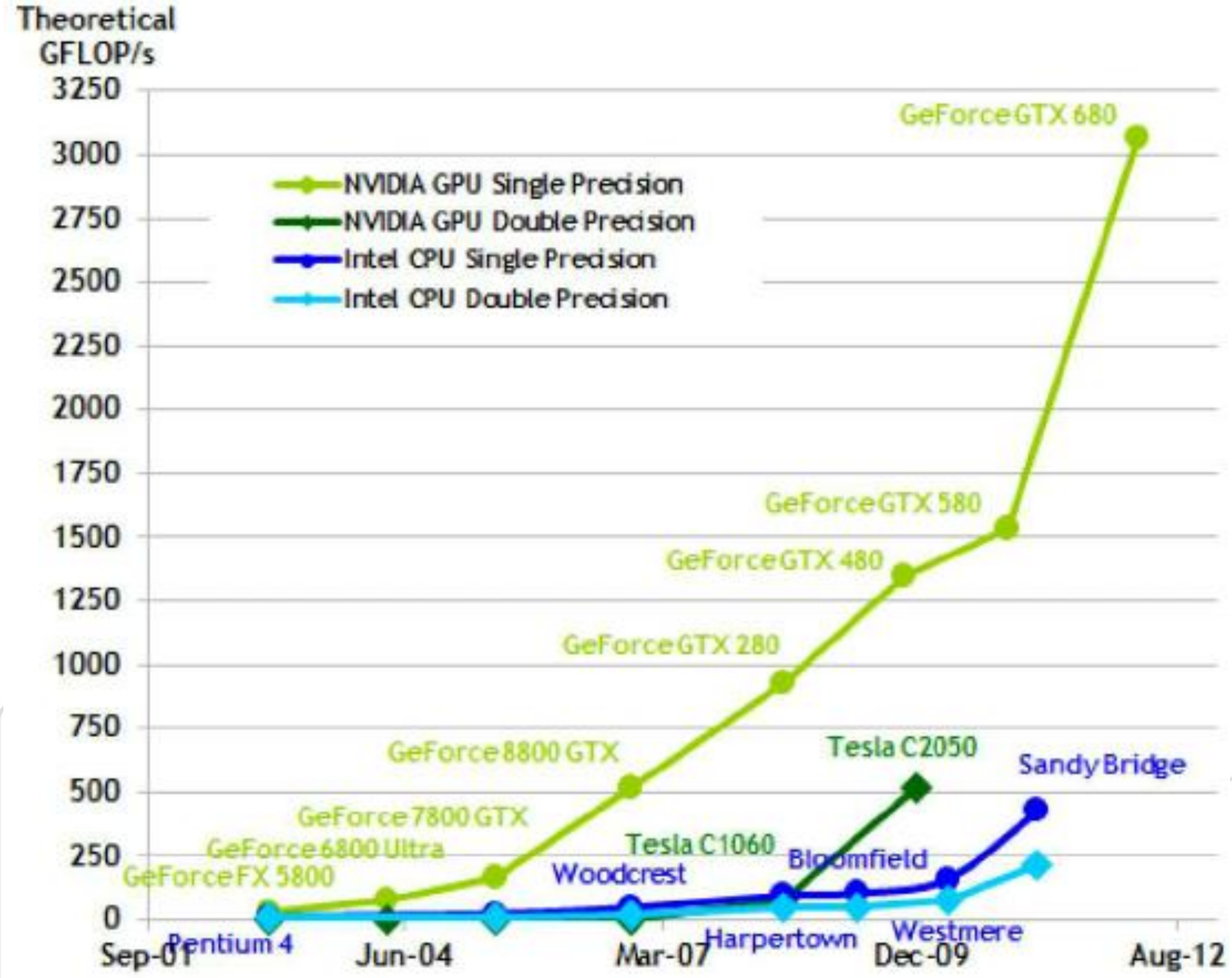
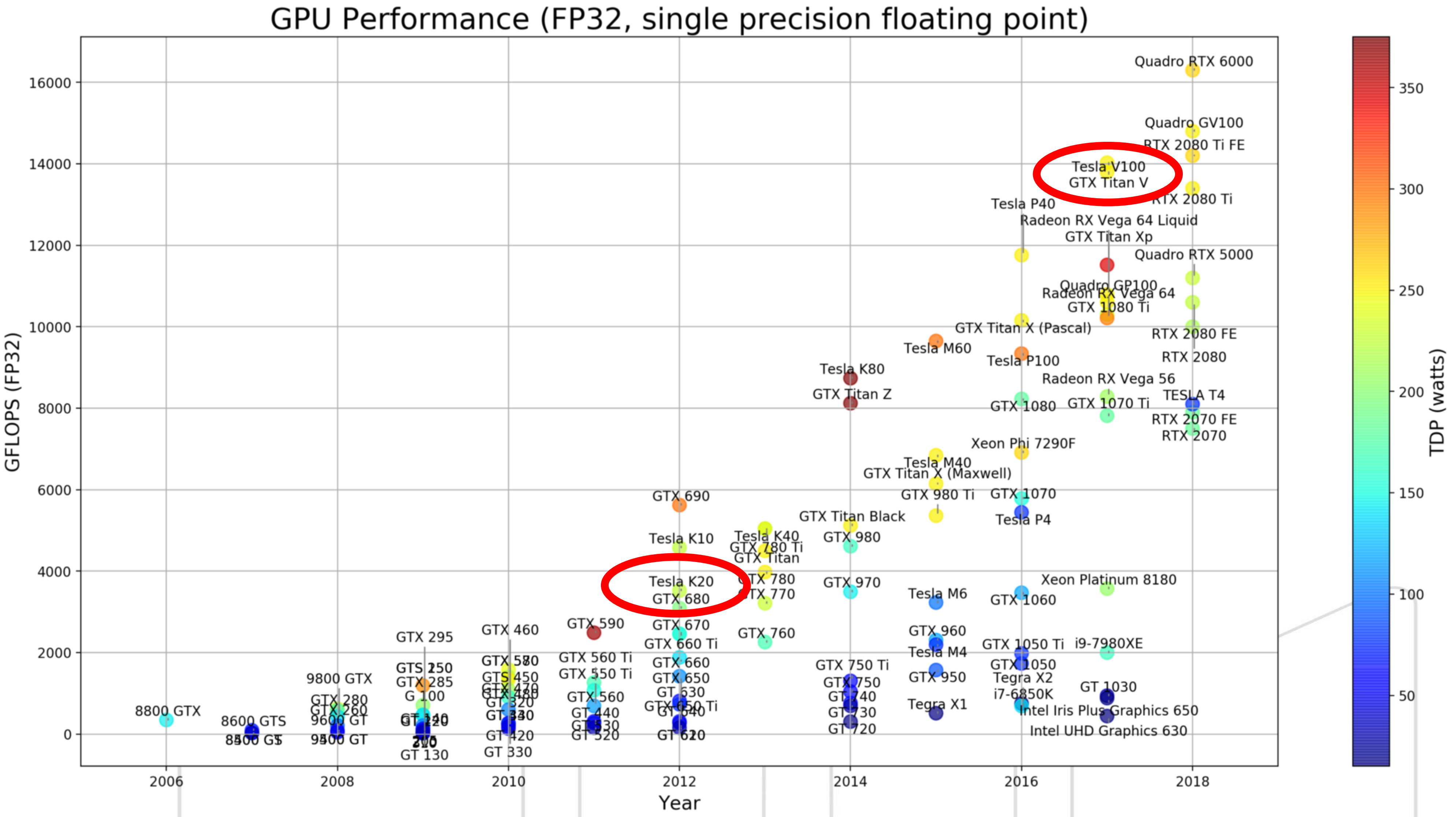
- 硬件变革:显卡运算性能的爆炸性增长
  – CPU与GPU性能对比

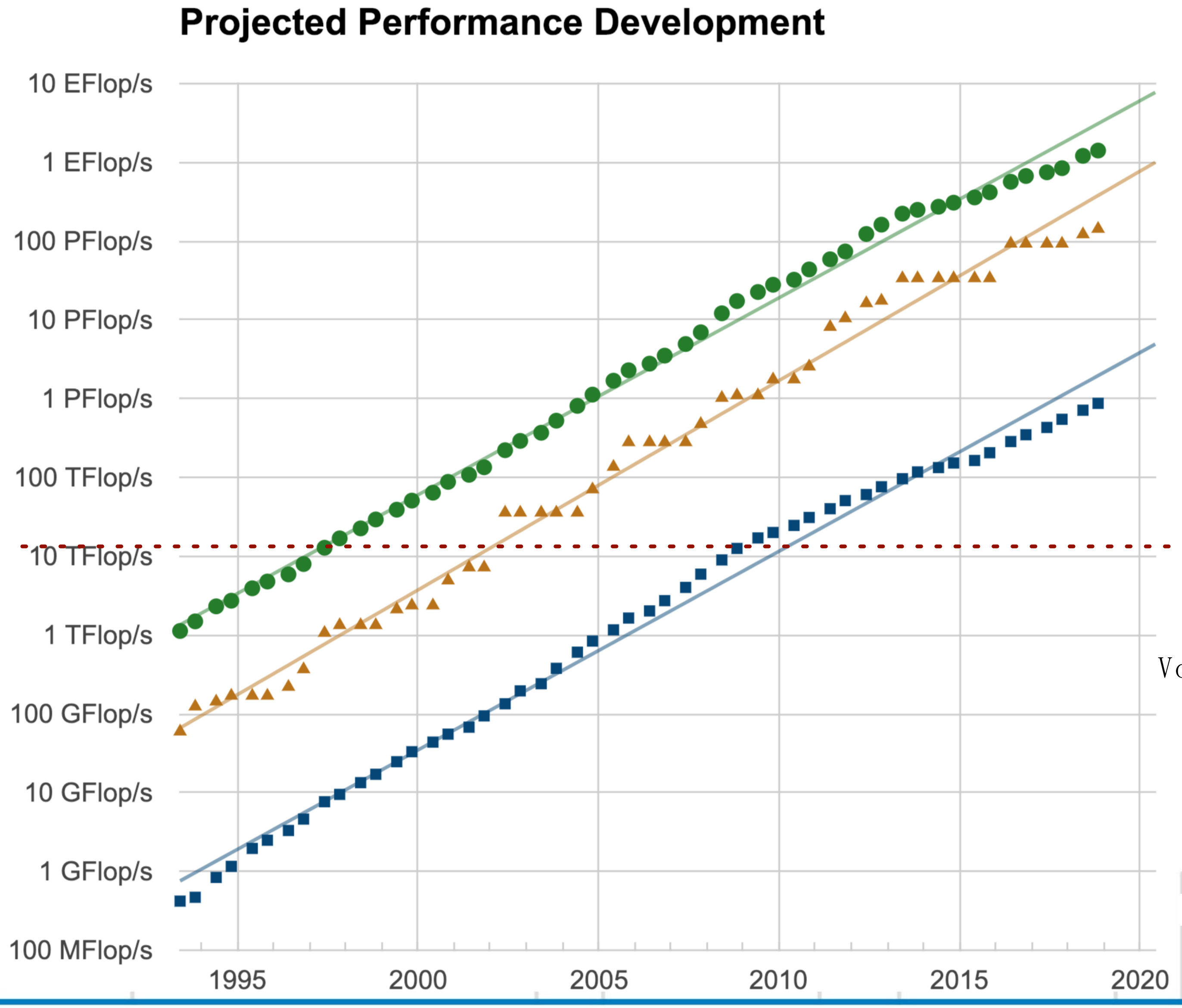


图片来自NVIDIA

- 硬件变革:显卡运算性能的爆炸性增长
  - – GPU运算速度发展



- 硬件变革:显卡运算性能的爆炸性增长
  - GPU与超级计算机



Volta V100 (15 TFlops/s)

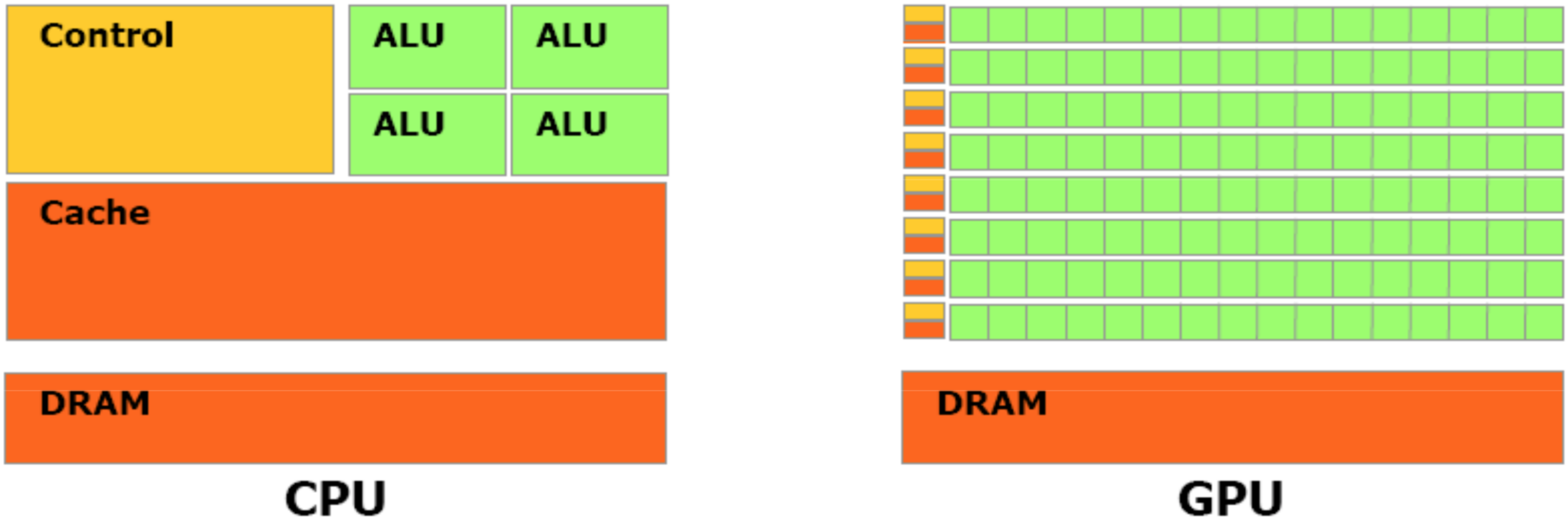
图片来自https://www.top500.org/statistics/perfdevel/

硬件变革:显卡运算性能的爆炸性增长：起源

- 将图形处理从CPU转移至为其特殊设计的芯片上
- NVidia GeForce™, AMD Radeon™, and Intel HD and Iris Pro Graphics
- GPU最初只用于处理特定的图形学相关计算（渲染）
- 当前，GPU越来越多地用于其他类型的通用计算
  - GPGPU (General-Purpose computing on the Graphics Processing Unit)

硬件变革:显卡运算性能的爆炸性增长

- GPGPU
  - 高度并行化：相同的指令应用于大量数据上
  - 大量运算核心

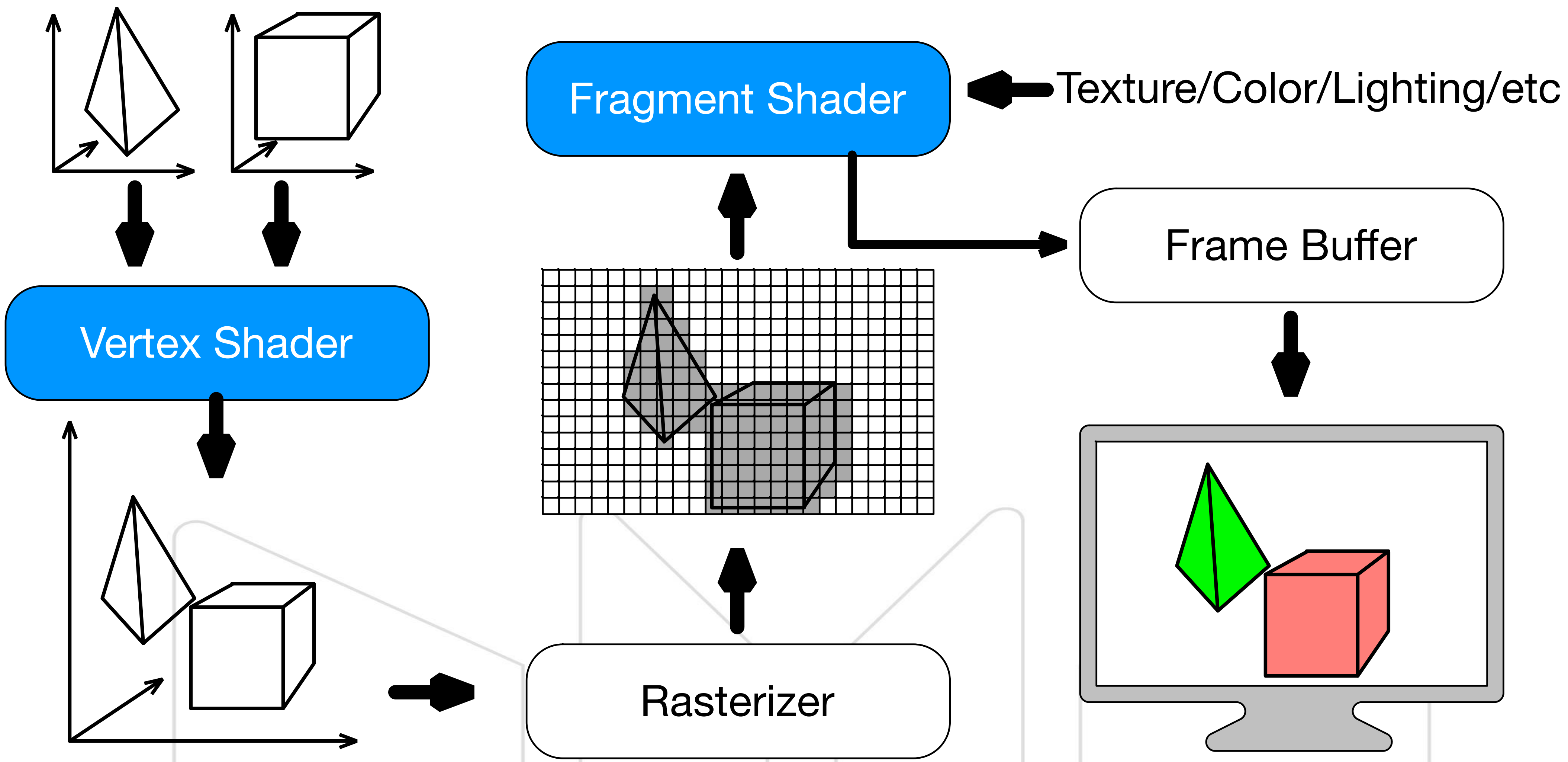


图片来自NVIDIA

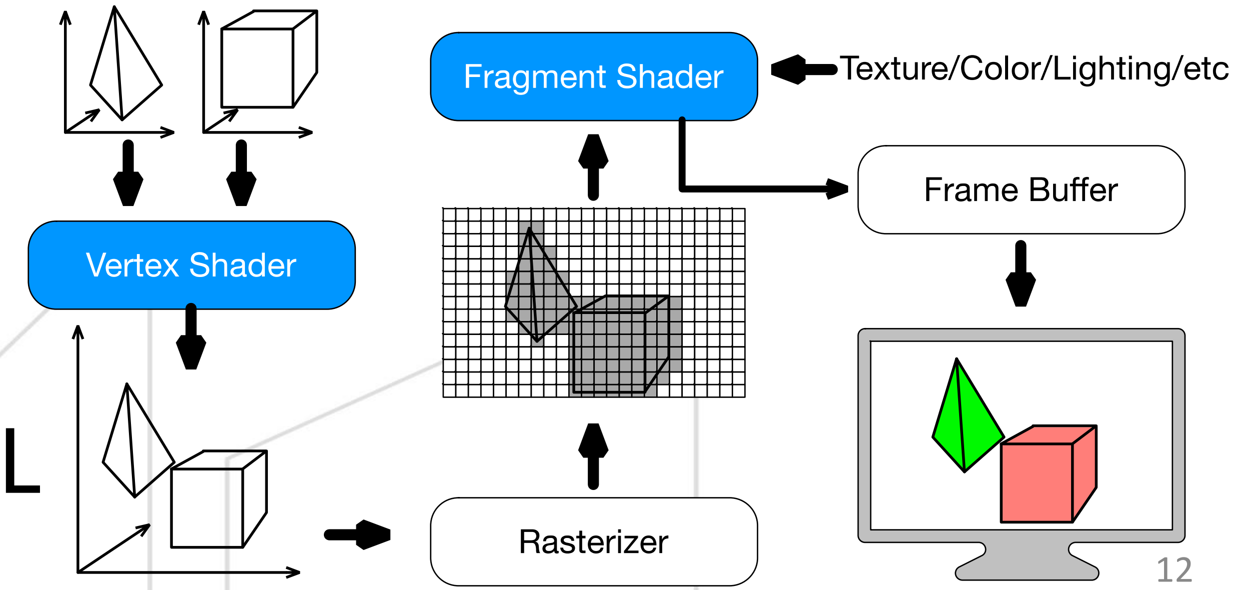
硬件变革:显卡运算性能的爆炸性增长

– GPGPU

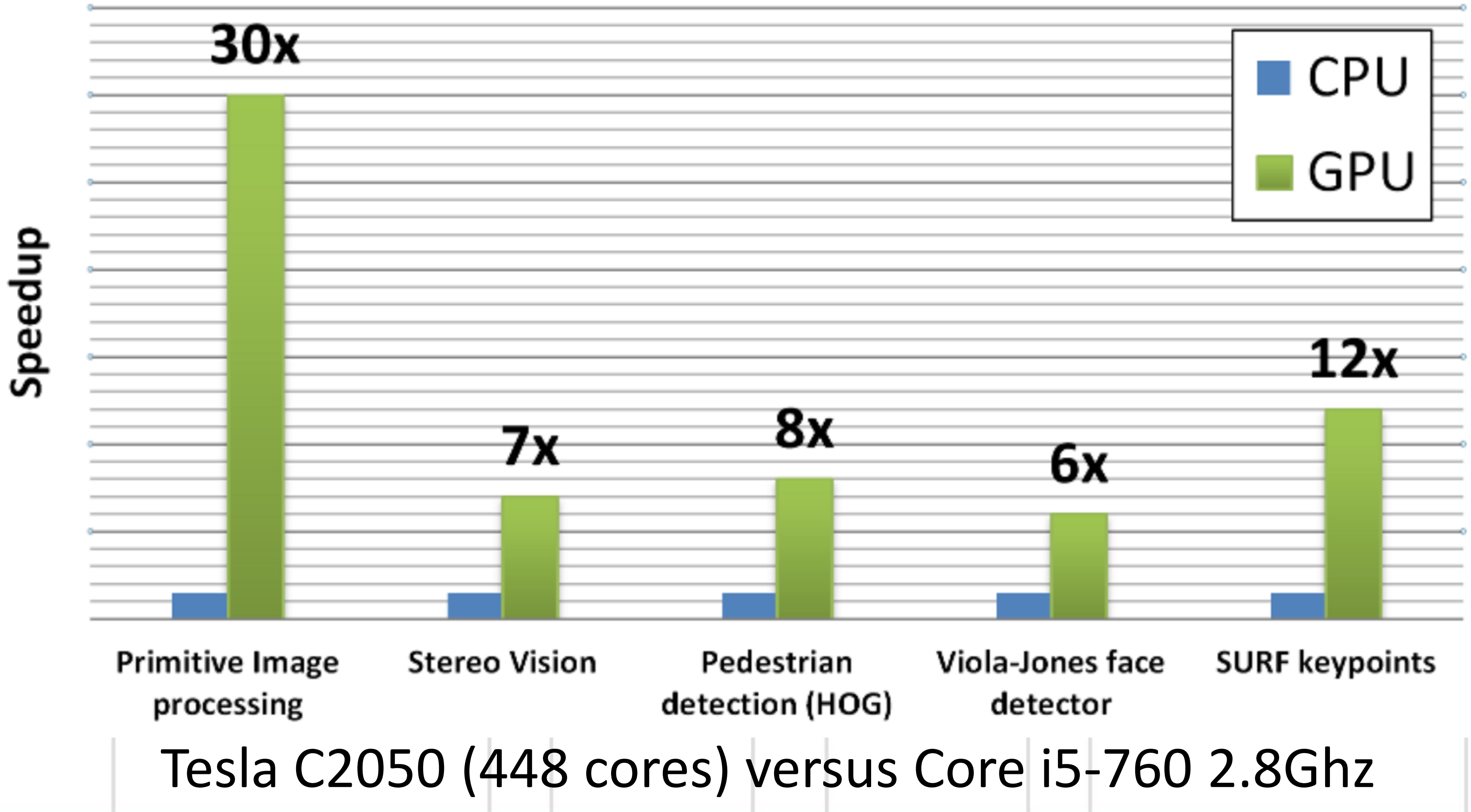
  • 图形绘制简易流程



- 硬件变革:显卡运算性能的爆炸性增长
  - GPGPU基本思路
  - Vertex shader 和 fragment shader 可由用户自行通过shading language编程
  - 把封装数据封装成图形绘制库所需的数据形式传入
  - 绘制过程中通过修改shader执行用户编写的程序
    - 通常是fragment shader
  - 将结果绘制到texture中传出
  - 需要很强的图形学编程能力
    - 出现专用工具，如CUDA、OpenCL

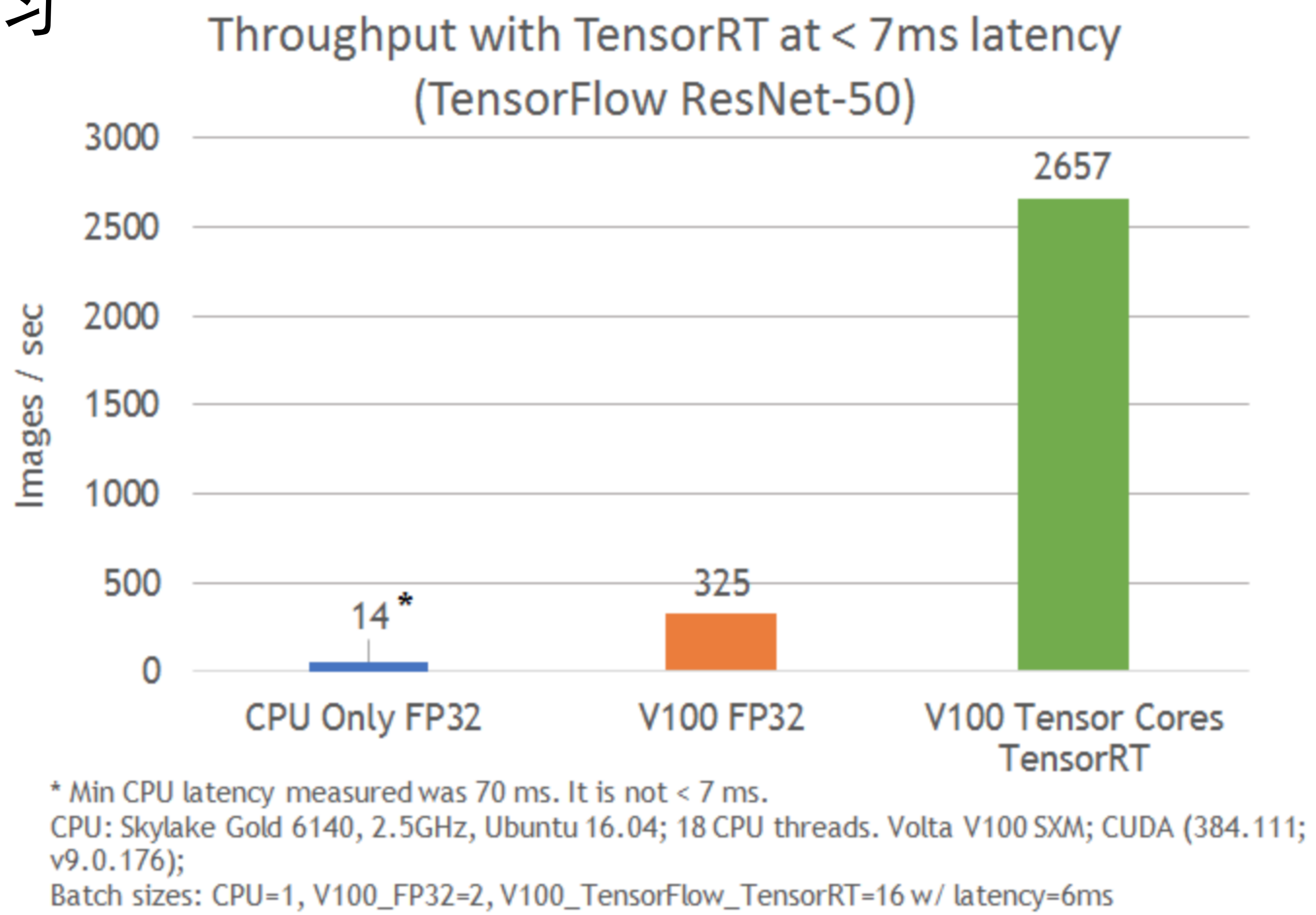


- 硬件变革:显卡运算性能的爆炸性增长
  - GPGPU加速效果
    - OpenCV——跨平台计算机视觉库



图片来自OpenCV.org

- 硬件变革:显卡运算性能的爆炸性增长
  - – GPGPU加速效果
    - TensorFlow——深度学习



图片来自Laurence Moroney

硬件变革:显卡运算性能的爆炸性增长

– PC上的高端独立显卡已逐渐取代专用图形工作站
– 由高速总线或局域网连接的PC集群常用于PowerWall、Caves等大规模图形显示
– PC集群也被应用于大规模计算，如，蛋白质折叠、天气预报等
– 如今多GPU也可以通过NVIDIA SLI (Scalable Link Interface)桥接

SGI图形工作站

多GPU通过SLI桥接

硬件变革:输入设备丰富

- 鼠标、平板电脑与手写笔、多点触控、力反馈、游戏控制器、扫描仪、数码相机（图像，计算机视觉）
- 体感交互设备
  - Xbox Kinect: “you are the controller”

Xbox Kinect

Leap Motion

Nimble UX

现代计算机图形学

硬件变革:输出设备丰富

– 智能手机/笔记本电脑/台式电脑/平板电脑
– 智能手表
– 头戴式显示（Head-Mounted Display, HMD)
– 3D沉浸式虚拟现实


Apple iPhone

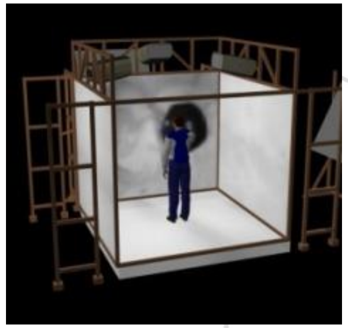

Android Phones


Microsoft’s first Surface

Tablets


Apple Watch


Android Wear


Brown’s old Cave


Microsoft Hololens


Oculus Rift


Google Cardboard

软件变革

– 算法与数据结构

- 建模算法：重现各种三维物体的形状、材质
- 渲染算法：产生自然的效果
- 数据结构：如用于加速光线追踪的几何算法

– 并行化

- 计算机图形学中的大多数操作都为embarrassingly parallel
  - 如，在渲染时计算像素颜色往往与其他像素无关

– 分布式与云计算

- 将操作发送至云端执行，隐藏执行过程直接获取执行结果
- 渲染甚至可以作为网络服务提供给用户
  - 如，超算上通过科学模拟产生的数据的可视化

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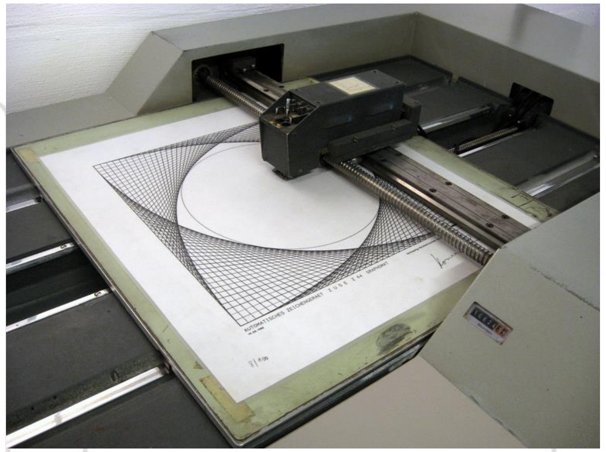
- 50年代
  - 1951年，MIT的Jay Forrester和Robert Everett为旋风一号（Whirlwind I）设计了第一个可视显示单元（VDU）
  - 1958年，CalComp开发了565滚筒绘图仪（drum plotter）
  - 1958年，Gerber公司开发了第一台平板绘图仪（flat plotter）

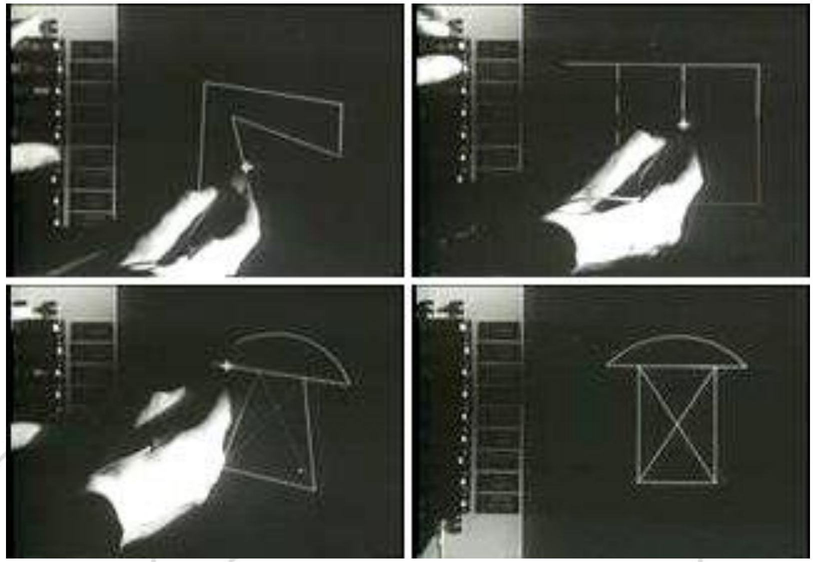


- 60年代
  - Spacewar！（星级飞行）为最早的电脑游戏
    - MIT学生Steve Russell在DEC PDP-1计算机上开发
    - 两个玩家个控制一艘星际战舰对战

计算机图形学发展史

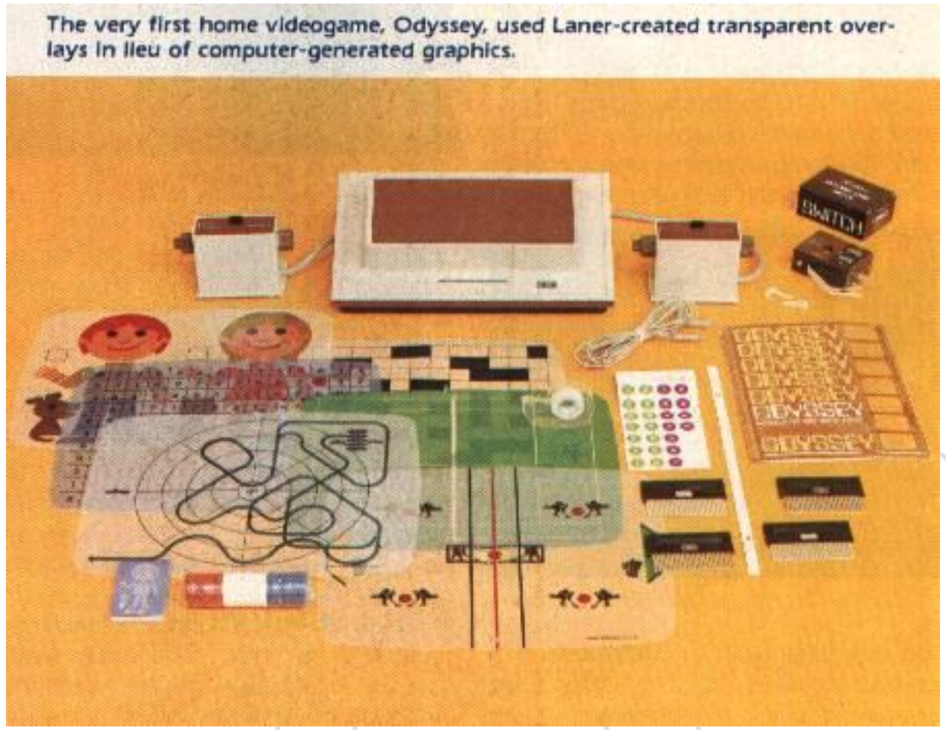
60年代

- 1963年，交互式系统Sketchpad (Robot Draftsman) 诞生
  - Ivan Sutherland博士论文
    - BS, 卡内基理工学院；MS, Caltech；PhD, MIT
  - 1988年图灵奖



60年代

– 第一台商业家庭视频游戏终端Magnavox Odyssey诞生
  - Ralph H. Baer设计，工程师William Harrison和William Rusch协助开发
  - 1966年开始，1968年产生第一个原型



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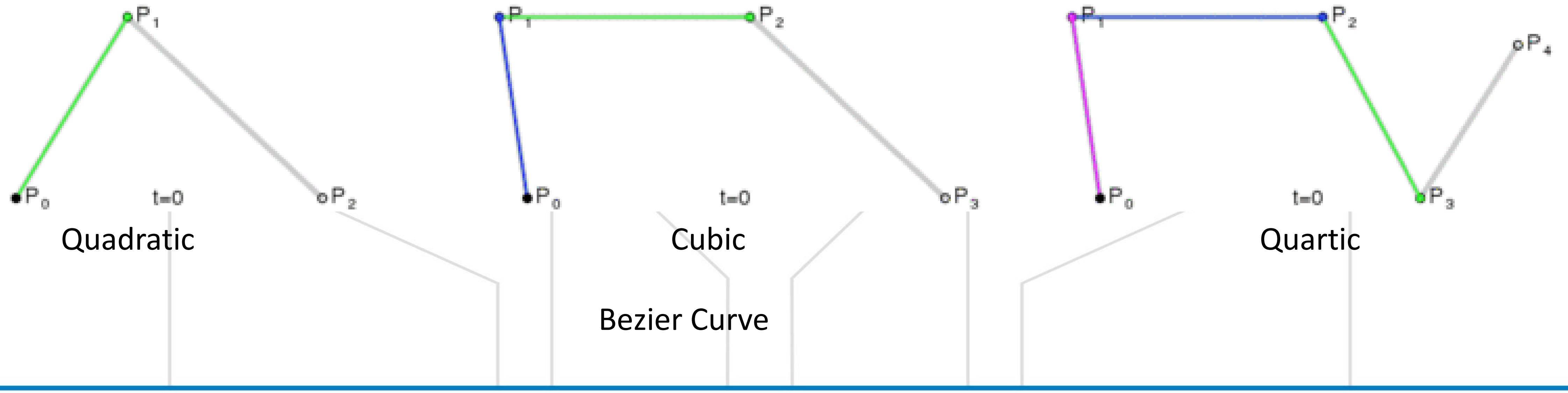
60年代

- 计算机辅助设计（Computer Aided Design, CAD)诞生
  - 1958年，MIT教授Steven Anson Coons提出CAD概念
  - 1964年，提出Coons surface
  - 1985年，ACM SIGGRAPH的Steven A. Coons奖因其命名
- 60年代末，法国工程师Pierre Bezier创造Bezier曲线和曲面
  - Bezier曲面成为当今CAD应用最广的曲面之一



Bezier Curve

- 70年代
  - 光栅化图形算法快速发展
    - 扫描转化（scan conversion），裁减（clipping），surface hidden removal（消隐），及其他相关算法出现
  - 标准化进程
    - 1974年，ACM SIGGRAPH（Special Interest Group on computer GRAPHics and Interactive Techniques）成立图形标准委员会
    - 国际标准组织（ISO）发布CGI (Computer Graphics Interface), CGM (Computer Graphics Metafile), GKS (Graphics Kernel System), PHIGS (Programmer’s Hierarchical Interactive Graphics Standard)

70年代

- 1970年，Bouknight提出第一个光反射模型（flat shading）
- 1971年，Henri Gouraud提出“漫反射（diffuse reflection）+插值（interpolation）”的反射模型（Gouraud shading）
- 1975年，Bui Tuong Phong提出基于法向量插值的局部反射模型（Phong shading)，为当今最有影响力的模型
  - Utah大学
  - 73年博士毕业论文，75年发表论文

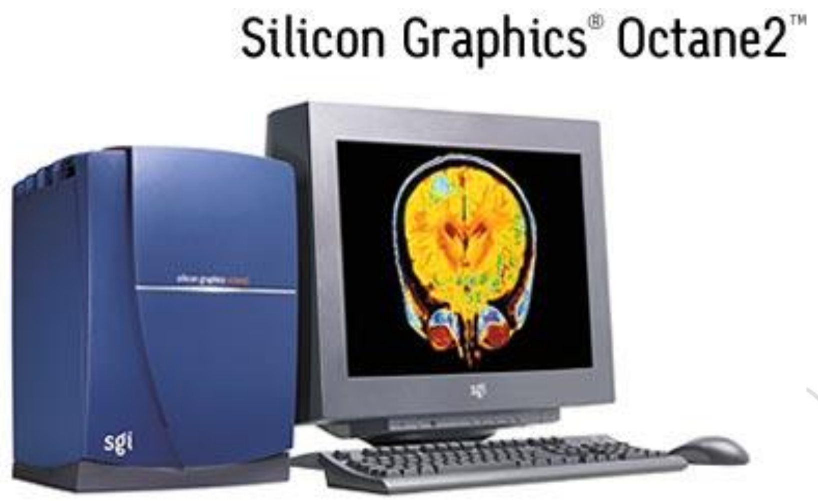
Flat shading

Gourand shading

Phong shading

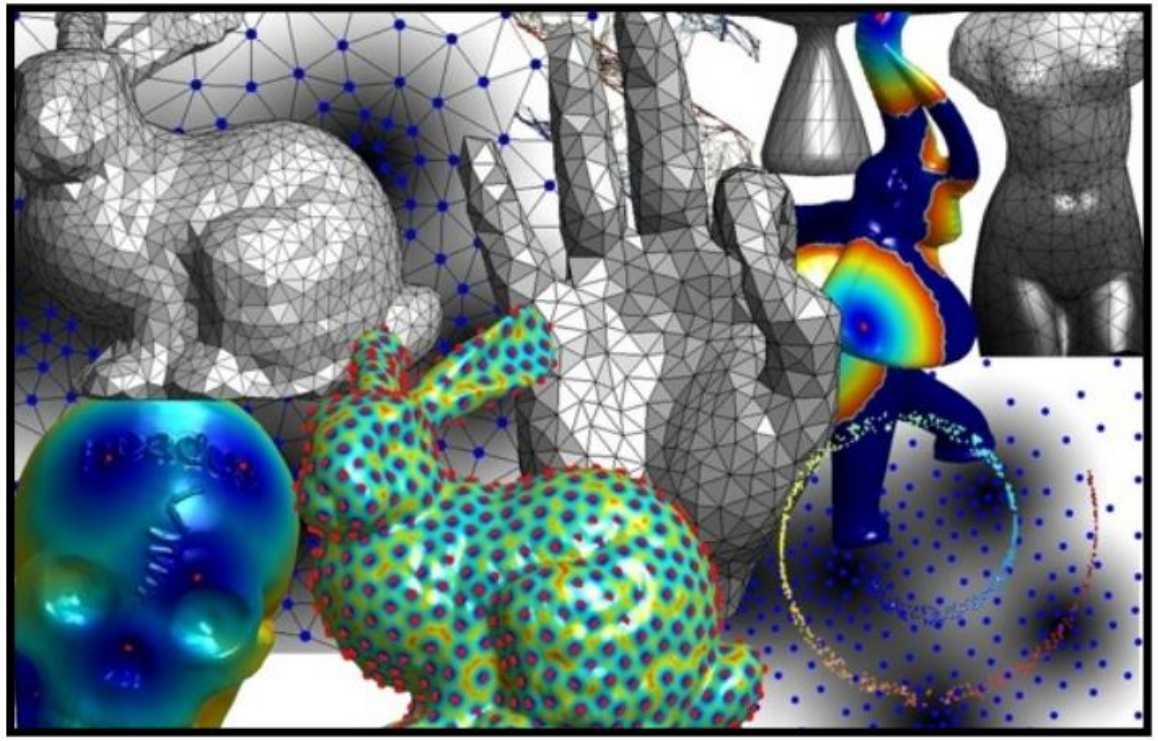
80年代

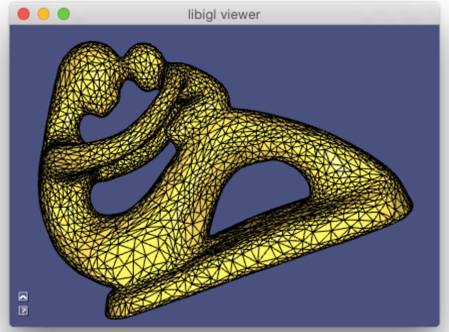
- 光线追踪（ray tracing）和辐射度（radiosity）算法
  - Whitted提出光线追踪算法，考虑光的反射和透射
  - 计算机图形学里程碑的发展
- 计算机图形硬件发展

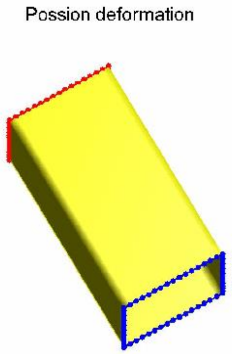


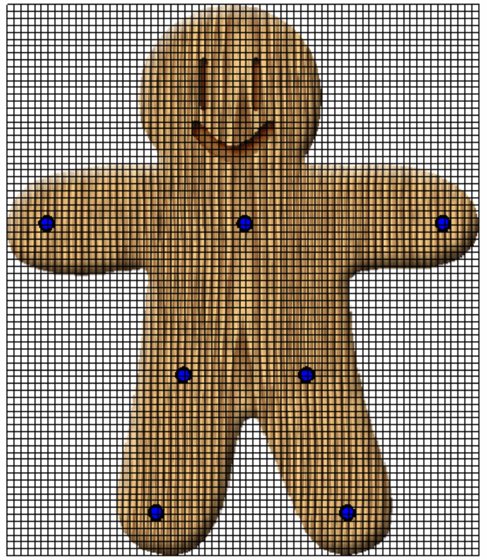
Graphics workstations such as these have been replaced with commodity hardware (CPU + GPU), e.g., MaxBuilts + Nvidia cards

- 90年代
  - 建模
    - Meshes
    - Subdivision
    - Implicit Surface
    - Procedural
    - Multi-resolution
  - 渲染
    - Volume rendering
    - Image-based rendering
    - Point-based rendering









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  - 建模
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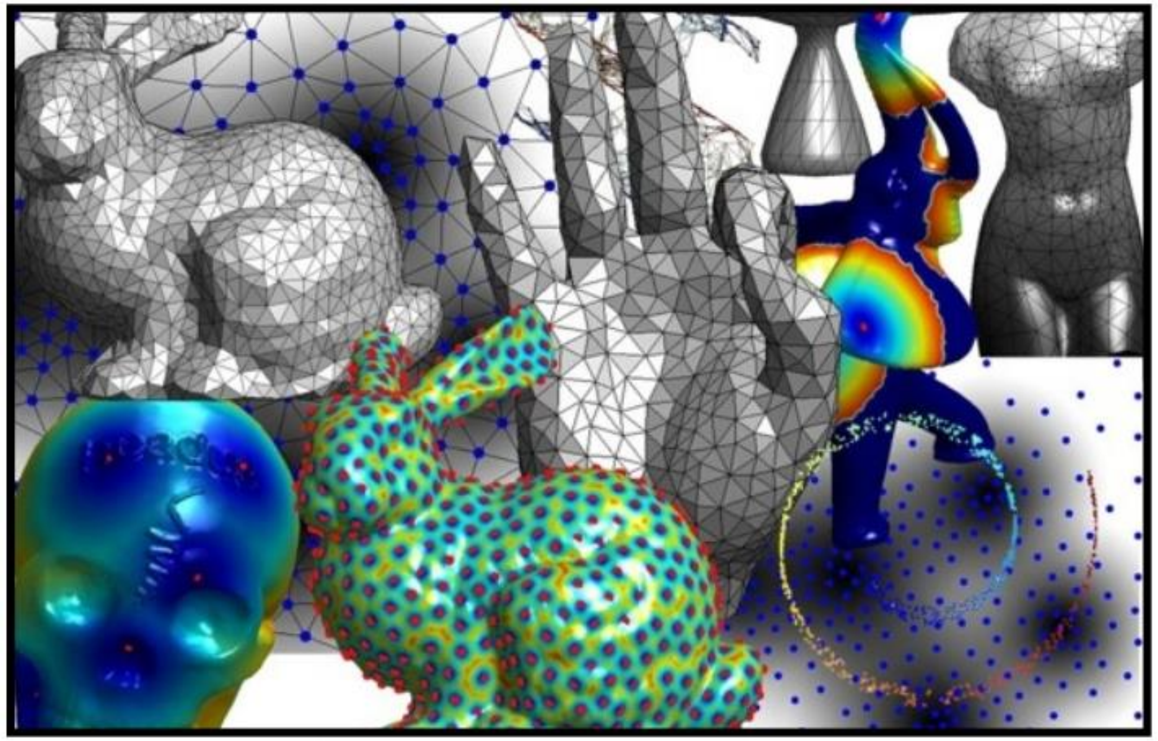
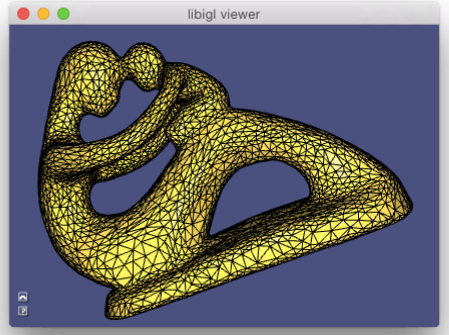
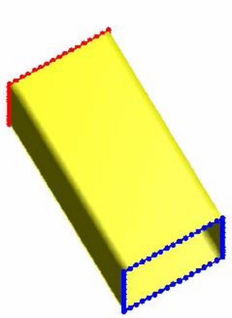
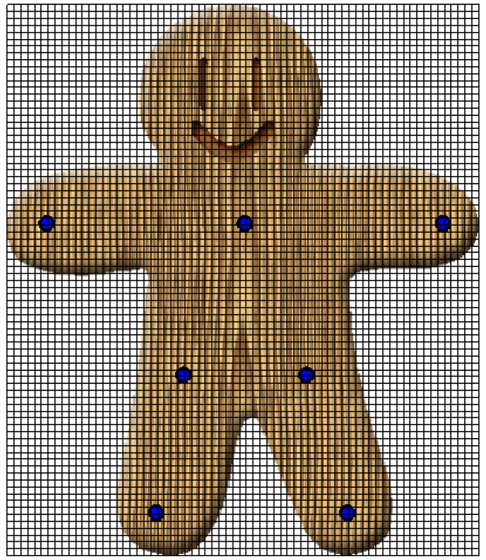
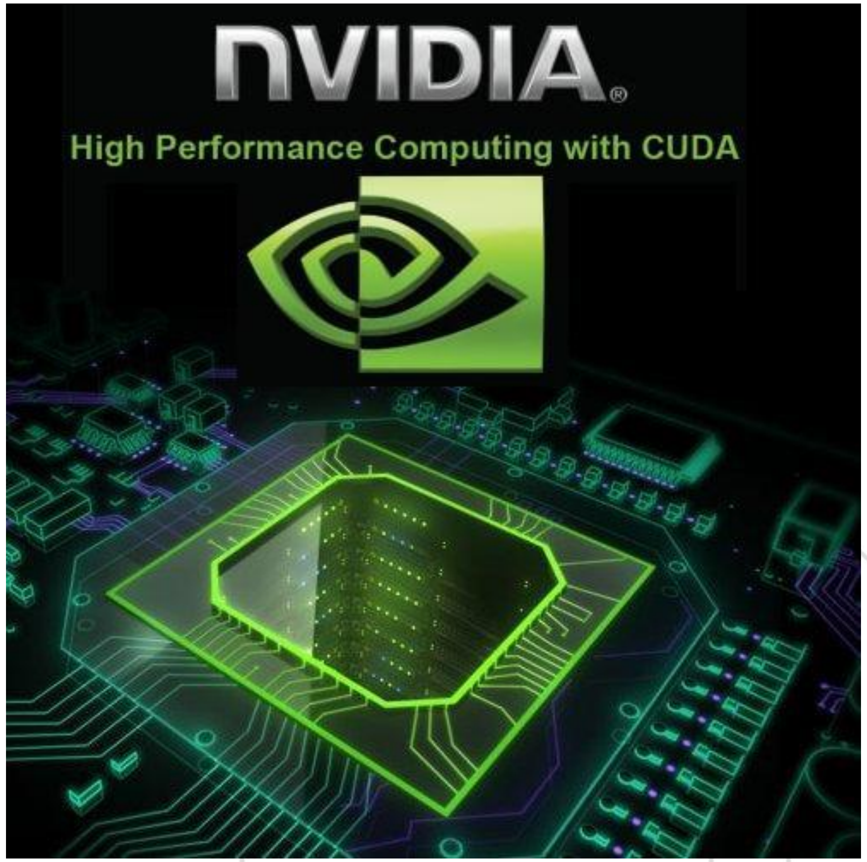


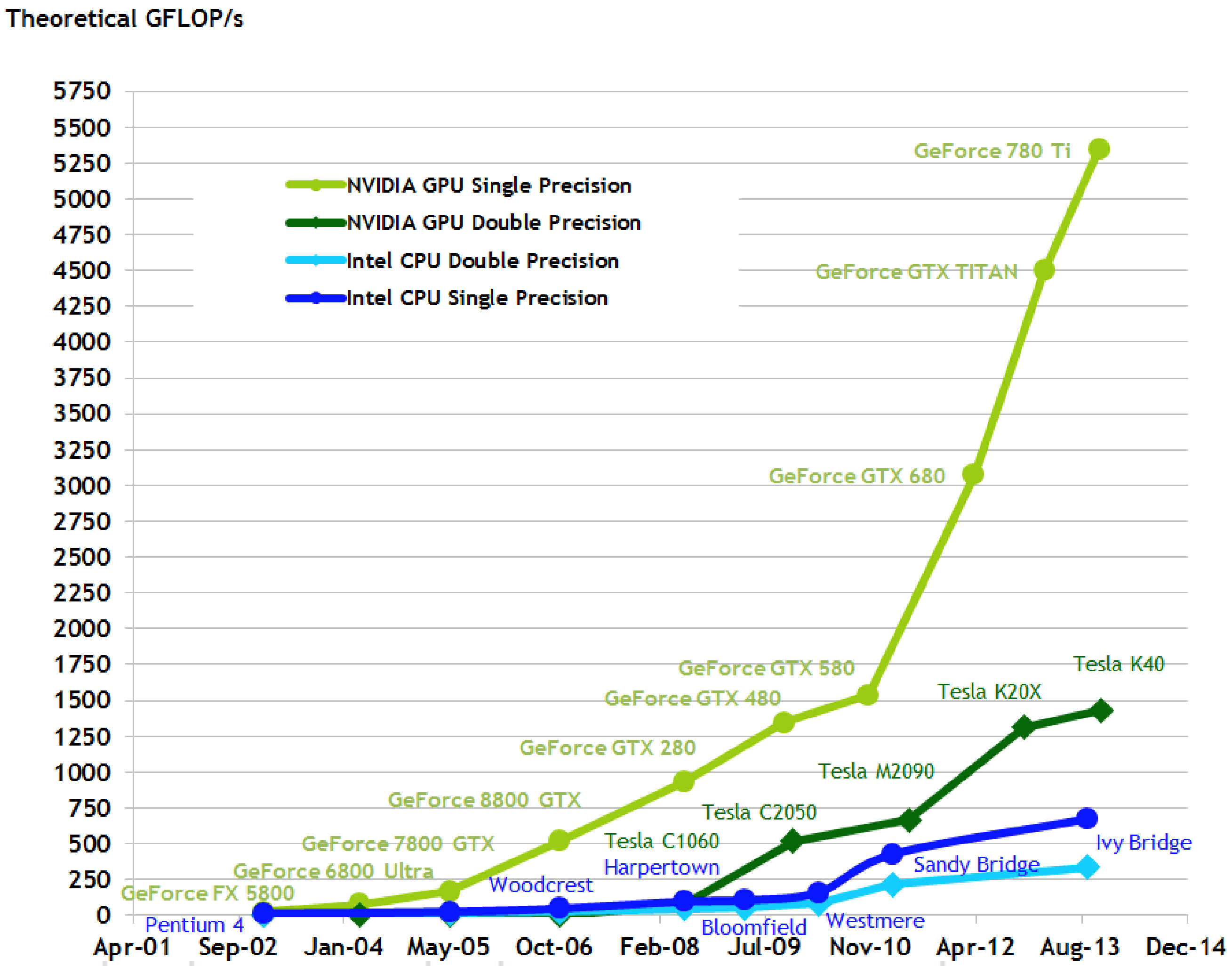






- 2000年后
  - 3D扫描技术
  - 图形硬件飞速发展
  - GPU并行编程

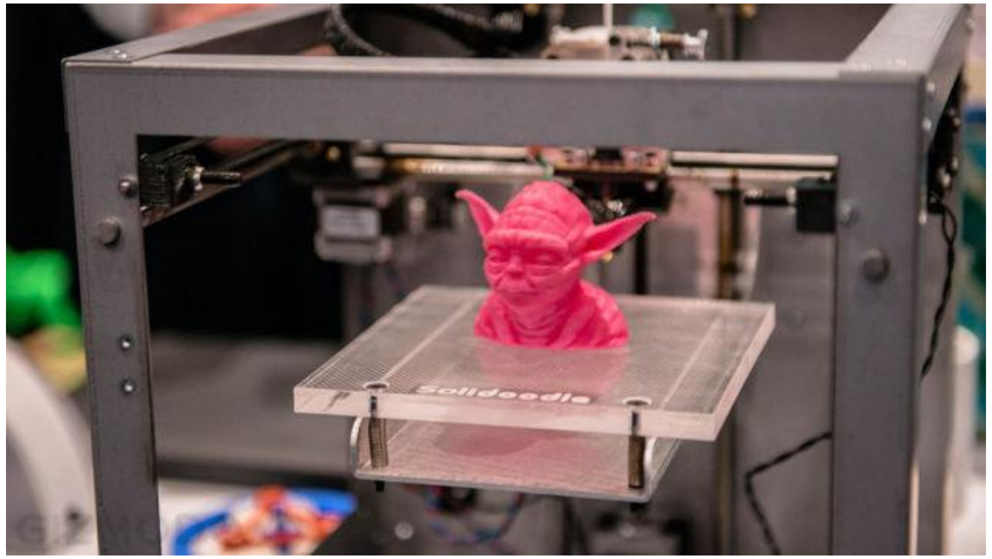




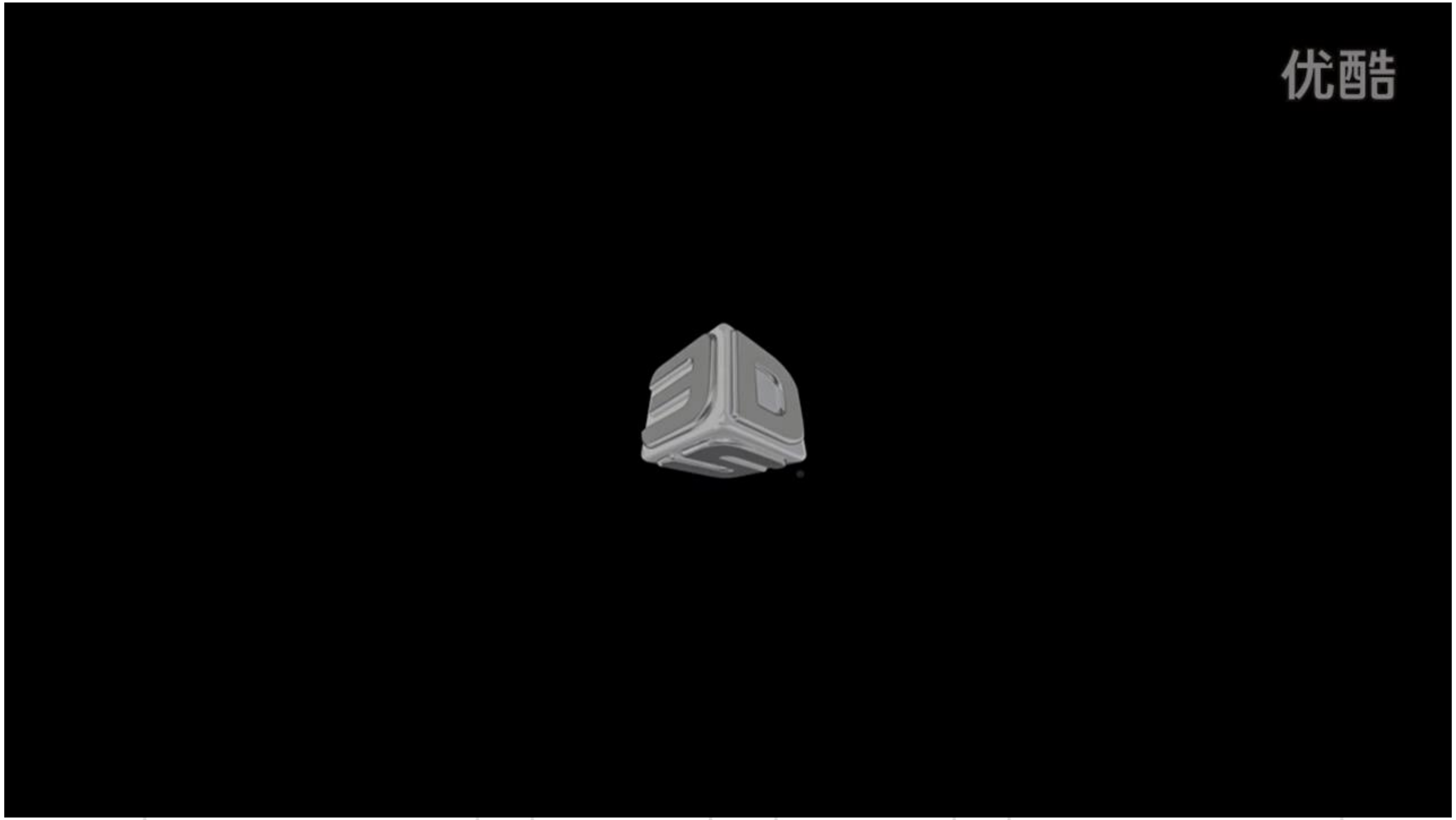
新趋势

– 体感设备：微软Kinects

- 新趋势
  - 3D打印




- 新趋势
  - 3D打印



- 新趋势
  - 新型交互设备：Leap Motion

- 新趋势
  - 虚拟现实：Cyberith Virtualizer

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计算机图形学应用

- 电影
  - 动画
  - 特效

计算机图形学应用

- 电影
  - 动作捕捉

- 游戏


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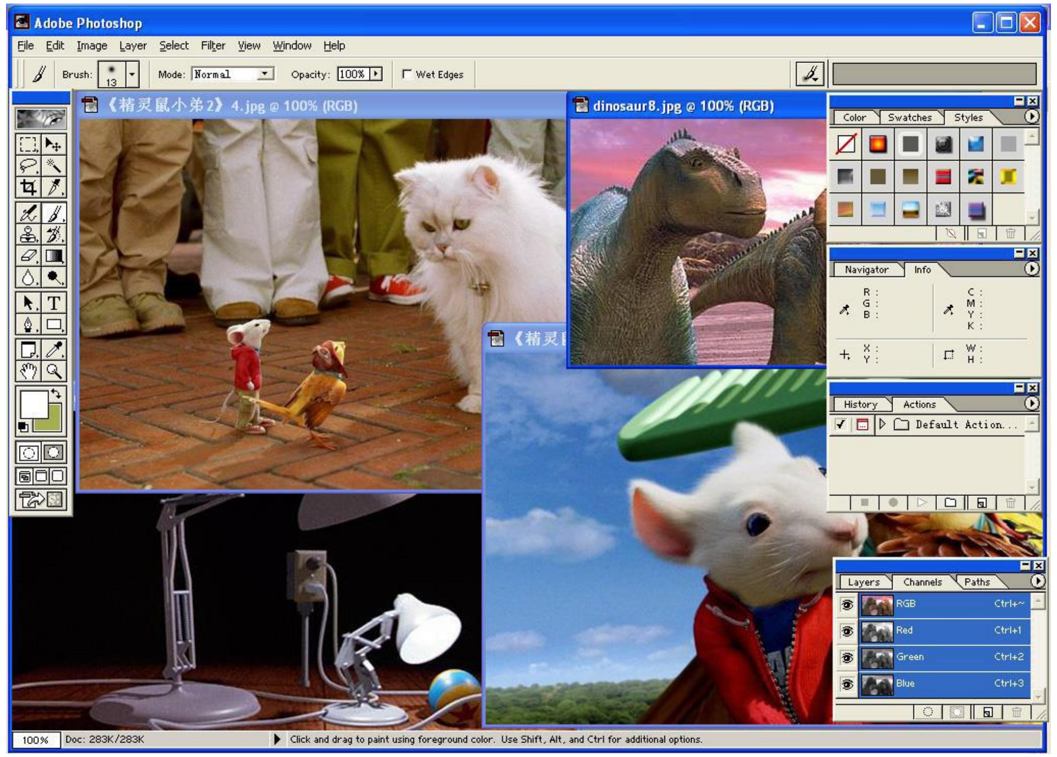
BOUNTY >
58,750
MILESTONES >
3
5/35
BUSTED
EVADE
MPH


AC 100
HP 100
AMMO 42/210

- 图像
  - 广告
  - 设计
  - 艺术

UI设计

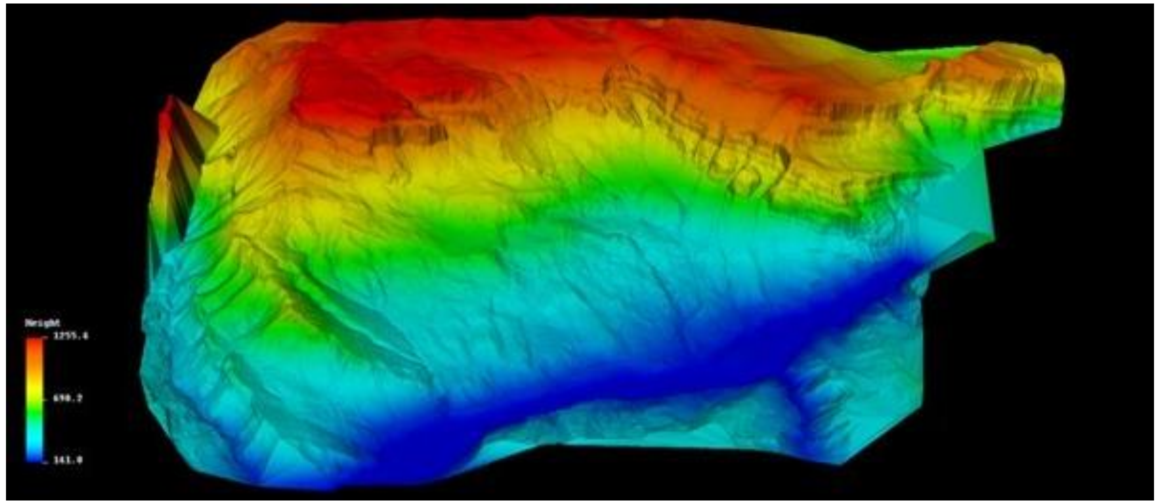

Adobe Photoshop
File Edit Image Layer Select Filter View Window Help
dinosaur8.jpg @ 100% (RGB)
Layers Channels Paths
RGB
Red
Green
Blue
Click and drag to paint using foreground color. Use Shift, Alt, and Ctrl for additional options.

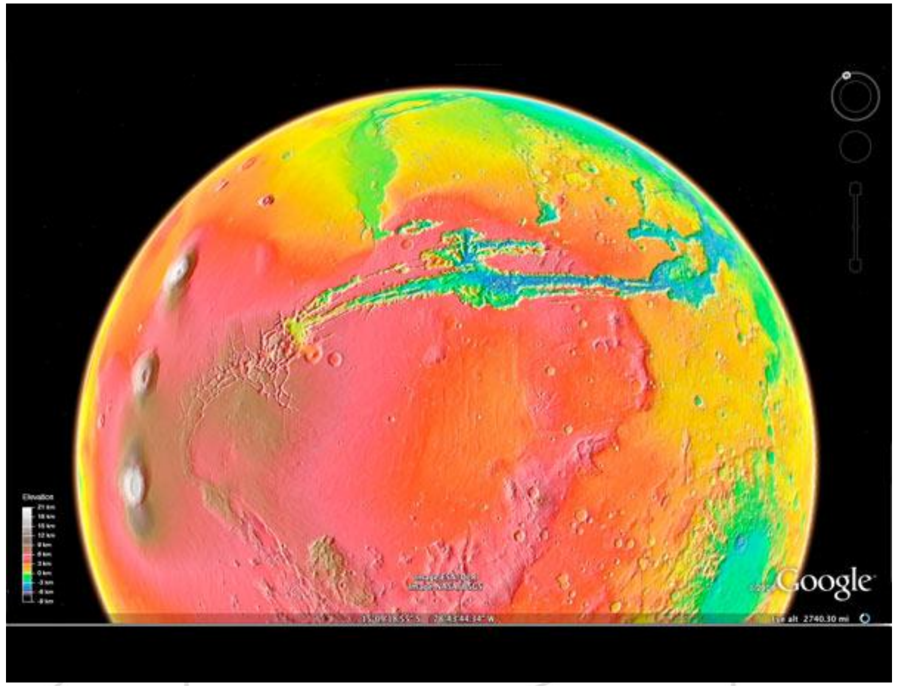

2:15
4:22
Great Big Momma Bird


CREATE A STORY
STREAMLINE NAVIGATION
MAKE IT RESPONSIVE
ENSURE ACCESSIBILITY
FORM FOLLOWS FUNCTION
USE PLEASANT COLOR THEMES
DEFINE FONT FAMILIES
BOOST OPTIMIZED IMAGES
MASTER MINIMALISM
ELIMINATE ERRORS

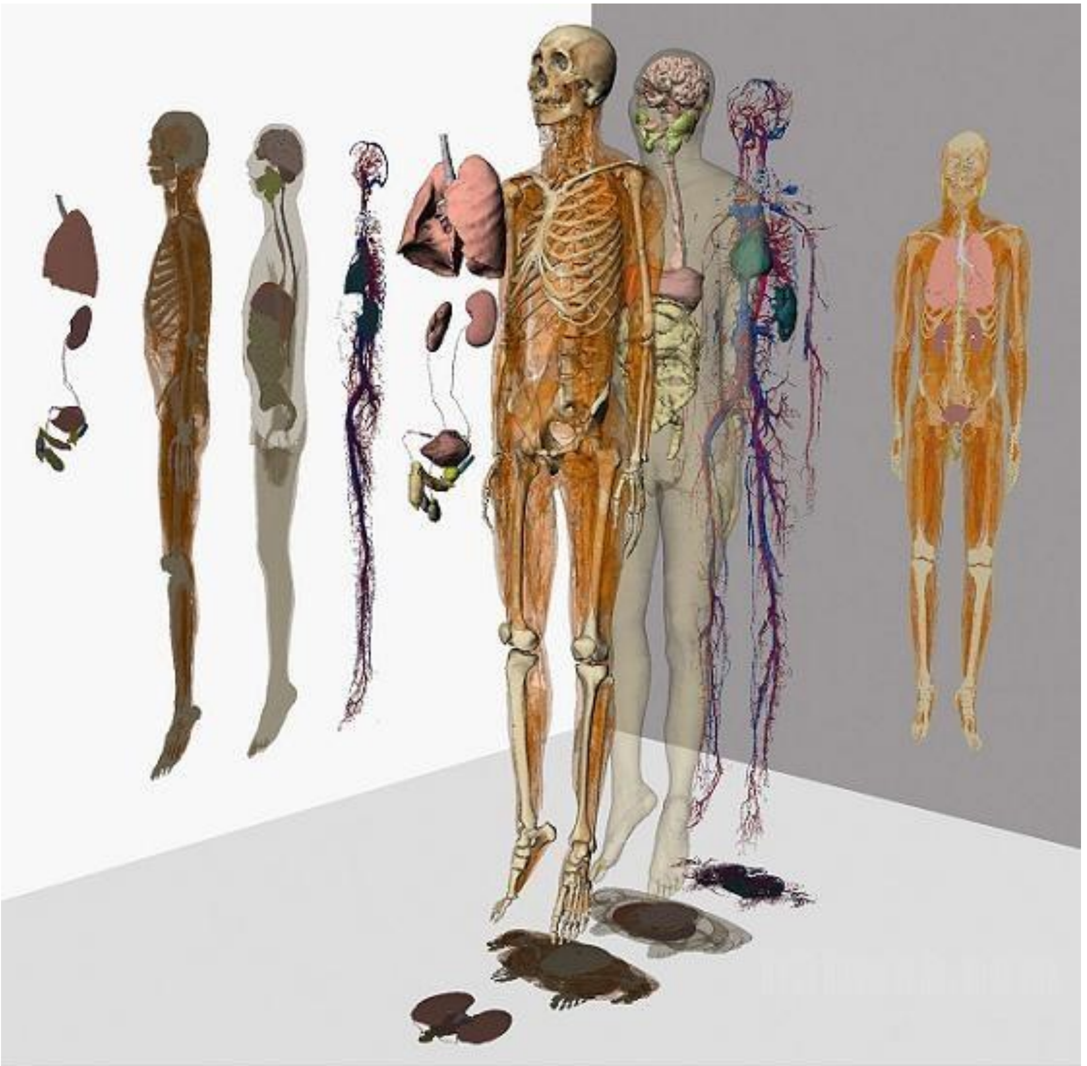
- 训练与模拟

- 地理科学
  - 几何对齐算法、数字地球及数字城市

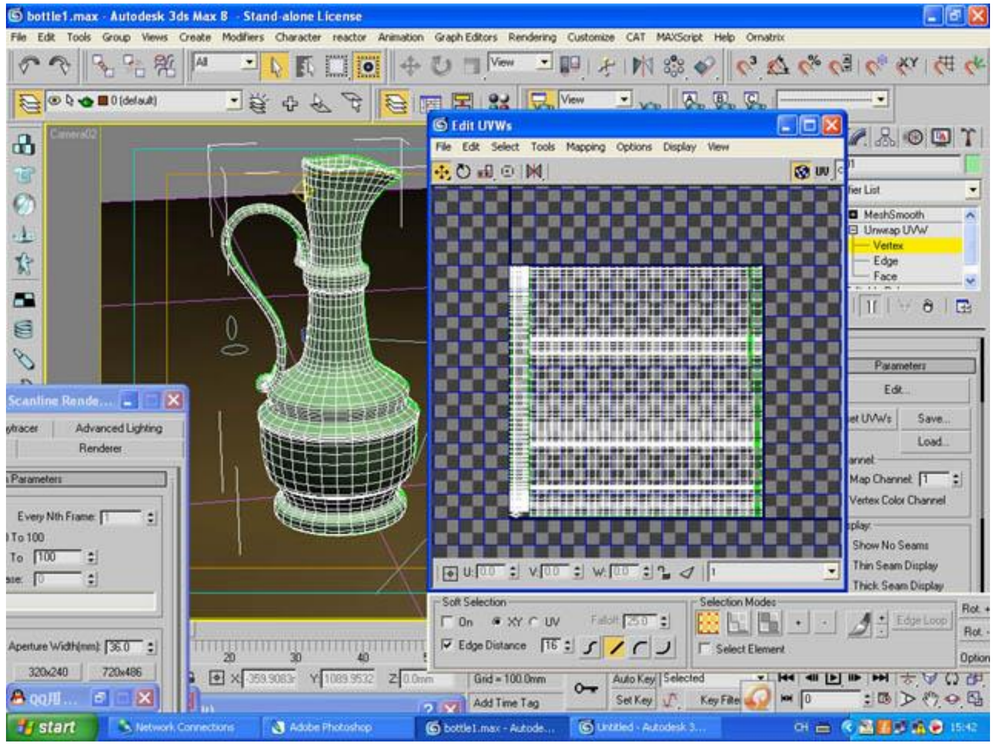




- 医学影像



- 计算机辅助设计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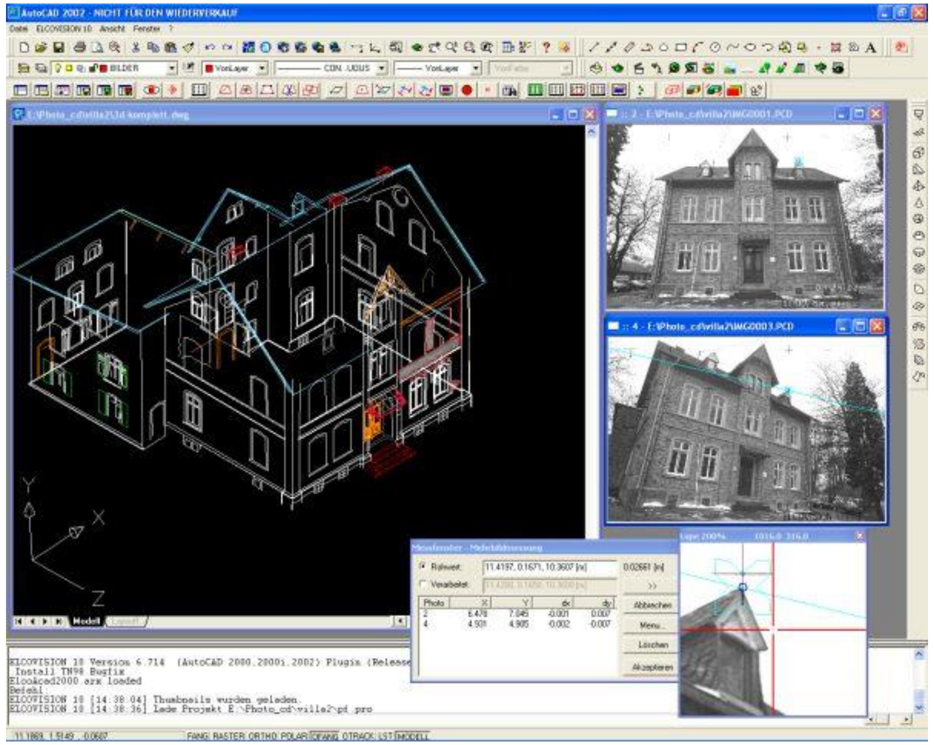
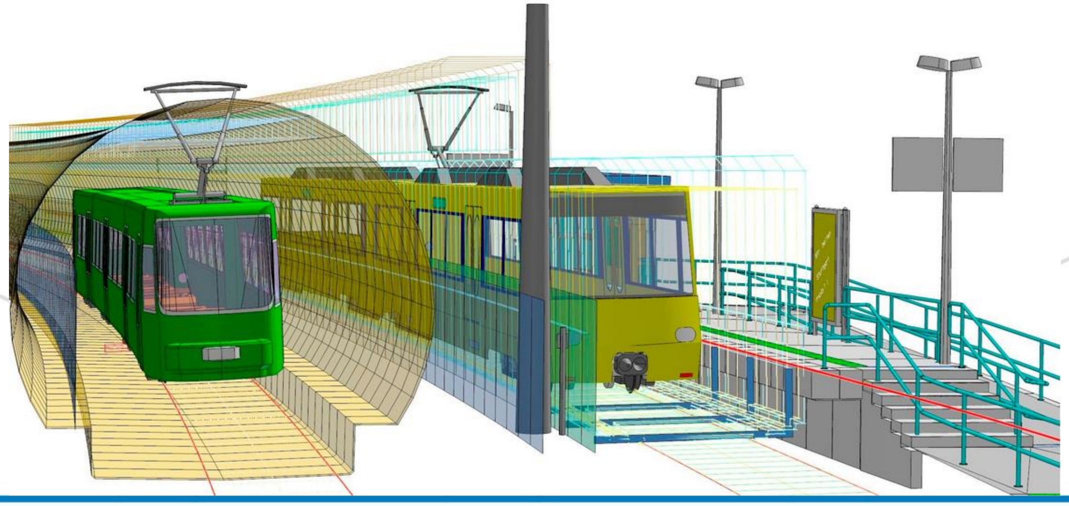
Edit UVWs





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为什么要学习计算机图形学？

- 广泛的应用
- 庞大的市场
  - 游戏、电影、教育、科学
  - 就业机会
- 兴趣
  - 发挥创造力绘制绚丽的图像

为什么要学习计算机图形学?

- 学以致用
  - Waking up every morning, thinking about the work undertaken and the technology developed which will have a tremendous impact and changes on human life, I will be extremely excited and agitated.

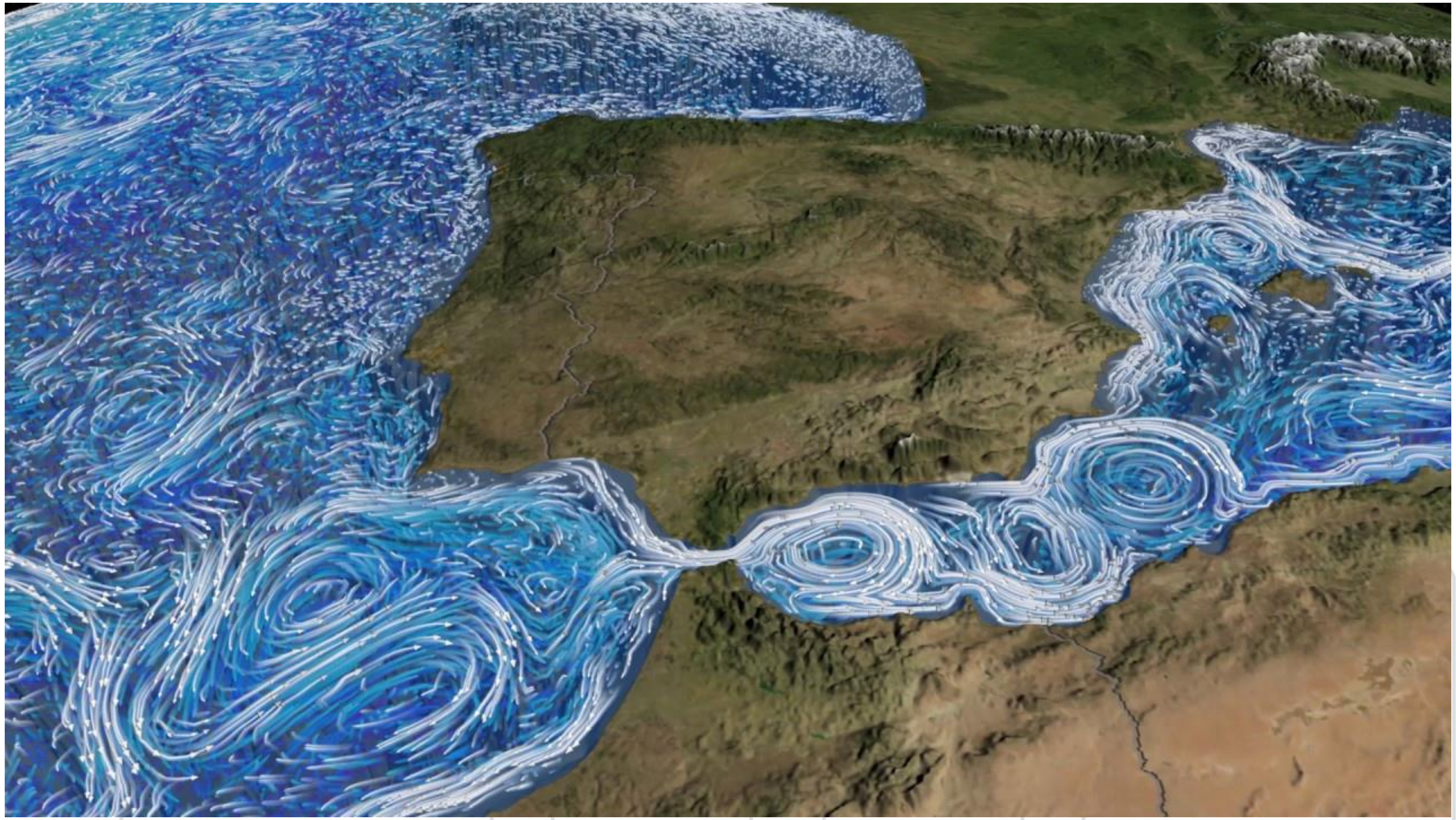
    – Bill Gates
  - 在美国，计算机图形学已经形成一条完整的产业链
  - 在中国，我们仍需要更多人才的参与
    - 尤其是工业设计、科学可视化等领域…

为什么要学习计算机图形学?

- 学以致用
  - 在中国，我们仍需要更多人才的参与
    - 新闻：“上海某企业用盗版CATIA软件造飞机! 被重罚了900万！”
      - 法国公司达索（飞机制造企业）起诉上海某企业
      - 达索代表作有幻影战斗机和阵风战斗
      - 我国歼10、歼20、飞豹战斗轰炸机、长征5火箭，歼11B、歼15、歼16、运20

为什么要学习计算机图形学?

- 学以致用
  - 在中国，我们仍需要更多人才的参与
    - 美国面向超级计算机的可视化系统向来不对华销售



图片来自NASA

学习计算机图形学需要什么?

- **跨学科的知识与技能**
  – 数学、物理、计算机、艺术
- **好奇心**
  – 对未知世界的强烈好奇心
  – 对技术的渴望与追求
- **创造力**
  – 敢想敢做：不断思考、积极尝试
- **实践**
  – 在实践中掌握知识：C++、线性代数、几何、优化方法…
  – 实践是掌握知识最好的方法

通过这门课我们将学习什么?

- 基础计算机图形学算法
- 三维几何处理
- 真实感渲染
  - 算法与数据结构
- OpenGL编程
  - 我们不是通过这门课学习如何使用软件设计模型渲染动画
  - 我们学习的是如何编制这些软件的基本技术
    - 需要熟练使用C++，更需要大量编程实践掌握这些技能
    - 课上内容涉及的数学知识大多较为基础
- 其他

国际会议

– ACM SIGGRAPH及ACM SIGGRAPH（Asia）

- ACM Special Interest Group on computer GRAPHics and interactive techniques
- 1967年，由布朗大学教授Andries van Dam以及IBM纽约科学中心负责人Sam Matsa创建
- 1974年，首届ACM SIGGRAPH在科罗拉多大学召开
- http://www.siggraph.org

https://s2019.siggraph.org/

https://sa2019.siggraph.org/en/

ACM SIGGRAPH参会人数

Year	Location	Attendees	Exhibitors	Notes
2019	Los Angeles	18,700[9]	180	[10]
2018	Vancouver	16,637[11]	160	[12] [13]
2017	Los Angeles	16,500[14]	150	
2016	Anaheim	14,000[15]	153	
2015	Los Angeles	14,800[16]	143	
2014	Vancouver	14,045[17]	175	
2013	Anaheim	17,162[18]	180	
2012	Los Angeles	21,212[19]	161[19]	
2011	Vancouver	15,872[20]	156	
2010	Los Angeles	22,549[20]	160	
2009	New Orleans	11,000[21]	140	
2008	Los Angeles	28,432[22]	230[22]	
2007	San Diego	24,043[23]	230[23]	
2006	Boston	19,764[24]	230[24]	
2005	Los Angeles	29,122[25]	250[25]	
2004	Los Angeles	27,825[26]	229[26]	
2003	San Diego	24,332[27]	240[27]	
2002	San Antonio	17,274[28]	225	
2001	Los Angeles	34,024[29]	303[29]	
2000	New Orleans	25,986[30]	316[30]	
1999	Los Angeles	42,690[31]	337[31]	
1998	Orlando	32,210[32]	327	
1997	Los Angeles	48,700[33]		
1996	New Orleans	28,500[34]	321[34]	
1995	Los Angeles	40,100[34]	297[34]	
1994	Orlando	25,000[34]	269[34]	
1993	Anaheim	27,000[34]	285[34]	
1992	Chicago	34,148[34]	253[34]	
1991	Las Vegas	23,100[34]	282[34]	
1990	Dallas	24,684[34]	248[34]	
1989	Boston	27,000[34]	238[34]	
1988	Atlanta	19,000[34]	249[34]	
1987	Anaheim	30,541[34]	274[34]	
1986	Dallas	22,000[34]	253[34]	
1985	San Francisco	27,000[34]	254[34]	
1984	Minneapolis	20,390[34]	218[34]	
1983	Detroit	14,000[34]	195[34]	
1982	Boston	17,000[34]	172[34]	
1981	Dallas	14,000[34]	124[34]	
1980	Seattle	7,500[34]	80[34]	
1979	Chicago	3,000[34]	79[34]	
1978	Atlanta	1,500[34]	44[34]	
1977	San Jose	750[34]	38[34]	
1976	Philadelphia	300[34]	10[34]	
1975	Bowling Green	300[34]		
1974	Boulder	600[34]		

截取自wikipedia

- ACM SIGGRAPH Asia 2017: Technical Paper Trailer

- ACM SIGGRAPH Asia 2017: Emerging Technologies Trailer

- Eurographics
  - Eurographics Symposium on Geometry Processing (SGP)
  - Eurographics Symposium on Rendering (EGSR)
  - Eurographics Symposium on Computer Animation (SCA)

计算机图形学前沿

- Pacific Graphics
  - PG 2018
  - Hong Kong
  - http://sweb.cityu.edu.hk/pg2018/

- Chinagraphics
  - Chinagraphics 2018
  - Guangzhou
  - http://www2.scut.edu.cn/chinagraph2018/

文章下载

– http://kesen.realtimerendering.com/

Ke-Sen Huang's Home Page

- I got my Ph. D from the Department of Computer Science of National Tsing-Hua University, Taiwan.
- My research interests include: animation synthesis, animation summarization, and motion retrieval.
- My Web Changelog

Paper Collection / Resources

- Open Access to ACM SIGGRAPH-Sponsored Content: For both SIGGRAPH and SIGGRAPH Asia, conference content is freely accessible in the ACM Digital Library for a one-month period that begins two weeks before each conference, and ends a week after it concludes.
- Journal of Computer Graphics Techniques
- Point-based Graphics Papers
- Physics-Based Animation Resources (Maintained by Christopher Batty) NEW
- Real-Time Rendering Resources (Maintained by Tomas Akenine-Möller, Eric Haines, and Naty Hoffman) NEW
- Visualization Paper Collection (IEEE VisWeek papers / EuroVis papers / IEEE Pacific Vis papers) (Maintained by ZJU-VAG) NEW

Computer Graphics Conference and Special Issue Calendar

- CFP - The Springer Encyclopedia of Computer Graphics and Games (ECGG) (PDF)
- 2013, 2012, 2011, 2010, 2009, 2008

SIGGRAPH 2017 papers on the web

Page maintained by Ke-Sen Huang. If you have additions or changes, send an e-mail.

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Note that when possible I link to the page containing the link to the actual PDF or PS of the preprint. I prefer this as it gives some context to the paper and avoids possible copyright problems with direct linking. Thus you may need to search on the page to find the actual document.

ACM Digital Library: ACM Transactions on Graphics (TOG) Volume 36, Issue 4 (July 2017) Proceedings of ACM SIGGRAPH 2017

ACM Digital Library (DOI) Link for the paper **Paper Abstract** **Author Preprint** **Paper Video** **Paper Presentation** **Paper Images** **Paper Data** **Demo Program or Source Code** **Related Links**

Changelog

Imaginative Imaging

CoLux: Multi-Object 3D Micro-Motion Analysis Using Speckle Imaging
Brandon M. Smith, Pratham Desai, Vishal Agarwal, Mohit Gupta (University of Wisconsin - Madison)

4D Imaging through Spray-On Optics
Julian Iseringhausen (University of Bonn), Bastian Goldlucke, Nina Pesheva, Stanimir Iliev, Alexander Wender, Martin Fuchs (Universitat Stuttgart), Matthias B. Hullin (University of Bonn)

Rainbow Particle Imaging Velocimetry for Dense 3D Fluid Velocity Imaging
Jinhui Xiong, Ramzi Idoughi, Andres A. Aguirre-Pablo, Abdulrahman B. Aljedaani, Xiong Dun, Qiang Fu, Sigurdur T. Thoroddsen, Wolfgang Heidrich (KAUST)

Epipolar Time-of-Flight Imaging
Supreeth Achar, Joseph R. Bartels, William L. . Red · Whittaker (Carnegie Mellon University), Kiriakos N. Kutulakos (University of Toronto), Srinivasa G. Narasimhan (Carnegie Mellon University)

Mappings and Deformations

Scalable Locally Injective Maps (TOG Paper)
Michael Rabinovich, Roi Poranne (ETH Zurich) , Daniele Panozzo (New York University), Olga Sorkine-Hornung (ETH Zurich)

Geometric Optimization via Composite Majorization
Anna Shtengel (Weizmann Institute of Science), Roi Poranne, Olga Sorkine-Hornung (ETH Zurich), Shahar Kovalsky (Duke University), Yaron Lipman (Weizmann Institute of Science)

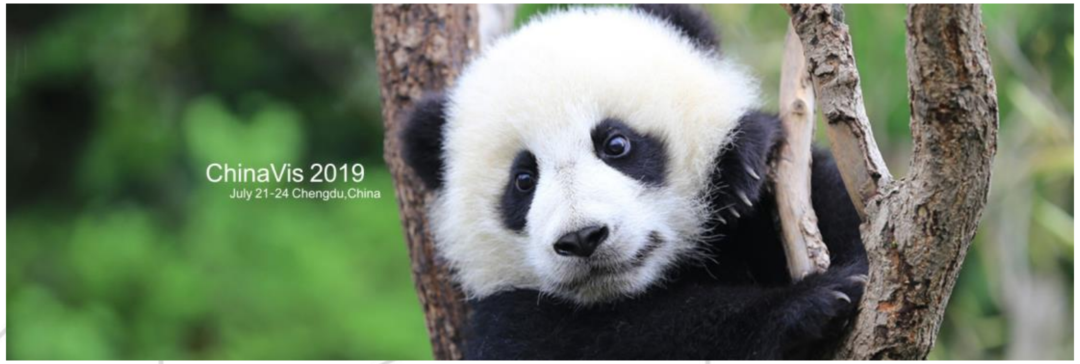
计算机图形学前沿

可视化会议

– VIS, EuroVis, PacificVis, ChinaVis

http://ieeevis.org/year/2019/welcome

http://eurovis2019.org/

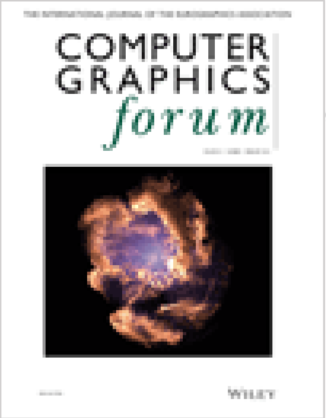


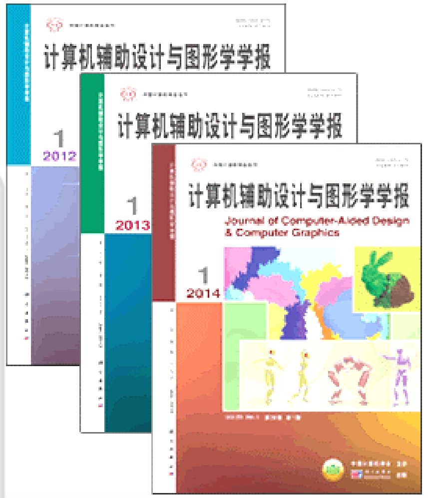
http://research.cbs.chula.ac.th/pvis2019/

http://chinavis.org/2019/

计算机图形学前沿

- 期刊（国际）
  - ACM Transactions on Graphics
  - IEEE Transactions on Graphics and Visualization
  - Computer Graphics Forum
  - Computer Aided Geometric Design
  - Computer-aided Design
  - The Visual Computer
  - Graphical Models
  - Computer & Graphics
  - Computer Graphics & Applications
- 期刊（国内）
  - 软件学报
  - 计算机学报
  - 计算机辅助设计与图形学学报
  - 中国图象图形学报
- 会议
  - Siggraph
  - Siggraph Asia
  - Eurographics
  - Pacific Graphics
  - Symposium on Geometry Processing
  - Shape Modeling International
  - Chinagraph
  - IEEE VIS
  - EuroVis, PacificVis, ChinaVis
  - IEEE VR





其他资源

- NVIDIA GameWorks™ Samples
  - https://developer.nvidia.com/gameworks-samples-overview

NVIDIA GameWorks™ OpenGL Samples

Get the documentation or download the NVIDIA GameWorks™ OpenGL samples here:

Download ›

New Browse or Clone Source from GitHub:

GitHub ›

New samples in 2.0:

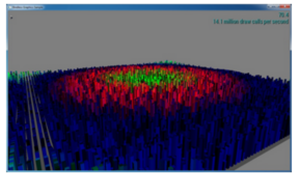
- Blended Antialiasing Sample
- Cascaded Shadow Mapping Sample
- Conservative Rasterization Sample
- Normal-Blended Decal Sample
- Weighted, Blended, Order-independent Transparency Sample

Bindless Graphics Sample

- Category: **Performance**

This sample demonstrates the large performance increase in OpenGL that is made possible by 'Bindless Graphics'. These extensions allow applications to draw large numbers of objects with only a few setup calls, rather than a few calls per object, thus reducing the driver overhead necessary to render highly populated scenery.

Docs ›

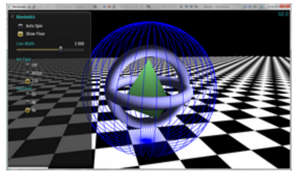


★NEW:Blended AA

- Category: **Performance, Visuals**

This sample implements a two-pass additive blending anti-aliasing technique using Target-Independent Rasterization (TIR), which should give comparable results to MSAA with a reduced memory footprint.

Docs ›

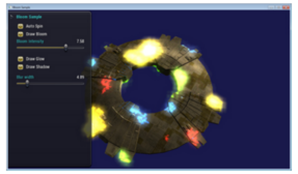


Bloom Sample

- Category: **Visuals**

This sample demonstrates creating a glow effect by post-processing the main scene. It heavily leverages FBO render targets across multiple steps/passes with custom effects processing shaders. It also integrates shadow mapping to demonstrate self-illumination cutting through the shadow effects.

Docs ›



NVIDIA GameWorks™ DirectX Samples

Get the documentation or download the NVIDIA GameWorks™ Direct3D samples here.

Download ›

New samples in 1.2:

- Antialiased Deferred Rendering
- Motion Blur D3D Advanced Sample

New Browse or Clone Source from GitHub:

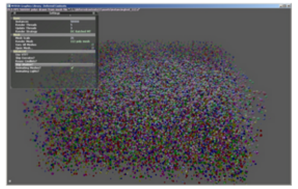
GitHub ›

D3D Deferred Contexts Sample

- Category: **Performance**

This sample shows how to use D3D11 Deferred Rendering contexts to lower the CPU overhead and improve performance when rendering large numbers of objects per frame, in situations where instancing is not feasible.

Docs ›

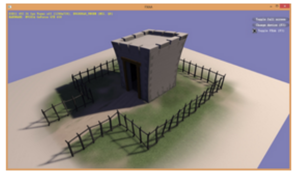


FXAA 3.11 Sample

- Category: **Performance,Visuals**

This sample presents a high performance and high quality screen-space software approximation to anti-aliasing called FXAA.

Docs ›

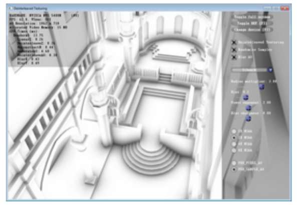


Deinterleaved Texturing Sample

- Category: **Performance,Visuals**

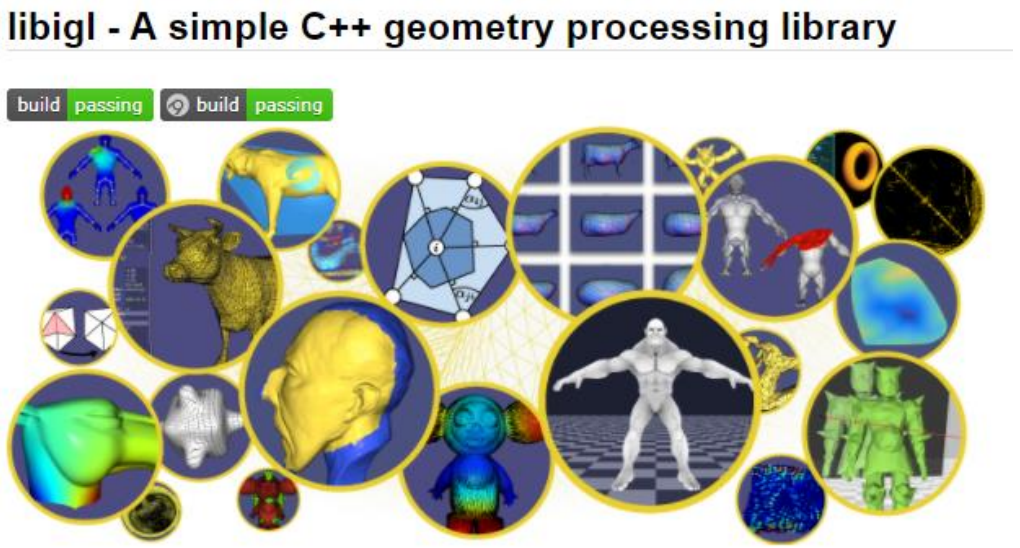
This sample demonstrates how a large, sparse and jittered post-processing filter (here a SSAO pass with a 4x4 random texture) can be made more cache-efficient by using a Deinterleaved Texturing approach.

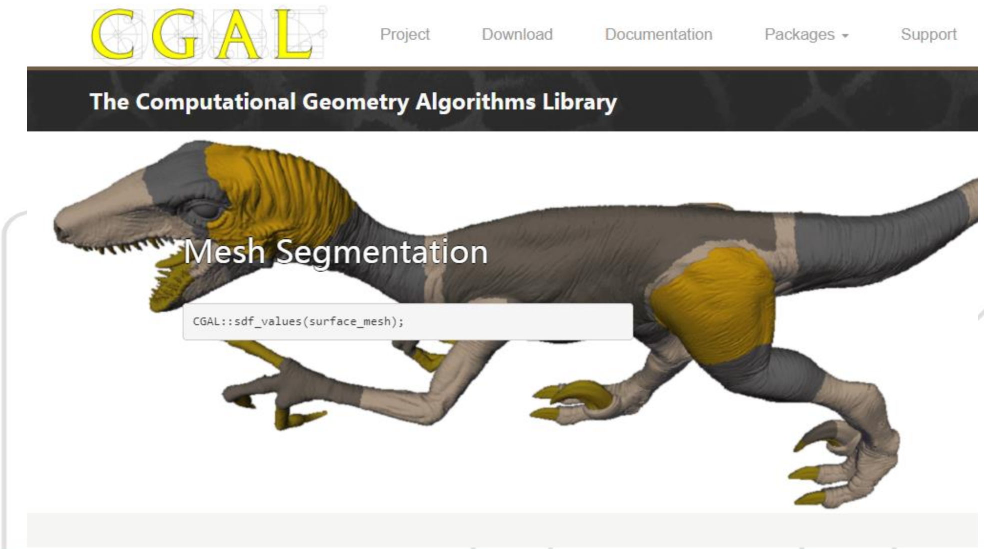
Docs ›



其他资源

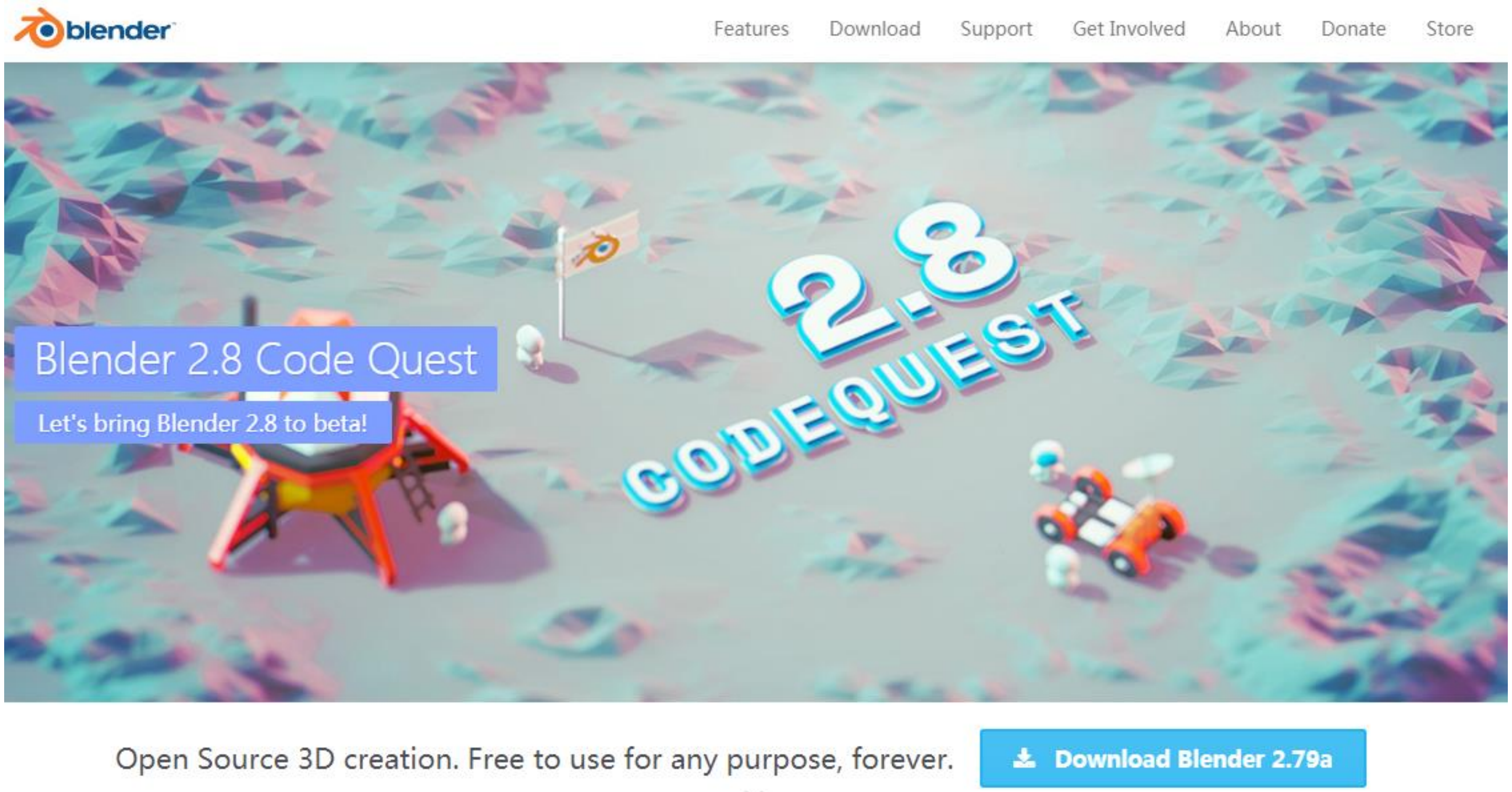
- CGAL：the Computational Geometry Algorithm Library
  - – https://www.cgal.org/index.html
- OpenMesh
  - – https://www.openmesh.org/
- Libigl
  - – https://libigl.github.io/





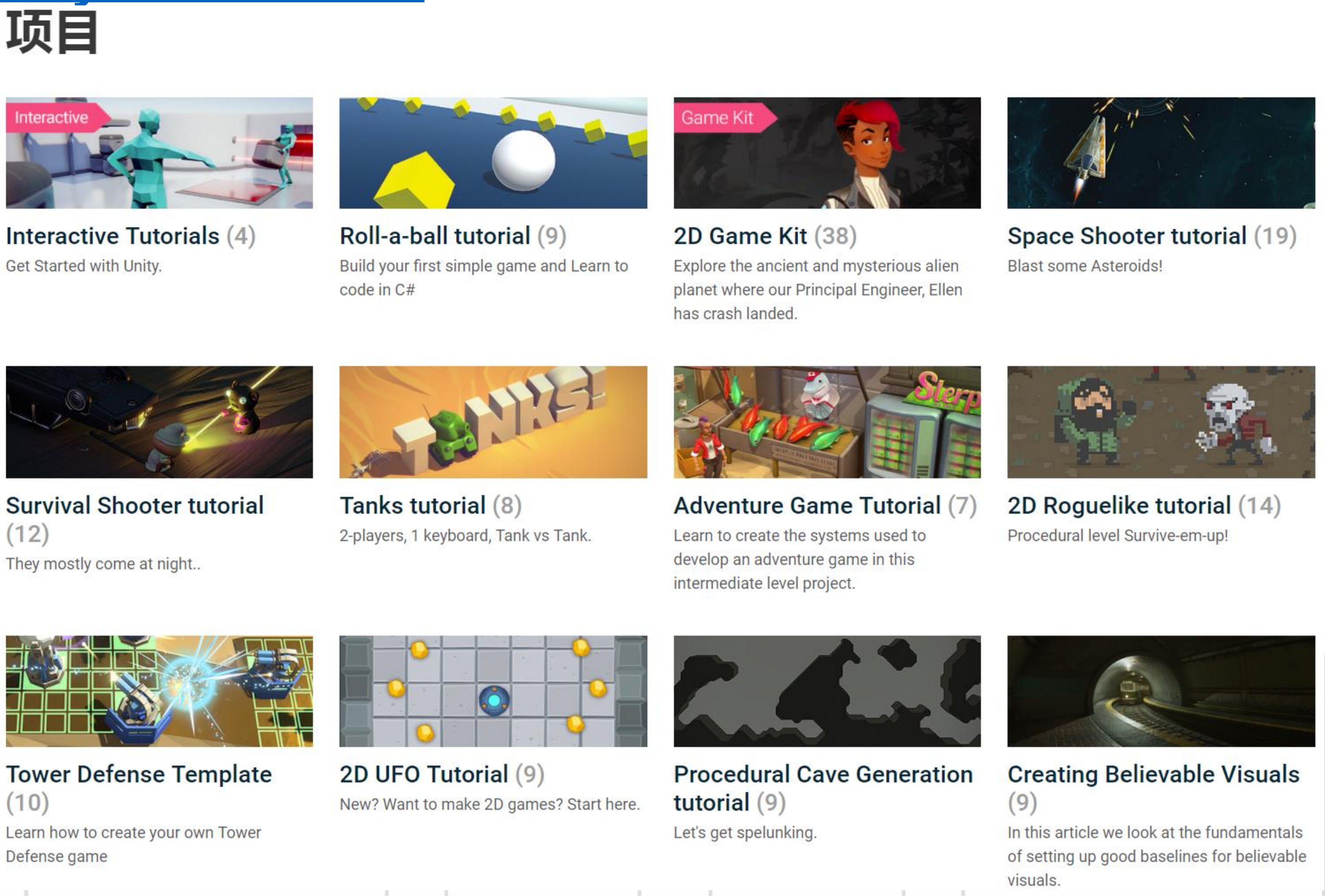
其他资源

- Blender
  - https://www.blender.org/



其他资源

- Unity 3D
  – https://unity3d.com/cn



Questions?