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Graphics Software Stack Evolution

David Blythe, Chief Graphics Software Architect, Intel

Introduction – Sunil Shenoy, Intel Corporate Vice President
General Manager of Visual Parallel Computing Group

SPCS006

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Sunil Shenoy

Intel Corporate Vice President
General Manager of Visual Parallel Computing Group

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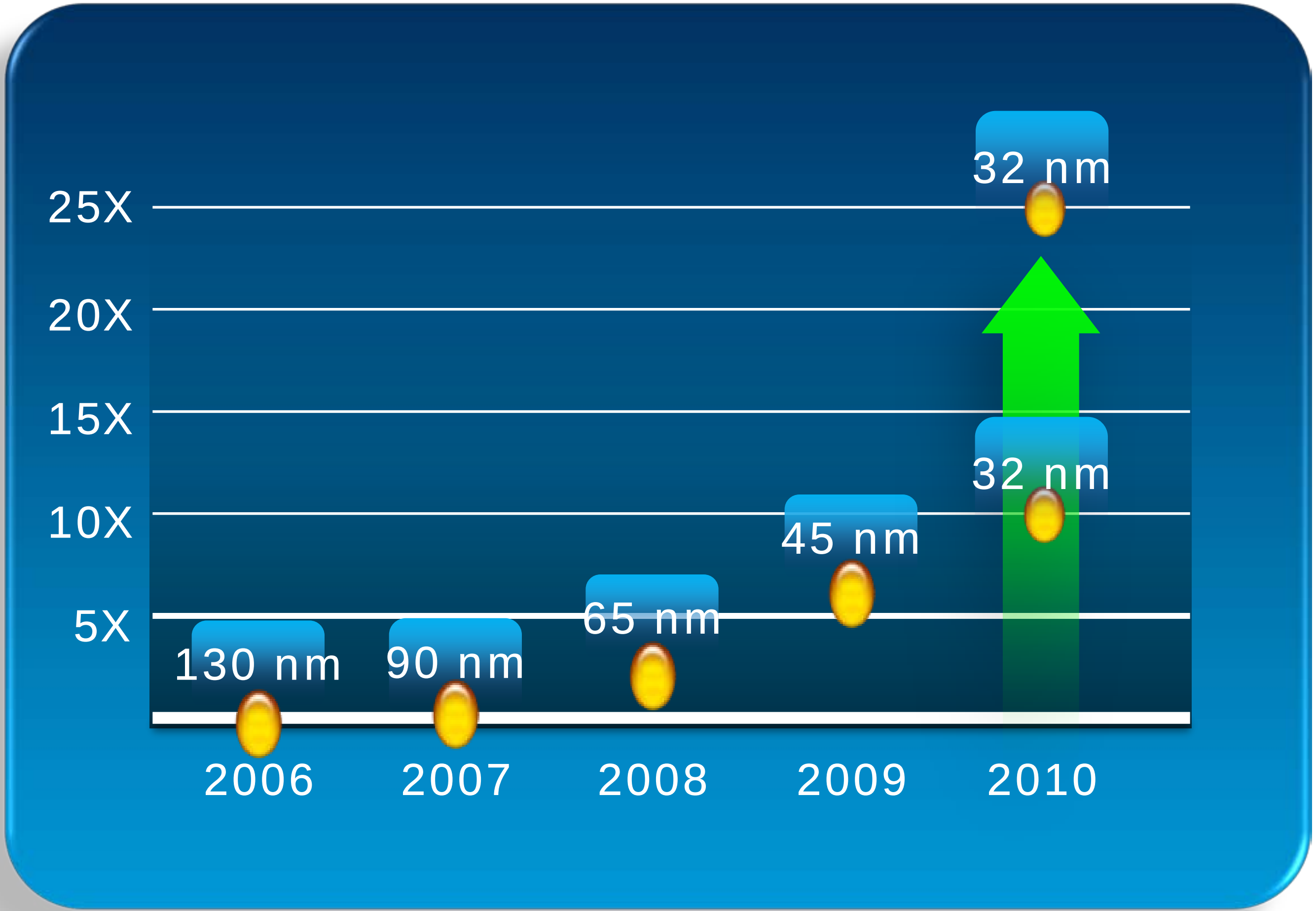
Building a Continuum with Intel® Architecture and Processor Graphics

Desktops Laptops Netbooks Tablets Smartphones Smart TVs Embedded

Its Not Just 3D Games

- Office & Productivity Apps
- Mainstream Games
- High End Games
- 3D Content Creation
- Perceptual Computing
- Multi High Res Display
- Imaging Apps
- High End Video Apps
- Mainstream Video Apps
- Web Video
- Web Games
- Browser Apps & Content (HTML)
- 3D User Interface

Looking at the Last 5 years…



25X
Performance Growth in 5 Years!

About David Blythe

Working at the hardware/software boundary for 25 years:

What	When	
DirectX*10/X11 on workstations	1985-1990	[Grad school]
IRISGL/OpenGL*/OpenGL++ on workstations	1991-2001	[SGI]
OpenGL ES on phones, embedded devices	2002-2003	[Khronos]
DirectX on PCs, phones	2003-2010	[Microsoft]
Processor graphics, media, computing across the continuum	2010-	[Intel]

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David Blythe

Chief Graphics Software Architect

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Agenda

- Goals
- Software Stacks and Abstractions
- Graphics Stack Historical Evolution
- Workstation Generation
- PC Generation
- Processor Graphics Generation

Goals

- Understand architecture of the SW/HW stack
  - Evolution over time
- Understand role of drivers, APIs, etc.
  - Look at evolution, dispel some myths
  - Look at tension points
- Understand how to make them better
  - Define what better means

Agenda

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- **Software Stacks and Abstractions**
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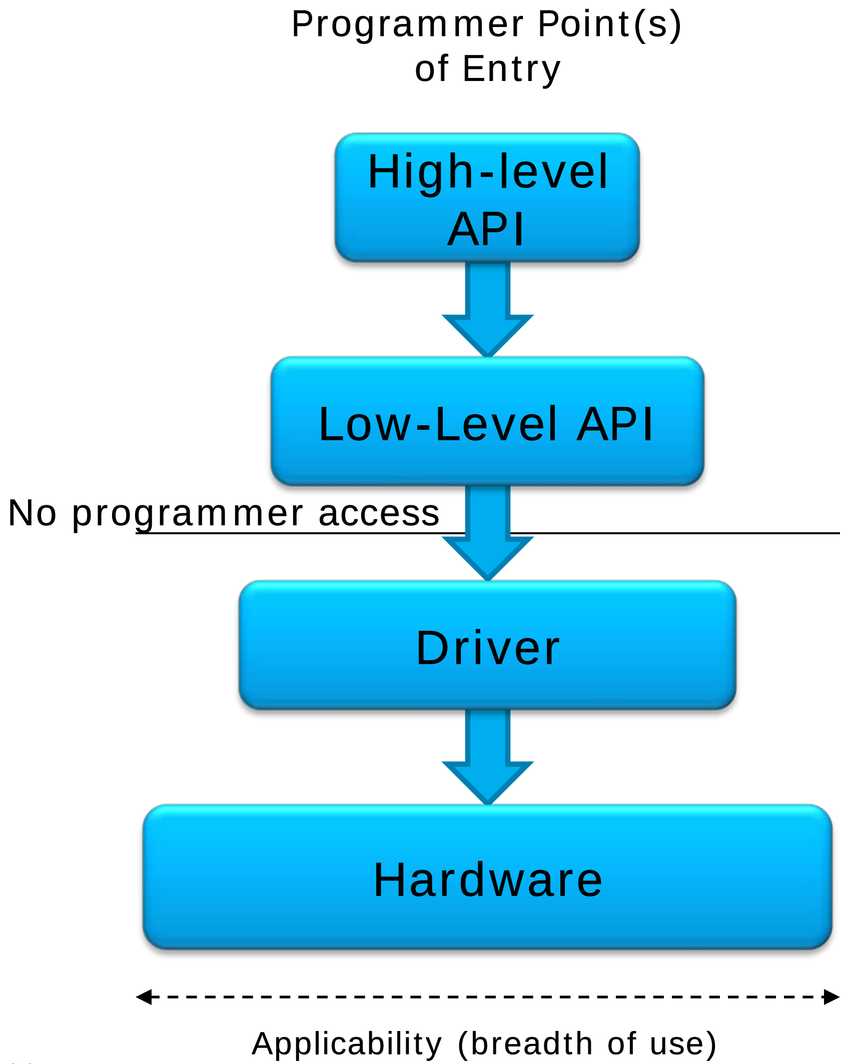
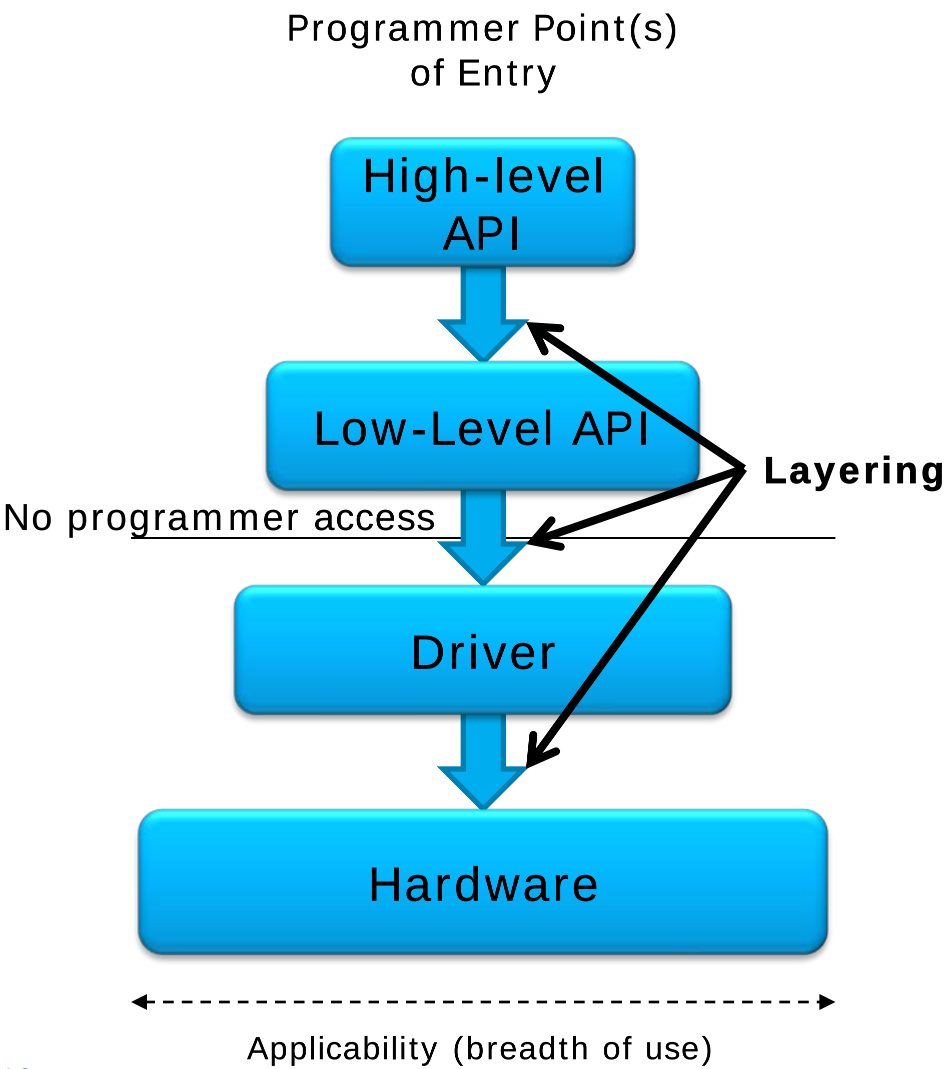
Software Stacks and Abstraction



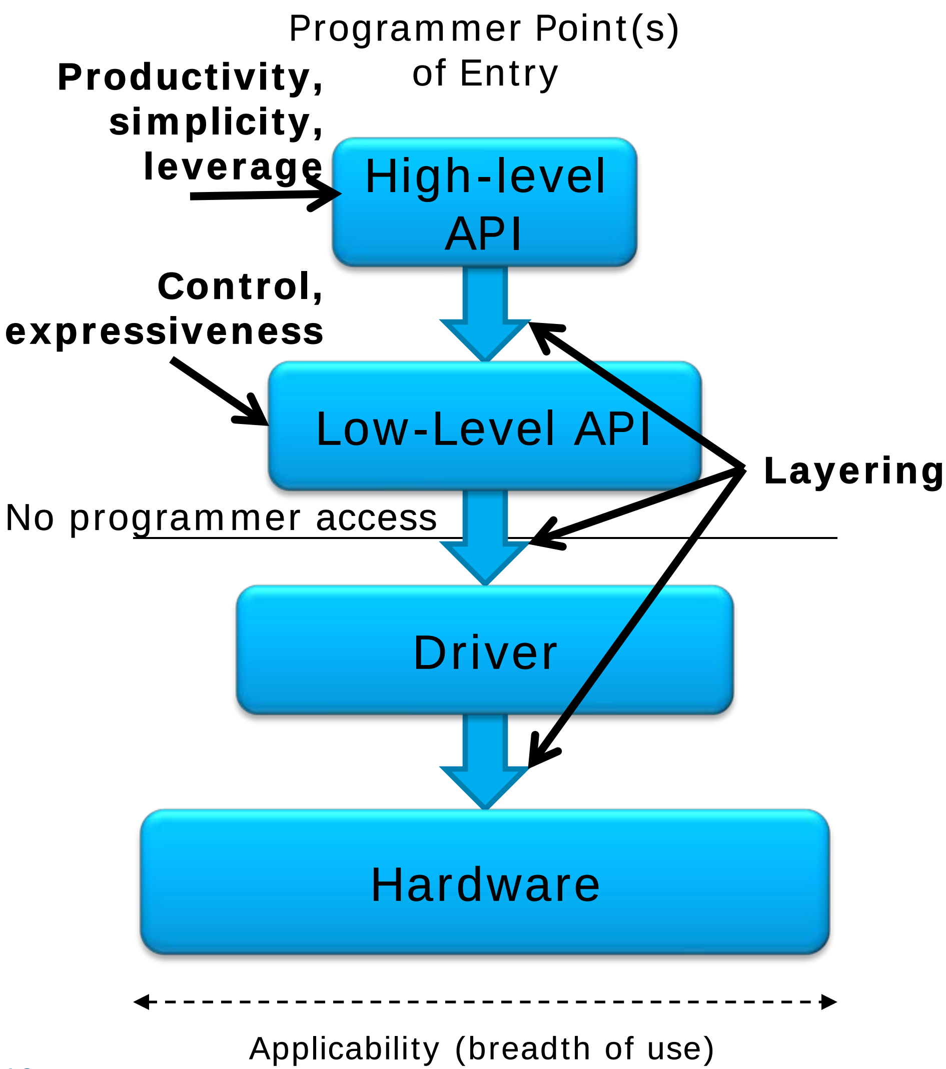
- Abstraction: reusable concepts, high-leverage, targeted

Software Stacks and Abstraction



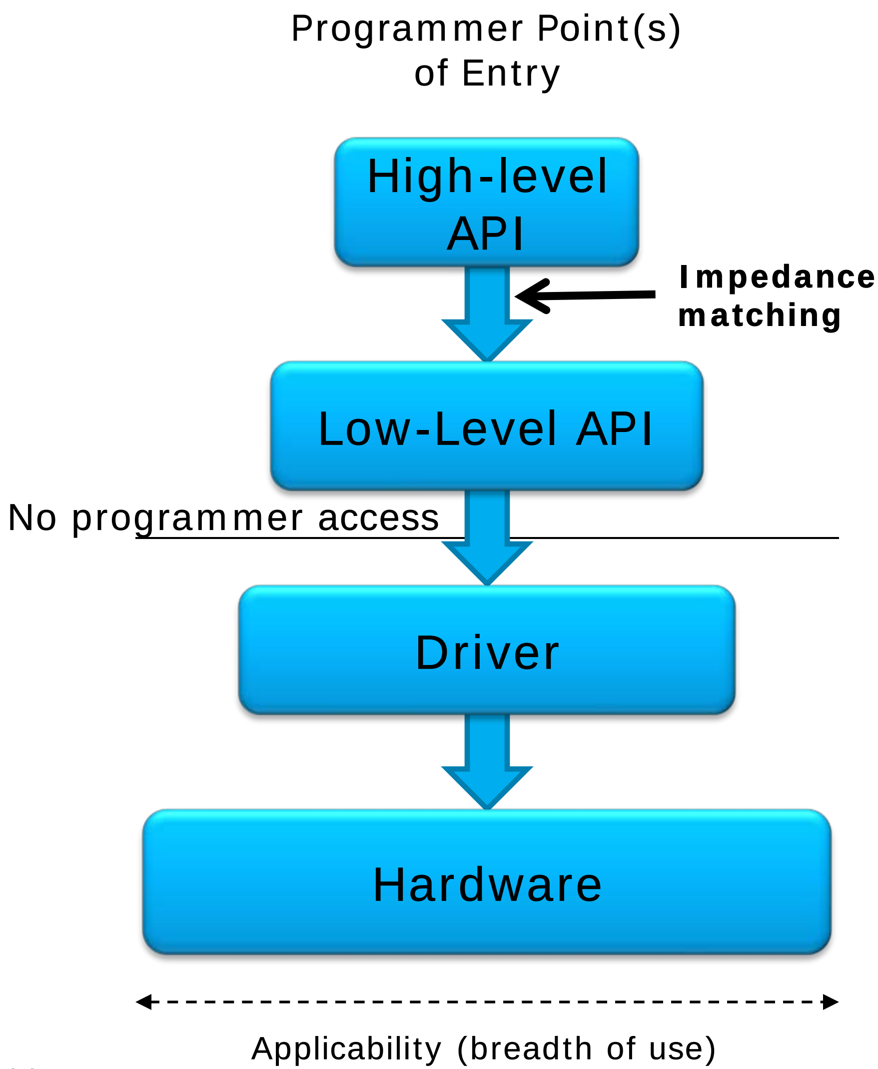
- Abstraction: reusable concepts, high-leverage, targeted
- Build in layers
  - More complex abstractions on top of smaller, less complex abstractions

Software Stacks and Abstraction



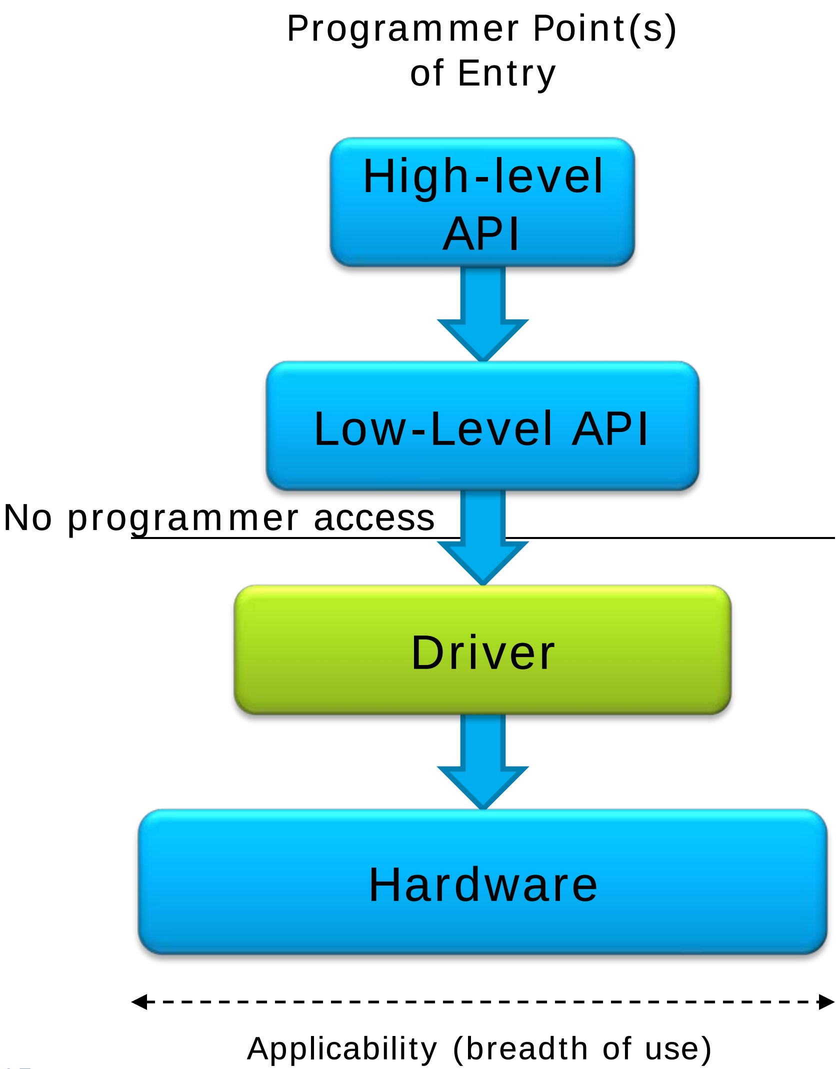
- Abstraction: reusable concepts, high-leverage, targeted
- Build in layers
  - More complex abstractions on top of smaller, less complex abstractions
- Higher-level abstractions are more purpose-specific
  - e.g., draw a line vs draw a menu
  - Multiple purpose-specific abstractions built on the same substrate

Building a Good Stack



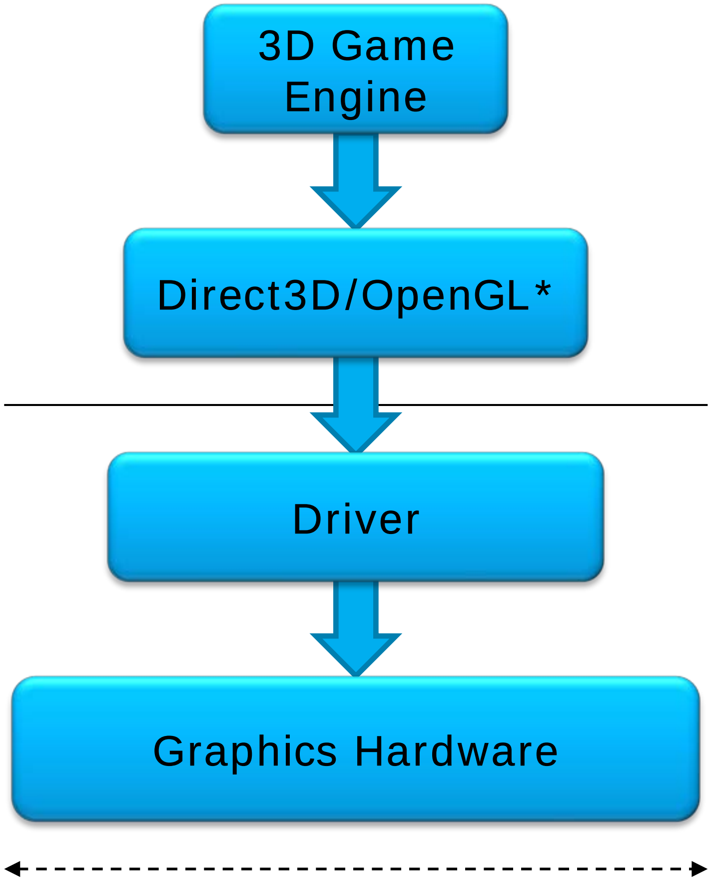
- Abstraction – layers need to have good impedance matches
- Each API must only make promises it can actually keep
  - Otherwise poor performance
  - If the HW is a poor match for low-level API
    - driver does extra work
  - If LL API a poor match for HL API
    - HL API does extra work
- Who is responsible for ensuring good matches?
  - For heterogeneous stacks - disparate standards
    - no one!
  - For closed OS vendor stacks
    - OS vendor

Building a Good Stack - Driver



- Driver really just another API
  - Purpose is to abstract HW into something low-level API can target
  - IHVs implement this layer
    - Responsible for making the HW appear uniform/portable
  - Interface to APIs is hidden to leave flexibility for later evolution
- Hiding implementation detail
  - Leaves room for evolution
  - **Tension on efficiency of abstraction vs. direct access**

Graphics Stack Example



- 3D Game engine is narrow in purpose
  - e.g. PowerPoint*, html browser, ...
  - Focus on higher level concepts
    - Drawing full scenes with shading/illumination
    - Managing level of detail, etc.
- Microsoft* Direct3D much broader
  - Can implement lots of different types of applications with lots of effort
    - e.g., painful to implement GUI
- Driver supports Direct3D runtime
  - Maps API to HW commands
  - Supports resource management between multiple applications
- Repeat this process ...

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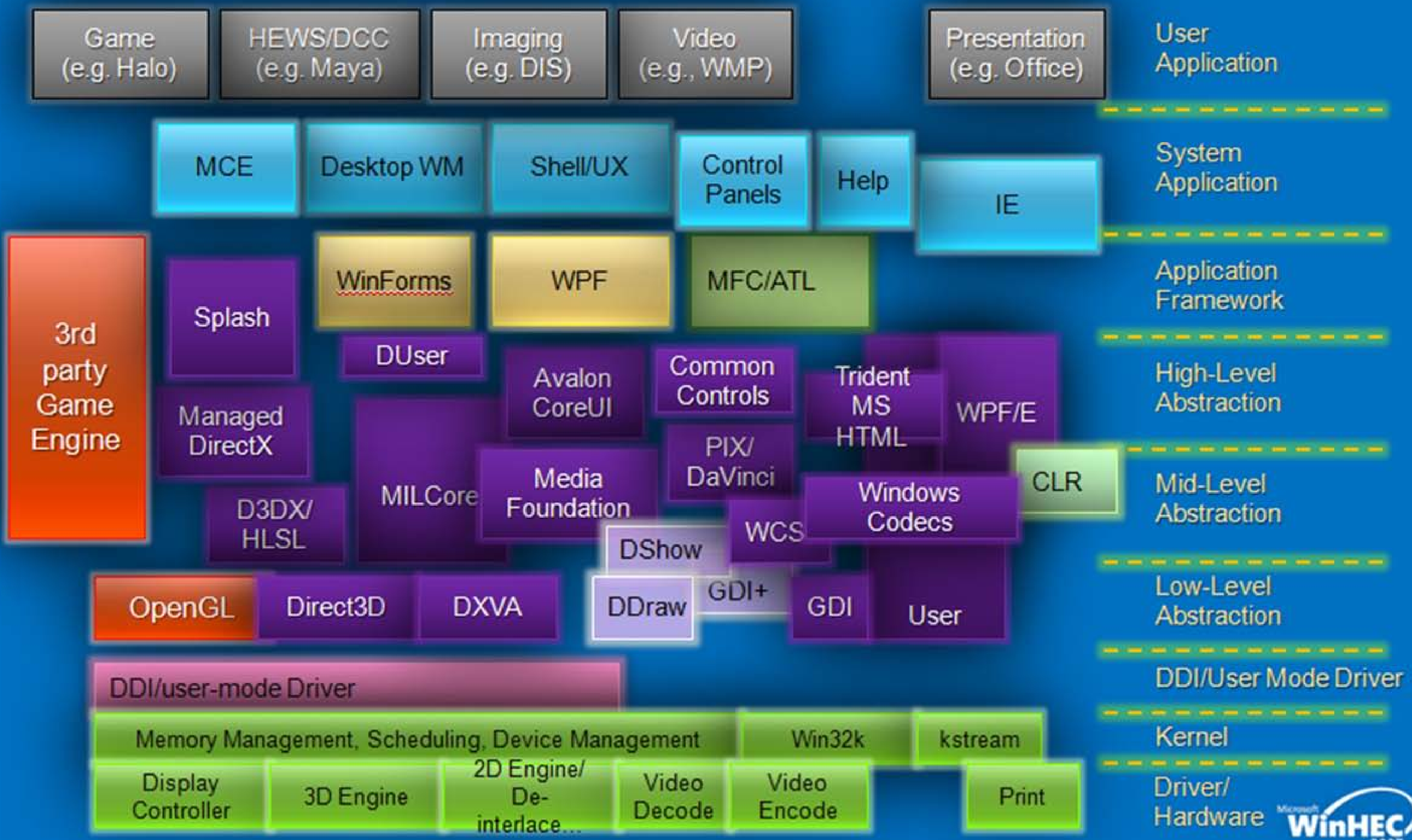
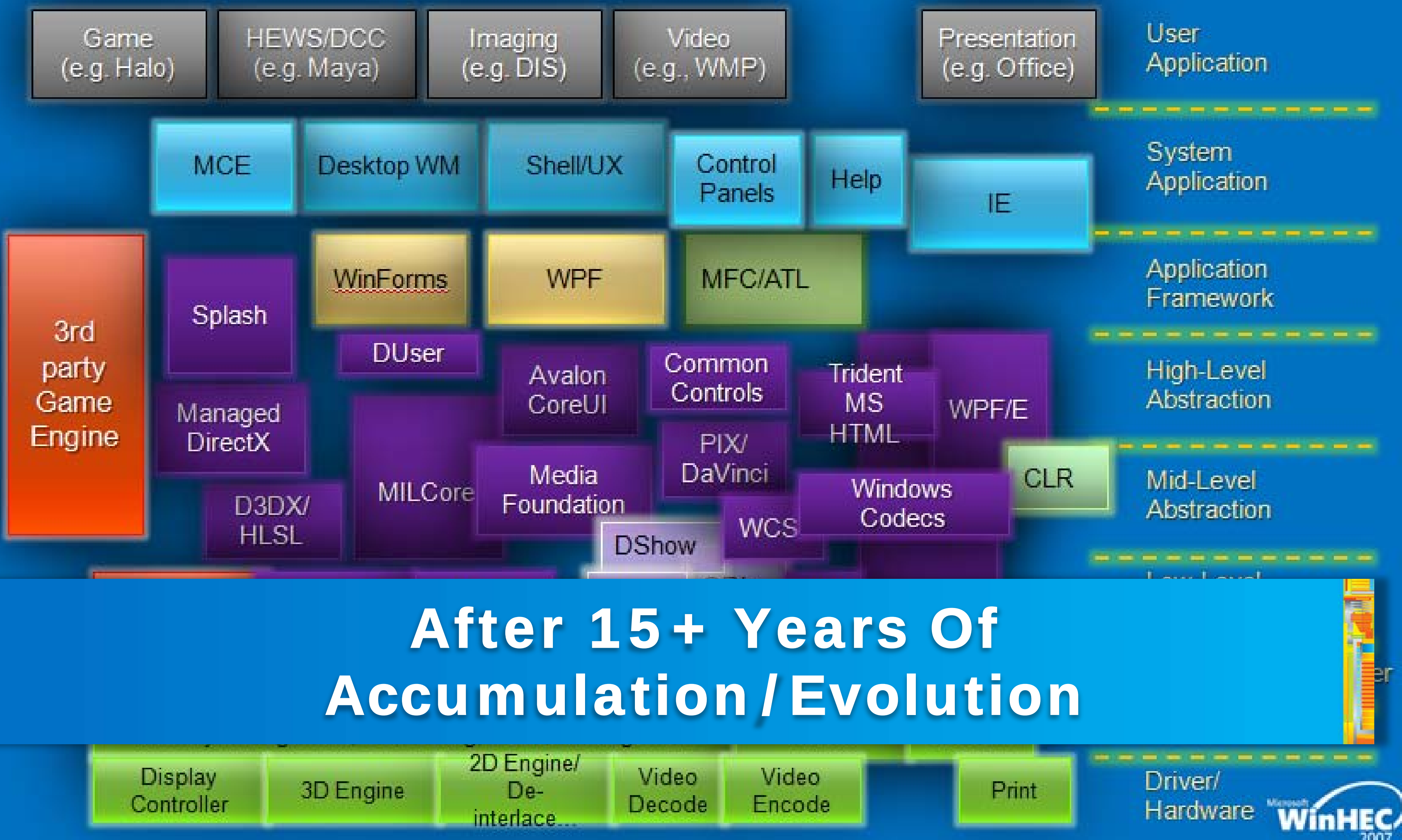
Graphics/Gaming/Multimedia/ Presentation Stacks



Graphics/Gaming/Multimedia/ Presentation Stacks



Observations About SW Stacks

- Vertical stacks are necessary
  - Not practical to have everyone program “to the metal”
- Broad usage → hard to replace
  - Large applications can’t easily port to new APIs
  - Lower parts of stack hardest to replace
- Evolution rather than revolution
  - Reduce barriers to adoption of new features
  - Design for extendibility extremely important
- Still room for new APIs
  - But, they need to <u>interoperate</u> with old APIs

Agenda

- Goals
- Software Stacks and Abstractions
- **Graphics Stack Historical Evolution**
- Workstation Generation
- PC Generation
- Processor Graphics Generation

Graphics Stack Evolution

- Learn from the Past!
- Graphics around for a long time
  - More that 50 years!
- No need to go back that far
  - Look at low-level APIs
  - Focus on last couple of decades

Spacewar 1962
computerhistory.org

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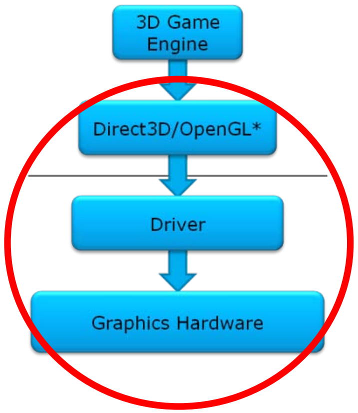
Evolution Over Last Few Decades



- Focus on system architecture

  = low-level API + driver + HW

  1990's – "Workstation" generation

  2000's – "PC" generation

  2010's – "Processor Graphics " generation

- How did/do things work?
- What worked/didn't work?

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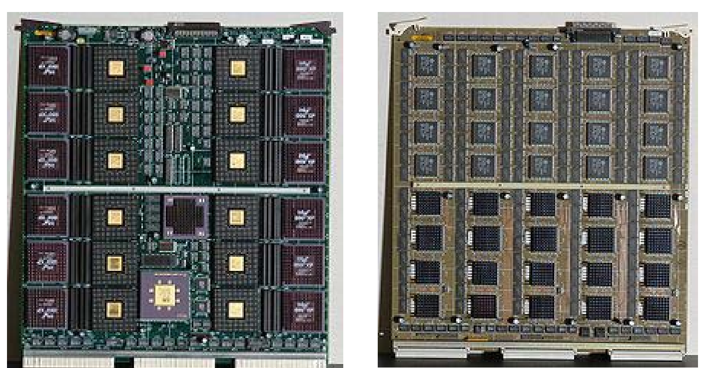


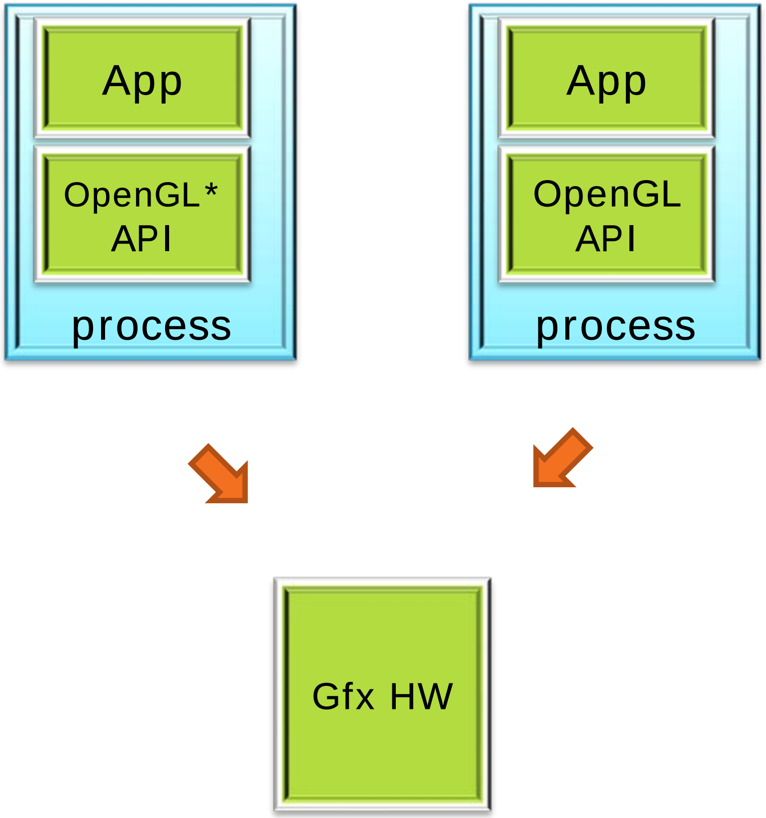
SGI* Reality Engine 1993

1990's Workstation Generation

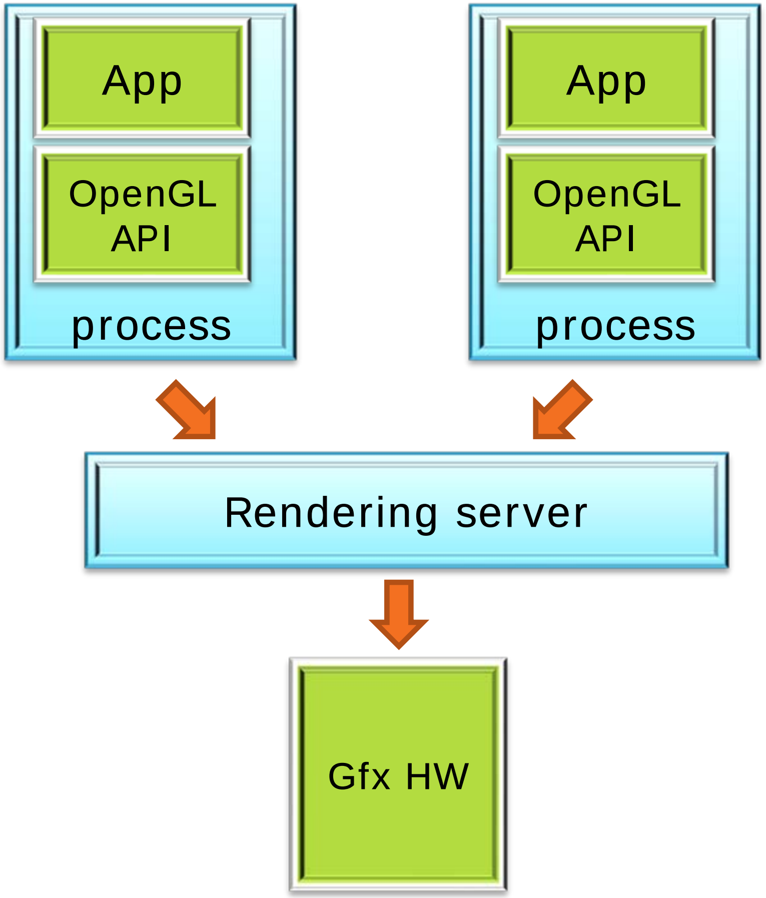
Fixed-Function, Immediate Mode APIs

- Fixed-function – performs a specific task
  - E.g., transform a vertex, shade a pixel
  - No programmability
- Immediate mode vs. declarative
  - Specify "how" to draw, step by step (GDI, OpenGL*)
  - Rather than "what" to draw (PHIGS, OpenInventor*)
  - Can implement declarative on top of immediate
    - Not vice-versa!
- Direct vs. Indirect rendering

Path to Hardware



Direct Rendering



“Indirect” Rendering

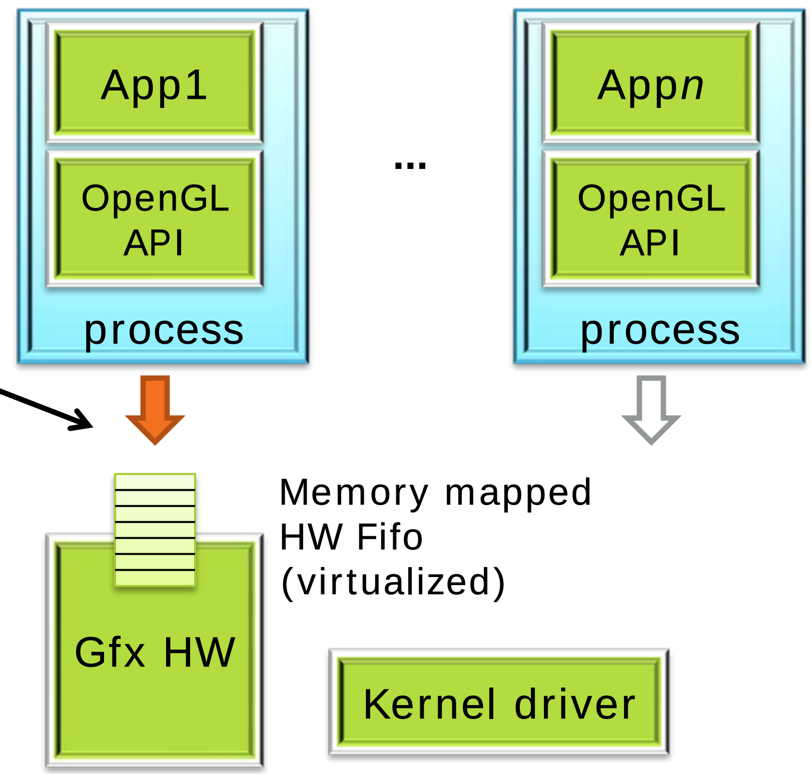
Workstation System Architecture

- OpenGL* - 3 layers:
  - API/library: command translation & submission
    - Assume HW validates command integrity
  - Kernel driver: global (machine wide) resource mgmt, app virtualization
    - context creation, memory allocation (textures, render targets), display, ...
  - HW: command execution

Command Submission

glVertex3fv():

- 1 jmp
- 3 loads
- 2 qw stores
- return

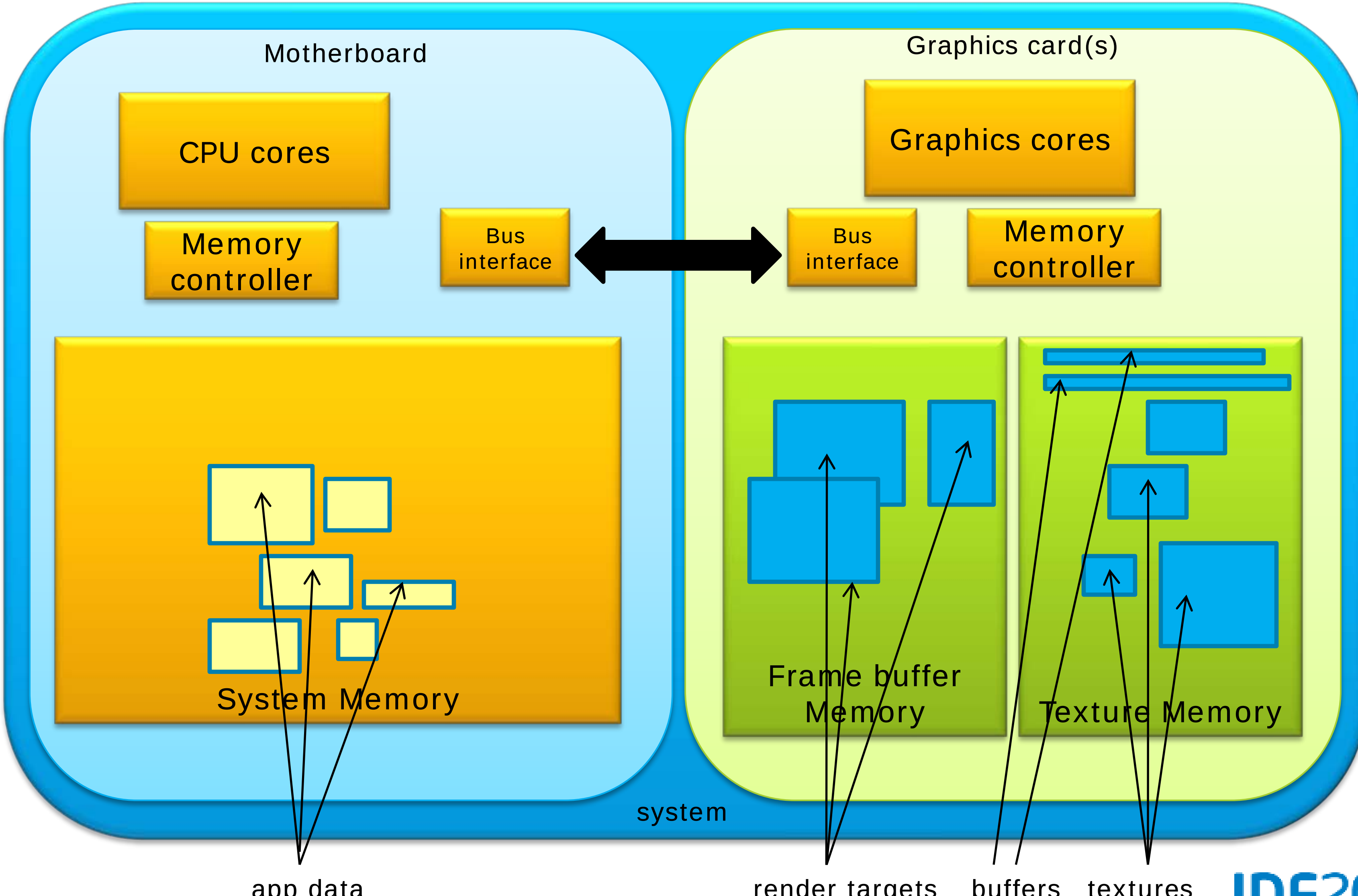


1993 OpenGL on Unix* workstation

OpenGL*

- Command stream sent to HW
  - State setting commands (color, lighting, texture maps)
  - Drawing commands (points, lines, triangles, images, ...)
- Best if 1:1 mapping API ↔ HW
  - Driver does (simple) translation of API commands to HW commands
- Pressure around overhead of managing state
  - Record state on host, defer state processing until draw time
    - E.g., bind a texture is slowest command

Workstation Resource Management



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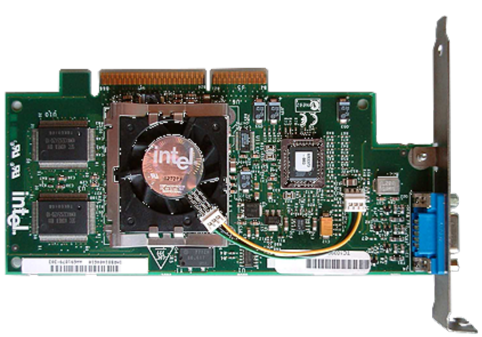


2000's – PC Generation

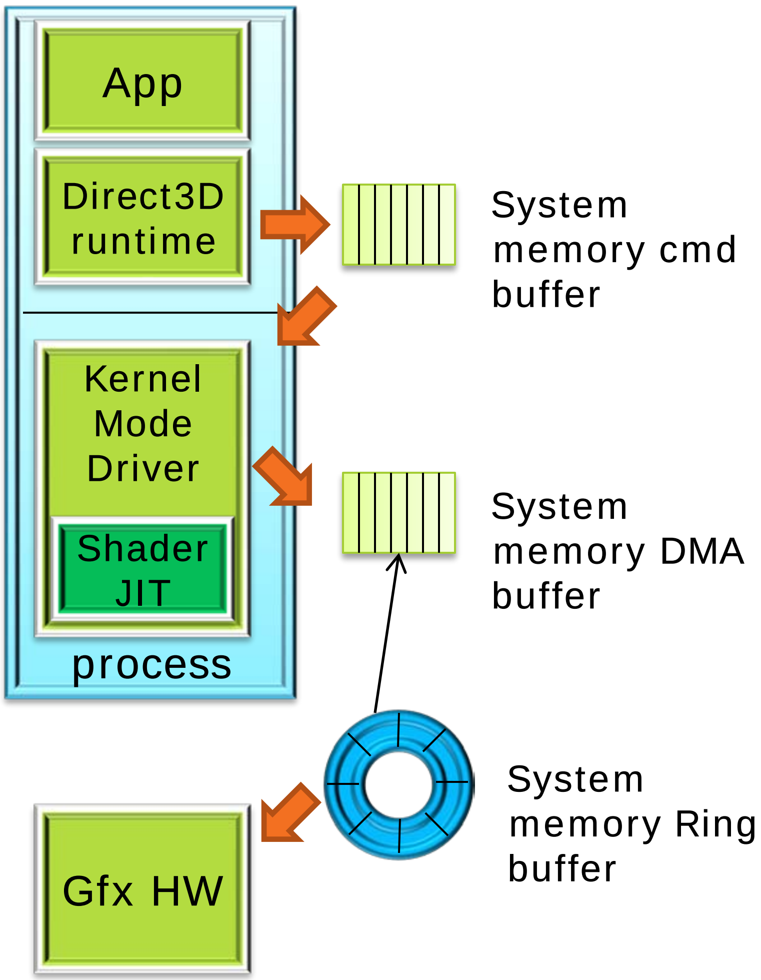
Rapid Feature Additions:

- Programmable vertex/pixel processing
  - New online JIT compilation stage
  - Runtime manages compiled shaders
  - Offline compiles to intermediate representation
    - E.g., HLSL
- Render to texture, lots of memory objects
  - Much more memory state to manage
- More logical pipeline stages
  - Tessellation, geometry shader
- Early "compute" APIs
  - DirectCompute, OpenCL*

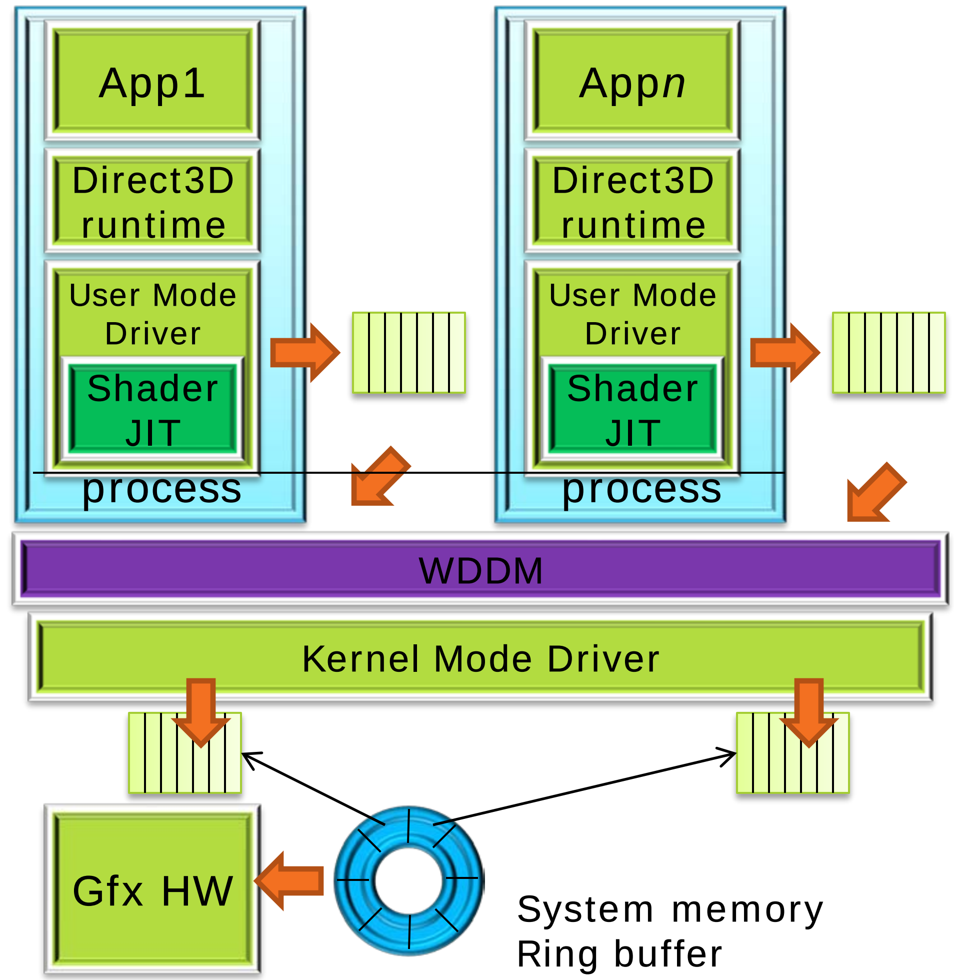
Changing System Requirements

- New challenges
  - Power management
  - Dynamic display configuration
  - Security/robustness, content protection
  - Hardware diversity
- Reuse 3D APIs for desktop rendering
  - Transition from “single app” to “multi-app”
- Virtualization of HW resources done in software
  - Oversubscribed memory → swapping/paging
  - Processing → time slicing
- Isolate applications from one another
  - i.e., enforce OS process boundaries

Buffer-based Command Submission



2003 Direct3D Microsoft* Windows*



2007 Direct3D Microsoft* Windows*

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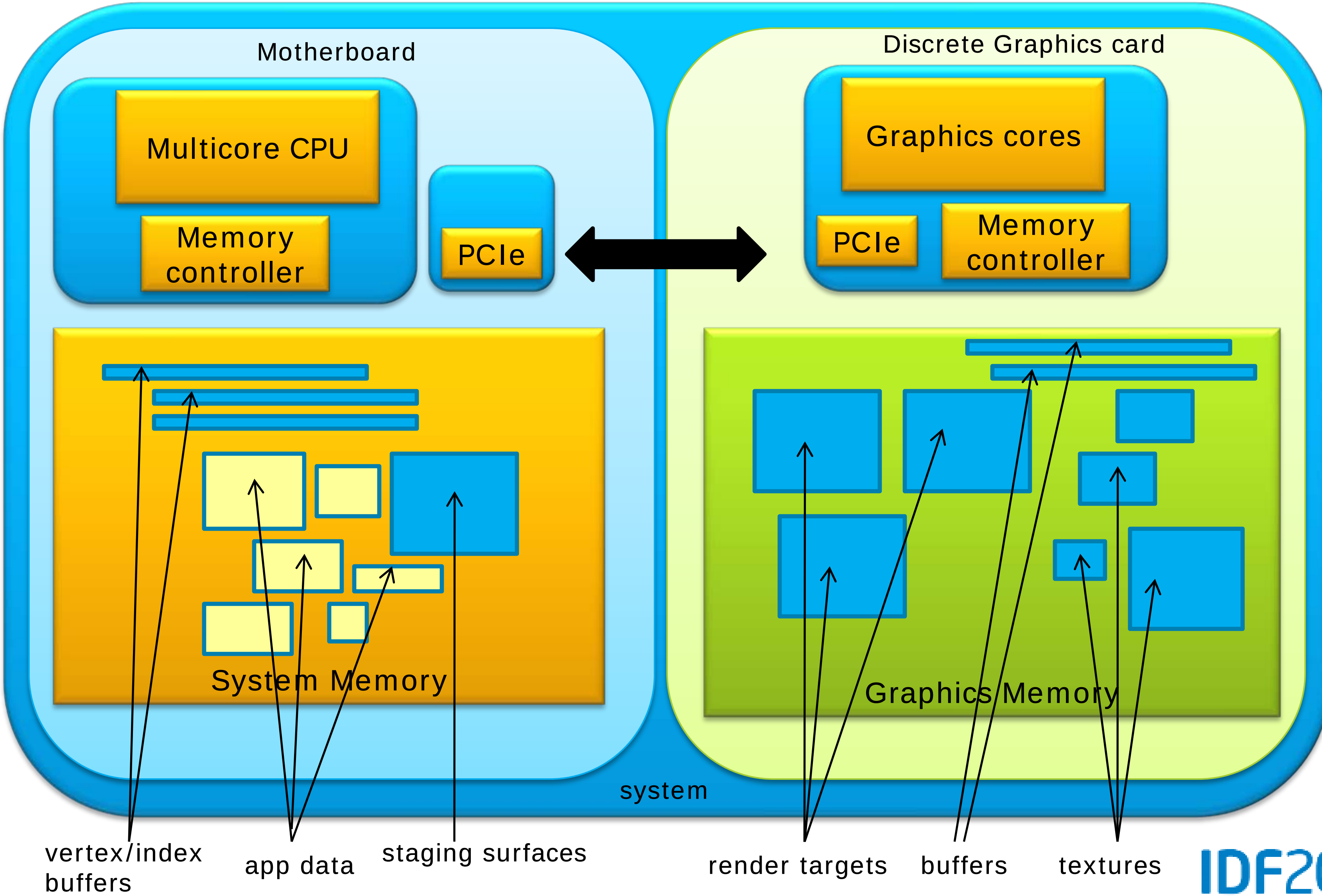
Resource Management



What Works

- Driver/low-level API factoring
  – APIs abstract driver model changes
  – Little driver-motivated API change
- Good compatibility over 15-20 years
  – E.g., Microsoft* Windows* still running Microsoft DirectX*7,8,9 ... apps
  – OpenGL* 1.0 (1993) apps still running
  – Not free, extra HW, SW work required
- Supports significant HW evolution
  – New API versions to expose new features
- “Resets” employed to address layer mismatches
  – E.g., major driver model change for Microsoft Windows Vista*
  – These are expensive for the ecosystem

Accumulated Problems

- Overhead in submitting commands to HW
  - Multiple memory writes
  - Driver transition from ring 3 to ring 0
- Latency and bandwidth constraints in moving data
- Complicated resource management
  - Which resources are in graphics memory vs. CPU memory?
  - Resource contents marshaled between memories
- Increasingly complicated API additions to overcome these problems

Applications are complex to write
Overheads limit scenarios

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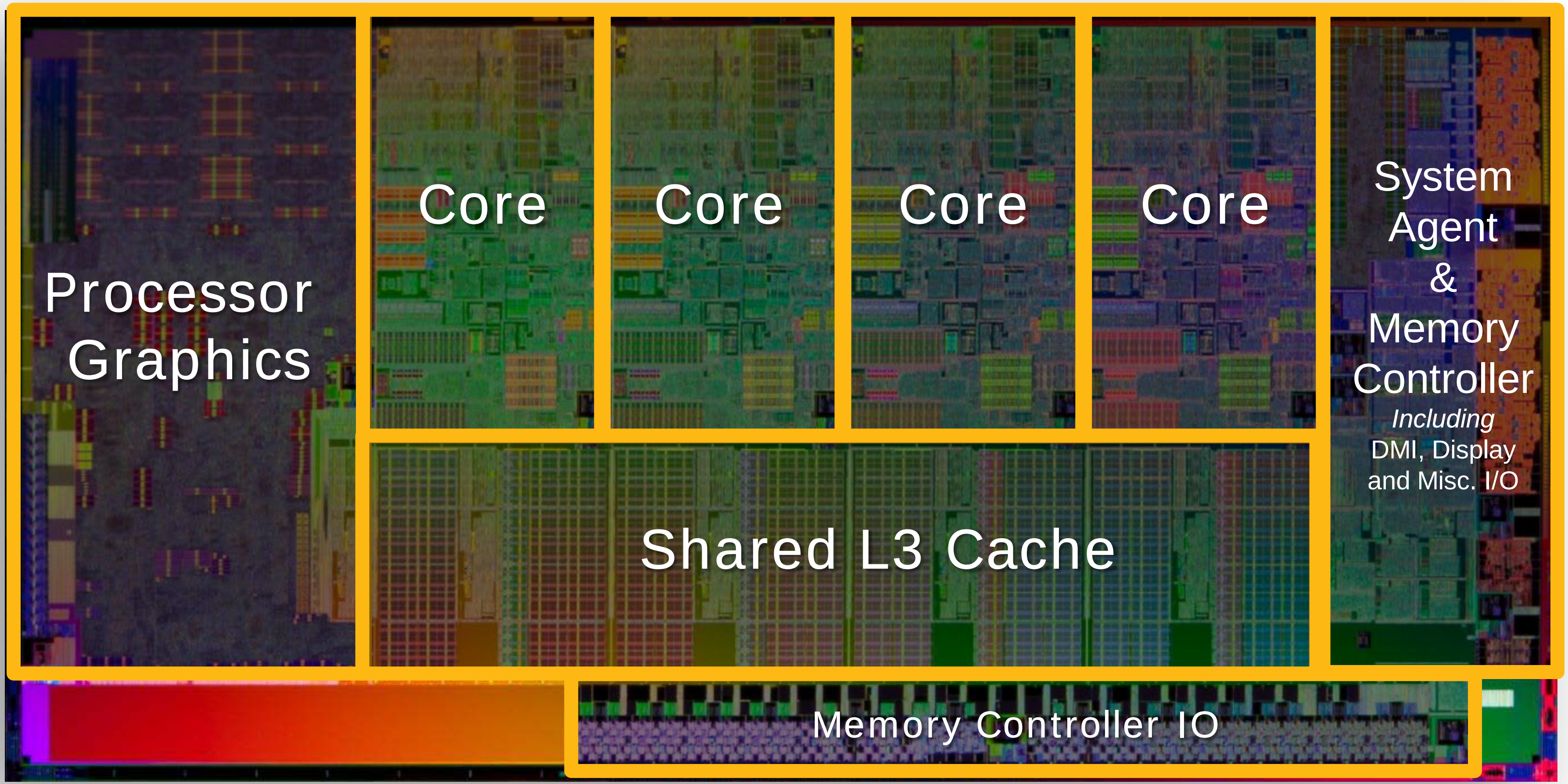
- PC Generation
- **Processor Graphics Generation**

2nd Generation Intel® Core™ processors (Sandy Bridge)

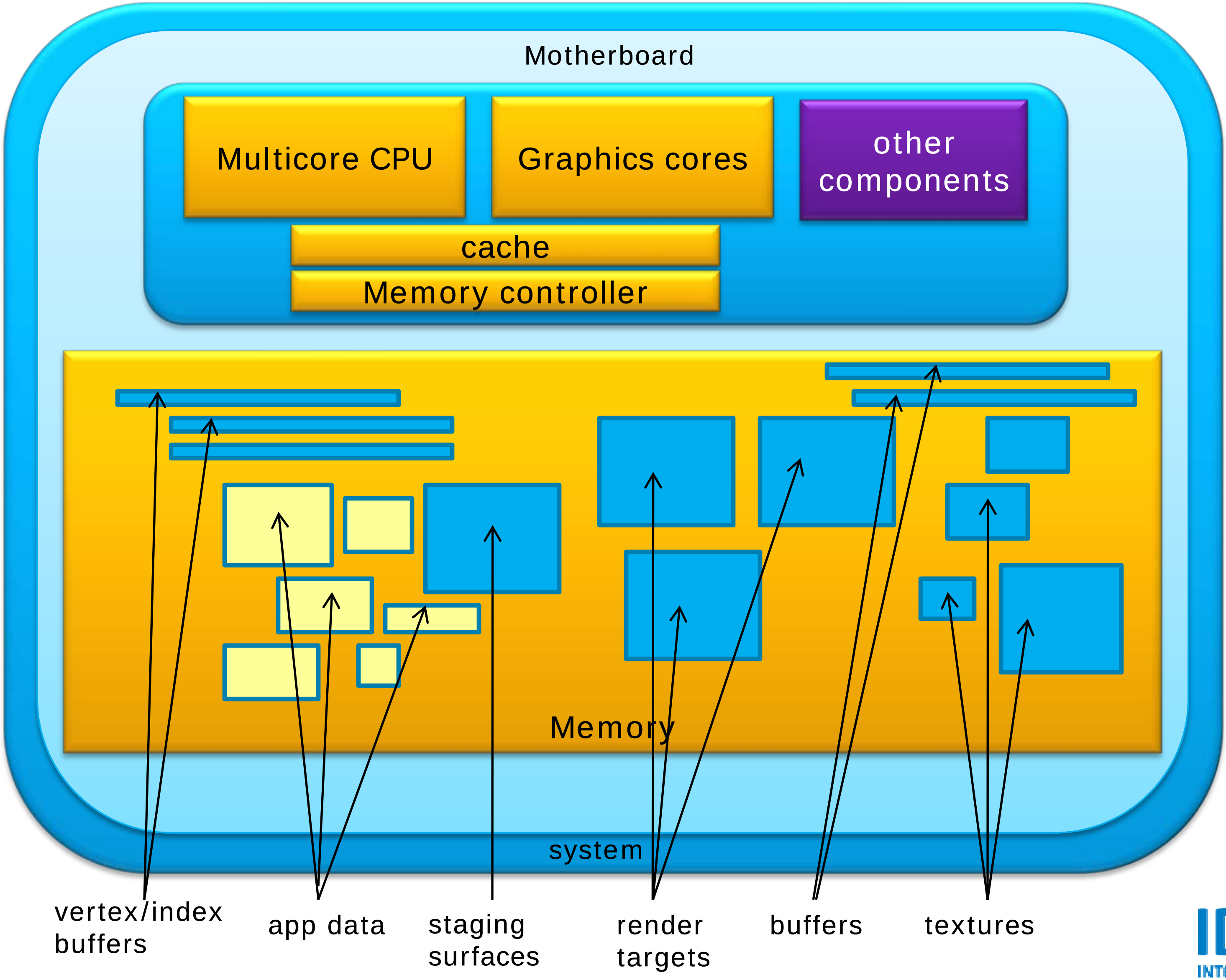
2010's – Processor Graphics Generation

- Graphics hardware acceleration ubiquitous
  - workstation, desktop, notebook, slate, phone
- On-die integration of CPU, Graphics, ...
  - Rename on-die graphics to **Processor Graphics**
  - Additional integration → system on a chip (SOC)
- What are the opportunities and challenges?

Early Example: Intel® Microarchitecture (Sandy Bridge)



Processor Graphics View



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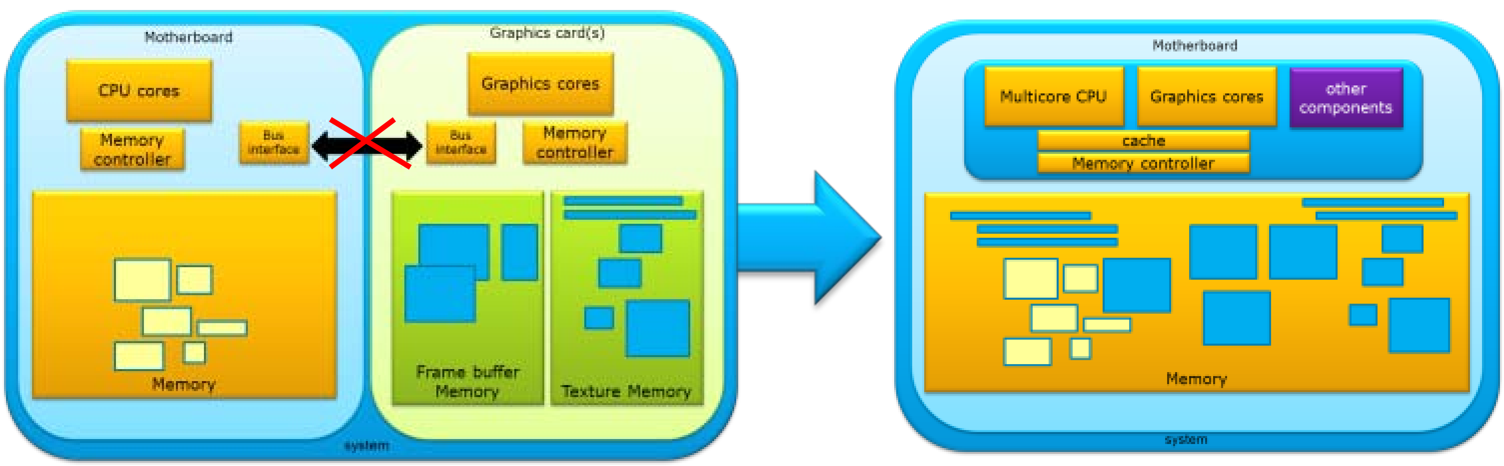
The Processor Graphics Opportunity

- Integration is efficiency
  - Higher bandwidths, lower latencies
- 3 classes of opportunities:
  - Improve data access and efficiency
  - Reduce command submission/return overhead
  - Agile allocation of power

More Efficient Data Management

- Graphics and other application resources in same physical memory
  - No external bus to cross
  - Move to same process address space
  - Remove copies and copying (marshaling)



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Thinking Bigger

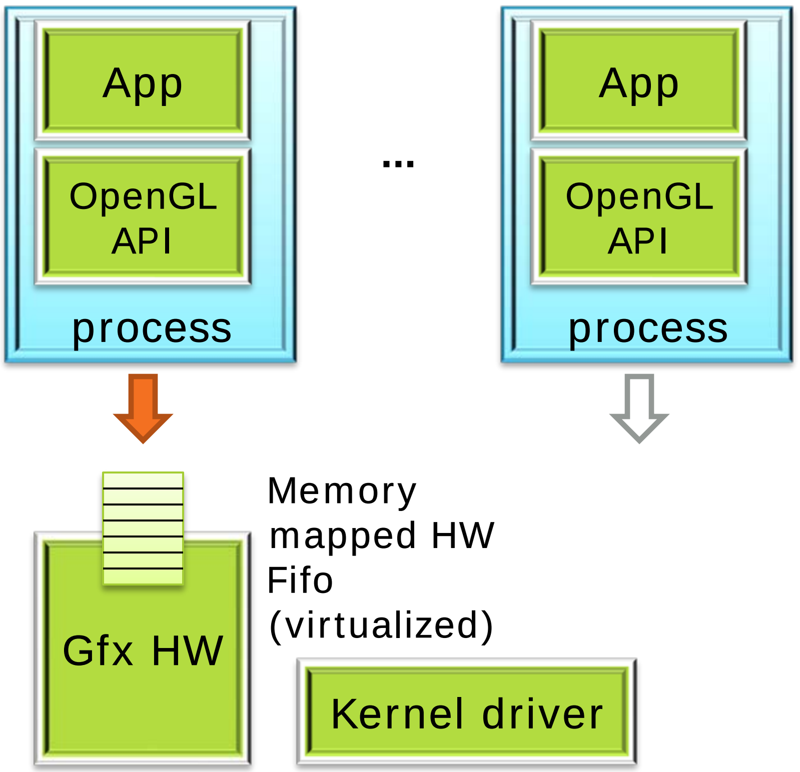
Eliminate memory allocation from APIs

- Use OS APIs instead
  - Malloc, HeapAlloc, ...
- Simplify graphics APIs to not create separate surfaces, vertex buffers, etc.
  - Flashback to workstation generation!
- Make surface “mapping” or “locking” a cheap operation
  - *“ ... what I most want to see is direct surfacing of the memory ...” - John Carmack*

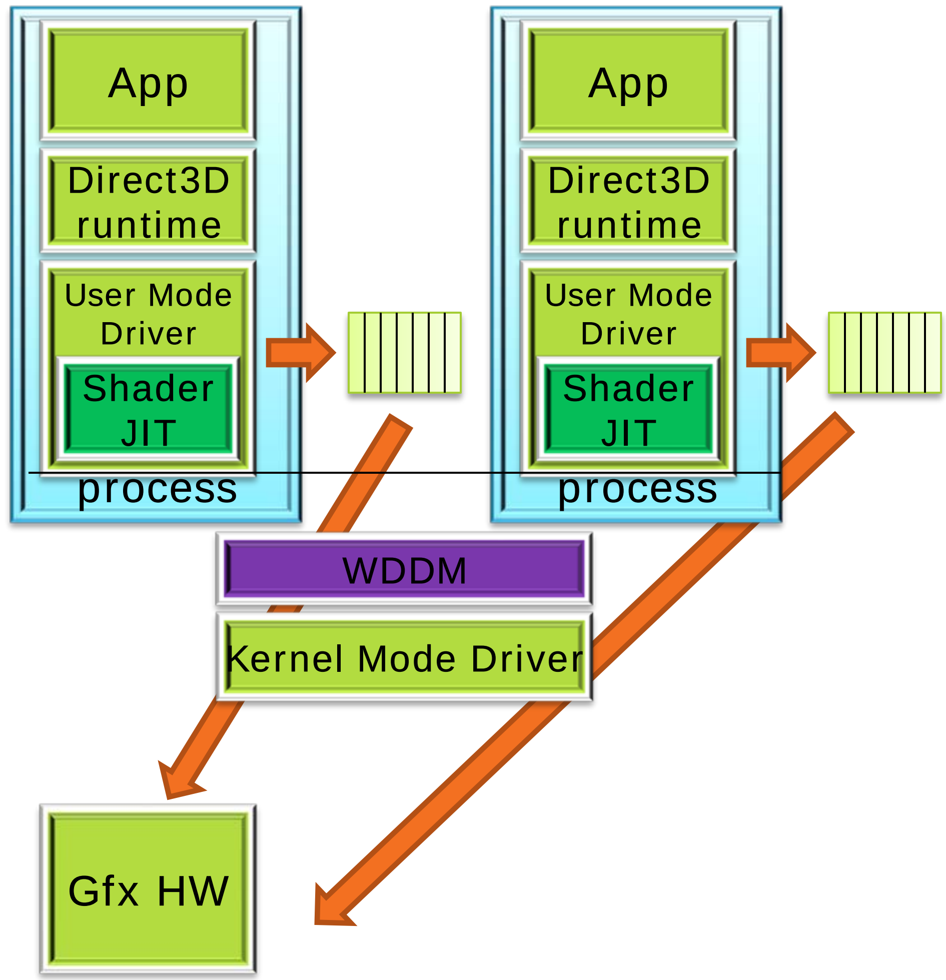
Command Submission Efficiency

- Previous attempts to improve efficiency
  - Direct3D 10 – refactor API
  - Increase amount of work per API call
- New opportunity:
  - Leverage shared physical memory
  - Avoid multiple copies of command buffers
- Can never compromise security, robustness
  - Must validate commands from untrusted ring 3

Can We Go Back to 1993?



1993 OpenGL* on Unix* workstation



Perhaps something like this?

Power Sharing

- Integration allows “big picture” power management
- Shift power between CPU, Graphics, other components

Power Allocation

- Track work, power, temperature
  - Adjust frequency, voltage on demand – power = $C_{dyn} * f * v^2$
  - Just need clever software
- Maybe add APIs to enable application hints
- Take further advantage of power "lulls"
  - Accumulate thermal credit for periods of low activity
  - E.g., Turbo = boost frequency beyond base
- New importance on running "lean" CPU code
  - No busy waiting, inefficient algorithms, ...
  - Untuned code is wasted power

API Evolution for Processor Graphics

- Change memory management model
  - Use OS memory allocation
- Change command submission model?
  - API is okay, underlying implementation is bad
- Better async communication between CPU and graphics
  - Are programmers comfortable with async programming?
- Application-assisted power management
  - Annotate CPU and graphics work phases

Summary

- Graphics API stack has evolved a lot
  - Useful insights from prior implementations
- Large, successful ecosystem built around current stack
- Significant improvement opportunities remain
  - Power management
  - Command transport
  - Memory management
- We can tackle these in Processor Graphics generation
  - Not in one big jump, but through a collection of changes

Call to Action

Processor Graphics generation is upon us

– Time to experiment and learn:

  - Power interactions between CPU and Graphics
  - Unified memory hierarchy

– And more to come ...

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