CS5182 Computer Graphics GPU and Computer Animation

2024/25 Semester A

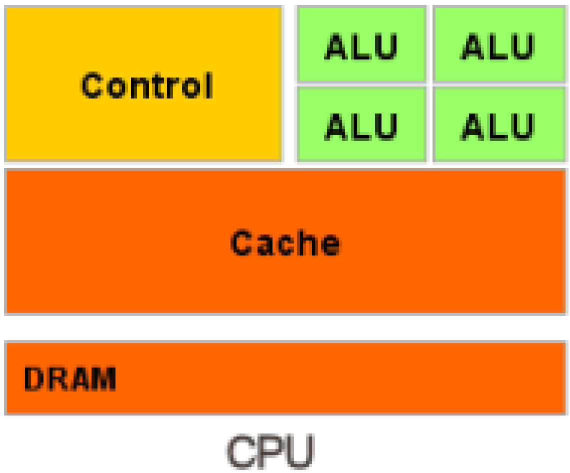
City University of Hong Kong (DG)

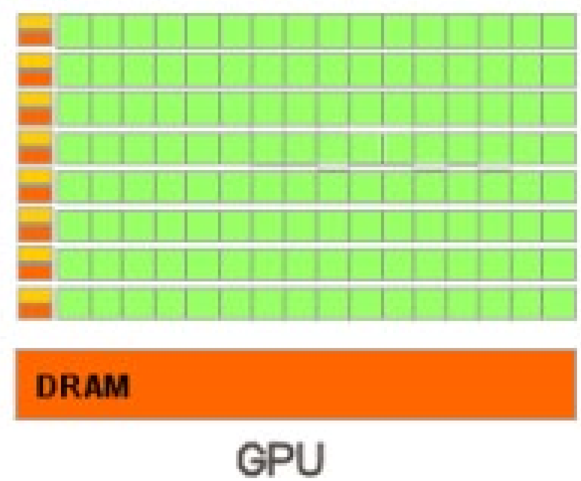
What is a GPU?

- GPU stands for Graphics Processing Unit
  - Simply, it is the processor that resides on your graphics card and performs rapid mathematical calculations.

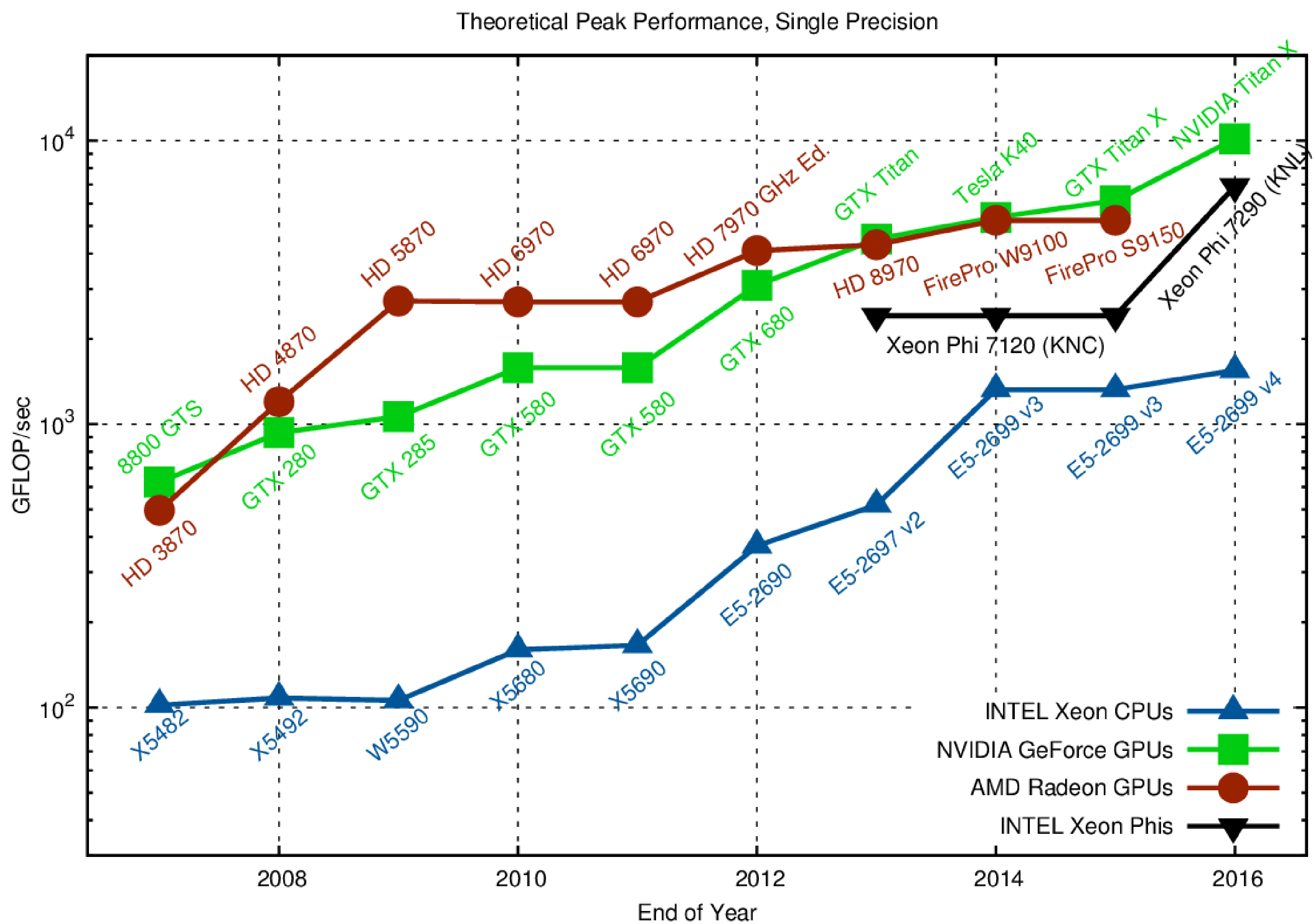
CPU vs. GPU

- In general, CPUs have the following features:
  - Good at control-heavy tasks but not data-heavy tasks
  - Few arithmetic units – not enough space
  - Optimized for low latency
  - Not for high bandwidth
- In general, GPUs have the following features:
  - Lots of calculations and parallelism
  - Simple control, multiple stages
  - Latency-tolerant





CPU vs. GPU

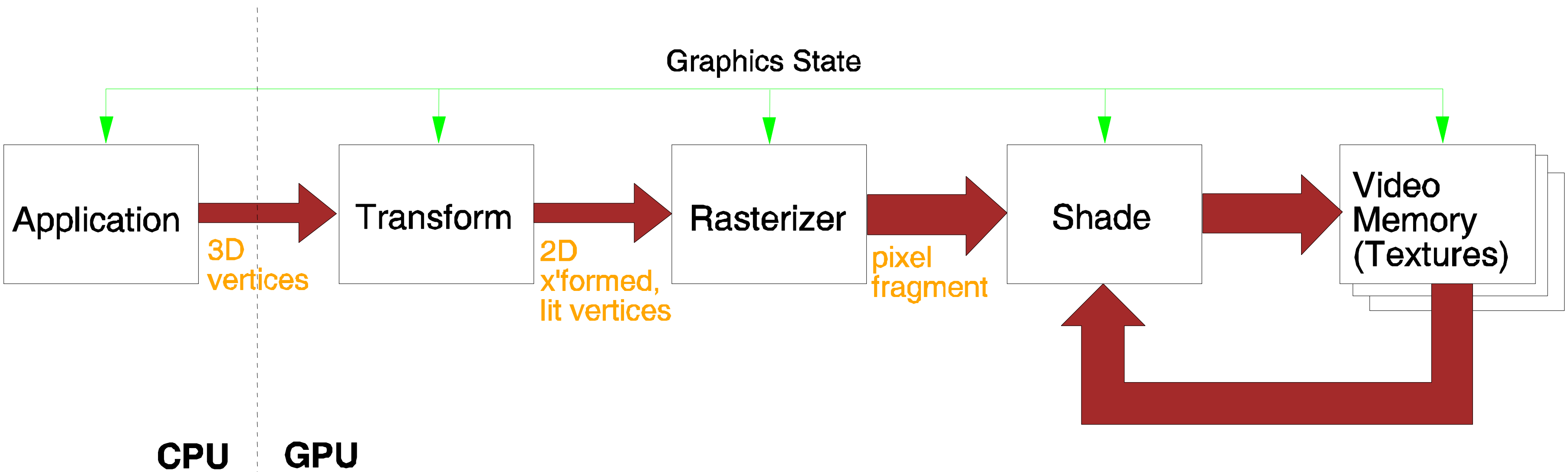

Theoretical Peak Performance, Single Precision
GFLOP/sec
End of Year
10^2
10^3
10^4
2008
2010
2012
2014
2016
8800 GTS
GTX 280
GTX 285
GTX 580
GTX 580
GTX 680
GTX Titan
Tesla K40
GTX Titan X
NVIDIA Titan X
HD 3870
HD 4870
HD 5870
HD 6970
HD 6970
HD 7970 GHz Ed.
HD 8970
FirePro W9100
FirePro S9150
Xeon Phi 7120 (KNC)
Xeon Phi 7290 (KNL)
X5482
X5492
W5590
X5680
X5690
E5-2690
E5-2697 v2
E5-2699 v3
E5-2699 v3
E5-2699 v4
INTEL Xeon CPUs
NVIDIA GeForce GPUs
AMD Radeon GPUs
INTEL Xeon Phis

More on Modern GPUs

- They are highly programmable
  - Programmable vertex, pixel, and video engines
  - With high-level language support
- They support high precision computations
  - 32-bit floating point throughout the pipeline. This is high enough for many applications.
- The computational performance and the flexibility of GPUs make them an attractive platform for general-purpose computation.

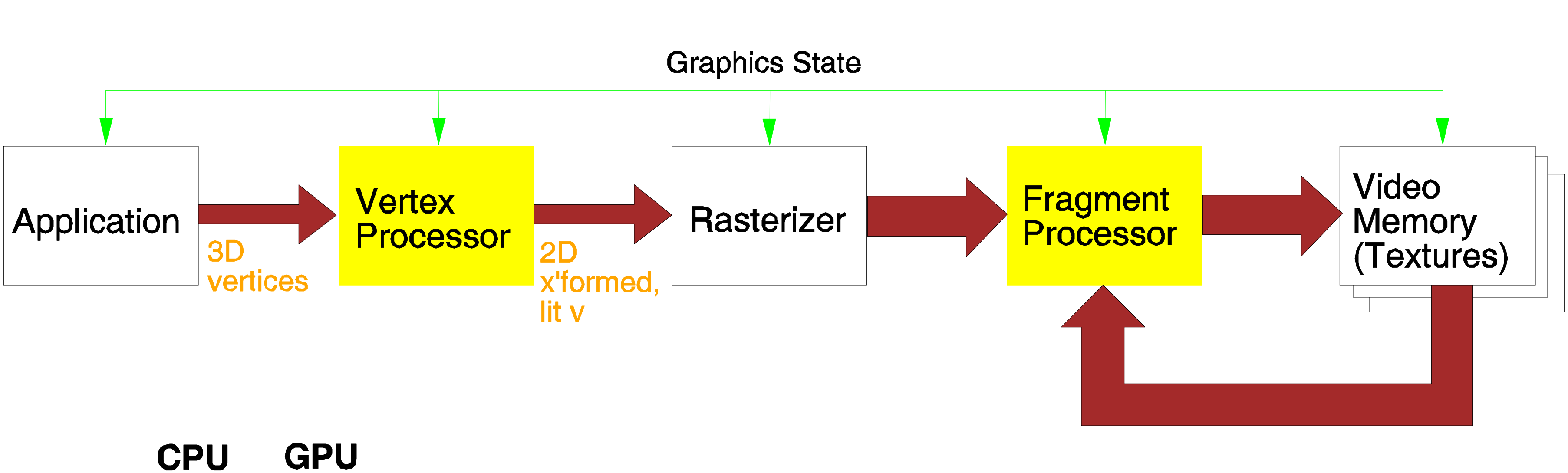
GPU Architecture

- The traditional hardware graphics pipeline

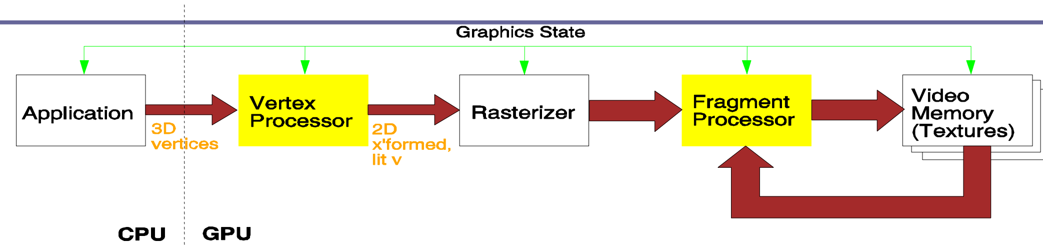


GPU Architecture

- The advanced hardware graphics pipeline with:
  - Programmable vertex processors
  - Programmable pixel (or fragment) processors



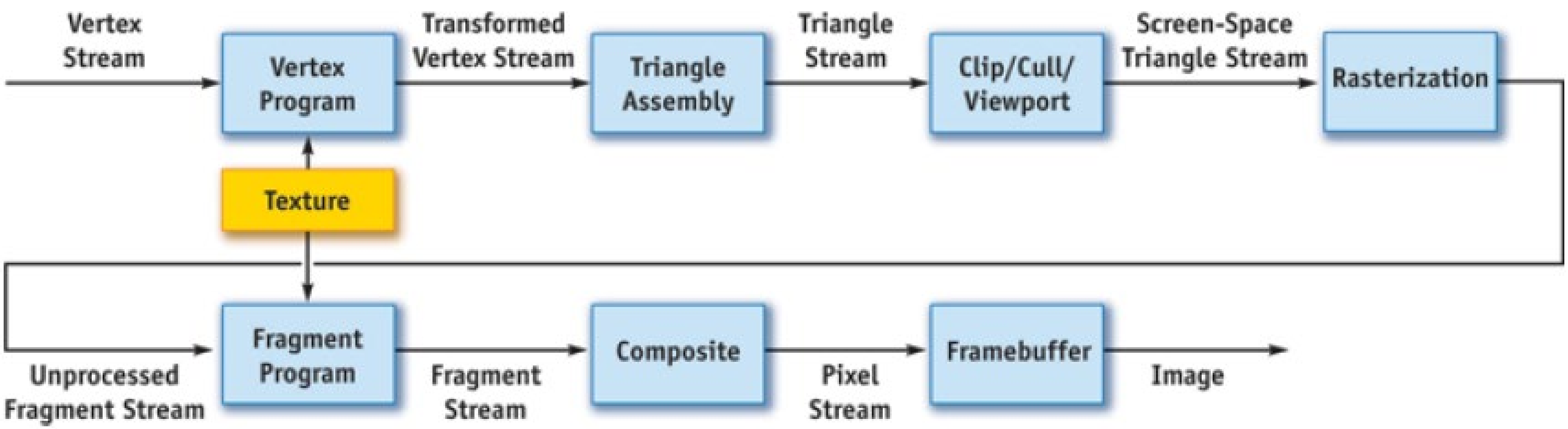
GPU Architecture



- Vertex processors
  - Transformation
  - Back-face removal
  - Per-vertex lighting computation
- Rasterizer
  - Clipping
  - Convert geometric representation (vertices) to image representation (fragments: pixel data– color, depth, etc.)
  - Interpolate per-vertex quantities across pixels
- Fragment processors
  - Depth comparison
  - Compute a color for each pixel
  - Optionally read colors from textures (images)

Stream Programming Model

- The graphics pipeline is a good match for the stream model as it is traditionally structured as operations connected by data flow between the operations.



Efficient Computation

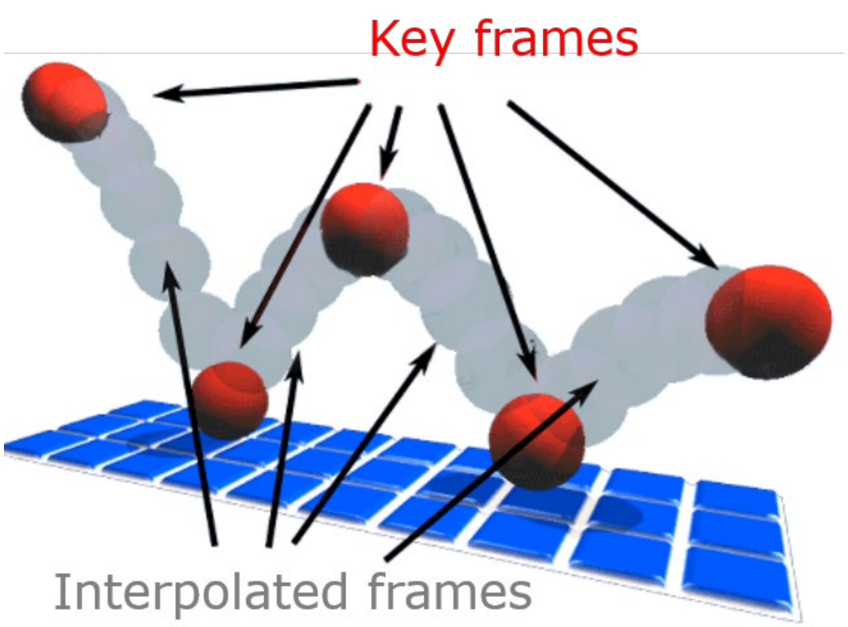
- Data-level parallelism
  - Same operations are performed on different subsets of same data.
  - For example, each triangle can be processed independently of all others during rendering.
- Task-level parallelism
  - Different operations are performed on the same or different data.
  - A common type of task parallelism is pipelining, i.e., moving a single set of data through a series of separate tasks where each task can execute independently of the others.
  - For example, the rendering is split up into several separate stages, with each stage handing over its data to the next stage without any need for iterations or backtracking.

Efficient Communication

- The performance of GPU parallelization is limited by the complexities of CPU-GPU communication. Three ways to improve communication efficiency:
  - Favor transferring entire streams instead of individual elements in off-chip communication, i.e., cheaper transfer cost per element.
  - Structuring applications as pipelines of kernels helps free off-chip storage of intermediate results.
  - Favor deep pipelining, i.e., maximizing the number of pipeline stages, to hide data accessing time.

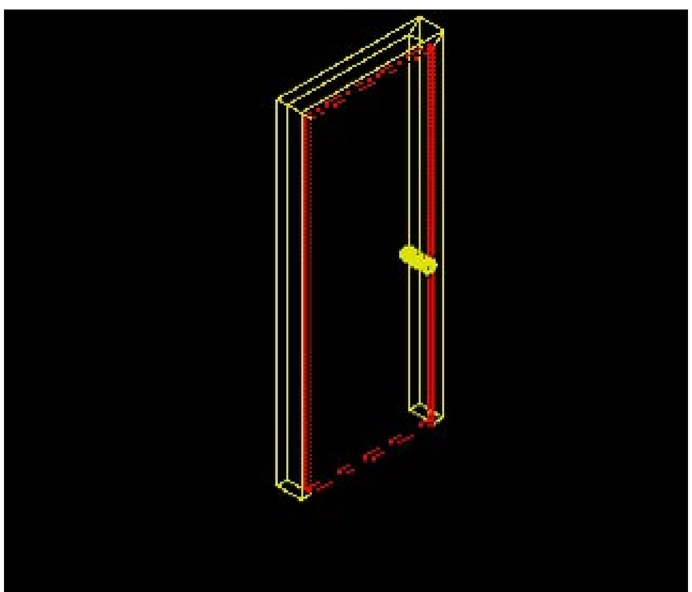
Computer Animation

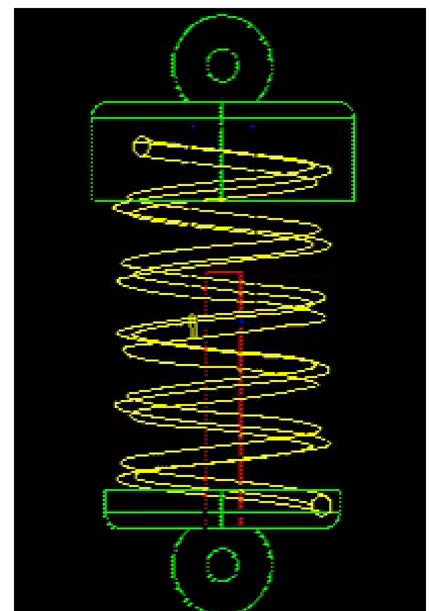
- Artist-directed (e.g., keyframing)
- Procedural (e.g., simulation)
- Data-driven (e.g., motion capture)



Computer Animation

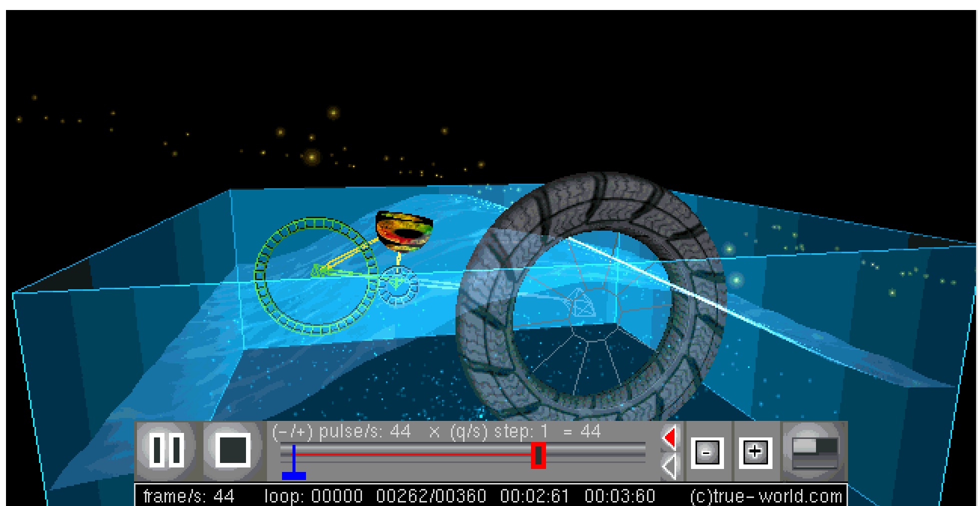
- Keyframing animation
  - Specify importation events only and computer fills in the rest via interpolation/approximation
  - “Events” do not have to be position, and could be color, light intensity, camera zoom, …





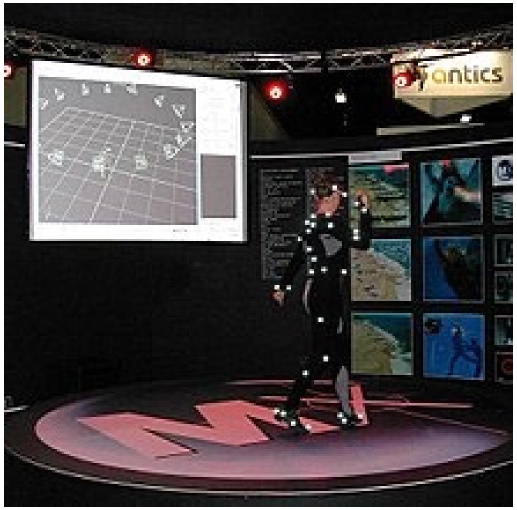
Computer Animation

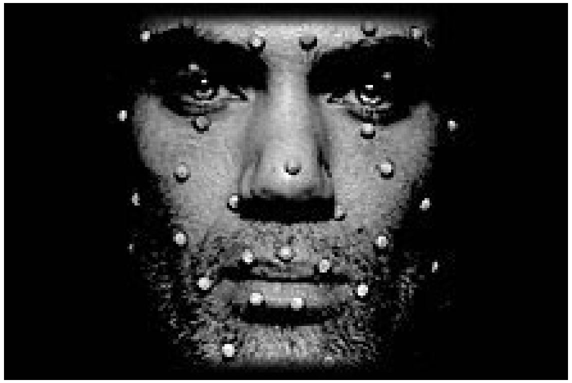
- Procedural animation
  - To produce a procedural animation, the animator defines a procedure or a set of operations to be performed.
  - Each operation can generate or alter data that passes through it and can be conditionally or non-conditionally executed.
  - With procedural animation methods (e.g., particle systems, rigid dynamics and flexible dynamics), the user specifies a set of rules, initial conditions and parameter values and runs simulations.

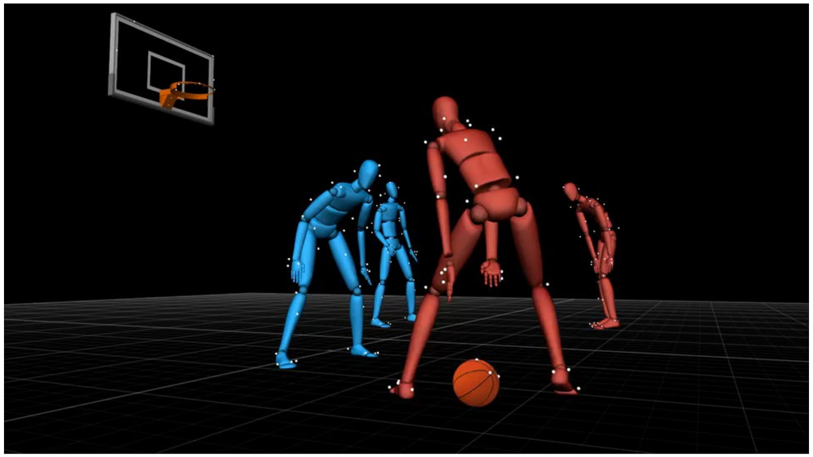


Computer Animation

- Motion capture (MoCap) animation
  - MoCap is sampling and recording motion of humans, animals, and inanimate objects as 3D data.







Computer Animation

- Mocap animation is the act of recording an actor's movement and applying it to a 3D character.

Current MoCap Technologies

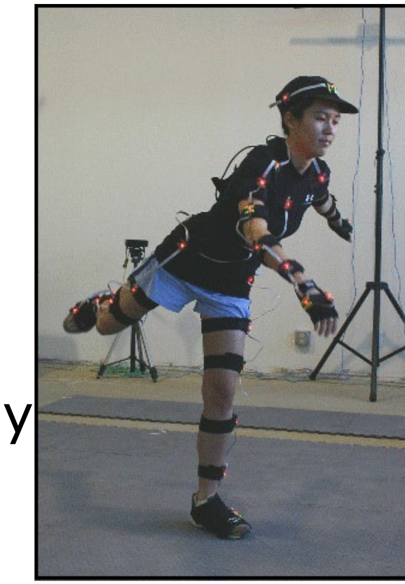
- Electromagnetic mocap
  - Calculate 3D position and orientation of each joint by the relative magnetic flux of three orthogonal coils on both the transmitter and each receiver.
  - Advantages

    -- measure 3D positions and orientations

    -- no occlusion problems

    -- Require no special lighting condition

    -- can capture multiple subjects simultaneously



  - Disadvantages

    -- magnetic perturbations (metal)

    -- cannot capture deformation (facial expression)

    -- hard to capture small bone movement (finger movement)

    -- not as accurate as optical mocap systems

Current MoCap Technologies

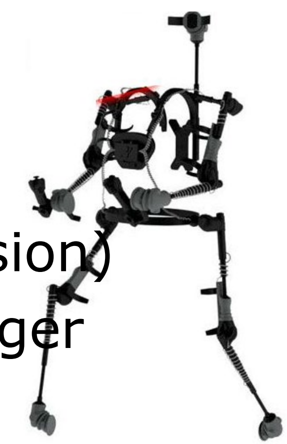
- Electromechanical mocap
  - Subject wears an exoskeleton to directly track body joint angles.

  - Advantages

    -- measure 3D orientations

    -- free-of-occlusion

    -- portable and outdoors capture (e.g. skiing)



  - Disadvantages

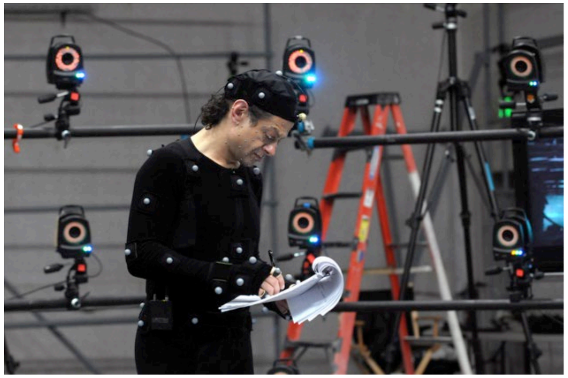
    -- Getting 3D position info is not easy

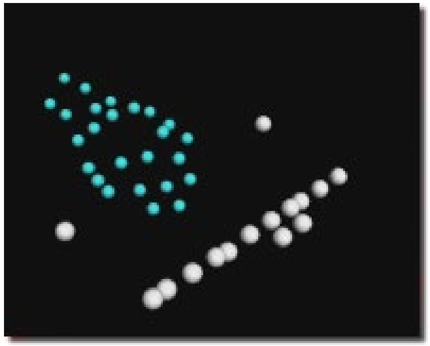
    -- cannot capture deformation (e.g., facial expression)

    -- hard to capture small bone movement (e.g., finger motion)

Current MoCap Technologies

- Optical mocap
  - Multiple calibrated cameras digitize different views of performance.
  - Wears retro-reflective markers.
  - Accurately measure 3D positions of markers.





Current MoCap Technologies

- Optical mocap
  - Advantages

    -- measure 3D positions and orientations

    -- the most accurate capture method

    -- very high frame rate

    -- can capture very detailed motion (body, finger, facial deformation, etc.)
  - Disadvantages

    -- has occlusion problems

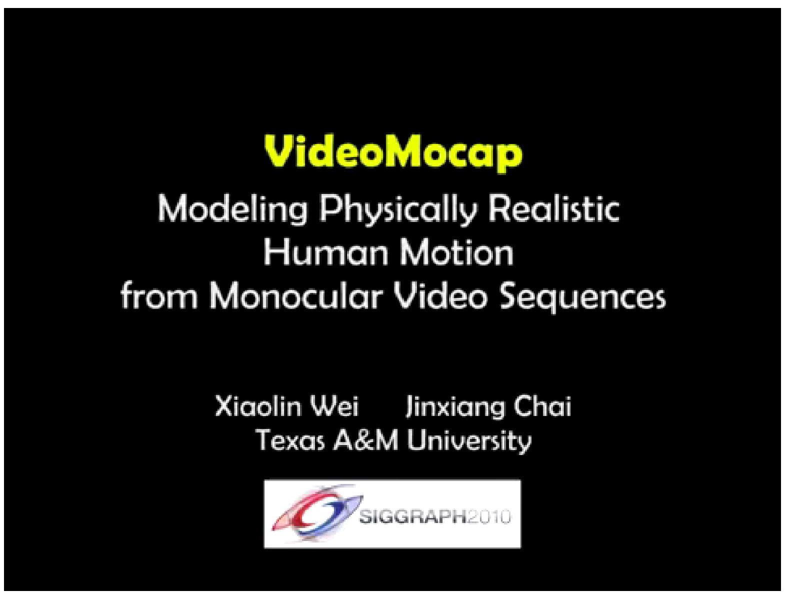
    -- hard to capture interactions among multiple actors

    -- expensive

Current MoCap Technologies

- Markerless mocap
  - Video-based mocap

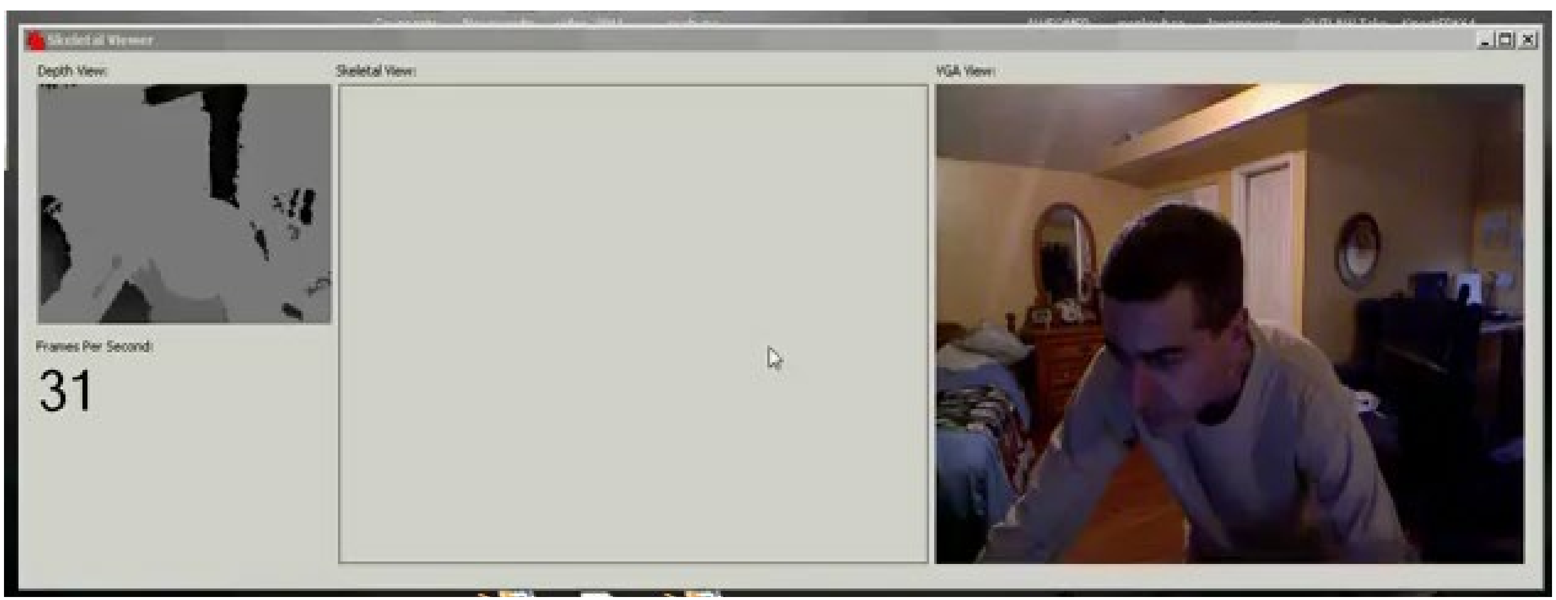
    -- Capture 3D performance from single-camera video streams



Current MoCap Technologies

- Markerless mocap
  - Depth sensor-based (e.g., Kinnect)

    -- Capture 3D performance from a single depth camera



Optical MoCap Pipeline

- Planning
  - Character/prop setup

    -- character skeleton topology (bones/joints number, DoFs for each bone)

    -- location and size of props

  - Marker setup

    -- the number of markers

    -- where to place markers

  - Character setup depends on the marker setup since bone rotations are determined from marker positions.

Optical MoCap Pipeline

- Calibration
  - Camera calibration

    -- determine the location and orientation of each camera

    -- determine camera parameters (e.g. focal length)

  - Subject calibration

    -- determine the skeleton size of actors/actresses (.asf file)

    -- relative marker positions in terms of bones

    -- determine the size and location of props

Optical MoCap Pipeline

- Processing markers
  - Each camera records capture session
  - Extraction: markers need to be identified in the image

    -- determine 2d position

    -- problem: occlusion, marker is not seen. Use more cameras
  - Markers need to be labeled

    -- which marker is which?

    -- problem: crossover, markers exchange labels. May require user intervention
  - Compute 3d position

    -- if a marker is seen by at least 2 cameras then its position in 3d space can be determined

Optical MoCap Pipeline

- Data processing