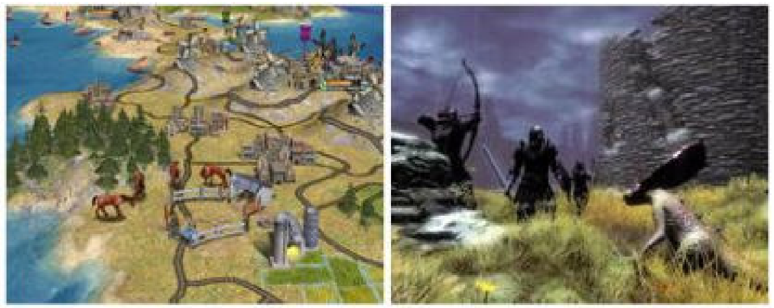
ENJMIN

ECOLE NATIONALE
DU JEU ET DES MEDIAS
INTERACTIFS NUMERIQUES

Gaming Technologies

Gamebryo Element™
3D GRAPHICS ENGINE
AND TOOLS



Alexandre Topol

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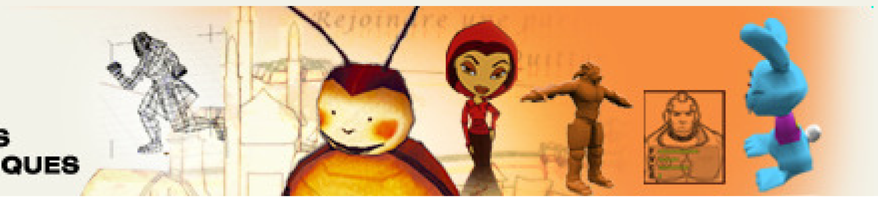
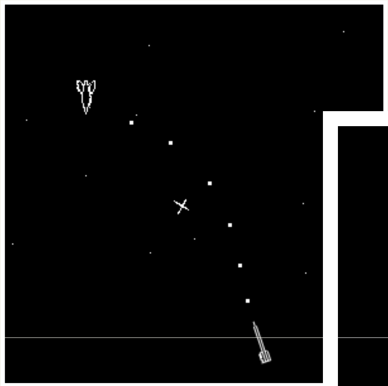
Qui suis-je ?

- Ingénieur (2000) et docteur (2002) en Informatique
- Ancien programmeur Ubisoft (en 1996)
- Enseignant au CNAM et à l'ENJMIN
  - Programmation 3D
  - Langages de shading
  - Physique
  - Animation
  - IHM
  - …
- Chercheur au laboratoire CEDRIC

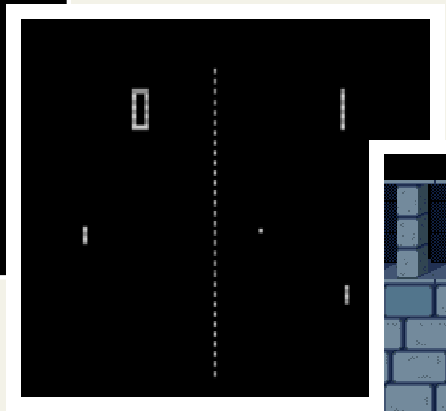
© Ubisoft – POD - 1997



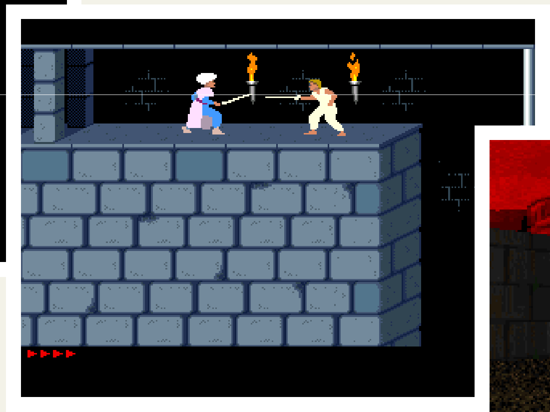
50 years of evolution ...



1961
Spacewar!
Steve Russel
(MIT)



1972
PONG
Nolan Bushnell
(Atari)



1989
Prince of Persia
Jordan Mechner
(Brøderbund)

1993
Doom
John Carmack
(Id Software)

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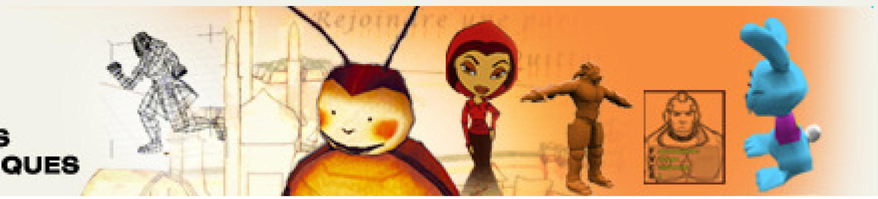
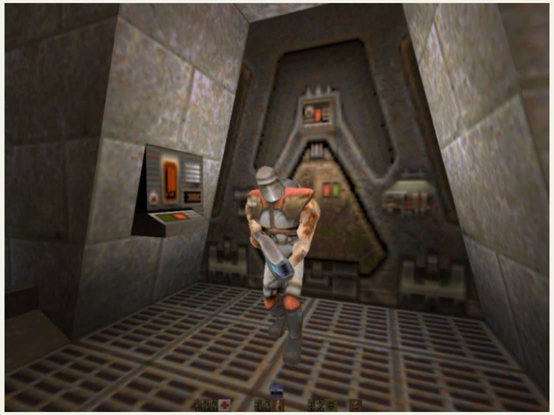


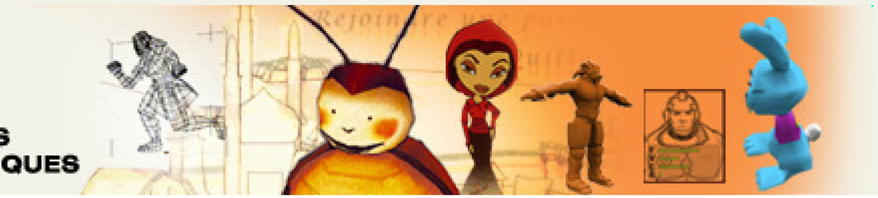
... of games ...



1997
Quake 2
Id Software
(Activision)

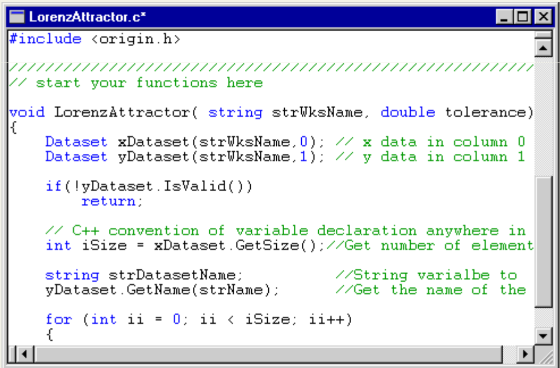
2004
Far Cry
Crytec
(UbiSoft)

2008
Assasin's Creed
(UbiSoft)

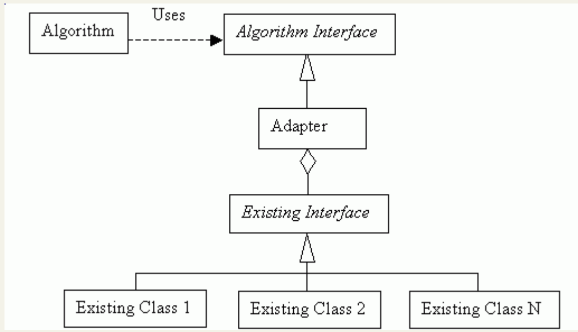


... and programming ...

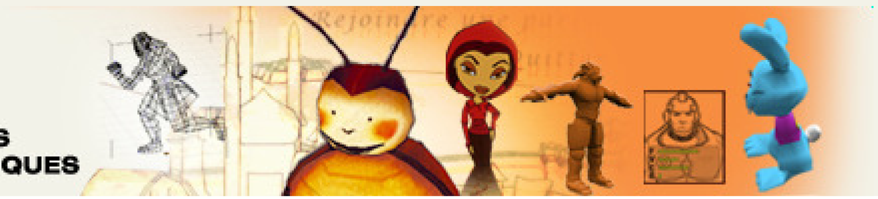
1960
BASIC



1972
C

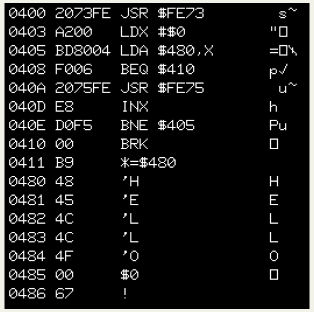


1983
C++

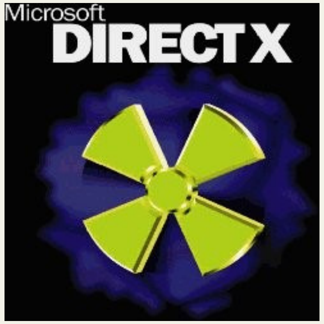


... methods

1993
Mods

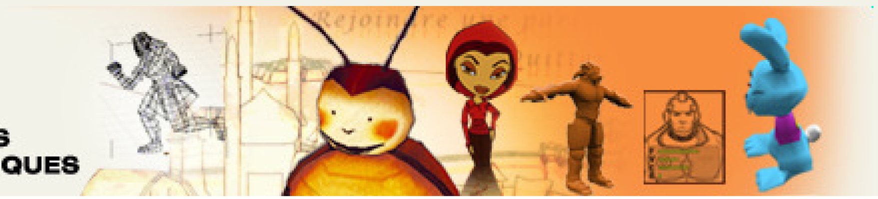


1995
3dfx ASM



1995
DirectX 1.0

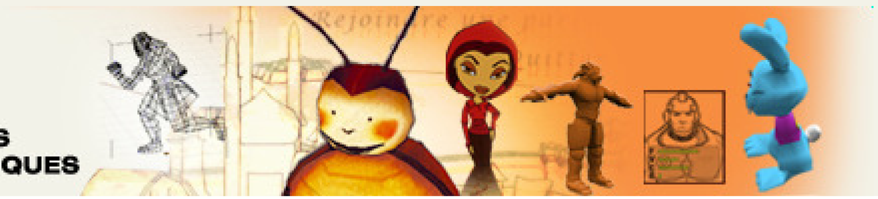
2002
Renderware



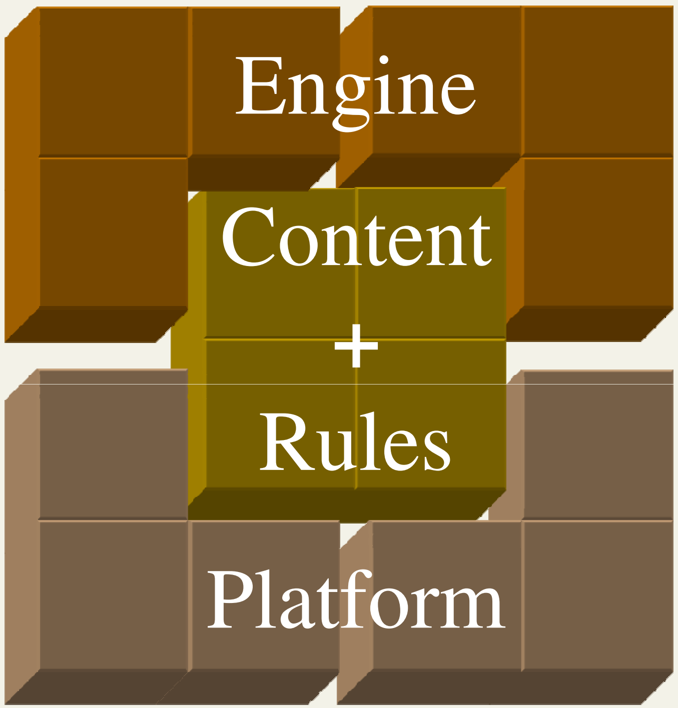
50 years of evolution

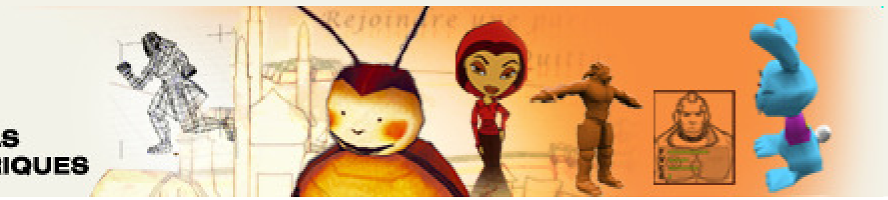
- Why these evolutions ?
  - For programming languages: need of more expressive power
  - For game programming methods : need of less development time
- How did we get there ?
  - To get closer to the heart of the game :

the gameplay

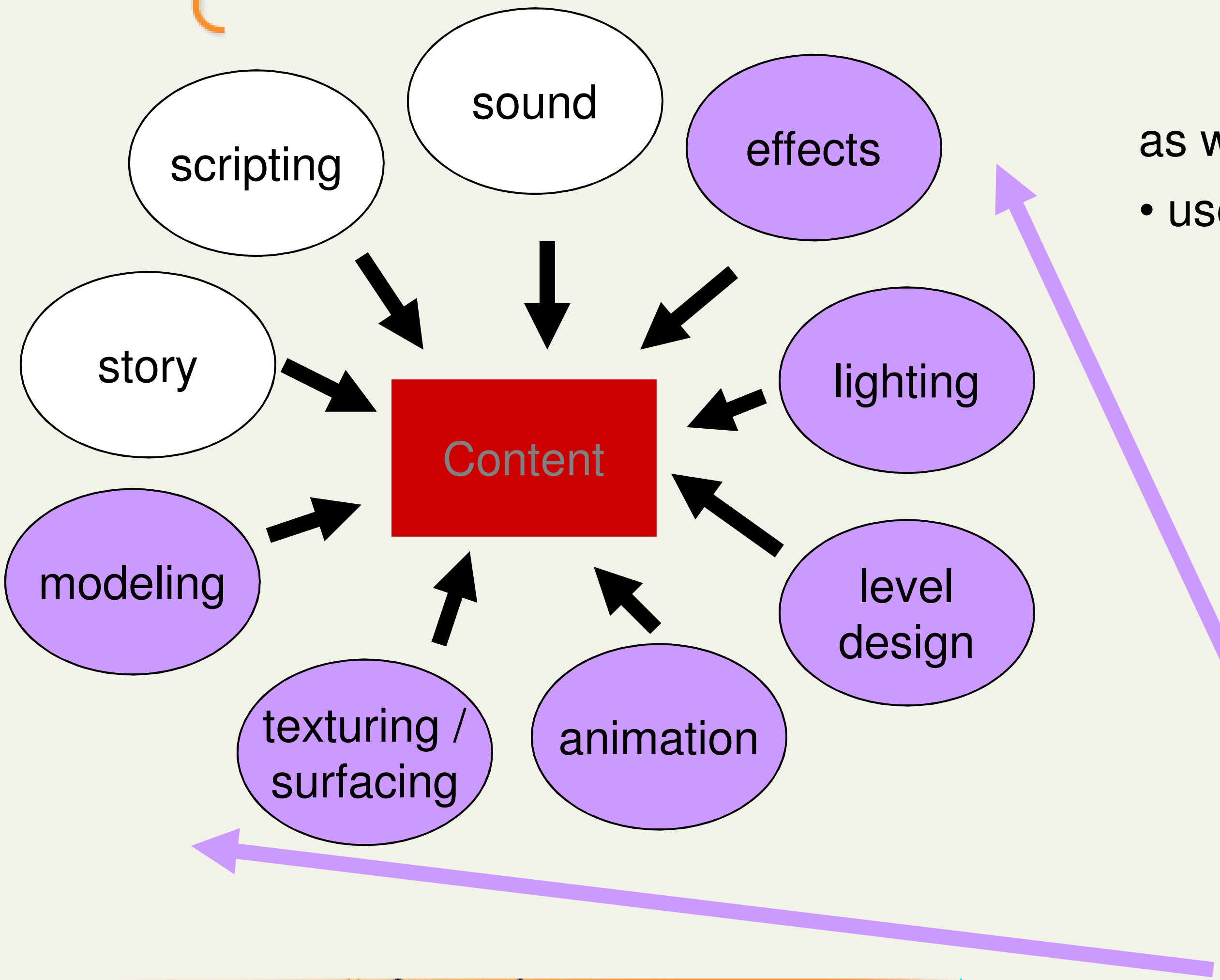


Game Components





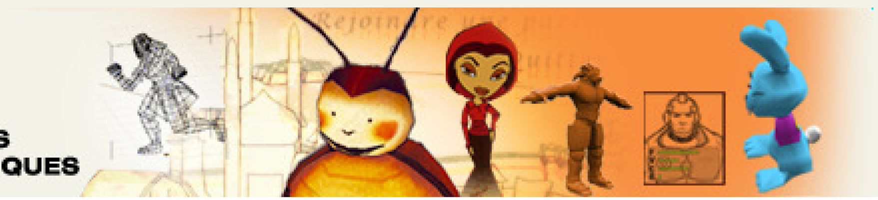
Content Components



as well as …

- user interface

visual technologies



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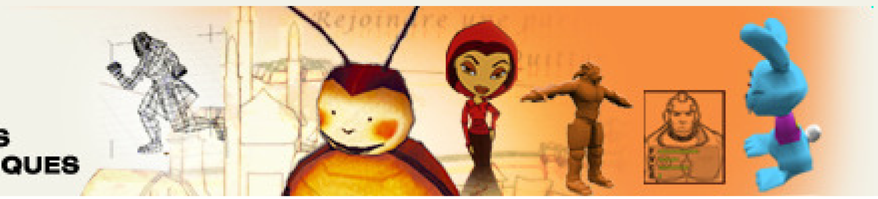
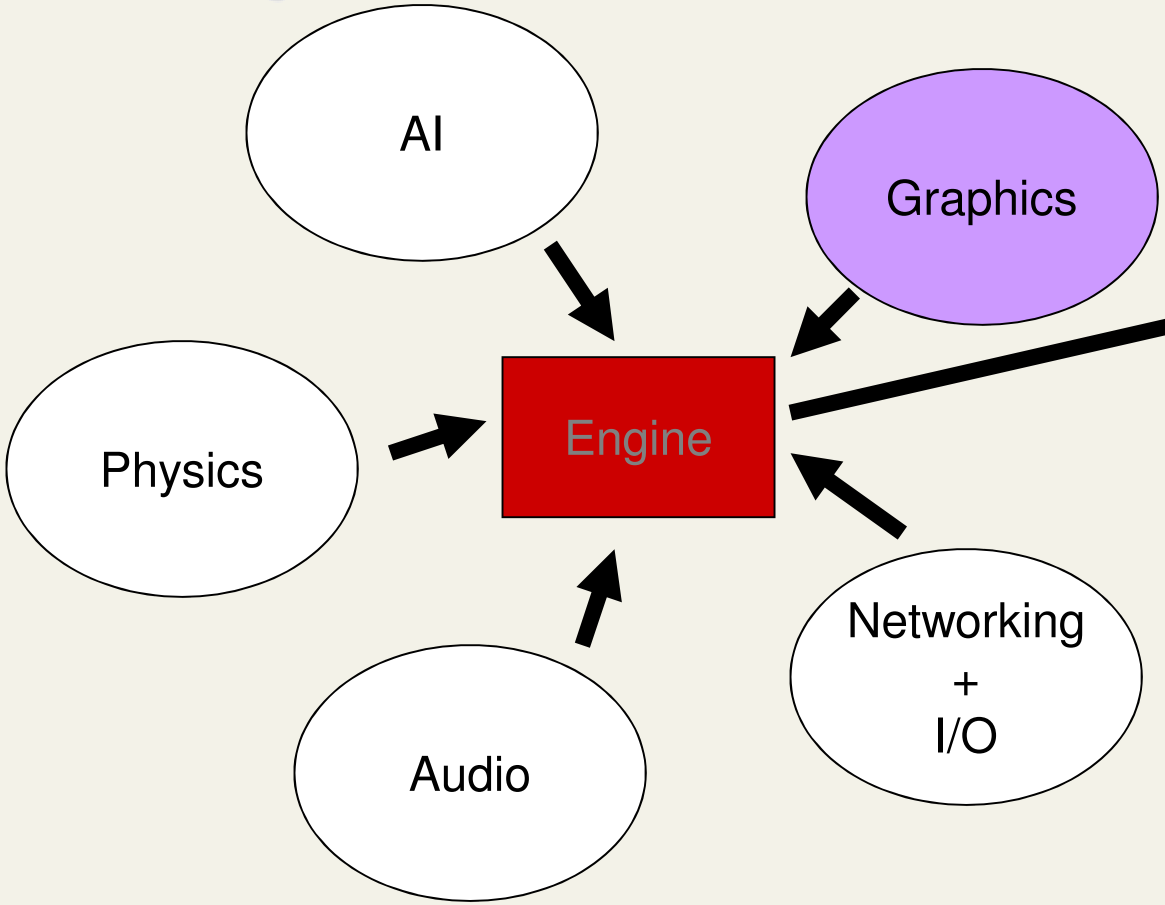
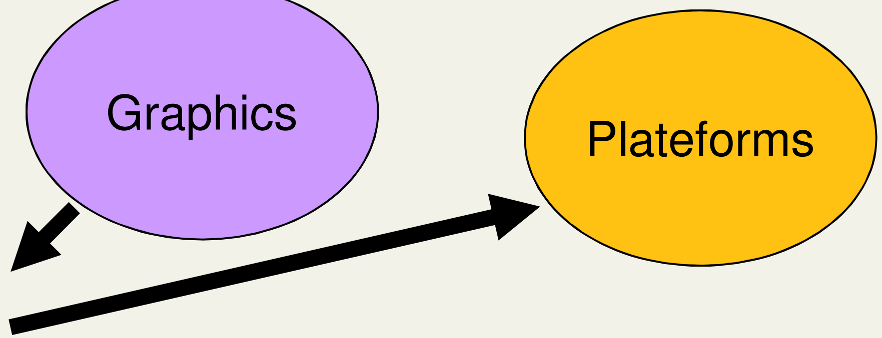
Content Creation

- Method driven for some
- Tool driven for others
- Combination of tools forms “Art Pipeline”
- Character Pipeline
  - 3D Model/Sculpting
  - Animation/Rigging
  - Skinning
  - Texturing
  - Lighting/Shading
- An artist often specializes on one part of pipeline
- Some tools in Game Engines (Emergent AnimationTool)



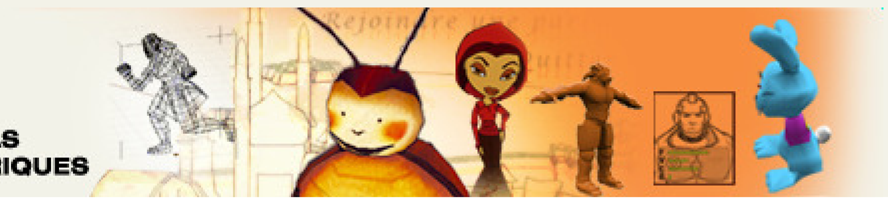
Game Engine Components



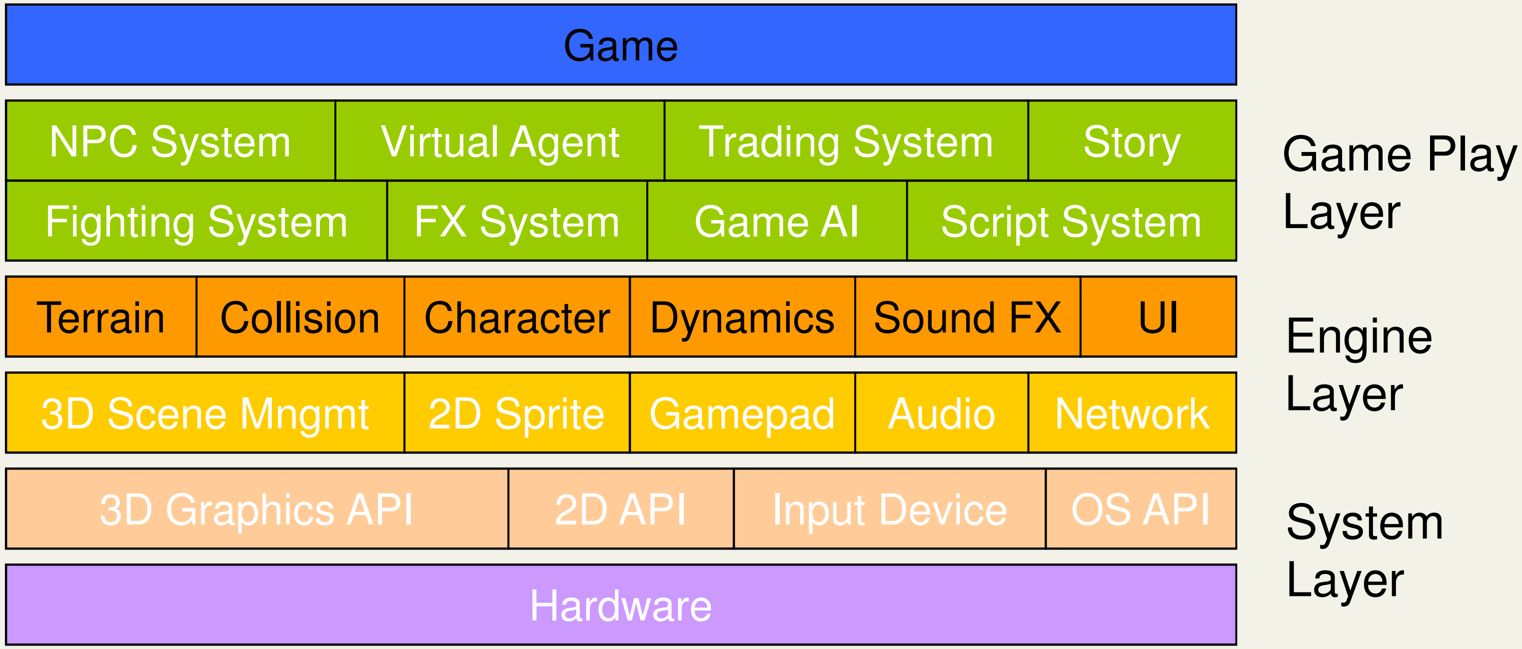


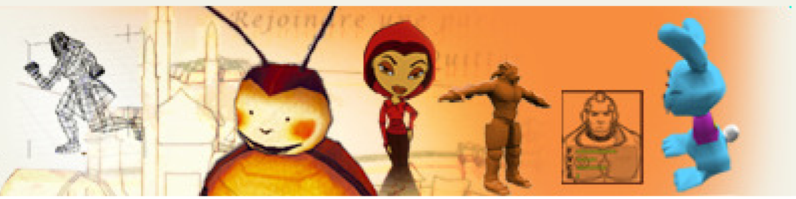
as well as …

- installation
- patching
- resource management
- multithreading
- disk i/o
- state save/restore



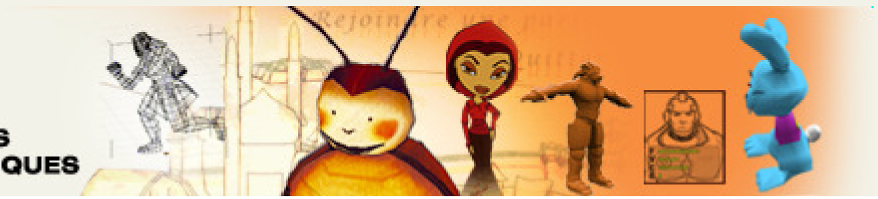
Game Engines





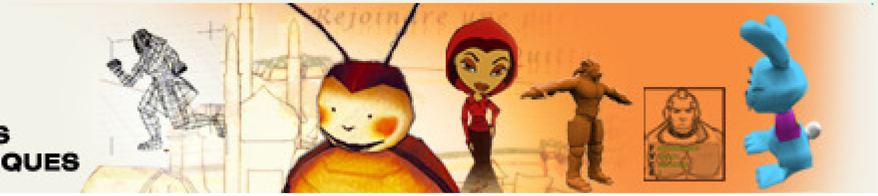
Games Engines Vs Σ(APIs)

- For instance : DirectX or { Ogre3D + OSG + Bullet + Wwise… }
- Each element is tightly embedded
- Same structures for different aspects
  - No need to dupicate objects
  - Same bounding boxes are used for both collision detection and object culling
- Most important: higher levels are gameplay oriented
- High level tools to design levels
  - Graphical & audio aspects
  - Triggers for audio or AI script
  - Physics parameters
  - …



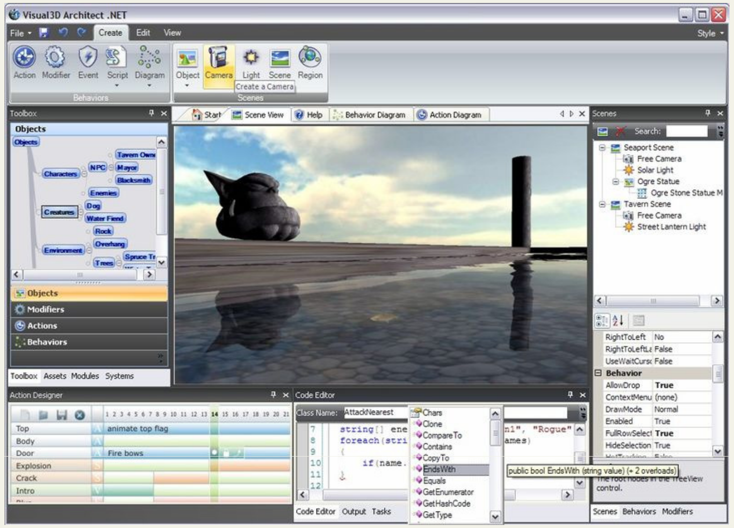
Game Engines

- Studio chooses to build or buy
  - Quake Source, Unreal engines
  - Renderware, Gamebryo middlewares
  - Often come with great authoring tools (level editors, etc.)
- Componentized software
- May buy specialized components
  - How many people can write a physics engine?
  - And how many studios can afford writing one ?
  - Video codecs, etc
- Engine may be optimized for game genre/style
  - Includes special features to answer special needs
  - Terrain vs indoor scenes, camera management, …



Game Engines

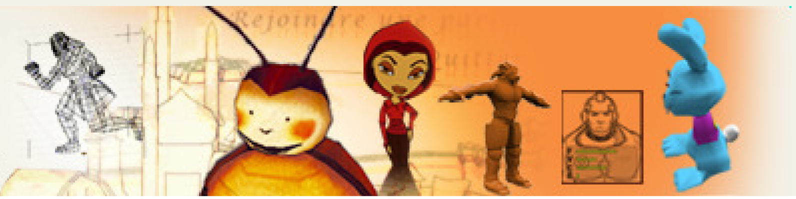
- 3D graphics tools
- Physics engine
- Audio
- Animation
- Character “AI”



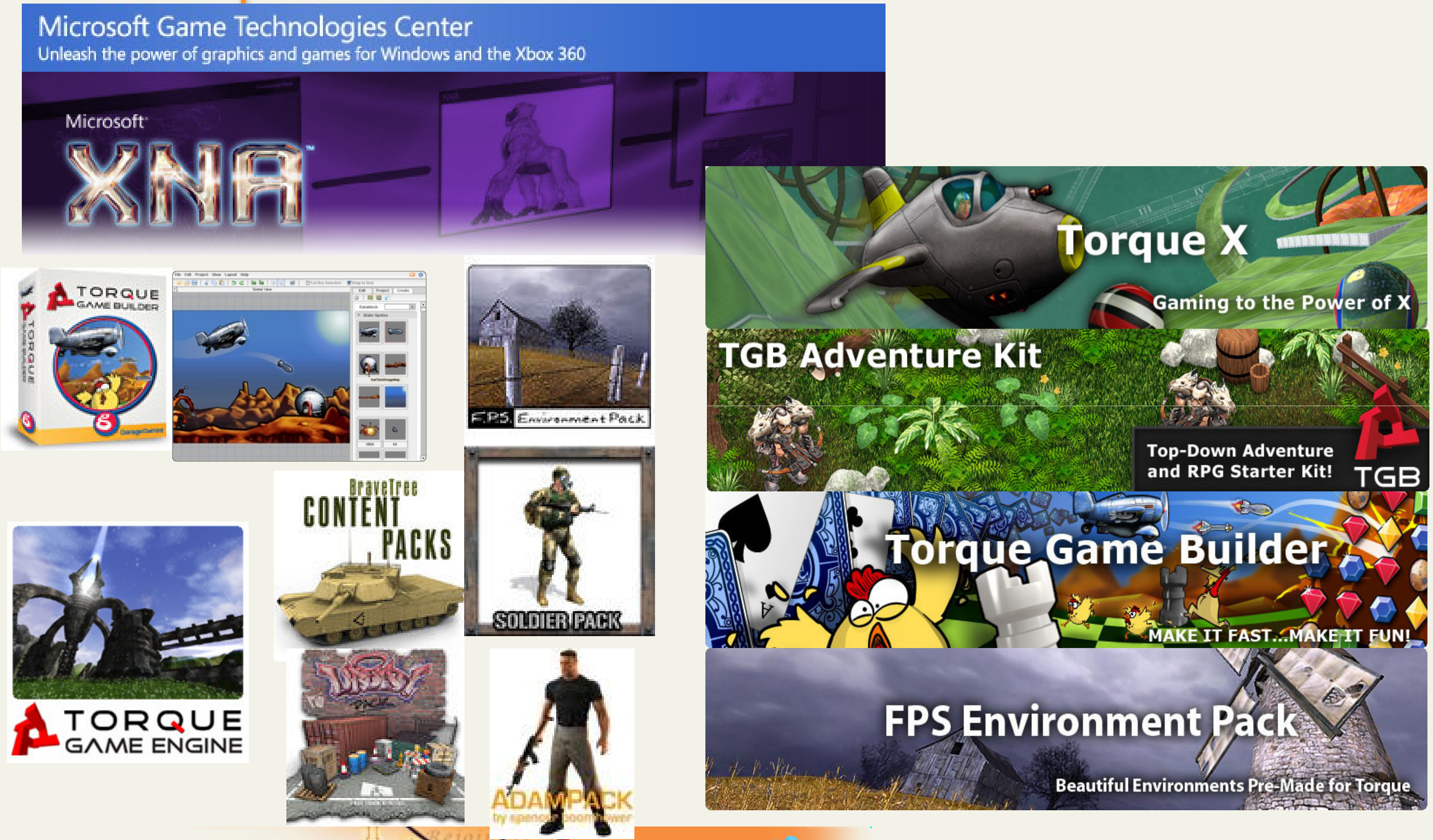
Visual3D Architect .NET Screenshot RealmWare Corporation

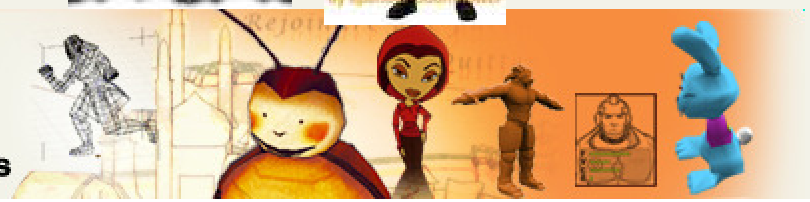
Cost: ranges from open source (CrystalSpace) to $100K+ (Unreal Engine)

- Typically tailored to a particular kind of game
  - First person shooter (FPS)
  - Real time strategy (RTS)
  - massively multiplayer online role-playing game (MMORPG)



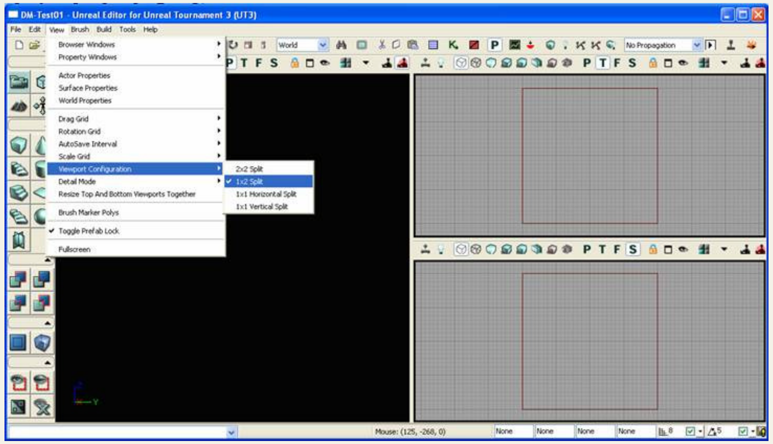
Game Engines

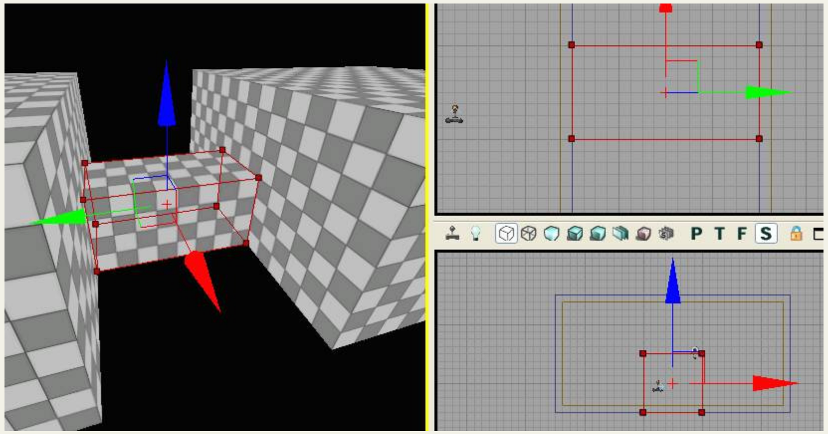


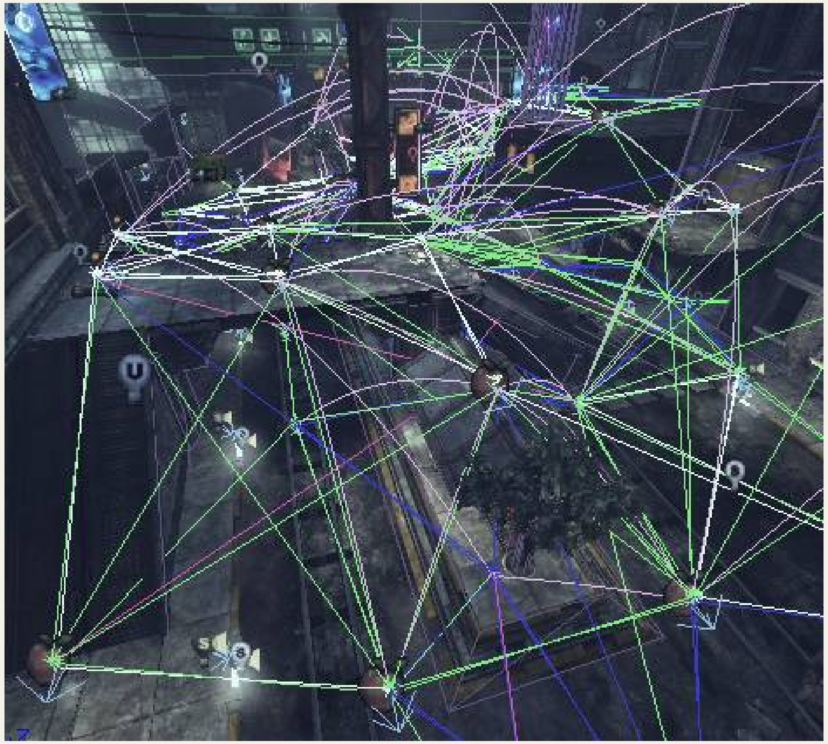


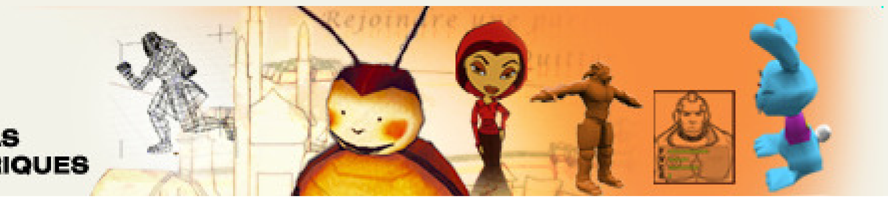
Game Engines

Unreal Engine 3







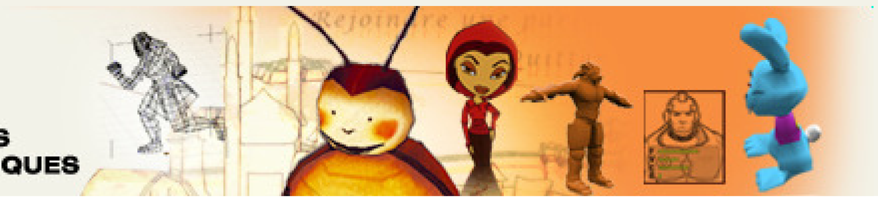


Game Engines

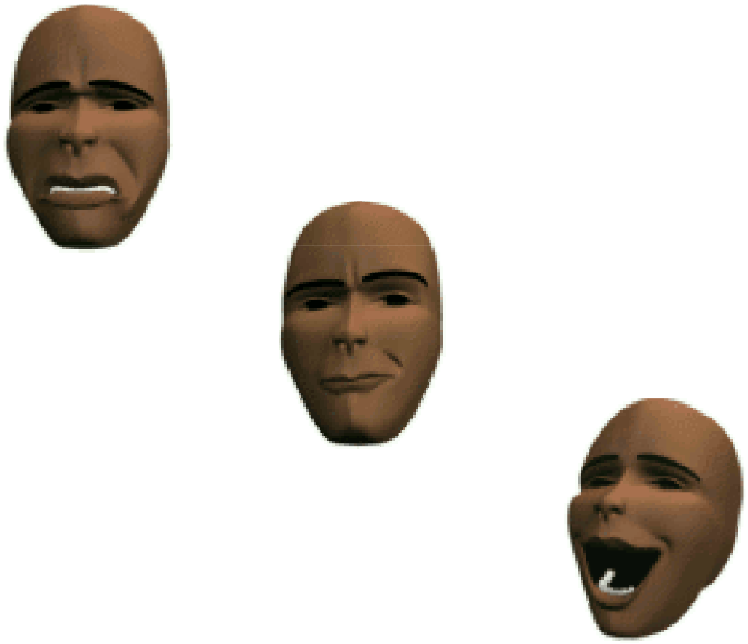
- *Engines:*
  - *Unity3D*
  - *UDK (vs Unreal Engine)*
  - *Cry Engine*
  - *Torque* ***– Low cost set of engines (2D, 3D, 3D+Shaders), large dev community***
  - *3D Game Studio* ***– Hundreds of games, C-script, many libraries of pre-made games***
  - *OGRE* ***– Scene-oriented, 3D engine, open source, Basic Physics***
  - *Crystal Space* ***– Used for Modeling and Simulation, Physics engine, True 6DOF***
  - ***Many others at http://www.devmaster.net/engines/***

- *Terrain Tools:*
  - *L3DT –* ***"Plugable" Terrain Generation engine, low cost, importing into Torque***
  - *Terragen 2 –* ***Amazing photorealistic terrains and terrain imagery – More real than real***

- *"Mod" tools:*
  - *Return to Castle Wofenstein / Enemy Territory -* **Based upon an older version of the Quake engine.**
  - *Quake III -* **One of the most heavily modified game ever. id has announced they will make the game code open source.**
  - *Counter Strike -* **A great starting point for tactical & law enforcement sims and FPS**
  - *Counter Strike: Source -* **A rebuild of the original but to use the Source engine.**



Game Engines Features (Rendering)



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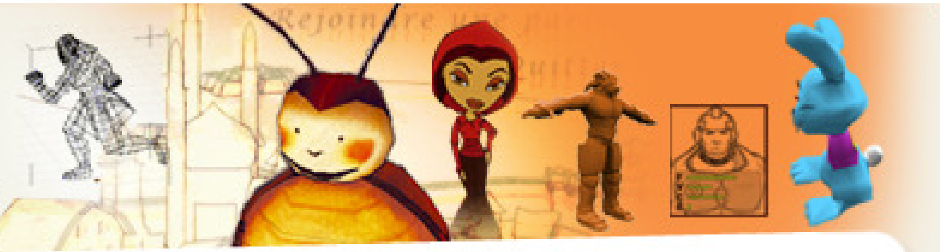
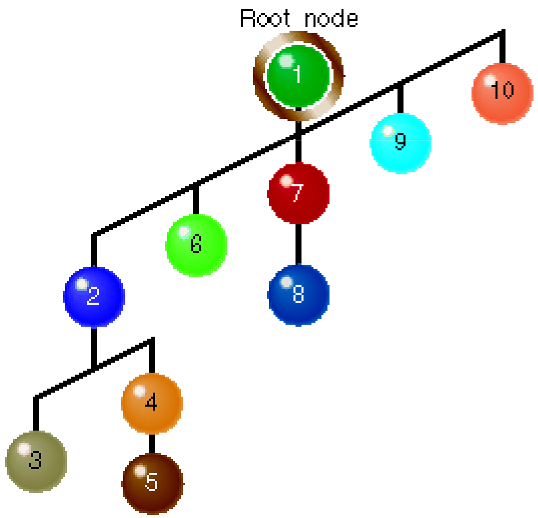
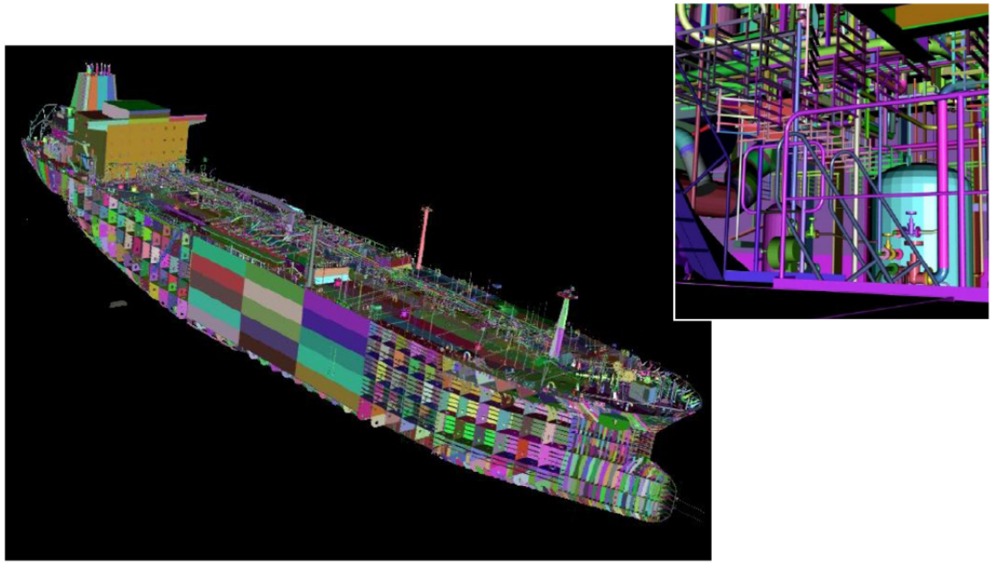


Game Engines Features (almost Rendering)





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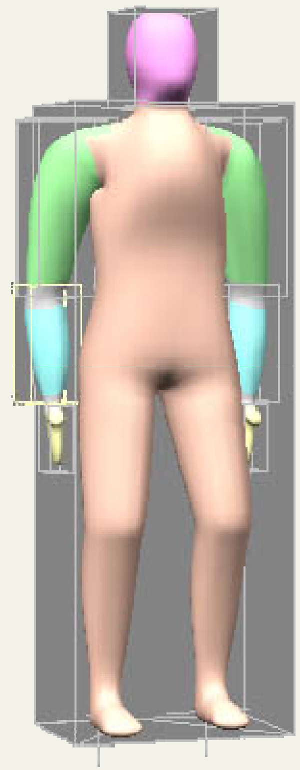
Visibility Management

- Render cost should be proportional to what is seen !
- And not proportionnal to the complexity of the scene

- Don't render objects that won't be seen:
  - Object outside viewing frustrum (➔ is clipping good ?)
  - Objects behind others (➔ is ZBuffer good ?)
- Don't render unnecessary details:
  - Details too small to be performed
  - ➔ LOD
  - ➔ Pixel culling

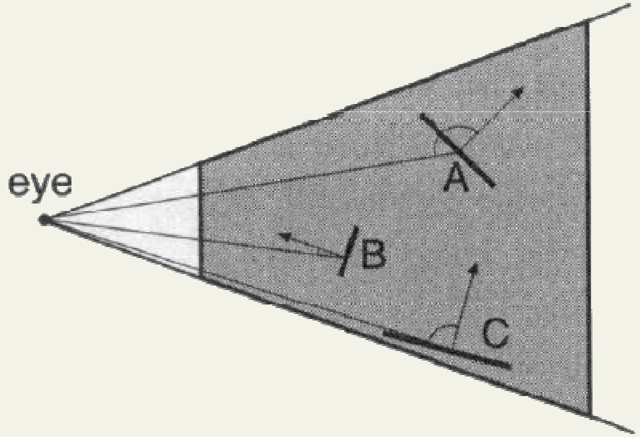
Culling

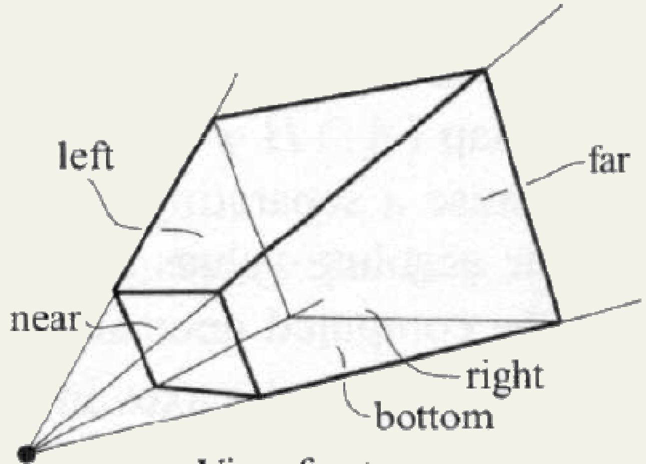
- Culling = throw away non-visible things
- General strategies:
  - Multi phase testing
  - First cheap and coarse
  - Then gradually increase cost/precision
  - Based on hierarchical bounding volumes



Basic culling

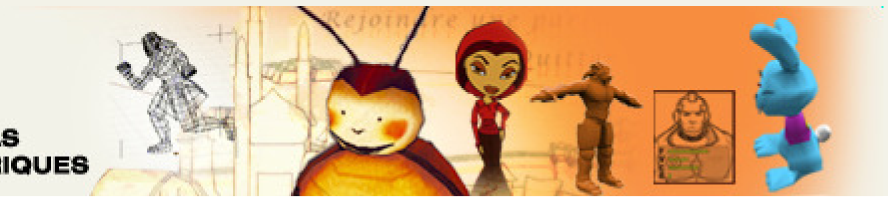
- Backface culling
- Polygon culling (clipping)





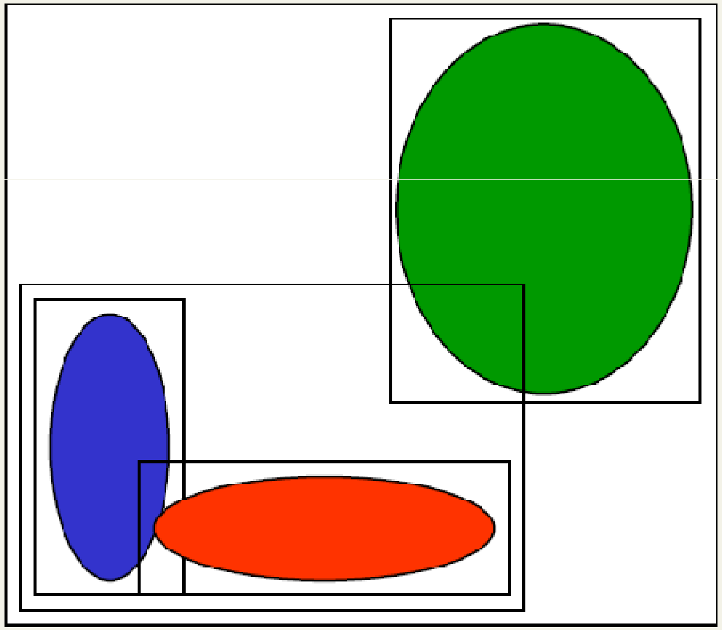
Scene graph

- Cascading transformations and behaviors
- Basic algorithm
  - From top node
  - Render all children
- With visibility management on:
  - Start from root node
  - For each node
    - Get bounding box
    - if visible:
      - Go down hierarchy
    - esle:
      - Cull



Bounding Volume Hierarchies

- BVHs

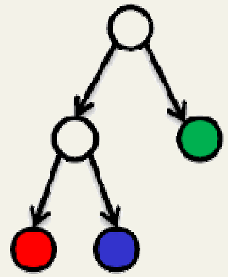


if bv cullable

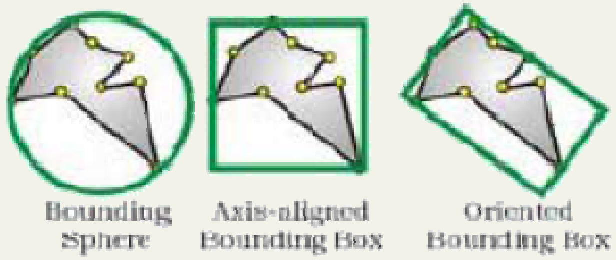
  cull all content

else for each child

  recurse

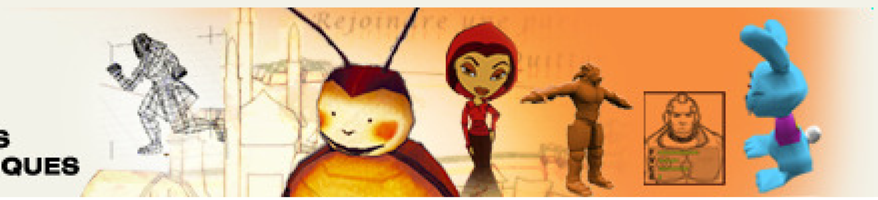


Bounding volumes



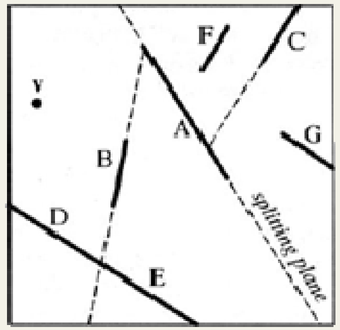
- BS – bounding sphere
  - BS vs BS is the easiest way to compute intersections
- AABB – Axis Aligned Bounding box
  - Boxes given a in the same global coordinate system
- OABB – Object Aligned Bounding Box
  - Boxes given in a local coordinate system

	Test	**Create**	**Update**	**Fit**
Sphere	Very cheap	Cheap	Free	Poor
AABB	Cheap	Very cheap	Medium	Medium
OBB	Medium	Expensive	Free	Very good

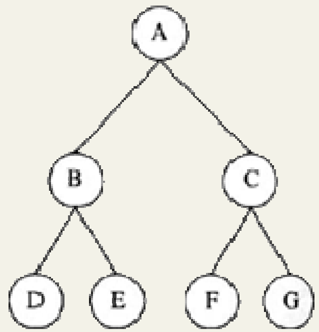


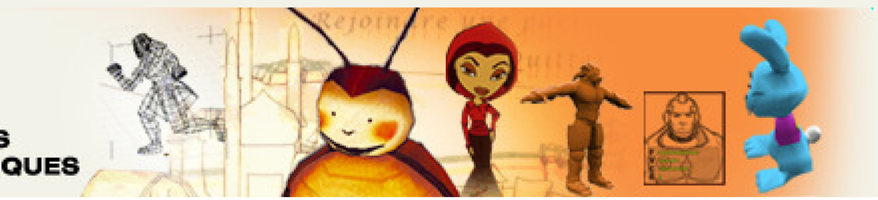
BSP Trees

- Binary Space Partitioning Trees
- A 3D "binary search tree"
- Good for terrains



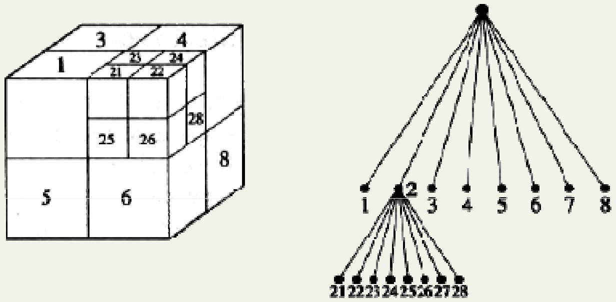
- BSP construction
  - Choose a plane defined by a random polygon
  - Classify all polygons as in, behind or in front
  - Split polygons if necessary
  - Recurse

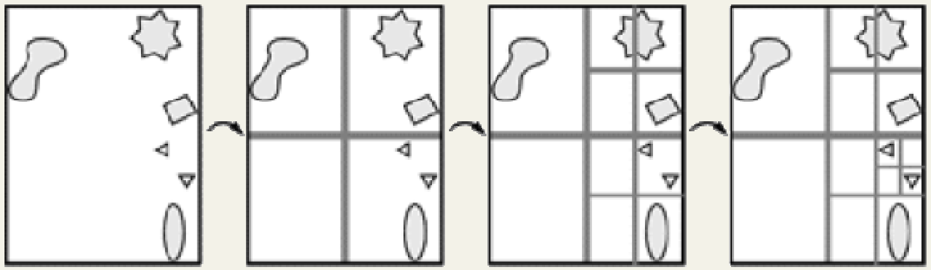




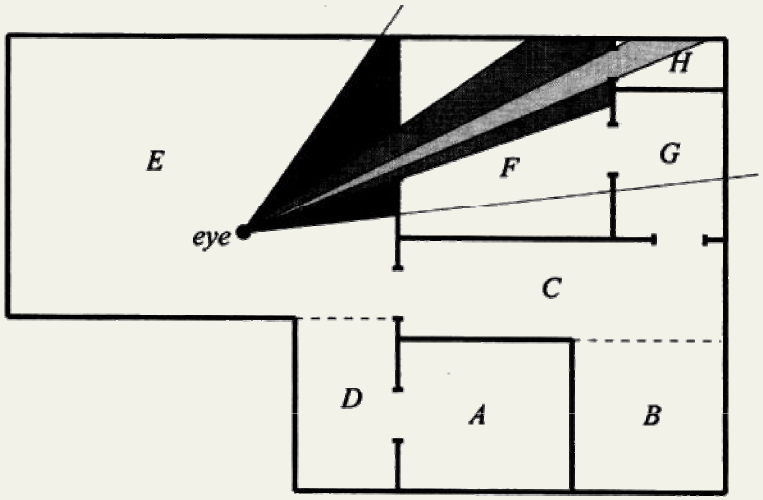
Octrees

- 3D "cube trees"
- Special case of BSP

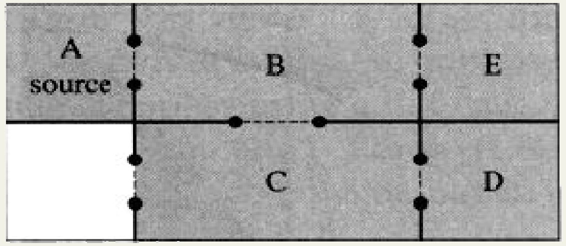




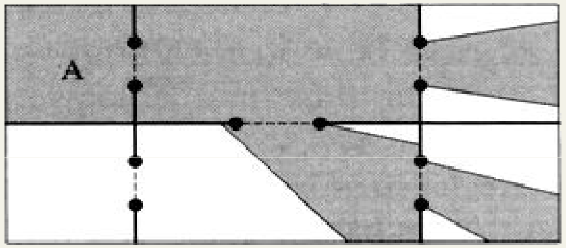
Portals & PVS



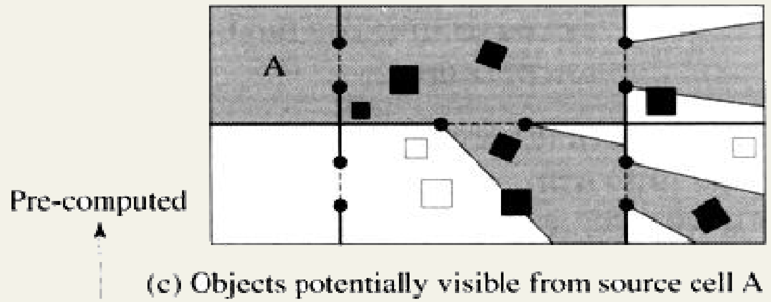

```
render( currentRoom, viewPort )

render( room, clipArea ):
  for all polygons
    if not portal
      render
    else
      render( portal.nextRoom,
              clipArea ∩ portal.silhouette )
```



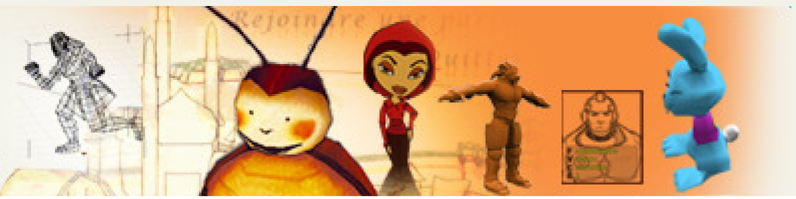
(a) Cells visible from source cell A – cell to cell visibility



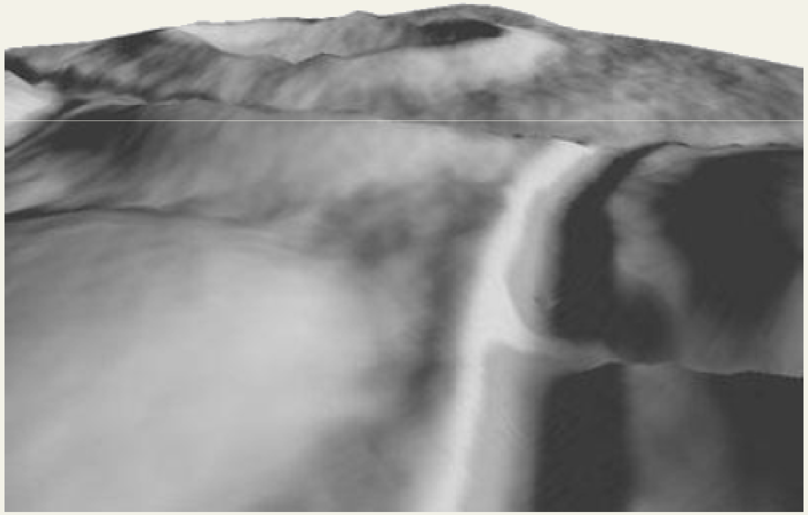
(b) The region potentially visible to a viewer positioned in A – cell region visibility

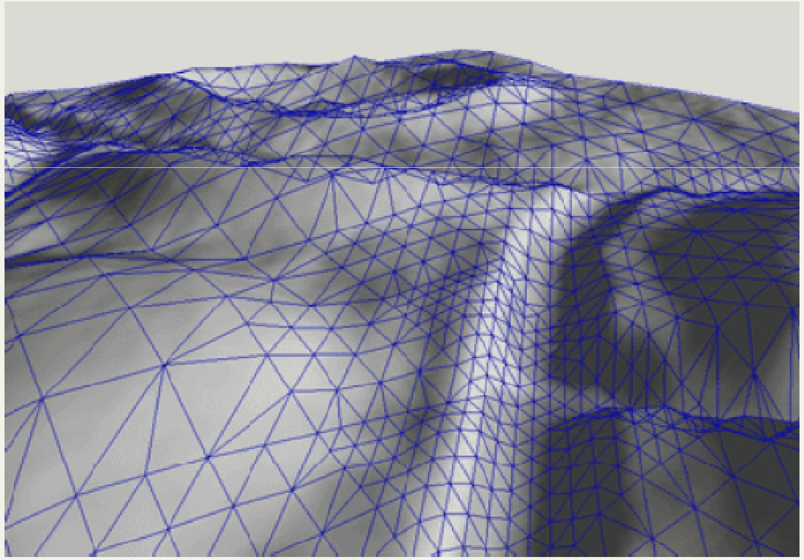


(c) Objects potentially visible from source cell A – the PVS



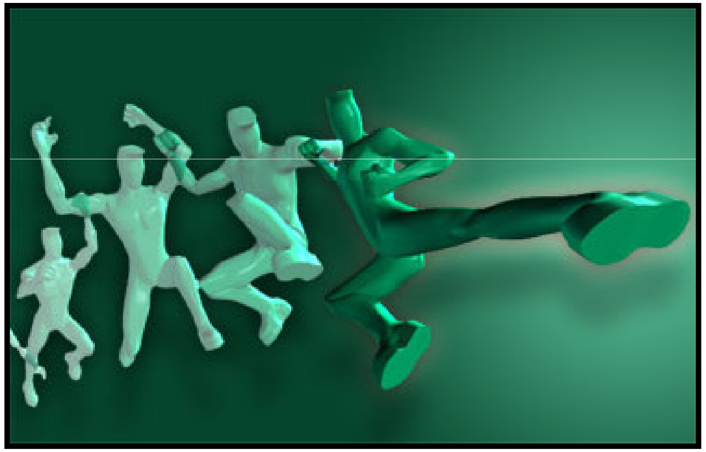
LOD





ECOLE NATIONALE
DU JEU ET DES MEDIAS
INTERACTIFS NUMERIQUES

Game Engines Features (besides Rendering)



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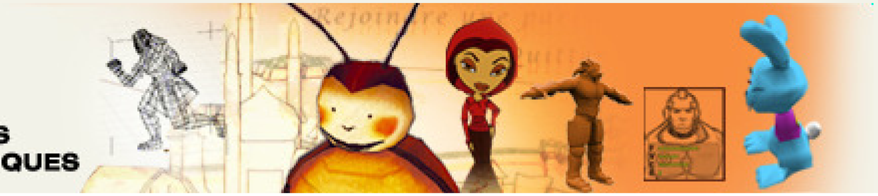
Interactive Programs

Battlefield 2

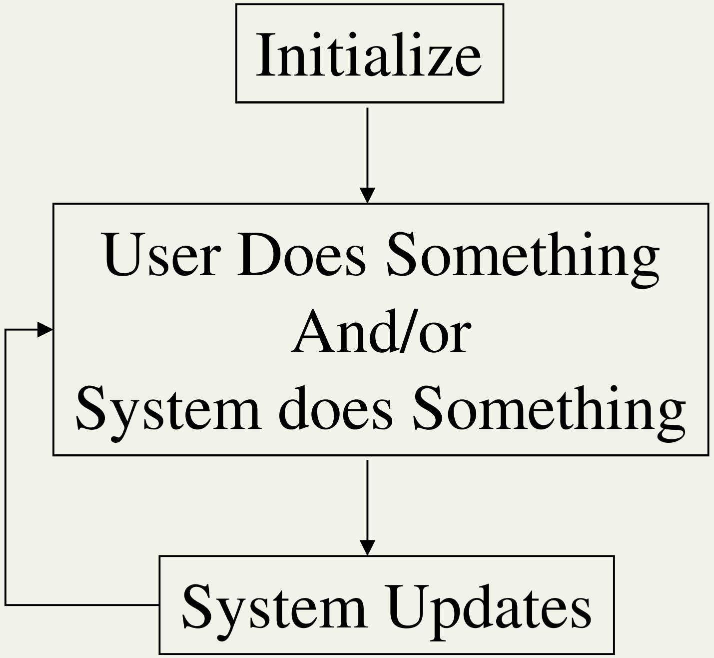
- Games are interactive programs
- Moreover, they are typically immersive in some way
- What are the important features of an interactive program?
- Which features are particularly important for immersive software like games?

Important Features

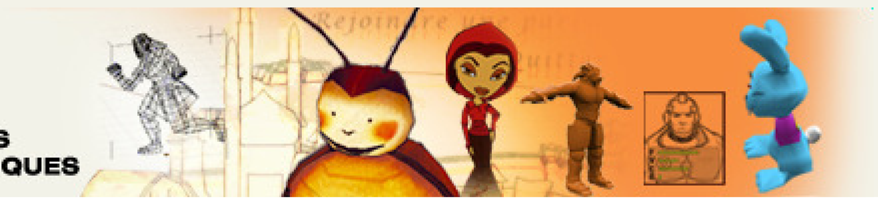
- User controls the action
  - Control is “direct” and “immediate”
- Program provides constant feedback about its state
  - The user must know and understand what is happening
  - The user must receive acknowledgment that their input was received



Interactive Program Structure



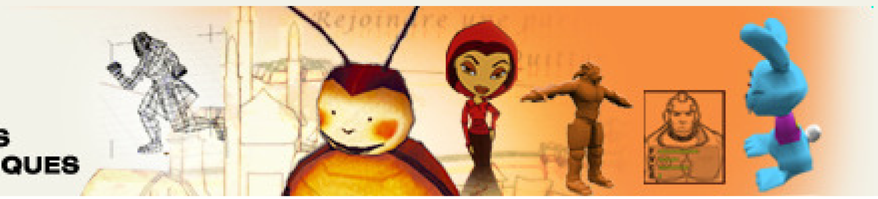
- Event driven programming
  - Everything happens in response to an event
- Events come from two sources:
  - The user
  - The system
- Events are also called *messages*
  - An event causes a message to be sent…



ECOLE NATIONALE
DU JEU ET DES MEDIAS
INTERACTIFS NUMERIQUES

User Events

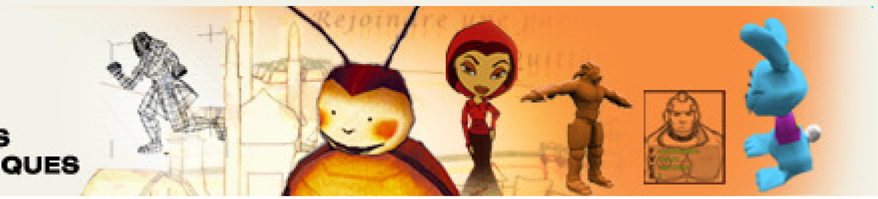
- Usually the OS manages user input
  - Interrupts at the hardware level …
  - Get converted into events in queues at the windowing level …
- It is generally up to the application to make use of the event stream
- User interface toolkits have a variety of methods for managing events
- The game engine gives easier manners to deal with user inputs
- There are two ways to get events: You can ask, or you can be told



Polling for Events

```
while ( not done )
        if ( e = checkEvent() )
                process event
        …
        draw frame
```

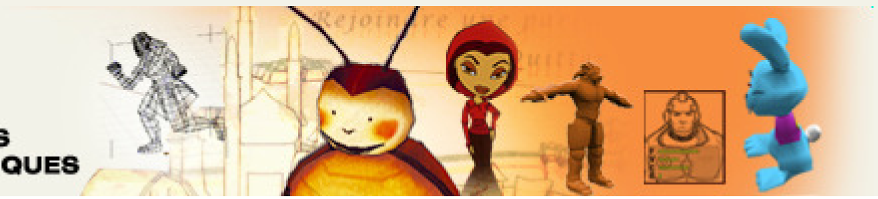
- Most game engines provide a *non-blocking* event query
  - Does not wait for an event, returns immediately if no events are ready
- What type of games might use this structure?
- Why wouldn't you always use it?



Waiting for Events

```
while ( not done )
        e = nextEvent();
        process event
        …
        draw frame
```

- Most game engines provide a blocking event function
  - Waits (blocks) until an event is available
- On what systems is this better than the previous method?
- What types of games is it most useful for?

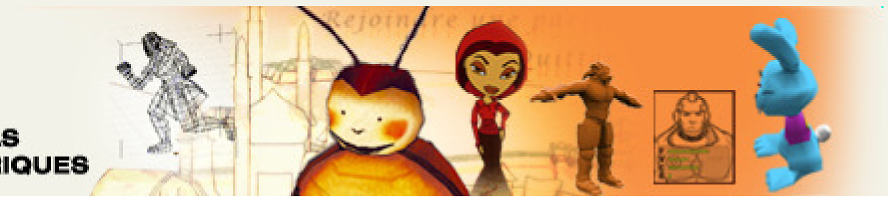


Real-Time Loop

- At the core of games with animation is a real-time loop:

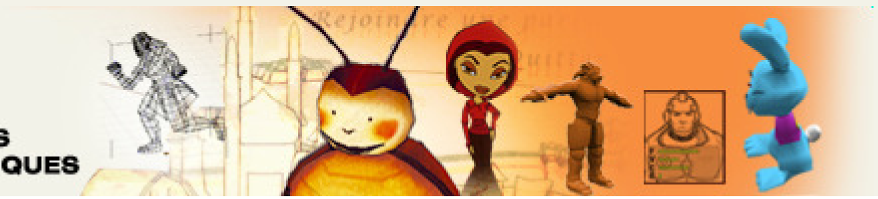
```
while ( true )
        process events
        update animation
        render
```

- What else might you need to do?
- The number of times this loop executes per second is the frame rate
  - # frames per second (fps)

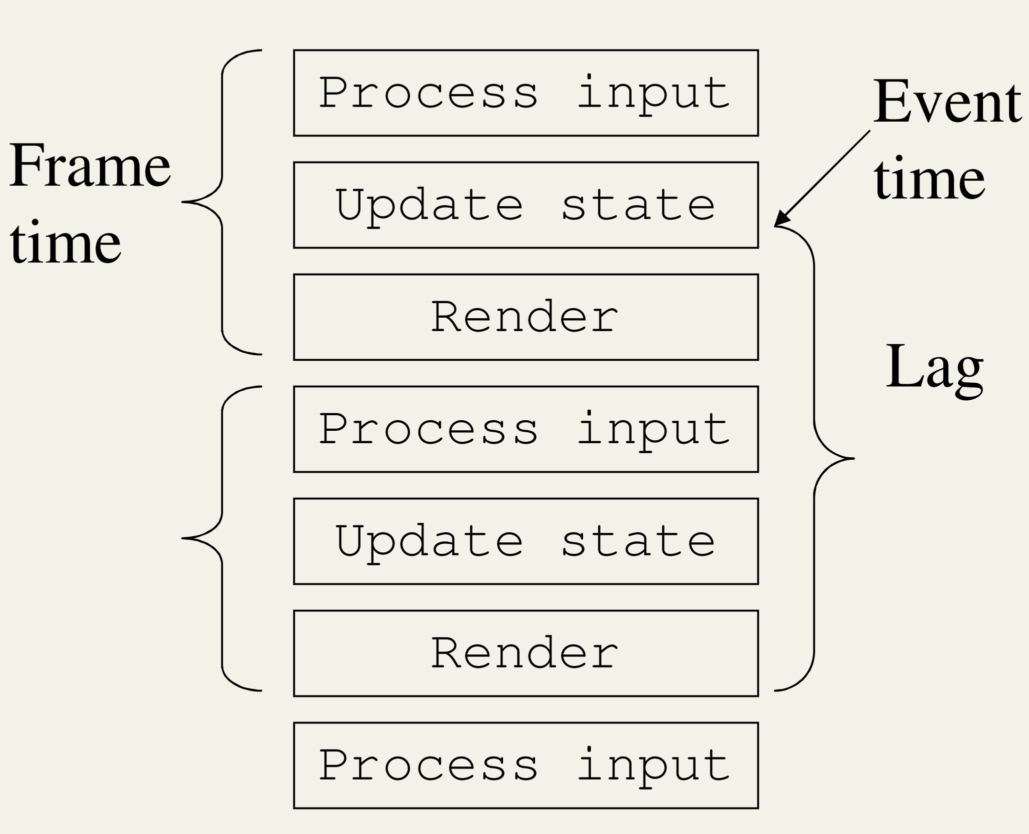


Lag

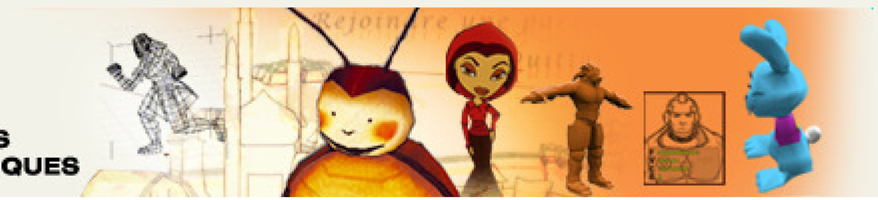
- *Lag* is the time between when a user does something and when they see the result - also called *latency*
  - Too much lag and causality is distorted
  - With tight visual/motion coupling, too much lag makes people motion sick
  - Too much lag makes it hard to target objects (and track them, and do all sorts of other perceptual tasks)
- High variance in lag also makes interaction difficult
  - Users can adjust to constant lag, but not variable lag
- From a psychological perspective, lag is the important variable



Computing Lag

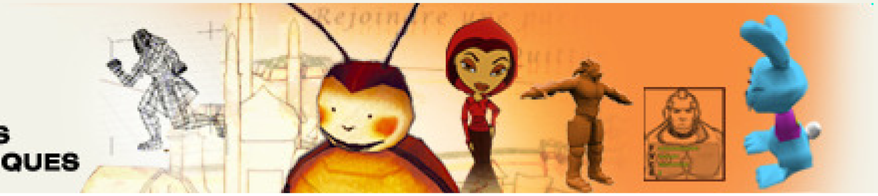


- Lag is NOT the time it takes to compute 1 frame!



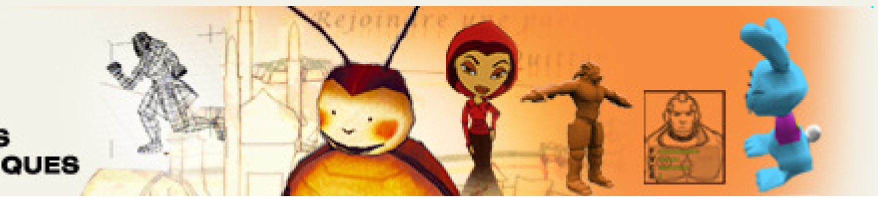
Reducing Lag

- Faster algorithms and hardware is the obvious answer
- Designers choose a frame rate and put as much into the game as they can without going below the threshold
  - Part of design documents presented to the publisher
  - Threshold assumes fastest hardware and all game features turned on
  - Options given to players to reduce game features and improve their frame rate
- There's a resource budget: How much time is dedicated to each aspect of the game (graphics, AI, sound, …)



Decoupling Computation

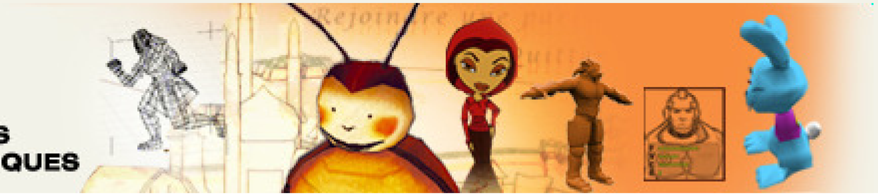
- It is most important to minimize lag between the user actions and their direct consequences
  - So the input/rendering loop must have low latency
- Lag between actions and other consequences may be less severe
  - Time between input and the reaction of enemy can be greater
  - Time to switch animations can be greater
- Technique: Update different parts of the game at different rates, which requires decoupling them
  - For example, run graphics at 60fps, AI at 10fps
  - Very common in real games



Animation

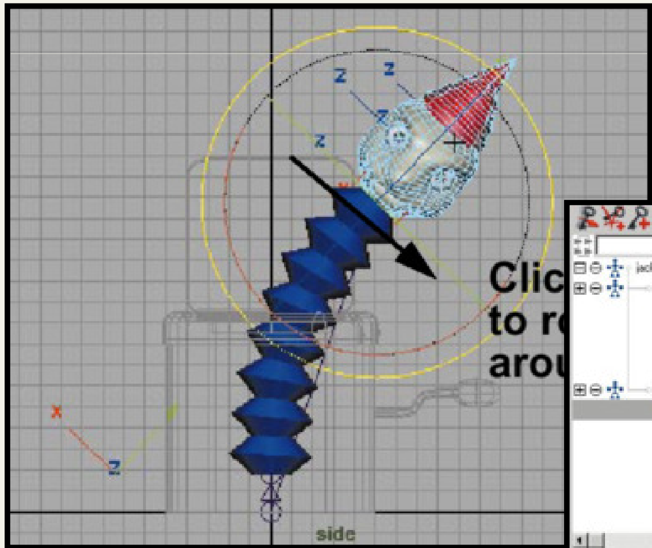
- Key-frame animation
  - Specification by hand
- Motion capture
  - Recording motion
- Procedural / simulation
  - Automatically generated
- Combinations
  - *e.g.* mocap + simulation

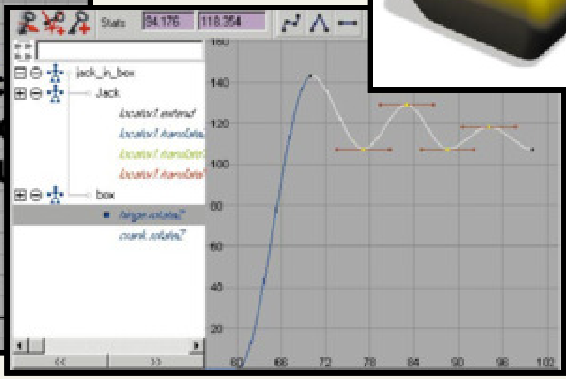
Jeff Lew

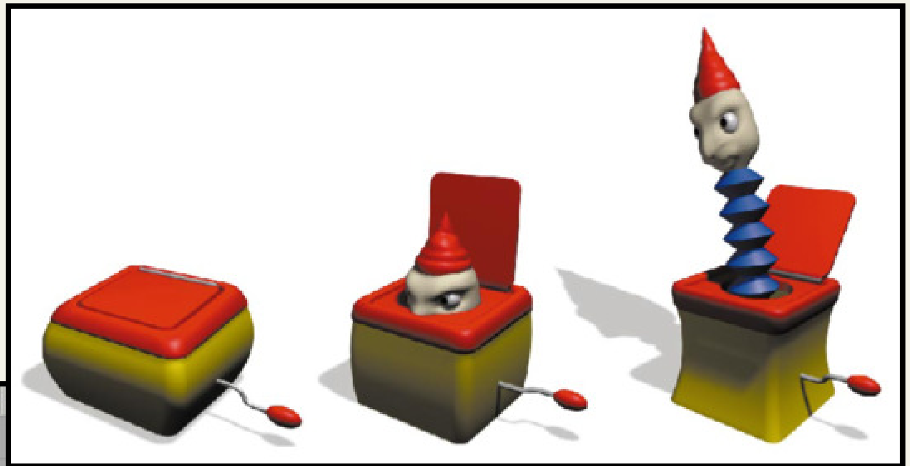


Key-framing (manual)

- Requires a highly skilled user
- Poorly suited for interactive applications
- High quality / high expense
- Limited applicability



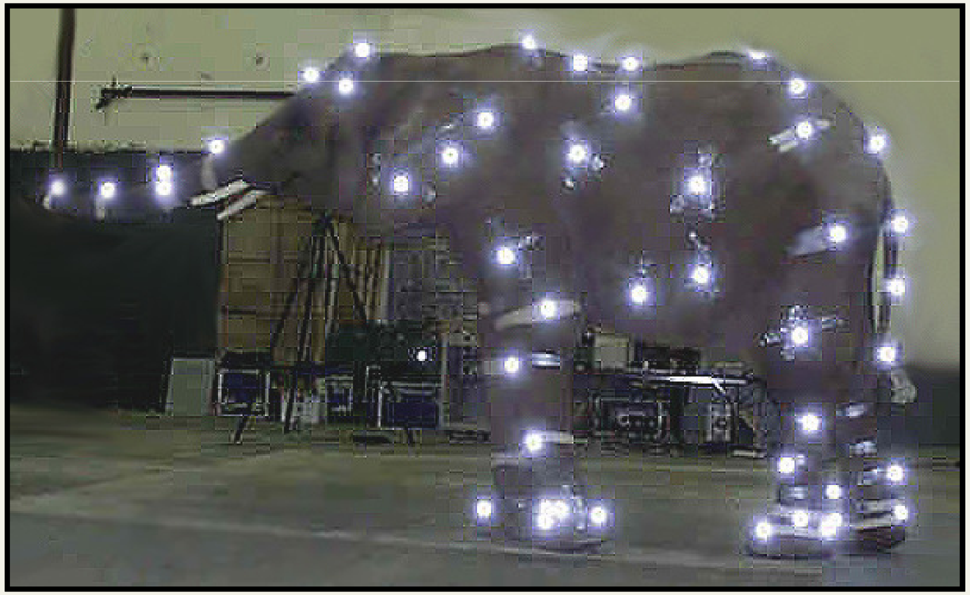


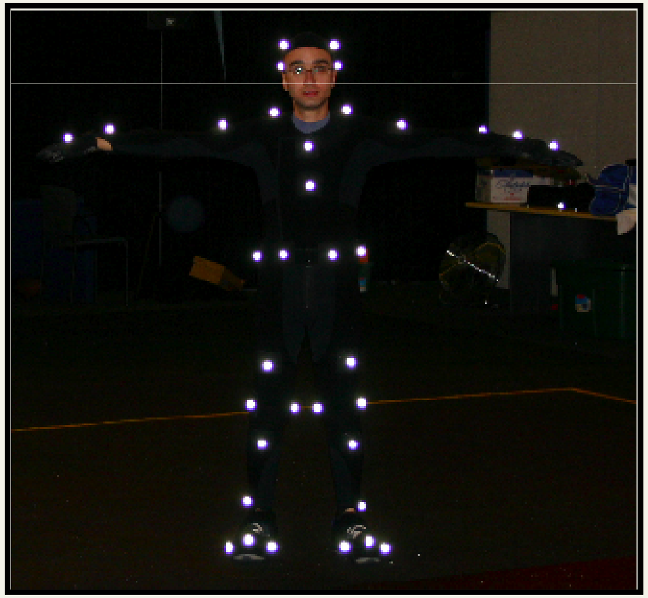


From *Learning Maya 2.0*

Motion Capture (recorded)

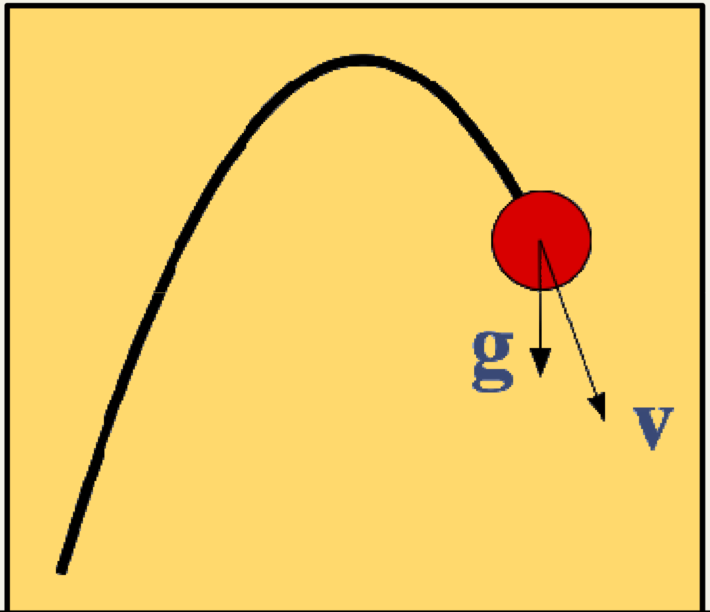
- Markers/sensors placed on subject
- Time-consuming clean-up
- Reasonable quality / reasonable price
- Manipulation algorithms an active research area



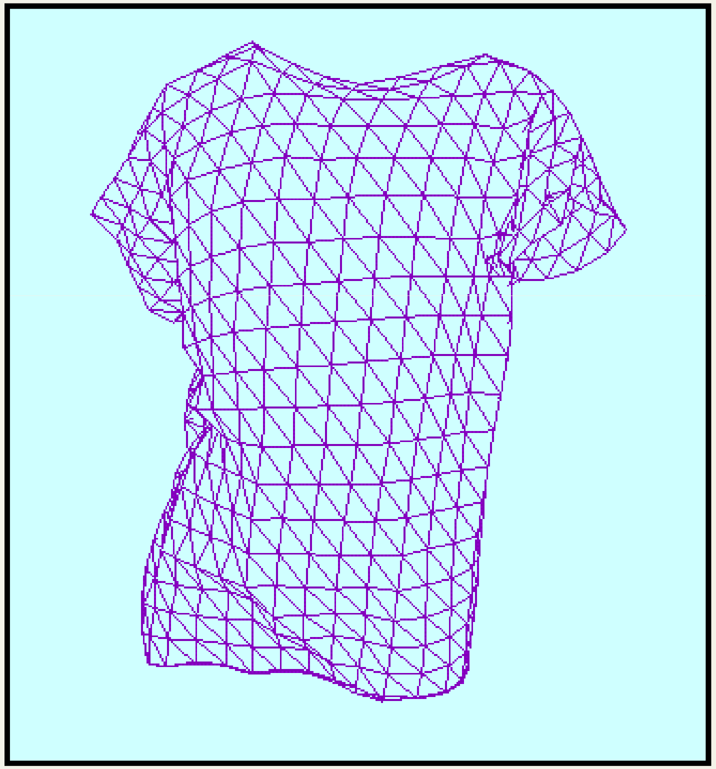


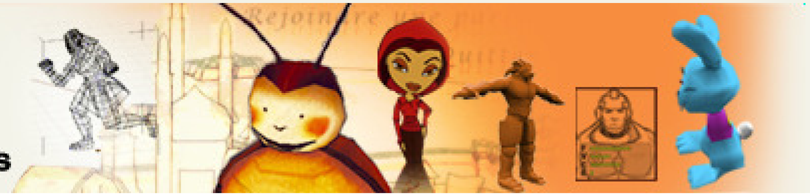
Simulation

- Generate motion of objects using numerical simulation methods



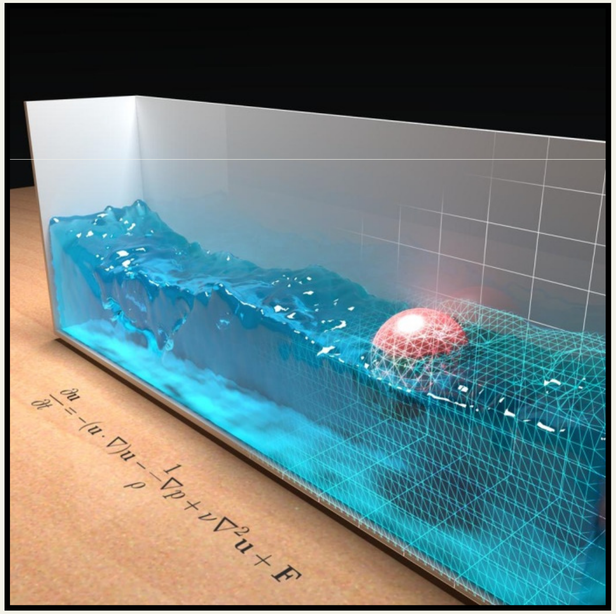
$$\mathbf{x}^{t+\Delta t} = \mathbf{x}^{t} + \Delta t\,\mathbf{v}^{t} + \frac{1}{2}\Delta t^{2}\,\mathbf{a}^{t}$$





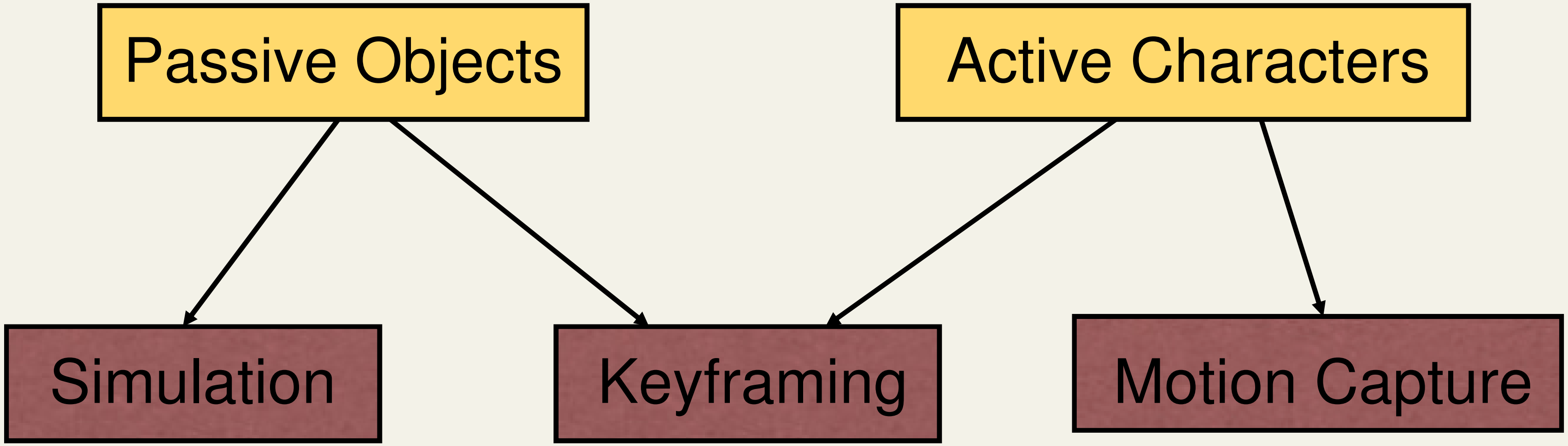
Simulation

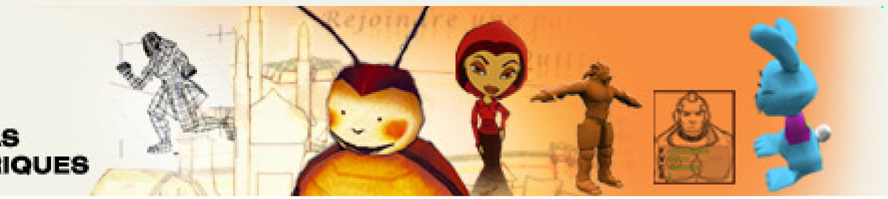
- Perceptual accuracy required
- Stability, easy of use, speed, robustness all important
- Control desirable



IGG

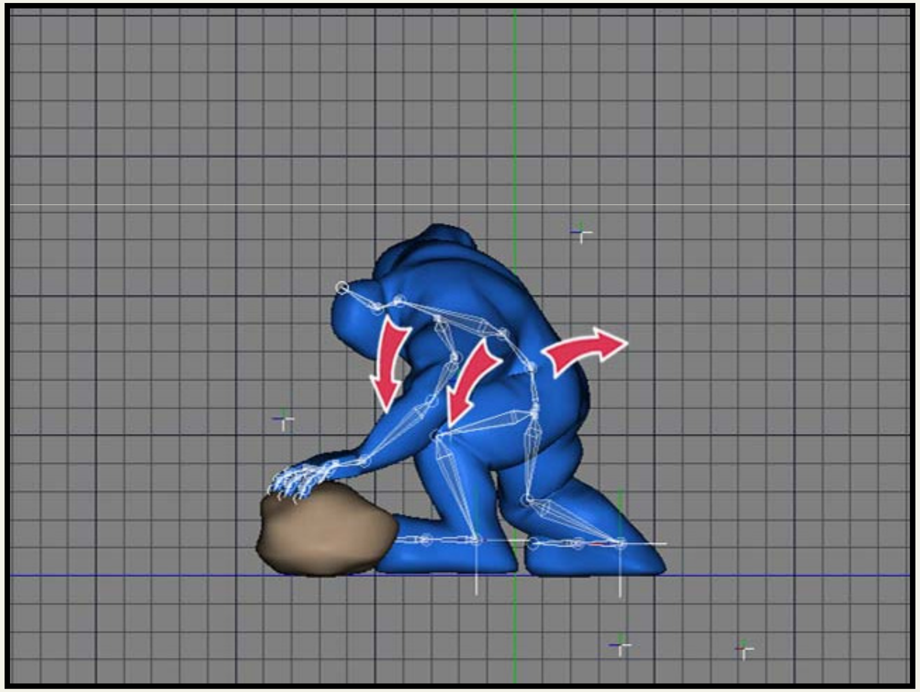
Animation


Passive Objects
Active Characters
Simulation
Keyframing
Motion Capture



Character Animation

- Key Frame or Motion Capture
- Usually skeletal animation based
- Two Components:
  - Skeleton motion
  - Skin move



Jeff Lew

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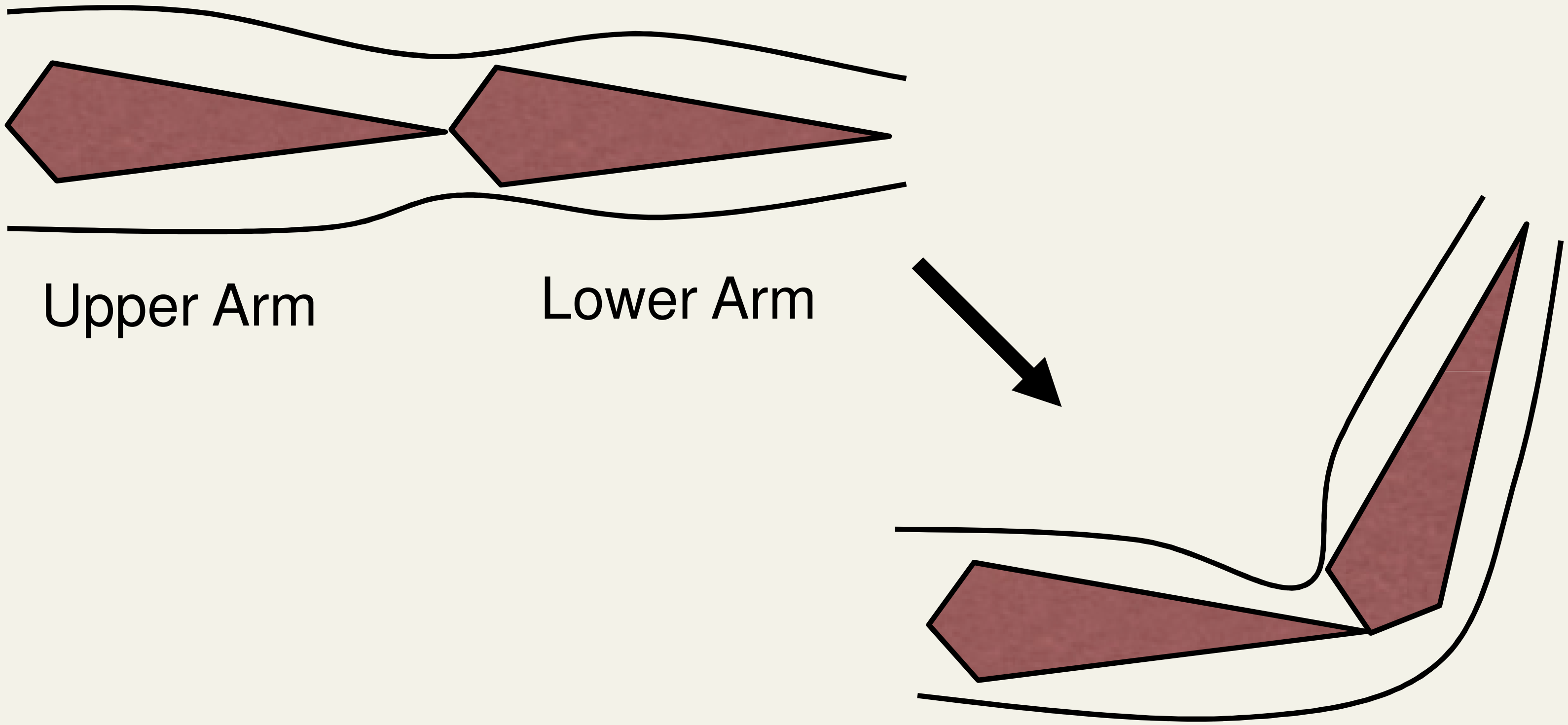
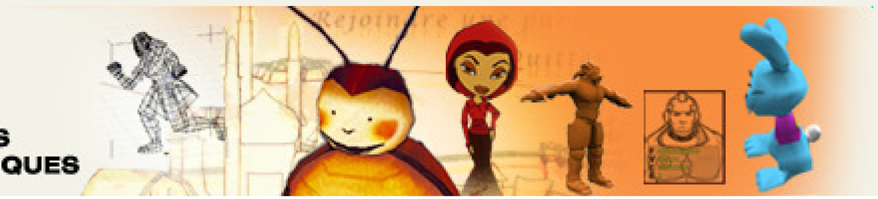
Character Animation

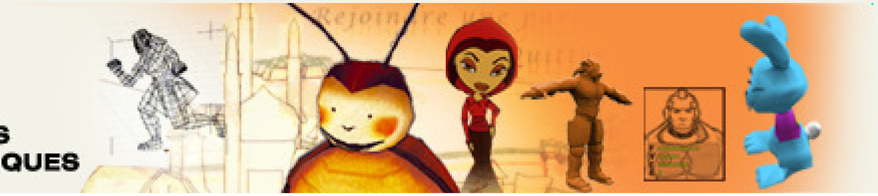




Character Animation

- Skin motion
  - Represent vertices in bone coordinate systems
  - Move bone coordinate systems
- Skeleton motion
  - Parameterized by the joint angles

Jeff Lew

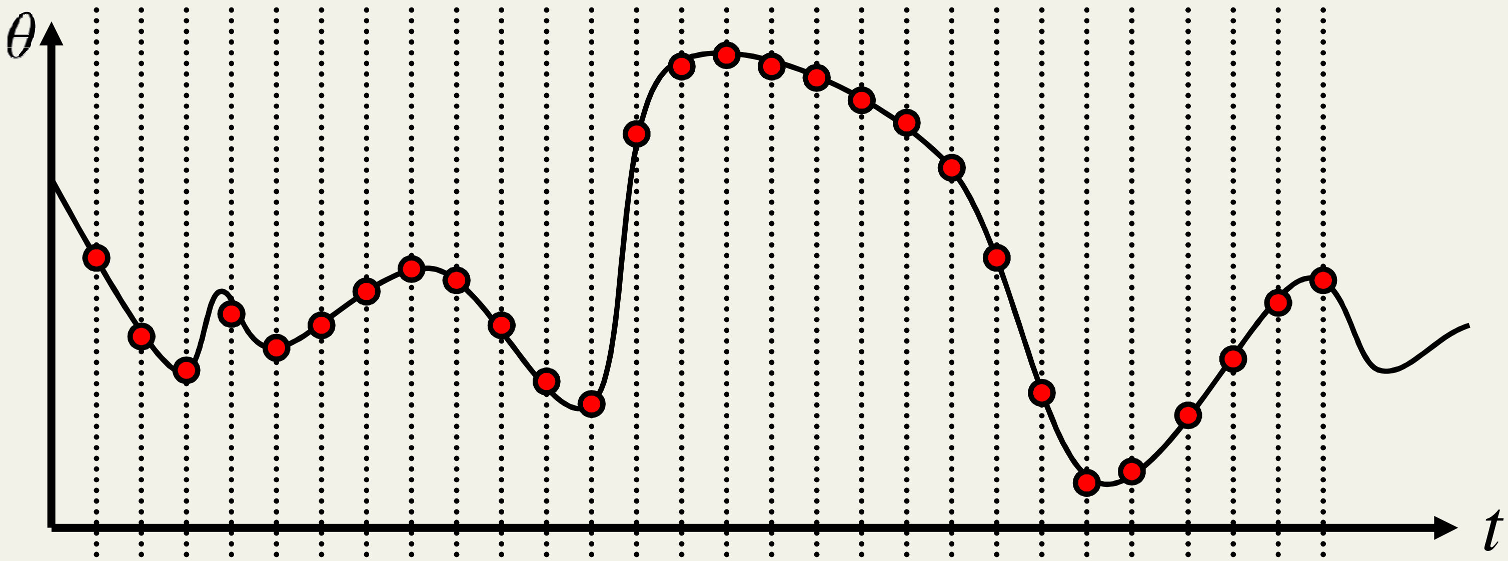


Character Animation

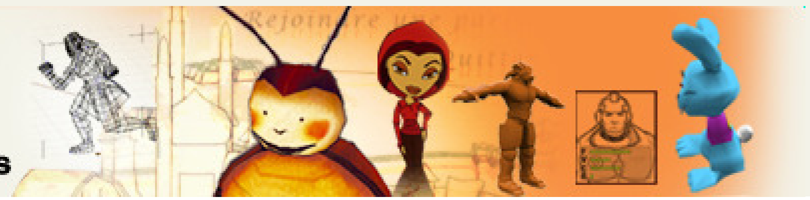
- Skeletal motion is a function of time

$$\theta = f(t)$$

- Representing this function

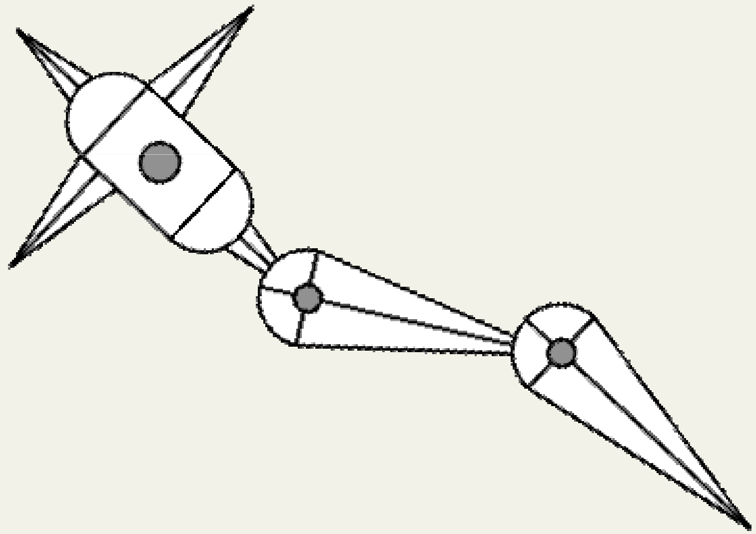


$$\theta_1 = f(t_1)$$
$$\theta_2 = f(t_2)$$
$$\theta_3 = f(t_3)$$
$$\dots$$
$$\theta_n = f(t_n)$$



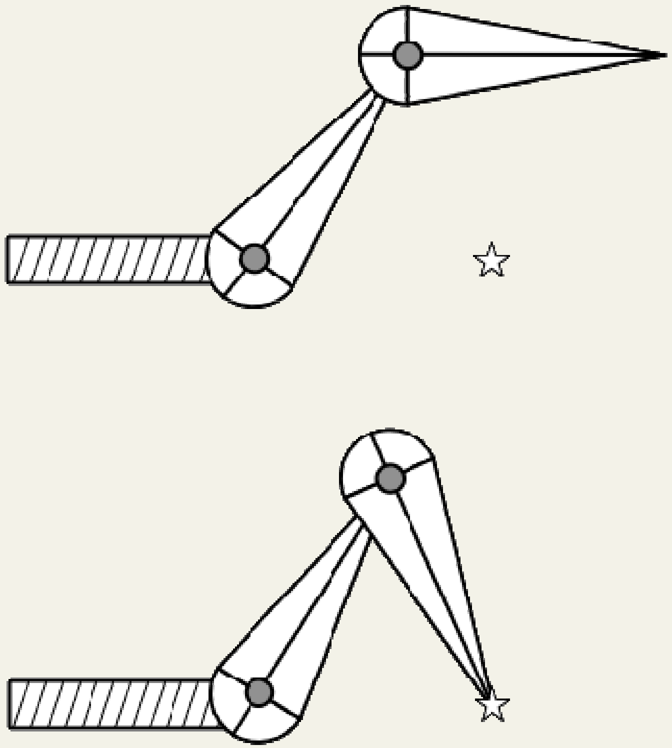
Forward Kinematics

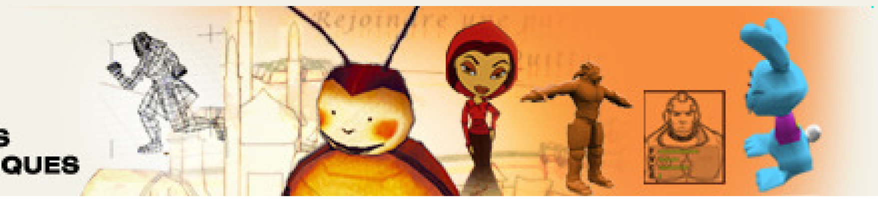
- Composite transformations down the hierarchy



Inverse Kinematics

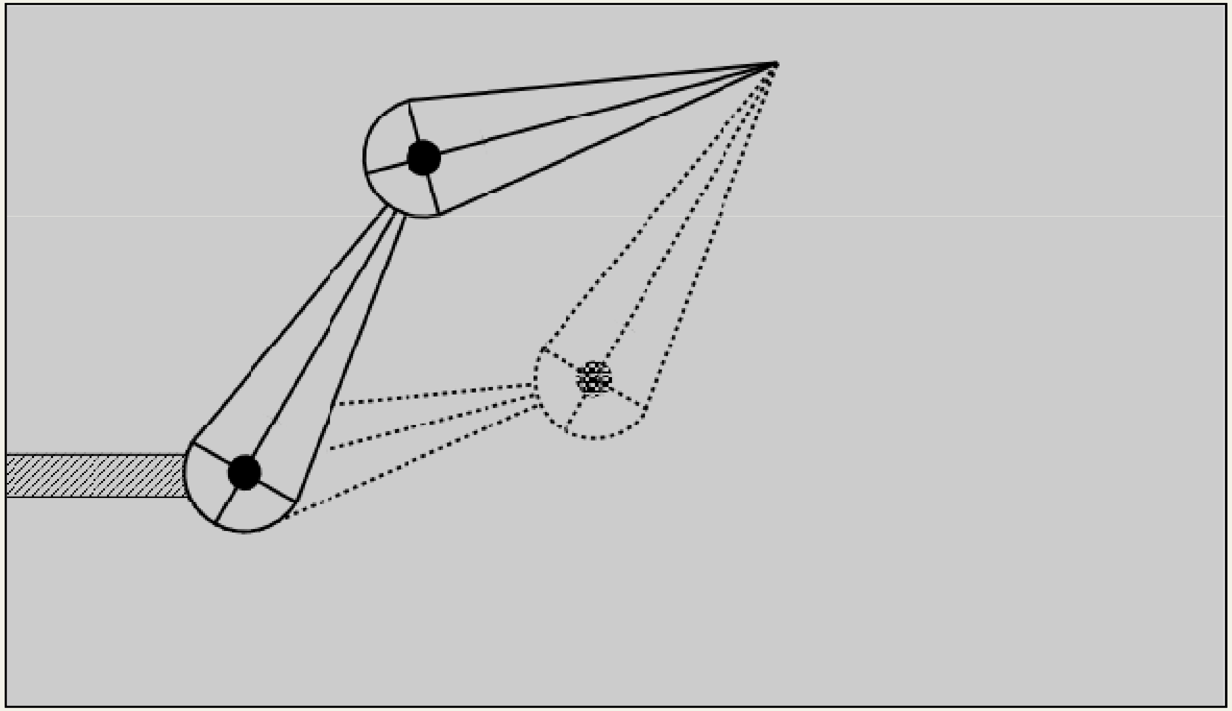
- Given
  - Root transformation
  - Initial configuration
  - Desired end point location
- Find
  - Interior parameter settings





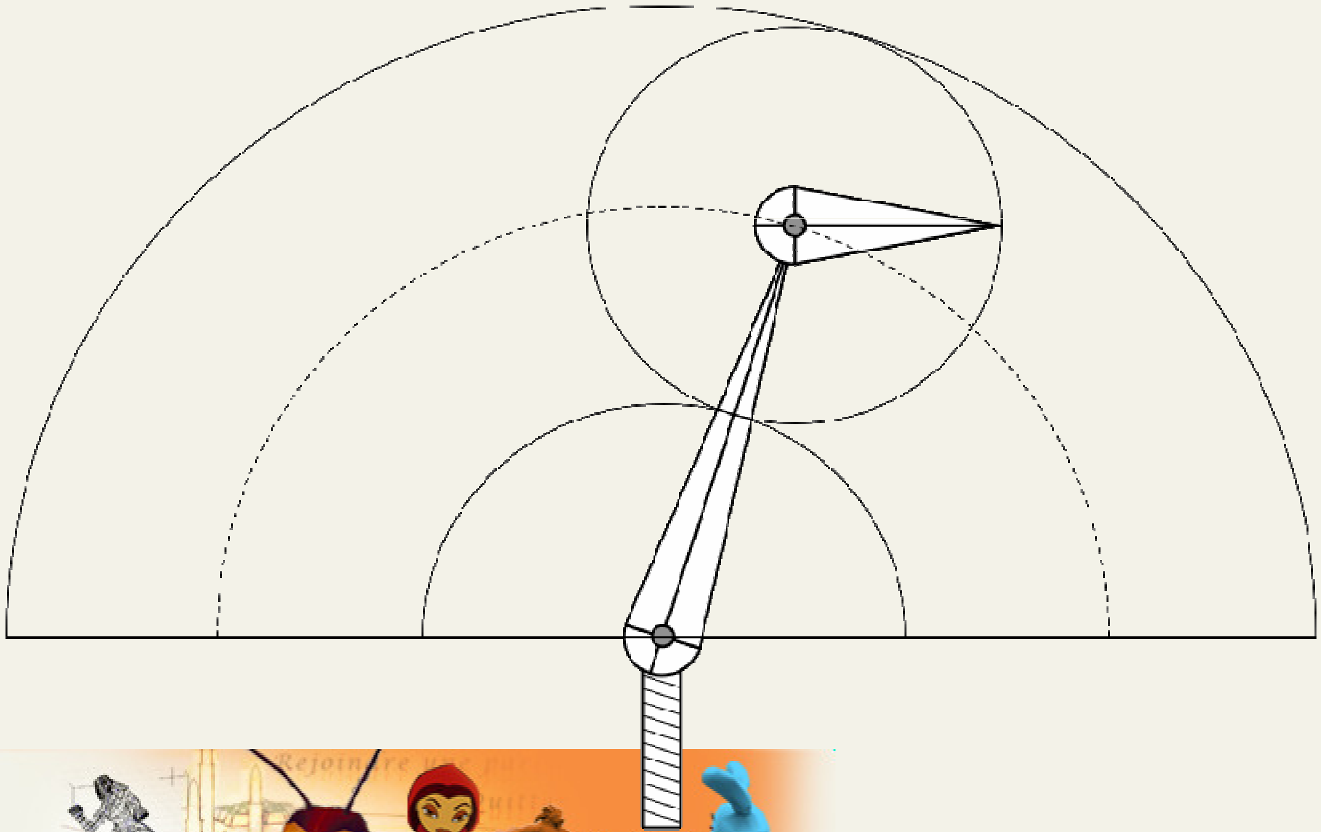
Inverse Kinematics

- Why is the problem hard?
  - Multiple solutions separated in configuration space

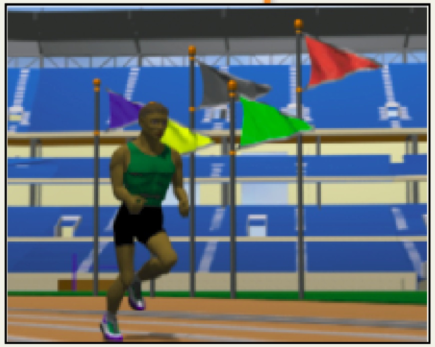


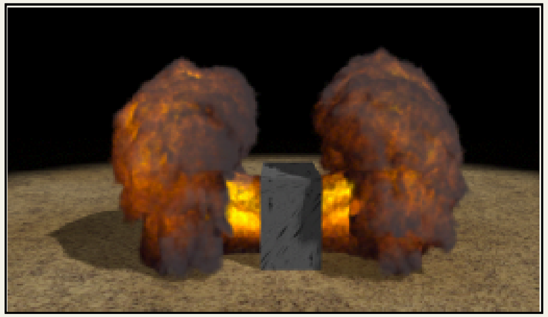
Inverse Kinematics

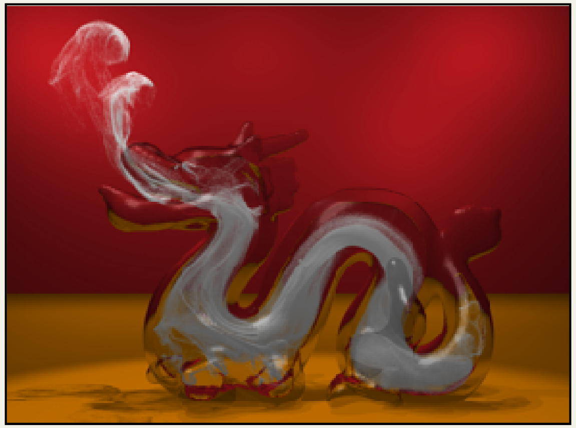
- Why is the problem hard?
  - Solutions may not always exist

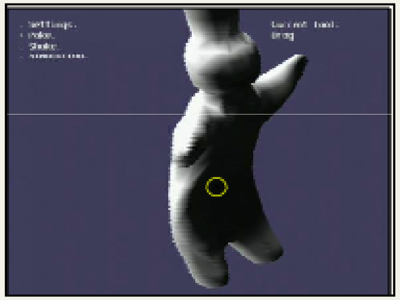


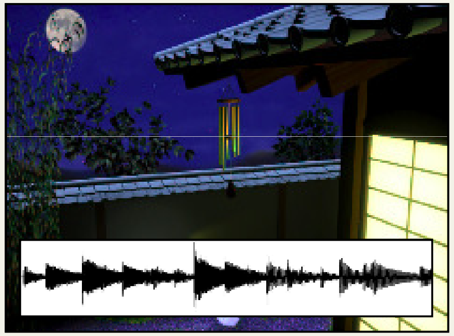
Physically Based Animation

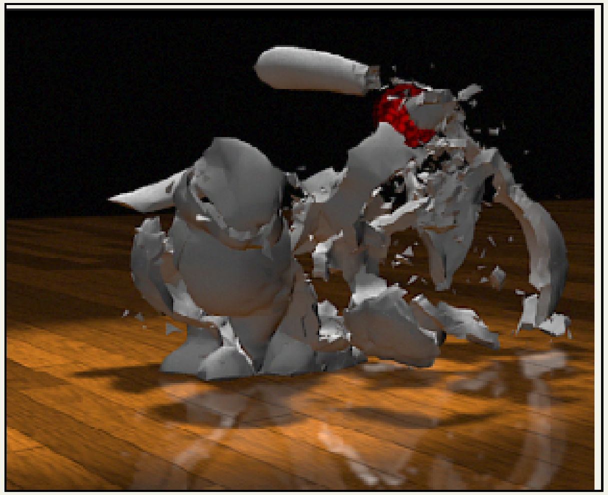


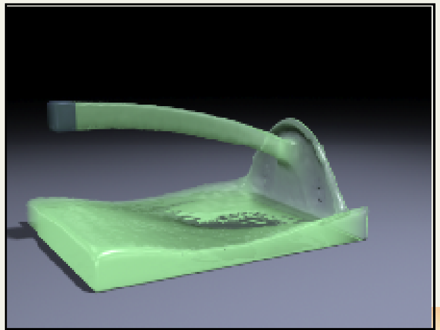


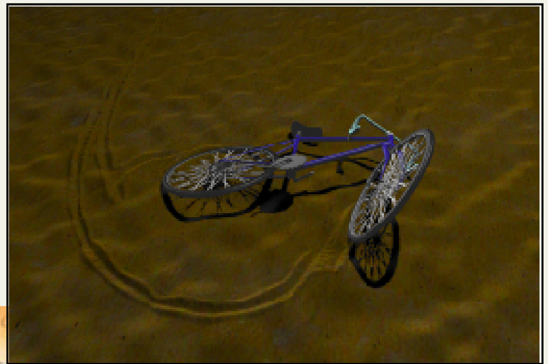


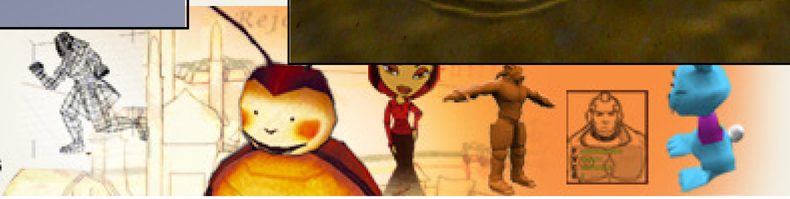












Physically Based Animation in Games

Half Life 2

Max Payne 2

Fuel

Black

Particle Systems

- Single particles are very simple
- Large groups can produce interesting effects
- Supplement basic ballistic rules
  - Collisions
  - Interactions
  - Force fields
  - Springs
  - Others...

Feldman, Klingner, O'Brien
SIGGRAPH 2005

Karl Sims
SIGGRAPH 1990

Basic Particles

$$\ddot{x} = \frac{1}{m}f$$

- Basic governing equation
  - is a sum of a number of things
    - Gravity: constant downward force proportional to mass
    - Simple drag: force proportional to negative velocity
    - Particle interactions: particles mutually attract and/or repel
      - Beware $O(n^2)$ complexity!
    - Force fields
    - Wind forces
    - User interaction

Spring Mass Systems

- Masses connected by springs

✸Can be used to model

⇨Deformable objects

⇨Cloth

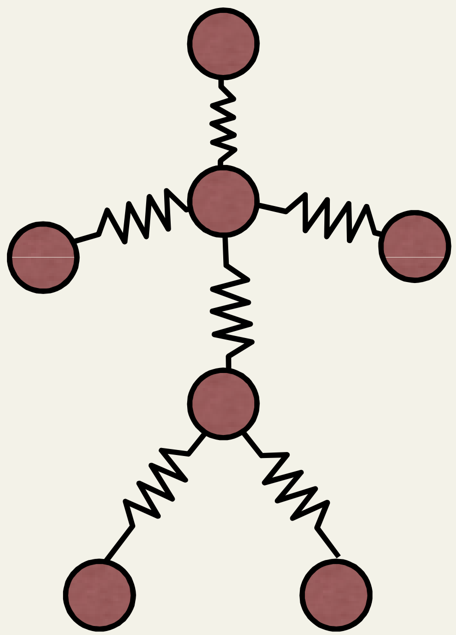
⇨Hair

⇨Rigid bodies

Hitman

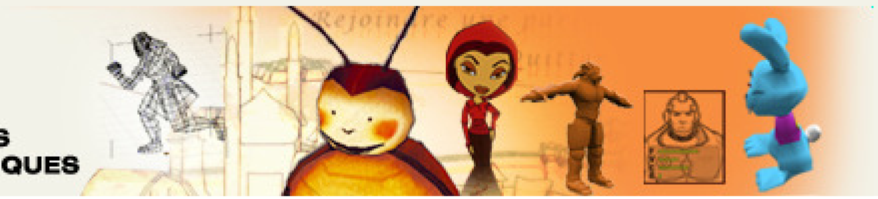
Spring Mass Systems

- Concrete example
  - The state
    - Position, velocity
  - The forces
    - Gravity, springs
  - The integration



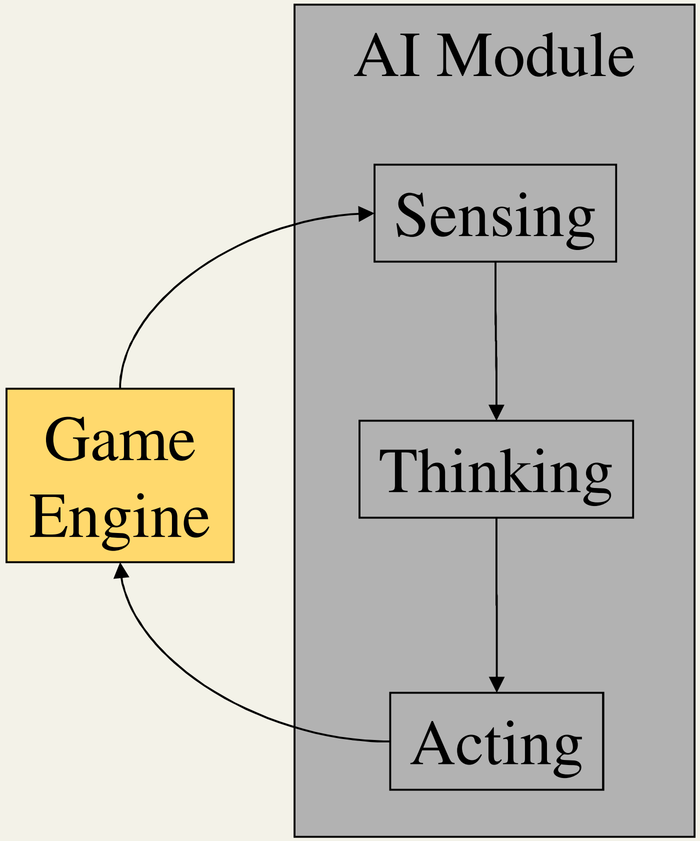
AI in the Game Loop

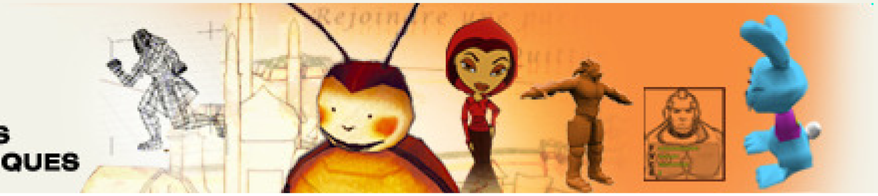
- AI is updated as part of the game loop, after user input, and before rendering
- There are issues here:
  - Which AI goes first?
  - Does the AI run on every frame?
  - Is the AI synchronized?



AI Update Step

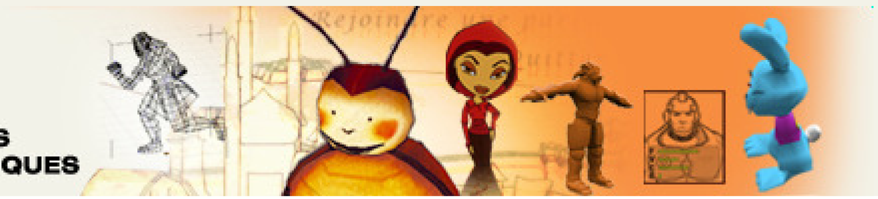
- The sensing phase determines the state of the world
  - May be very simple - state changes all come by message
  - Or complex - figure out what is visible, where your team is, etc
- The thinking phase decides what to do given the world
  - The core of AI
- The acting phase tells the animation what to do
  - Generally not interesting





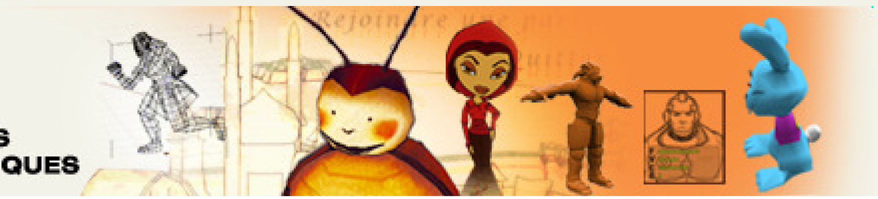
AI by Polling

- The AI gets called at a fixed rate
- Senses: It looks to see what has changed in the world. For instance:
  - Queries what it can see
  - Checks to see if its animation has finished running
- And then acts on it
- Why is this generally inefficient?



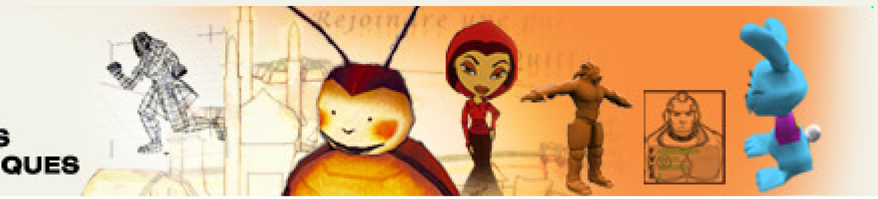
Event Driven AI

- Event driven AI does everything in response to events in the world
  - Events sent by message (basically, a function gets called when a message arrives, just like a user interface)
- Example messages:
  - A certain amount of time has passed, so update yourself
  - You have heard a sound
  - Someone has entered your field of view
- Note that messages can completely replace sensing, but typically do not. Why not?
  - Real system are a mix - something changes, so you do some sensing



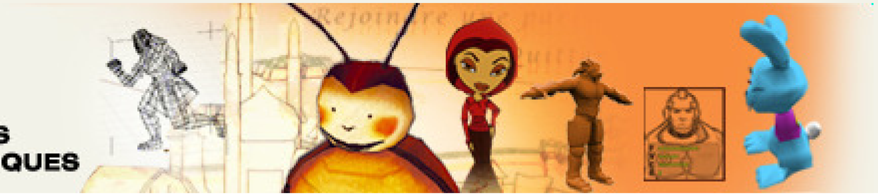
AI Techniques in Games

- Basic problem: Given the state of the world, what should I do?
- A wide range of solutions in games:
  - Finite state machines, Decision trees, Rule based systems, Neural networks, Fuzzy logic, …
- Even a wider range of solutions in the academic world:
  - Complex planning systems, logic programming, genetic algorithms, Bayes-nets, …
  - Typically, too slow for games



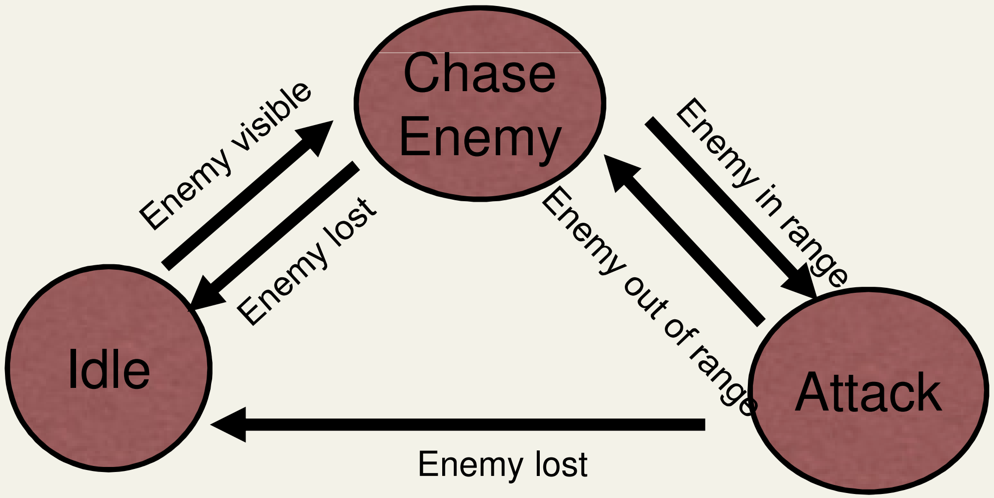
Goals of Game AI

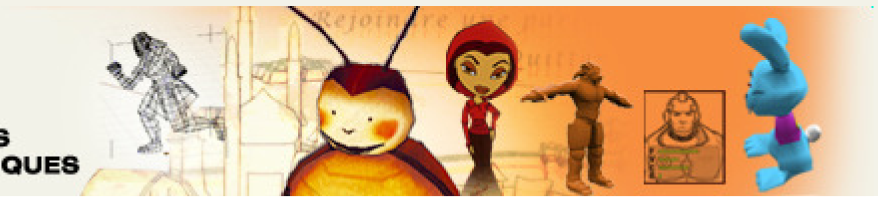
- Several goals:
  - Goal driven - the AI decides what it should do, and then figures out how to do it
  - Reactive - the AI responds immediately to changes in the world
  - Knowledge intensive - the AI knows a lot about the world and how it behaves, and embodies knowledge in its own behavior
  - Characteristic - Embodies a believable, consistent character
  - Fast and easy development
  - Low CPU and memory usage
- These conflict in almost every way



Finite State Machines (FSMs)

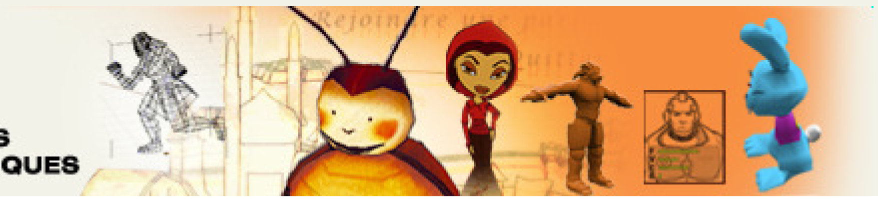
- A set of *states* that the agent can be in
- Connected by *transitions* that are triggered by a change in the world
- Normally represented as a directed graph, with the edges labeled with the transition event
- Ubiquitous in computer game AI





Quake Bot Example

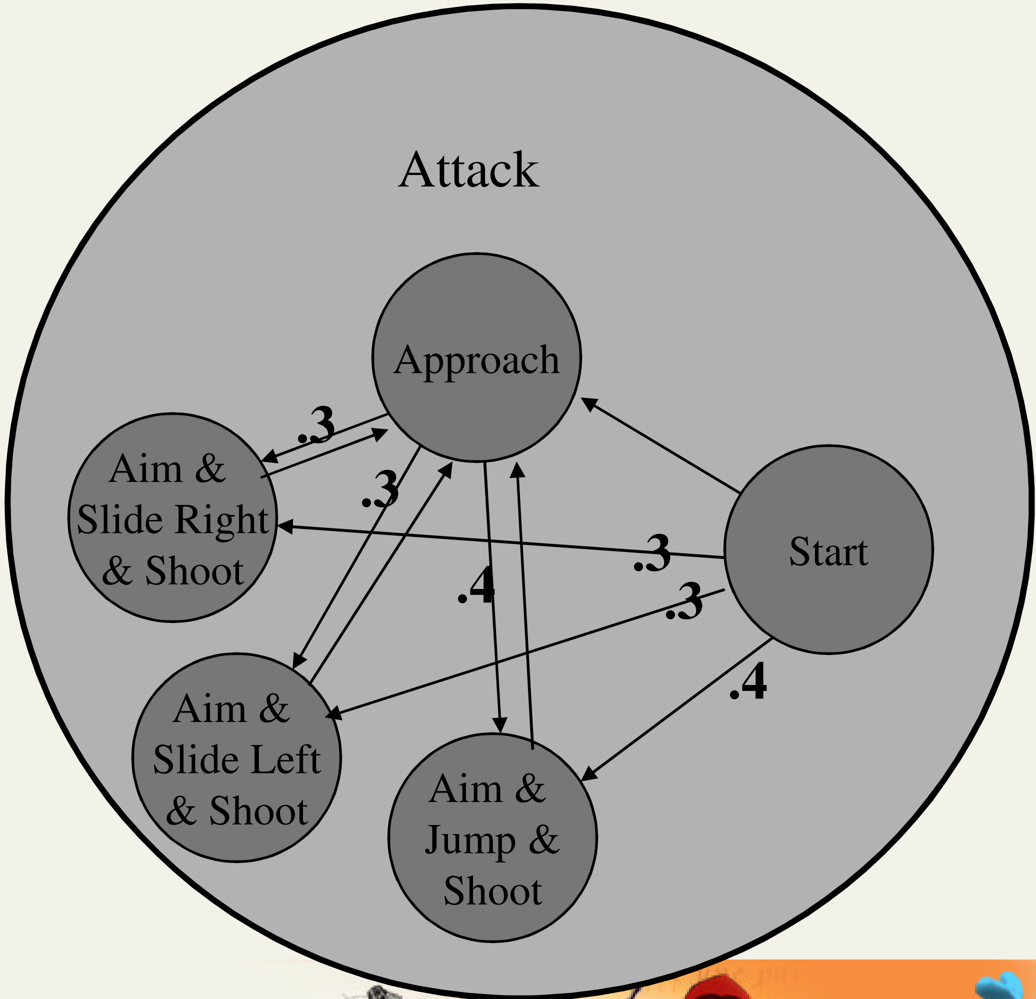
- Types of behavior to capture:
  - Wander randomly if don't see or hear an enemy
  - When see enemy, attack
  - When hear an enemy, chase enemy
  - When die, respawn
  - When health is low and see an enemy, retreat
- Extensions:
  - When see power-ups during wandering, collect them
- Borrowed from John Laird and Mike van Lent's GDC tutorial



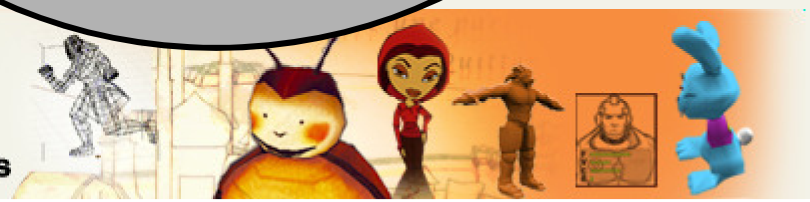
Hierarchical FSMs

- What if there is no simple action for a state?
- Expand a state into its own FSM, which explains what to do if in that state
- Some events move you around the same level in the hierarchy, some move you up a level
- When entering a state, have to choose a state for it’s child in the hierarchy
  - Set a default, and always go to that
  - Or, random choice
  - Depends on the nature of the behavior

Non-Deterministic Hierarchical FSM (Markov Model)

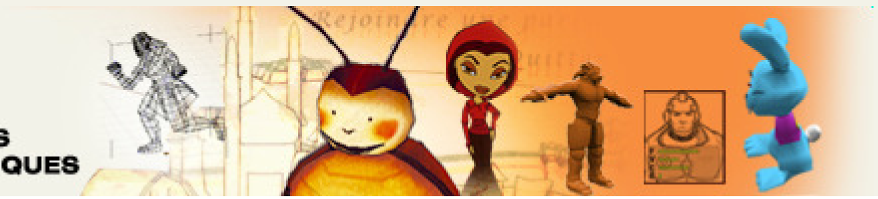


- Adds variety to actions
- Have multiple transitions for the same event
- Label each with a probability that it will be taken
- Randomly choose a transition at run-time
- Markov Model: New state only depends on the previous state



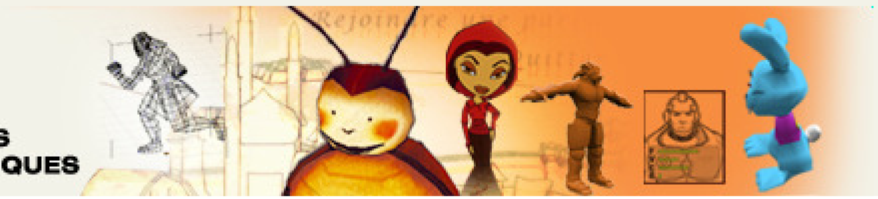
FSM Advantages

- Very fast – one array access
- Expressive enough for simple behaviors or characters that are intended to be “dumb”
- Can be compiled into compact data structure
  - Dynamic memory: current state
  - Static memory: state diagram – array implementation
- Can create tools so non-programmer can build behavior
- Non-deterministic FSM can make behavior unpredictable



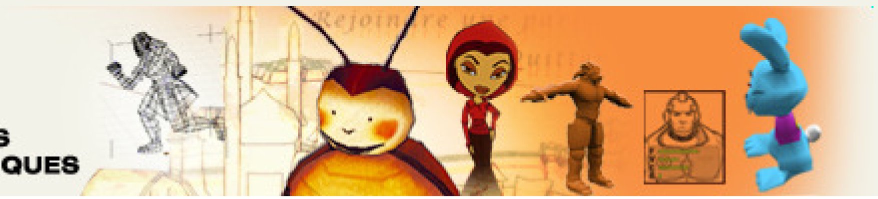
FSM Disadvantages

- Number of states can grow very fast
  - Exponentially with number of events: $s=2^e$
- Number of arcs can grow even faster: $a=s^2$
- Propositional representation
  - Difficult to put in “pick up the better powerup”, “attack the closest enemy”
  - Expensive to count: Wait until the third time I see enemy, then attack
    - Need extra events: First time seen, second time seen, and extra states to take care of counting



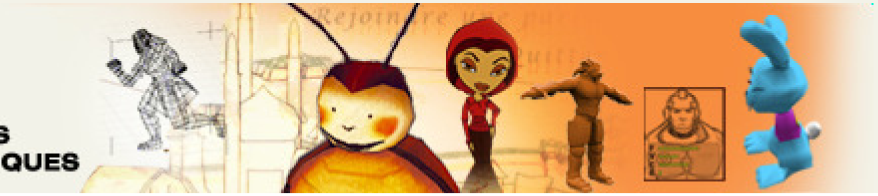
Path Finding

- Very common problem in games:
  - In FPS: How does the AI get from room to room?
  - In RTS: User clicks on units, tells them to go somewhere. How do they get there? How do they avoid each other?
  - Chase games, sports games, …
- Very expensive part of games
  - Lots of techniques that offer quality, robustness, speed trade-offs
- A* usual solution



Path Finding Problem

- Problem Statement (Academic): Given a start point, A, and a goal point, B, find a path from A to B that is clear
  - Generally want to minimize a cost: distance, travel time, …
    - Travel time depends on terrain, for instance
  - May be complicated by dynamic changes: paths being blocked or removed
  - May be complicated by unknowns – don't have complete information
- Problem Statement (Games): Find a reasonable path that gets the object from A to B
  - Reasonable may not be optimal – not shortest, for instance
  - It may be OK to pass through things sometimes
  - It may be OK to make mistakes and have to backtrack



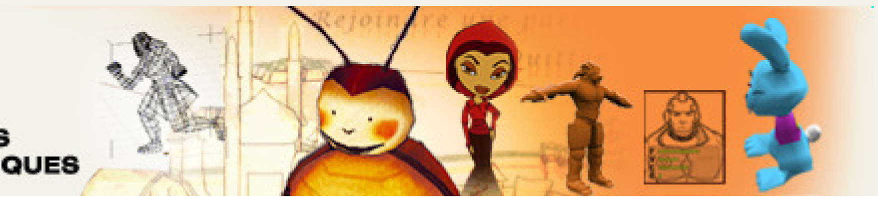
A* Problems

- Discrete Search:
  - Must have simple paths to connect waypoints
    - Typically use straight segments
    - Have to be able to compute cost
    - Must know that the object will not hit obstacles
  - Leads unnatural paths
    - Infinitely sharp corners
    - Funny paths across grids
- Efficiency is not great

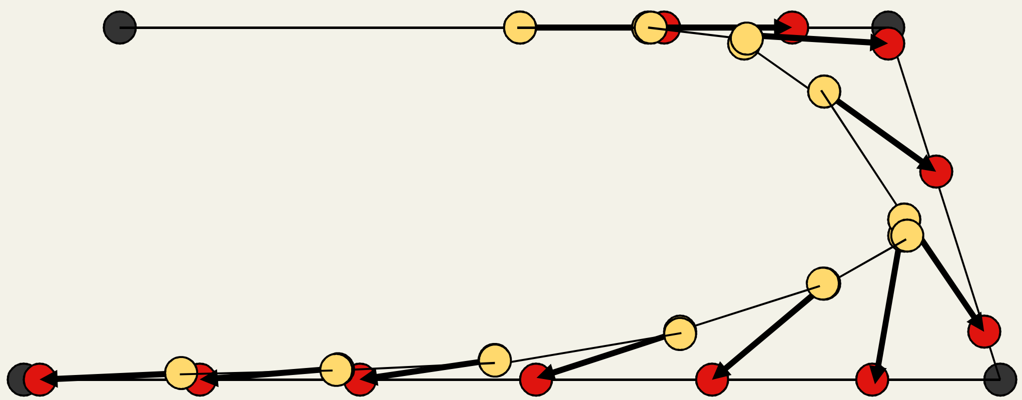
Starcraft

Chase the Point

- Instead of tracking along the path, the agent chases a target point that is moving along the path
- Start with the target on the path ahead of the agent
- At each step:
  - Move the target along the path using linear interpolation
  - Move the agent toward the point location, keeping it a constant distance away or moving the agent at the same speed
- Works best for driving or flying games

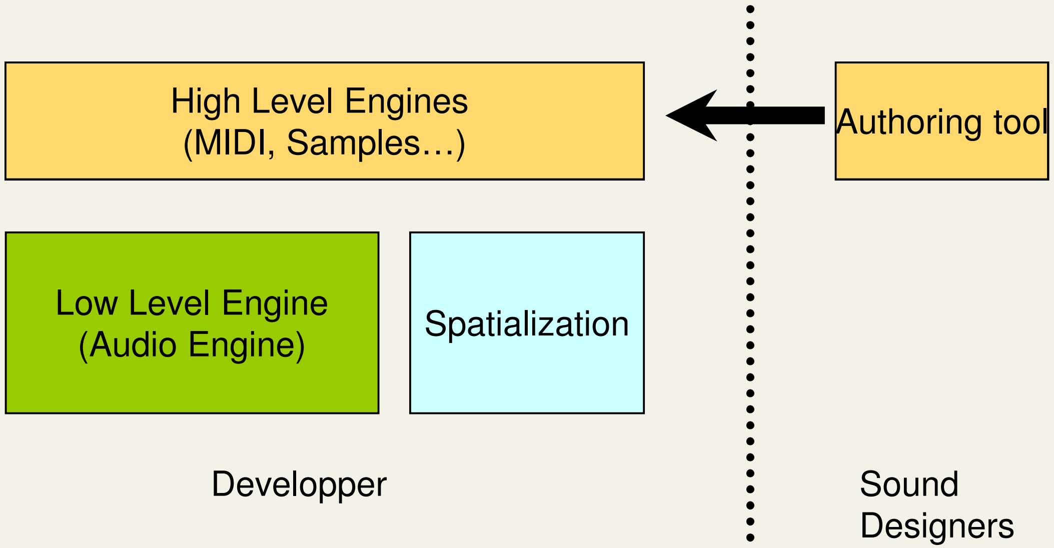


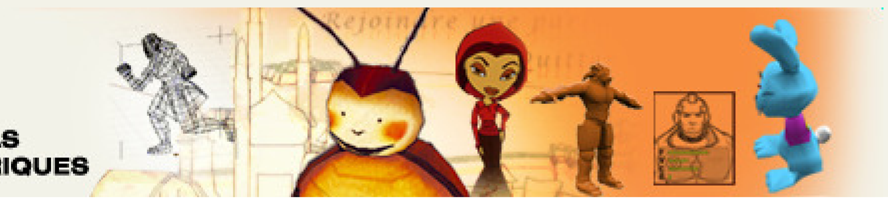
Chase the Point Demo



Audio

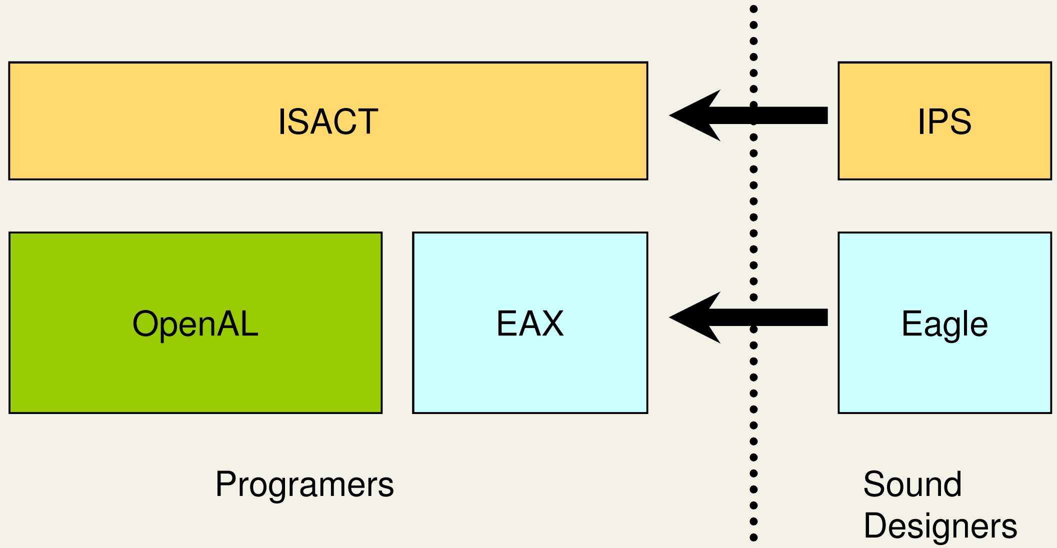
- Generic Engine

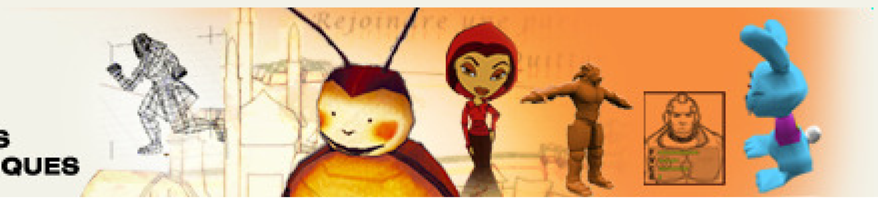




Audio

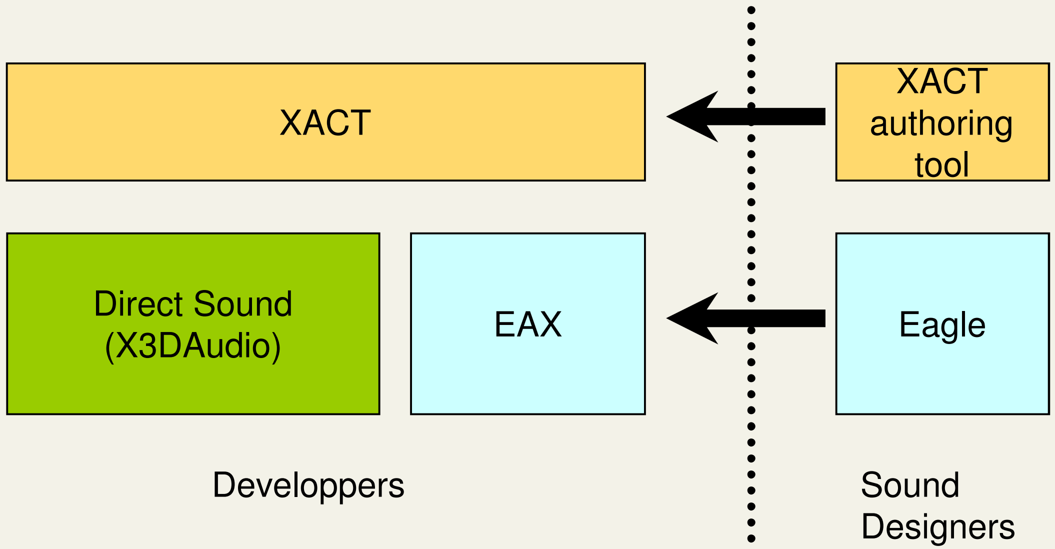
- Creative Labs





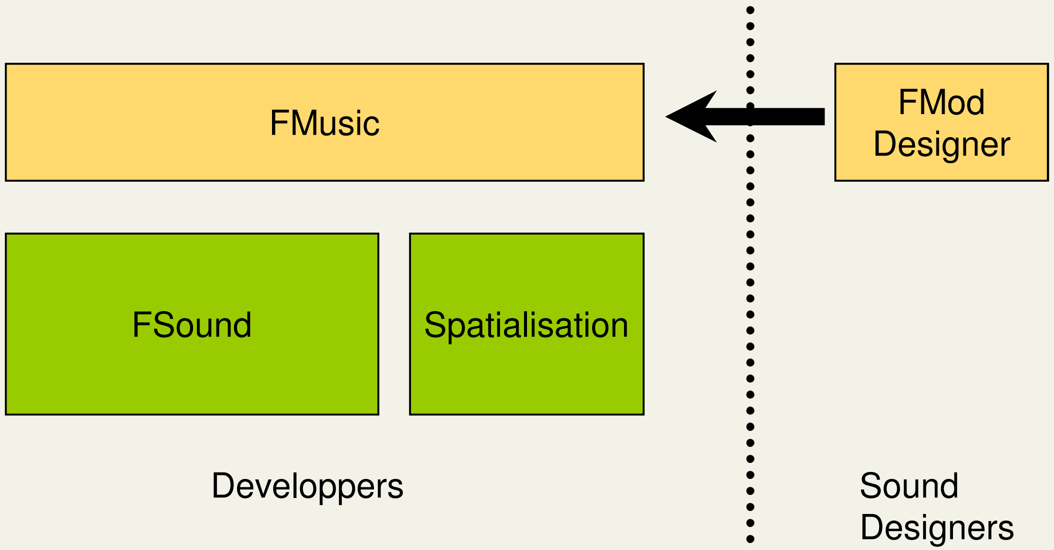
Audio

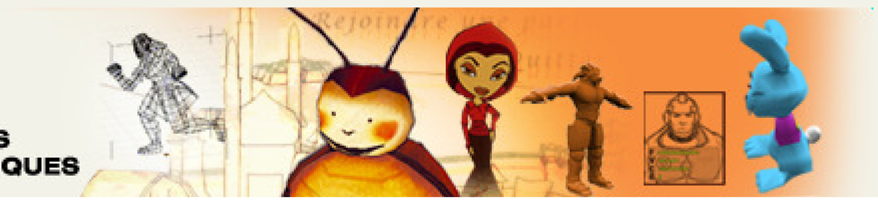
- Microsoft



Audio

- Firelight





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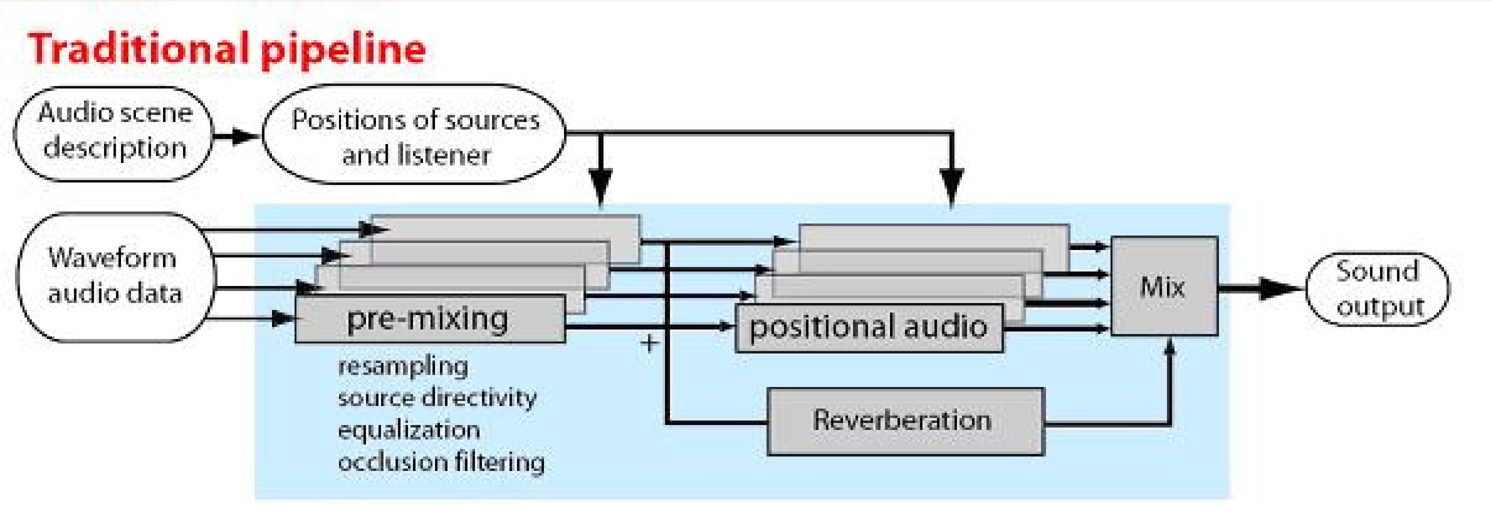
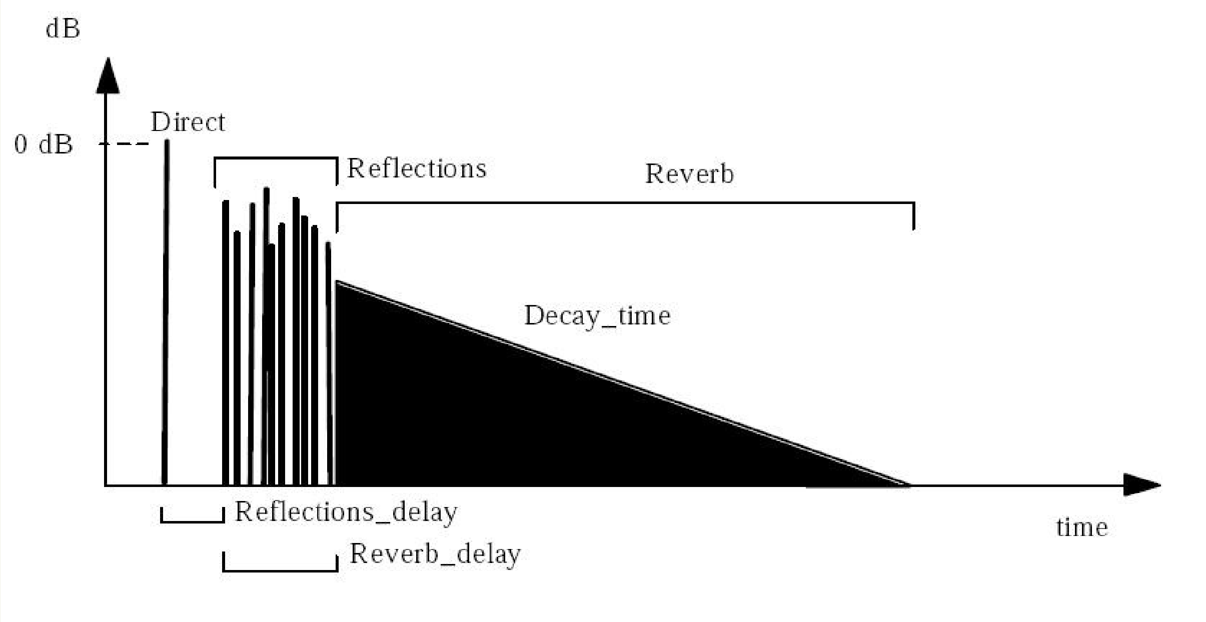
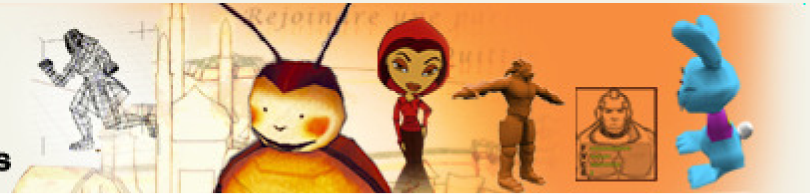

Traditional pipeline
Audio scene description
Positions of sources and listener
Waveform audio data
pre-mixing
resampling
source directivity
equalization
occlusion filtering
positional audio
Reverberation
Mix
Sound output

Audio

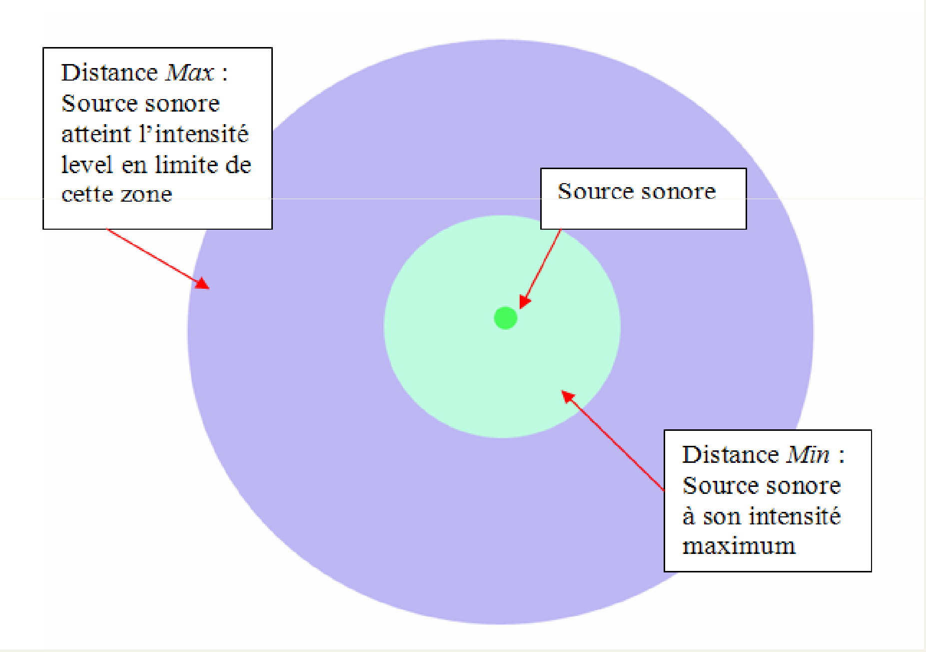
- Reverbation





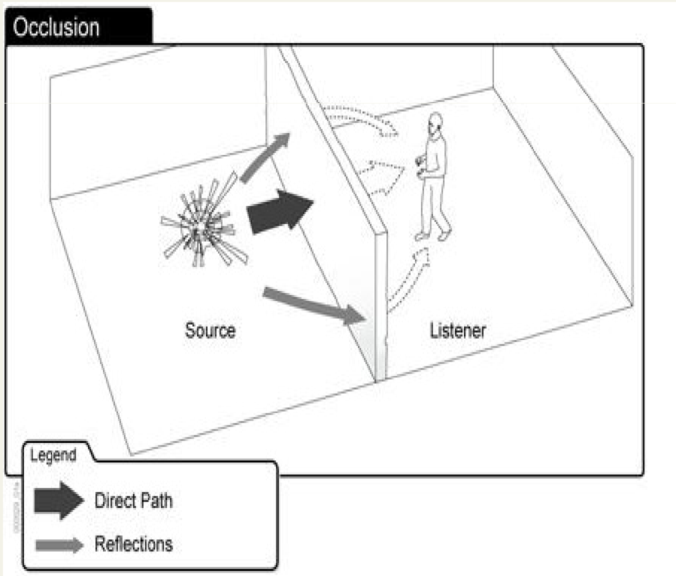
Audio

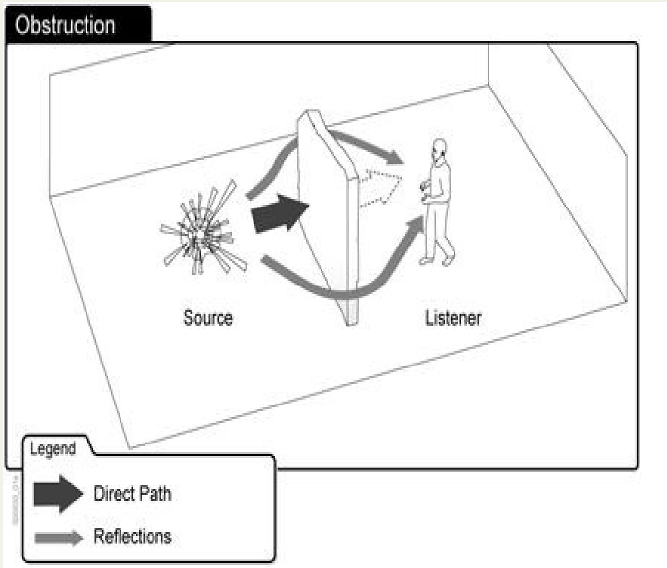
- Audible sphere

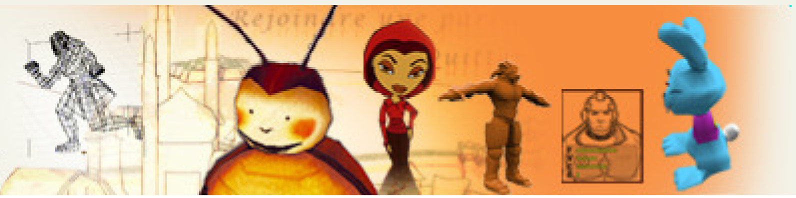


Audio

- Occlusions and obstructions







ENJMIN

Network problematics

- Lag/response time
  - f° of distance ? Sure ! But not only
  - f° of ressources & capacity (bandwidth, CPU, memory, …)
- Unreliable transmission
  - Packet loss, packet reordering
  - TCP stream Vs UDP datagram
- Network topologies
- Time sync problem without a global clock
  - Global Vs
- How to minimize the number of messages ?
  - Prediction techniques : Dead reckoning
  - Range of interest (RoI) : similar to culling and collision detection

ECOLE NATIONALE
DU JEU ET DES MEDIAS
INTERACTIFS NUMERIQUES