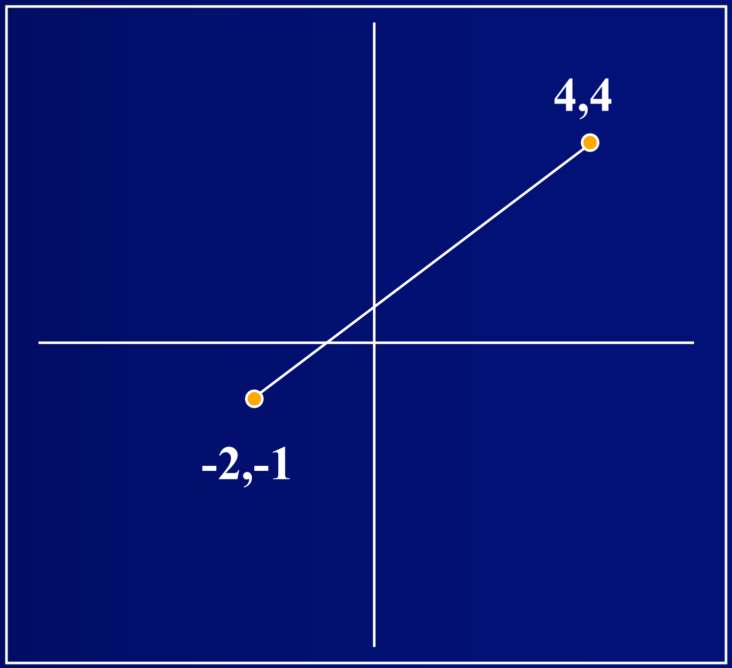
Arcade Games:
2D Bit-mapped Graphics

John Laird and Sugih Jamin

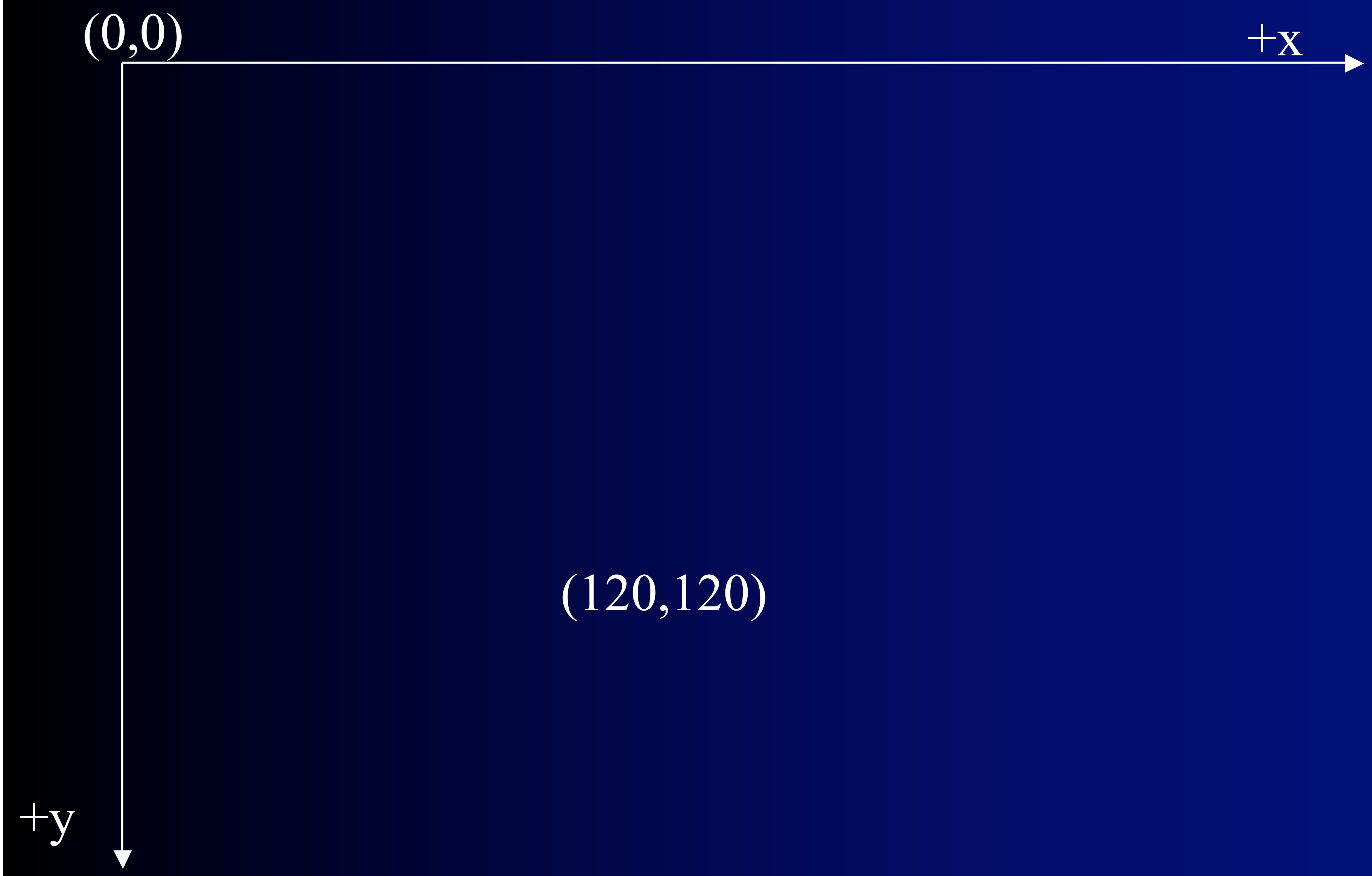
September 11, 2006

2D Graphics

- Most 2D games use sprite instead, but basic primitives applicable in 3D graphics
- Points
  - x,y
- Lines
  - Two points
  - Draw by drawing all points in between
  - Low-level support for this in hardware or software



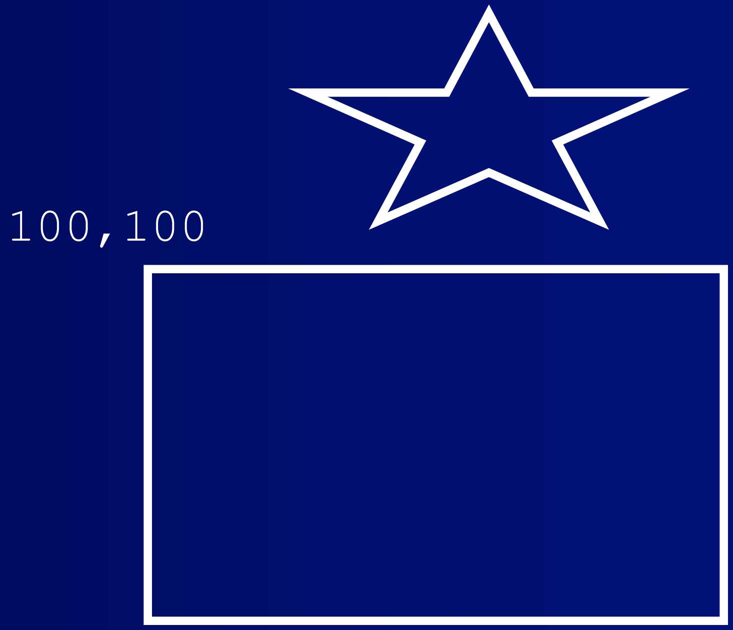
Coordinate System



Polygons

- Defined by vertices
- Closed: all lines connected
- Draw one line at a time
- Can be concave or convex
- Basis for many games
- Basis for 3D graphics (triangle)

- Required data:
    - Position: x, y
    - Number of vertices
    - List of vertices
    - Color (shading)



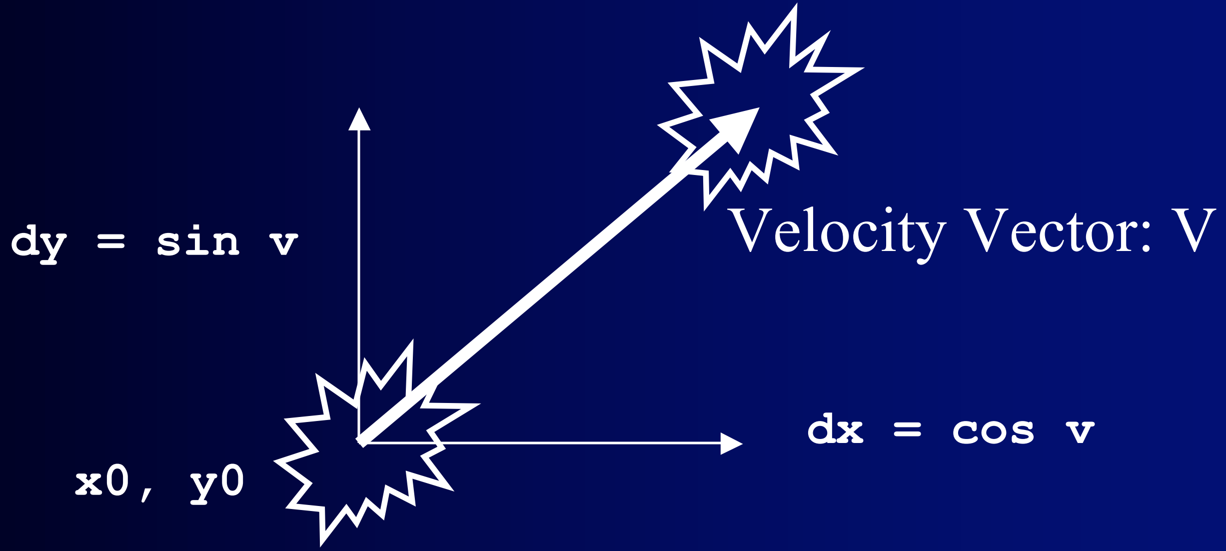
```
moveto(100,100)
lineto(100,300)
lineto(500,300)
lineto(500,100)
lineto(100,100)
```

Operations on Polygon

- Translation: moving
- Scaling: changing size
- Rotation: turning
- Clipping and scrolling

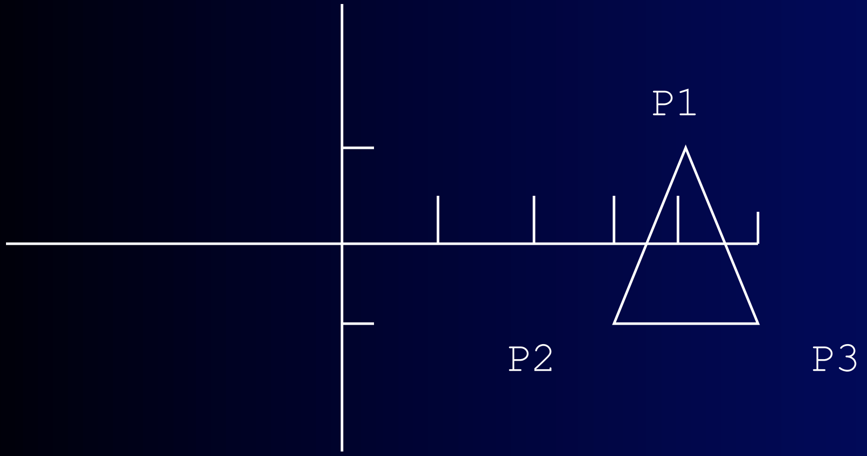
Translation: Moving an Object

- To move an object, just add in changes to position:
  - $x = x_0 + dx$
  - $y = y_0 + dy$
- If have motion, the *dx* and *dy* are the x and y components of the velocity vector.



Positioning an object

- Problem: If we move an object, do we need to change the values of every vertex?
- Solution: change frame of reference
  - *World* coordinate system for object positions
    - coordinates relative to screen
  - *Local* coordinate system for points in object
    - coordinates relative to the position of the object (frame of reference)

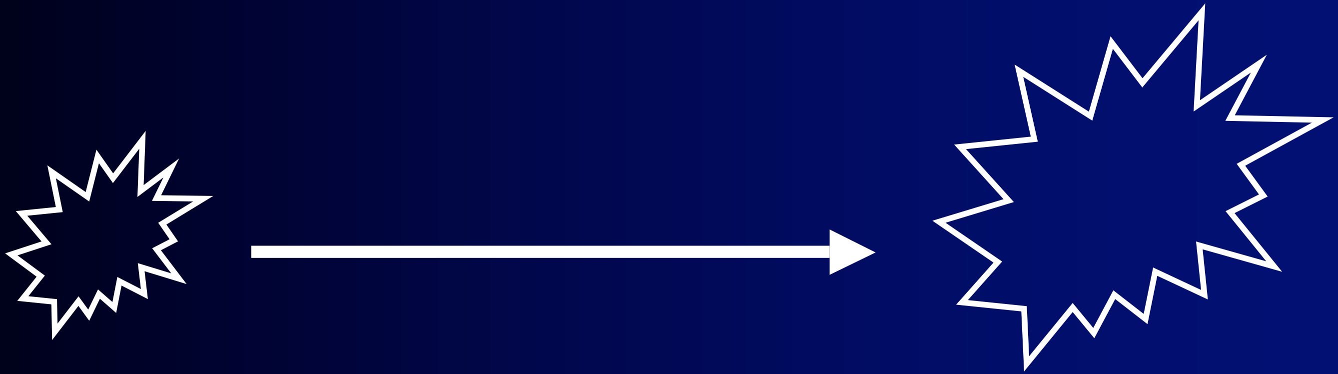


Triangle location: 4,0

P1: 0, 1
P2: -1, -1
P3: 1, -1

Scaling: Changing Size

- Multiply the coordinates of each vertex by the scaling factor.
- Everything just expands from the center.
- `object[v1].x *= scale`
- `object[v1].y *= scale`



Rotation: Turning an Object

- Spin object around its center in the z-axis.
- Rotate each point the same angle
  - Positive angles are clockwise
  - Negative angles are counterclockwise
- $x = x_0 * \cos(\text{angle}) - y_0 * \sin(\text{angle})$
- $y = y_0 * \cos(\text{angle}) + x_0 * \sin(\text{angle})$
- Note: angle measured in radians not degrees!

Matrix Operations

- Translation, rotation, scaling can all be collapsed into matrix operations:

- Translation:

$$\begin{vmatrix} x & y & 1 \end{vmatrix} \quad * \quad \begin{vmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ dx & dy & 1 \end{vmatrix}$$

- Scaling:

$$\begin{vmatrix} x & y & 1 \end{vmatrix} \quad * \quad \begin{vmatrix} sx & 0 & 0 \\ 0 & sy & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

sx, sy = scaling values

- Rotation:

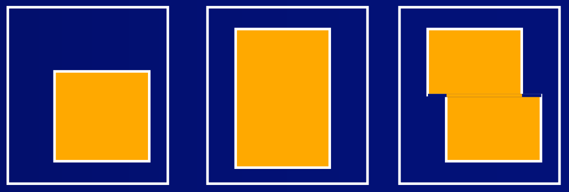
$$\begin{vmatrix} x & y & 1 \end{vmatrix} \quad * \quad \begin{vmatrix} \cos & -\sin & 0 \\ \sin & \cos & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

Putting it all together

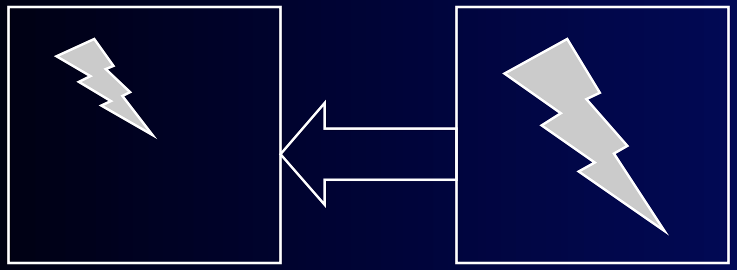
$$\begin{vmatrix} x & y & 1 \end{vmatrix} * \begin{vmatrix} sx*cos & -sx*sin & 0 \\ sy*sin & sy*cos & 0 \\ dx & dy & 1 \end{vmatrix}$$

Common Problems: Flicker and Tearing

- Video update slower than display
- Change video buffer during updating
- Solution:
  - Double buffering -- write to a "virtual screen" that isn't being displayed.
  - Either BLT buffer all at once, or switch pointer.

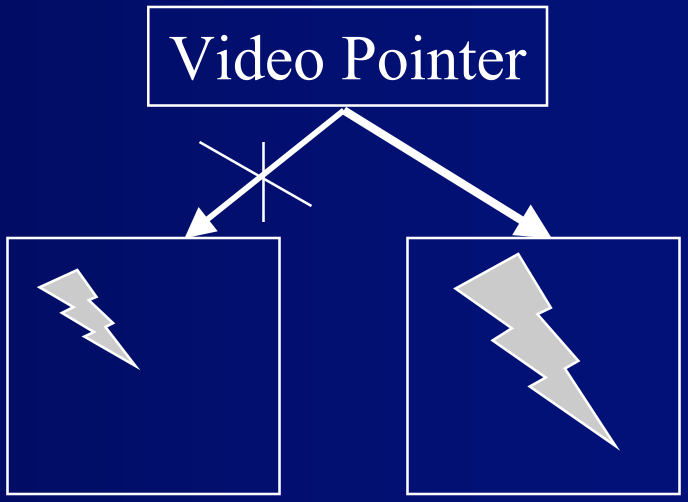


Frame 1 Frame 2 Displayed



Video Buffer

Backup Buffer



Video Pointer

Clipping

- Display the parts of the objects on the screen
  - Can get array out of bound errors if not careful
  - Easy for sprites – done in DirectX
- Approaches:
  - Border vs. image space or object space

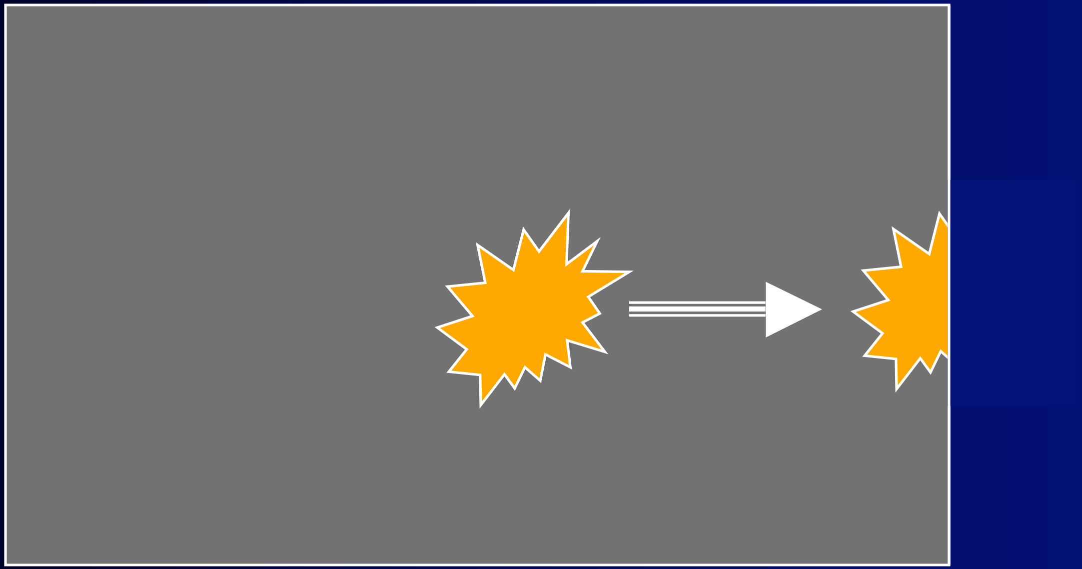


Image Space vs. Object Space

- Image space:
  - What is going to be displayed
  - Primitives are pixels
  - Operations related to number of pixels
    - Bad when must do in software
    - Good if can do in parallel in hardware – have one “processor”/pixel

- Object space:
  - Objects being simulated in games
  - Primitives are objects or polygons
  - Operations related to number of objects

Border Clipping

- Create a border that is as wide as widest object
  - Only render image, not border
  - Restricted to screen/rectangle clipping
  - Still have to detect when object is outside border
  - Requires significantly more memory

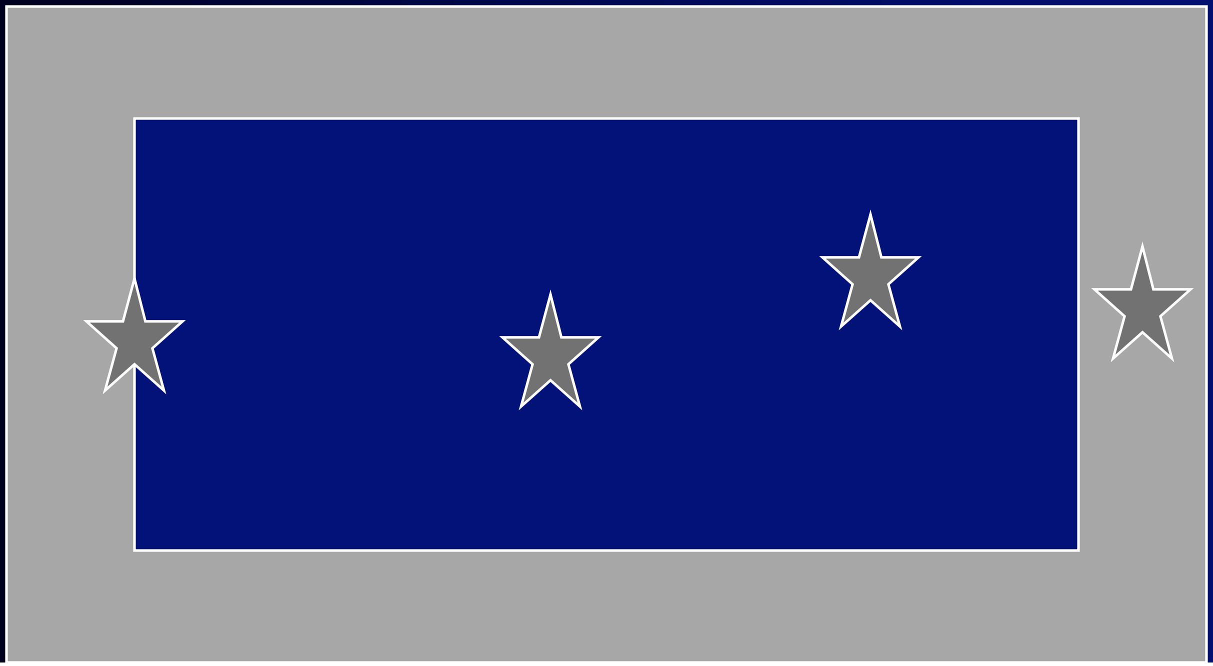
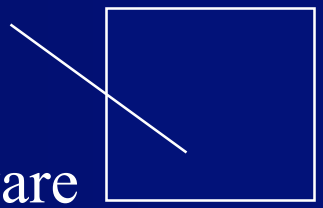


Image Space Clipping

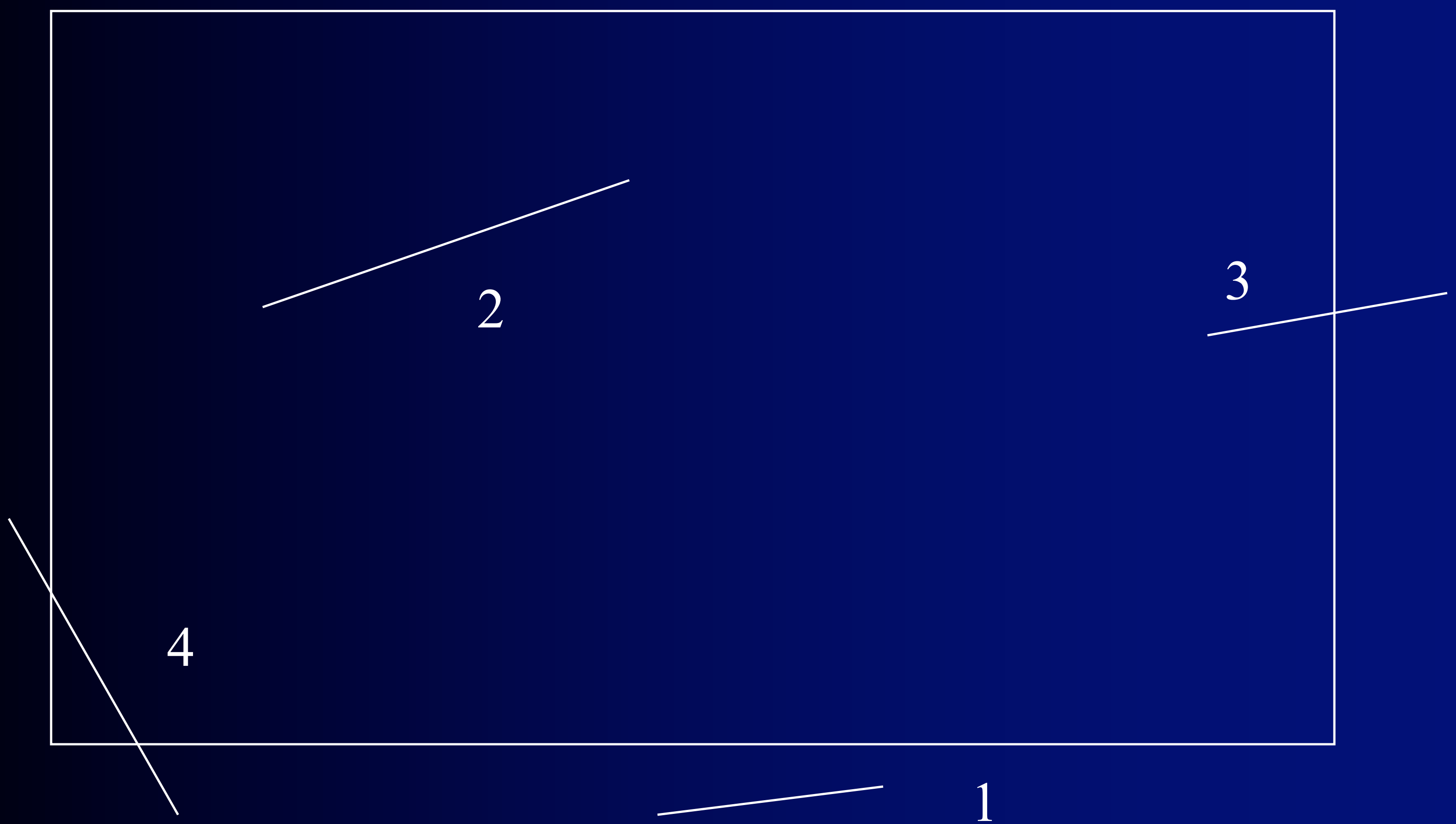
- Image Space:
  - The pixel-level representation of the complete image.
- Clipping
  - For each pixel, test if it is inside the visible region
  - If buffer is 320x200, test 0-319 in x, 0-199 in y.
- Evaluation
  - Easy to implement
  - Works for all objects: lines, pixels, squares, bit maps
  - Works for subregions
  - Expensive! Requires overhead for every point rendered if done in software
  - Cheap if done in hardware (well the hardware cost something)

Object Space Clipping

- Object space:
  - Analytical representation of lines, polygons, etc.
- Clipping
  - Change object to one that doesn't need to be clipped (e.g., shorten the line)
  - New object is passed to render engine without any testing for clipping
- Evaluation
  - Usually more efficient than image space software
    - But hardware support of image space is fast
  - Need different algorithm for different types of objects
    - Lines are easy. Concave objects are problematic
    - Usually just worry about bitmaps



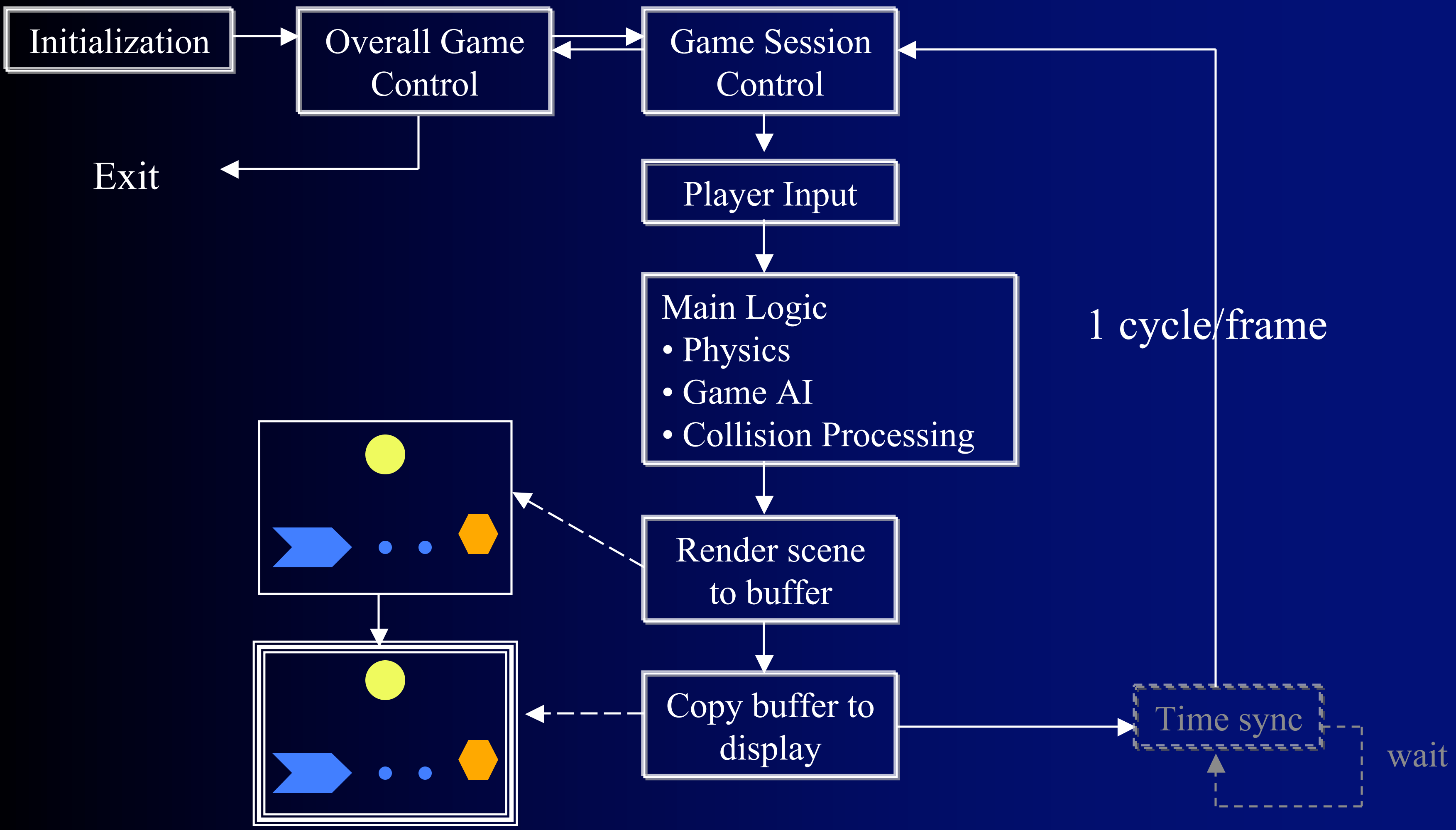
Line Clipping Cases



Arcade Games

- Examples
  - Missile Command, Space Invaders, Breakout, Centipede, Pac-Man, Frogger, Tempest, Joust,
- Important Traits:
  - Easy-to-learn – simple controls
  - Move objects around the screen
  - Single-screen – or simple scrolling
  - Infinite Play
  - Multiple Lives
  - Scoring – highest score
  - Little to no story

Game Loop



Initialization

Overall Game Control

Game Session Control

Exit

Player Input

Main Logic
- Physics
- Game AI
- Collision Processing

1 cycle/frame

Render scene to buffer

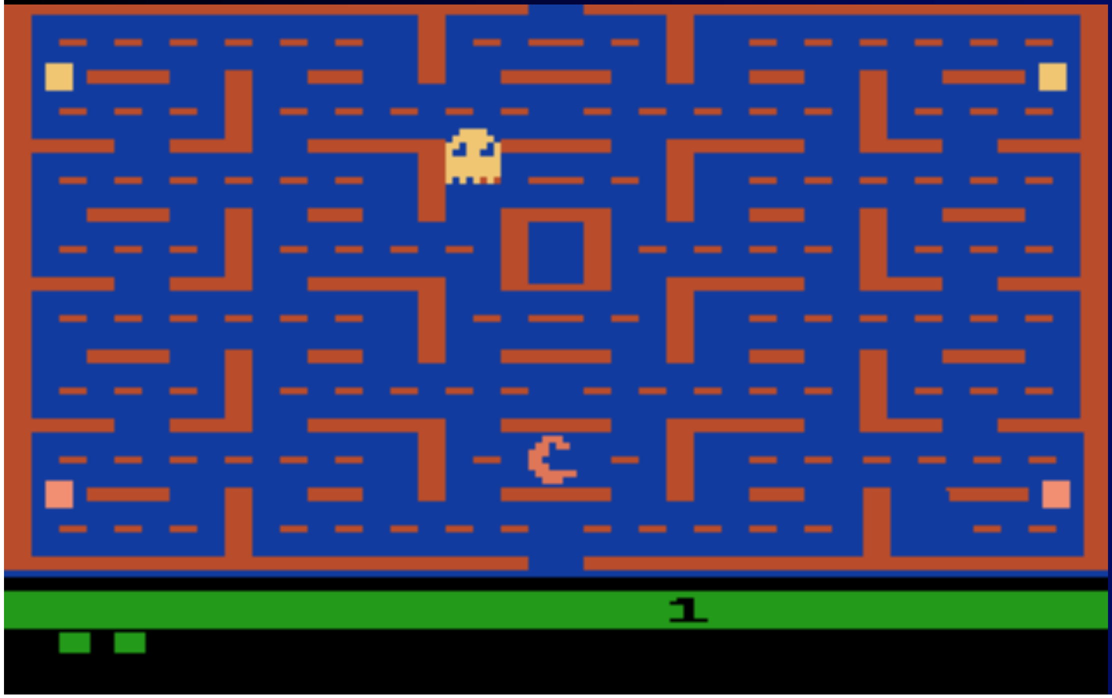
Copy buffer to display

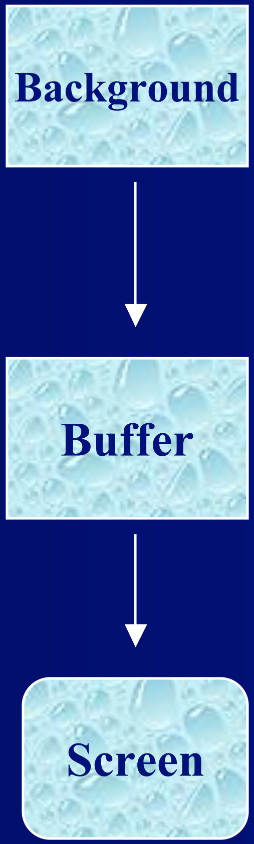
Time sync

wait

Static Objects

- Background, frame, fixed building, maze structure, …
- Draw only once
- Can be very complex





Background

Buffer

Screen

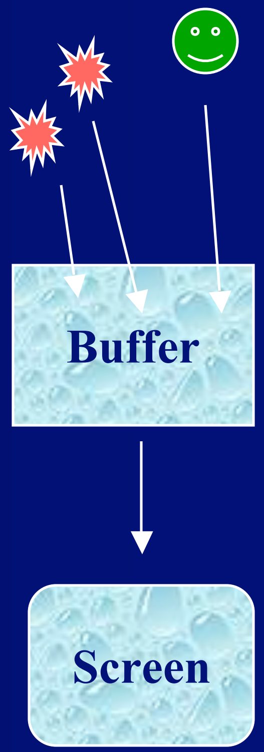
Dynamic Objects: Sprites

Usually small number of pixels

Most be draw on screen 30 times/second

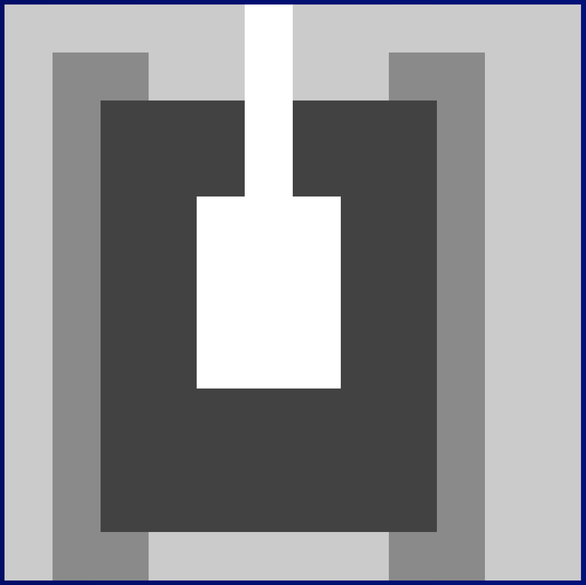
  - Save background that sprite covers

- Player’s Sprite
  - Paddle, gun, tank, …
  - User can move it, turn, shoot, …
- Game Sprites
  - All of the other objects in the game that move
  - Bullets/missiles shot by player
- Most common interaction is collision
  - Fast collision detection is important



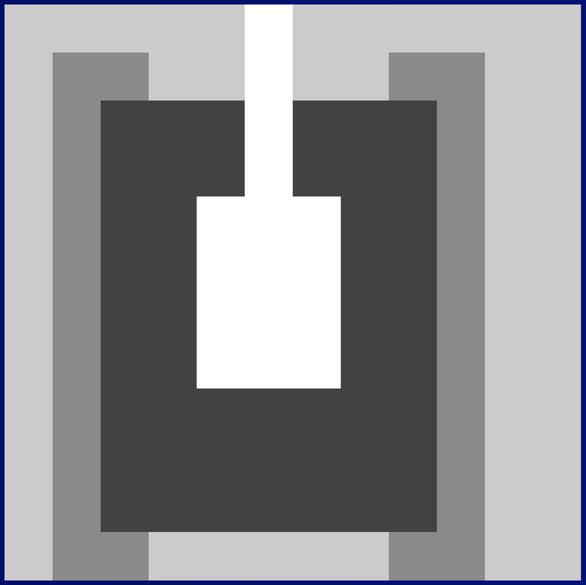
Sprites:

- Object that moves around, displayed as a bit map
  - NxM pixels:12 x 12 = 144. 100 x 100 = 10,000.
  - Displayed on a background



Sprite Data

- Static
  - Size
  - Image sets
  - Weapons, shields, worth, ...
- Dynamic
  - Position
  - Velocity
  - Pose
  - Current image
  - Strength, health, ...
  - Saved background

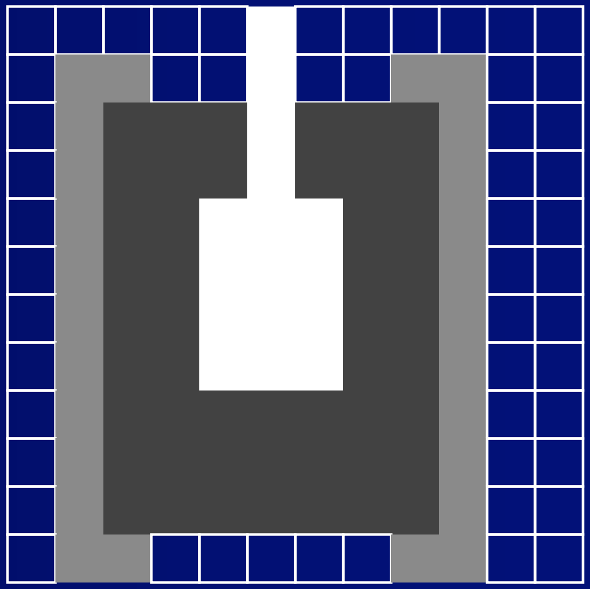


Creating Sprites

- Create Sprite in 2D or 3D drawing package
  - 2D
    - Gimp
    - Photoshop
    - Corel’s Paint Shop Pro (was JASC) or Painter (was Fractal Design)
  - 3D
    - Blender 3D
    - Milkshape 3D
    - 3D Studio Max
    - Maya
- Save as file

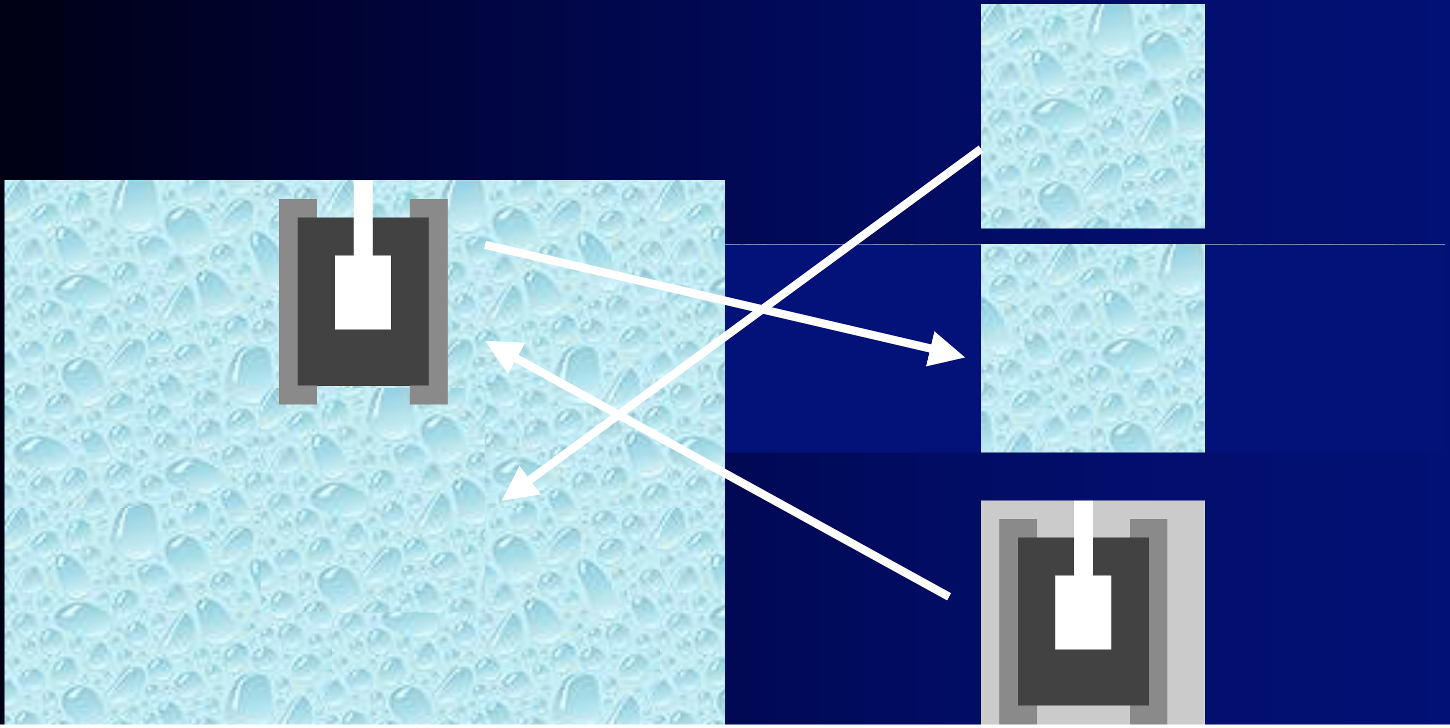
Drawing the Sprite

- Some parts of the sprite are transparent
  - Use a special code (255) to be transparent
  - When drawing the pixels, don’t copy that code
  - Is expensive because done for every pixel
- Some sprites have no transparencies
  - Can have separate draw function
  - Avoid test for transparency



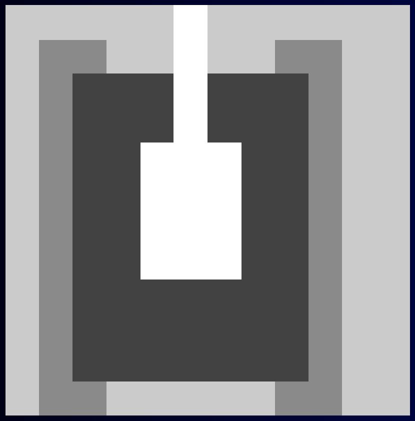
Sprite Movement and Display

- Compute new position of Sprite
- If Sprite moved, erase Sprite by restoring saved background
- Save background where Sprite will go
- Draw Sprite

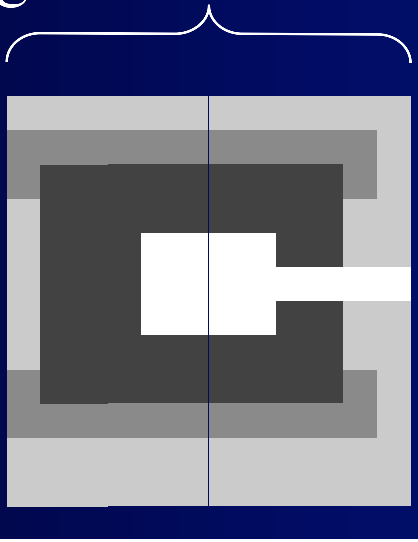


Run-Length Encoding

- Compress Sprites in files using “run-length encoding” (RLE).
  - Instead of representing every pixel, encode number of consecutive pixels of same kind in a row
  - Big win if lots of same color in a row (transparent)
  - Doesn’t capture vertical or 2D structure well.
- Not so good:



Long runs of same color



- Much better:

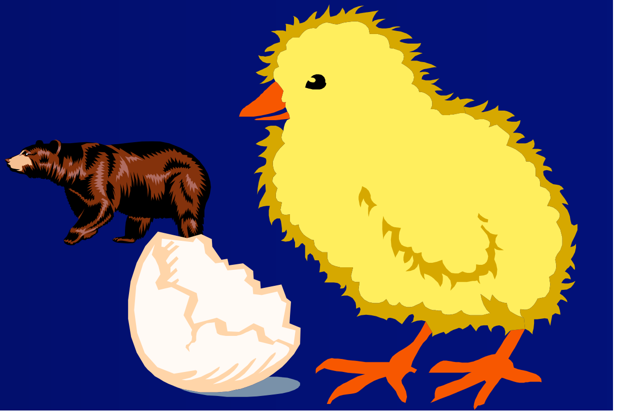
12 ■ 11 ■ 1 ■ 1 ■ 9 ■

Sprite Scaling

- Used to show change in depth (distance)
- Options:
  - Dynamic computation
    - Can lead to very blocky pictures when they get big
  - Pre-store different sizes
    - Hard to get large numbers of intermediate sizes
  - Pre-store different sizes for major size changes: x2
    - Dynamically compute intermediate sizes
- Supported in Direct-X (in hardware and software)

Depth

- Can fake depth by scaling but what if overlap?
  - Want closer objects to cover distant objects
  - Associate depth with each Sprite - usually small number
- Image space solution
  - Maintain shallowest depth rendered
  - Add pixel if closer than previous
  - Lots of work at each pixel if in software
  - Hardware Z-buffer to rescue - standard for game machines
- Object space solution
  - Sort objects by depth
    - O(#_of_objects * log(#_of_objects))
  - Draw back to front



Sprite Rotation

- Store each orientation as a separate bit map
  - 16 different pictures is reasonable start

  - Pick the closest one to the current orientation
- Calculating from scratch usually too slow
- Sometimes supported by hardware

Sprite Animation

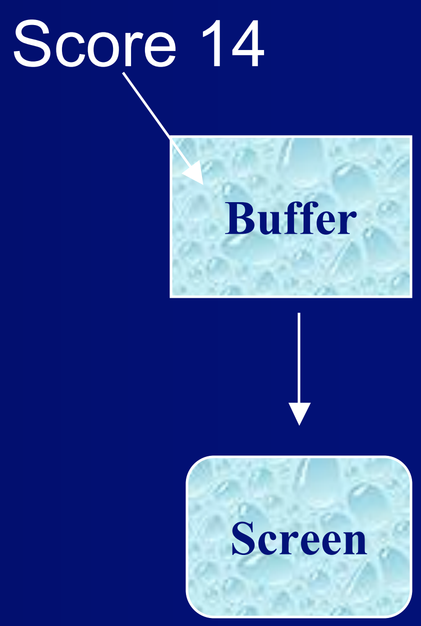
- Changes in the display as state of object changes
  - Example: standing, sitting, jumping, singing, shooting

- Choose the current bit-map based on object state
  - Might require separate timer for animation changes

- Storage if including rotation
  - #_of_bitmaps = #_of_angles * #_of_states

Semi-static Objects

- Rarely changes, doesn’t move
- Examples: Walls that can be damaged
- Change drawing on screen or buffer
- Not worth redrawing every cycle
- Do not have to save background



Score 14

Buffer

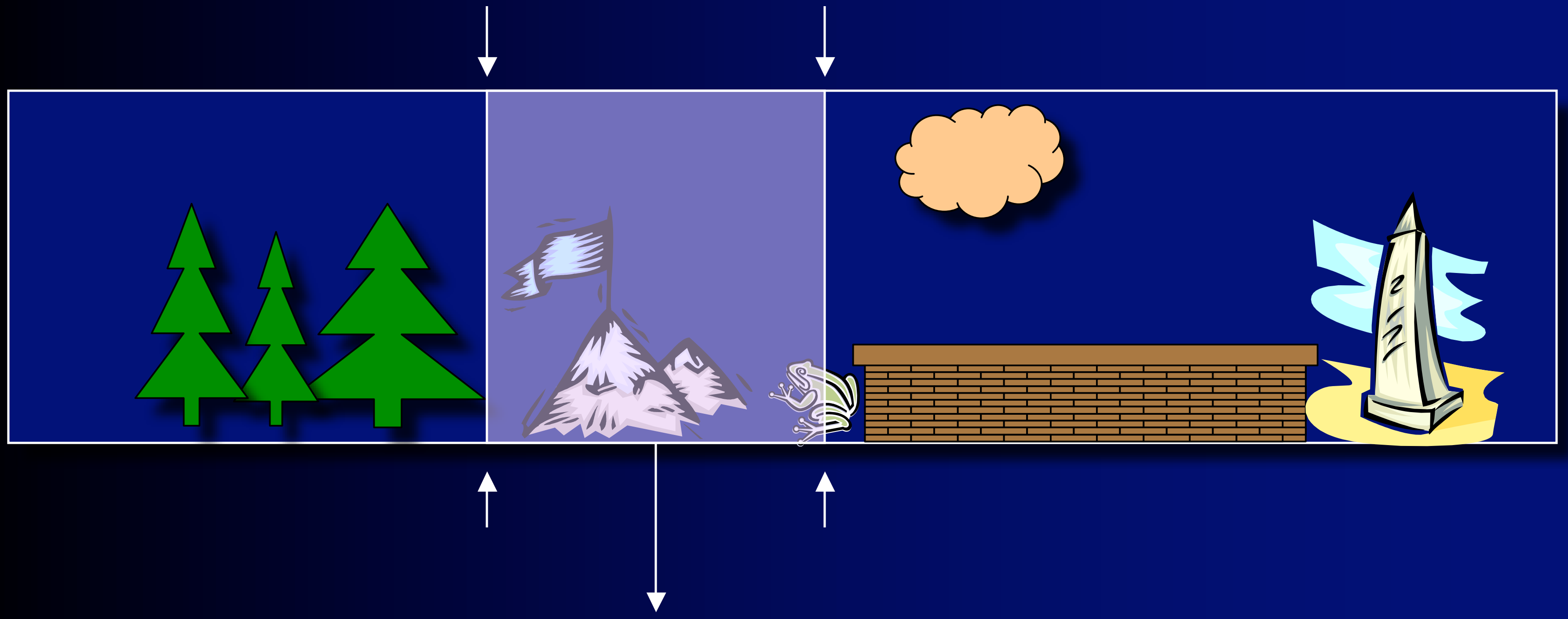
Screen

Dynamic Background

- If the background is scrolling or changing a lot
  - Redraw complete buffer from scratch
  - Avoid saving background for sprites
  - More drawing
- Either
  - Draw from back to front
  - Draw using z-buffer or z-list

Scrolling - simple

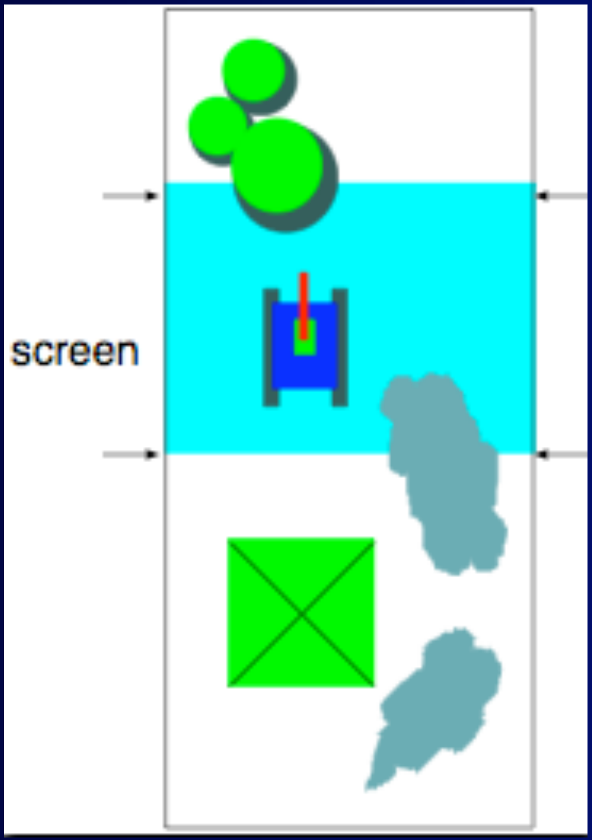
Horizontal scrolling: usually side view of world



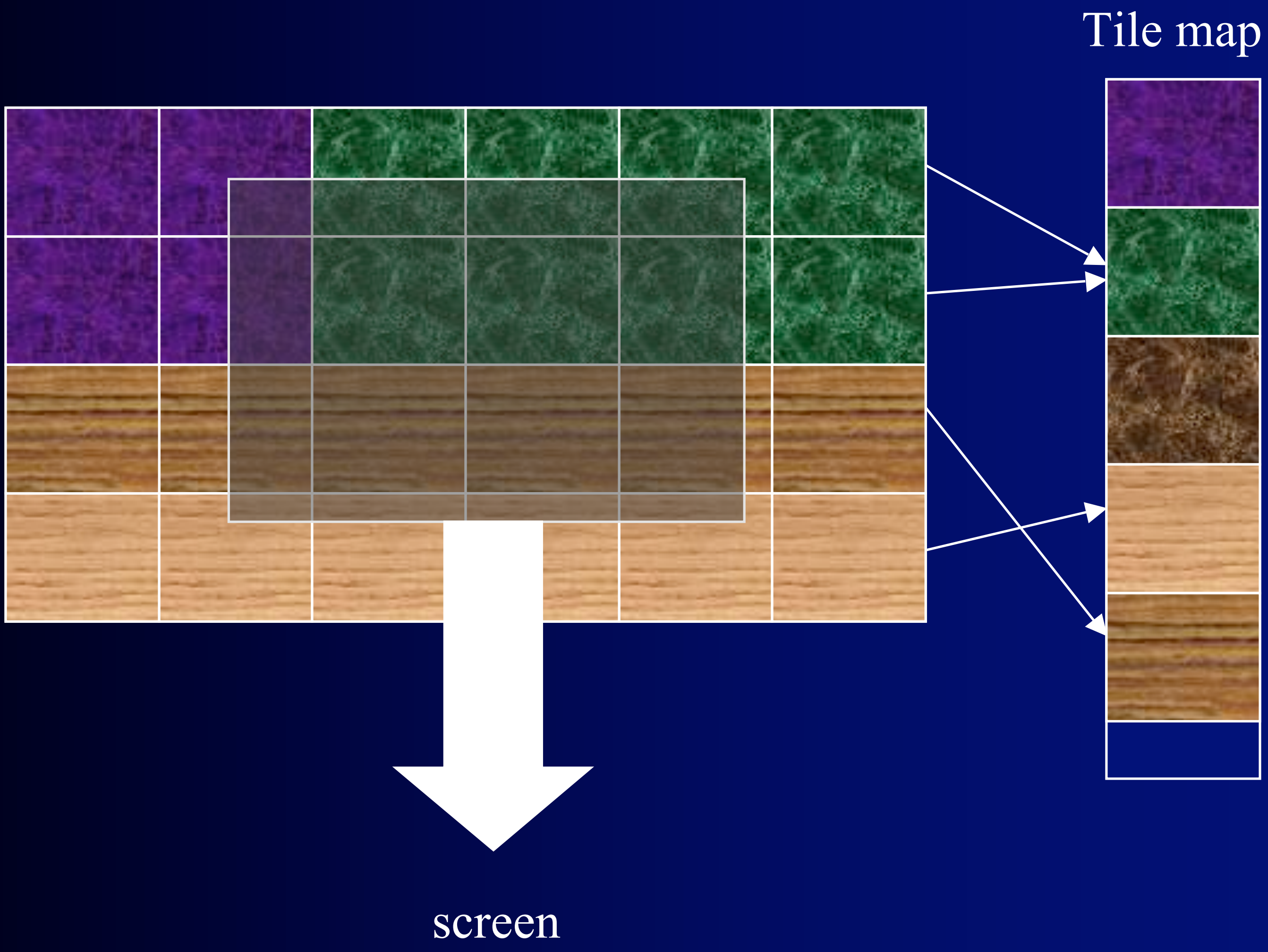
screen

Scrolling - simple

Vertical scrolling: usually top view of world

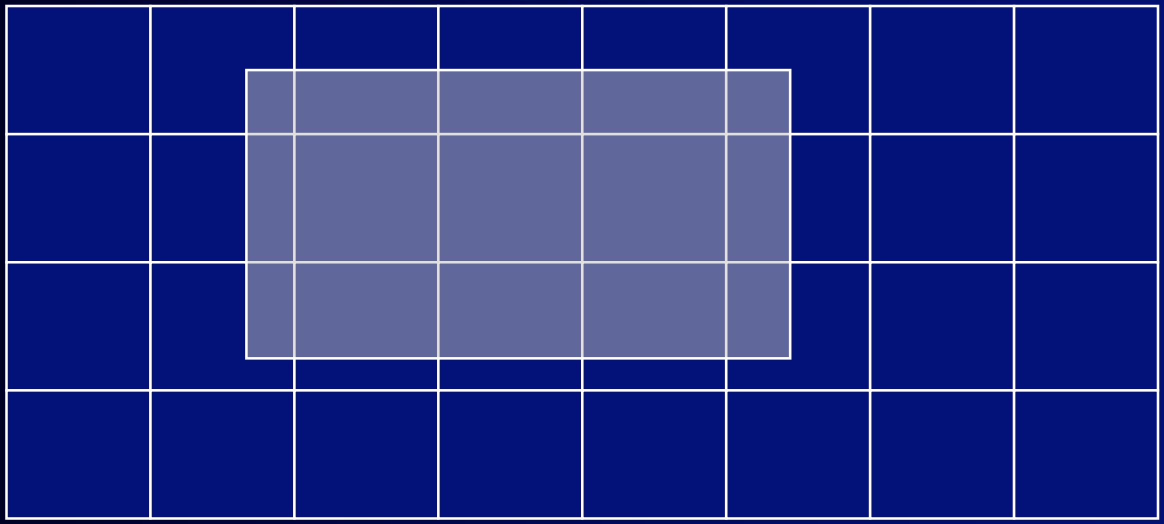


Scrolling – Tile Based



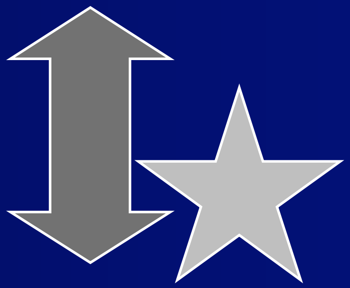
Scrolling – Sparse

- Object-based
  - Keep list of objects with their positions
  - Each time render those objects in current view
  - Go through list of object – linear in # of objects
- Grid-based
  - Overlay grid with each cell having a list of objects
  - Only consider objects in cells that are in view



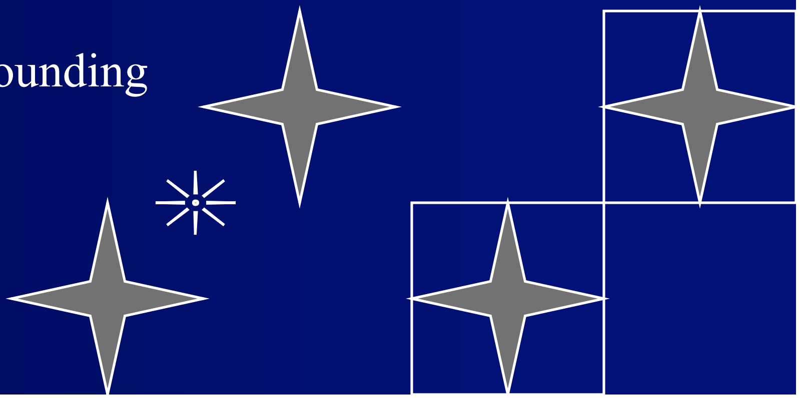
Collision Detection

- Image Space:
  - Pixel by pixel basis. Expensive.
- Object Space:
  - Hard for complex and concave spaces:



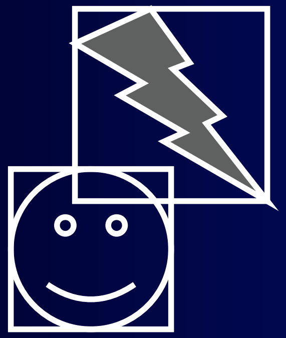
- Standard Approach:
  - Cheat!
  - Create a bounding box or circle
    - test each vertex to see in another object

  - Hide this by making your objects boxy
  - Don’t have objects like:
    - Can use multiple bounding shapes and bounding areas



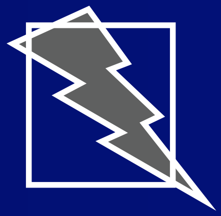
Sprite Collisions

- Easiest:
  - Use the bounding box that includes all the pixels

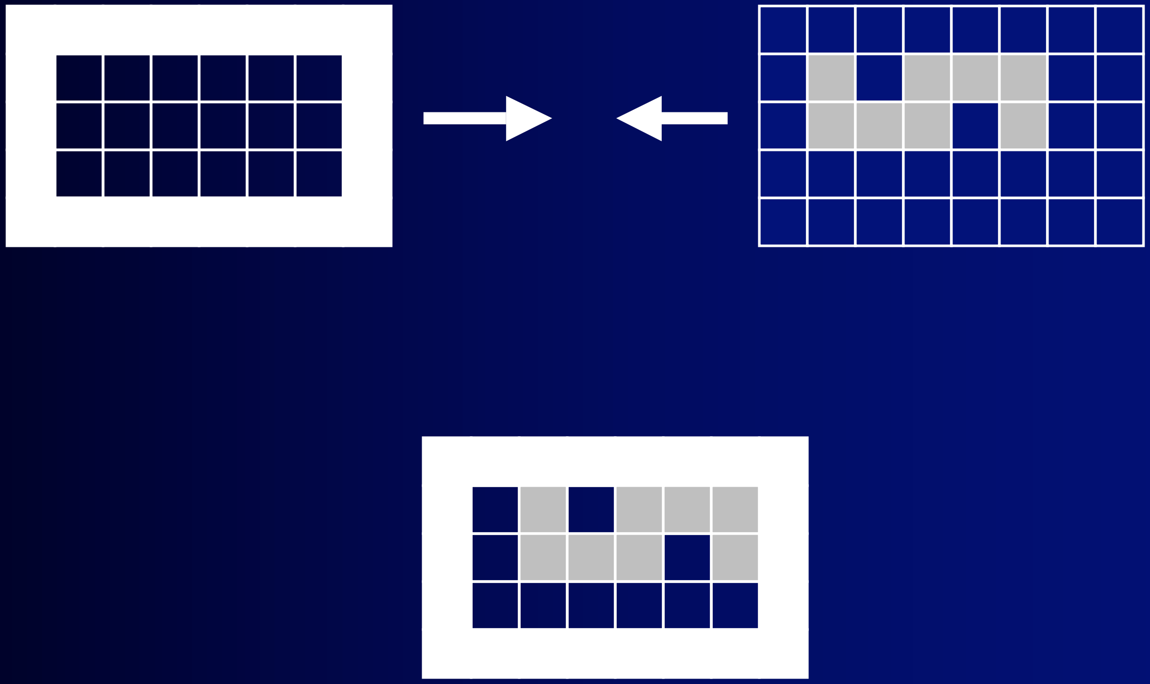


Test if vertex of one in bounding box of other

- Tricky:
  - Use something a little smaller to avoid some fake collisions
  - If things happen fast enough, people can’t tell
- Almost right but expensive:
  - Test if non-transparent pixels overlap
  - Can still miss some cases...



Collision?



Be extra careful if variable time step is used in game loop