Arcade Games: Architecture and 2D Graphics

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Arcade Games

- Examples
  - Missile Command, Space Invaders, Breakout, Centipede, Pac-Man, Frogger, Tempest, Joust, …
- Game Definition
  - 2D environment
    - Move objects around screen in 2D
    - Major interaction is via collisions
  - Simple rules
    - Rules embedded in physics of game
  - Simple goals
    - Hit things: get points
    - Avoid getting hit: stay alive

Important Traits of Arcade Games:

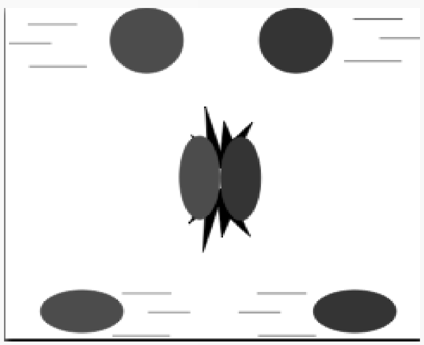
- Easy-to-learn – simple controls
- Single-screen – or simple scrolling
- Often Infinite Play
- Multiple Lives
- Scoring – Highest score
- Little to no story

Game Engine = World Simulation

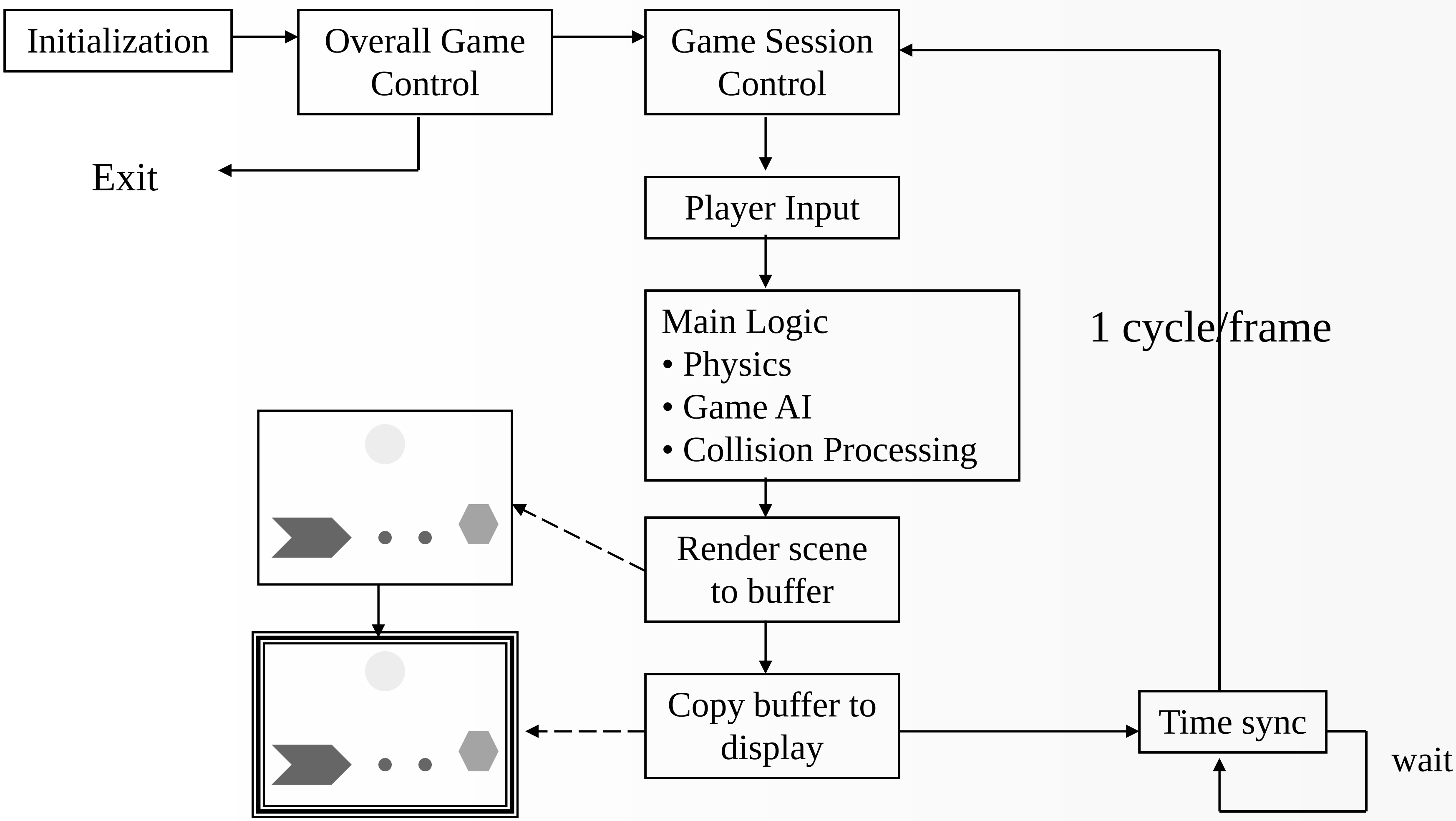
Discrete simulation: each cycle computes a ``snapshot" of the world

Difference between a technical simulation and a game:

- Continual behavior
  - Not just run a program and get an answer
- Real-time and highly interactive
  - Update at around 30 times/second
  - Necessary to avoid clunky action or missed player input
  - Rendered time always lags behind real time/game time by at least 1 frame
  - Consistency is important (to both)
- Simple physics: velocity, elastic collisions
  - Usually no mass, accelerations, momentum

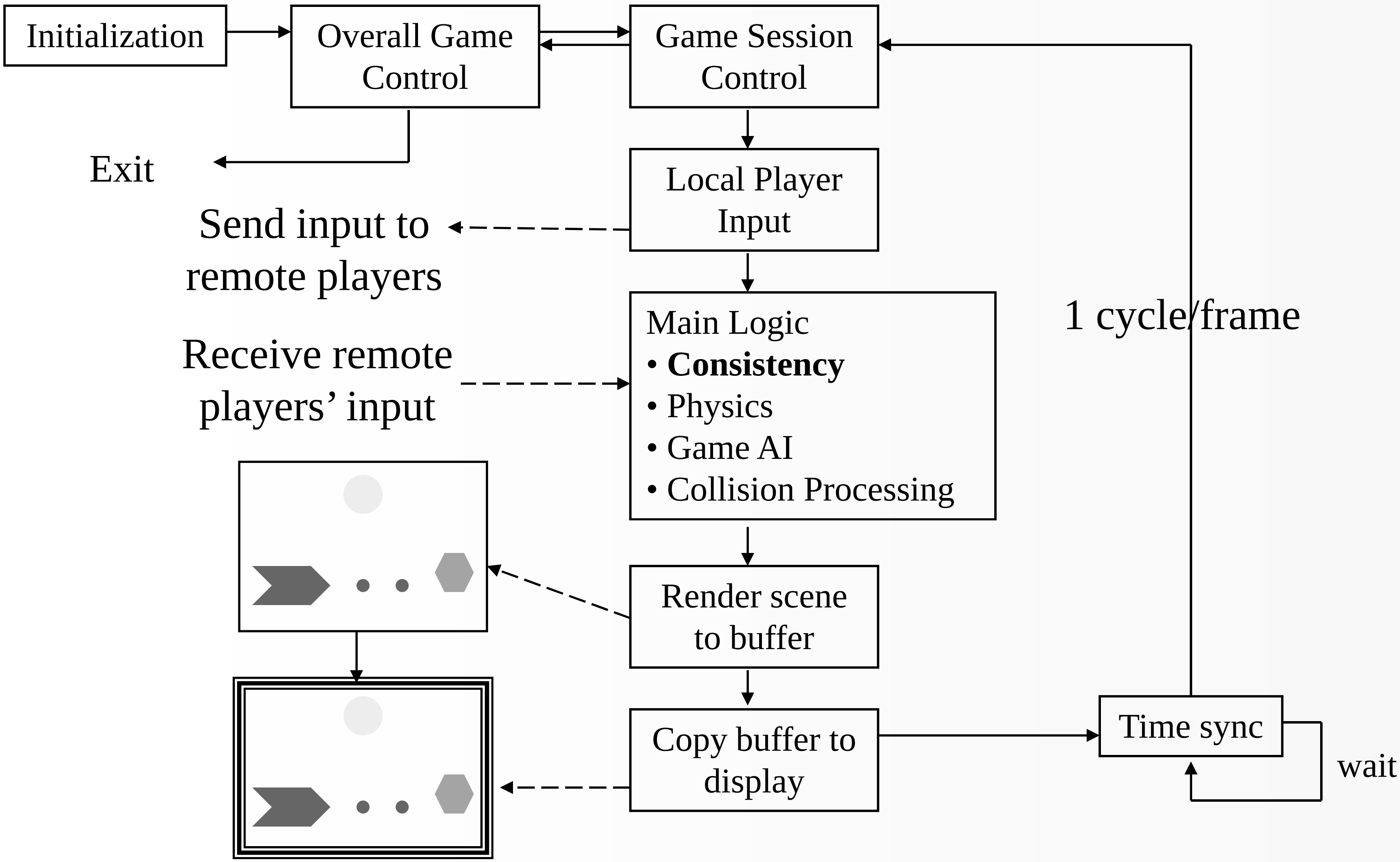


Game Loop



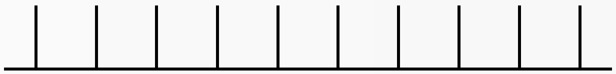
Initialization
Overall Game Control
Game Session Control
Exit
Player Input
Main Logic
• Physics
• Game AI
• Collision Processing
1 cycle/frame
Render scene to buffer
Copy buffer to display
Time sync
wait

Multi-player Game Loop

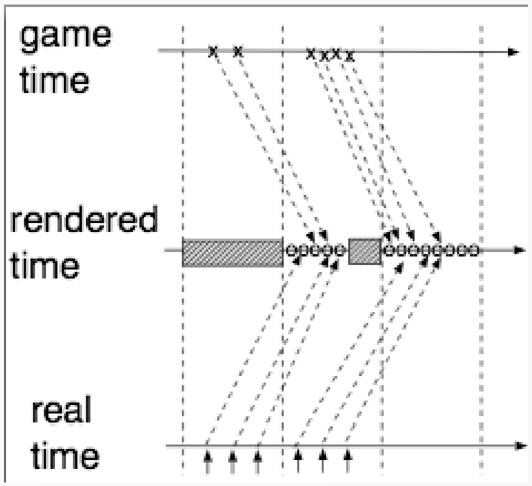


Simulation Types: Fixed Discrete

- Fixed Discrete (tied to real time)
  - Update world model each time step
  - Each time step is same size
  - Wait if done too early
  - Detect interactions by examination
- Pros:
  - Simpler physics
  - Smoother graphics
- Cons:
  - Computation must fit into time step
  - Time step limits max frame rate



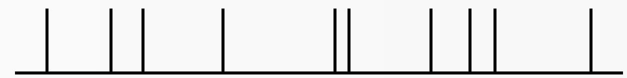
Game events



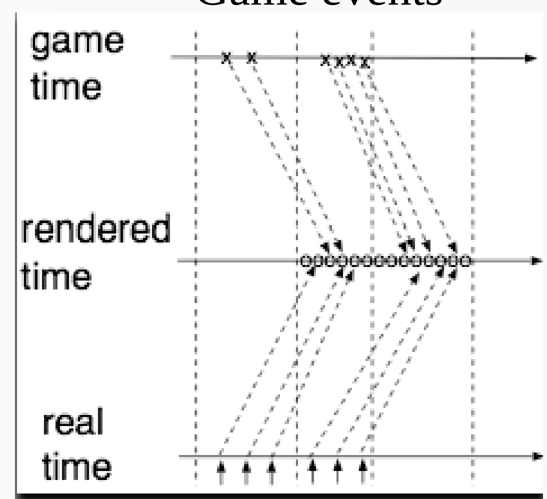
User inputs

Simulation Types: Variable Discrete

- Variable Discrete
  - Time steps are variable
  - dictated by amount of computation
  - fast as possible
- Pros:
  - No busy wait
  - Faster hardware gives smoother interaction and higher frame rate
- Cons
  - Requires a little bit more work on physics calculation
  - Jerky motion if frame rate too low



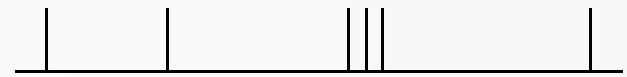
Game events



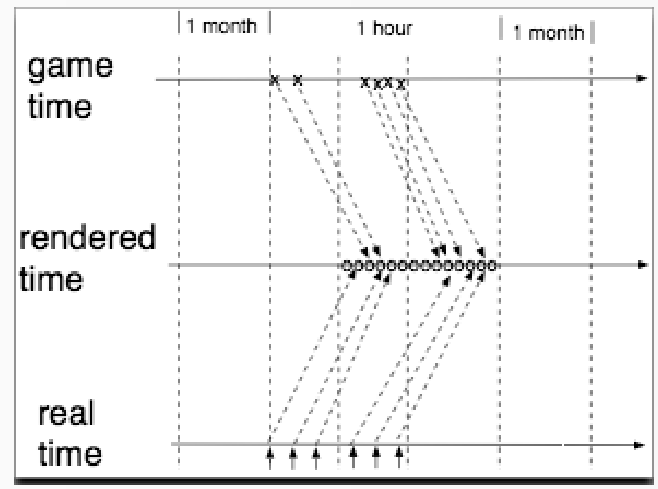
User inputs

Simulation Types: Event Based

- Event-based
  - Skip ahead to next predicted event (collision)
  - Game time stretches and contracts as necessary
  - Computed analytically
  - Not suitable for real-time interactive game
  - But can be used with some “simulation” game (fast forward to when the ship reaches port or meets pirates)

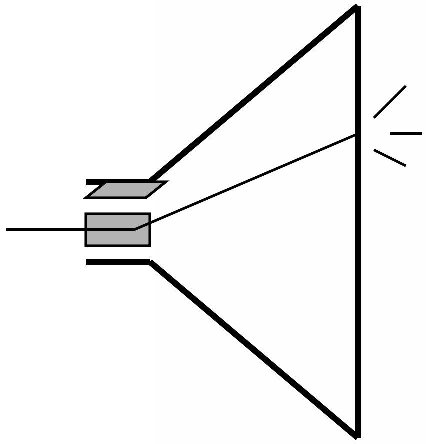


Game events

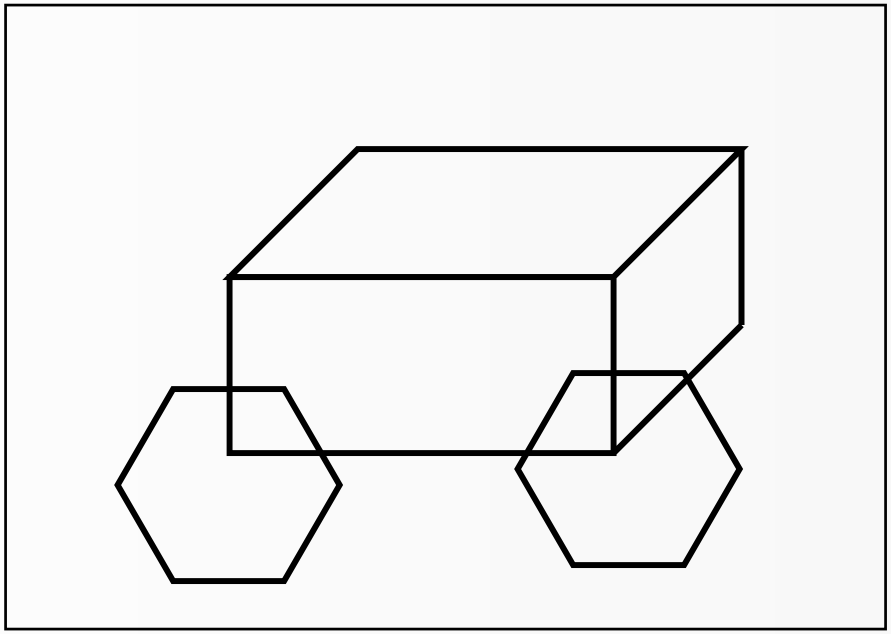


User inputs

Vector Graphics



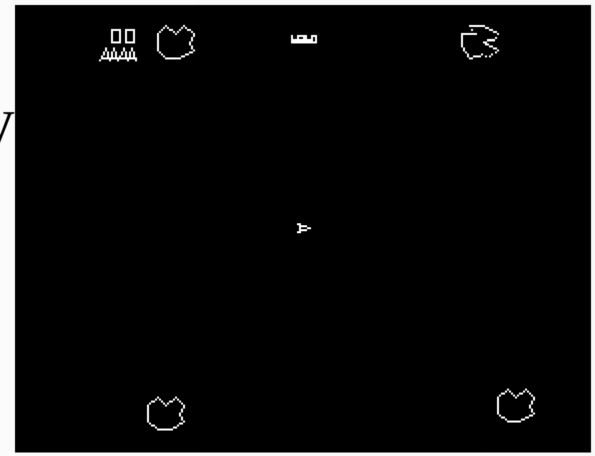
Directly control electronic gun of CRT



- Drawings defined as lines
- Lines stored as endpoints
- Look like wireframes
- No curved lines
- Limited variation in color or intensity.

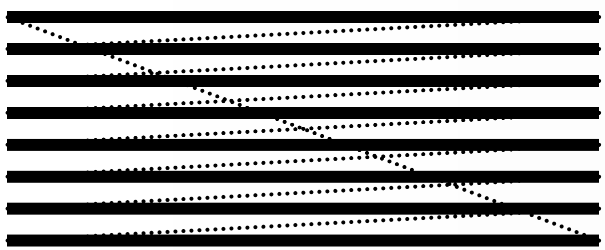
History of 2D graphics: Vector

- Example: Asteroids, Battlezone
  - http://www.squadron13.com/games/asteroids/asteroids.htm
- Advantages:
  - Control the electronic gun directly
  - Only draw what is on the screen
  - No jagged lines (aliasing)



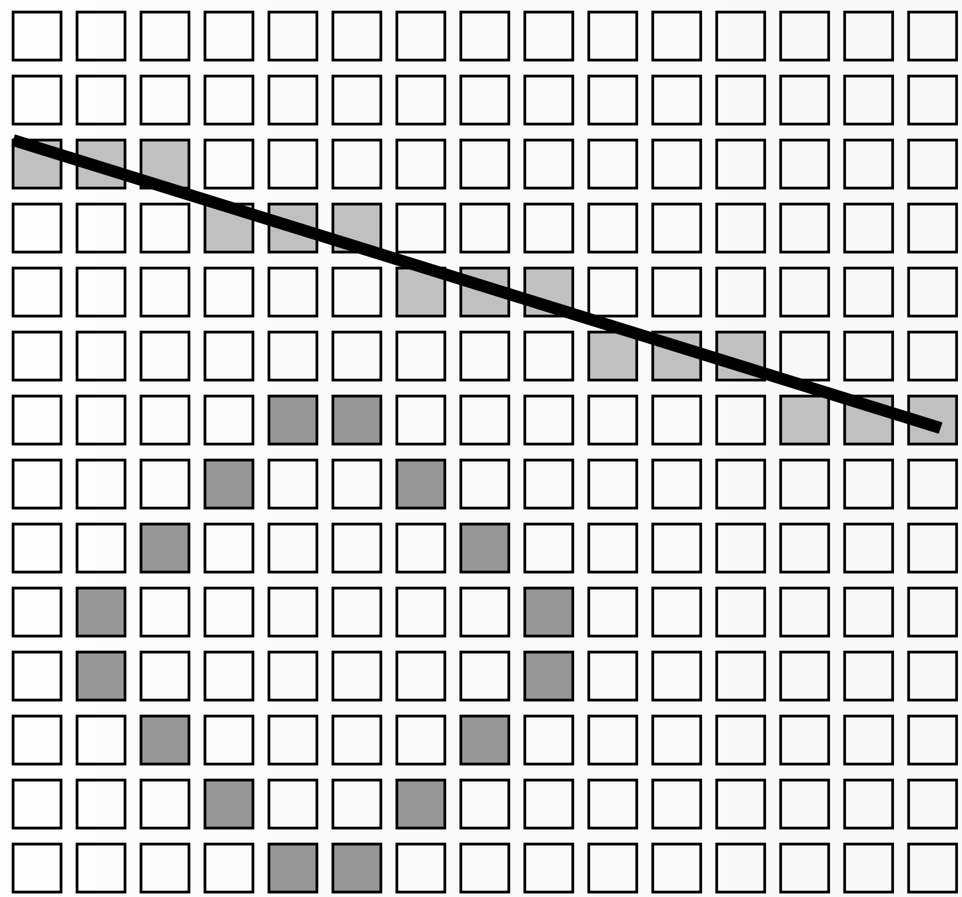
- Problems:
  - Hard to draw filled objects
  - Must draw everything as lines: text, circles, surfaces, ...
  - $$'s: Can't use commercial TV technology
- Example Displays:
  - Textronics, GDP

Raster Graphics



Screen is made up of “picture elements” = pixels.

Color defined by mixture of 3-guns: Red, Green, Blue



Raster Graphics

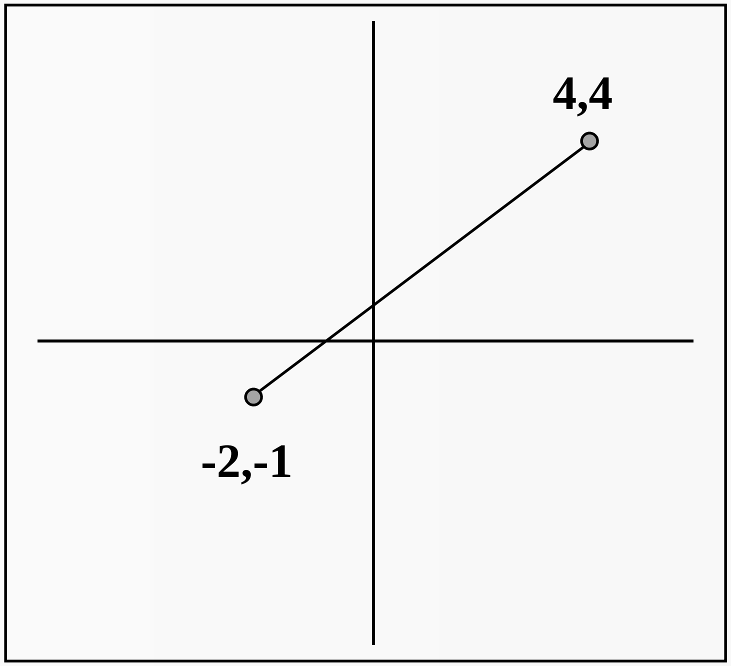
- Advantages:
  - Cheaper
  - Can easily draw solid surfaces
  - Maps screen onto 2D memory
  - Can move blocks of image around, control individual pixels
- Problems:
  - Memory intensive
  - Aliasing problems

Current Approach

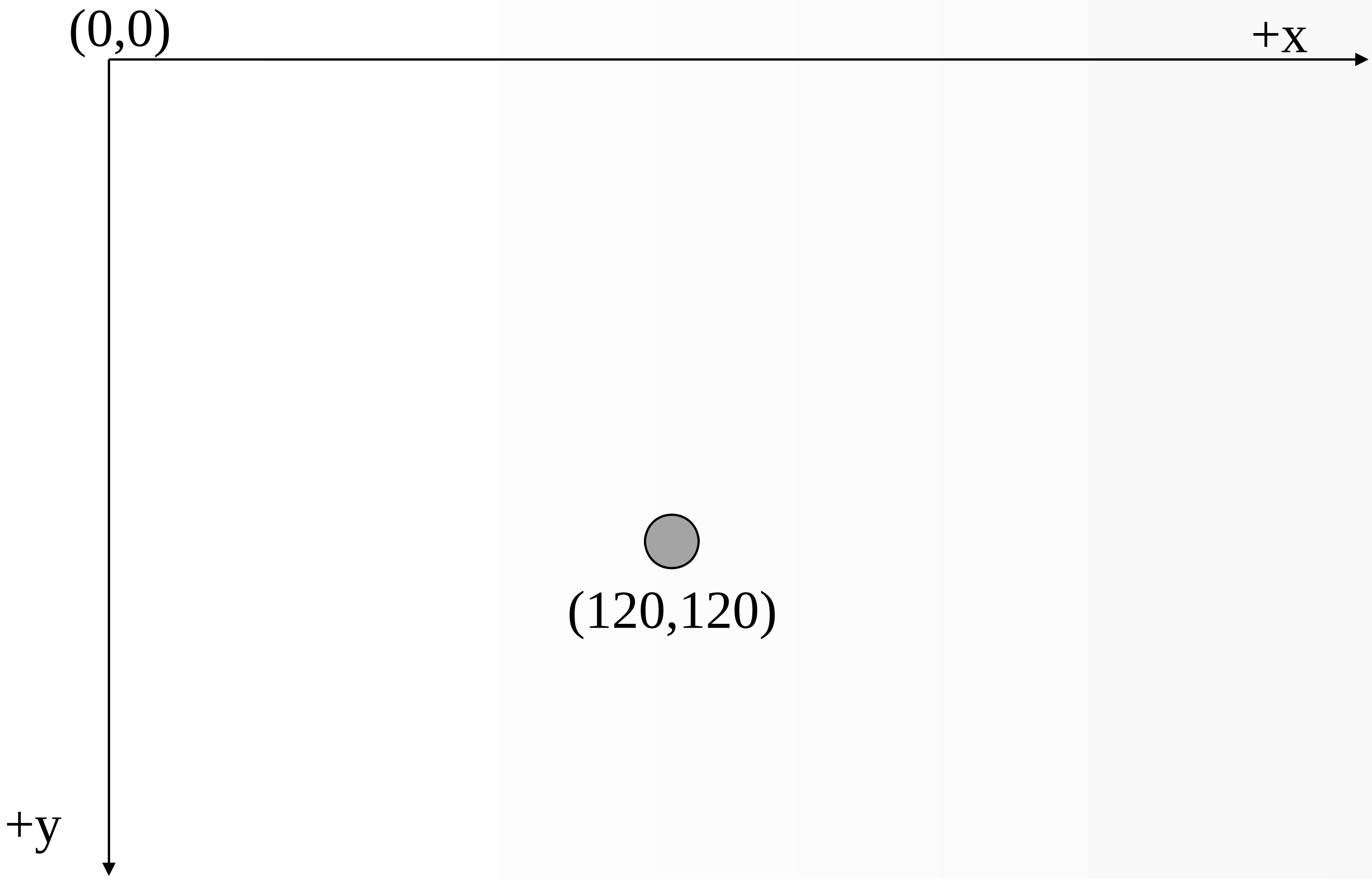
- Use Raster Graphics as underlying technology
  - Memory is cheap!
  - Get access is every point on the screen
- Create drawing primitives similar to vector graphics
  - Drawing lines, etc. with hardware support.
- Support surfaces, textures, sprites, fonts, etc. directly

2D Graphics

- Points
  - x,y
- Lines
  - Two points
  - Draw all points in between
  - Low-level hardware support



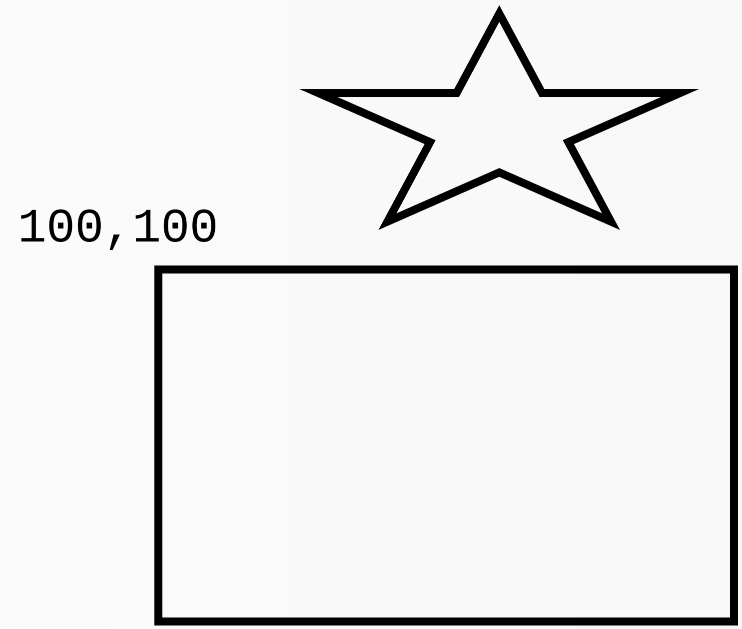
Coordinate System



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)



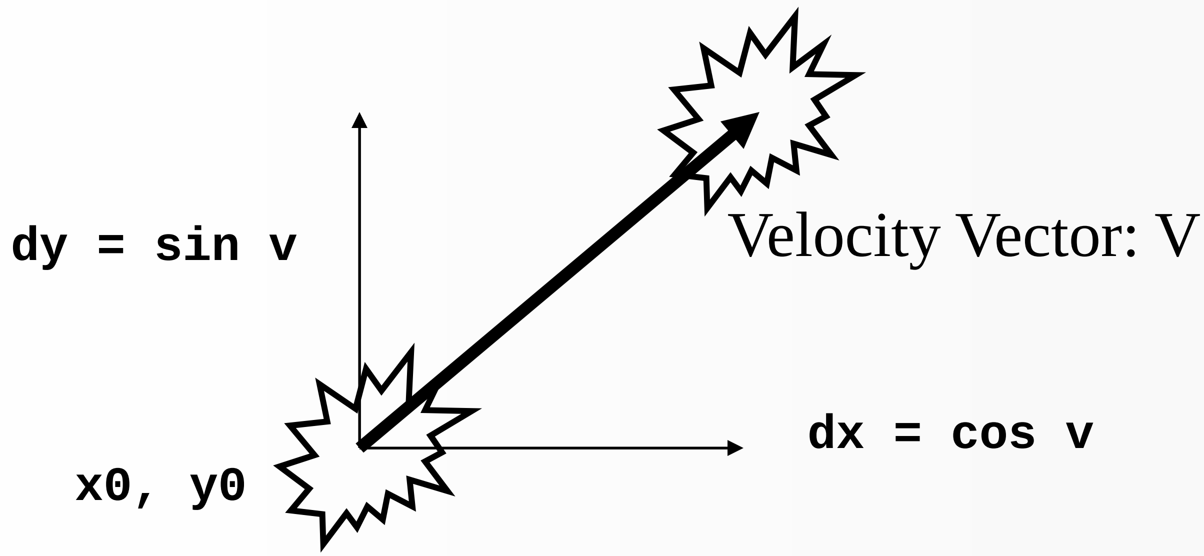

```
moveto(100,100)
lineto(100,300)
lineto(500,300)
lineto(500,100)
lineto(100,100)
```

Operations on Polygon

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

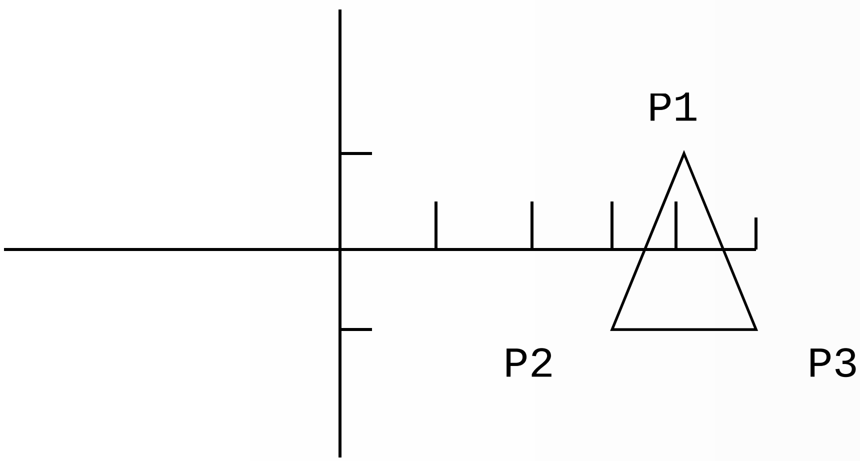
Translation: Moving an Object

- 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)

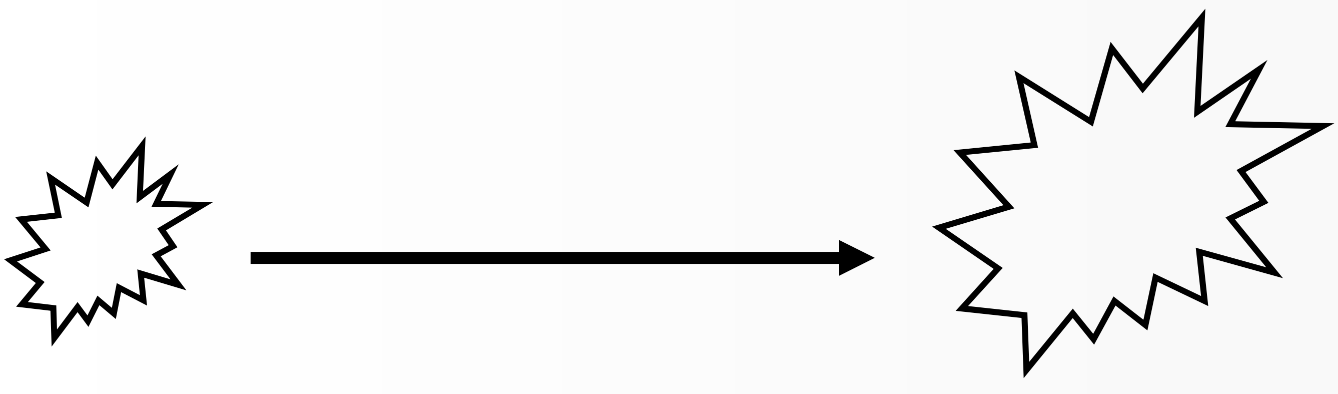


Triangle location: 4,0

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

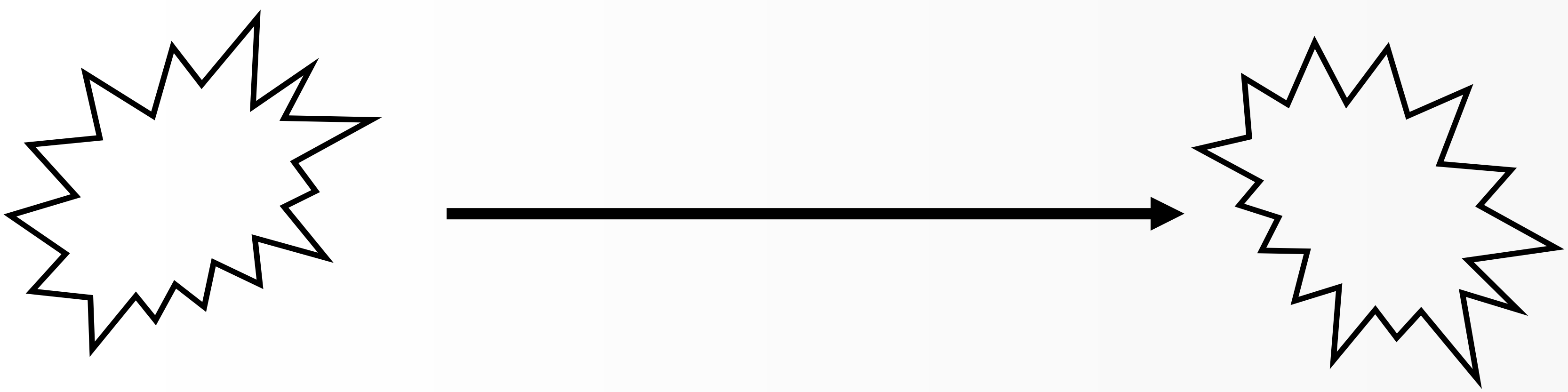
Scaling: Changing Size

- 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(angle) - y`$_0$` * sin(angle)`
- `y = y`$_0$` * cos(angle) + x`$_0$` * sin(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:

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

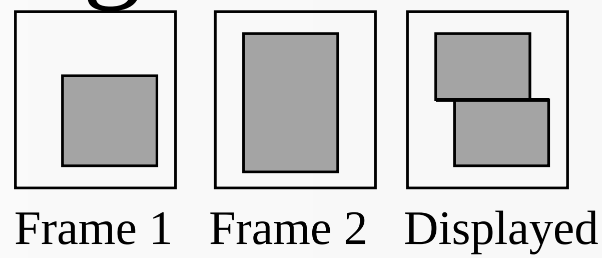
Putting it all together

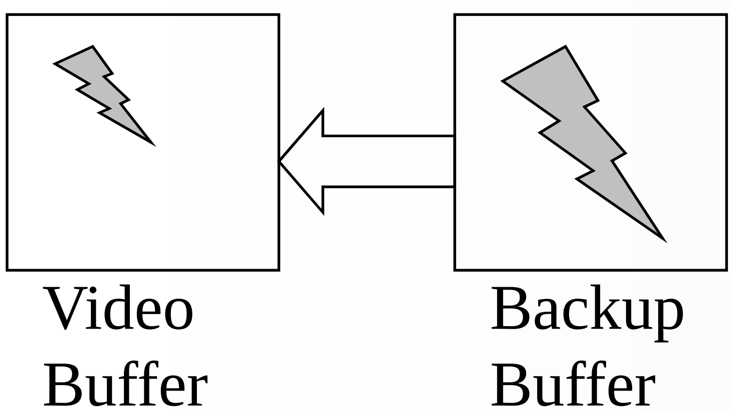
$$
\begin{vmatrix} x & y & 1 \end{vmatrix} \quad * \quad \begin{vmatrix} sx*cos & -sx*sin & 0 \\ sy*sin & sy*cos & 0 \\ dx & dy & 1 \end{vmatrix}
$$

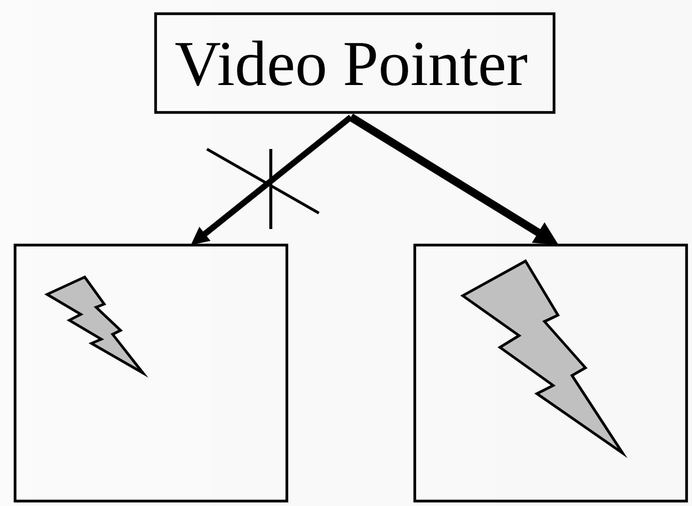
- Using Standard Trig functions
  - Use table look-up
  - Prestore all rotations you are going to need

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.

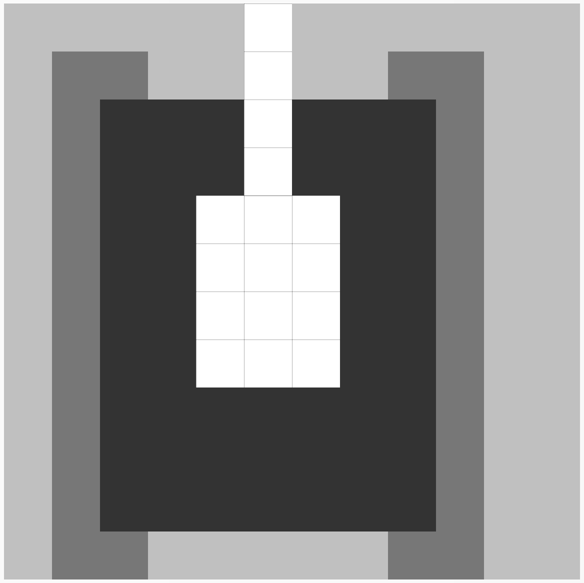






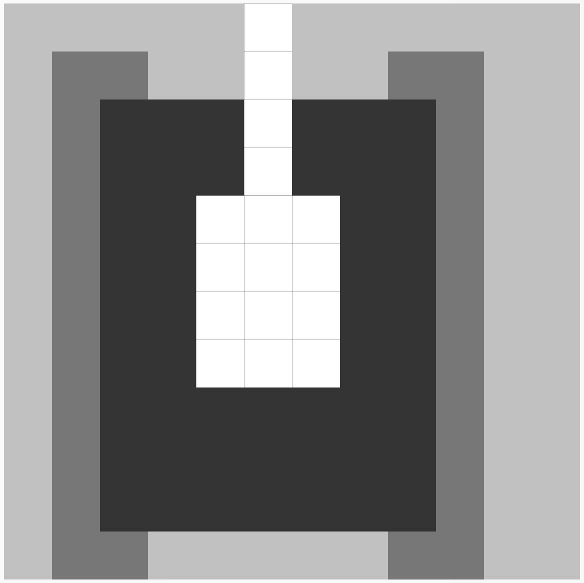
Sprites:

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



Sprite Data

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

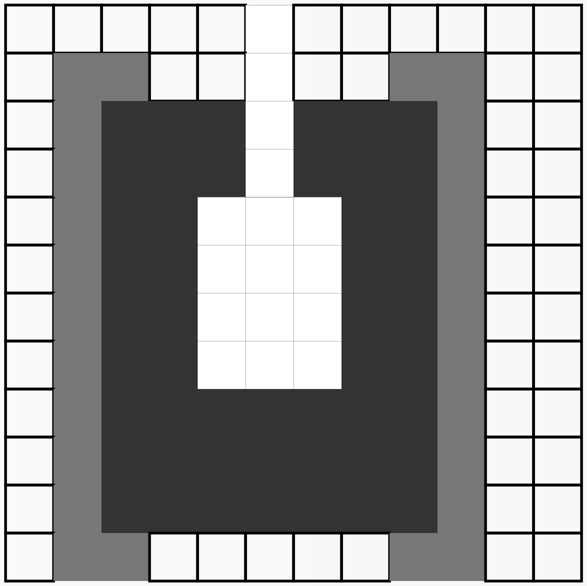


Creating Sprites

- Create Sprite in 2D or 3D drawing package
  - 2D
    - Gimp
    - Photoshop
    - Paint
  - 3D
    - 3D Studio Max
    - Maya
    - Blender 3D
    - Milkshape 3D
- Save as file

Drawing the Sprite

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

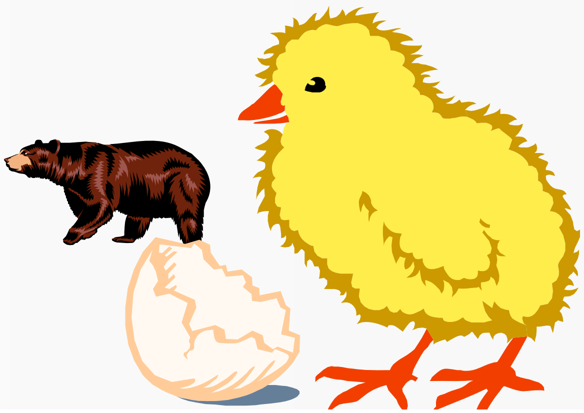


Sprite Scaling

- 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)

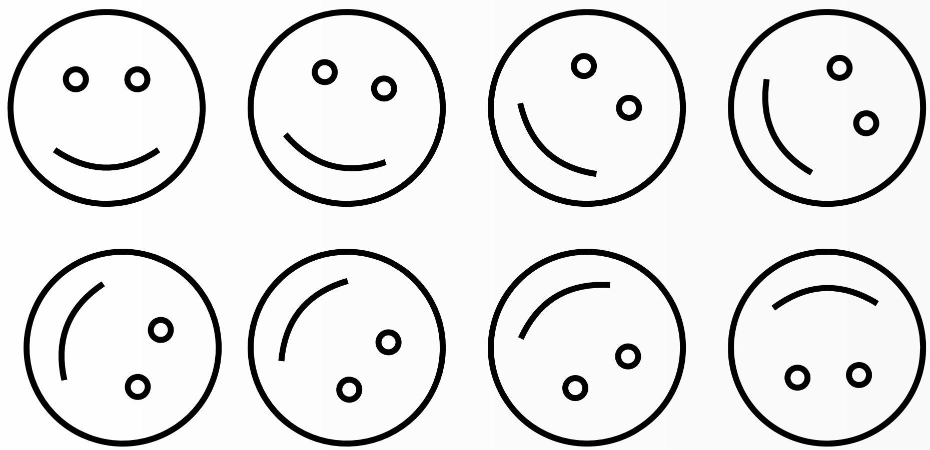
Depth

- 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 -
- 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

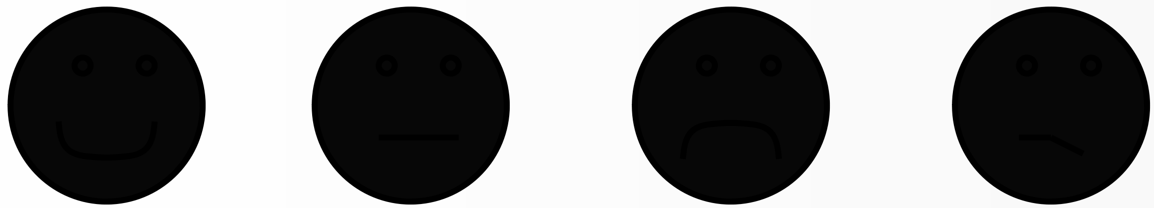


  - Pick the closest one to the current orientation
- Now supported by hardware

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



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

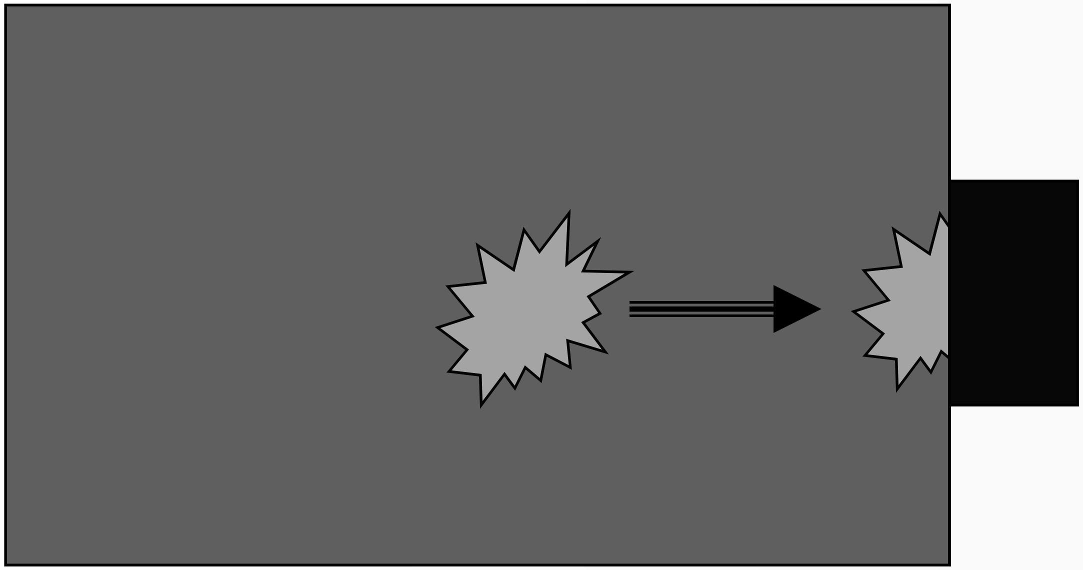


Image Space vs. Object Space

- 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

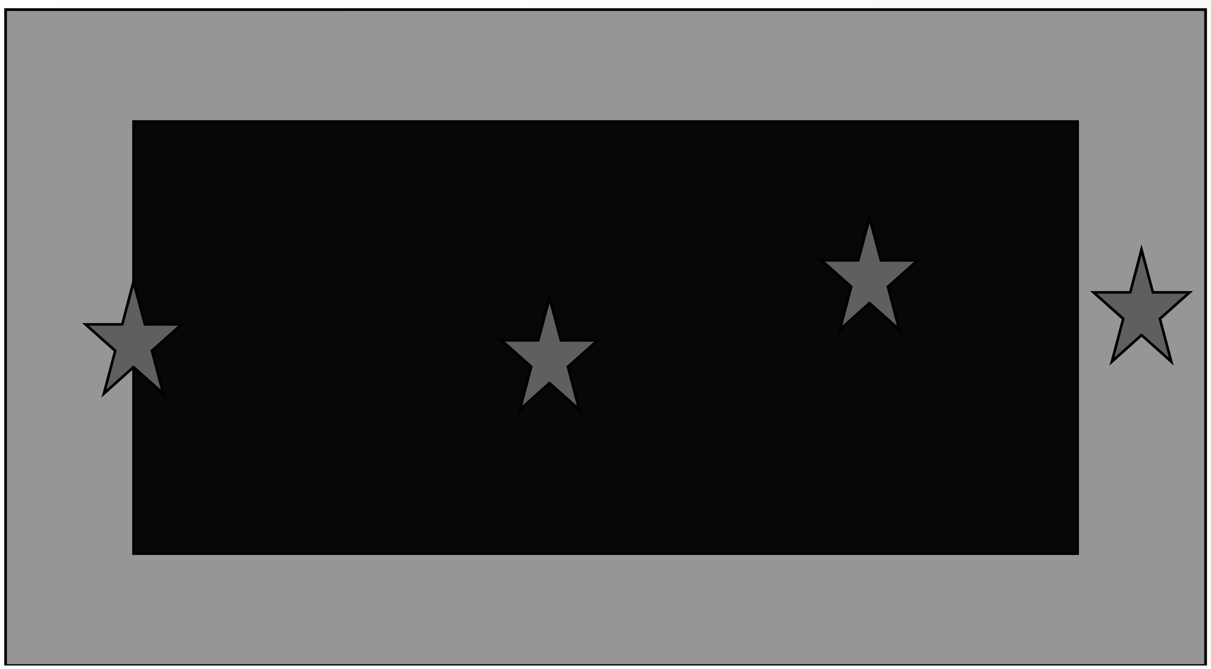
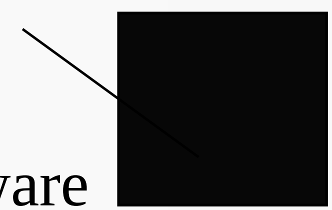


Image Space Clipping

- 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)

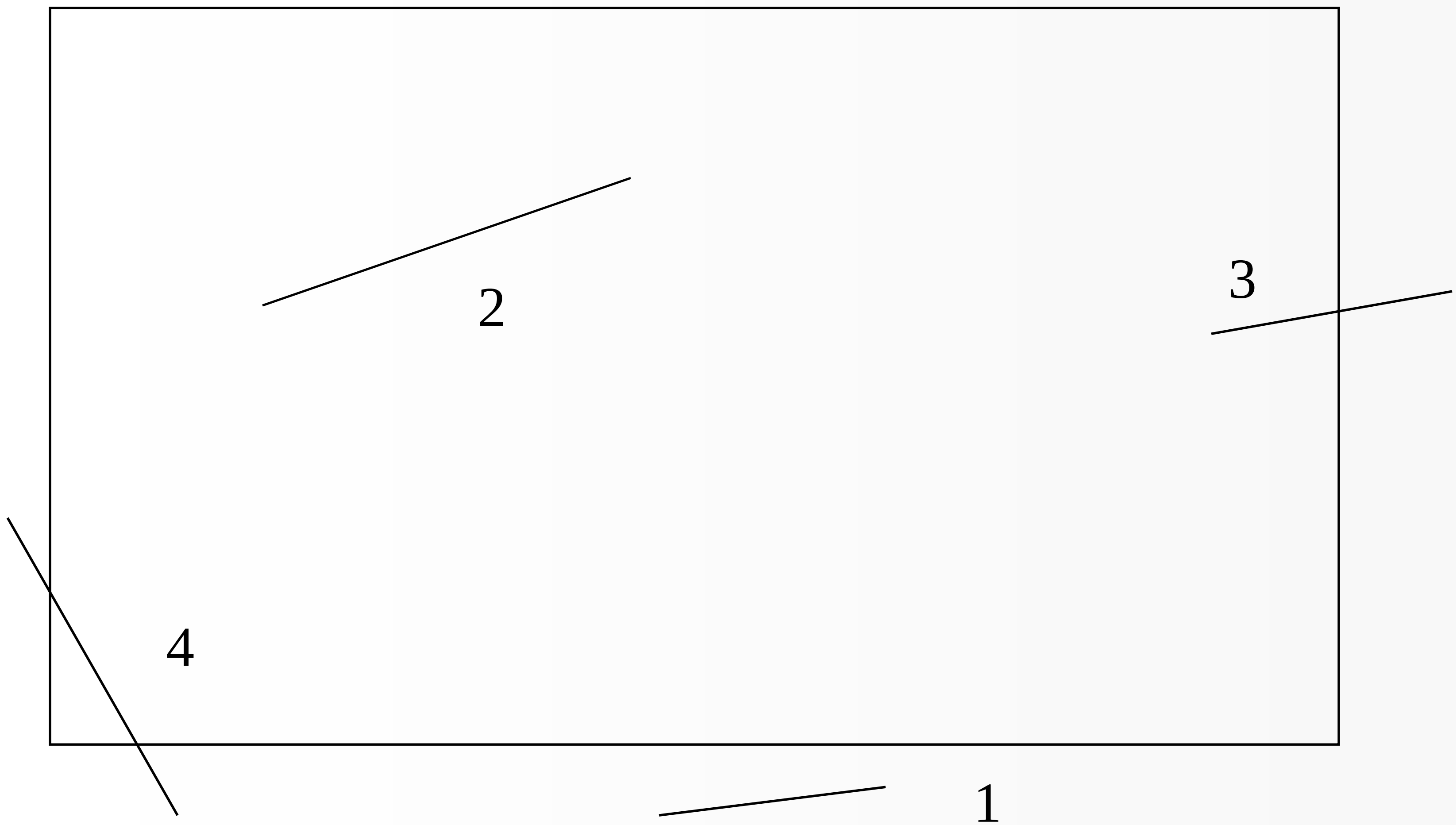
Object Space Clipping

- 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



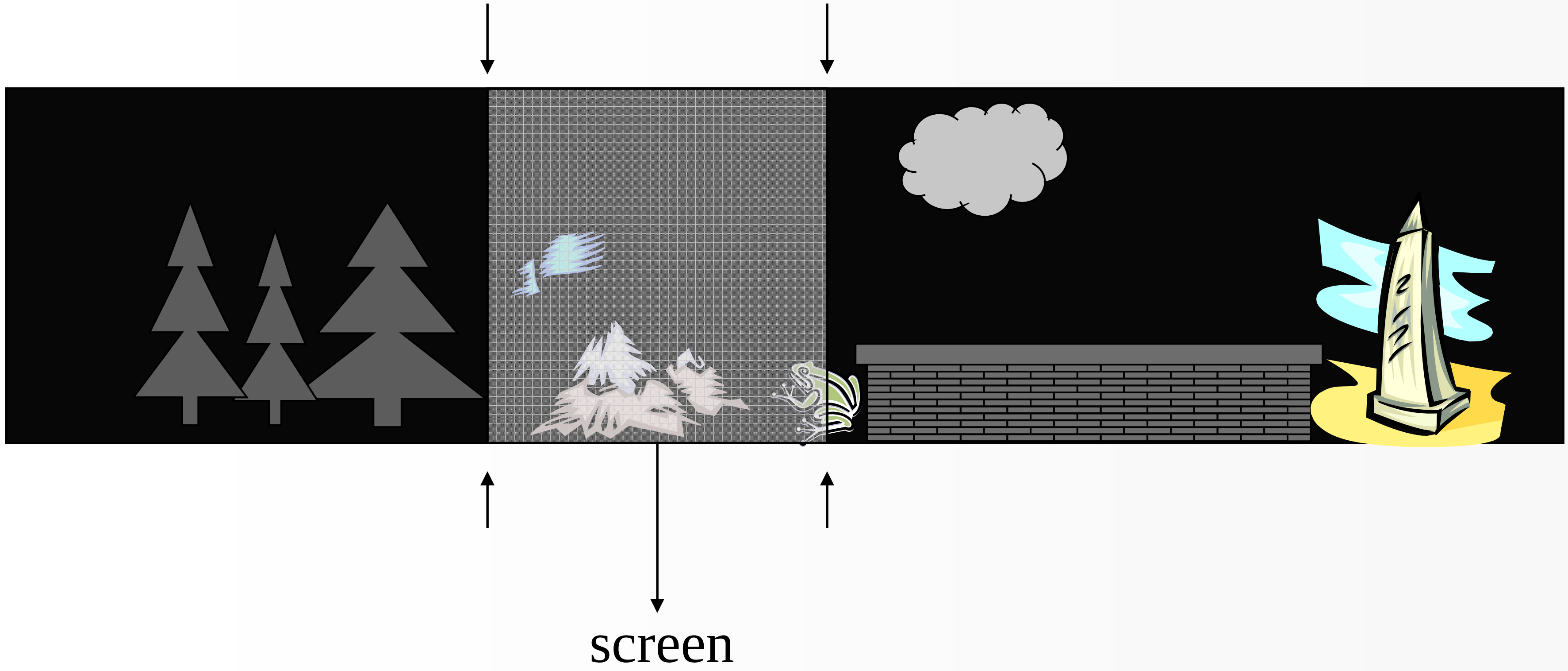
- Evaluation
  - Usually more efficient than image space software
    - But hardware support of image space is fast
  - Need different algorithm for different types of objects
    - Lines are easy. Concave objects are problematic
    - Usually just worry about bitmaps

Line Clipping Cases



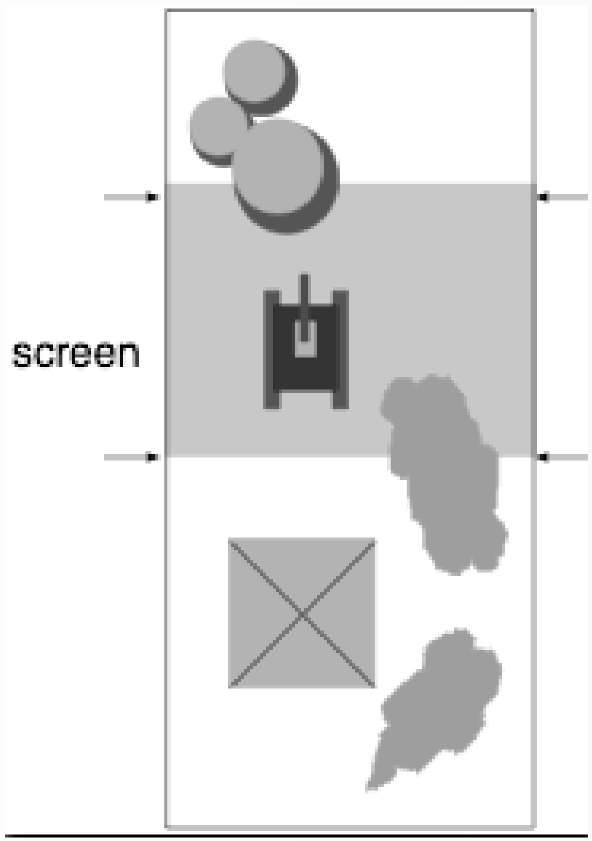
Scrolling - simple

Horizontal scrolling: usually side view of world

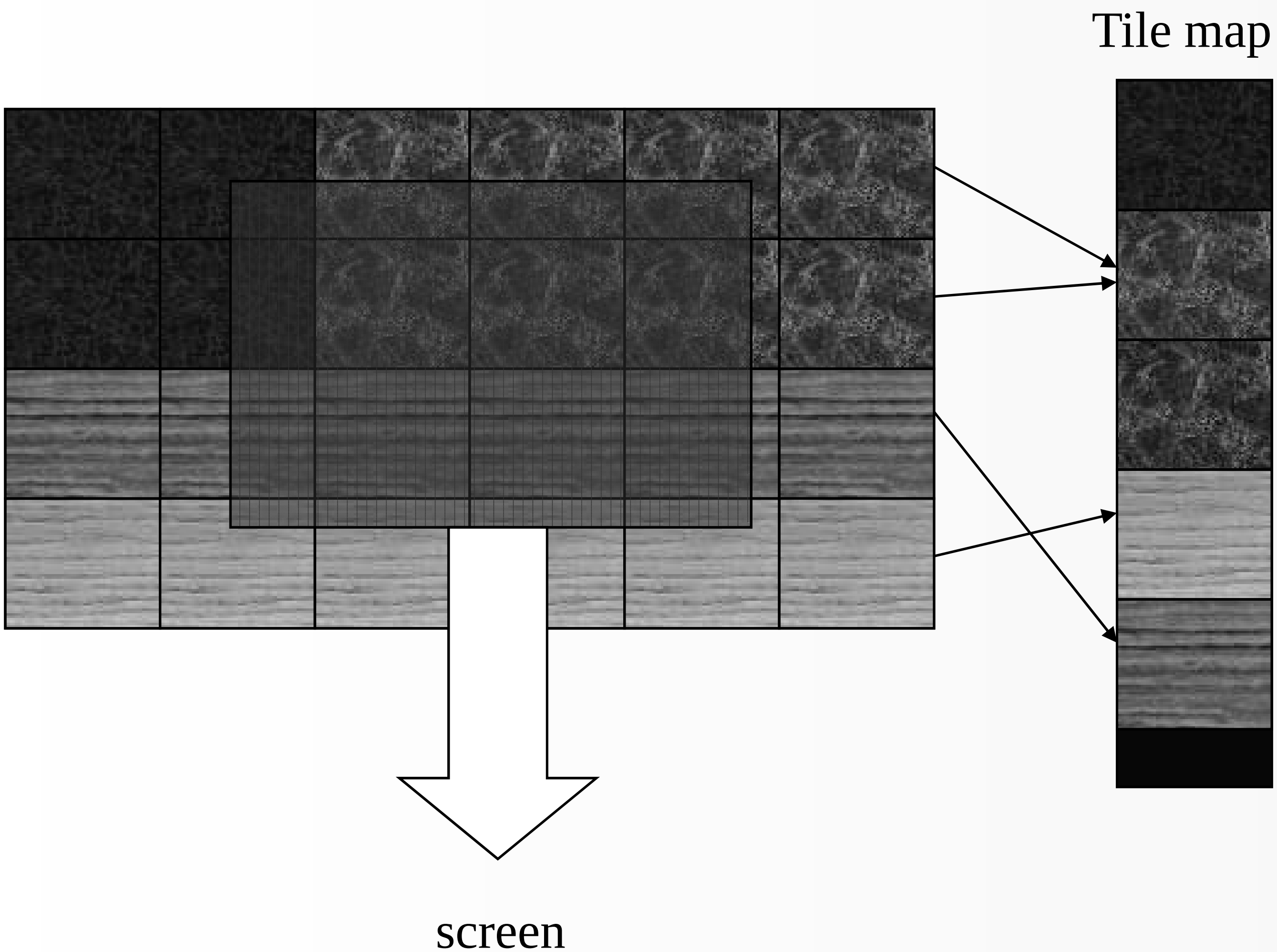


Scrolling - simple

Vertical scrolling: usually top view of world

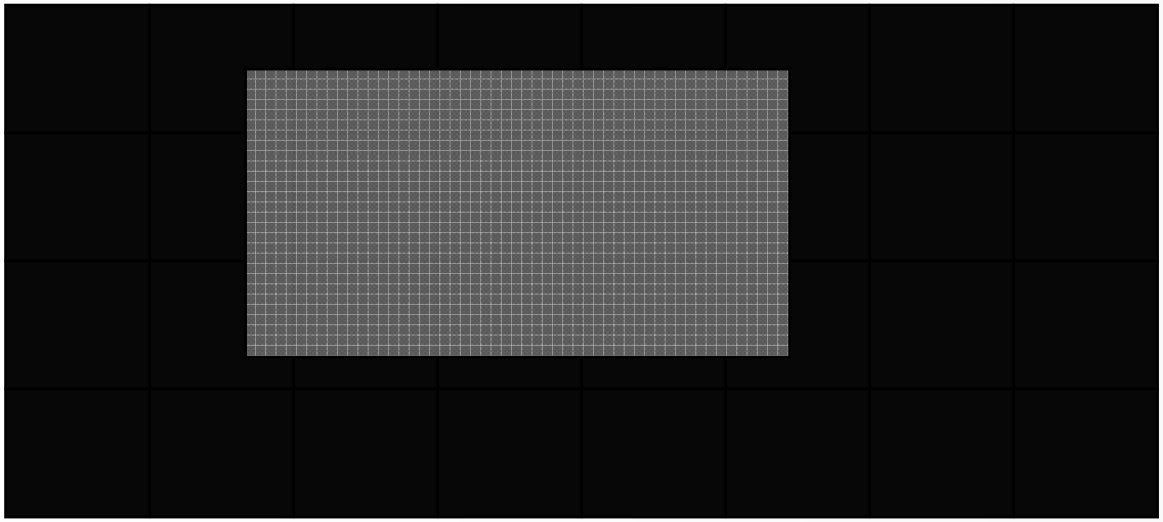


Scrolling – Tile Based



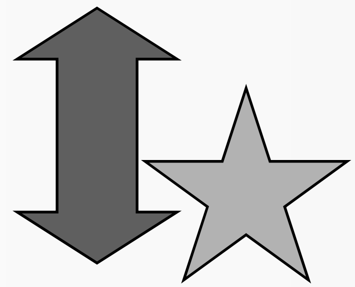
Scrolling – Sparse

- 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

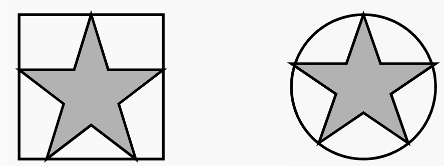


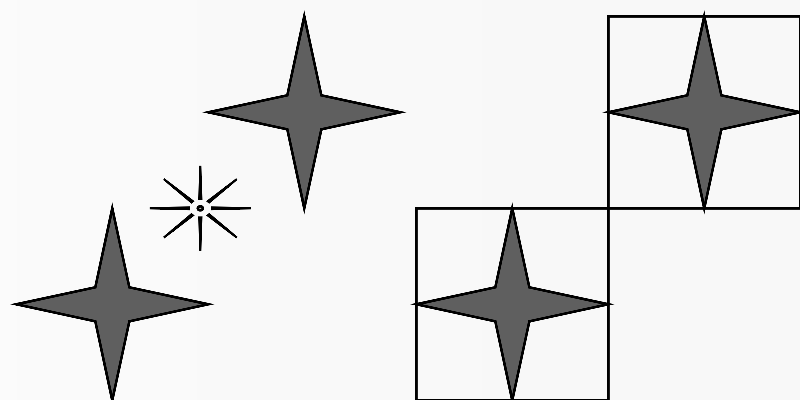
Simple Collision Detection

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



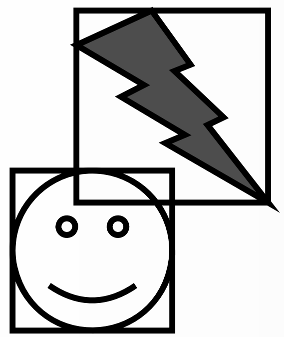
- Standard Approach:
  - Cheat!
  - Create a bounding box or circle
    - test each vertex to see in another object
  - Hide this by making your objects boxy or round
  - Don’t have objects like:





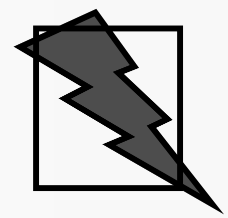
Sprite Collisions

- Easiest:
  - Use the bounding box (or circle) that includes all the pixels



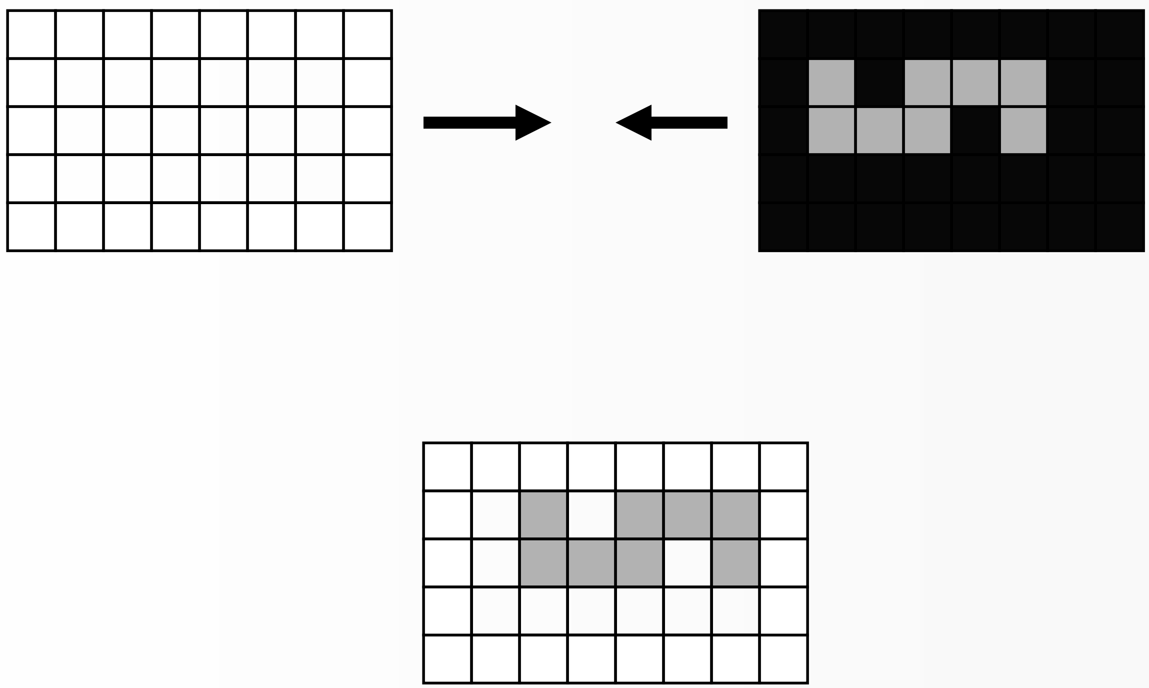
Test if vertex of one in bounding box of other

- 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