Module- 5

Applications of Physics in Animation & Computing

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Chapter-1
Physics of Animation

Syllabus

Physics of Animation: Taxonomy of physics based animation methods, Frames, Frames per Second, Size and Scale, Weight and Strength, Motion and Timing in Animations, Constant Force and Acceleration, The Odd rule, Odd rule Scenarios, Motion Graphs, Examples of Character Animation : Jumping, Parts of Jump, Jump Magnification, Stop Time, Walking: Strides and Steps, Walk Timing. **Numerical Problems**

Statistical Physics for Computing : Descriptive statistics and inferential statistics, Poisson distribution and modeling the probability of proton decay, Normal Distributions (Bell Curves), Monte Carlo Method : Determination of Value of π. **Numerical Problems.**

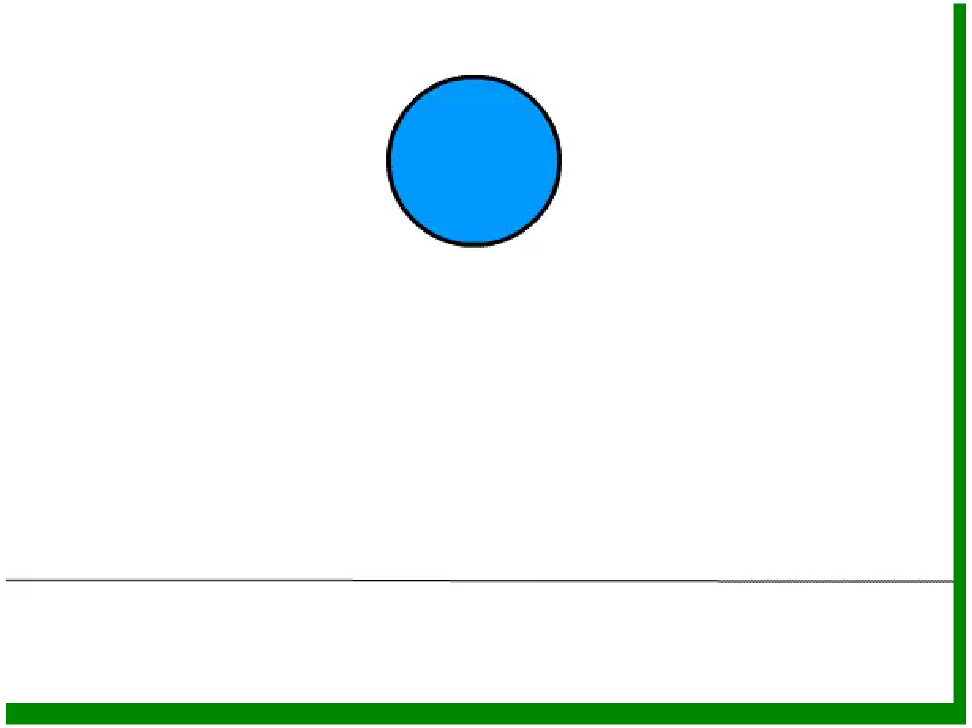
Animation

Animation

What is Animation…!!!?

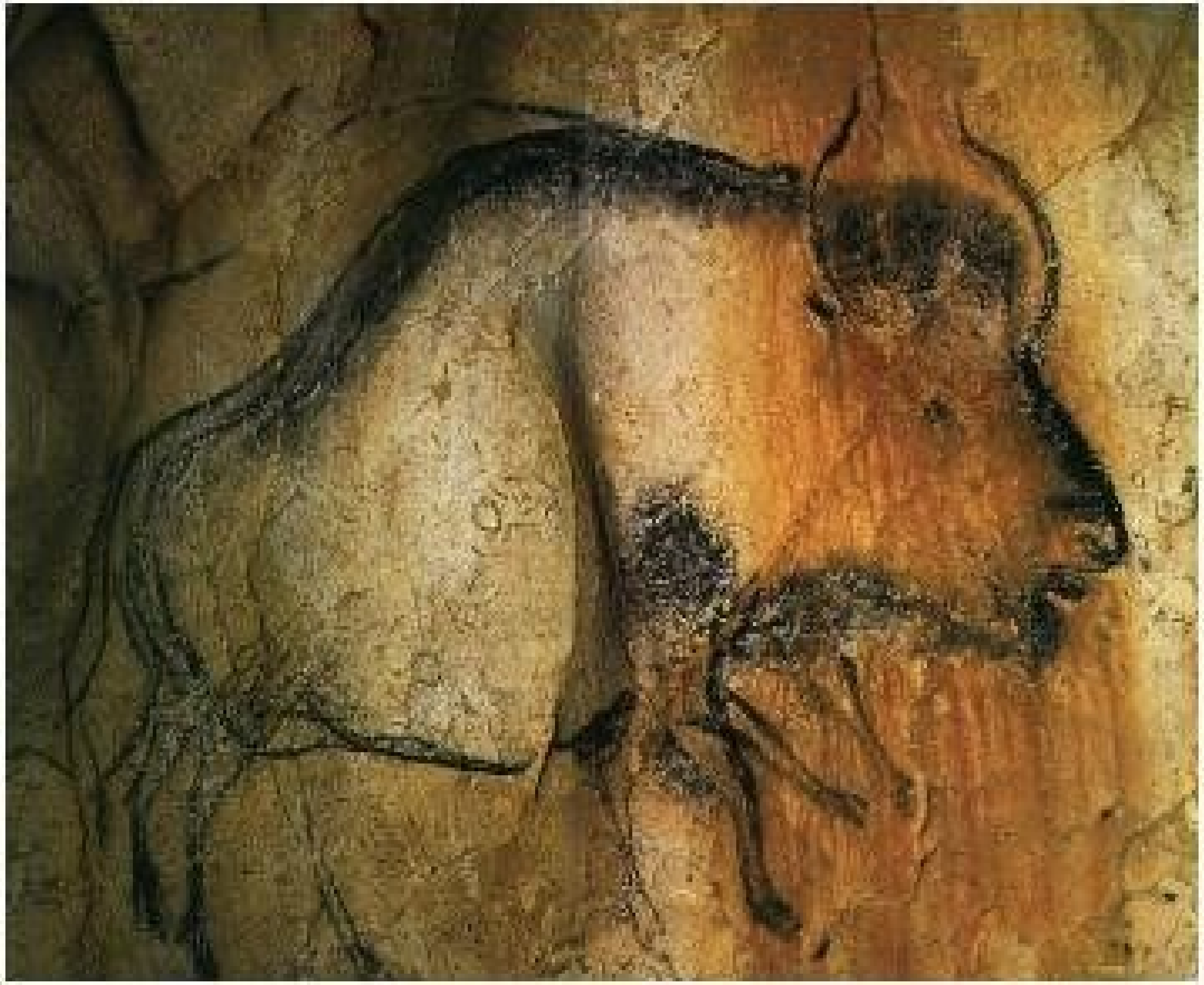
- **Animation** is the rapid display of a sequence of images to create an illusion of movement.
- **Ex:** Even after the object is removed, the impression of an object seen by the eye remains on the retina for **1/16th** of a second- "**optical illusion**"

  When multiple images appear in fast succession, the brain blends them into a single moving image.
- The most common method of presenting **animation** is as a **motion picture**



History of Animation

- Paleolithic (old stone age) cave paintings
  - animals depicted with multiple legs in superimposed positions to convey the perception of motion



History of Animation

- Zoetrope
  - As the cylinder spins, one looks through the slits at the pictures
  - One sees a rapid succession of images, producing the illusion of motion
  - The earliest known zoetrope was created in China around 180 CE (may have existed in China even 300 or so years before that)

History of Animation

- Phenakistoscope
  - A spinning disc attached vertically to a handle
  - A series of drawings around the disc's center
  - A series of equally spaced radial slits
  - The user spins the disc and looks through the moving slits at the disc's reflection in a mirror
  - Invented by a Belgian physicist Joseph Plateau in 1841

History of Animation

- Praxinoscope
  – Improved on the zoetrope by replacing slits with an inner circle of mirrors
  – Invented in France in 1877 by Charles- Émile Reynaud
  – In 1889, he invented an improved version that allowed one to project the images onto a screen

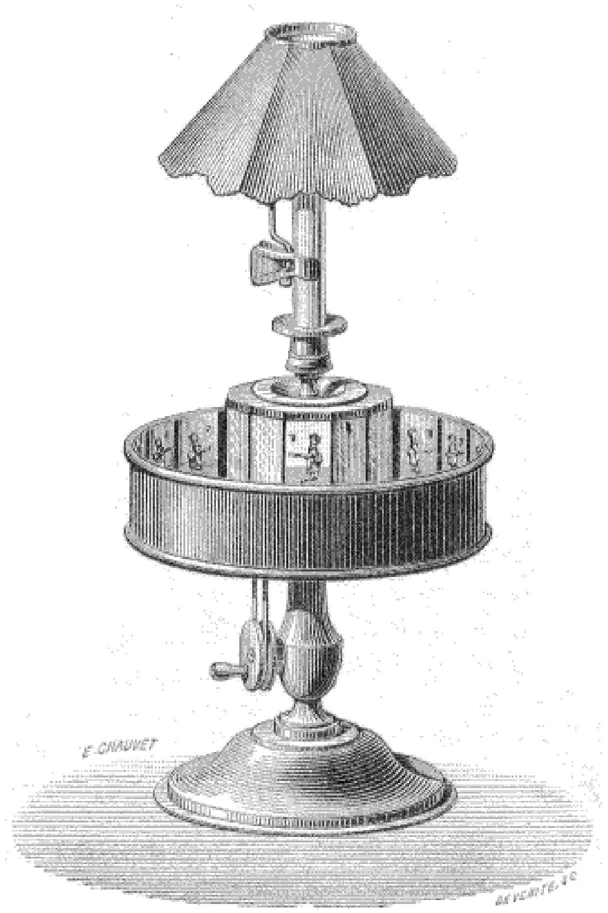
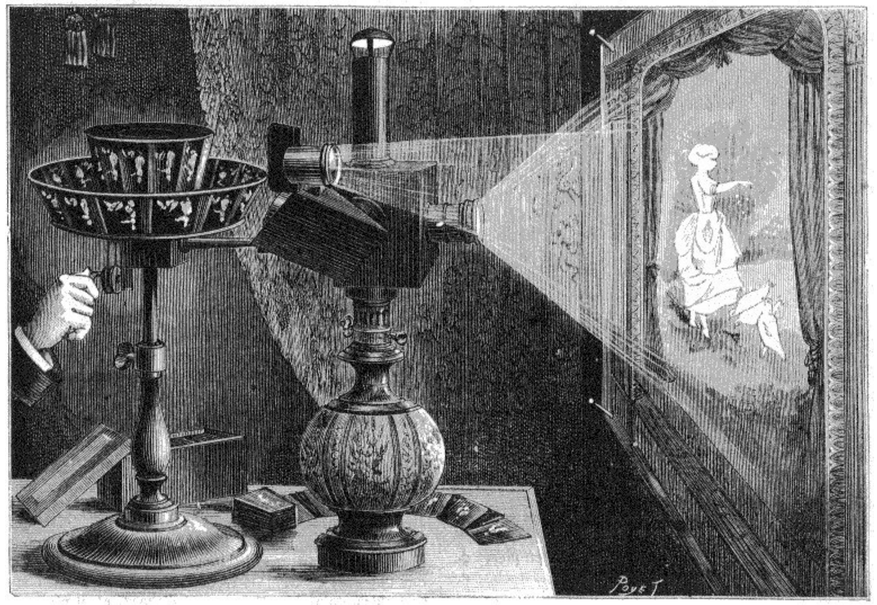


Fig. 2. — Le Praxinoscope.



Nouveau praxinoscope à projection de M. Reynaud.

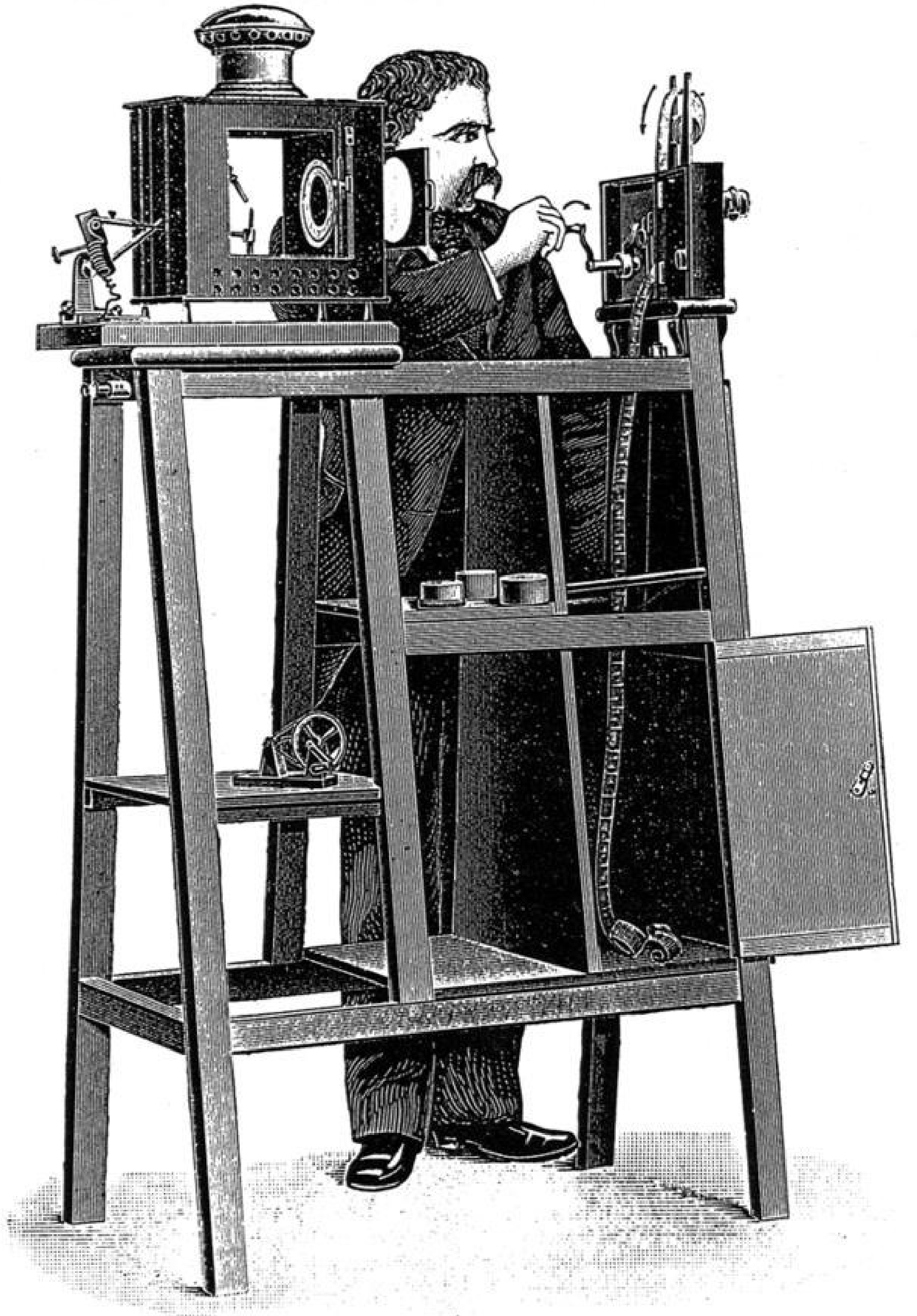
History of Animation

- Flip book
  - The first form of animation to employ a linear sequence of images, rather than a circular set
  - In 1868, John Barnes Linnett patented it under the name *kineograph* ("moving picture“)

[Click for movie]

History of Animation

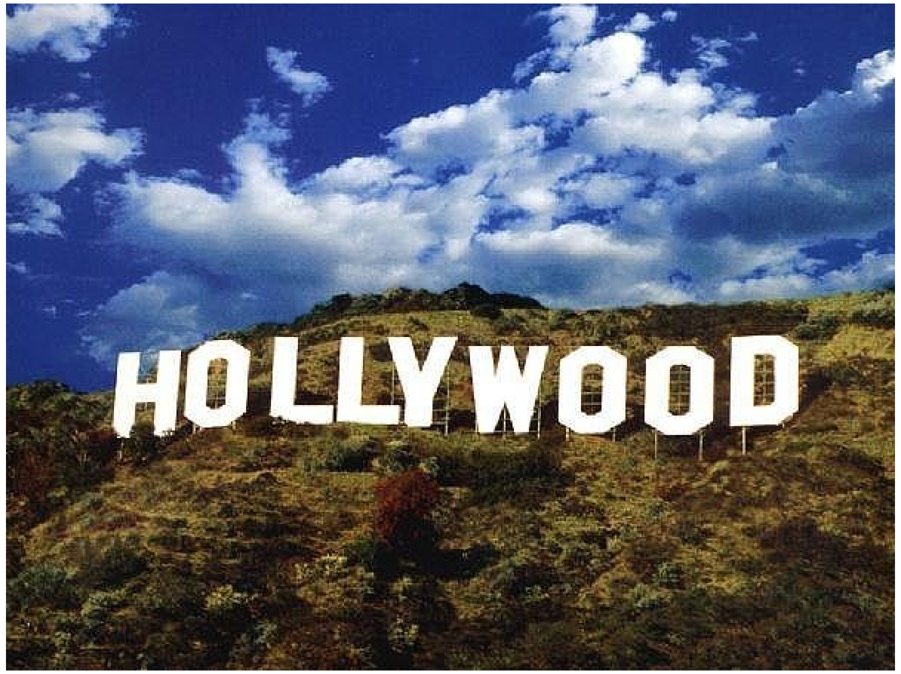
- Cinematograph
  - Fed the linear film through with a hand operated crank
  - Projected the images onto a large screen
  - Invented in 1895 by the Lumiere brothers
  - Took their “film projector” around the world, charged admission for movies
  - Original films were 17 meters long and lasted 50 seconds



Le cinématographe Lumière: projection.

Hollywood

- First film studio established in Hollywood in 1911, followed by 15 more later that year
- Charlie Chaplin Studios established in 1917
- Silent Film Era until 1929
- 1st Academy Awards in 1929

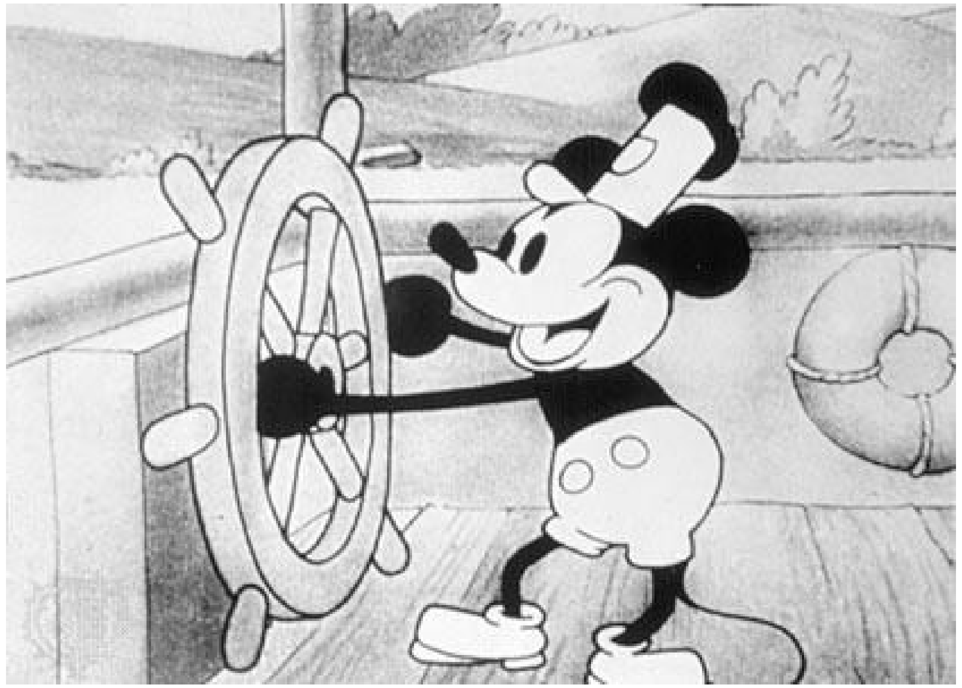


Golden Age of Hollywood

- 1927-1963

Cartoons

- Produced in large numbers in the Golden Age of Hollywood; usually shown before feature films
- First animated full length film: Snow White, 1937 (took 4 years to make)
- Moved to TV in the 1950’s, when TV became popular
  - Flintstones: first successful prime time TV cartoon



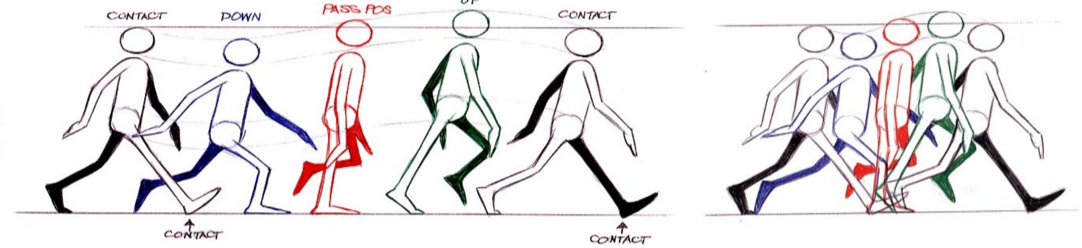
Cartoon Computer Animation

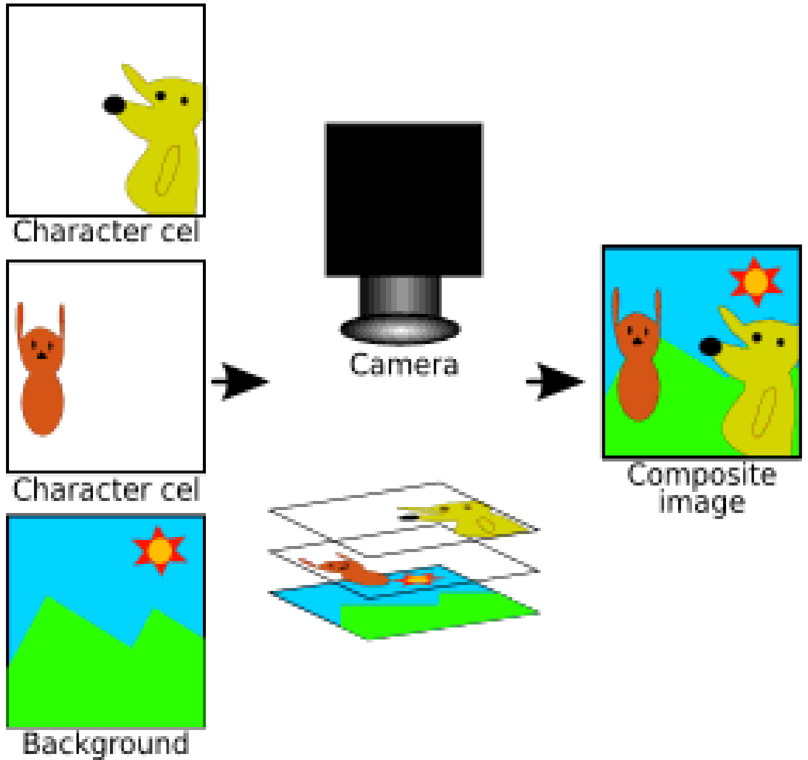
- Traditional Animation was replaced with 2D Computer Animation circa 1990 while still using the concepts of static backgrounds, key framing, animation cycles, etc

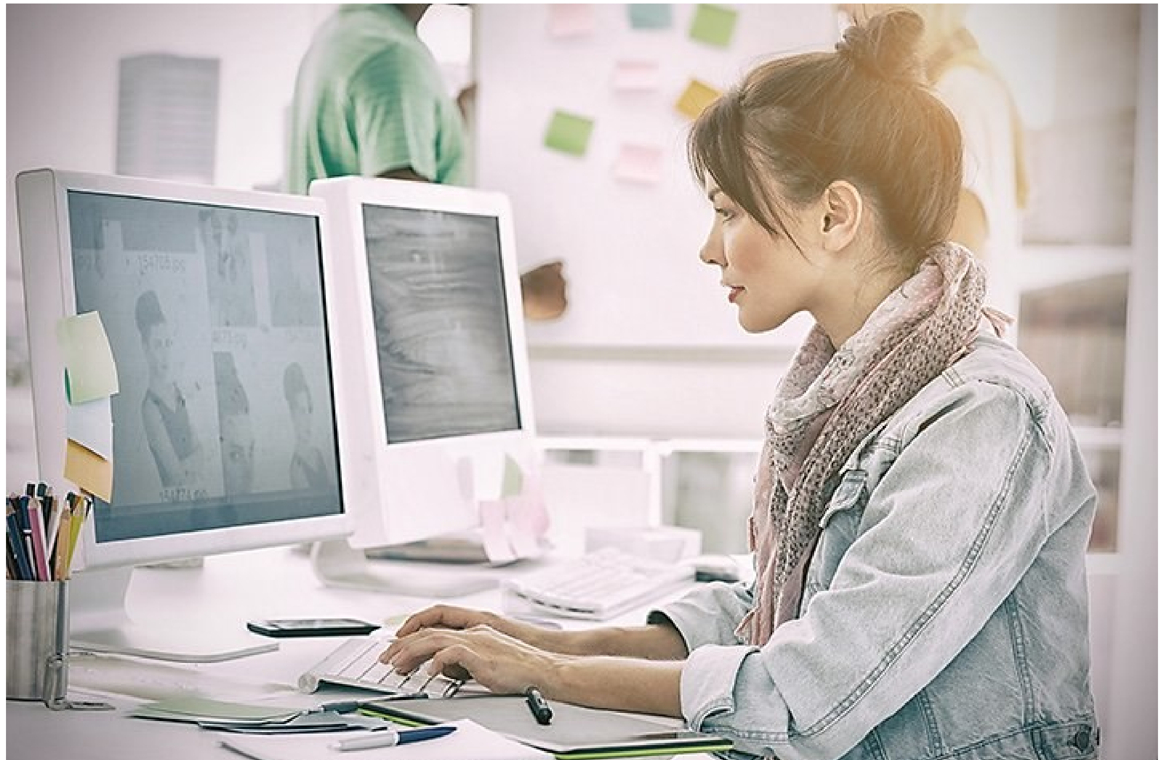
How Animation is created……..!!!!?

Typical examples include:

- Keyframing (hand-drawn animation)
- Data-Driven (motion capture-Computer)
- Procedural (rules, flocks)
- **Simulation (laws of physics)**







How Animation is created…….!!!!?

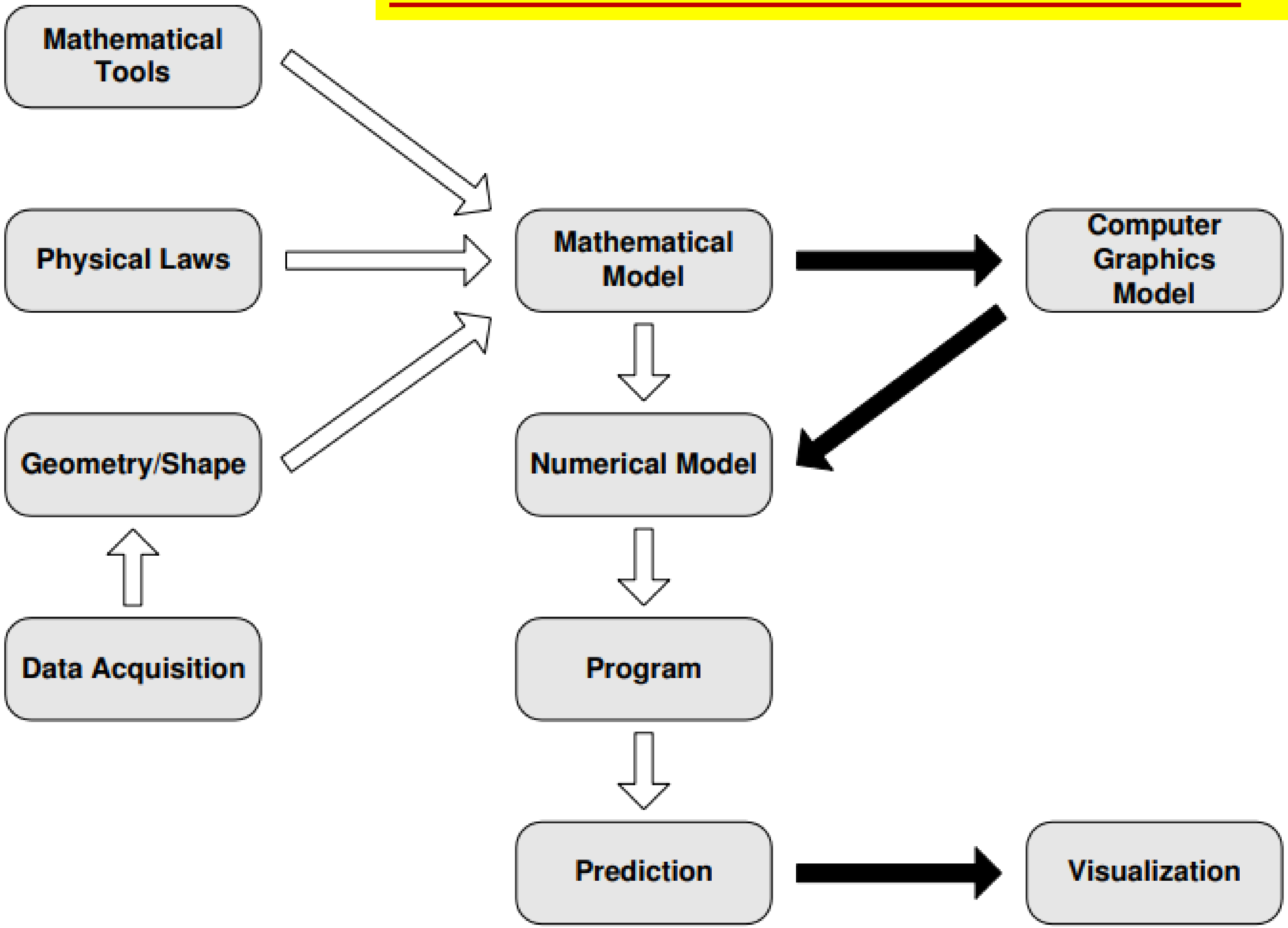


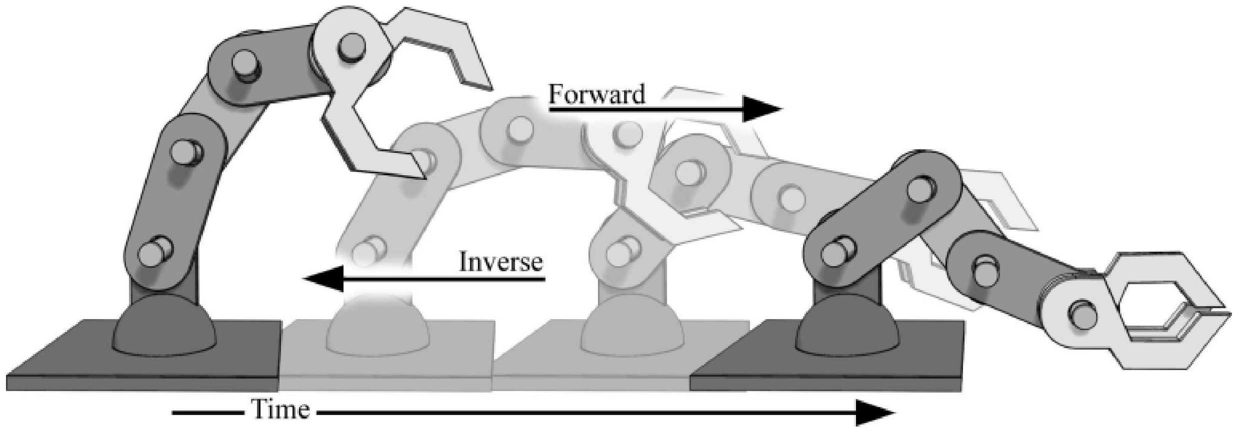
Figure 1.1: Schematic overview of physics-based animation and simulation. The white arrows are typical of the engineering disciplines, whereas the black arrows are typical extra steps taken in computer graphics.

Taxonomy Based Animation Methods

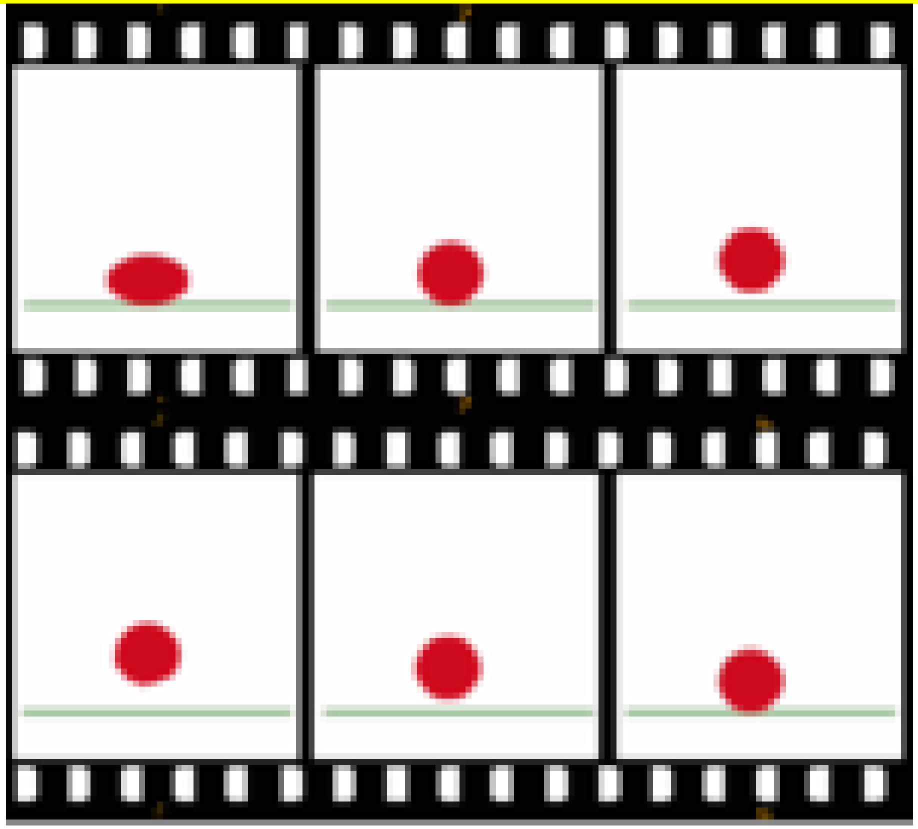
The field of ***physics-based animation*** and simulation can roughly be subdivided into two large groups:

- **Kinematics** : The study of motion without consideration of mass or forces.
- **Dynamics :** The study of motion taking mass and forces into consideration.

- kinematics and dynamics come in two flavors or subgroups.
  - **Inverse** is the study of motion knowing the starting and ending points.
  - **Forward** is the study of motion solely given the starting point.



Frames and Frames per Second



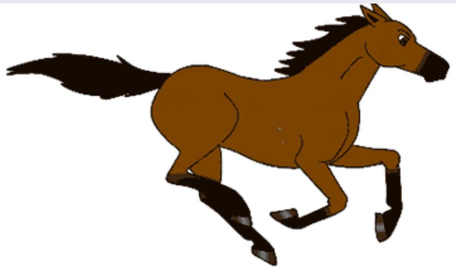
Frame : A frame is a single image in a sequence of pictures.

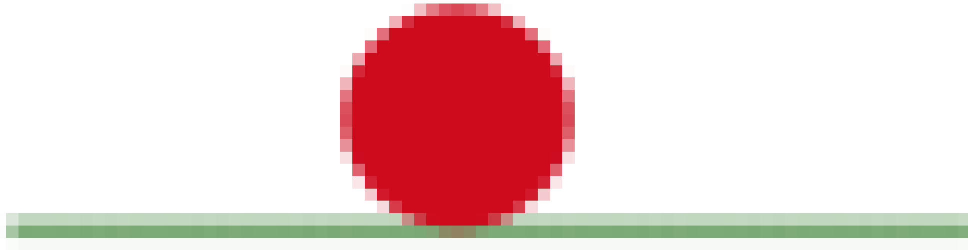
Frames per Second : Number of such frames displayed per second.

In general, one second of a video is comprised of **24 or 30 frames per second** also known as FPS.

Sl. No.	System	FPS
1	PAL (Australia, Middle East, Africa)	25
2	NTSC (America, West Indies, Specific Rim Countries)	30

- PAL : Phase Alternating Line
- NTSC : National Television Standard Committee.





Size and Scale

Larger Characters : Weight & Strength (Hulk)

Smaller Characters : Agility and Speed (Jerry)

While designing **animation**, we come across different situations to do with **size** and **scale**

Human or animal-based characters

- That are much larger than we see in our everyday experience.(Hulk, Superhero, Monsters)
- That are much smaller than in our everyday experience (fairies and elves)
- Characters that need to be noticeably older, heavier, lighter, or more energetic than others.
- Characters that are child versions of older characters.

Scale and Proportion

Creating a larger or smaller character isn't just a matter of scaling everything about the character uniformly.

- **For ex**: While scaling a cube, its volume changes much more dramatically than its surface area.
- Doubling the size of the cube along each dimension, its height increases by 2 times, the surface area increases by 4 times, and its volume increases by 8 times.

Weight and Strength

Body weight is proportional to volume.

- Ability of muscles & bones depend more on cross-sectional area than volume
- To increase muscle/bone's strength, it is needed to increase the cross-sectional area.

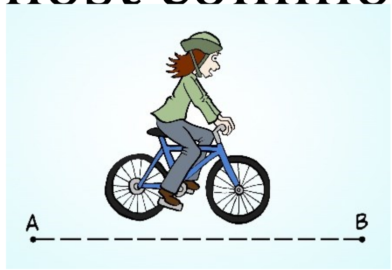
- **Strength** increases by squares & **weight** increases by cubes, the proportion of a character's weight that it can lift does not scale proportionally to its size
- ***<u>Ex</u>***: A man 6 feet tall weighing 180 pounds and can lift 90 pounds.

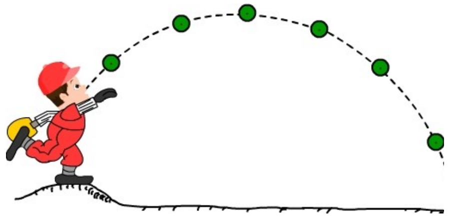
- If you scale up the body size by a factor of 2, the weight increases by a factor of 8. Such a character could then lift more weight.
- But since the character weighs 8 times more than it did before, it can not lift the arms and legs as easily as a normal man.
- Such a giant gains **strength**, but loses agility.

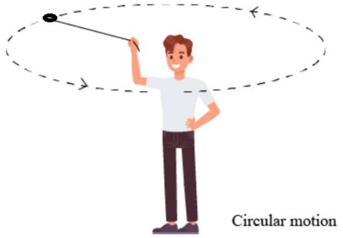
Motion and Timing in Animation

Introduction to Motion:

- **Motion** is an essential component in games and animations. The motion is governed by the Newton's laws and kinematic equations.
- When animating a scene, there are several types of motion to consider. These are the most common types of motion: **1. Linear, 2.Parabolic, 3. Circular, 4. Wave**



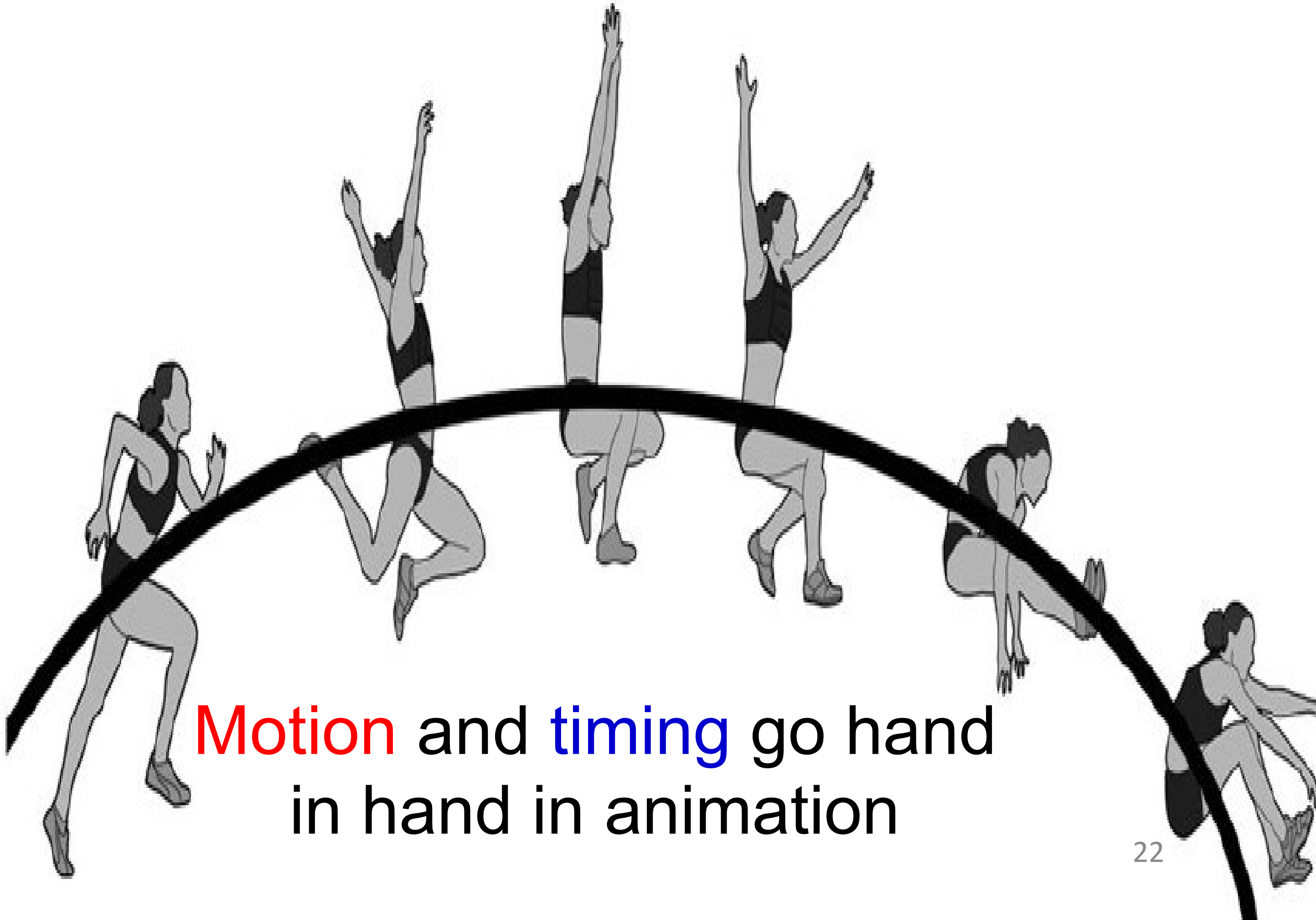




Motion Lines and Paths:

- Individual drawings or poses have a line of action, which indicates the visual flow of action at that single image.

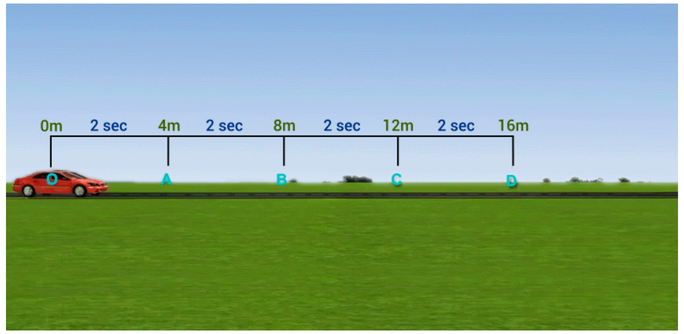
- **Motion** has a path of action, which indicates the path along which the object or character moves. The path of action refers to the object's motion in space.

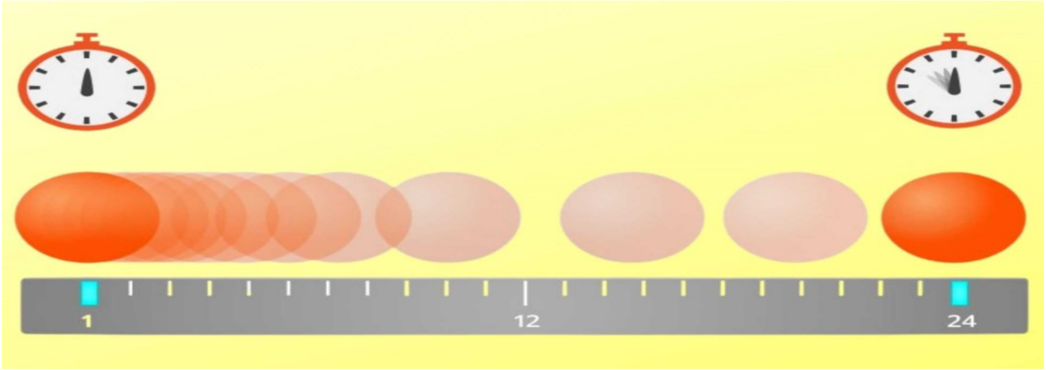


Motion and timing go hand in hand in animation

Timing and Timing Tools in Animation

- **Timing** in animation refers to the choice of when something should be done.
- It helps to create movement that obeys laws of physics & to add interest to the animations.
- Animators, have the ability to move forward and backward in time to place objects when and where they are to be.



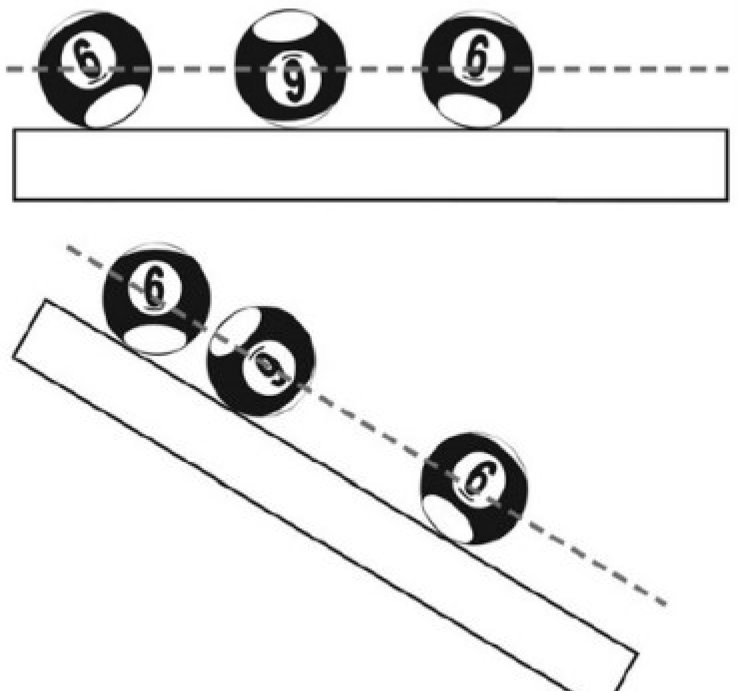


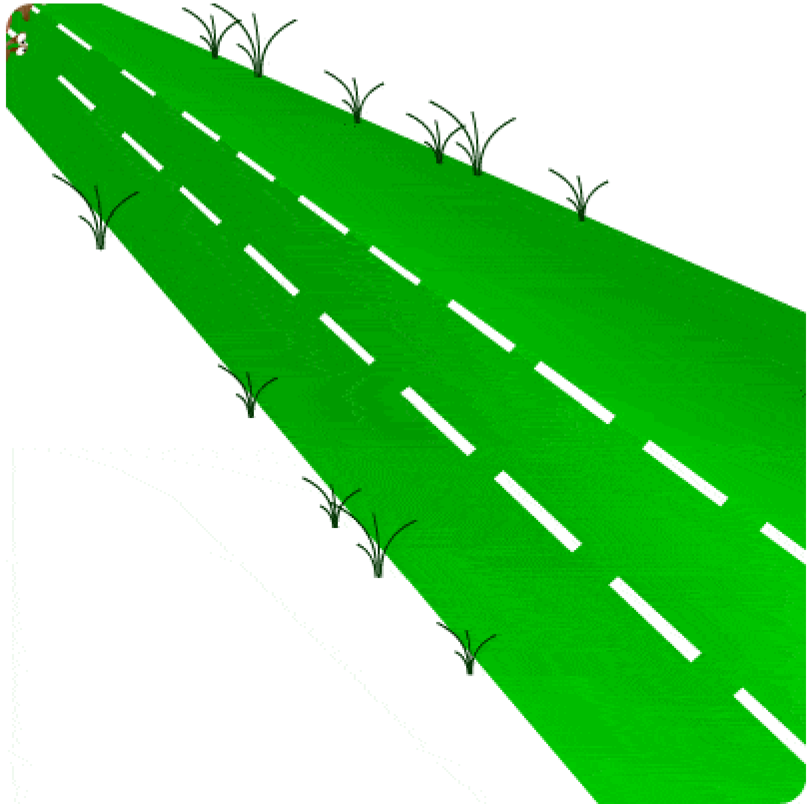
Timing Tools:

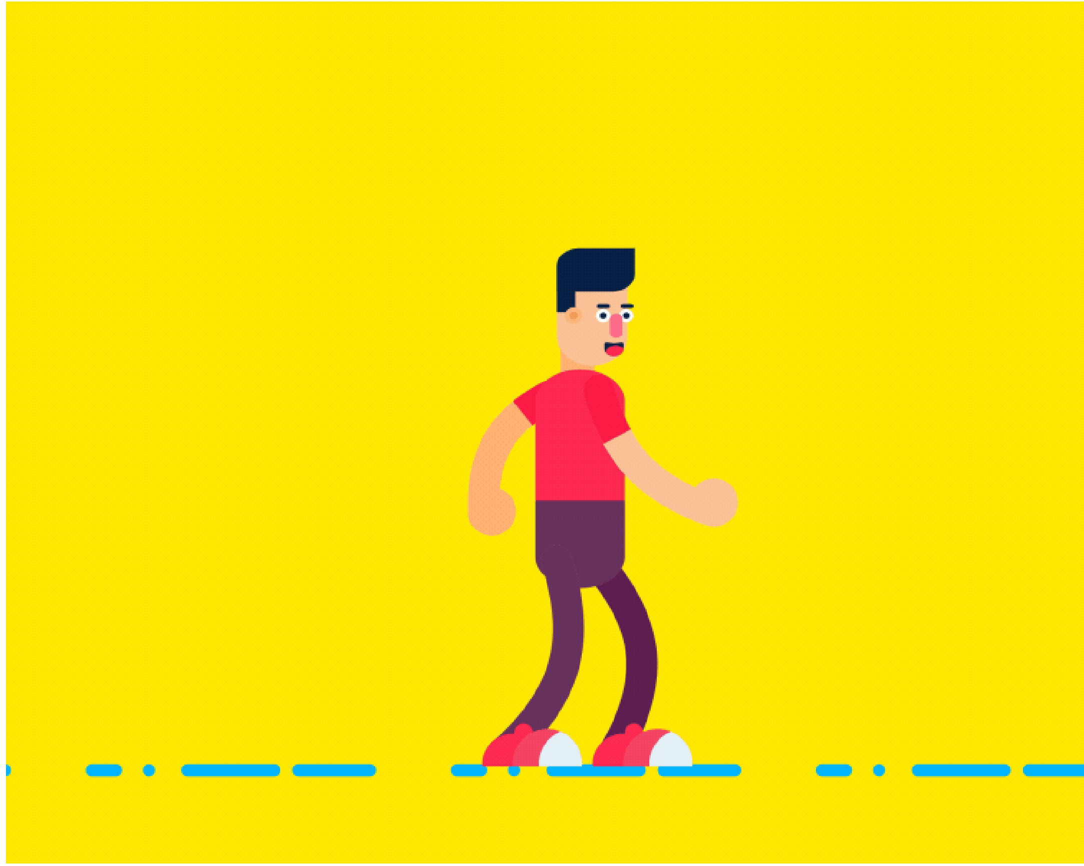
- In animation, timing of action consists of placing objects or characters in particular locations at specific frames to give the illusion of motion
- Animators work with very small intervals of time and most motion sequences are measured in seconds or fractions of seconds.
- Fortunately, physics has some tried-and-true laws that can help to figure out accurate timing.

Linear Motion Timing

- **Linear motion** refers to motion in a straight line.
- An object moving with linear motion might speed up, slow down or move with a constant speed and it follows a linear path.
- ***Ex:*** A heavy ball rolling on a table or incline is an example of linear motion. The ball is rotating, but its centre of gravity follows a **linear path**.

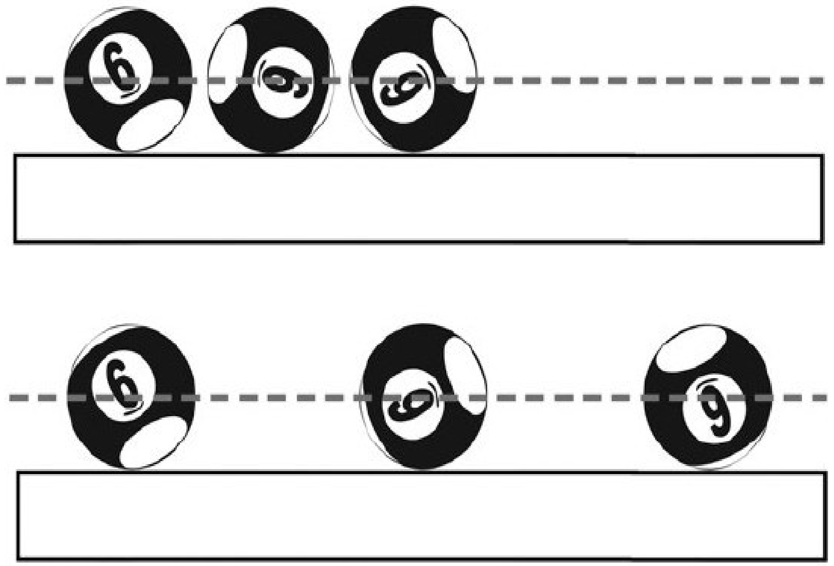


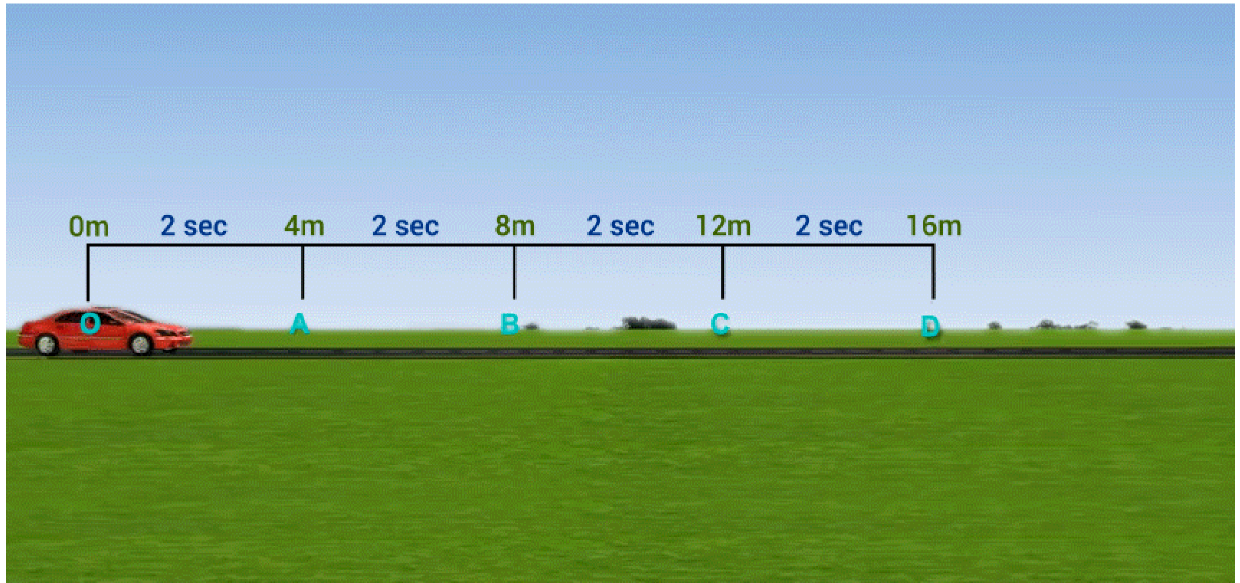




Uniform Motion Timing

- When **uniform motion** occurs, the net force on the object is zero. There might be several forces acting on the object, but when both the magnitude and direction of the forces are added up, they add up to zero.
- It is a type of linear motion with constant speed and **no acceleration or deceleration**.
- Uniform motion is the easiest to animate because the distance the object travels between consecutive frames is always the same.
- The longer the distance between frames, the higher the speed.





Accelerated Motion Timing: Slow-in and Slow-out

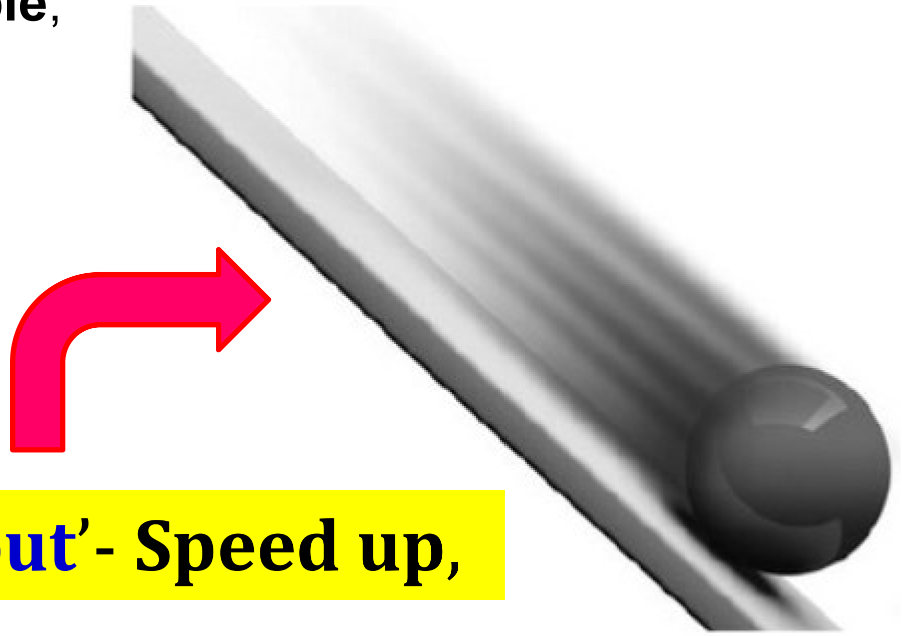
✓ When motion is accelerating or decelerating, referred as a '**slow-out**' or '**slow-in**'.

✓ '**slow-out**', sometimes called ease-out—object is speeding up, from a position.

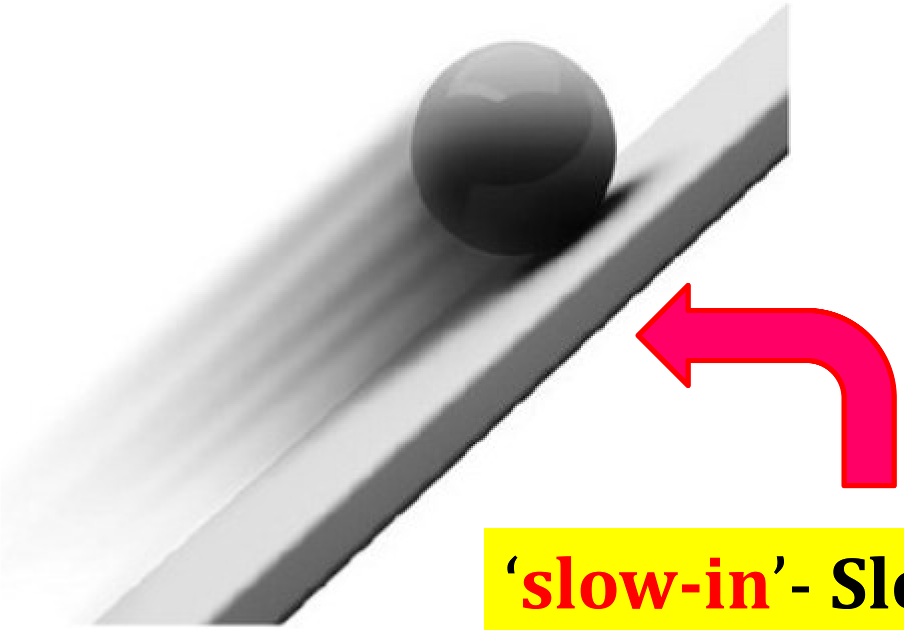
- The term slow out essentially means "**speed up.**"
- One can think of slow out as the same as ease out, as in easing out from a position and speeding up to full speed.

✓ **'slow-in',** sometimes called ease-in—object is slowing down, often in preparation for stopping.

For example,



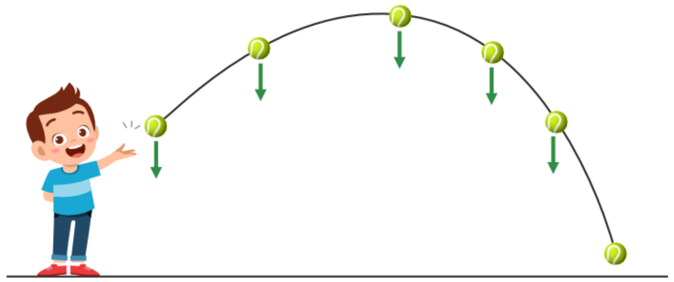
'**slow-out**'- **Speed up,**



'**slow-in**'- **Slow down**

Constant Force and Acceleration

- Timing for acceleration can be calculated very accurately when the **net force** being exerted is **constant**.
- **Constant Force** : A constant force is a force that doesn't vary over time.



- Examples : (i) Gravity pulling an object to the ground
  (ii) Friction bringing an object to a stop
- **Constant forces** result in constant acceleration. Because of constant acceleration, we can easily figure out the timing for such sequences using principles of physics.
- The resulting acceleration depends on the direction of the force and motion,

  ❖ When constant net force is applied to an *unmoving* object, the result is acceleration.

  ❖ When constant net force is applied to a *moving* object in the same direction as the motion, the result is acceleration.

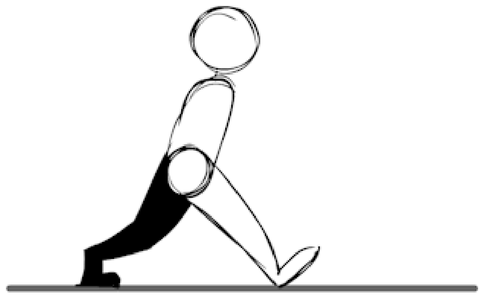
  ❖ When constant net force is applied in the direction opposite the existing motion, the result is deceleration (acceleration in the opposite direction).

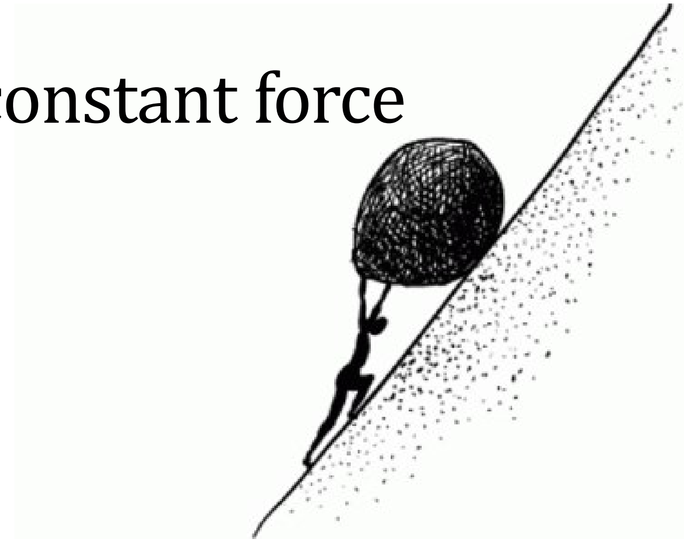
Forces Exerted by Characters

- ✓ Forces exerted by characters are rarely constant throughout an entire motion in animation.
- ✓ For the purposes of animation, the character motion could be divided into short time segments and consider each of these segments to be responding to constant net force.
- ✓ This will make it easier for one to calculate the timing for each individual segment.

Ex: (i) The **push for a jump**. Force exerted by character during the **push** is somewhat constant and timing is very short. In such case, the timing for a constant force is an excellent starting point.

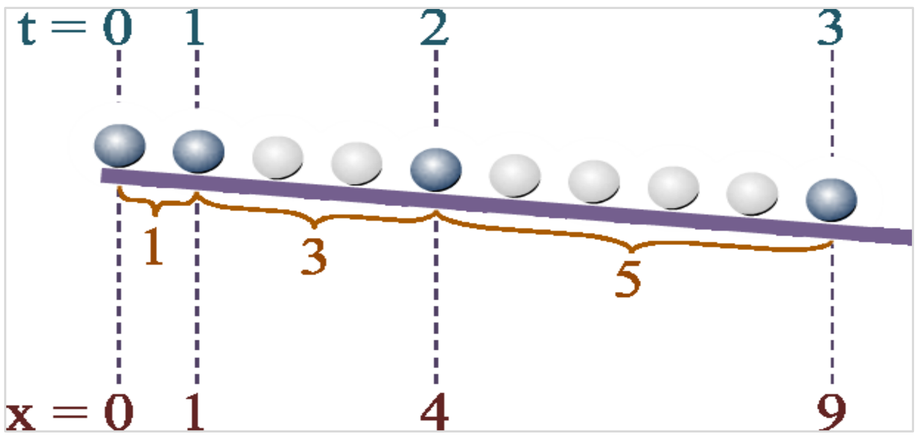
(ii) A character **walking** and **pushing a rock** is not exerting a constant force





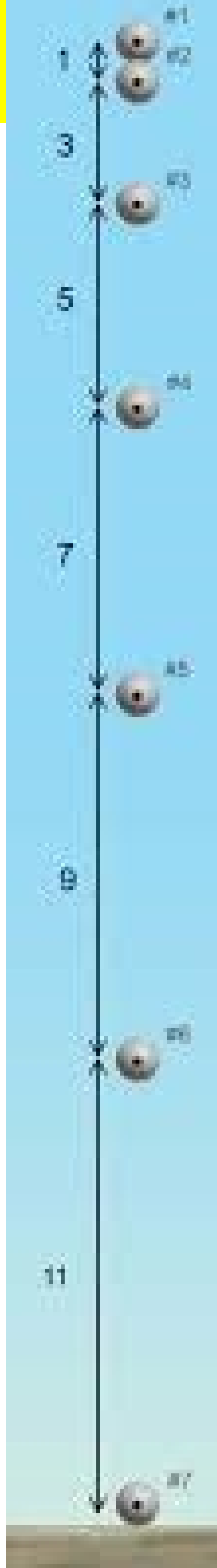
The Odd Rule

- When acceleration is constant, the '**Odd Rule**' is used to time the frames (Simple Pattern of **Odd Numbers**).

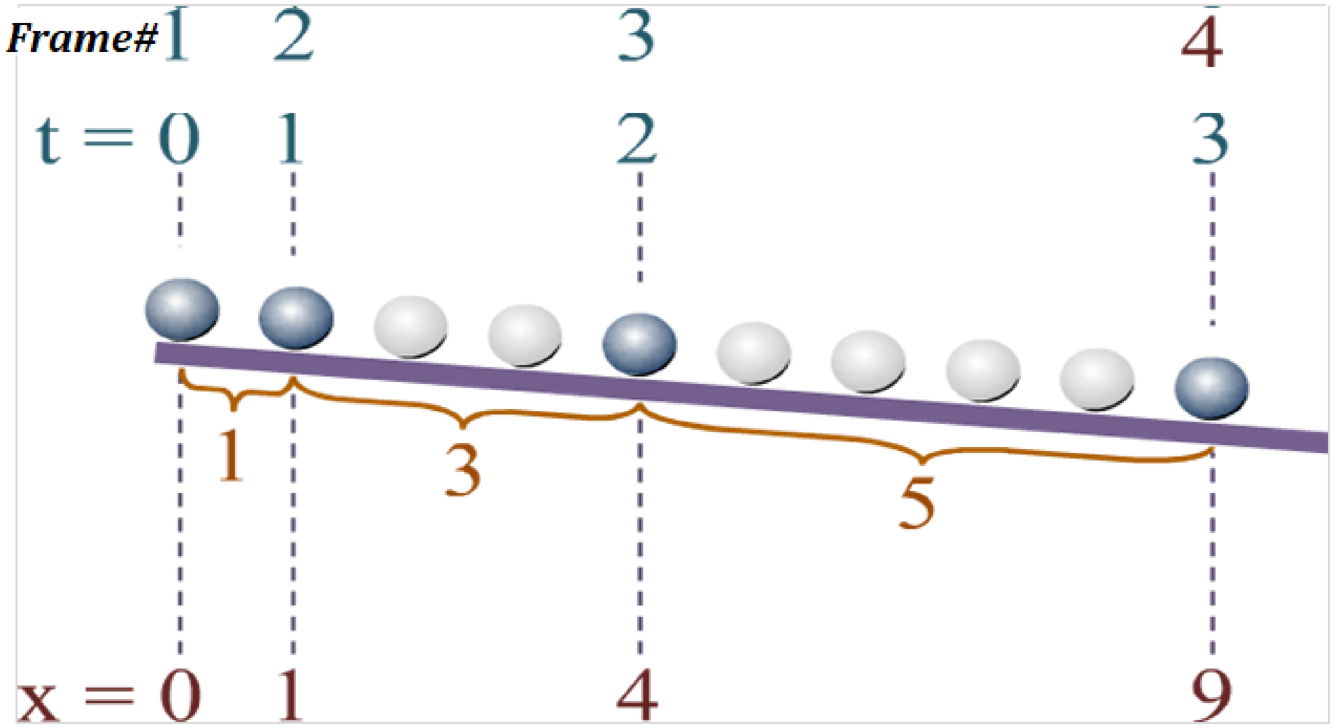


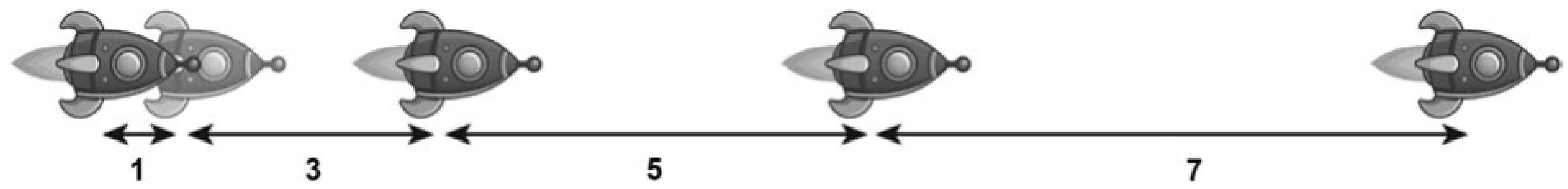
- Between consecutive frames, the distance covered by object is a multiple of an odd number.
- For acceleration, distance between frames increases by multiples of 1, 3, 5, 7……..
- For deceleration, the multiples start at a higher odd number, ……………7, 5, 3, 1
- **"Odd Rule"** is a multiplying the system based on the smallest distance travelled between two frames in the sequence.
- For a slow-out: it is the distance between the **first two frames**
- For a slow-in: it is the distance between the **last two frames**

Base distance

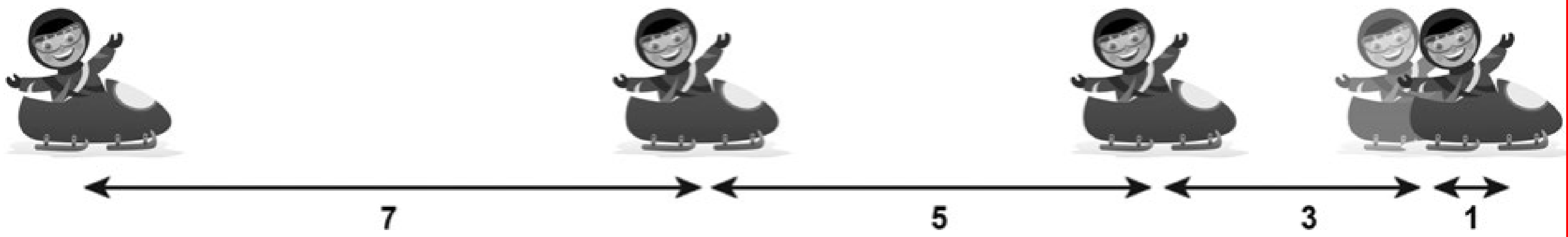


The Odd Rule

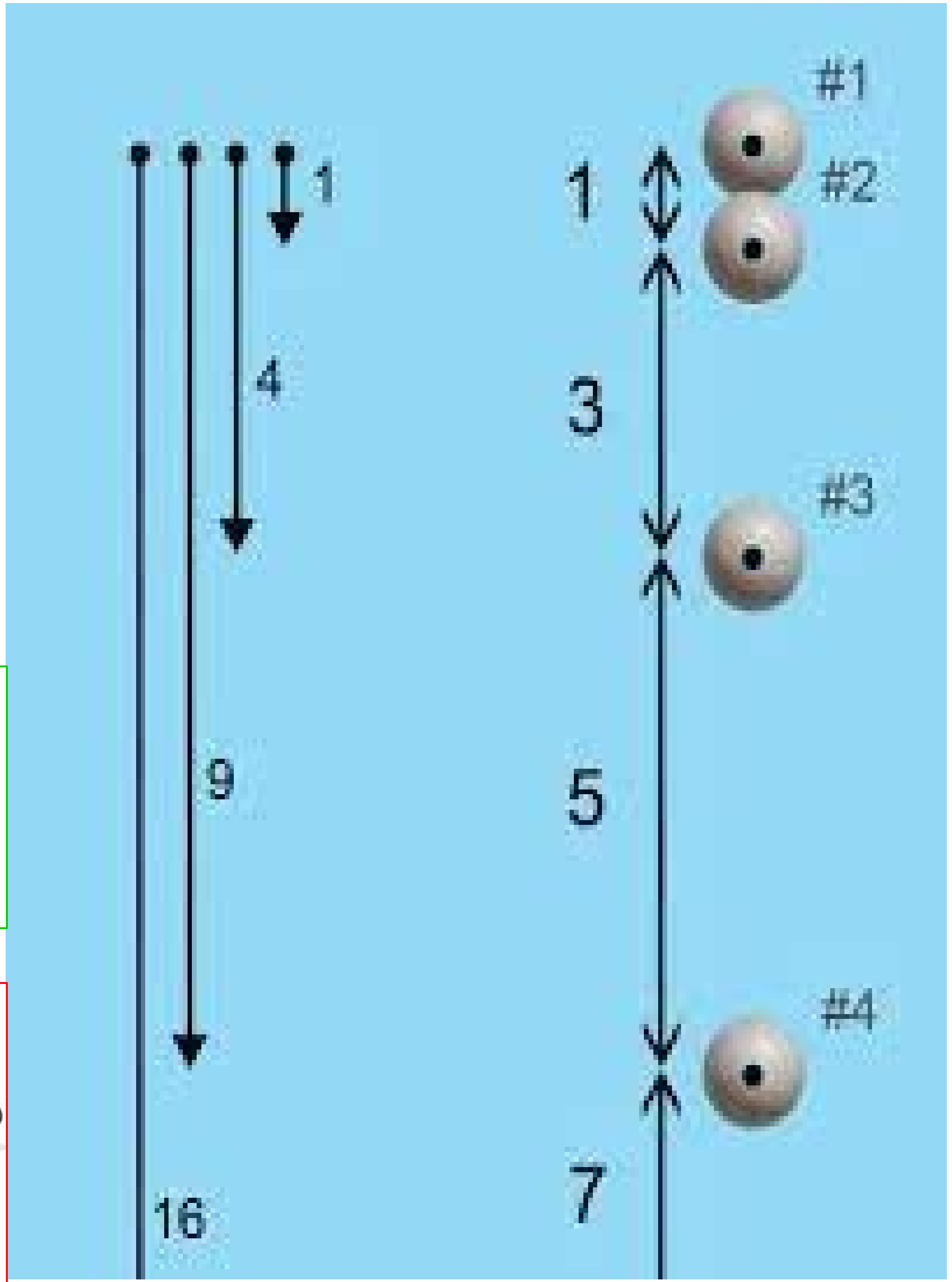




Rocket speeding up using the Odd Rule.



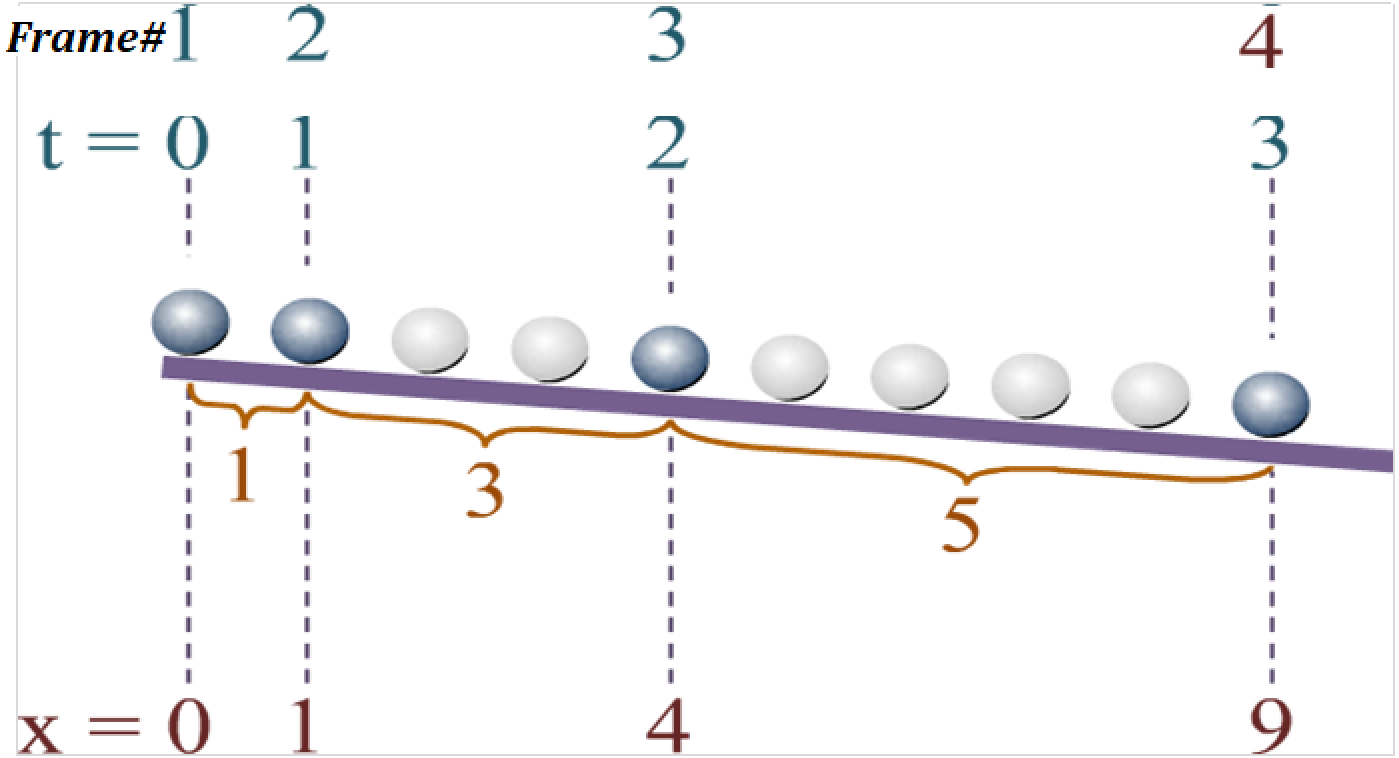
Sled coming to a stop using the Odd Rule.



The Odd Rule Multipliers

- ✓ Odd multipliers for **Consecutive Frames** $= ((\text{Frame\#} - 1) \times 2 - 1)$
- ✓ Multiplier **for distance** from first frame to current frame $= (\text{Current Frame\#} - 1)^2$

	Multiply by Base distance to get Distance between	
Frame #	Consecutive Frames	1^{St} Frame & this Frame
1	n/a	0
2	1	1
3	3	4
4	5	9
5	7	16
6	9	25
7	11	36



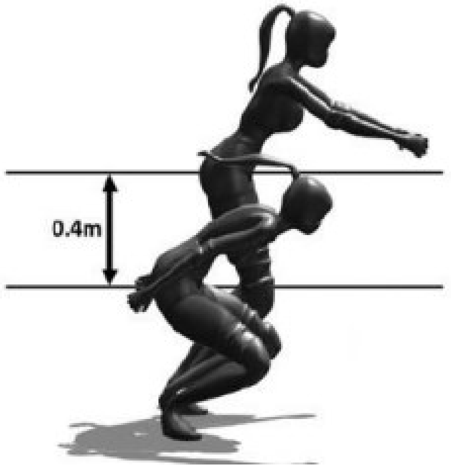
The Odd Rule Scenarios

1. Base Distance Known, Speeding up: **Base Distance** $\times$ odd rule multipliers from the first frame

2. Base Distance Known, Slowing down : **Base Distance** $\times$ odd rule multipliers from the last frame

3. Total Distance and **Number of Frames Known, Speeding Up:**

$$\boldsymbol{Base\ Distance} = \frac{Total\ Distance}{(Last\ frame\ no. - 1)^2}$$



Example: Suppose there is a jump push (takeoff) with constant acceleration over 5 frames, and the total distance traveled is 0.4m. Using the above formula, we find the base distance.

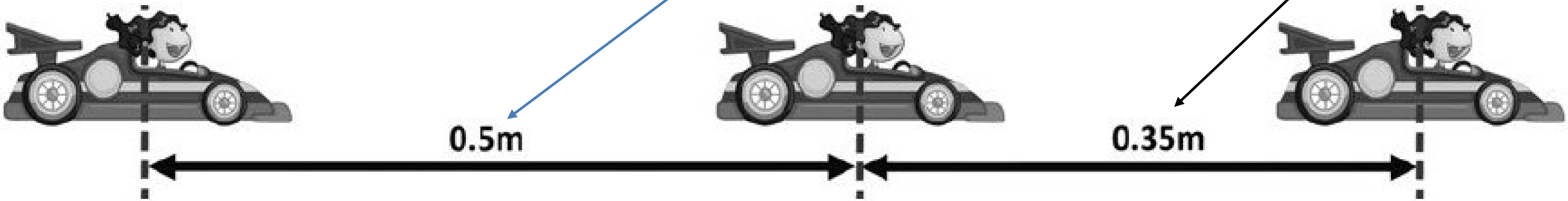
$$\text{Base distance} = \frac{0.4m}{(5-1)^2} = \frac{0.4m}{16} = 0.025m$$

The Odd Rule Scenarios

4. First Key Distance Known, Slowing down : A moving object is about to slow down.

- The distance between the last two consecutive frames just before slow down are considered to find the **Base distance**.

- Distance b/w the first two frames is the **first key distance** & the next frame is first slow in distance.



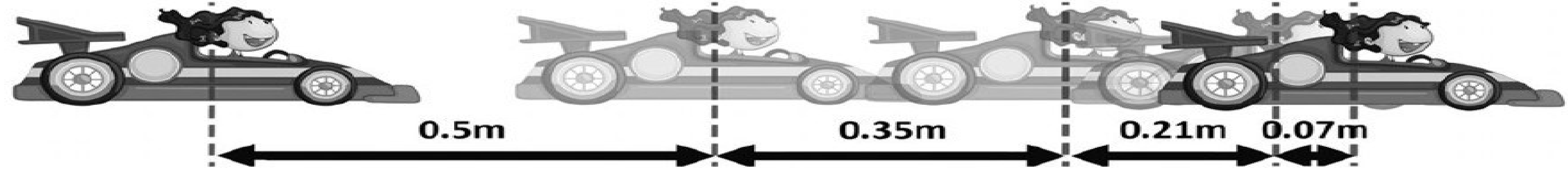
- One of the features of the **Odd Rule** is that the **Base distance** is always half the difference between any two adjacent distances.

i.e., **Base distance** $= \dfrac{0.5m - 0.35m}{2} = 0.07m$ ⟹ **2. Base Distance Known, Slowing down**

- To figure out how many frames are in the slow-in,

$$\text{Consecutive Frame Multiplier} = \frac{\textit{First Distance}}{\textit{Base Distance}} = \frac{0.5}{0.07} = 7$$

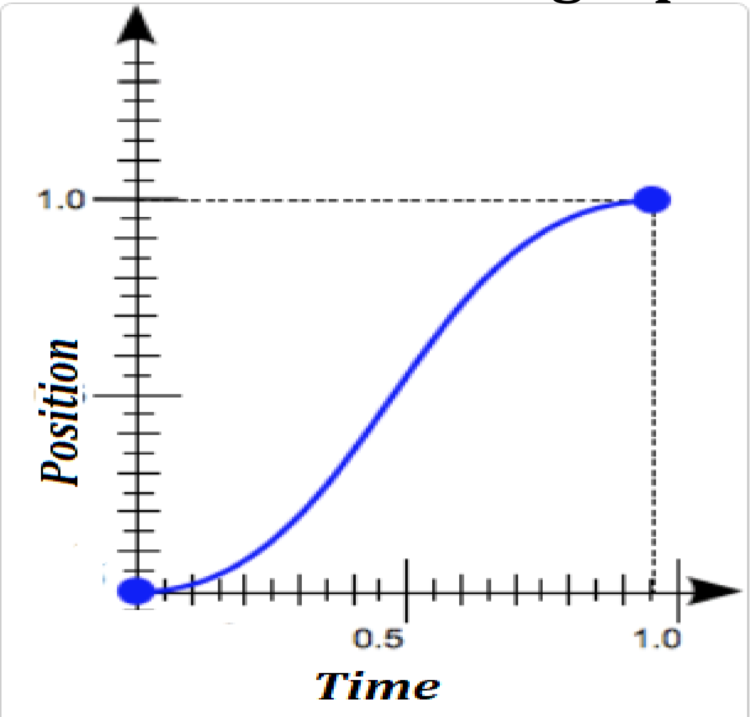
- Thus Consecutive Frame Multiplier '7' Corresponds to '5' Frames

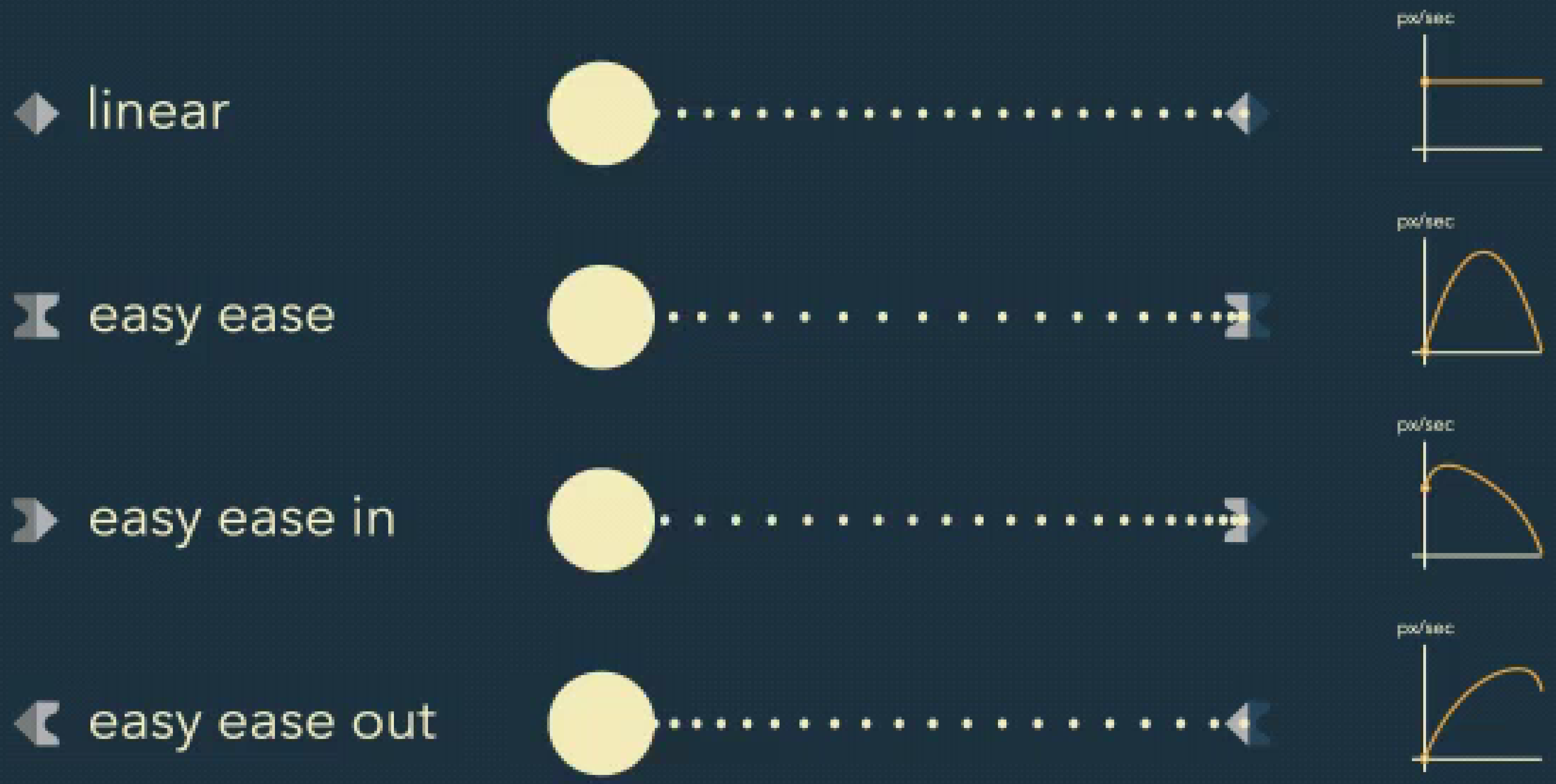


Frame #	Consecutive Frame multiplier	Distance from previous Frame
1	7	7*0.07=0.50m
2	5	5*0.07=0.35m
3	3	3*0.07=0.21m
4	1	1*0.07=0.07m

The Motion Graphs

- A motion graph plots an object's position against time.
- If one is using animation software, understanding and using motion graphs is a key skill in animating.
- For designing the animation, drawing motion graphs before animating can **help to visualize the motion**.
- On a motion graph, the time goes from left to right across the bottom of the graph, while the object's position is plotted vertically against the time.




linear
easy ease
easy ease in
easy ease out
px/sec
px/sec
px/sec
px/sec

Examples of Character Animation

Jumping:

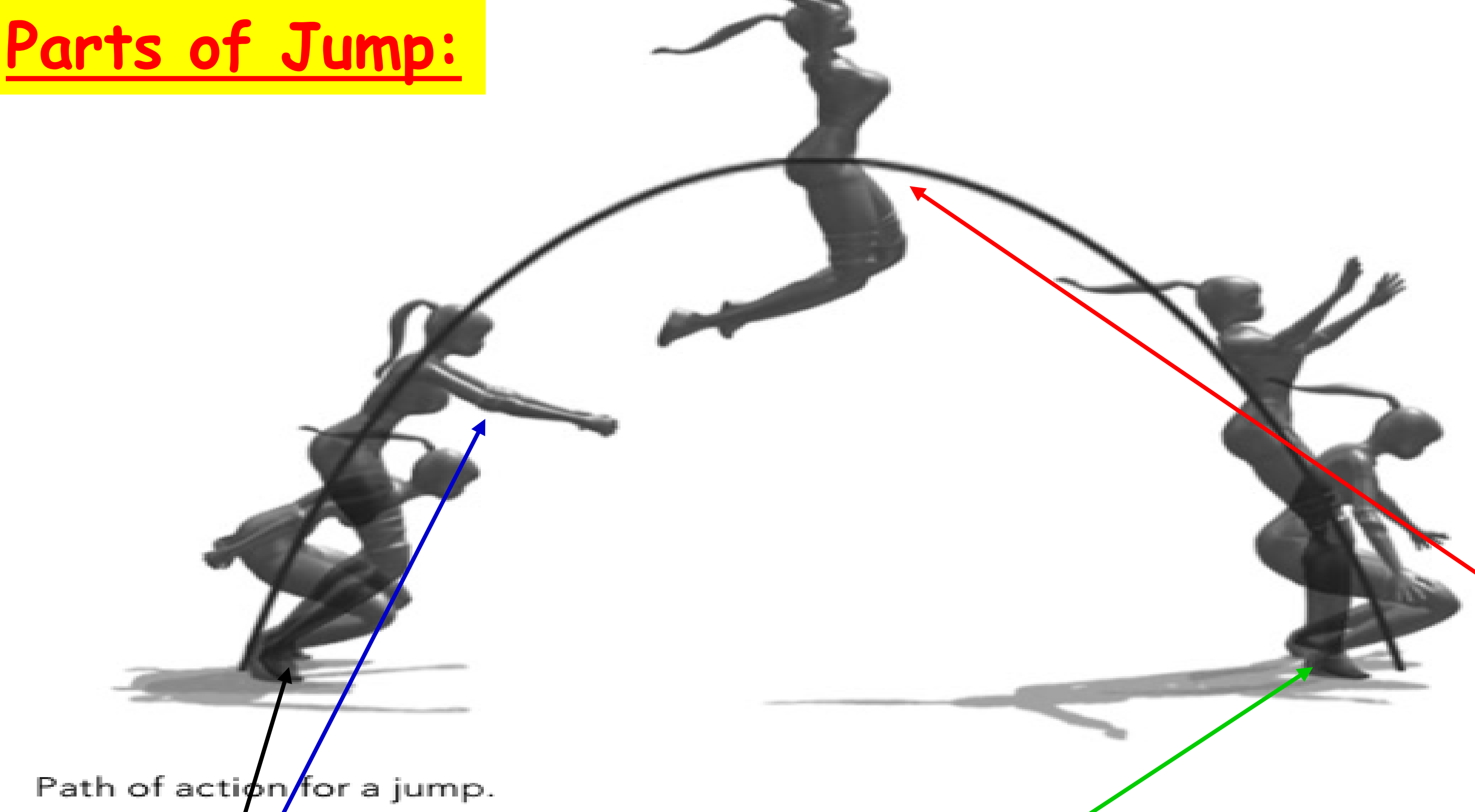
- A jump is an action where the character's entire body is in the air, and both the character's feet leave the ground at roughly the same time.
- A jump action mainly includes a takeoff, free movement through the air, and a landing.

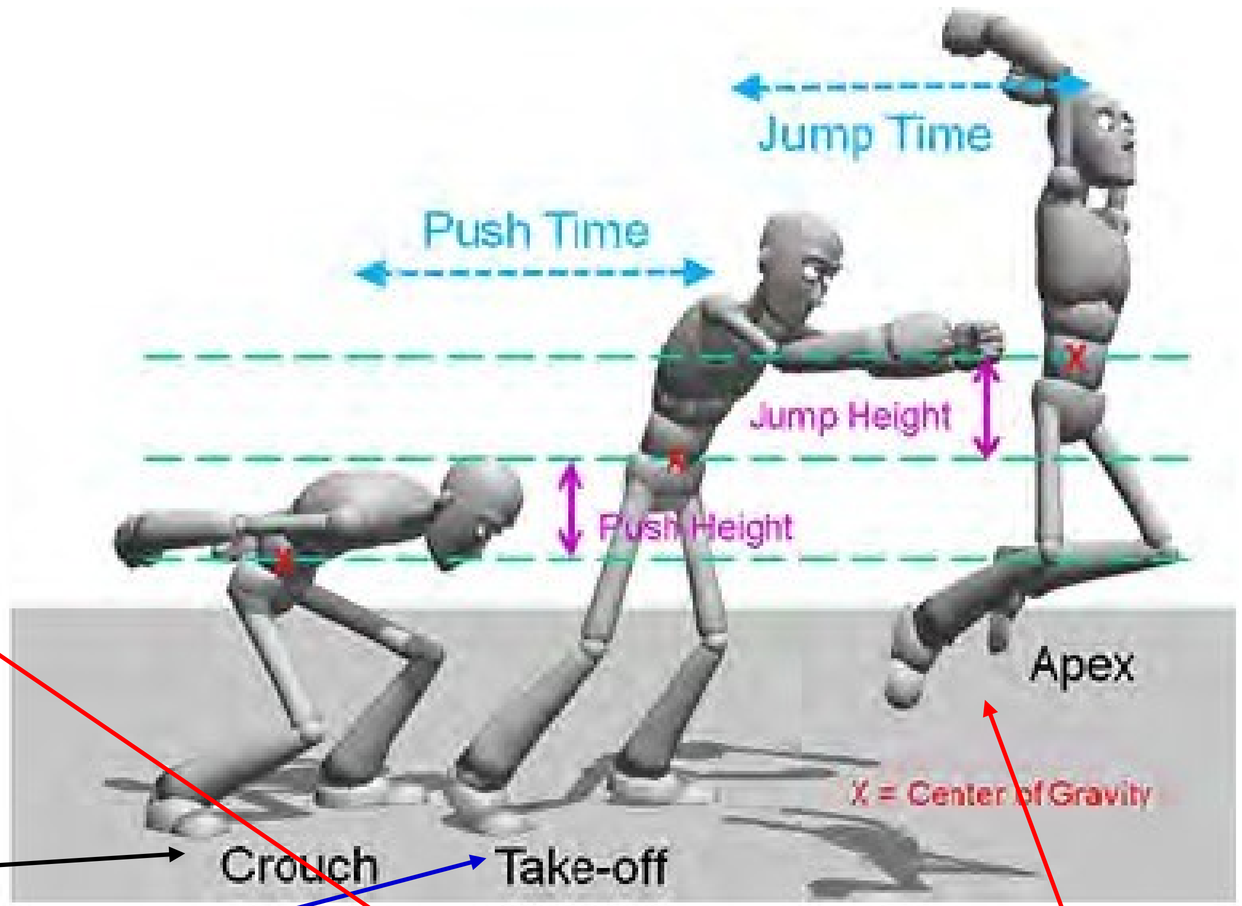
Parts of Jump:

- **Crouch**—A squatting pose taken as preparation for jumping.
- **Takeoff**—Character pushes up fast and straightens legs with feet still on the ground. The amount of time (or number of frames) needed for the push is called the **push time**.
- **In the air**— Both the character's feet are off the ground, and the character's CG moves in a parabolic arc as any free-falling body would.
- **Landing**—Character touches the ground and bends knees to return to a crouch.

Stop Height : It is the distance from the character's CG when his/her feet hit to the ground to the point where the character stops crouching is called the **stop height**. The stop height is not always exactly the same as the push height.

Parts of Jump:





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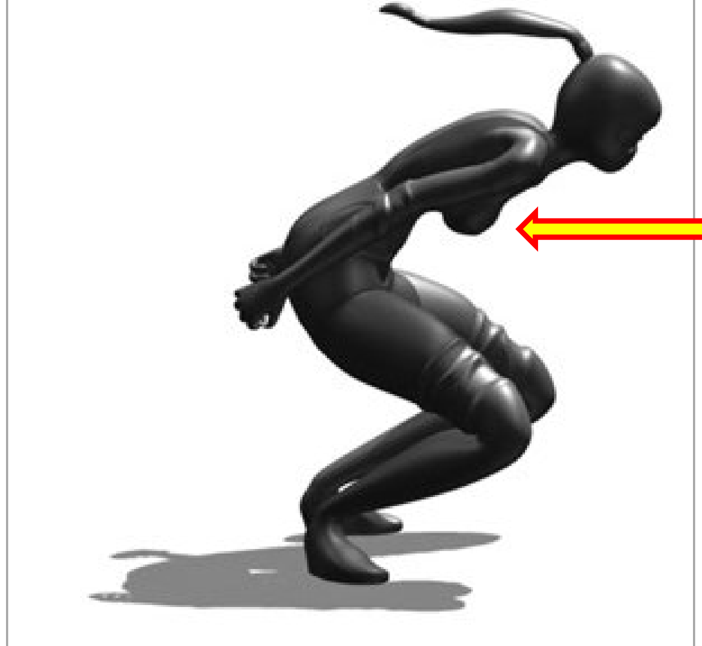

Crouch.

- **Crouch**—A squatting pose taken as preparation for jumping.

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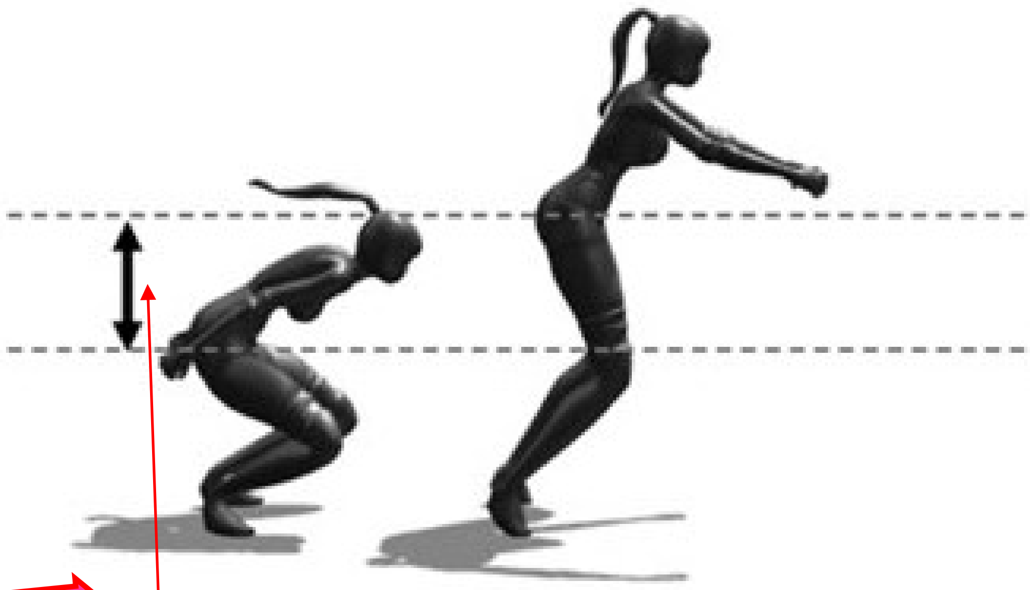

Push height.

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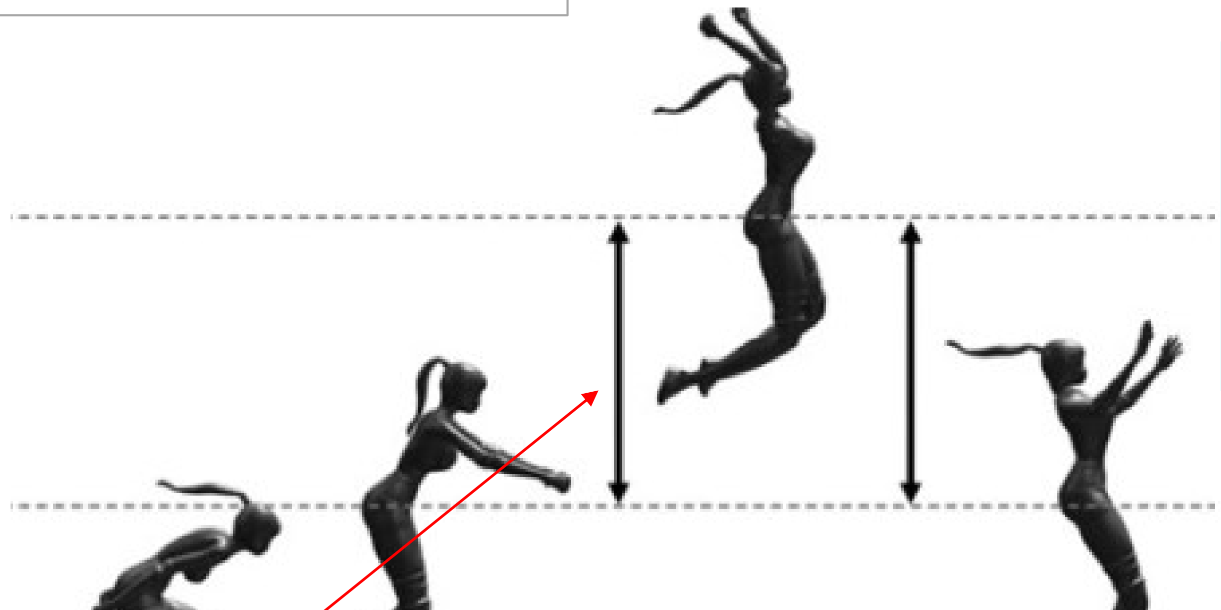
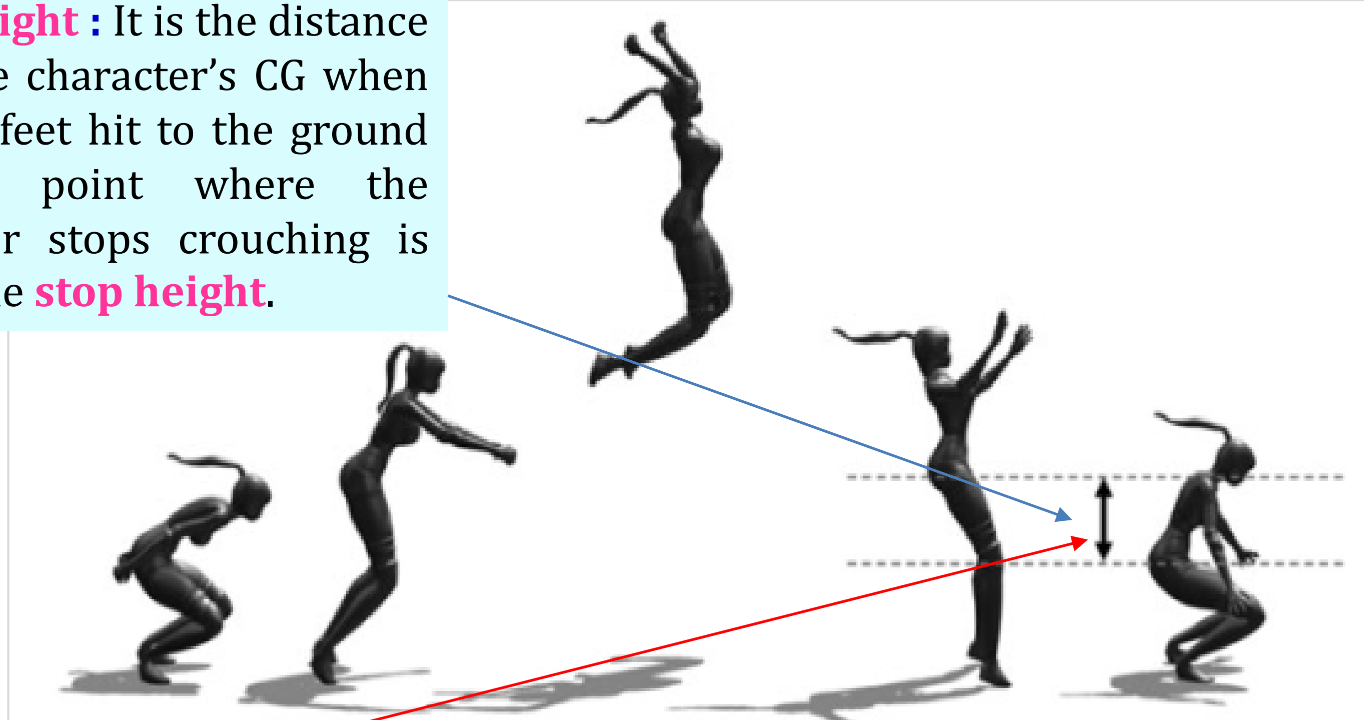


Jump height.

- **In the air**— Both the character's feet are off the ground, and the character's CG moves in a parabolic arc as any free-falling body would.

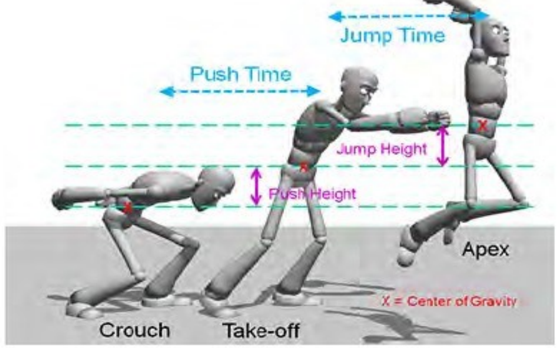


Stop height.

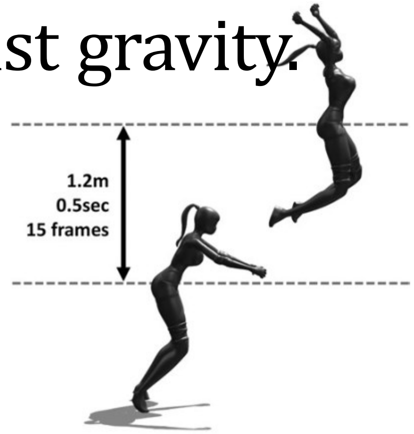
- **Landing**—Character touches the ground and bends knees to return to a crouch.

Calculation of Jump Actions

- When animating the timing for a jump, one need to first decide on:
  - **Jump height or Jump time**
  - **Push height**
  - **Stop height**
  - **Horizontal distance that character travel during jump**
- From these factors, one can calculate the timing for the jump sequence.



- When planning the jump animation, the most likely scenario is that you know the jump height (inch or cm) using for the animation.
- Placement and timing for frames while the character is in the air, follow the same rules as any object thrown into the air against gravity.



Example:

- Jump height = 1.2m
- Jump time for 1.2m $= \sqrt{\frac{2h}{g}} = \sqrt{\frac{2\times 1.2}{9.8}} = 0.5\ s$
- Jump time at 30fps = 0. 5 * 30 = 15 s

Jump Magnification

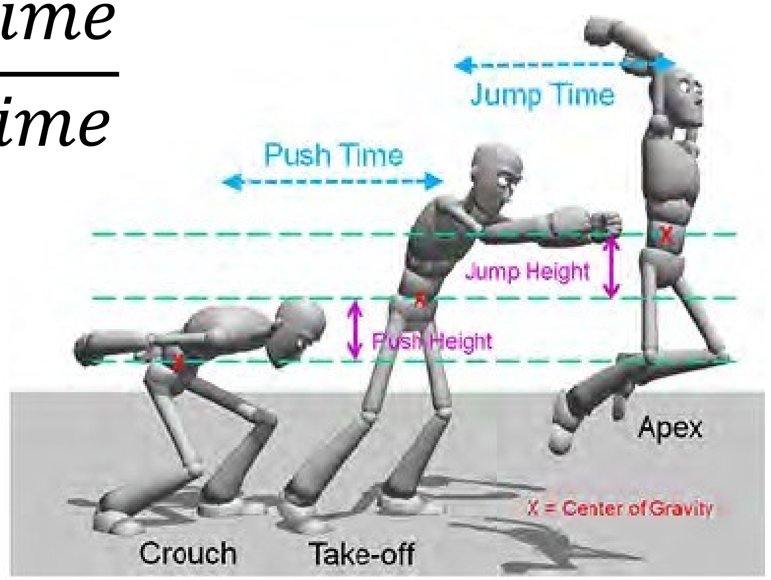
- When calculating the remainder of the timing for the entire jump action, one can use a factor **jump magnification (JM)**.
- The JM is the ratio of the jump height to the push height.

$$JM = \frac{Jump\ Height}{Push\ Height}$$

- JM can be used to calculate the push timing and stop timing

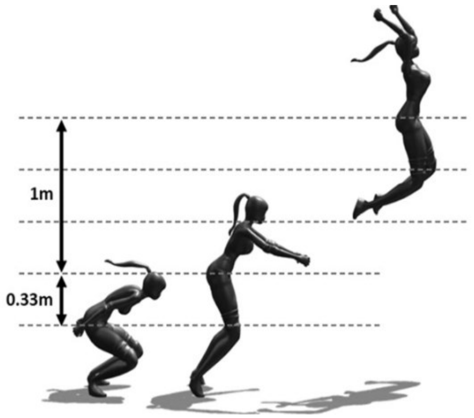
$$JM = \frac{Jump\ Height}{Push\ Height} = \frac{Jump\ Time}{Push\ Time}$$

$$\rightarrow Push\ Time = \frac{Jump\ Time}{JM}$$



Example:

- Jump height = 1m
- Push height = 0.33m
- $JM = \frac{Jump\ Height}{Push\ Height} = 3$



Example:

- JM= 3
- Jump time = 15 s
- $Push\ Time = \frac{15}{3} = 5\ s$

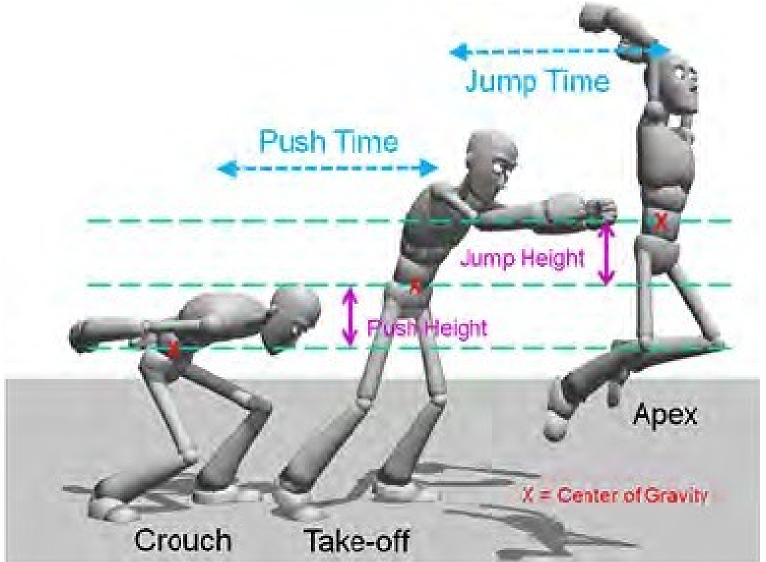
Jump Magnification & Jump Acceleration

- Jump Magnification is in fact an exact ratio that tells one how much the character has to accelerate against gravity to get into the air.
- Let's look at the formula for **JM** and how it is related it to acceleration.

$$JM = \frac{\textbf{Jump Height}}{\textbf{Push Height}} = \frac{Jump\ Time}{Push\ Time} = \frac{Push\ Acceleration}{Jump\ Acceleration}$$

But magnitude of jump acceleration is always equal to gravitational acceleration, with deceleration as the character rises and acceleration as it falls.

$$JM = \frac{Push\ Acceleration}{Jump\ Acceleration} = \frac{Push\ Acceleration}{Gravitational\ Acceleration}$$



Landing & Stop Time

- **Landing** : The forces on landing are similar to takeoff. If the landing has faster timing, the forces will be larger.
- **Stop Time** : The stop height is often a *bit larger* than the push height, but the timing of the push and stop are the *same* in the sense that the CG moves the same distance per frame in the push and stop.

$$\frac{Push\ Height}{Push\ Frames} = \frac{Stop\ Height}{Stop\ Frames} \Rightarrow \frac{Push\ Height}{Push\ time} = \frac{Stop\ Distance}{Stop\ time}$$

- i.e., $$\frac{Stop\ Time}{Push\ Time} = \frac{Stop\ Height}{Push\ Height}$$

$$\rightarrow\ Stop\ Time = \frac{(Push\ Time \times Stop\ Height)}{Push\ Height}$$

Example:

- Push Time = 5 s
- Push Height = 0.4m
- Stop Height $= 0.5m$

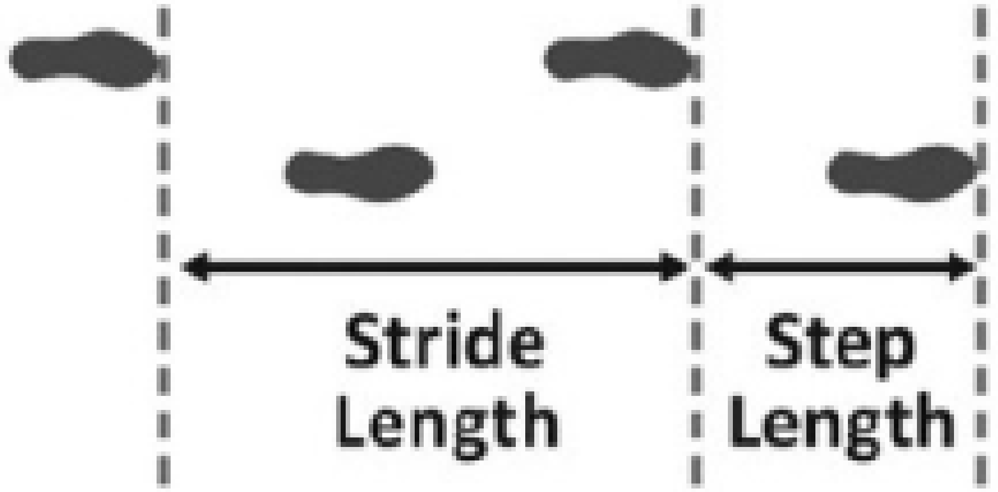
$$\rightarrow\ Stop\ Time = \frac{(5 \times 0.5)}{0.4} = 6\ s$$

Walking : Strides and Steps

- **Walking** : Walks feature is based on the basics of **mechanics**.
- The ability to animate walk cycles is one of the most important skills in animation.

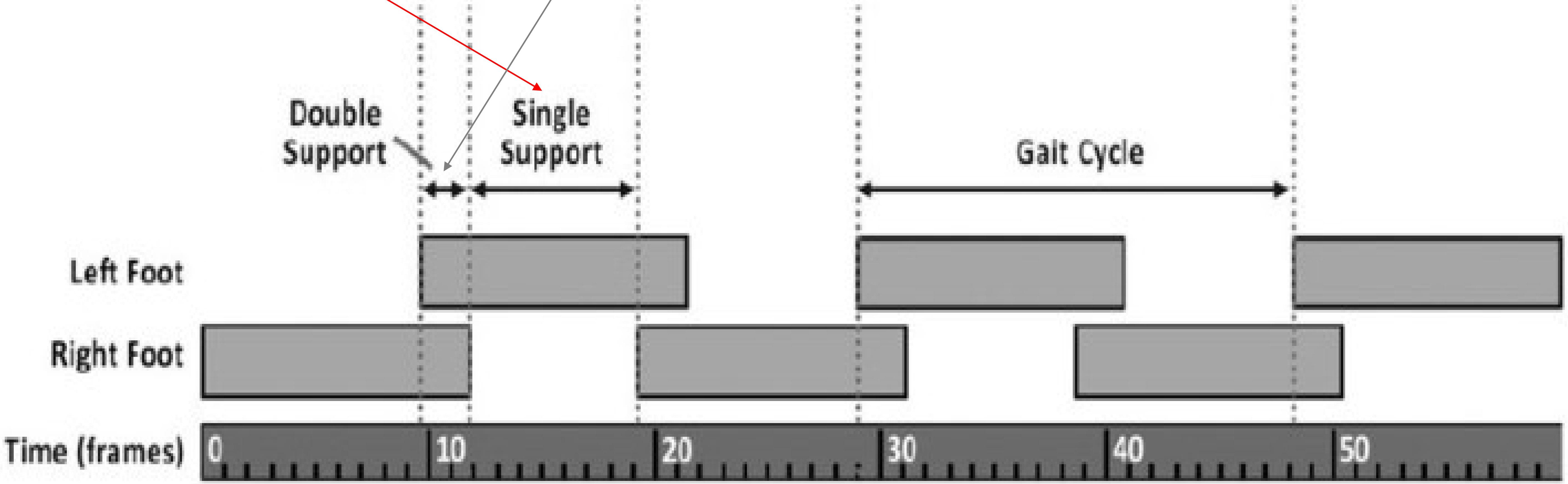
Strides and Steps :

- A **step** is one step with one foot.
- A **stride** is two steps, one with each foot.
- Stride length is the distance that character travels in a stride.
- Step and stride length indicate lengthwise spacing for the feet during a walk.



Gait :

- It is the timing of the motion for each foot, including how long each foot is on the ground or air.
- During a walk, the number of feet, that character has on the ground changes from one foot (**single support**) to two feet (**double support**) and then back to one foot.
- A normal walking gait ranges from 1/ 3 to 2/3 sec per step, with 1/2 sec being average.



Numerical Problems

Odd rule multipliers and Odd rule Scenarios, Jump magnification (JM), Stop time

Example 1. **Given the base distance 0.5 cm for the slow out. Calculate the distance between the frames**

(a) #4 and #5

(b) #1 and #7

using odd rule multipliers.

Given: Base Distance = **0.5 cm**

Solution: We know that, for **Consecutive Frames** $= ((\text{Frame\#} - 1) \times 2 - 1)$

Multiplier **for distance** from first frame to current frame $= (\text{Current Frame\#} - 1)^2$

(a) Multiplier for consecutive frames **#4** and **#5** $= ((5 - 1) \times 2 - 1) = 7$

∴ distance between the frames **#4** and **#5** $= 0.5 \times 7 = 3.5$ **cm**

(b) Multiplier for **#1** and **#7** $= (7 - 1)^2 = 36$

∴ distance between the frames **#1** and **#7** $= 0.5 \times 36 = 18$ **cm**

Example 2. **Given the base distance 1 m for the slow in. Calculate the distance between the frames.**

(a) #2 and #3

(b) #1 and #4

using odd rule multipliers.

Solution:

Example 3. **While animating a Speeding up car, the total distance travelled over 6 frames is 25m. Calculate the base distance.**

Solution:

$$\boldsymbol{Base\ Distance} = \frac{Total\ Distance}{(Last\ frame\ no.-1)^2}$$

$$\boldsymbol{Base\ Distance} = \frac{25}{(6-1)^2}$$

$$\boldsymbol{Base\ Distance} = \frac{25}{25}$$

$$\boldsymbol{Base\ Distance} = 1\ m$$

Example 4. **A slowing-in object in an animation has a first frame distance 0.5m and the first slow in frame 0.35m. Calculate the base distance and the number of frames in sequence.**

Solution:

Example 5. **In a case of animating a jump the Push Height is 0.5m and the JM is 5. Calculate the Jump Height and Push Acceleration. Given Gravitational Acceleration 10ms^{-2}**

Solution:

Example 6. **The jump animation is associated with a Push Time of 5 frames, Push Height 0.4m and Stop Height 0.5m. Calculate the Stop time. Express the push time and stop time in second if the animation is played at 30fps.**

Solution:


THANK YOU!