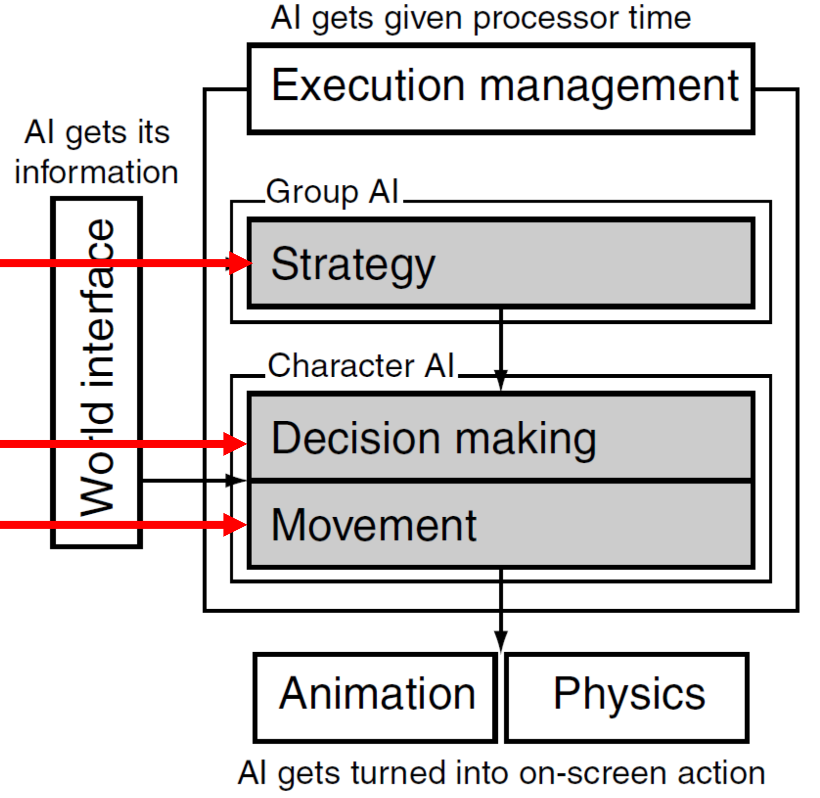
Artificial Intelligence

Lecture 05 – Randomness and Probability

Edirlei Soares de Lima
<edirlei.slima@gmail.com>

Game AI – Model

- Pathfinding
- Steering behaviours
- Finite state machines
- Automated planning
- Behaviour trees
- **Randomness**
- Sensor systems
- Machine learning



Randomness in Games

- Game programmers have a special relationship with random numbers. They can be used for several tasks:
  - Damage calculation;
  - Critical hits probability;
  - Item drop probability;
  - Reward probability;
  - Enemy stats;
  - Spawning enemies and items;
  - Shooting spread zones;
  - Decision making;
  - Procedural content generation;
  - …

Randomness and Probability

- Although most programming languages include functions to generate pseudo-random numbers, there are some situations where some control over the random numbers is extremely important.
  - **Gaussian Randomness**: normal distribution of random numbers.
  - **Filtered Randomness**: manipulation of random numbers so they appear more random to players over short time frames.
  - **Perlin Noise**: consecutive random numbers that are related to each other.

Gaussian Randomness

- Normal distributions (also known as Gaussian distributions) are all around us, hiding in the statistics of everyday life.

Height of Trees

Height of People

Gaussian Randomness

- Normal distributions (also known as Gaussian distributions) are all around us, hiding in the statistics of everyday life.

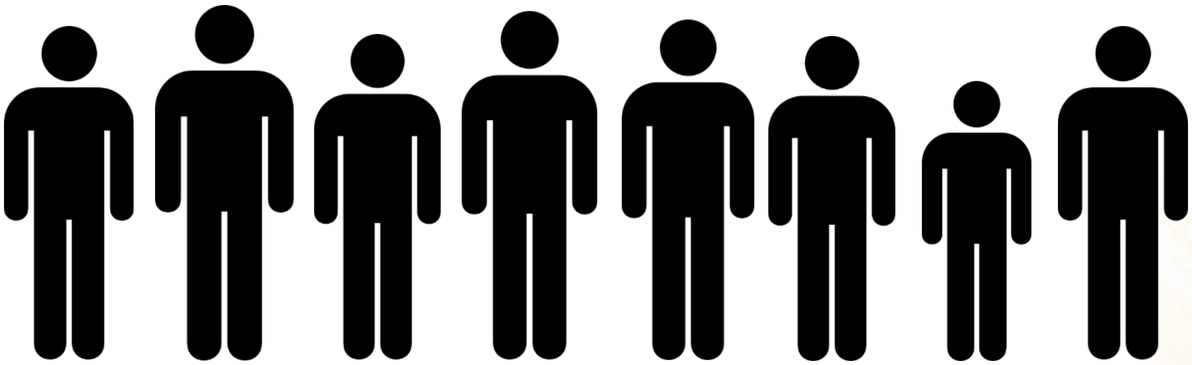
Speed of Runners in a Marathon

Speed of Cars on a Highway

Gaussian Randomness

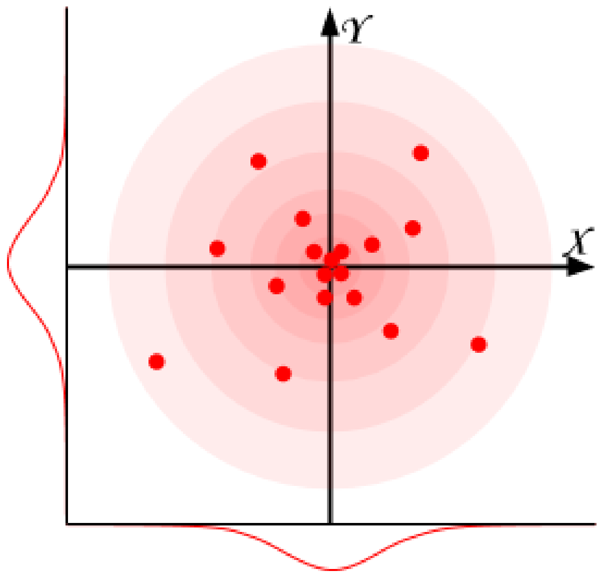
- There is randomness in previous examples, but they are not <u>uniformly random</u>.

- **Example:**
  - The chance of a man growing to be 170 cm tall is not the same as the chance of him growing to a final height of 150 cm tall or 210 cm tall.
  - We see a normal distribution with the height of men centered around 170 cm.

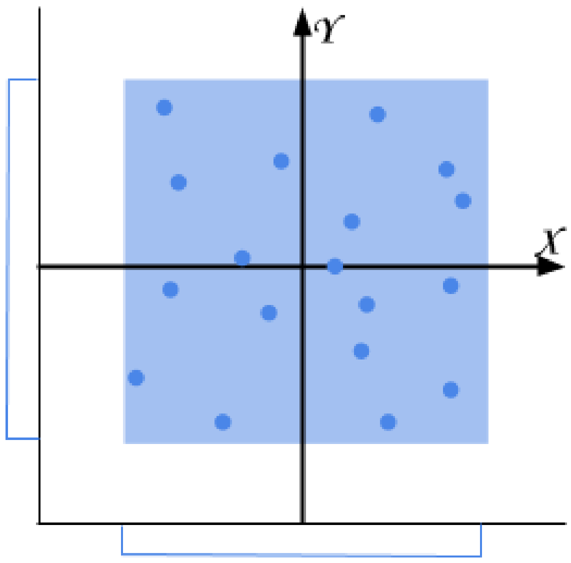


Gaussian Randomness

- Normal Distribution vs. Uniform Distribution:



Normal Distribution



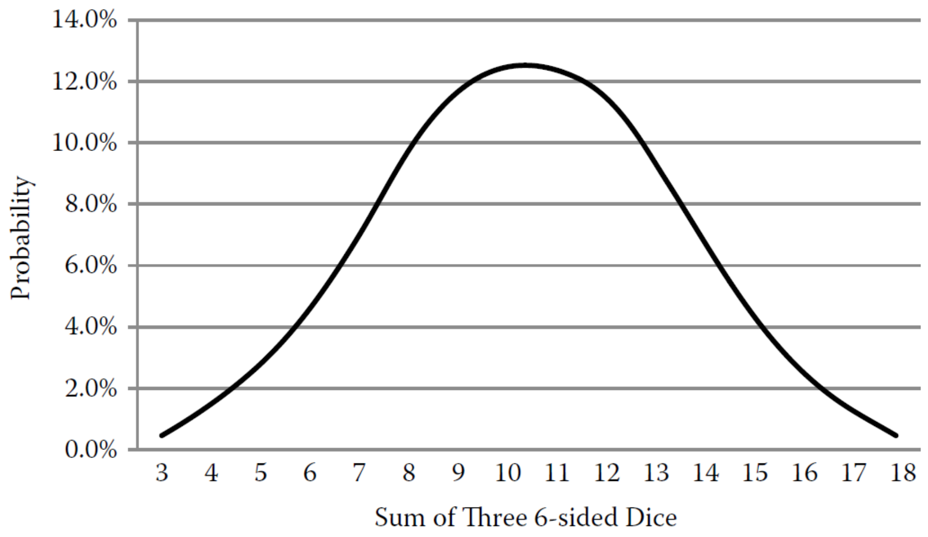
Uniform Distribution

Gaussian Randomness

- The large majority of distributions in life are closer to a normal distribution than a uniform distribution.

- **Central Limit Theorem**: when several independent random variables are added together, the resulting sum will follow a normal distribution.

  – Example: roll and sum three 6-sided dices.



Gaussian Randomness

- Why do most distributions in life follow a normal distribution?
  - Almost everything in the universe has more than one contributing factor, and those factors have random aspects associated with them.
- Example: what determines how tall a tree will grow?
  - Genes, precipitation, soil quality, air quality, amount of sunlight, temperature, exposure to insects, ...
  - For an entire forest, each tree experiences varying aspects of each quality, depending on where the tree is located.

Gaussian Randomness

- How Gaussian randomness can be generated?
  - Box-Muller Transform (Marsaglia polar method):

```
public static float NextGaussian()
{
  float v1, v2, s;
  do{
    v1 = 2.0f * Random.Range(0f, 1f) - 1.0f;
    v2 = 2.0f * Random.Range(0f, 1f) - 1.0f;
    s = v1 * v1 + v2 * v2;
  }while (s >= 1.0f || s == 0f);

  s = Mathf.Sqrt((-2.0f * Mathf.Log(s)) / s);
  return v1 * s;
}
```

Gaussian Randomness

- We can change the normal distribution according to a specific mean and standard deviation:

```
public static float NextGaussian(float mean, float std_dev)
{
  return mean + NextGaussian() * std_dev;
}
```

- We can also guarantee that values never fall outside the limits:

```
public static float NextGaussian(float mean, float std_dev,
                                  float min, float max){
  float v;
  do{
    v = NextGaussian(mean, standard_deviation);
  }while (v < min || v > max);
  return v;
}
```

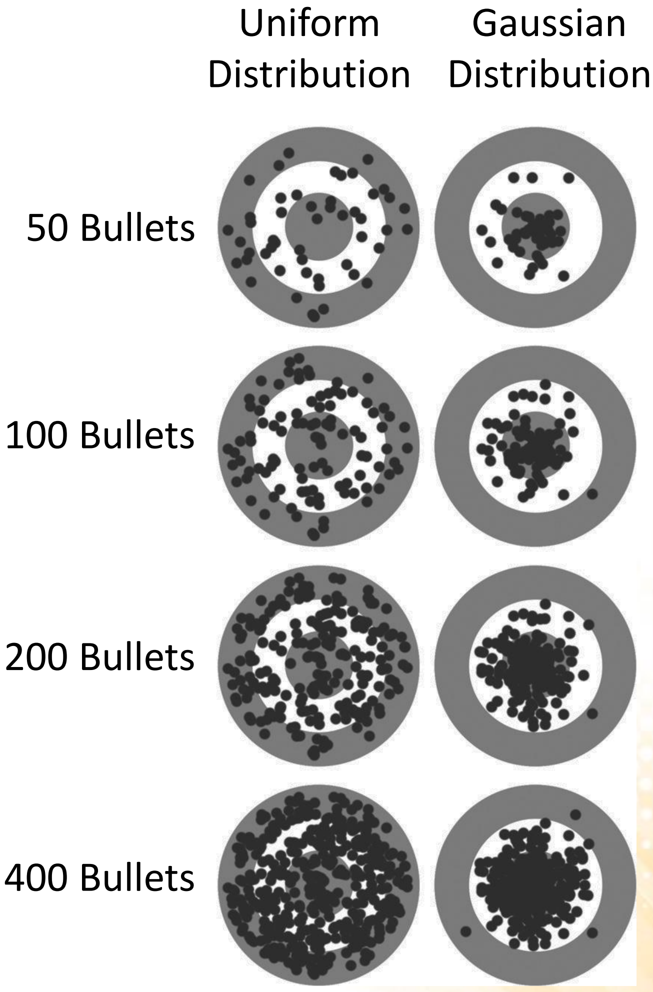
Gaussian Randomness

- Testing the gaussian random numbers:

```
void Start () {
  Texture2D texture = new Texture2D(128, 128);
  GetComponent<Renderer>().material.mainTexture = texture;
  for (int x = 0; x < 300; x++) {
    texture.SetPixel((int)NextGaussian(64, 10, 0, 128),
                     (int)NextGaussian(64, 10, 0, 128),
                      Color.black);
  }
  texture.Apply();
}
```

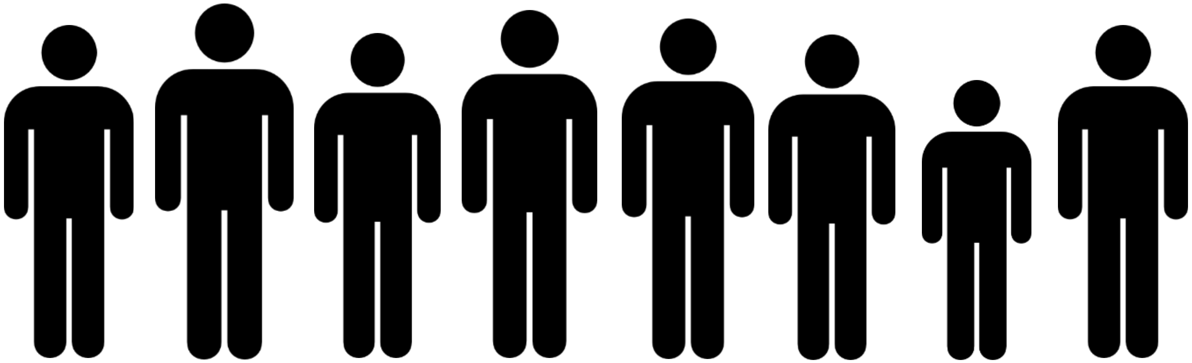
Applications of Gaussian Randomness

- Gun aiming variation.
- Any aspect of an NPC that may vary within a population:
  - Average or max acceleration.
  - Size, width, height, or mass.
  - Fire or reload rate for firing.
  - Refresh rate or cool-down rate for healing or special abilities.
  - Chance of striking a critical hit.
  - Level of intelligence.



Exercise 1

1) Create a random population of 100 characters whose height follow a normal distribution in Unity. You can use any object to represent the characters, such as cubes or cylinders.



Randomness Test

- **Exercise 1:** grab a piece of paper and start writing down 0’s and 1’s in a random sequence with a 50% chance of each—do it until you have a list of 100 numbers.

- **Exercise 2:** take out a coin and start flipping it, recording the sequence of heads and tails as 0s and 1s. Flip it 100 times and write the results in the paper.

Randomness Test

- **Exercise 3:** compare the two lists you made to a list created by a pseudo-random number generator function, with the same 50% chance of either a 0 or a 1. Example:

01101100001100001010000001001011110011100111000110

10101011011111101001011110011111101011111110100001 1

What are the differences between the hand-generated list, the coin flip list, and the computer generated one?

Randomness Test

- It's very likely that the coin flip and computer generated lists contain many <u>more long runs of 0's or 1's</u> compared to the hand-generated list.
  - Most people don't realize that real randomness almost always contains these long runs.
  - Most people simply don't believe a fair coin or real randomness will produce those long runs of heads or tails.

Randomness in Games

- Many games include situations where a uniformly distributed random number determines something that affects the player, either positively or negatively.
- Players have expectations and they believe in "fair probability".
- Randomness is too random for many uses in games:
  - If the player don't believes in the game randomness, he/she will thing that the game is either broken or cheating—all of which are terrible qualities to attribute to a game or an AI.

Randomness in Games

- We have now entered the realm of psychology, and we have temporarily left mathematics.
  - If the player thinks the game is cheating, then the game effectively is cheating despite what is really happening.
  - Perception is far more important than reality when it comes to the player's enjoyment of the game.

- **Solution?**
  - Make the numbers slightly less random!
  - When generating a random sequence of numbers, if the next number will hurt the appearance of randomness, pretend that you never saw it and generate a new number.

Identifying Anomalies

- What makes a sequence of random numbers look less random?

  1. The sequence has a pattern that stands out (e.g. 11001100 or 111000).
  2. The sequence has a long run of the same number (e.g. 01011111110).

- The goal is to write some rules to identify these anomalies, and then throw out the last number that triggers a rule.

Filtering Binary Randomness

- **Rules:**
  1. If the newest value will produce a run of 4 or more equal values, then there is a 75% chance to flip the newest value.
     - This doesn’t make runs of 4 or more impossible, but progressively much less likely (the probability of a run of 4 occurring goes from 1/8 to 1/128).
  2. If the newest value causes a repeating pattern of four values, then flip the last value.
     - Example: 11001100 becomes 11001101
  3. If the newest value causes a repeating pattern of two values with three repetitions each, then flip the last value.
     - Example: 111000 becomes 111001

Filtering Binary Randomness

- Original sequence:

01101100001100001010000001001011110011100111000110
10101011011111101001011110011111101011111101000011

- Filtered sequence (highlighted numbers are flipped):

01101100011000101010001001001011100111001110010110
10101011011101101001011100111011101011101101000110

Filtering Binary Randomness

```
public class BinaryRandom {
  private List<int> generatedNumbers;
  private int maxHistory;

  public BinaryRandom(int historySize){
    maxHistory = historySize;
    generatedNumbers = new List<int>();
  }

  public int NextBinary(){
    int value = Random.Range(0, 2);
    if (generatedNumbers.Count > maxHistory)
      generatedNumbers.RemoveAt(0);
    if (FilterValue(value))
      value = FlipValue(value);
    generatedNumbers.Add(value);
    return value;
  }

  ...
```

Filtering Binary Randomness

```
...

private int FlipValue(int value){
  if (value == 1)
    return 0;
  else
    return 1;
}

private bool FilterValue(int value){
  if (FourRunsBinaryRule(value))
    return true;
  if (FourRepetitionsPatternBinaryRule(value))
    return true;
  if (TwoRepetitionsPatternBinaryRule(value))
    return true;
  return false;
}

...
```

Filtering Binary Randomness

```
...

private bool FourRunsBinaryRule(float value){
  if (generatedNumbers.Count < 3)
    return false;
  for (int i = generatedNumbers.Count - 1;
       i >= generatedNumbers.Count - 3; i--)
  {
    if (generatedNumbers[i] != value)
      return false;
  }
  if (Random.Range(0, 4) == 0)
    return false;
  return true;
}

...
```

Rule 1: if the newest value will produce a run of 4 or more equal values, then there is a 75% chance to flip the newest value.

Filtering Binary Randomness

```
...

private bool FourRepetitionsPatternBinaryRule(float value){
  if (generatedNumbers.Count < 7)
    return false;
  if (generatedNumbers[generatedNumbers.Count - 1] != value)
    return false;
  int count = 0;
  for (int i = generatedNumbers.Count - 2;
       i >= generatedNumbers.Count - 7; i-=2)
  {
    if (generatedNumbers[i] == generatedNumbers[i - 1])
      count++;
  }
  if (count < 3)
    return false;
  return true;
}

...
```

Rule 2: if the newest value causes a repeating pattern of four values, then flip the last value.

Filtering Binary Randomness

```
  ...

  private bool TwoRepetitionsPatternBinaryRule(float value){
    if (generatedNumbers.Count < 5)
      return false;
    if ((generatedNumbers[generatedNumbers.Count - 1] != value) ||
        (generatedNumbers[generatedNumbers.Count - 2] != value))
      return false;
    for (int i = generatedNumbers.Count - 3;
         i >= generatedNumbers.Count - 5; i--)
    {
      if (generatedNumbers[i] == value)
        return false;
    }
    return true;
  }
}
```

Rule 3: if the newest value causes a repeating pattern of two values with three repetitions each, then flip the last value.

Filtering Integer Ranges

- **Rules:**
  1. Repeating numbers.
     - Example: [7, 7] or [3, 3].
  2. Repeating numbers separated by one digit.
     - Example: [8, 3, 8] or [6, 2, 6].
  3. A counting sequence of 4 that ascends or descends.
     - Example: [3, 4, 5, 6].
  4. Too many values (4) at the top or bottom of a range within the last 10 values.
     - Example: [6, 8, 7, 9, 8, 6, 9].
  5. Patterns of two numbers that appear in the last 10 values.
     - Example: [5, 7, 3, 1, 5, 7].
  6. Too many (4) of a particular number in the last 10 values.
     - Example: [9, 4, 5, 9, 7, 8, 9, 0, 2, 9].

Filtering Integer Ranges

- Original sequence:

22312552222577750677564061448482102435500989388459
59607889964957780753281574605482138446235103745368

- Filtered sequence (highlighted numbers are thrown out):

22312552222577750677564061448482102435500989388459
59607889964957780753281574605482138446235103745368

Exercise 2

2) Based on the binary filter, create a class to filter integer ranges according to the following rules:

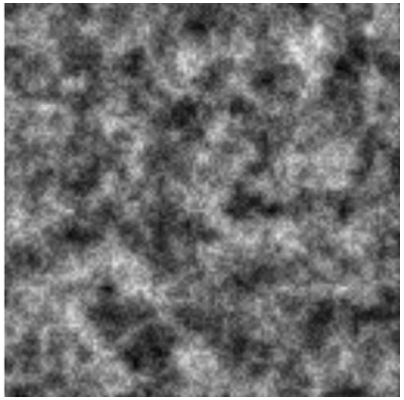
   1. Avoid repeating numbers (e.g.: [7, 7] or [3, 3]).
   2. Avoid repeating numbers separated by one digit (e.g.: [8, 3, 8] or [6, 2, 6].
   3. Avoid ascends or descends counting sequences of 4 numbers (e.g.: [3, 4, 5, 6]).
   4. Avoid 4 repetitions of a particular number in the last 10 values (e.g.: [9, 4, 5, 9, 7, 8, 9, 0, 2, 9]).

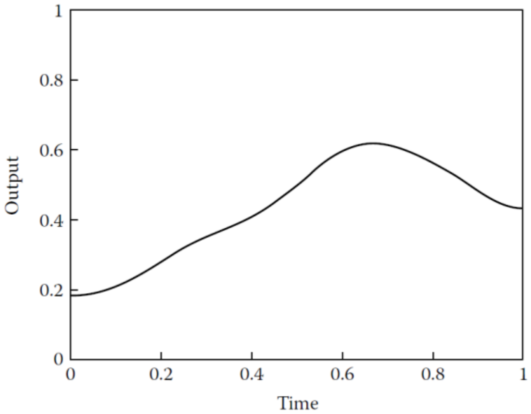
Filtering Floating-Point Ranges

- **Rules:**
  1. Reroll if two consecutive numbers differ by less than 0.02.
     - Example: [0.875, 0.856].
  2. Reroll if three consecutive numbers differ by less than 0.1.
     - Example: [0.345, 0.421, 0.387].
  3. Reroll if there is an increasing or decreasing run of 5 values.
     - Example: [.342, 0.572, 0.619, 0.783, 0.868].
  4. Reroll if there are too many values (4) at the top or bottom of a range within the last 10 values.
     - Example: [0.325, 0.198, 0.056, 0.432, 0.119, 0.043].

Perlin Noise for Game AI

- Perlin noise is a type of gradient noise typically used in computer graphics to generate organic textures.





- Perlin noise generates a form of coherent randomness, where consecutive random numbers are related to each other.
  - This "smooth" nature of randomness don't generates wild jumps from one random number to another, which can be a very desirable trait.

Perlin Noise for Game AI

- Possible applications of Perlin noise for game AI:
  - Movement (direction, speed, acceleration);
  - Layered onto animation (adding noise to facial movement or gaze);
  - Attention (guard alertness, response time);
  - Play style (defensive, offensive);
  - Mood (calm, angry, happy, sad, depressed, manic, bored, engaged);

Perlin Noise in Unity

- Unity has a function to compute 2D Perlin noise:

```
float Mathf.PerlinNoise(float x, float y);
```

- It returns the Perlin noise value between 0.0 and 1.0.

- Although the noise plane is two-dimensional, we can ignore one coordinate and sample the noise from just one-dimension.

Perlin Noise in Unity

- **Example:** movement direction:

```
public class WanderAgent : MonoBehaviour
{
  public float speed = 2;
  public float rotationFactor = 1.2f;
  public float seed = 0.5f;

  void Update ()
  {
    transform.forward = new Vector3(Mathf.PerlinNoise(Time.time *
                        seed, 0.0f) * rotationFactor,
                        transform.forward.y, transform.forward.z);
    transform.position += transform.forward * Time.deltaTime * speed;
  }
}
```

Further Reading

- Rabin, S., Goldblatt, J., and Silva, F. (2013). **Game AI Pro: Collected Wisdom of Game AI Professionals.** Steven Rabin (ed.), A K Peters/CRC Press, ISBN: 978-1466565968.
  - **Chapter 3: Advanced Randomness Techniques for Game AI**