TP 2.1 - GENERADORES PSEUDOALEATORIOS

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ABSTRACT

La simulación es fundamental para estudiar y predecir eventos de naturaleza aleatoria. Para reproducir esta azarosidad se pueden utilizan números aleatorios, pero para eso primero es necesario poder generarlos. Realizar números realmente independientes y casuales entre ellos es dificil y costoso. En éste trabajo estudiaremos algunas de las formas de generar pseudo-aleatoriedad.

1 Introducción.

Producir números aleatorios es impracticable en la gran mayoría de los casos, se puede ver muy facilmente en algunos de los generadores de números aleatorios, generadores de ahora en más, más conocidos: random.org genera sus números a partir del ruido atmosférico; ERNIE ha pasado por diferentes tecnologías, pero actualmente hace uso de la propiedades cuánticas de la luz; RAND Corporation tal vez la más sencilla de las mencionadas, utiliza una ruleta electrónica. Para obviar ésta dificultad de conseguir verdadera azarosidad ingenieros, matemáticos e informáticos han ideado diferentes métodos para conseguir acercarse lo más posible ésta aleatoriedad (pseudo-aleatoriedad). A continuación estudiaremos los métodos **GLC** (Generador lineal congruencial) y **Parte media del cuadrado**. Utilizaremos dichos métodos utilizando distintos parámetros para generar secuencias de números pseudoaleatorios, las cuales analizaremos mediante distintas pruebas para comprobar su efectividad.

2 Marco teórico.

A continuación detallaremos algunos conceptos que se utilizarán en el siguiente trabajo:

Aleatoriedad Capacidad de un evento de ser impredecible, casual y azaroso. Estudiados matemáticamente éstos eventos no demuestran una tendencia y correlación, en otras palabras no desvelan patrones.

Pseudo-aleatoriedad Se refiere a eventos que se acercan a una aleatoriedad real, pero que fueron hechos por procesos deterministas. Sus parámetros estadísticos tienden a ser similares a los de naturaleza aleatoria. Sin embargo, dependen de la calidad de su generador, ya que se pueden encontrar casos donde se generan patrones muy visibles.

Generador de números pseudo-aleatorios Algoritmos que producen secuencias de números pseudo-aleatorios. Son deterministas porque utilizan parámetros que se trabajan mediante un algoritmo para llegar a un resultado pseudo-aleatorio. En algunos casos incluso, como el generador *Parte media del cuadrado*, cada elemento de la secuencia depende directamente del elemento anterior. La calidad del generador dependerá entonces no sólo del algoritmo que utilice sino también de los parámetros iniciales elegidos. [2]

Semilla Número inicial de la secuencia de números pseudo-aleatorios.

Aclaración si bien entendemos perfectamente la diferencia entre aleatoriedad y pseudo-aleatoriedad, usaremos dichos términos de manera indistinta, ya que buscamos que ésta pseudo-aleatoriedad se acerque lo más posible a la aleatoriedad real.

3 Metodología de trabajo.

Codificaremos los generadores a estudiar, y a su vez, las tres pruebas de aleatoriedad. Cada generador originará una cantidad fija de números para posteriormente estudiar su distribución con las distintas pruebas aplicadas y mediante las visualizaciones obtenidas.

Las gráficas que se utilizarán en el estudio serán: un histograma para visualizar la frecuencia absoluta de las casillas en las que se clasificarán las secuencias, y un diagrama de dispersión de la secuencia obtenida. Este último se basa en el hecho que si la secuencia X es aleatoria, no debería encontrarse correlación entre los valores sucesivos de la misma. Así, si se grafica X_j contra X_{j+1}, donde X_j corresponde al valor j en la secuencia pseudo-aleatoria, se debería obtener para un buen generador, un gráfico que rellene el espacio entero sin un patrón discernible. [3]

Posterior al desarrollo del estudio inicial, al encontrar ciertas ineficiencias en el generador Parte media del cuadrado, nos propusimos estudiarlo más a fondo. Buscamos tener conocimiento de sus limitaciones y poder obrar para obtener un mejor rendimiento. Para este caso se generaron distintos gráficos para visualizar la longitud de los ciclos generados, así como la frecuancia de las longitudes de dichos ciclos.

4 Generadores estudiados.

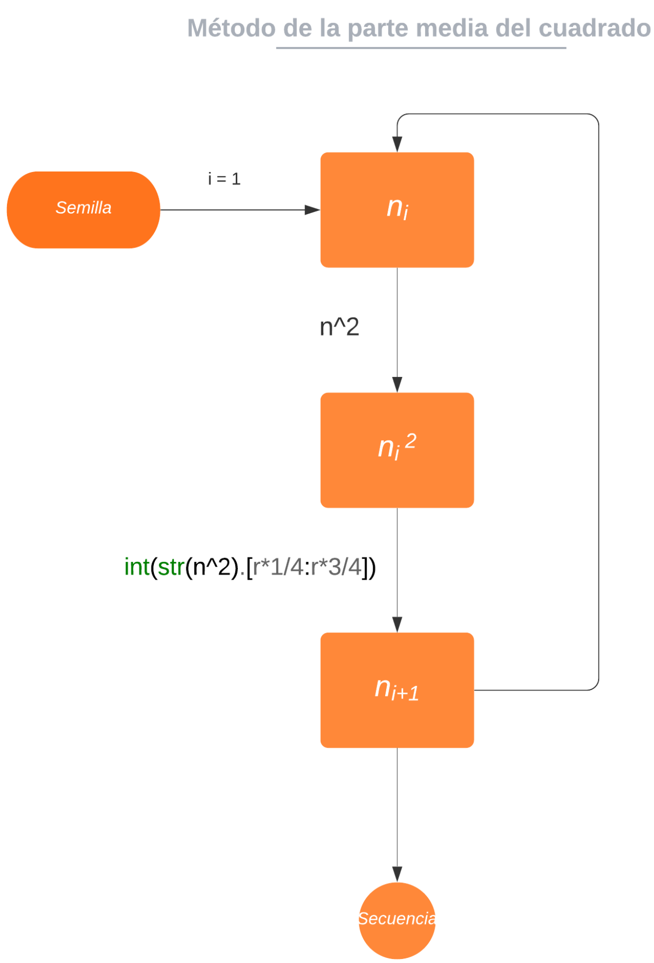
A continuación detallaremos los generadores estudiados, dando una breve descripción del mismo e incluyendo un diagrama de flujo donde se muestre su algoritmo. [2]

4.1 Parte media del cuadrado.

4.1.1 Proceso

Creado por John von Neumann, uno de los padres de la informática, consiste en elegir una semilla de r dígitos, elevarla al cuadrado, y del número obtenido tomar los r dígitos del medio, éstos números serán nuestro nuevo elemento de la secuancia. A continuación volver a ejecutar el procedimiento con el elemento recientemente obtenido. En caso de que un número elevado no tenga r cifras, se debe completar con ceros a la izquierda. El número de dígitos r debe ser par, ya que si no lo es, no se asegura que la cantidad de dígitos de n al cuadrado permita tomar $n = 512$, entonces $512^2 = 265.225$. En éste caso no hay parte media exacta que tomar para generar el elemento siguiente de la secuencia.

4.1.2 Diagrama de flujo.



4.2 Generador lineal congruencial - GLC.

4.2.1 Proceso.

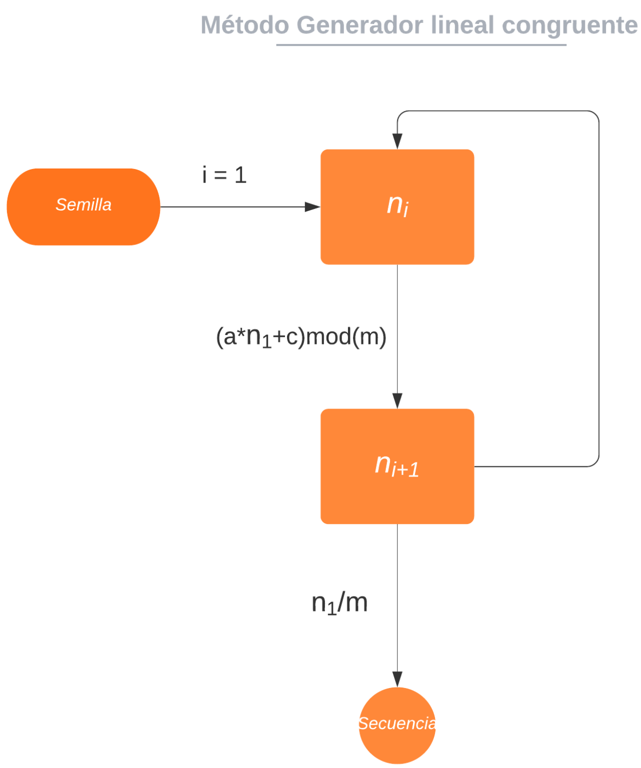
Creado en 1949 por Derrick H. Lehemer, éste algoritmos utiliza la función:

$$X_{i+1} = (aX_i + c)mod(m) \tag{1}$$

la cual se aplica a cada elemento de la secuancia para conseguir el siguiente. Siendo X_0 la semilla, m es el período máximo que puede tener el generador, a el multiplicador y c el incremento. Éstos elementos deben cumplir las siguientes restricciones para que el generador funcione correctamente.

- $m > 0$
- $0 \leq a < m$
- $c \leq m$
- $0 \leq X_0 < m$

4.2.2 Diagrama de flujo.



5 Métodos de prueba

A continuación explicaremos de manera genérica las pruebas utilizadas, posteriormente detallaremos dichas pruebas en nuestro caso en particular. [4]

5.1 Prueba de bondad de ajuste utilizando χ^2.

Una variable aleatoria, teoricamente debe tener cierta distribución F. Ésta prueba verifica si se cumple la hipótesis nula,

$$H_0 : \text{La muestra se comporta con distribución } F. \tag{2}$$

o por el contrario la hipótesis alternativa,

$$H_1 : \text{La muestra no se comporta con distribución } F. \tag{3}$$

Para eso, se divide el conjunto de resultados en clases $i \in (i_0 \, ; i_m)$, y se contabilizan las ocurrencias de cada clase dentro de la muestra, siendo ésta la frecuencia observada de dicha clase, O_i. A continuación obtener la frecuencia esperada para cada clase, E_i, que se obtiene multiplicando la cantidad de observaciones por la probabilidad de cada clase, np_i. Obtener el valor de χ_c^2 con c grados de libertad para las frecuencias de la siguiente manera.

$$\chi_c^2 = \sum_{i=1}^{m} \frac{(O_i - E_i)^2}{E_i} \tag{4}$$

La hipótesis nula se evaluará con un nivel de riesgo α, obtendrémos el valor p, que se consigue como la probabilidad de obtener un X mayor o igual al valor obtenido de χ_c^2 suponiendo la hipótesis nula,

$$P(X \geq \chi_c^2 \mid H_0) \tag{5}$$

Si el valor p obtenido es menor al α elegido se puede rechazar la hipótesis en caso contrario no podemos rechazarla pero no podemos afirmar que se cumpla. [5]

5.1.1 Prueba de bondad de ajuste aplicada en nuestro caso de estudio

Definimos la variable aleatoria X : número generado por el generador pseudo-aleatorio. La distribución F de X debería ser uniforme, ya que nuestro generador debería producir cualquier número con la misma frecuencia que cualquier otro. De ésta manera la probabilidad p de cada clase de número aleatorio es la misma para todas. En nuestro estudio hemos decidido generar números de hasta dos cifras decimales, así la probabilidad de cada clase son los casos favorables, 1 sobre los casos posibles 100, $p = \frac{1}{100} = 0.01$. De ésta forma,

$$x \sim U(0, 1) \tag{6}$$

Ahora podemos calcular las frecuencias teóricas, que sabemos debe ser la misma para todas las clase debido su distribución. La obtenemos multiplicando la cantidad de números generados n por la probabilidad obtenida, $E_i = np$.

5.2 Prueba de espera utilizando χ^2.

También llamada prueba de huecos, distancias o gap, evalúa la independencia de las clases entre ellas, para eso define las distintas esperas que no son más que las posibles dintancias entre dos ocurrencias de la misma clase, ejemplo: en la secuencia de clases [A, B, C, A] la distancia entre las dos ocurrencias de la clase A es 3. Se cuentan la ocurrencia de cada longitud de distancia, es decir: en la secuencia [A,A,B,B,A] hay dos ocurrencias de la longitud 1 y una ocurrencia de la longitud 3. Una vez obtenidas las frecuencias observadas O_i para cada longitud se definen las frecuencias esperadas E_i De aquí en adelante se procede de la misma manera que en la prueba de Bondad de ajuste.

5.2.1 Prueba de espera aplicada a nuestro caso de estudio.

Como nuestro generador se asume que devuelve secuencias que siguen una distribución uniforme, la distribución de la variable aleatoria D : *Distancia entre dos elementos de la misma clase en la secuencia pseudo-aleatoria* se debería comportar de manera geométrica [6] con parámetro $p = 0.01$. Ésto se basa en el hecho que la distribución geométrica es la única distribución discreta (en nuestro caso, la variable D es discreta) que no posee memoria, propiedad que se busca en un generador aleatorio. A su vez, la probabilidad de que ocurra un éxito, esto es, que se de una ocurrencia de cierta longitud de distancia, depende directamente de que no suceda antes. De ésta afirmación obtenemos lo siguiente:

$$D \sim G(0.01) \tag{7}$$

Se aclara que cuando una longitud, no vuelve a tener ocurrencia antes de terminar la secuencia de números, no se suma una acontecimiento para esa distancia. Tómese el ejemplo: [..., A, B, B]. En éste caso, la clase de longitud A no suma una nueva ocurrencia, ya que es indeterminado cuando volverá a ocurrir. Ésta regla se aplicará inevitablemente para todas las esperas.

Por otro lado, debido a que las longitudes posibles son infinitas se define un tope n, así la última clase de longitud de distancia será, $D \geq n$.

Se procede a obtener las probabilidades de cada longitud de distancia:

$$P(D = d) = (1 - p)^{d-1} p \tag{8}$$

para cada longitud menor a n, y para las longitudes mayores o iguales a n:

$$P(D \geq n) = \sum_{m=0}^{\infty} (1 - p)^{m+n-1} p = (1 - p)^n \tag{9}$$

Una vez obtenidas las probabilidades, se procede a obtener las frecuencias esperadas de cada longitud. Multiplicamos la probabilidad de la distancia correspondiente por la sumatoria de las ocurrencias de todas los largos de espera. Así nos queda:

$$E_i = (\sum_{1}^{n} O_i) * p_i \tag{10}$$

Nos queda realizar el cálculo de χ_c^2 de igual manera que para la prueba de Bondad de ajuste.

Las hipótesis en éste caso son:

$$H_0 : \text{La variable X es independiente de si mísma, no tiene memoria.} \tag{11}$$

Más concretamente:

$$H_0 : \text{La variable D se comporta con distribución } \textit{Geométrica.} \tag{12}$$

La hipótesis alternativa,

$$H_1 : \text{La variable X es dependiente de si mísma, tiene memoria.} \tag{13}$$

Refiriéndose a la variable D:

$$H_1 : \text{La variable D no se comporta con distribución } \textit{Geométrica.} \tag{14}$$

6 Herramientas utilizadas.

6.1 Lenguaje de programación.

Se utilizó el lenguaje de programación **Python** en su versión 3 para el desarrollo de la simulación. Se utilizaron además módulos de la biblioteca estándar de Python, asi como bibliotecas externas para añadir más funcionalidad.

6.1.1 Bibliotecas y módulos.

Para graficar los arreglos que almacenan el dinero disponible y la apuestas realizadas se utilizó la biblioteca ***Matplotlib 3.1.1***, en particular el método *pyplot* perteneciente a dicha biblioteca.

Para aplicar el cálculo de χ^2 se utilizó el módulo **stats** de la biblioteca **scipy**, en particular el método *chisquare* perteneciente a dicho módulo.

Para obtener el tiempo actual y utilizarlo en la semilla de los generadores, se utilizó el módulo **time**.

Se utilizaron además, para cuestiones de conteo en las gráficas, las clases *MaxNLocator* (perteneciente al módulo *ticker* de **Matplotlib**) y *Counter* (perteneciente a la biblioteca **Collections**).

6.2 Parámetros utilizados.

Para realizar el experimento se utilizaron los siguientes parámetros y valores:

Nivel de riezgo α: 0,05

Cantidad de números generados: 10000

Cantidad de simulaciones: 4

Para realizar los conteos de distancias sobre el Generador de Medios de Cuadrados se utilizaron los siguientes parámetros:

Cantidad de números generados: 2000

Cantidad de simulaciones: 500

6.3 Parámetros de los generadores

Para realizar el experimeto se utilizaron los siguientes conjuntos de parámetros y valores en los generadores de números aleatorios.

Semillas: Se utilizaron cada vez, la parte menos significativa del tiempo en el que se solicita con la longitud pasada como parámetro.

Para el GLC La obtención de la semilla en este caso se trabajó con una longitud asignada de 6. Para este generador se decidió aplicar tres conjuntos de parámetros, siendo los primeros dos los utilizados en distintos lenguajes de programación. El último conjunto se asignó con valores arbitrarios, como se muestra en la siguiente tabla:

Table 1: Resultados pruebas aplicadas a los valores obtenidos

	C	**Java**	**Arbitrarios**
Multiplicador (a)	22.695.477	25.214.903.917	101
Incremento (c)	1	11	1
Módulo (m)	2^{32}	$2^{48} - 1$	2^{16}

Para el Medio de los cuadrados Para este generador se analizaron tres estados utilizando el algoritmo con distintas longitudes de semillas. En particular, se utilizaron las longitudes de: **4, 6 y 8**.

7 Resultados obtenidos.

7.1 Gráficas y pruebas

A continuación se mostrarán los resultados de las pruebas aplicadas a las secuencias obtenidas en cada generador. Se mostrará, además, los histogramas que grafican la frecuencia absoluta obtenida de cada casilla (se aclara que si bien los *bins* del histograma se corresponden con cada casilla, el eje de las mismas está acotado por una cuestión de legibilidad).

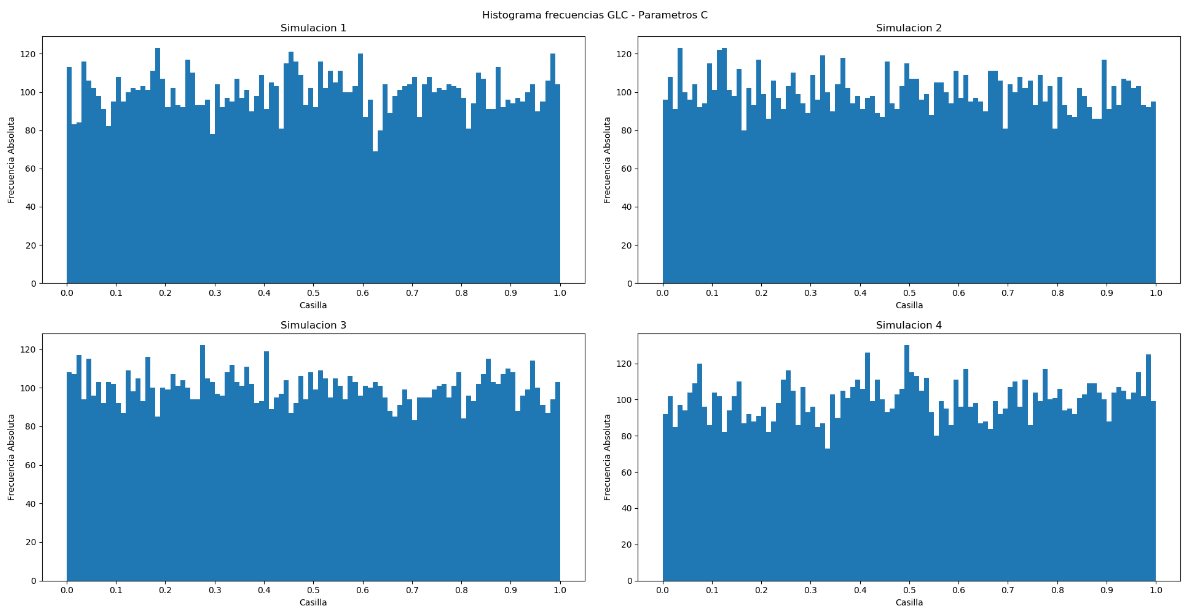
Se agrega además, un diagrama de dispersión de cada secuencia, mediante el cual se podrán observar (si existiesen) patrones en la secuencia generada.

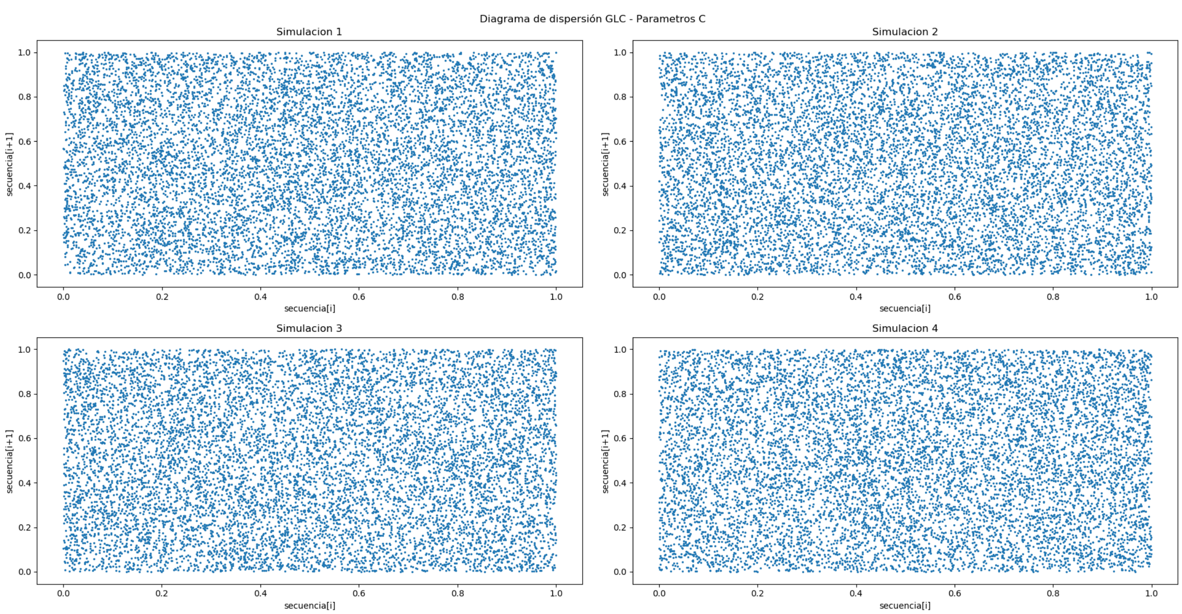
Para el caso del segundo generador (Parte media del cuadrado), se añadirá un breve análisis de cada simulación.

7.1.1 GLC - Parametros C

Table 2: Resultados pruebas aplicadas a los valores obtenidos

Corrida	Prueba de bondad de ajuste χ^2	Resultado	Prueba de espera con χ^2	Resultado
1	0.39995758347481636	Pasa	0.21983495405261527	Pasa
2	0.6733298591890715	Pasa	0.802696776774392	Pasa
3	0.9961579096460544	Pasa	0.0713111034283072	Pasa
4	0.16518448832060476	Pasa	0.9220470187716897	Pasa

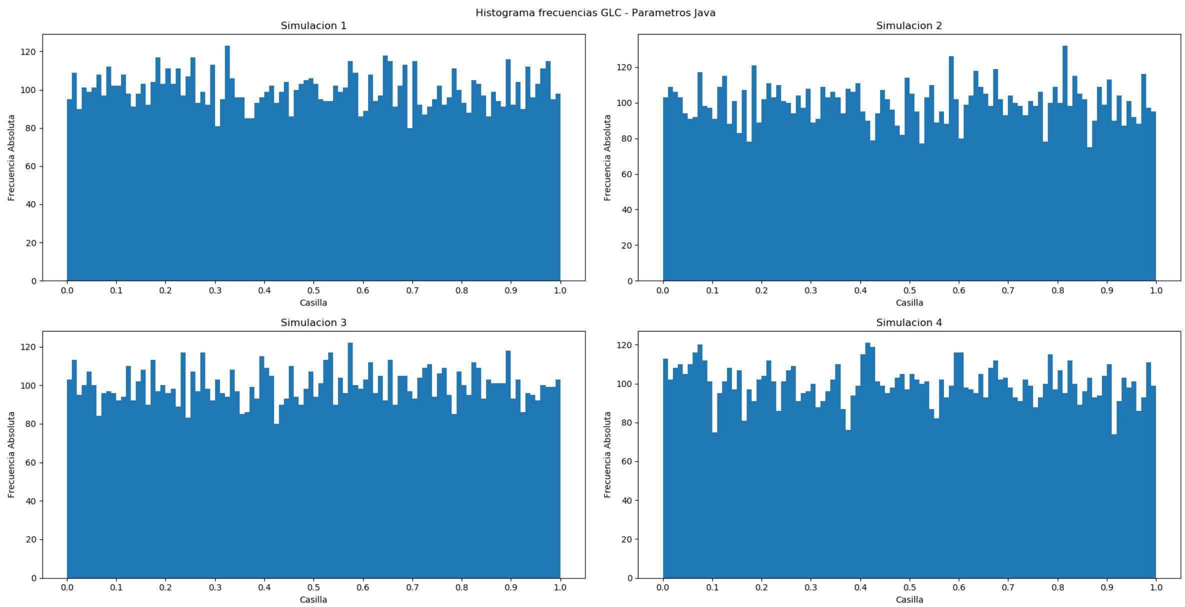


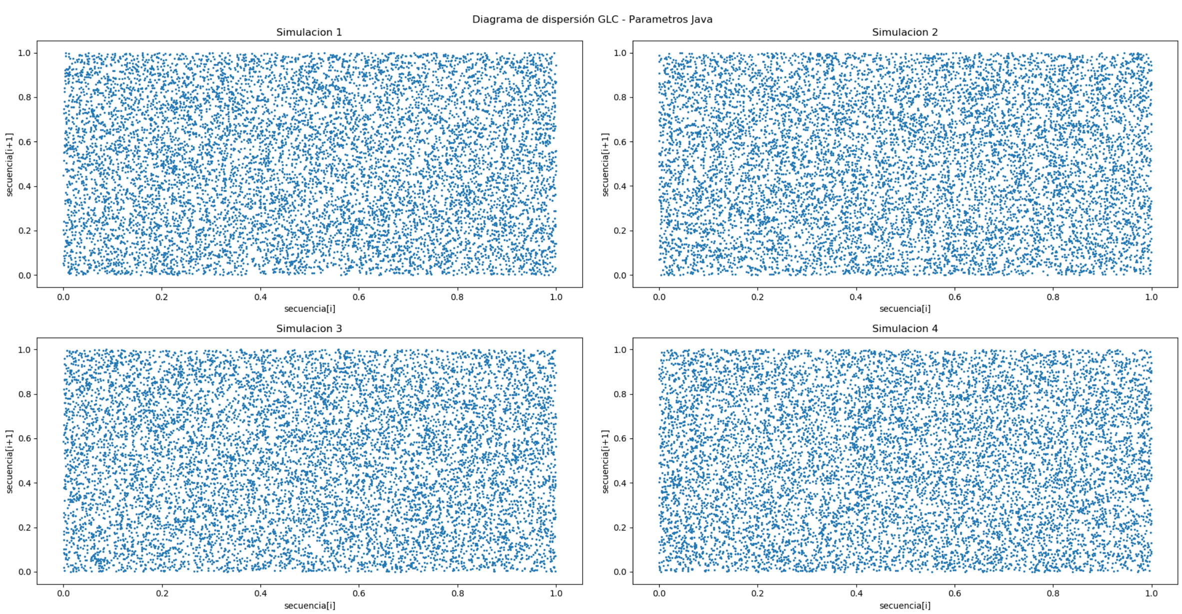


7.1.2 GLC - Parametros Java

Table 3: Resultados pruebas aplicadas a los valores obtenidos

Corrida	Prueba de bondad de ajuste χ^2	Resultado	Prueba de espera con χ^2	Resultado
1	0.8896503180962972	Pasa	0.08346475087609456	Pasa
2	0.10439329981635695	Pasa	0.9650923366874455	Pasa
3	0.9532734899107099	Pasa	0.13677218095142887	Pasa
4	0.6754987233332966	Pasa	0.9392827908884442	Pasa

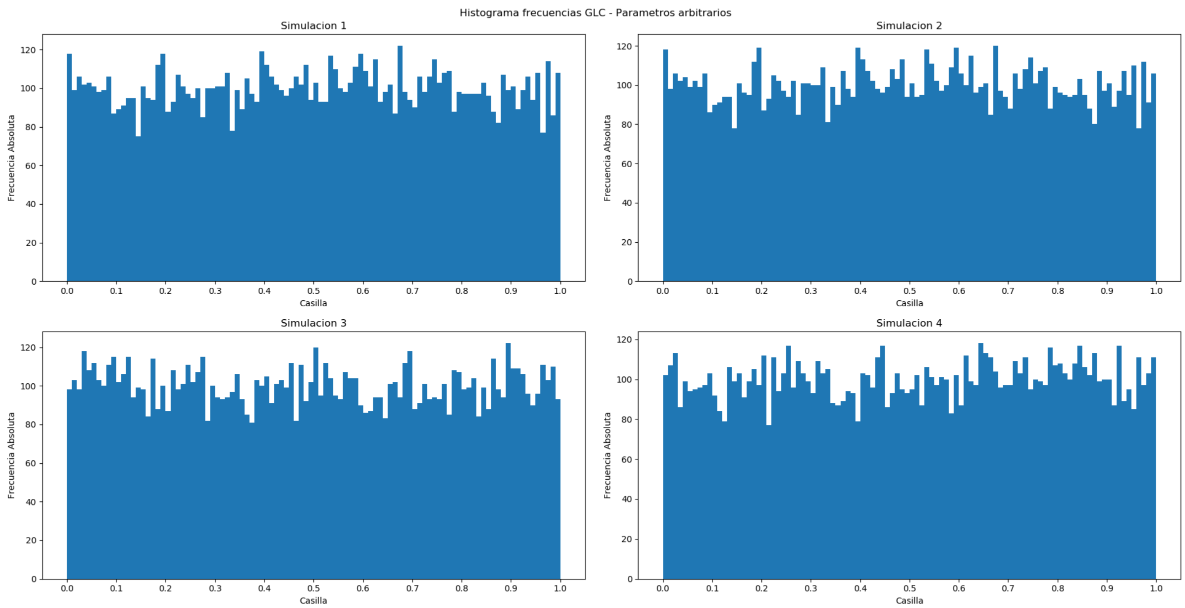


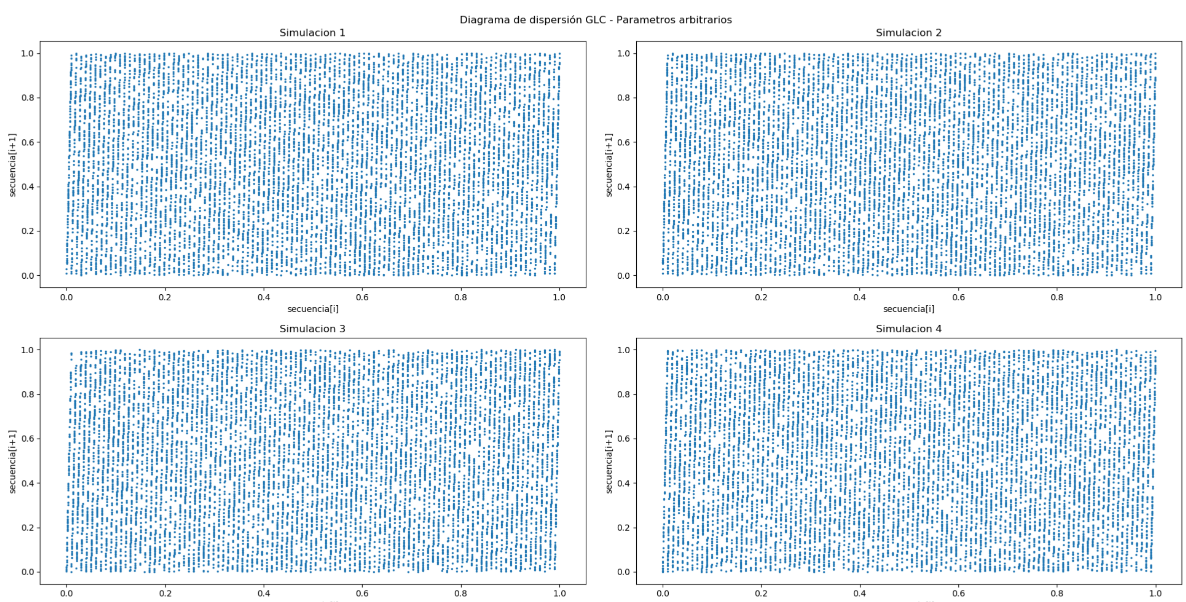


7.1.3 GLC - Parametros arbitrarios

Table 4: Resultados pruebas aplicadas a los valores obtenidos

Corrida	Prueba de bondad de ajuste χ^2	Resultado	Prueba de espera con χ^2	Resultado
1	0.7885204091719398	Pasa	0.000363550488100684	No Pasa
2	0.8322502368328377	Pasa	0.0007422527311356957	No Pasa
3	0.7136736573002587	Pasa	0.002426258515947576	No Pasa
4	0.8318526253782651	Pasa	0.0019539934767340917	No Pasa





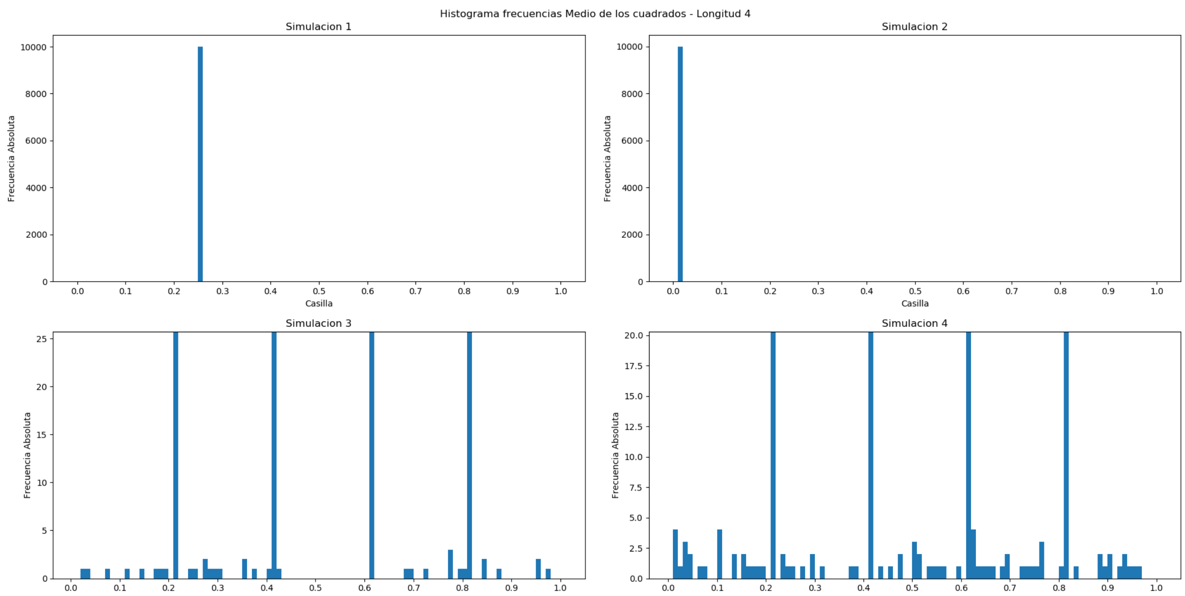
Observación Obsérvese que en el caso de los parámetros arbitrarios seleccionados, se puede notar que las frecuencias mostradas en el histograma se asemejan a las obtenidas en los conjuntos de parámetros anteriores. Es decir, las mismas tienden a la uniformidad, tal como se muestra en el hecho que todas las corridas pasan la prueba de bondad de ajuste.

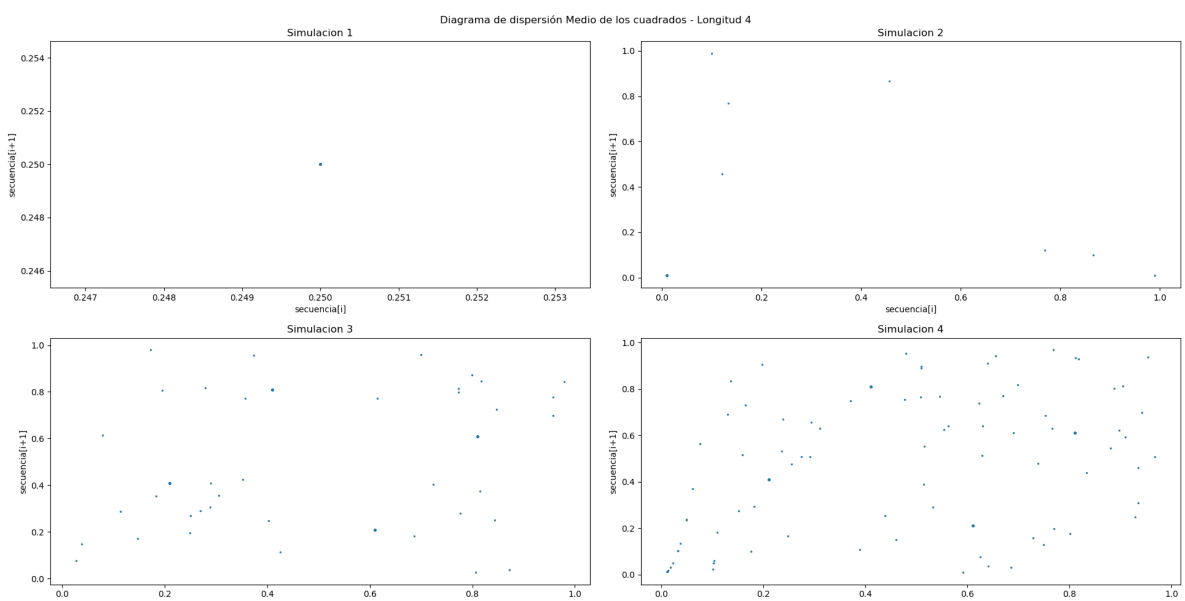
Sin embargo, al momento de analizar la independecia de estos números generados, podemos observar viendo el diagrama de dispersión que las secuencias forman un patrón claro. Esto se refleja también en los resultados de la prueba de espera, ya que ninguna corrida con estos parámetros logró pasar la prueba.

7.1.4 Medio de los cuadrados - Longitud 4

Table 5: Resultados pruebas aplicadas a los valores obtenidos

Corrida	Prueba de bondad de ajuste χ^2	Resultado	Prueba de espera con χ^2	Resultado
1	0.0	No Pasa	0.0	No Pasa
2	0.0	No Pasa	0.0	No Pasa
3	0.0	No Pasa	0.0	No Pasa
4	0.0	No Pasa	0.0	No Pasa





Simulación 1 Se generó un único valor, debido a que la semilla inicial fue 2500, y al elevarlo al cuadrado se obtiene 625000, del cual su parte media, vuelve a ser 2500, generando la siguiente secuencia: $[\mathbf{0.25}, \mathbf{0.25}, \mathbf{0.25}, \mathbf{0.25}, ...]$ [Anexo 1.1].

Simulación 2 Sucedió algo similar. Los primeros números sí son diferentes, pero rápidamente se encuentra un ciclo de un sólo número que ocupa el 99% de la secuencia. La secuencia es la siguiente: $[0.133, 0.7689, 0.1207, 0.4568, 0.8666, 0.0995, 0.99, \mathbf{0.01}, \mathbf{0.01}, \mathbf{0.01}, \mathbf{0.01}, ...]$ [Anexo 1.2].

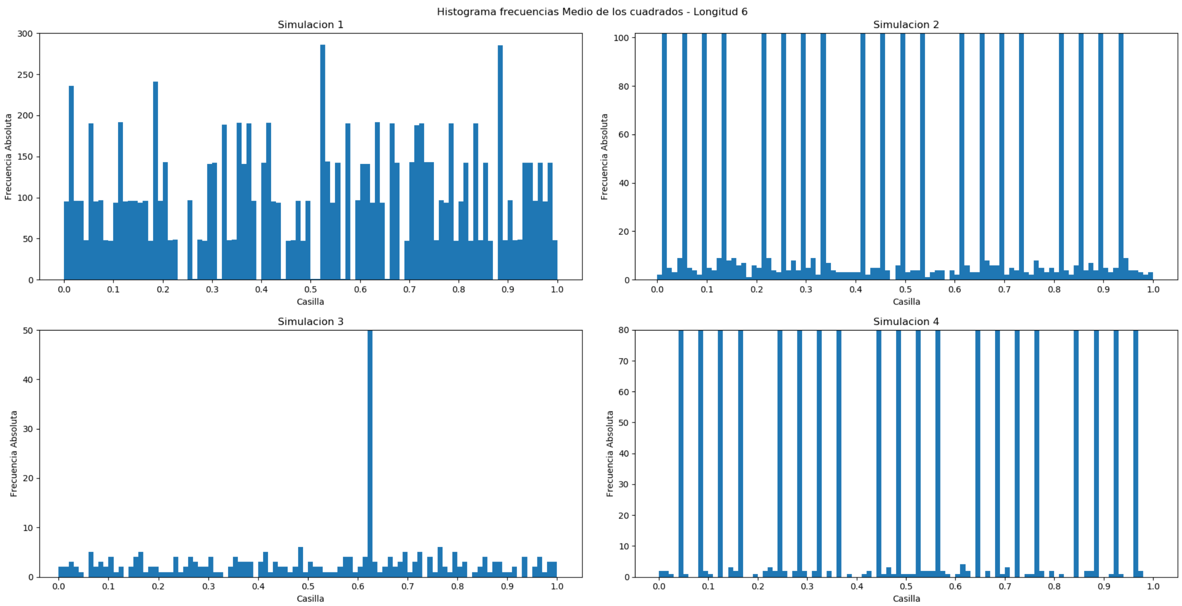
Simulación 3 La secuencia genera 37 números antes de que se empieze a generar el patrón, que en éste caso tiene longitud 4, como se ve en la gráfica, esos 4 valores ocupán la mayor parte de la lista. $[..., 0.2504, 0.27, 0.29, \mathbf{0.41}, \mathbf{0.81}, \mathbf{0.61}, \mathbf{0.21}, \mathbf{0.41}, \mathbf{0.81}, ...]$ [Anexo 1.3].

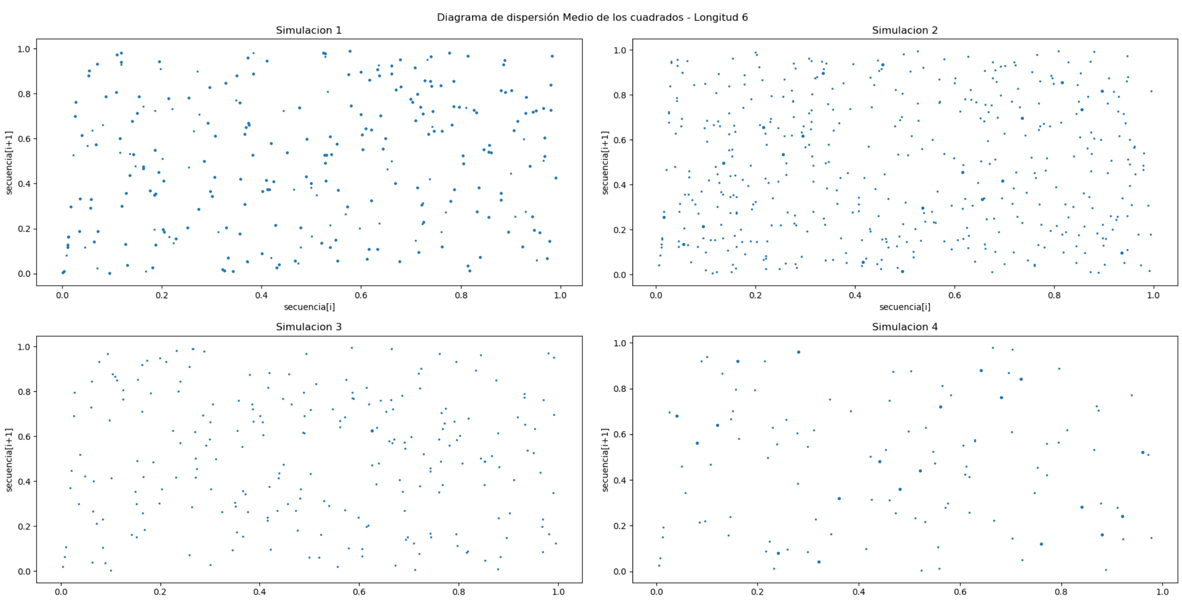
Simulación 4 Se genera el patrón a partír del elemento número 81, pero curiosamente, el ciclo obtenido es el mismo. La secuencia generada es la siguiente: $[..., 0.0609, 0.3708, 0.7492, 0.13, 0.69, \mathbf{0.61}, \mathbf{0.21}, \mathbf{0.41}, \mathbf{0.81}, \mathbf{0.61}, \mathbf{0.21}, ...]$ [Anexo 1.4].

7.1.5 Medio de los cuadrados - Longitud 6

Table 6: Resultados pruebas aplicadas a los valores obtenidos

Corrida	Prueba de bondad de ajuste χ^2	Resultado	Prueba de espera con χ^2	Resultado
1	0.0	No Pasa	0.0	No Pasa
2	0.0	No Pasa	0.0	No Pasa
3	0.0	No Pasa	0.0	No Pasa
4	0.0	No Pasa	0.0	No Pasa





Simulación 1 Aunque parece más prometedor, la realidad es que existe un patrón, a partir del sexagésimo número, en éste caso el ciclo generado es de 210. [Anexo 2.1].

Simulación 2 Se generan 426 elementos antes de comenzar el ciclo que tendrá una longitud de 20 [Anexo 2.2].

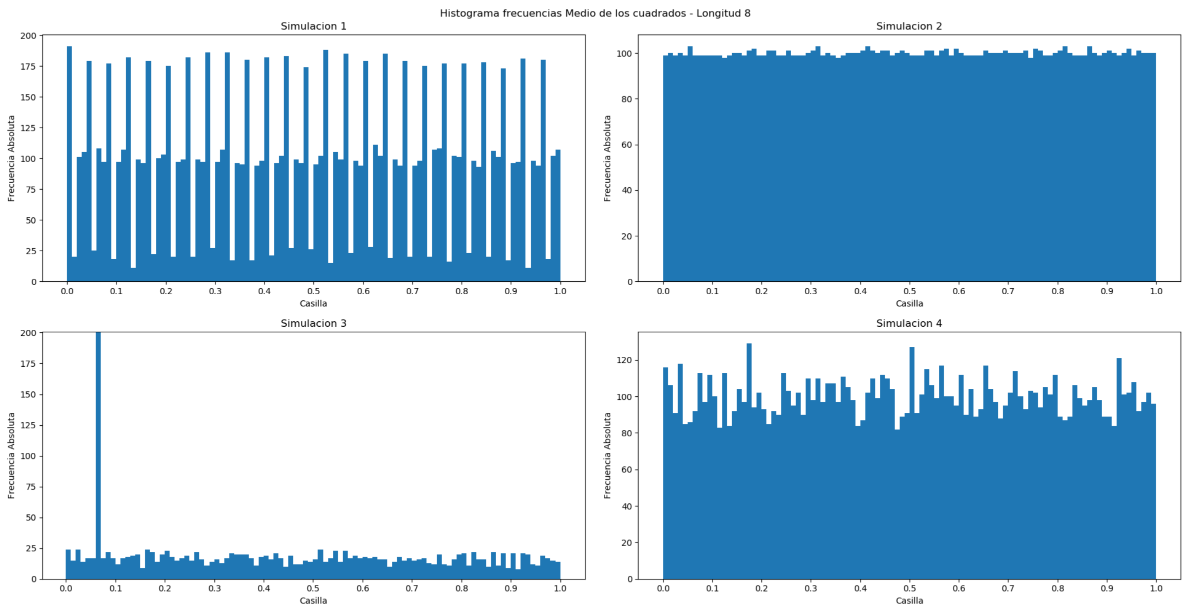
Simulación 3 Luego de 226 números generados, comienza un patrón de longitud 1, como se ve a continuación: $[..., 0.438677, 0.43751, 0.415, 0.225, \mathbf{0.625}, \mathbf{0.625}, ...]$ [Anexo 2.3].

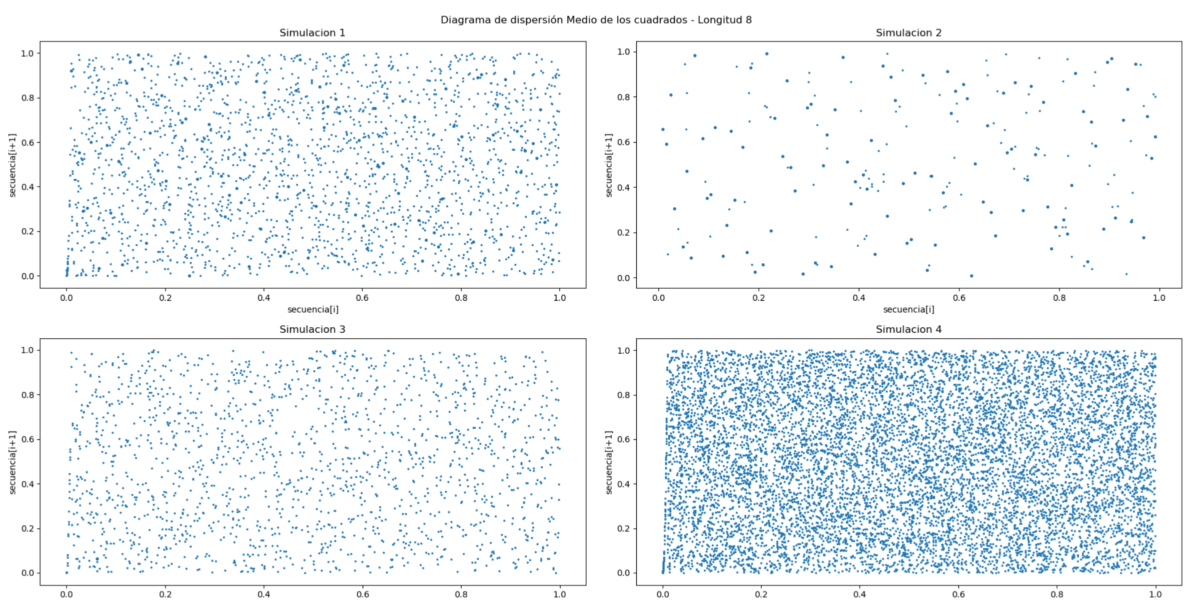
Simulación 4 De manera similar a la simulación 2, pero más rapidamente, se genera el ciclo a partir del elemento 91, con la misma longitud de 20 [Anexo 2.4].

7.1.6 Medio de los cuadrados - Longitud 8

Table 7: Resultados pruebas aplicadas a los valores obtenidos

Corrida	Prueba de bondad de ajuste χ^2	Resultado	Prueba de espera con χ^2	Resultado
1	0.0	No Pasa	0.0	No Pasa
2	1.0	Pasa	0.0	No Pasa
3	0.0	No Pasa	0.0	No Pasa
4	0.3731264216073612	Pasa	0.4630227371128709	Pasa



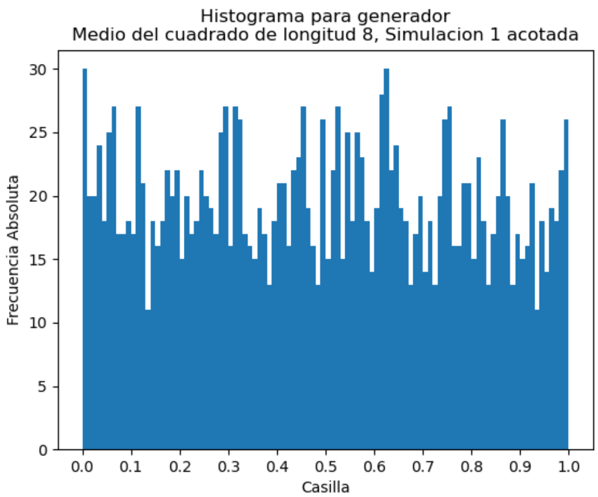


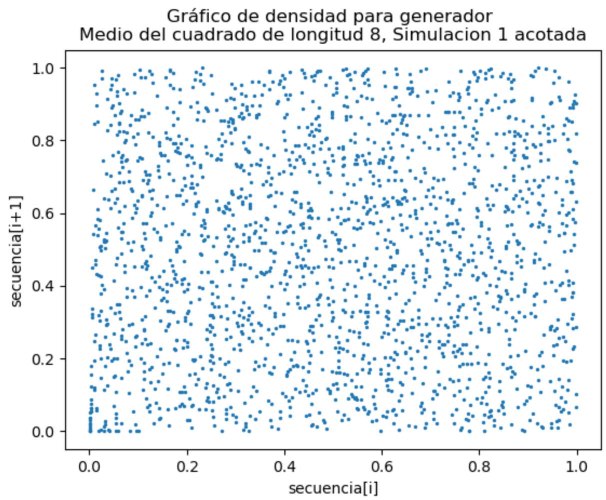
Simulación 1 En este caso, 1962 son los números generados antes de encontrar el ciclo, que tendrá una longitud de 100 [Anexo 3.1], sin embargo, si bien parece que es una buena longitud hasta el comienzo del ciclo, las pruebas de

Bondad de ajuste junto con su gráfica demuestran que no es uniforme y la prueba de esperas, demuestra que no es independiente. Si decidimos aplicar los testeos para los primeros 1962 números de la secuencia obtenemos los siguiente resultados:

Table 8: Resultados pruebas aplicadas a la simulación uno de Medio del cuadrado de longitud 8 acotada a 1962 números.

Corrida	Prueba de bondad de ajuste χ^2	Resultado	Prueba de espera con χ^2	Resultado
1	0.4290140529311694	Pasa	0.6860698825804389	Pasa





Como se ve en el histograma, si se nota una mayor uniformidad y claramente se eliminó el patrón que se observaba en el anterior. En cuanto al nuevo diagrama de densidad podemos ver que a simple vista se asemeja a algo aleatorio.

Simulación 2 La distancia hasta el patrón es de 108, siendo el ciclo de longitud 100 [Anexo 3.2] y conteniendo un elemento de cada casilla que generaría si no fuese por los 108 primeros elementos de la secuencia una verdadera uniformidad. Lamentablemente al ser ésta distribución causa de un patrón demasiado exacto, sus elementos se alejan completamente de la independencia, haciendo no pasar la prueba de esperas.

Simulación 3 Se genera un patrón luego de los primeros 1672 elementos generando un ciclo de longitud 1: $[..., 0.16503742, 0.3735, 0.0225, \mathbf{0.0625}, \mathbf{0.0625}, \mathbf{0.0625}, ...]$ [Anexo 3.3].

Simulación 4 La unica secuencia generada que contiene un ciclo visible. Y la única que pasa las dos pruebas utilizadas [Anexo 3.4].

8 Estudios posteriores, para generador Parte media del cuadrado.

La idea de éste análisis, de ahora en más llamado *Patrones en Medio del cuadrado*, enfocado en el método de generación Parte media del cuadrado, es tratar de conseguir el comportamiento en base a lo longitud elegida. Decidimos generar un diagrama de caja y bigotes para la variable aleatoria C : distancia desde el comienzo de la simulación hasta el inicio de algún patrón simple, dentro de los números generados. Cabe resaltar que la distancia 2001, se refiere en realidad a distancias indefinidas, es decir, que no se generó un patrón observable dentro de la secuencia. Por otro lado la longitud del patrón es otro factor a considerar, ya que en una secuancia de 2000 numeros pseudo-aleatorios se puede considerar (de manera totalmente arbitraria), más aleatorio una longitud de patrón de mil en compáración a uno de largo dos. Para visualizar éstos largos, se empleó un gráfico de bastones para las frecuencias absolutas de la variable discreta P : largo del patrón dentro de la secuencia de números pseudo-aleatorios. En éste caso el largo 0 también se refiere a un valor indefinido, en el caso de que no se haya generado un patrón visible dentro de la secuencia.

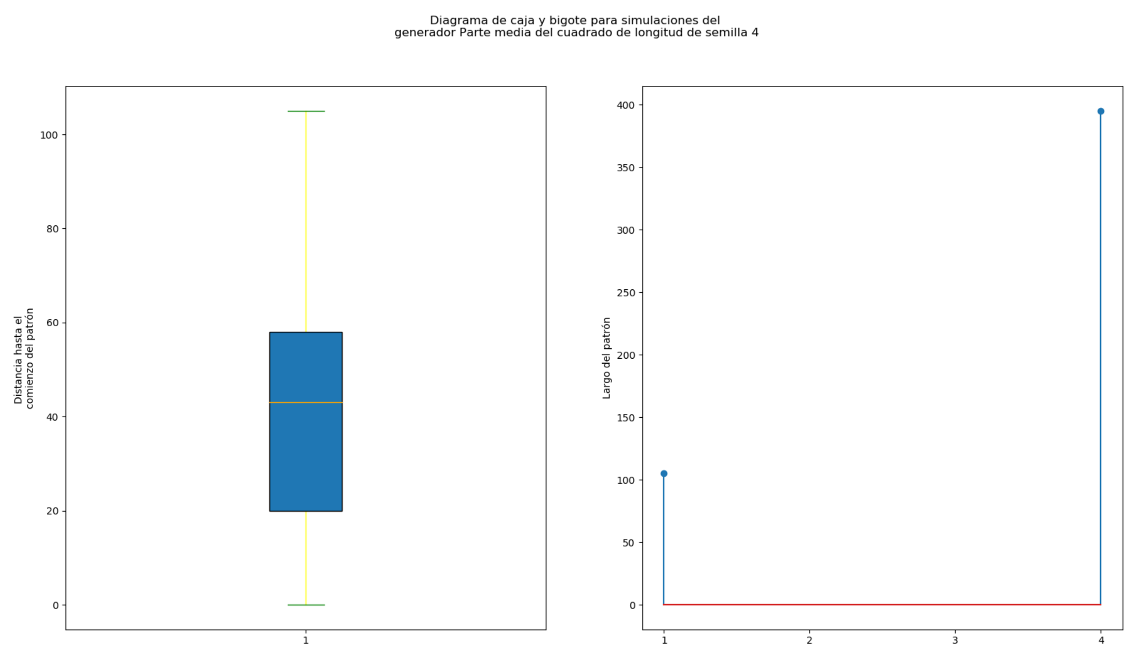
8.1 Parámetros utilizados.

Cantidad de números generados: 2000

Cantidad de simulaciones: 500

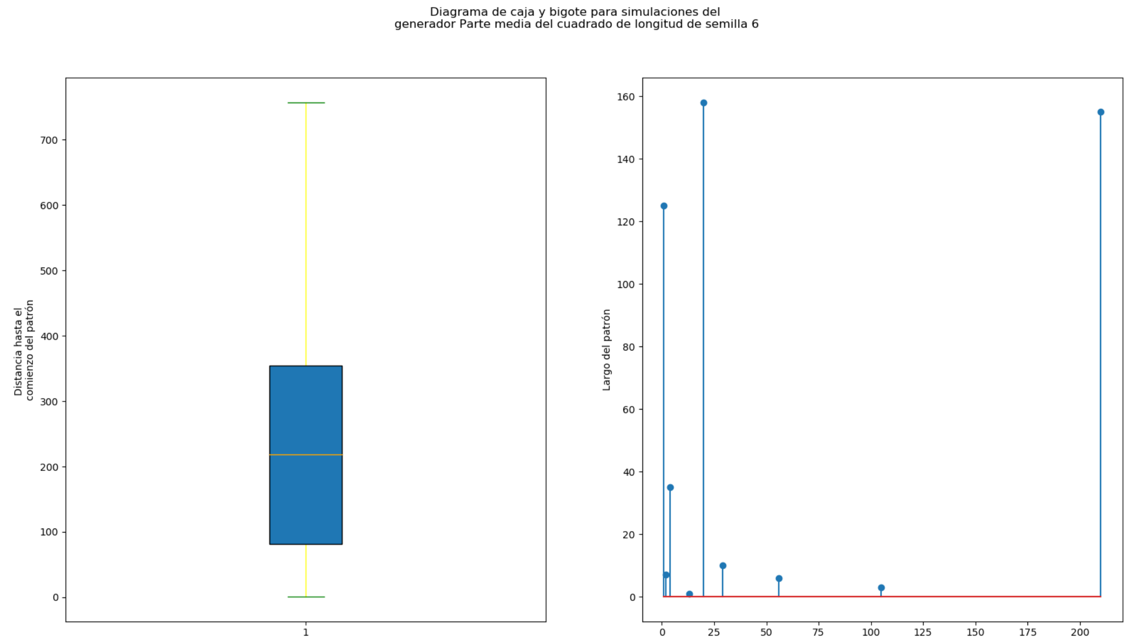
9 Resultados obtenidos para Patrones en Medio del cuadrado.

9.1 Longitud 4



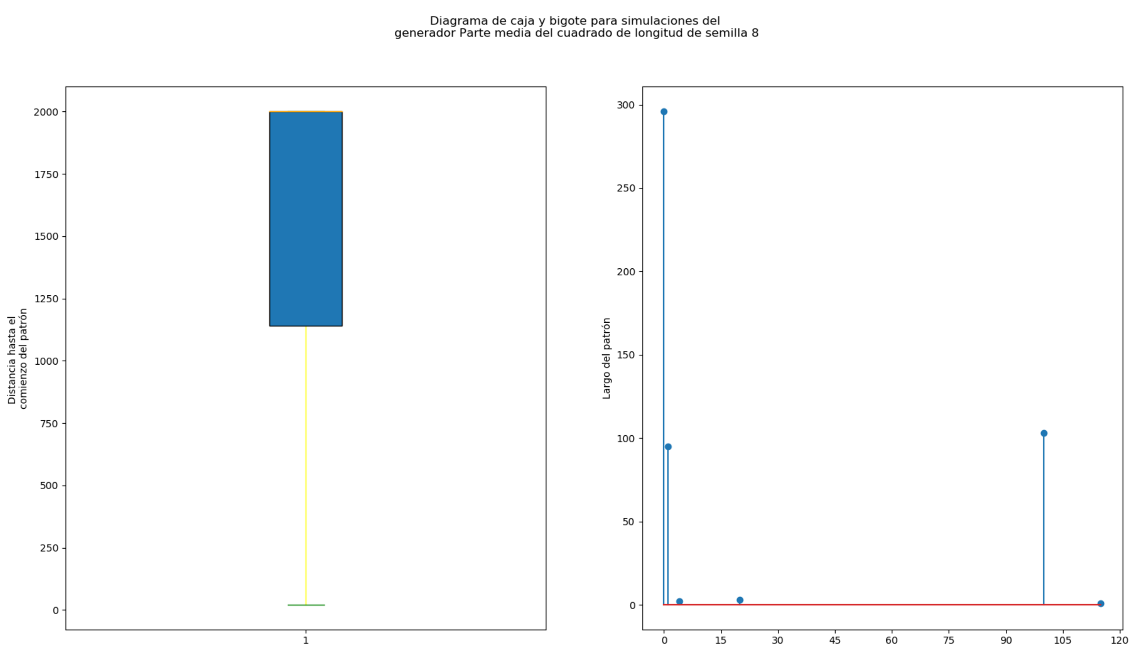
Análisis Como se observa en el diagrama de caja y bigote, se ha generado un ciclo en todas las simulaciones. La mitad de las observaciones de la variable C se encuentran rondando el valor 40. En cuanto a la longitud de los ciclos solamente se han encontrado de longitud 1 y 4, teniendo ésta última cera del 80% de las ocurrencias.

9.2 Longitud 6



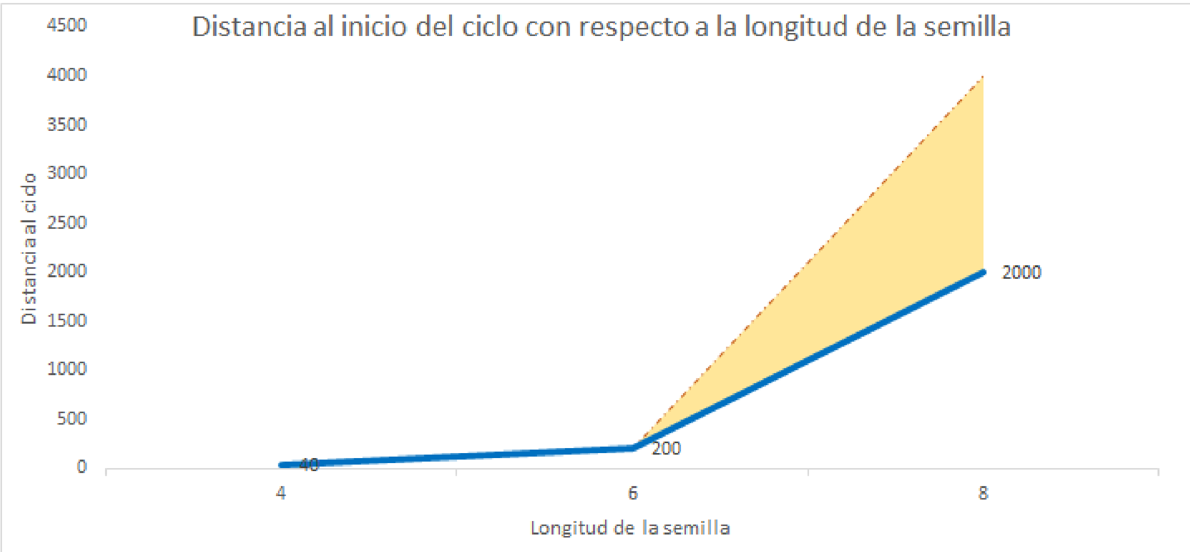
Análisis Nuevamente se ha obtenido un ciclo en todas las simulaciones, en este caso la mediana se encuentra cerca del 200 y en el caso de la longitud de los ciclos, nos encontramos con más valores, siendo los más frecuentados, el 1, el 20 y el 208

9.3 Longitud 8



Análisis En éste caso el 25% de las observaciones encuentra el ciclo al rededor del elemento 1200, y su mediana al igual que sus cuartiles superiores superan la cantidad de números generados, así, este es el resultado más favorable. En cuanto al largo de los patrones que sí se han generado las mayores ocurrencias se encuentran en el largo 1 y 100, teniendo una frecuencias muy cercanas.

9.4 Comparación distancias obtenidas entre longitudes



10 Conclusiones.

10.1 Estudio inicial

10.1.1 GLC

Prueba de Bondad de ajuste Como se puede ver los p-valores obtenidos son mayores el α elegido, $0, 05$, entonces la prueba de uniformidad es superada para los 3 generadores utilizados, y podemos seguir considerando la hipótesis nula de uniformidad, no así confirmarla.

Prueba de Esperas Utilizando los parámetros de C y de Java, ésta prueba es superada, ya que de la misma manera, los p-valores obtenidos superan el nivel de riezgo y no se rechaza la hipótesís nula de independencia. No sucede lo mismo para el generador de parámetros arbitraios, ninguno de los p-valores superla 0,05, y así aceptamos la hipótesis alternativa de independencia.

10.1.2 Medio del cuadrado

Prueba de Bondad de ajuste En el caso de Parte media del cuadrado, la situaciuón es más desfavorable. Los largos de semillas 4 y 6 no pasan la prueba de uniformidad y en el caso de la de 8 solamente dos semillas lo hacen. Ésto se debe a los patrones claramente generados y que ocupan gran parte de la secuencia y así, la distribuciónes se alejan demasiado dde la uniforme esperada. Así rechazamos la hipótesis nula de uniformidad.

Prueba de Esperas De manera similar, las longitudes 4 y 6 y las 3 primeras simulaciones de la longitud 8, aceptan la hipótesis alternativa de independencia, al tener un p-valor menor al nivel de riezo de 5%.

Éste generador tiene demasiadas deficiencias Si un número de la secuencia contiene ceros en su parte más significativa o su centro terminará generando ciclos. Es posible que el generador llegué a ciclos demasiado cortos inluso de longitud uno." Aún así, decidimos, estudiar más detalladamente éste generador, para conocer sus capacidades y poder generarlo de la mejor manera posible.

10.2 Estudio *Patrones en Medio del cuadrado*.

A partir de éste estudio, confirmamos lo que el estudio inicial indicaba, la calidad del simulador Parte media del cuadrado es proporcional, a la longitud de la semilla utilizada. Lo cuál tiene sentido simplemente al pensar en la cantidad posible de números disponibles para cada longitud: 89 para la longitud 2, 8999 para la longitud 4, 899999 para para la 6 y 89999999 para la de 8. Si bien no es el único factor, ya que como vimos también hubo valores para la variable C muy cortos para la longitud 8, da muchas más posibilidades de que no sea así. Recomendamos, en caso de tener que utilizar éste generador, generar una cantidad de números pseudoaleatorios, que se encuentre entre la mediana o tercer cuartíl obtenidos en éste estudio.

10.3 Conclusiones finales.

Podemos concluir que el generador GLC es dependiente de los parámetros elegidos, pero no tanto de la semilla utilizada, ésto facilita que una vez obtenidos esos parámetros podemos despreocuparnos de cuál sea el valor inicial. Para la obtención de los parámetros ya hay muchos que ya están aceptados y son utilizados normalmente, es recomendable utilizar alguno de ellos.

Por otra parte, el generador Parte media del cuadrado, al tener sólo dos parámetros, semilla y longitud y al ser un algortimo sencillo, se vuelve mucho más dependiende del valor inicial. También su calidad va mejorando en función del largo elegido, a partir del largo 8 empezamos a notar un funcionamiento deseado más probable de ocurrir, pero siempre sujeto al valor de la semilla. En caso de tener que utilizar éste generador, reiteramos la recomendación sobre la cantidad de números pseudo-aleatorios generados que desarollamos en el estudio posterior sobre patrones de éste generador. En general no aconsejamos utilizar éste generador ya habiendo demostrado sus falencias.

Recalcamos, por último, de la misma forma que el generador Medio del cuadrado superó la prueba de uniformidad y no la de esperas, existen otras pruebas no utilizadas en este trabajo que analizan otros parámetros del generador y que podrían demostrar una posible poca calidad en dicha propiedad para el generador GLC.

De todas formas acorde al alcance de éste estudio, consideramos al generador pseudo-aleatorio GLC utilizando parámetros conocidos, como un generador aleatorio.

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Anexo I - Secuencias generadas

Se marcarán en negrita los números para los cuales se repite el patrón en determinada secuencia.

A Longitud 4.

A.1 Secuencia 1.

[**0.25**, 0.25, ...]

A.2 Secuencia 2.

[0.133, 0.7689, 0.1207, 0.4568, 0.8666, 0.0995, 0.99, **0.01**, 0.01, ...]

A.3 Secuencia 3.

[0.6869, 0.1831, 0.3525, 0.4256, 0.1135, 0.2882, 0.3059, 0.3574, 0.7734, 0.8147, 0.3736, 0.9576, 0.6997, 0.958, 0.7764, 0.2796, 0.8176, 0.8469, 0.7239, 0.4031, 0.2489, 0.1951, 0.8064, 0.028, 0.0784, 0.6146, 0.7733, 0.7992, 0.872, 0.0384, 0.1474, 0.1726, 0.979, 0.8441, 0.2504, 0.27, 0.29, **0.41, 0.81, 0.61, 0.21**, 0.41, 0.81, 0.61, 0.21, ...]

B Longitud 6.

B.1 Secuencia 1.

[0.761042, 0.184925, 0.197255, 0.909535, 0.253916, 0.473335, 0.046022, 0.118024, 0.929664, 0.275152, 0.708623, 0.146556, 0.478661, 0.116352, 0.537787, 0.214857, 0.16353, 0.74206, 0.653043, 0.465159, 0.372895, 0.050681, 0.568563, 0.263884, 0.634765, 0.926605, 0.596826, 0.201274, 0.511223, 0.348955, 0.769592, 0.271846, 0.900247, 0.444661, 0.723404, 0.313347, 0.186342, 0.72334, 0.220755, 0.73277, 0.951872, 0.060304, 0.636572, 0.223911, 0.136135, 0.532738, 0.809776, 0.73717, 0.419608, 0.070873, 0.022982, 0.528172, 0.965661, 0.501166, 0.167359, 0.009034, 0.081613, 0.660681, 0.499383, 0.38338, **0.980224, 0.83909, 0.072028, 0.188032, 0.356033, 0.759497, 0.835693, 0.38279, 0.528184, 0.978337, 0.143285, 0.530591, 0.526809, 0.527722, 0.490509, 0.599079, 0.895648, 0.185339, 0.350544, 0.881095, 0.328399, 0.845903, 0.551885, 0.577053, 0.990164, 0.424746, 0.409164, 0.415178, 0.372771, 0.958218, 0.181735, 0.02761, 0.762312, 0.119585, 0.300572, 0.343527, 0.010799, 0.116618, 0.599757, 0.708459, 0.914154, 0.677535, 0.053676, 0.881112, 0.358356, 0.419022, 0.579436, 0.746078, 0.632382, 0.906993, 0.636302, 0.880235, 0.813655, 0.034459, 0.187422, 0.127006, 0.130524, 0.036514, 0.333272, 0.070225, 0.93155, 0.785402, 0.856301, 0.251402, 0.202965, 0.194791, 0.943533, 0.254522, 0.781448, 0.660976, 0.889272, 0.804689, 0.524386, 0.980676, 0.725416, 0.228373, 0.154227, 0.785967, 0.744125, 0.722015, 0.30566, 0.428035, 0.213961, 0.779309, 0.322517, 0.017215, 0.296356, 0.826878, 0.727226, 0.857655, 0.572099, 0.297265, 0.36648, 0.30759, 0.611608, 0.064345, 0.140279, 0.678197, 0.95117, 0.724368, 0.708999, 0.679582, 0.831694, 0.714909, 0.094878, 0.001834, 0.003363, 0.011309, 0.127893, 0.356619, 0.177111, 0.368306, 0.649309, 0.602177, 0.617139, 0.860545, 0.537697, 0.118063, 0.938871, 0.478754, 0.205392, 0.185873, 0.548772, 0.150707, 0.712599, 0.797334, 0.741507, 0.832631, 0.274382, 0.285481, 0.499401, 0.401358, 0.088244, 0.787003, 0.373722, 0.668133, 0.401705, 0.366907, 0.620746, 0.325596, 0.012755, 0.16269, 0.468036, 0.057697, 0.328943, 0.203497, 0.411029, 0.944838, 0.718846, 0.739571, 0.965264, 0.734589, 0.620998, 0.638516, 0.702682, 0.761993, 0.633332, 0.109422, 0.973174, 0.067634, 0.574357, 0.885963, 0.930437, 0.71301, 0.38326, 0.888227, 0.947203, 0.193523, 0.451151, 0.537224, 0.609626, 0.643859, 0.554411, 0.371556, 0.053861, 0.901007, 0.813614, 0.96774, 0.520707, 0.135779, 0.435936, 0.040196, 0.615718, 0.108655, 0.805909, 0.489316, 0.430147, 0.026441, 0.699126, 0.777163, 0.982328, 0.968299, 0.602953, 0.55232, 0.057382, 0.292693, 0.669192, 0.817932, 0.012756, 0.162715, 0.476171, 0.738821, 0.85647, 0.54086, 0.529539, 0.411552, 0.375048, 0.661002, 0.923644, 0.118238**, 0.980224, 0.83909, 0.072028, 0.188032, 0.356033, 0.759497, 0.835693, 0.38279, 0.528184, 0.978337, 0.143285, 0.530591, 0.526809, 0.527722, 0.490509, 0.599079, 0.895648, 0.185339, 0.350544, 0.881095, 0.328399, 0.845903, 0.551885, 0.577053, 0.990164, 0.424746, 0.409164, 0.415178, 0.372771, 0.958218, 0.181735, 0.02761, 0.762312, 0.119585, 0.300572, 0.343527, 0.010799, 0.116618, 0.599757, 0.708459, 0.914154, 0.677535, 0.053676, 0.881112, 0.358356, 0.419022, 0.579436, 0.746078, 0.632382, 0.906993, 0.636302, 0.880235, 0.813655, 0.034459, 0.187422, 0.127006, 0.130524, 0.036514, 0.333272, 0.070225, 0.93155, 0.785402, 0.856301, 0.251402, 0.202965, 0.194791, 0.943533, 0.254522, 0.781448, 0.660976, 0.889272, 0.804689, 0.524386, 0.980676, 0.725416, 0.228373, 0.154227, 0.785967, 0.744125, 0.722015, 0.30566, 0.428035, 0.213961, 0.779309, 0.322517, 0.017215, 0.296356, 0.826878, 0.727226, 0.857655, 0.572099, 0.297265, 0.36648, 0.30759, 0.611608, 0.064345, 0.140279, 0.678197, 0.95117, 0.724368, 0.708999, 0.679582, 0.831694, 0.714909, 0.094878, 0.001834, 0.003363, 0.011309, 0.127893, 0.356619, 0.177111, 0.368306, 0.649309, 0.602177, 0.617139, 0.860545, 0.537697, 0.118063, 0.938871, 0.478754, 0.205392, 0.185873, 0.548772, 0.150707, 0.712599, 0.797334, 0.741507, 0.832631, 0.274382, 0.285481, 0.499401, 0.401358, 0.088244, 0.787003, 0.373722, 0.668133, 0.401705, 0.366907, 0.620746, 0.325596, 0.012755, 0.16269, 0.468036, 0.057697, 0.328943, 0.203497, 0.411029, 0.944838, 0.718846, 0.739571, 0.965264, 0.734589, 0.620998, 0.638516, 0.702682, 0.761993, 0.633332, 0.109422, 0.973174, 0.067634, 0.574357, 0.885963, 0.930437, 0.71301, 0.38326, 0.888227, 0.947203, 0.193523, 0.451151, 0.537224, 0.609626, 0.643859, 0.554411, 0.371556, 0.053861, 0.901007, 0.813614, 0.96774, 0.520707, 0.135779, 0.435936, 0.040196, 0.615718, 0.108655, 0.805909, 0.489316, 0.430147, 0.026441, 0.699126, 0.777163, 0.982328, 0.968299, 0.602953, 0.55232, 0.057382, 0.292693, 0.669192, 0.817932, 0.012756, 0.162715, 0.476171, 0.738821, 0.85647, 0.54086, 0.529539, 0.411552, 0.375048, 0.661002, 0.923644, 0.118238, ...]

B.2 Secuencia 2.

[0.497219, 0.226733, 0.407853, 0.344069, 0.383476, 0.053842, 0.89896, 0.129081, 0.661904, 0.116905, 0.666779, 0.594234, 0.114046, 0.00649, 0.04212, 0.774094, 0.22152, 0.07111, 0.056632, 0.207183, 0.924795, 0.245792, 0.413707, 0.153481, 0.556417, 0.599877, 0.852415, 0.611332, 0.726814, 0.25859, 0.868788, 0.792588, 0.195737, 0.312973, 0.952098, 0.490601, 0.689341, 0.191014, 0.486348, 0.534377, 0.558778, 0.232853, 0.220519, 0.628629, 0.174419, 0.421987, 0.073028, 0.333088, 0.947615, 0.974188, 0.042259, 0.785823, 0.517787, 0.103377, 0.686804, 0.699734, 0.62767, 0.969628, 0.178458, 0.847257, 0.844424, 0.051891, 0.692675, 0.798655, 0.849809, 0.175336, 0.742712, 0.621114, 0.7826, 0.46276, 0.146817, 0.555231, 0.281463, 0.22142, 0.026816, 0.719097, 0.100495, 0.099245, 0.84957, 0.769184, 0.644025, 0.7682, 0.13124, 0.223937, 0.147779, 0.838632, 0.303631, 0.191784, 0.781102, 0.120334, 0.480271, 0.660233, 0.907614, 0.763172, 0.431501, 0.193113, 0.29263, 0.632316, 0.823523, 0.190131, 0.149797, 0.439141, 0.844817, 0.715763, 0.316672, 0.281155, 0.048134, 0.316881, 0.413568, 0.03849, 0.48148, 0.82299, 0.31254, 0.681251, 0.102925, 0.593555, 0.307538, 0.579621, 0.960503, 0.566013, 0.370716, 0.430352, 0.202843, 0.145282, 0.106859, 0.418845, 0.431134, 0.876525, 0.296075, 0.660405, 0.134764, 0.161335, 0.028982, 0.839956, 0.526081, 0.761218, 0.452843, 0.066782, 0.459835, 0.448227, 0.907443, 0.452798, 0.026028, 0.677456, 0.946631, 0.11025, 0.155062, 0.044223, 0.955673, 0.310882, 0.647617, 0.407778, 0.282897, 0.030712, 0.943226, 0.675287, 0.012532, 0.157051, 0.665016, 0.24628, 0.653838, 0.50413, 0.147056, 0.625467, 0.208968, 0.667625, 0.72314, 0.931459, 0.615868, 0.293393, 0.079452, 0.31262, 0.731264, 0.747037, 0.064279, 0.131789, 0.36834, 0.674355, 0.754666, 0.520771, 0.202434, 0.979524, 0.467266, 0.337514, 0.9157, 0.50649, 0.53212, 0.151694, 0.011069, 0.122522, 0.01164, 0.135489, 0.357269, 0.641138, 0.057935, 0.356464, 0.066583, 0.433295, 0.744557, 0.365126, 0.316995, 0.48583, 0.030788, 0.9479, 0.51441, 0.617648, 0.489051, 0.17088, 0.199974, 0.9896, 0.30816, 0.962585, 0.569882, 0.765493, 0.979533, 0.484898, 0.12607, 0.893644, 0.599598, 0.517761, 0.076453, 0.845061, 0.128093, 0.407816, 0.313889, 0.526304, 0.9959, 0.81681, 0.178576, 0.889387, 0.009235, 0.085285, 0.273531, 0.819207, 0.100108, 0.021611, 0.467035, 0.121691, 0.808699, 0.994072, 0.179141, 0.091497, 0.371701, 0.161633, 0.125226, 0.681551, 0.511765, 0.903415, 0.158662, 0.17363, 0.147376, 0.719685, 0.946499, 0.860357, 0.214167, 0.867503, 0.561455, 0.231717, 0.692768, 0.927501, 0.258105, 0.618191, 0.160112, 0.635852, 0.307765, 0.719295, 0.385297, 0.453778, 0.914473, 0.260867, 0.051591, 0.661631, 0.75558, 0.901136, 0.04609, 0.124288, 0.447506, 0.26162, 0.445024, 0.04636, 0.149249, 0.275264, 0.770269, 0.314332, 0.804606, 0.390815, 0.736364, 0.23194, 0.796163, 0.875522, 0.538772, 0.275267, 0.771921, 0.86203, 0.09572, 0.162318, 0.347133, 0.501319, 0.320739, 0.873506, 0.012732, 0.162103, 0.277382, 0.940773, 0.053837, 0.898422, 0.16209, 0.273168, 0.620756, 0.338011, 0.251436, 0.220062, 0.427283, 0.570762, 0.76926, 0.760947, 0.040336, 0.626992, 0.118968, 0.153385, 0.526958, 0.684733, 0.859281, 0.363836, 0.376634, 0.853169, 0.897342, 0.222664, 0.579256, 0.537513, 0.920225, 0.81405, 0.677402, 0.873469, 0.948093, 0.880336, 0.991472, 0.016726, 0.279759, 0.265098, 0.276949, 0.700748, 0.047759, 0.280922, 0.91717, 0.200808, 0.323852, 0.880117, 0.605933, 0.1548, 0.96304, 0.446041, 0.952573, 0.39532, 0.277902, 0.229521, 0.679889, 0.249052, 0.026898, 0.723502, 0.455144, 0.15606, 0.354723, 0.828406, 0.2565, 0.79225, 0.660062, 0.681843, 0.909876, 0.874335, 0.461692, 0.159502, 0.440888, 0.382228, 0.098243, 0.651687, 0.695945, 0.339443, 0.22155, 0.084402, 0.123697, 0.300947, 0.569096, 0.870257, 0.347246, 0.579784, 0.149486, 0.346064, 0.760292, 0.043925, 0.929405, 0.793654, 0.886671, 0.185462, 0.396153, 0.937199, 0.341965, 0.940061, 0.714683, 0.77179, 0.659804, 0.341318, 0.497977, 0.981092, 0.541512, 0.235246, 0.34068, 0.062862, 0.951631, 0.60156, 0.874433, 0.633071, 0.778891, 0.671189, 0.494673, 0.701376, 0.928293, 0.727893, 0.828219, 0.946711, 0.261717, 0.495788, 0.80574, 0.216947, 0.066, 0.356, **0.736, 0.696, 0.416, 0.056, 0.136, 0.496, 0.016, 0.256, 0.536, 0.296, 0.616, 0.456, 0.936, 0.096, 0.216, 0.656, 0.336, 0.896, 0.816, 0.856**, 0.736, 0.696, 0.416, 0.056, 0.136, 0.496, 0.016, 0.256, 0.536, 0.296, 0.616, 0.456, 0.936, 0.096, 0.216, 0.656, 0.336, 0.896, 0.816, 0.856, ...]

B.3 Secuencia 3.

[0.880604, 0.463404, 0.743267, 0.445833, 0.767063, 0.385645, 0.722066, 0.379308, 0.874558, 0.851695, 0.384373, 0.742603, 0.459215, 0.878416, 0.614669, 0.817979, 0.089644, 0.036046, 0.299314, 0.58887, 0.767876, 0.633551, 0.386869, 0.667623, 0.72047, 0.07702, 0.93208, 0.773126, 0.723811, 0.902363, 0.258983, 0.072194, 0.211973, 0.932552, 0.653232, 0.712045, 0.008082, 0.065318, 0.266441, 0.990806, 0.696529, 0.152647, 0.301106, 0.664823, 0.989621, 0.349723, 0.306176, 0.743742, 0.152162, 0.153274, 0.492919, 0.96914, 0.232339, 0.98141, 0.165588, 0.419385, 0.883778, 0.063553, 0.038983, 0.519674, 0.061066, 0.729056, 0.522651, 0.164067, 0.91798, 0.68728, 0.353798, 0.173024, 0.937304, 0.538788, 0.292508, 0.56093, 0.642464, 0.759991, 0.58632, 0.771142, 0.659984, 0.57888, 0.102054, 0.415018, 0.23994, 0.571203, 0.272867, 0.456399, 0.300047, 0.028202, 0.795352, 0.584803, 0.994548, 0.125724, 0.806524, 0.480962, 0.324445, 0.264558, 0.990935, 0.952174, 0.635326, 0.639126, 0.482043, 0.365453, 0.555895, 0.019251, 0.370601, 0.345101, 0.0947, 0.96809, 0.198248, 0.302269, 0.366548, 0.357436, 0.760494, 0.351124, 0.288063, 0.980291, 0.970444, 0.761557, 0.969064, 0.085036, 0.231121, 0.416916, 0.818951, 0.68074, 0.406947, 0.60586, 0.066339, 0.400862, 0.690343, 0.573457, 0.85293, 0.489584, 0.692493, 0.546555, 0.722368, 0.815527, 0.084287, 0.104298, 0.878072, 0.010437, 0.10893, 0.865744, 0.512673, 0.833604, 0.895628, 0.149514, 0.354436, 0.624878, 0.472514, 0.26948, 0.61947, 0.74308, 0.167886, 0.185708, 0.487461, 0.618226, 0.203387, 0.366271, 0.154445, 0.853258, 0.049214, 0.422017, 0.098348, 0.672329, 0.026284, 0.690848, 0.270959, 0.418779, 0.37585, 0.263222, 0.285821, 0.693644, 0.141998, 0.163432, 0.710018, 0.12556, 0.765313, 0.703987, 0.597696, 0.240508, 0.844098, 0.501433, 0.435053, 0.271112, 0.501716, 0.718944, 0.880475, 0.236225, 0.80225, 0.605062, 0.100023, 0.0046, 0.02116, 0.447745, 0.475585, 0.181092, 0.794312, 0.931553, 0.790991, 0.666762, 0.571564, 0.685406, 0.781384, 0.560955, 0.670512, 0.586342, 0.79694, 0.113363, 0.851169, 0.488666, 0.794459, 0.165102, 0.25867, 0.910168, 0.405788, 0.6639, 0.76321, 0.489504, 0.614166, 0.199875, 0.950015, 0.5285, 0.31225, 0.500062, 0.062003, 0.844372, 0.964074, 0.438677, 0.43751, 0.415, 0.225, **0.625**, 0.625, ...]

B.4 Secuencia 4.

[0.911197, 0.279972, 0.38432, 0.701862, 0.610267, 0.425811, 0.315007, 0.22941, 0.628948, 0.575586, 0.299243, 0.546373, 0.523455, 0.005137, 0.026388, 0.696326, 0.869898, 0.72253, 0.0496, 0.46016, 0.747225, 0.3452, 0.16304, 0.582041, 0.771725, 0.559475, 0.012275, 0.150675, 0.702955, 0.145732, 0.237815, 0.555974, 0.107088, 0.467839, 0.873329, 0.703542, 0.971345, 0.511109, 0.232409, 0.013943, 0.194407, 0.794081, 0.564634, 0.811553, 0.618271, 0.259029, 0.096022, 0.220224, 0.49861, 0.611932, 0.460772, 0.310835, 0.618397, 0.414849, 0.099692, 0.938494, 0.770988, 0.422496, 0.50287, 0.878236, 0.298471, 0.084937, 0.214293, 0.921489, 0.141977, 0.157468, 0.796171, 0.888261, 0.007604, 0.05782, 0.343152, 0.753295, 0.453357, 0.532569, 0.629739, 0.571208, 0.278579, 0.606259, 0.549975, 0.4725, 0.25625, 0.664062, 0.978339, 0.147198, 0.667251, 0.223897, 0.129866, 0.865177, 0.531241, 0.217, 0.089, **0.921, 0.241, 0.081, 0.561, 0.721, 0.841, 0.281, 0.961, 0.521, 0.441, 0.481, 0.361, 0.321, 0.041, 0.681, 0.761, 0.121, 0.641, 0.881, 0.161**, 0.921, 0.241, 0.081, 0.561, 0.721, 0.841, 0.281, 0.961, 0.521, 0.441, 0.481, 0.361, 0.321, 0.041, 0.681, 0.761, 0.121, 0.641, 0.881, 0.161, ...]

C Longitud 8.

C.1 Secuencia 1.

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C.2 Secuencia 2.

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C.3 Secuencia 3.

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C.4 Secuencia 4.

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