

# Pseudorandom Numbers

MATH 242 Modern Computational Math

How do computers generate "random" numbers? Today we will consider two algorithms that produce *pseudorandom* numbers.

## Middle-Square Method

One early approach for creating pseudorandom numbers is the *middle-square method*. This method is simple. Start with a number with an even number of digits. Suppose the number is  $N$  and it has  $k$  digits. Square  $N$ , producing a number with  $2k$  digits. Extract the middle  $k$  of these digits and repeat. This produces a sequence of  $k$ -digit numbers, which we can regard as a longer sequence of decimal digits. For some starting values, this sequence of decimal digits will appear approximately random.

It will be helpful to have a function that determines how many digits are in a given integer. Here is such a function:

```
In [1]: # determine how many digits are in the decimal representation of a number
def howManyDigits(num):
    return ceil(log(num, 10)) # log base 10 of num
```

Try it out:

```
In [2]: howManyDigits(123456)
```

```
Out[2]: 6
```

Now here is a function that uses the middle-square method to produce a sequence of numbers.

```
In [11]: # compute the middle square sequence
# input:
# seed: the starting value, which should have an even number of digits
# numIter: number of iterations to perform
# return: sequence of numbers produced by the middle-square method
def middleSquare(seed, numIter):
    # initializations
    num = seed
    seq = [num]
    k = howManyDigits(num)

    for i in range(numIter):
        # square the number
        num = num^2
        #print(num)

        # extract the middle k digits
        num = num // (10^(k//2)) # ignore the rightmost k/2 digits
        num = num % (10^k)      # keep the next k digits

        # append the middle k digits to the sequence
        seq.append(num)

    return seq
```

```
In [6]: middleSquare(5146, 10)
```

```
Out[6]: 26481316
23164969
2719201
51724864
52533504
28462225
21362884
13162384
2634129
40208281

[5146, 4813, 1649, 7192, 7248, 5335, 4622, 3628, 1623, 6341, 2082]
```

It would be useful to have a function that converts a list of numbers into a list of decimal digits. Here is such a function:

```
In [7]: # convert a list of big numbers to a list of digits in order
def extractDigits(seq):
    # initialize a list for the digits
    allDigits = []

    # use the initial value to determine how many digits per number
    digitsPerNum = howManyDigits(seq[0])

    # loop over all numbers in the sequence
    for num in seq:
        # initialize a list for the digits in num
        digits = []

        # extract the digits in num, starting with the ones place
        for i in range(digitsPerNum):
            digits.append(num % 10)
            num = num // 10

        # reverse the digits, then concatenate digits to the end of allDigits
        digits.reverse()
        allDigits += digits

    # return the big list of digits
    return allDigits
```

Observe how `extractDigits` works:

```
In [8]: extractDigits([1234, 77, 12345, 9876])
```

```
Out[8]: [1, 2, 3, 4, 0, 0, 7, 7, 2, 3, 4, 5, 9, 8, 7, 6]
```

```
In [9]: seq = middleSquare(5146, 10)
print(seq)
print(extractDigits(seq))
```

```
Out[9]: 26481316
23164969
2719201
51724864
52533504
28462225
21362884
13162384
2634129
40208281
[5146, 4813, 1649, 7192, 7248, 5335, 4622, 3628, 1623, 6341, 2082]
[5, 1, 4, 6, 4, 8, 1, 3, 1, 6, 4, 9, 7, 1, 9, 2, 7, 2, 4, 8, 5, 3, 3, 5, 4, 6, 2, 2, 3, 6,
2, 8, 1, 6, 2, 3, 6, 3, 4, 1, 2, 0, 8, 2]
```

```
In [13]: seq = middleSquare(2394, 100)
print(seq)
```



```

# compute the next number and append it to the list
vals[i+1] = (multiplier*vals[i] + increment) % modulus

# return the list
return vals

```

Try it out:

```

In [21]: seq = linearCongruential(37, 1, 100, 17, 20)
print(seq)
digits = extractDigits(seq)
print(digits)
print(digits.count(1))
print(digits.count(2))
print(digits.count(3))
print(digits.count(4))

```

```

Out[21]: [17, 30, 11, 8, 97, 90, 31, 48, 77, 50, 51, 88, 57, 10, 71, 28, 37, 70, 91, 68]
[1, 7, 3, 0, 1, 1, 0, 8, 9, 7, 9, 0, 3, 1, 4, 8, 7, 7, 5, 0, 5, 1, 8, 8, 5, 7, 1, 0, 7, 1,
2, 8, 3, 7, 7, 0, 9, 1, 6, 8]
8
1
3
1

```

In [0]:

## Questions to investigate

1. Experiment with the linear congruential method using various choices for the multiplier, increment, and modulus. What do you observe?
2. Do certain parameters produce sequences of digits that you would consider random?
3. Do certain parameters produce sequences of digits that you would consider definitely not random?
4. What cycles of numbers do you observe?

```

In [23]: seq = linearCongruential(53, 0, 100, 17, 100)
print("sequence: ", seq)
digits = extractDigits(seq)
print("digits: ", digits)
counts = [digits.count(i) for i in range(10)]
print("digit counts: ", counts)

```

```

Out[23]: sequence: [17, 1, 53, 9, 77, 81, 93, 29, 37, 61, 33, 49, 97, 41, 73, 69, 57, 21, 13, 89,
17, 1, 53, 9, 77, 81, 93, 29, 37, 61, 33, 49, 97, 41, 73, 69, 57, 21, 13, 89, 17, 1, 53, 9,
77, 81, 93, 29, 37, 61, 33, 49, 97, 41, 73, 69, 57, 21, 13, 89, 17, 1, 53, 9, 77, 81, 93,
29, 37, 61, 33, 49, 97, 41, 73, 69, 57, 21, 13, 89, 17, 1, 53, 9, 77, 81, 93, 29, 37, 61,
33, 49, 97, 41, 73, 69, 57, 21, 13, 89]
digits: [1, 7, 0, 1, 5, 3, 0, 9, 7, 7, 8, 1, 9, 3, 2, 9, 3, 7, 6, 1, 3, 3, 4, 9, 9, 7, 4,
1, 7, 3, 6, 9, 5, 7, 2, 1, 1, 3, 8, 9, 1, 7, 0, 1, 5, 3, 0, 9, 7, 7, 8, 1, 9, 3, 2, 9, 3,
7, 6, 1, 3, 3, 4, 9, 9, 7, 4, 1, 7, 3, 6, 9, 5, 7, 2, 1, 1, 3, 8, 9, 1, 7, 0, 1, 5, 3, 0,
9, 7, 7, 8, 1, 9, 3, 2, 9, 3, 7, 6, 1, 3, 3, 4, 9, 9, 7, 4, 1, 7, 3, 6, 9, 5, 7, 2, 1, 1,
3, 8, 9, 1, 7, 0, 1, 5, 3, 0, 9, 7, 7, 8, 1, 9, 3, 2, 9, 3, 7, 6, 1, 3, 3, 4, 9, 9, 7, 4,
1, 7, 3, 6, 9, 5, 7, 2, 1, 1, 3, 8, 9, 1, 7, 0, 1, 5, 3, 0, 9, 7, 7, 8, 1, 9, 3, 2, 9, 3,
7, 6, 1, 3, 3, 4, 9, 9, 7, 4, 1, 7, 3, 6, 9, 5, 7, 2, 1, 1, 3, 8, 9]
digit counts: [10, 35, 10, 35, 10, 10, 10, 35, 10, 35]

```

```

In [27]: seq = linearCongruential(5, 0, 17, 1, 100)
print("sequence: ", seq)
counts = [seq.count(i) for i in range(17)]
print("counts: ", counts)

```

```
Out[27]: sequence: [1, 5, 8, 6, 13, 14, 2, 10, 16, 12, 9, 11, 4, 3, 15, 7, 1, 5, 8, 6, 13, 14, 2,
10, 16, 12, 9, 11, 4, 3, 15, 7, 1, 5, 8, 6, 13, 14, 2, 10, 16, 12, 9, 11, 4, 3, 15, 7, 1,
5, 8, 6, 13, 14, 2, 10, 16, 12, 9, 11, 4, 3, 15, 7, 1, 5, 8, 6, 13, 14, 2, 10, 16, 12, 9,
11, 4, 3, 15, 7, 1, 5, 8, 6, 13, 14, 2, 10, 16, 12, 9, 11, 4, 3, 15, 7, 1, 5, 8, 6]
counts: [0, 7, 6, 6, 6, 7, 7, 6, 7, 6, 6, 6, 6, 6, 6, 6]
```

```
In [30]: p = 1009
seq = linearCongruential(5, 0, p, 13, 10000)
print("sequence: ", seq)
digits = extractDigits(seq)
print("digits: ", digits)
counts = [digits.count(i) for i in range(10)]
print("counts: ", counts)
```

```
Out[30]: sequence: [13, 65, 325, 616, 53, 265, 316, 571, 837, 149, 745, 698, 463, 297, 476, 362,
801, 978, 854, 234, 161, 805, 998, 954, 734, 643, 188, 940, 664, 293, 456, 262, 301, 496,
462, 292, 451, 237, 176, 880, 364, 811, 19, 95, 475, 357, 776, 853, 229, 136, 680, 373,
856, 244, 211, 46, 230, 141, 705, 498, 472, 342, 701, 478, 372, 851, 219, 86, 430, 132,
660, 273, 356, 771, 828, 104, 520, 582, 892, 424, 102, 510, 532, 642, 183, 915, 539, 677,
358, 781, 878, 354, 761, 778, 863, 279, 386, 921, 569, 827, 99, 495, 457, 267, 326, 621,
78, 390, 941, 669, 318, 581, 887, 399, 986, 894, 434, 152, 760, 773, 838, 154, 770, 823,
79, 395, 966, 794, 943, 679, 368, 831, 119, 595, 957, 749, 718, 563, 797, 958, 754, 743,
688, 413, 47, 235, 166, 830, 114, 570, 832, 124, 620, 73, 365, 816, 44, 220, 91, 455, 257,
276, 371, 846, 194, 970, 814, 34, 170, 850, 214, 61, 305, 516, 562, 792, 933, 629, 118,
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899, 459, 277, 376, 871, 319, 586, 912, 524, 602, 992, 924, 584, 902, 474, 352, 751, 728,
613, 38, 190, 950, 714, 543, 697, 458, 272, 351, 746, 703, 488, 422, 92, 460, 282, 401,
996, 944, 684, 393, 956, 744, 693, 438, 172, 860, 264, 311, 546, 712, 533, 647, 208, 31,
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