# Random number generation (in C++) - past, present and potential future

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# What is Random?

It represents an event or entity, which cannot be determined but only described probabilistically,

For example:

- Falling rain drops which hit the ground in random pattern,
- Distribution of stars with in the universe is a random, and
- Babies cry in random and so on

# What are the use of Random Numbers?

They are mainly used in:

- Simulations be it a numerical calculation or a cartoon game,
- Binning analog data in channel format,
- Testing a product and so on.

# What is the plan of this presentation?

- Historic evolution of random numbers and their applications,
- Modern development and implementation in C++, and beyond.

## How did random numbers and their applications evolve?

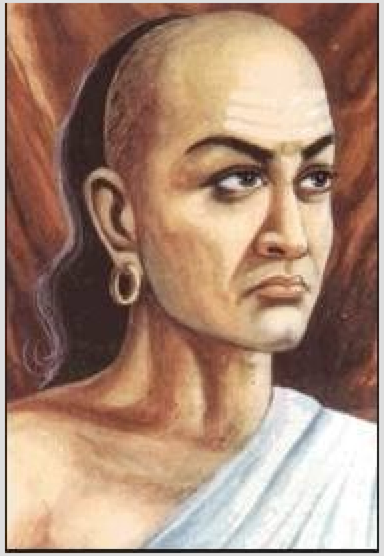
**Since pre-historic period, random numbers were generated from dice for gambling**

**In bronze age gambling became unethical**

**Random numbers from dice**

**Made Kings to give up their crowns to opponents**

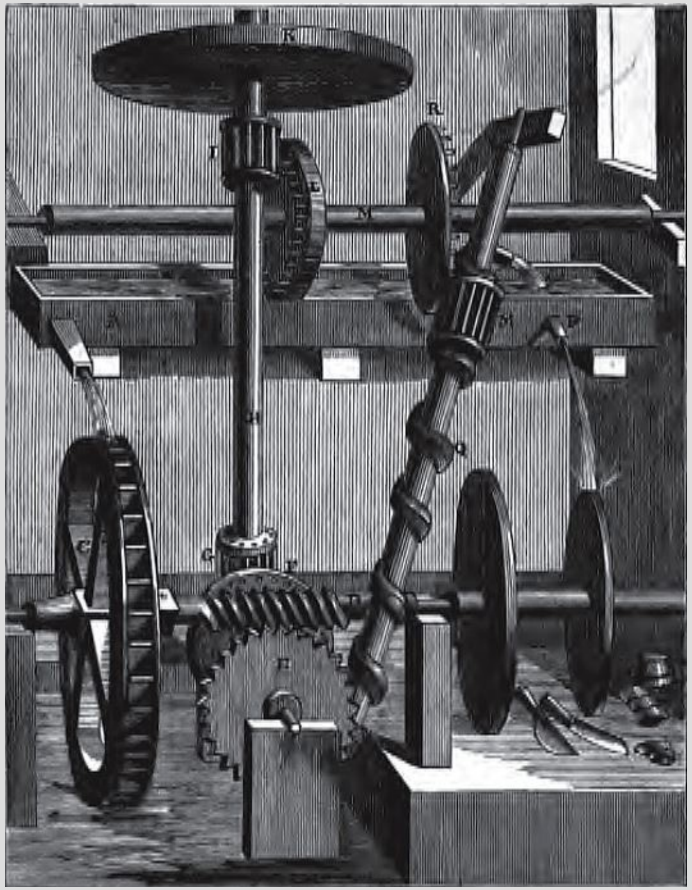
**In 300 BC, Prof Chanakya of Takshashila University**



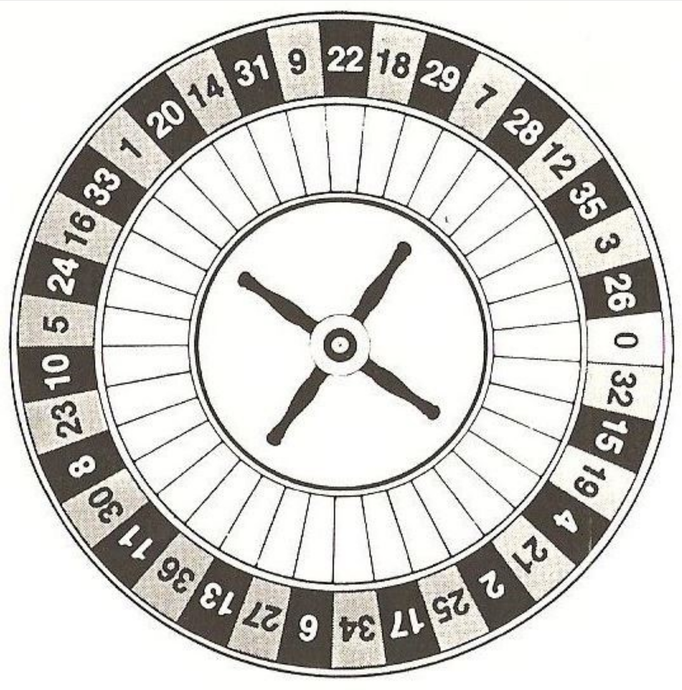
**prescribed laws and taxations to regulate gambling.**

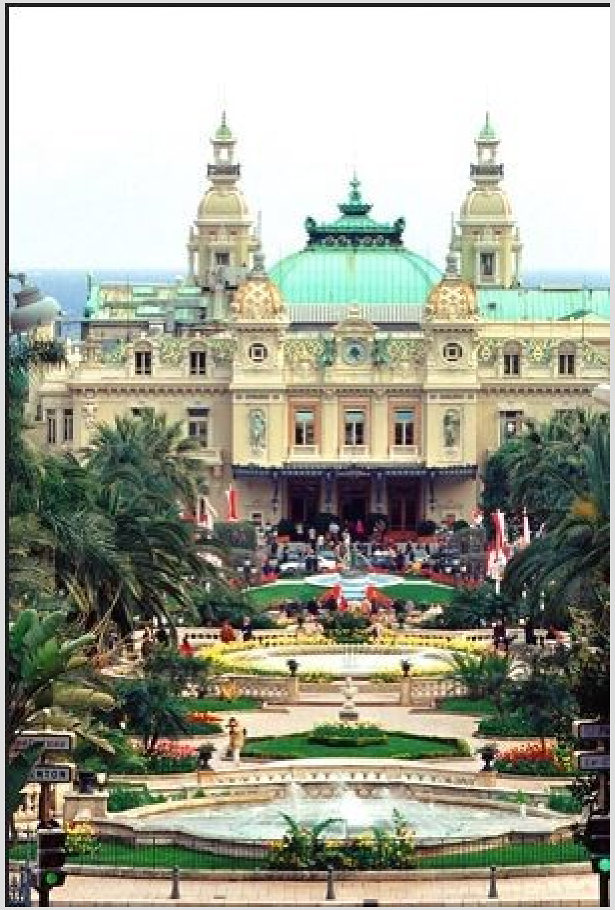
**In 1650 Blaise Pascal, who introduced the computer in the form of his mechanical calculator**

**Designed perpetual motion experiment**

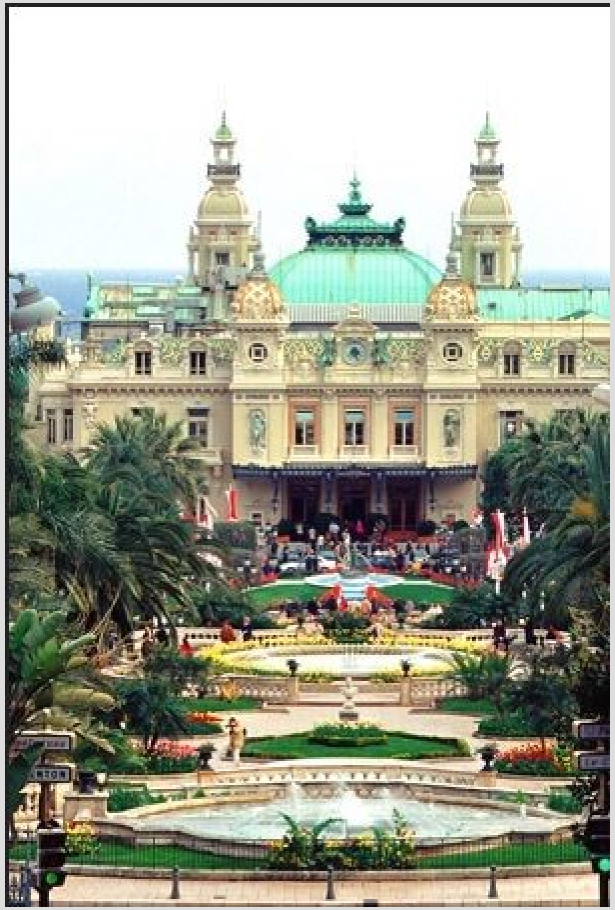


## That lead the way to the Roulette



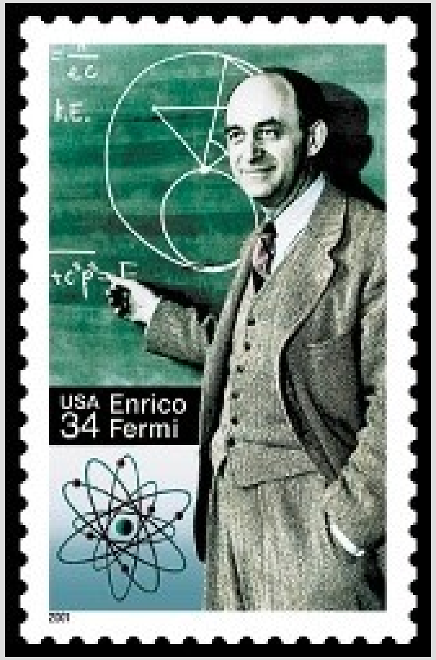


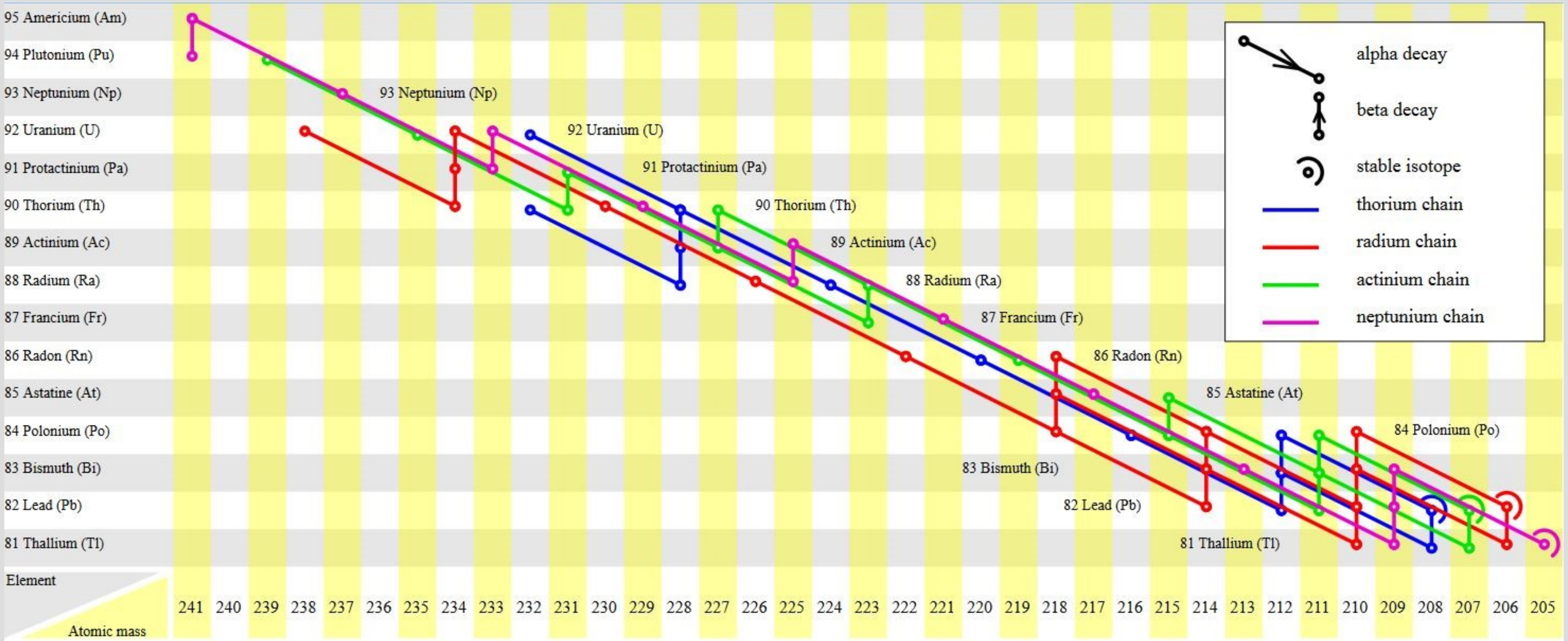
**Casino de Monte-Carlo**
**Monaco - MC 98000**



**Casino de Monte-Carlo**
**Monaco - MC 98000**

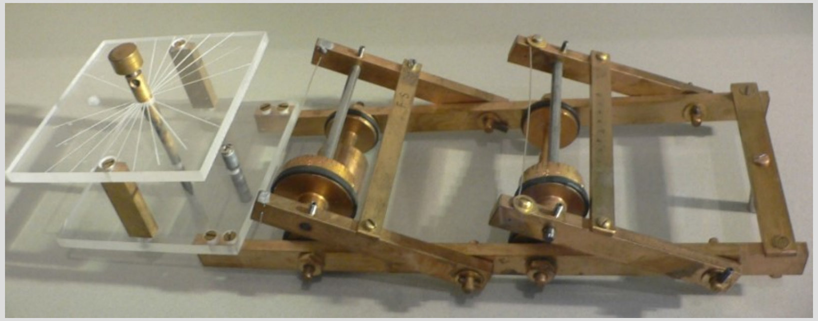
**In 1930**



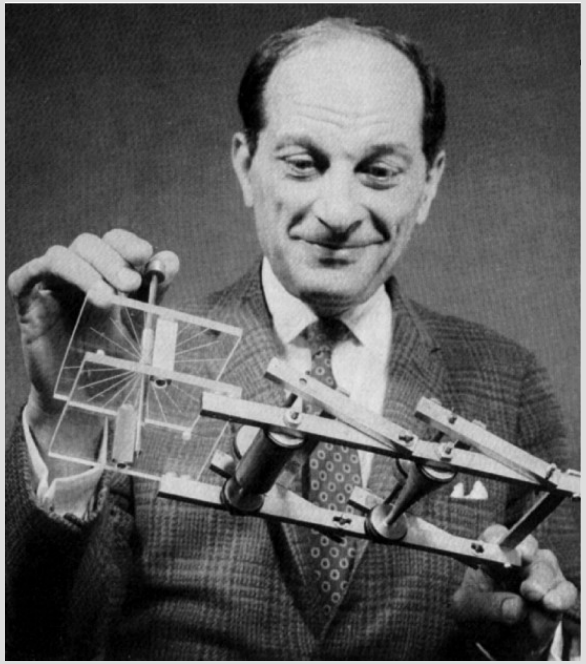

**FERMIAC The Monte Carlo trolley**

statistical sampling techniques



**Random number generator**

## In 1940



Stan Ulam

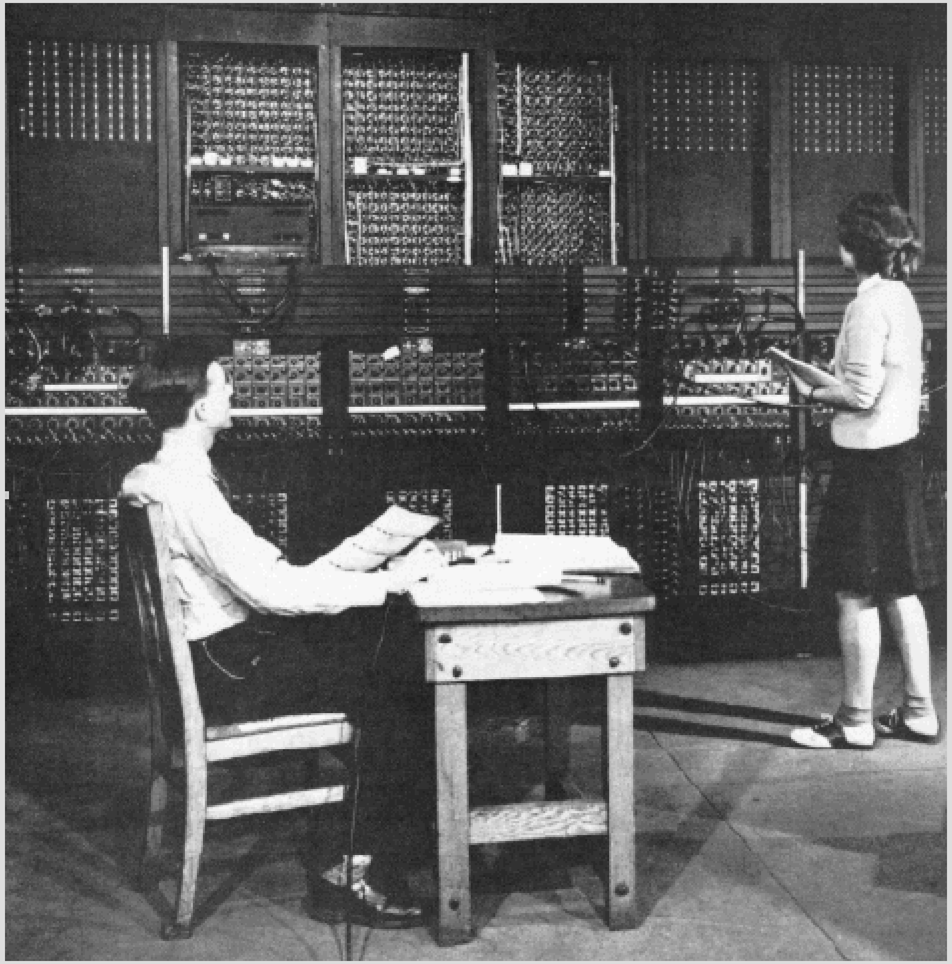
**While playing solitaire during his recovery from a surgery, he had thought about playing hundreds of games to estimate statistically the probability of a successful outcome**

**This lead to the idea of Monte Carlo Method!**

ENIAC - first electronic general-purpose computer

John von Neumann

Used Monte Carlo Method and employed random numbers to solve complicated problems.



Obtained random numbers from:

- nuclear radioactivity;
- voltage fluctuation;
- Solar flare and

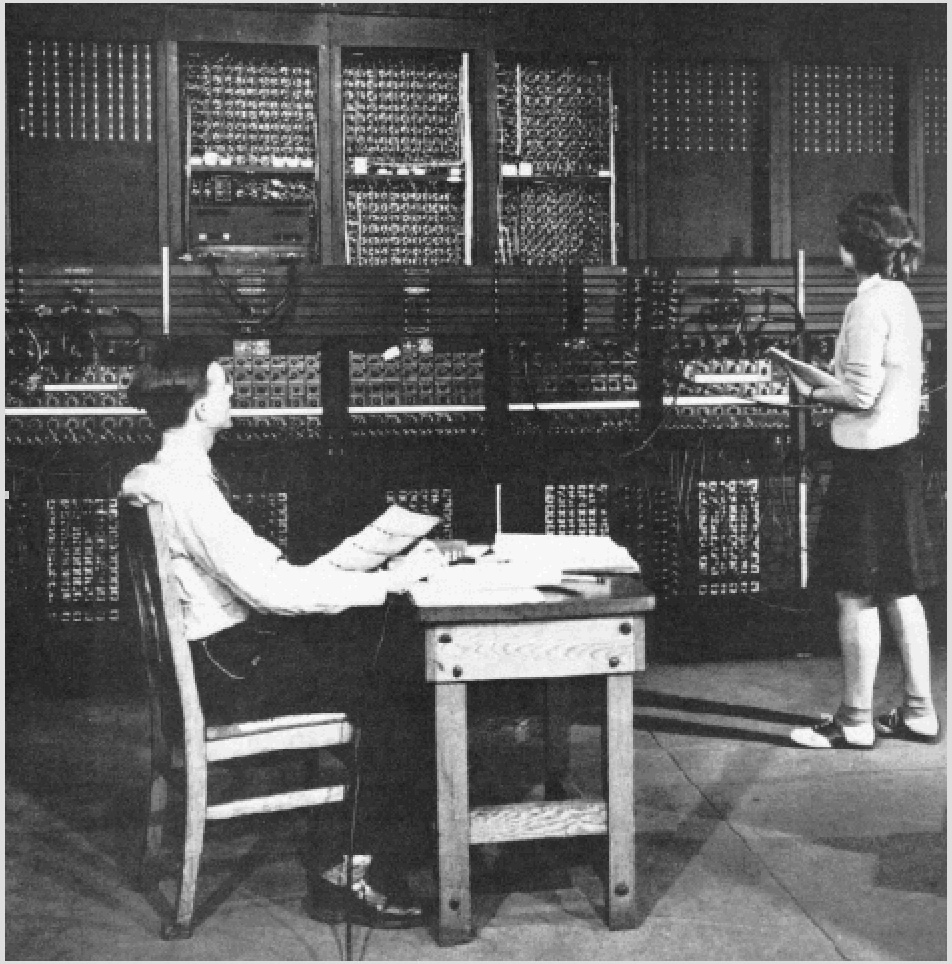
stored in punch cards.

But reading from punch card was very slow!

## ENIAC - first electronic general-purpose computer

**John von Neumann**

**Used Monte Carlo Method and employed random numbers to solve complicated problems.**



**So, he developed pseudo-random numbers, using the 13th century mid-square method**

Let, Seed $x_0 = 0.7891$, then

$x_0^2 = 0.62\ 2678\ 81$
$\Rightarrow x_1 = 0.2678$

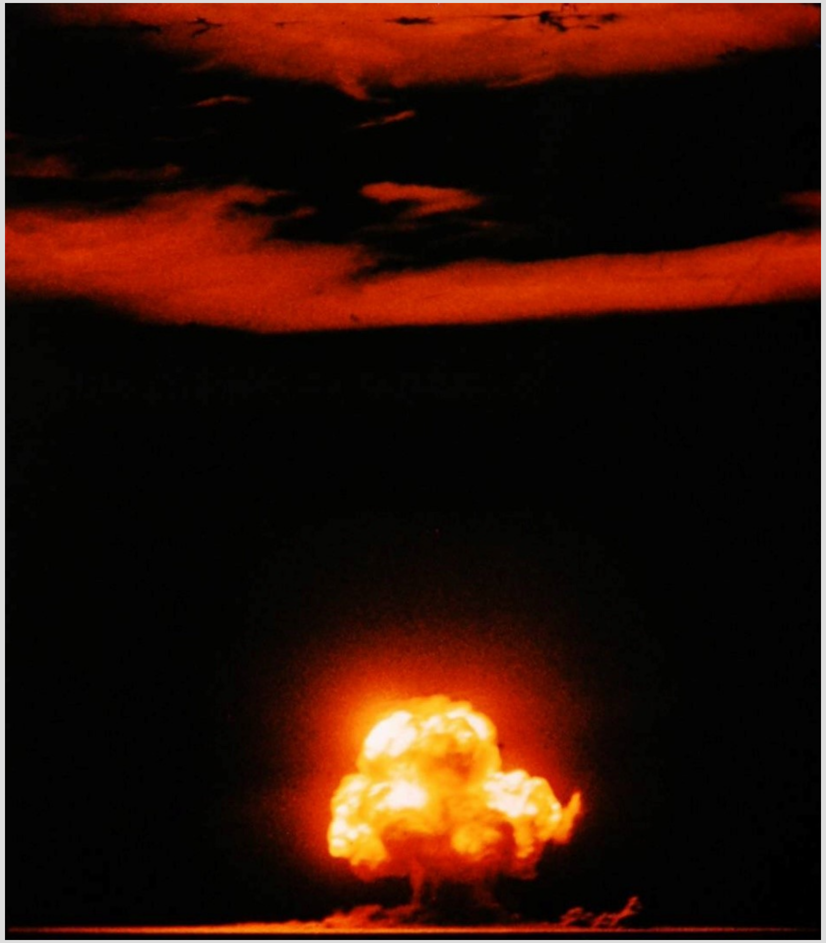
$x_1^2 = 0.07\ 1716\ 84$
$\Rightarrow x_2 = 0.1716$

$x_2^2 = 0.02\ 9446\ 56$
$\Rightarrow x_3 = 0.9446$

**"Any one who considers arithmetical methods of producing random digits is, of course, in a state of sin."**

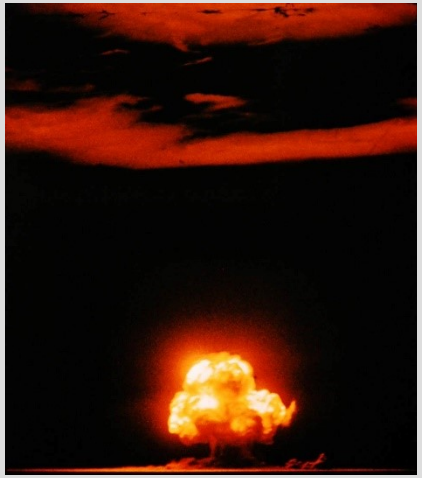
**He applied Monte Carlo Methods and**

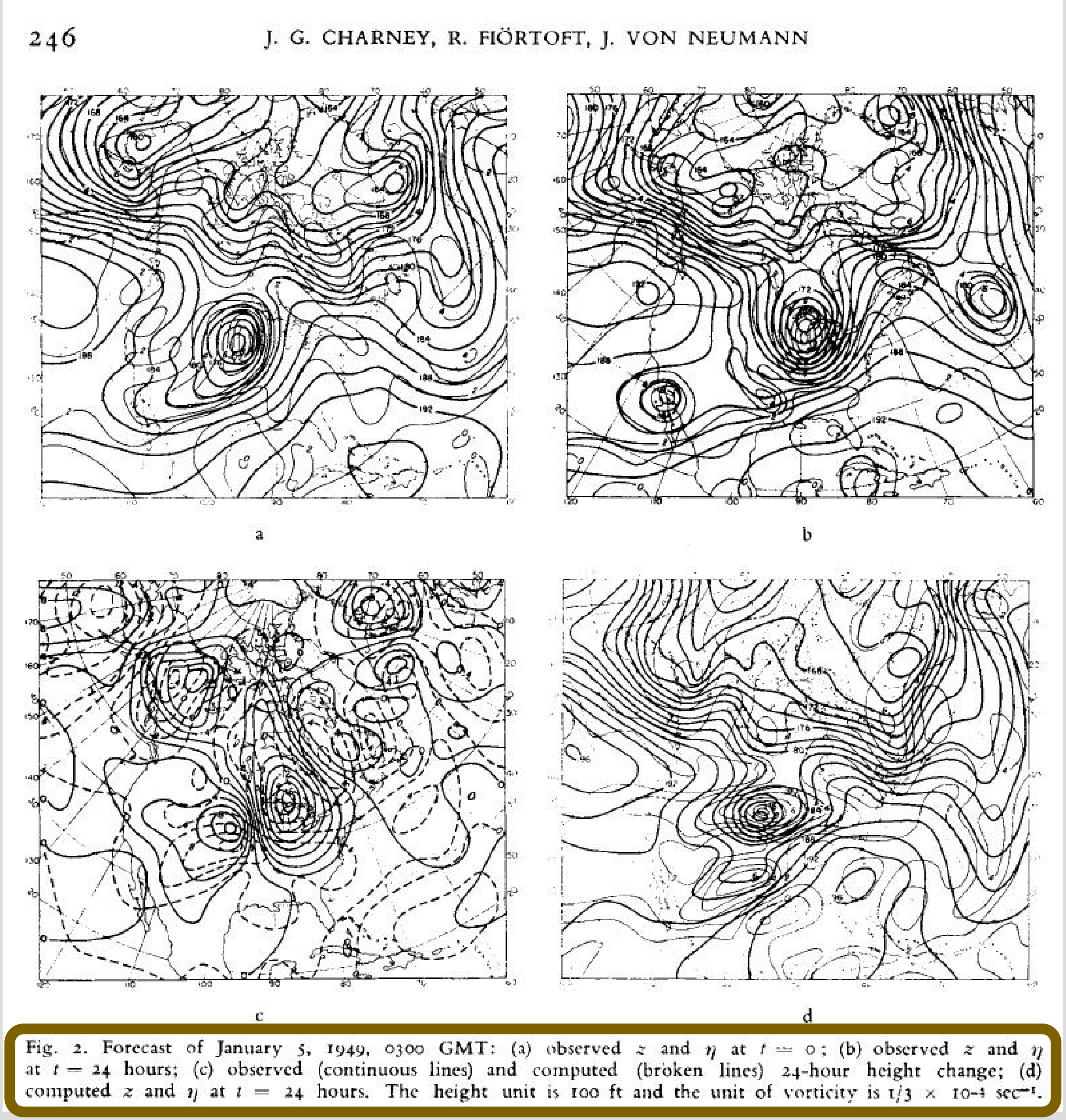
**John von Neumann**



**He applied Monte Carlo Methods and**

**John von Neumann**





246 J. G. CHARNEY, R. FIÖRTOFT, J. VON NEUMANN

a

b

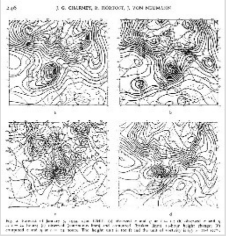
c

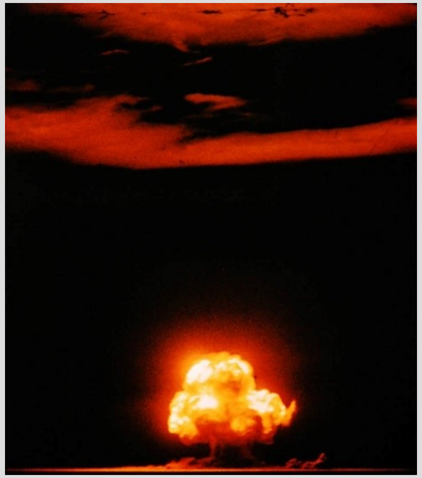
d

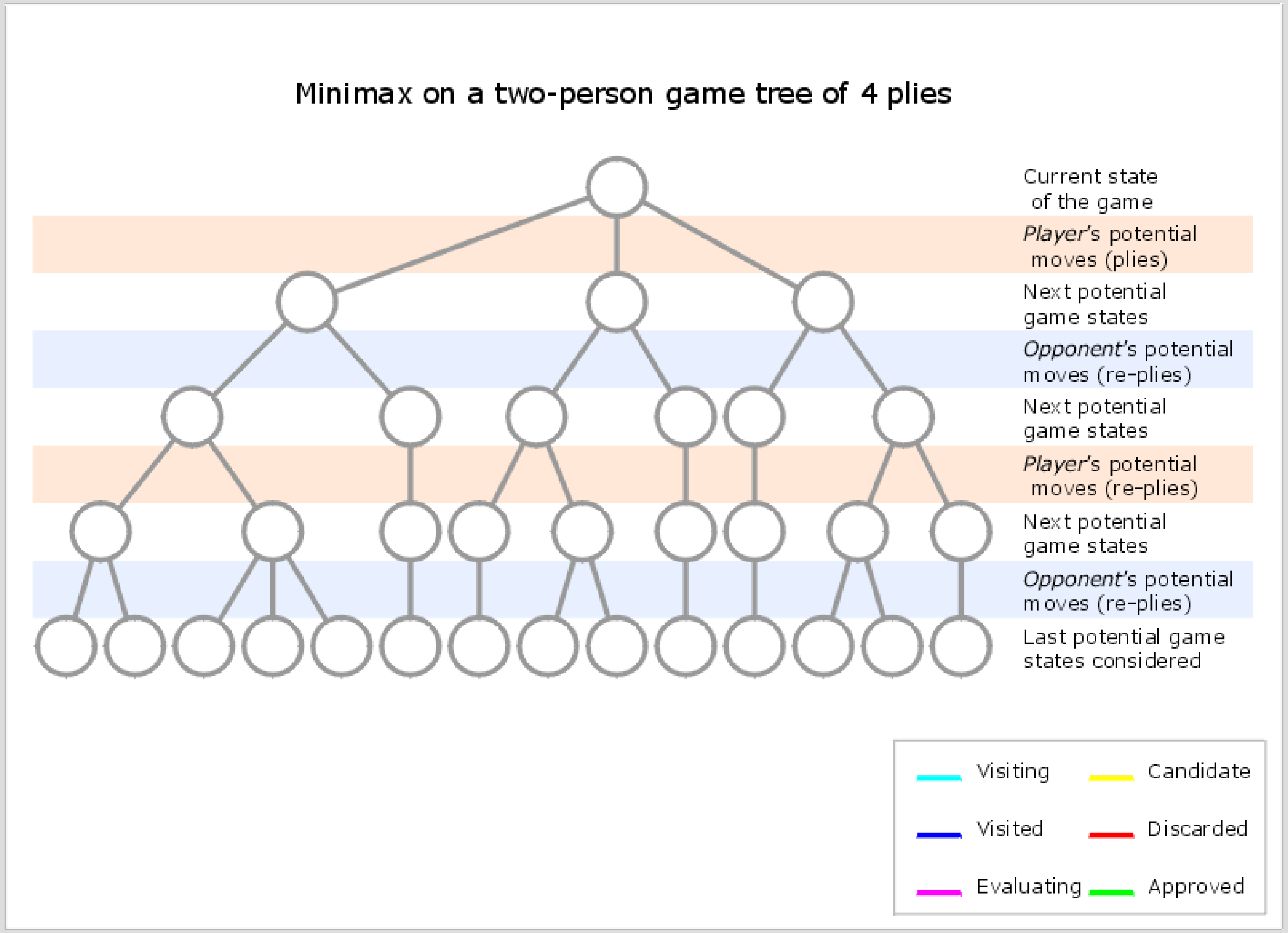
Fig. 2. Forecast of January 5, 1949, 0300 GMT: (a) observed $z$ and $\eta$ at $t = 0$; (b) observed $z$ and $\eta$ at $t = 24$ hours; (c) observed (continuous lines) and computed (broken lines) 24-hour height change; (d) computed $z$ and $\eta$ at $t = 24$ hours. The height unit is 100 ft and the unit of vorticity is $1/3 \times 10^{-4}$ sec$^{-1}$.

# He applied Monte Carlo Methods and

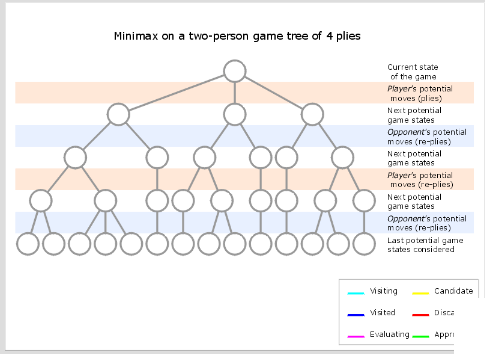
## John von Neumann



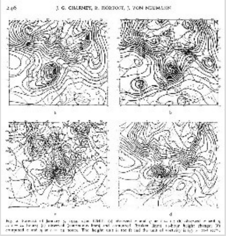


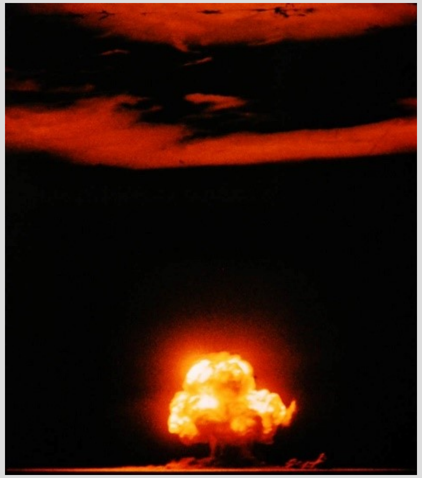


# He applied Monte Carlo Methods and

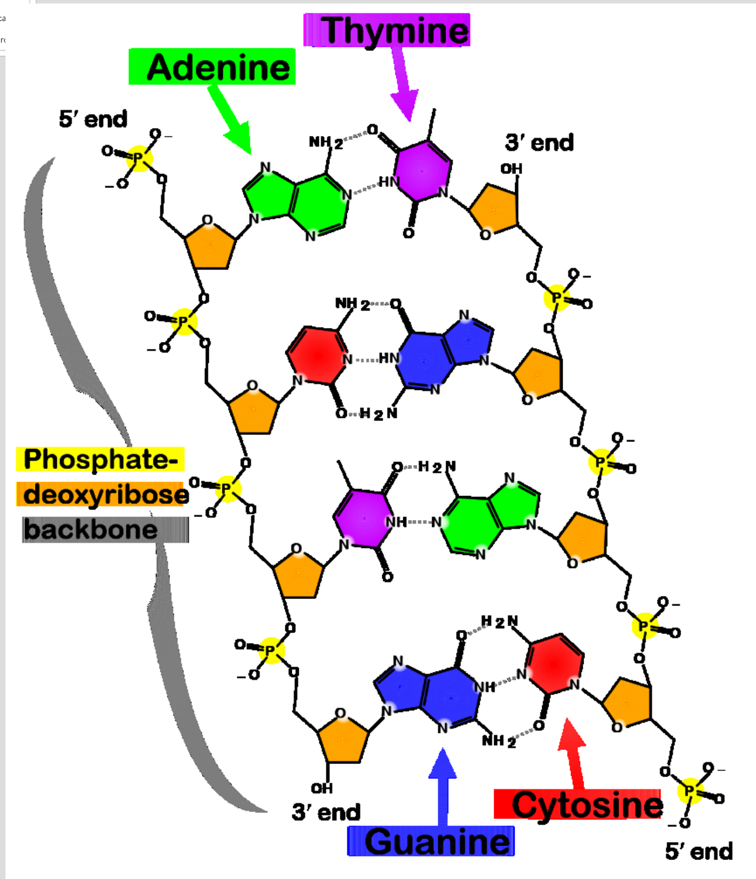



## John von Neumann

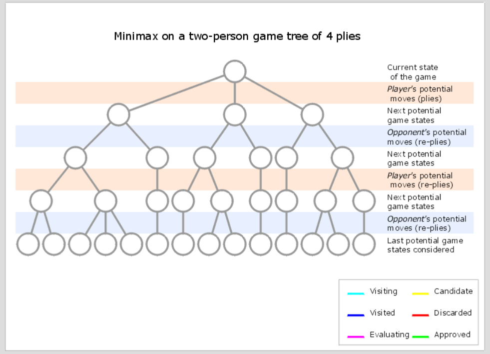




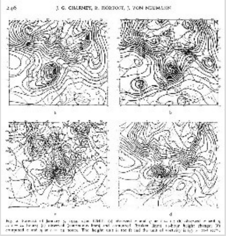
replicators

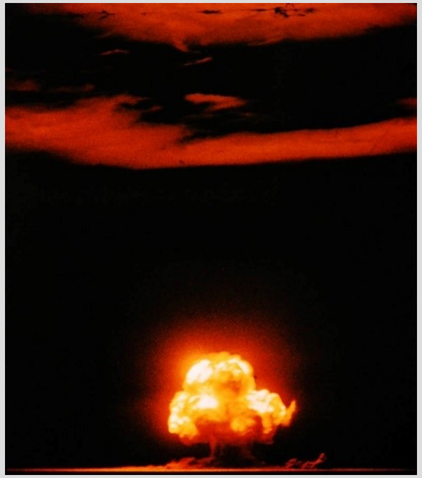


## He applied Monte Carlo Methods and

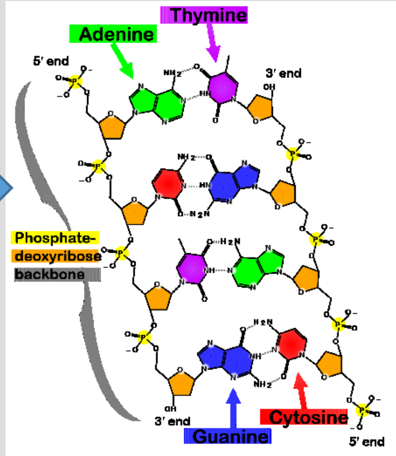



## John von Neumann





replicators




**In 1957**

## Fortran (Formula Translating System)

Multiplicative Congruential Generator (MCG)

$$X_n = (\mathrm{a}X_{n-1}) \bmod \mathrm{m}$$

```
RANDOM = MOD(A*SEED,M)
PRINT*, RANDOM
SEED = RANDOM
```

Linear congruential generator

$$X_n = (\mathrm{a}X_{n-1} + \mathrm{b}) \bmod \mathrm{m}$$

In 1972

# C

```c
static unsigned long int next = 1;

int rand(void) // RAND_MAX assumed to be 32767
{
        static const unsigned long int a = 1103515245;
        static const unsigned short b = 12345;
        next = next * a + b;
        return (unsigned int)(next/65536) % 32768;
}

void srand(unsigned int seed)
{
        next = seed;
}
```

In 1972

# C

```
static unsigned long int next = 1;

int rand(void) // RAND_MAX assumed to be 32767
{
        static const unsigned long int a = 1103515245;
        static const unsigned short b = 12345;
        next = next * a + b;
        return (unsigned int)(next/65536) % 32768;
}

void srand(unsigned int seed)
{
        next = seed;
}
```

```
#include <cstdlib>
#include <cstdio>
#include <ctime>

int main()
{
        srand(time(NULL));
        printf("Random numbers:\n");
        float random = 0;
        for (int i = 0; i < 10; ++i) {
                random = (float) rand()/RAND_MAX;
                printf("%f\n", random);
        }
}
```

```
Random numbers:

0.003143
0.569353
0.033021
0.545427
0.627430
0.035096
0.817377
0.055635
0.282266
0.187628
```

→ BCPL

→ 1972 C (proximity to hardware)

Machine code (100011 00011)

→ Assembly language (mov ax,@data)

**1983 C++**

C with Classes (of Simula)

→1967 Simula (OOP)

→ ALGOL

→ Fortran

→ Speedcoding

In 1983

# C++

```
int rand (void);

void srand (unsigned int seed);

#define RAND_MAX 32767
```

```
std::random_shuffle (data.begin(), data.end());
```

Initial data is {1, 2, 3, 4, 5, 6, 7, 8, 9, 10}

Shuffled data is {6, 10, 5, 2, 3, 7, 9, 8, 1, 4}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# Improvements to TR1's Facility for Random Number Generation


*Document #:* WG21/N1933 = J16/06-0003
*Date:* 2006-02-23
*Revises:* None
*Project:* Programming Language C++
*Reference:* ISO/IEC IS 14882:2003(E)


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## Contents



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*If the numbers are not random, they are at least higgledy-piggledy.*

— George Marsaglia

*I cannot do it without compters.*

— William Shakespeare

**In 2011**

**C++ 11**

**<random> (26.5 Random number generation N3797)**

**Distribution(Engine)**

In 2011

# C++ 11

<random> (26.5 Random number generation N3797)

Random = Distribution(Engine)

**Engines:**

linear_congruential_engine
subtract_with_carry_engine
mersenne_twister_engine

**Engines Adaptors:**

discard_block_engine
independent_bits_engine
shuffle_order_engine

**True random number generator:**

random_device

**Distributions:**

Uniform distributions
Normal distributions
Bernoulli distributions
Rate-based distributions
Piecewise distributions
Canonical numbers

## linear_congruential_engine

$$X_n = (\mathrm{a}X_{n-1} + \mathrm{b}) \bmod \mathrm{m}$$

minstd_rand0: $\mathrm{a} = 16807;\ \mathrm{b} = 0;\ \mathrm{m} = 2,147,483,647$

minstd_rand: $\mathrm{a} = 48271;\ \mathrm{b} = 0;\ \mathrm{m} = 2,147,483,647$

## linear_congruential_engine

$$X_n = (\mathrm{a}X_{n-1} + \mathrm{b}) \bmod \mathrm{m}$$

minstd_rand0: $\mathrm{a} = 16807;\ \mathrm{b} = 0;\ \mathrm{m} = \mathbf{2,147,483,647}$

minstd_rand: $\mathrm{a} = 48271;\ \mathrm{b} = 0;\ \mathrm{m} = \mathbf{2,147,483,647}$

# subtract_with_carry_engine

1991 George Marsaglia and Arif Zaman

Linear Congruential algorithm => $X_n = (aX_{n-1} + b) \bmod m \quad = f(X_{n-1})$

Lagged Fibonacci algorithm => $f(X_{n-1}, X_{n-2})$ => $f(X_{n-S}, X_{n-R})$; where, S < R < 0

$$X_n = (X_{n-S} - X_{n-R} - cy_{n-1}) \bmod m$$

where, $cy_n = (X_{n-S} - X_{n-R} - cy_{n-1} < 0)\ ?\ 1 : 0;$

ranlux24_base: 24-bit number S = 10; R = 24;

ranlux48_base: 48-bit number S = 5; R = 12;

# mersenne_twister_engine

1997Makoto Matsumoto and Takuji Nishimura

“Twisted Generalized Feedback Shift Register”

Period length = Mersenne prime = $2^{19937}-1$

MT19937 uses a 32-bit word length

MT19937-64 uses a 64-bit word length

## random_device

Generates random numbers from hardware where available

```
CRTIMP2_PURE unsigned int __CLRCALL_PURE_OR_CDECL _Random_device();

unsigned int operator()()
{
        return (_Random_device());
}
```

```
std::random_device rd;

std::default_random_engine e1(rd());
```

*Required behaviour:* The 10000th consecutive invocation of a default-constructed object of type mt19937 shall produce the value 4123659995.

```
void my_random_generator::check_mt19937()
{
        mt19937 engine;
        static long long random_number = 0;

        for(int i =0; i != 9999; ++i) engine();

        random_number = engine();

        // If the implementation is correct then the 10000th consecutive
        // invocation of a default-constructed object of type mt19937
        // shall produce the value 4,123,659,995, ref. C++11 ISO statement.

        if(random_number == 4123659995)
                cout    << "\n  Note:\n\t The pseudorandom number generator\n\t "
                        << "Mersenne twister: MT19937 has been tested\n\t and "
                        << "it shows it is implemented properly.\n";
        else
                cout    << "\nWarning:\n\t "
                        << "The pseudorandom number generator\n\t "
                        << "Mersenne twister: MT19937 has been "
                        << "tested\n\t and it shows it is NOT "
                        << "implemented properly.\n";
}
```

```cpp
// A Uniform Distribution based on default_random_engine:
// Using Bind function:

auto dist = bind(uniform_real_distribution<double>{0.0, 1.0}, default_random_engine{});


Random = dist();
```

```cpp
class uniform_dist {

public:

        double operator()() { return uniform(engine); }

        uniform_dist() :uniform{ 0.0, 1.0 } {}

        void discard(unsigned long long z) { engine.discard(z); }

        void discard_distribution(unsigned long long z)
        {
                for (auto i = z; i != 0; --i)
                        uniform(engine);
        }

        uniform_dist(double low, double high) : uniform(low, high) {}

private:

        default_random_engine engine;

        uniform_real_distribution <double> uniform;
};
```

```cpp
// A Normal distribution based on
// Mersenne Twister engine:

class normal_dist {
public:
        double operator()() { return normal(engine); }

        normal_dist() :normal {0.0, 1.0} {}

        void discard(unsigned long long z) { engine.discard(z); }

        void discard_distribution(unsigned long long z)
        {
                for (auto i = z; i != 0; --i)
                        normal(engine);
        }

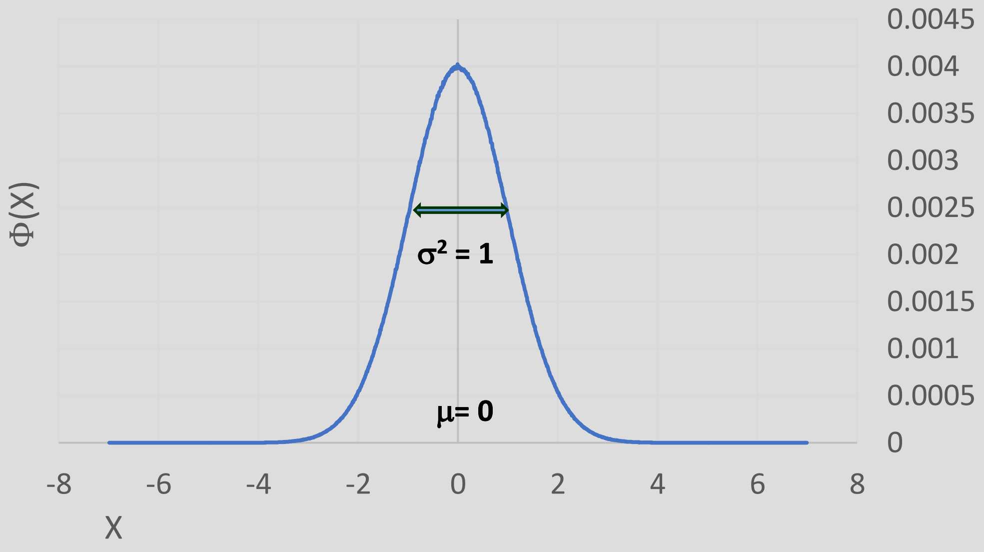
         normal_dist(double mean, double std_dev) : normal( mean, std_dev ) {}

private:

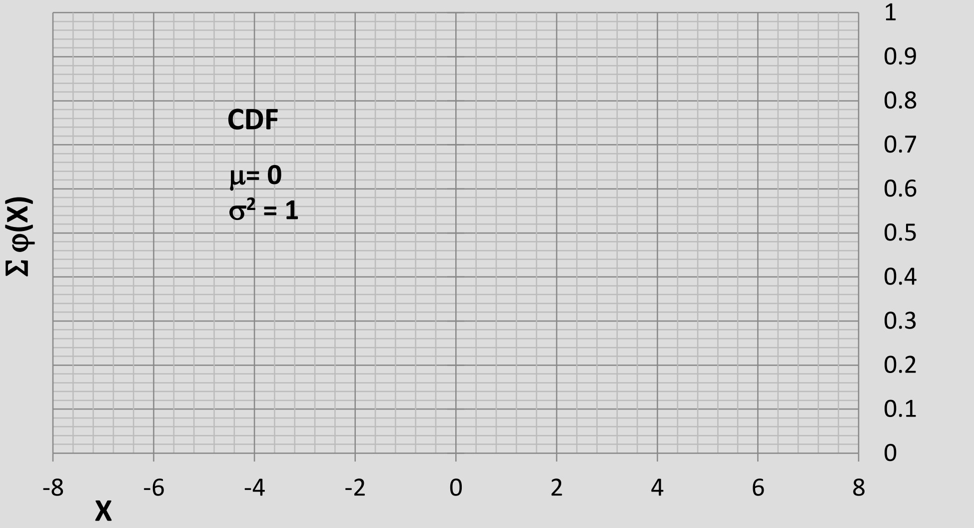
        mt19937 engine;

        normal_distribution<double> normal;
};
```

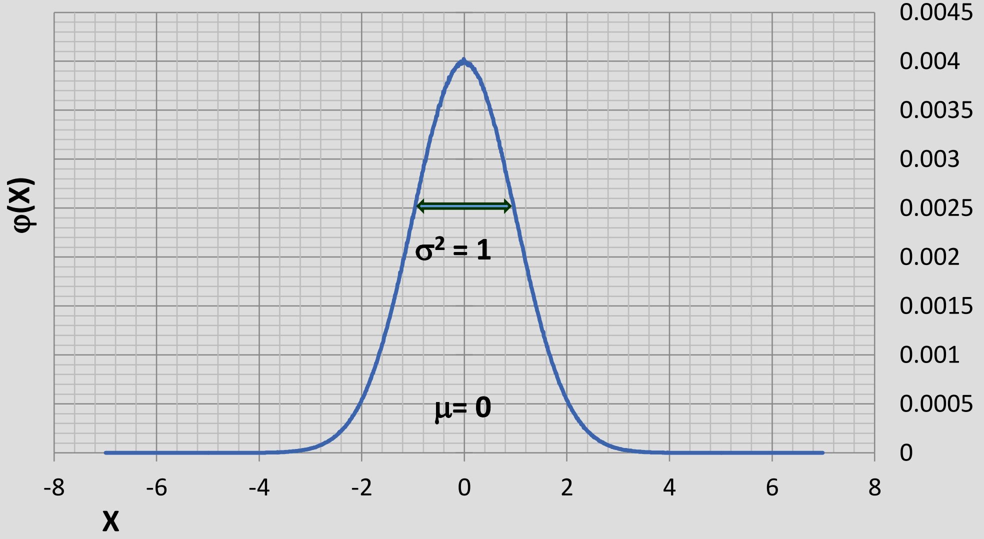
# Normal distribution



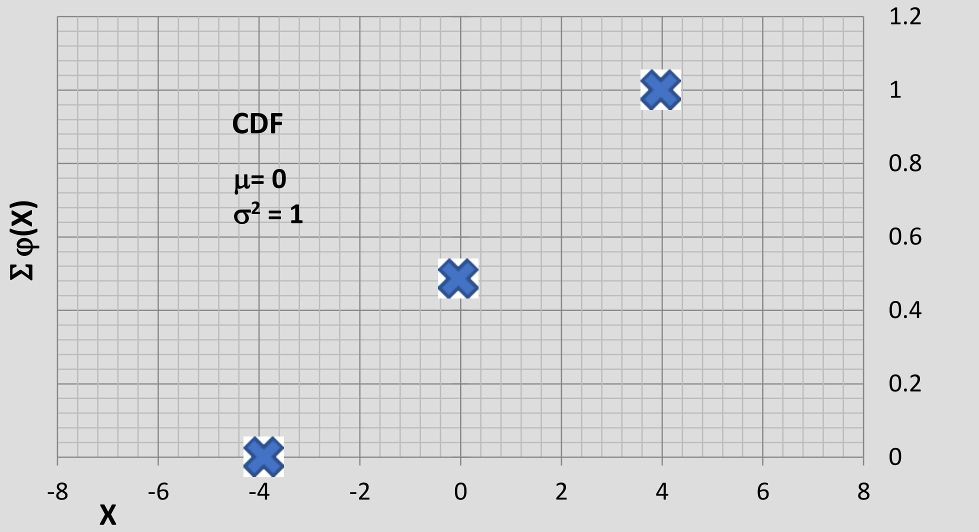
**Cumulative normal distribution**



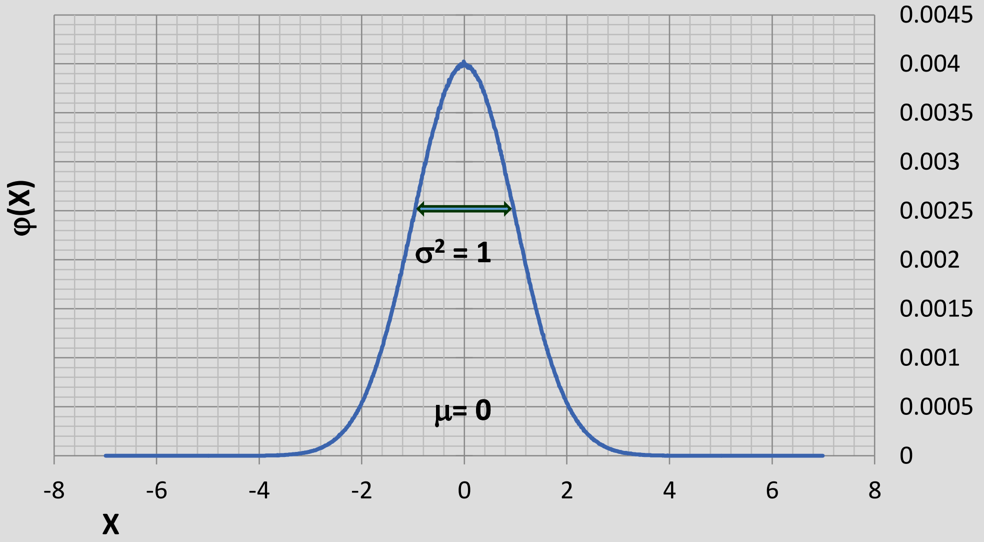

**Probability normal distribution**



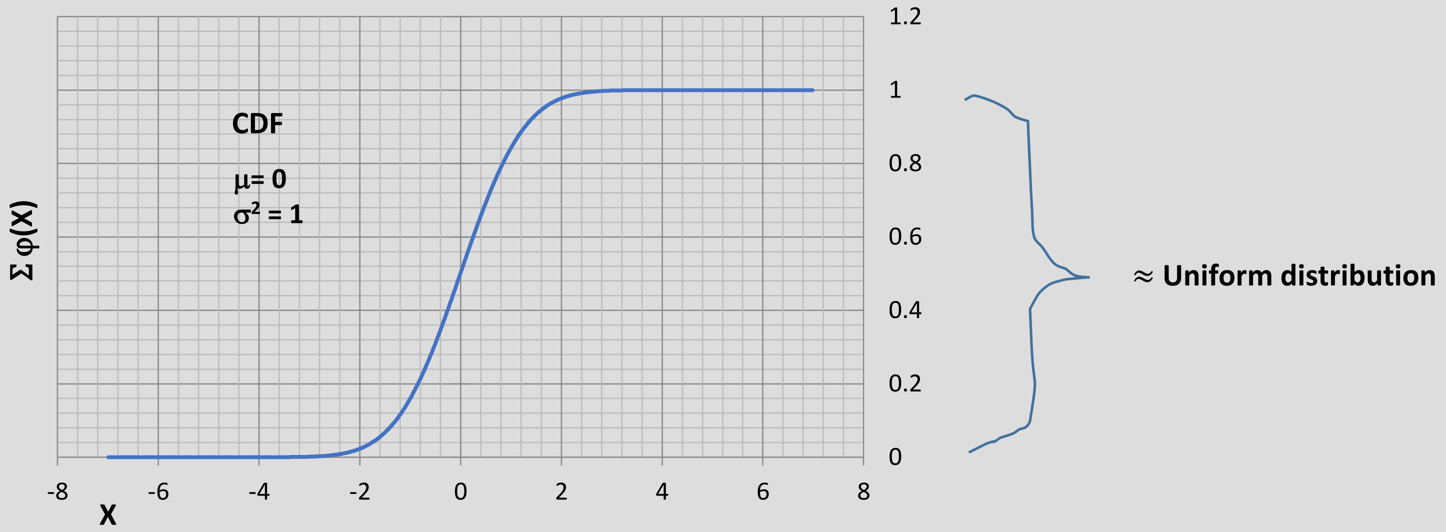
**Cumulative normal distribution**



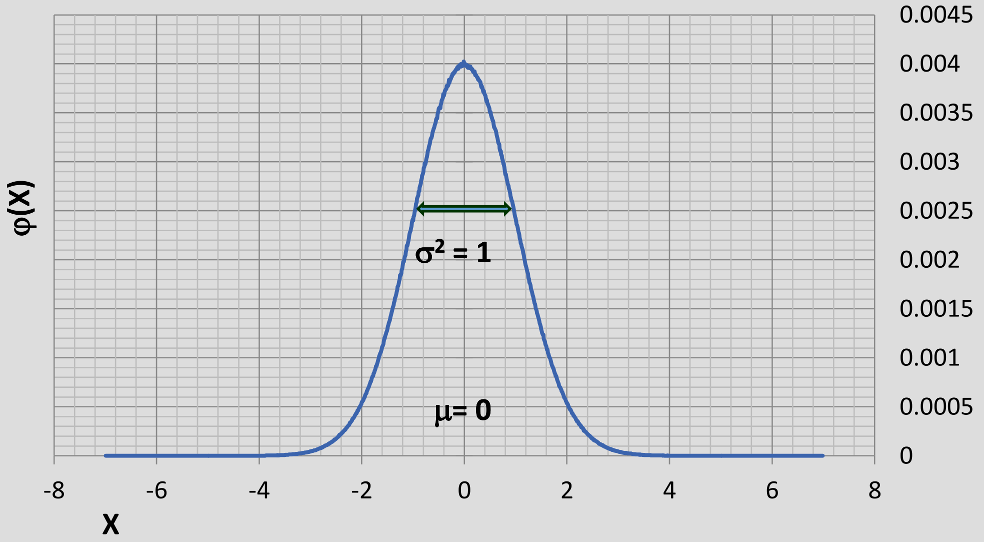

**Probability normal distribution**



**Cumulative normal distribution**




**Probability normal distribution**



http://home.online.no/~pjacklam/notes/invnorm/index.html

Pseudo-code algorithm for rational approximation

The algorithm below assumes p is the input and x is the output.

```
  Coefficients in rational approximations.
  a(1) <- -3.969683028665376e+01
  a(2) <-  2.209460984245205e+02
  a(3) <- -2.759285104469687e+02
  a(4) <-  1.383577518672690e+02
  a(5) <- -3.066479806614716e+01
  a(6) <-  2.506628277459239e+00

  b(1) <- -5.447609879822406e+01
  b(2) <-  1.615858368580409e+02
  b(3) <- -1.556989798598866e+02
  b(4) <-  6.680131188771972e+01
  b(5) <- -1.328068155288572e+01

  c(1) <- -7.784894002430293e-03
  c(2) <- -3.223964580411365e-01
  c(3) <- -2.400758277161838e+00
  c(4) <- -2.549732539343734e+00
  c(5) <-  4.374664141464968e+00
  c(6) <-  2.938163982698783e+00

  d(1) <-  7.784695709041462e-03
  d(2) <-  3.224671290700398e-01
  d(3) <-  2.445134137142996e+00
  d(4) <-  3.754408661907416e+00
```

```
Define break-points.

p_low  <- 0.02425
p_high <- 1 - p_low

Rational approximation for lower region.

if 0 < p < p_low
  q <- sqrt(-2*log(p))
  x <- (((((c(1)*q+c(2))*q+c(3))*q+c(4))*q+c(5))*q+c(6)) /
       ((((d(1)*q+d(2))*q+d(3))*q+d(4))*q+1)
endif

Rational approximation for central region.

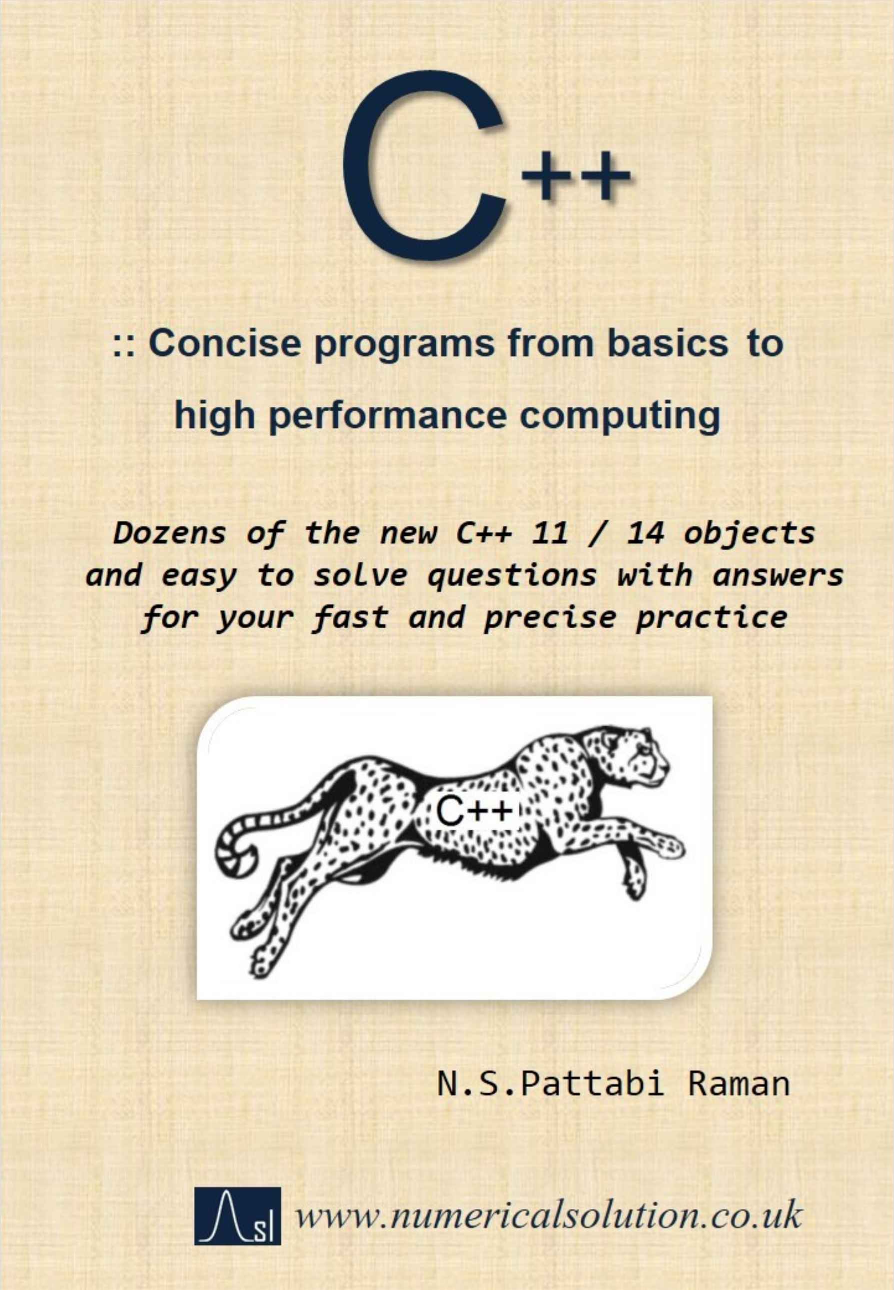
if p_low <= p <= p_high
  q <- p - 0.5
  r <- q*q
  x <- (((((a(1)*r+a(2))*r+a(3))*r+a(4))*r+a(5))*r+a(6))*q /
       (((((b(1)*r+b(2))*r+b(3))*r+b(4))*r+b(5))*r+1)
endif

Rational approximation for upper region.

if p_high < p < 1
  q <- sqrt(-2*log(1-p))
  x <- -(((((c(1)*q+c(2))*q+c(3))*q+c(4))*q+c(5))*q+c(6)) /
        ((((d(1)*q+d(2))*q+d(3))*q+d(4))*q+1)
endif
```

**Please avoid coding random number generators or distributions!**

**Make use of your compliers and**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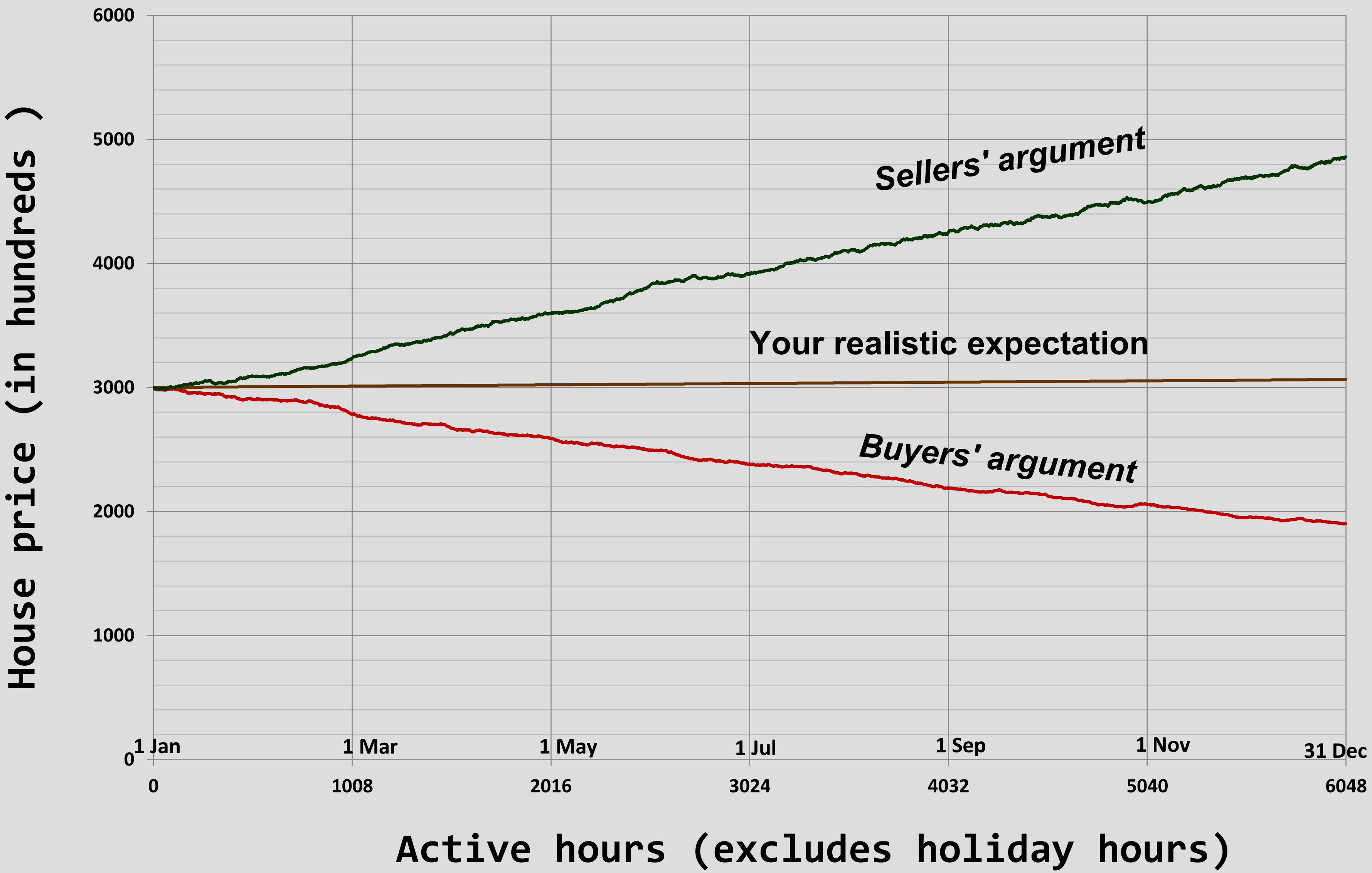
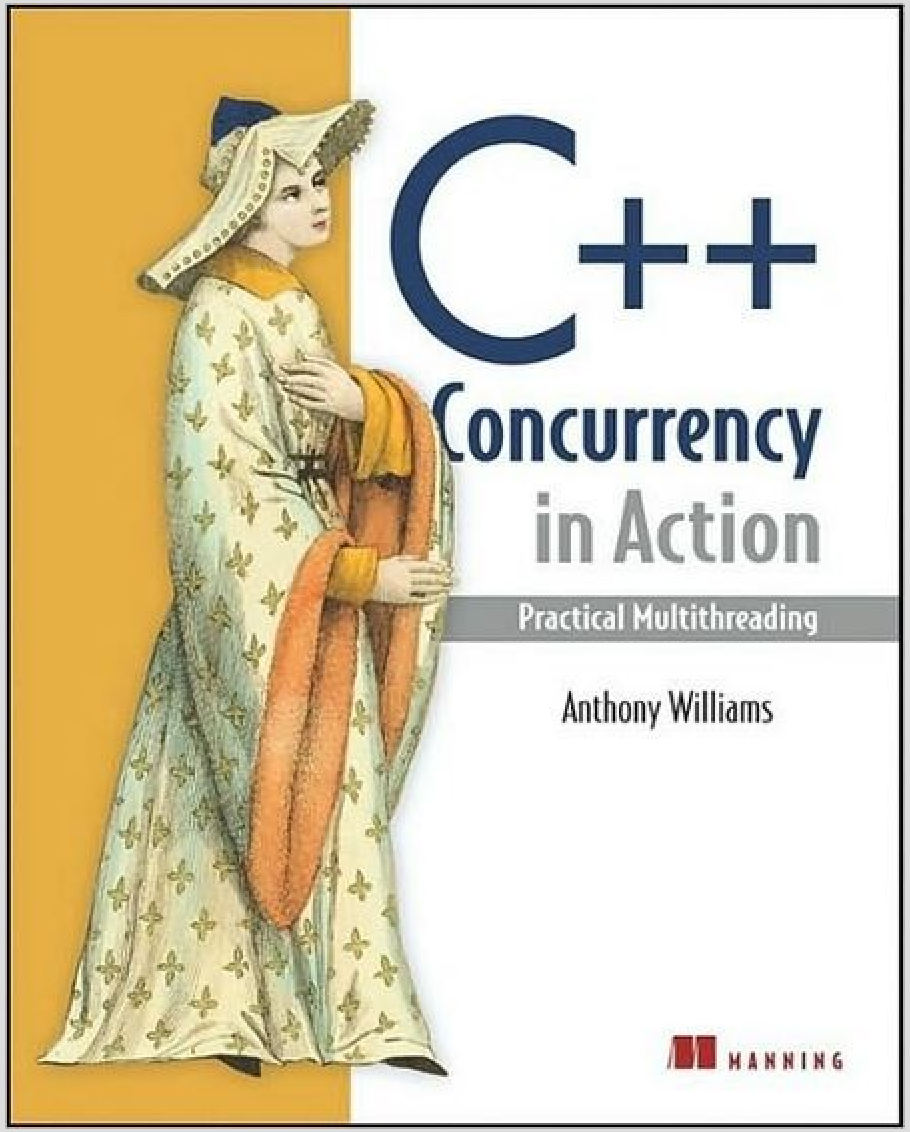
N.S.Pattabi Raman
www.numericalsolution.co.uk

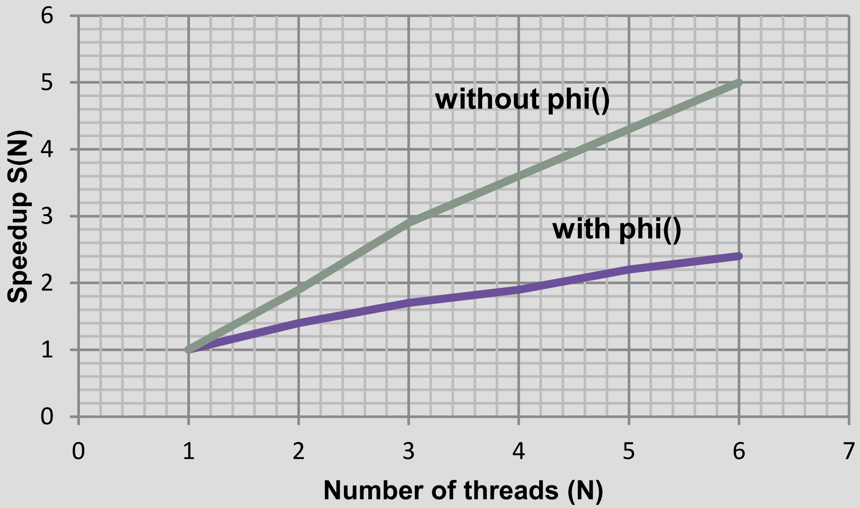
$$V_t = V_{t\text{-}dt}(\,1 + r.dt + sigma.phi().\sqrt{dt}),$$

```
for(i = 1; i < T; ++i) {
        dX = phi()*sqrt_dt;
        dS = S*(r_dt + sigma*dX);
        S += dS;
        data[i] = S;
}
```

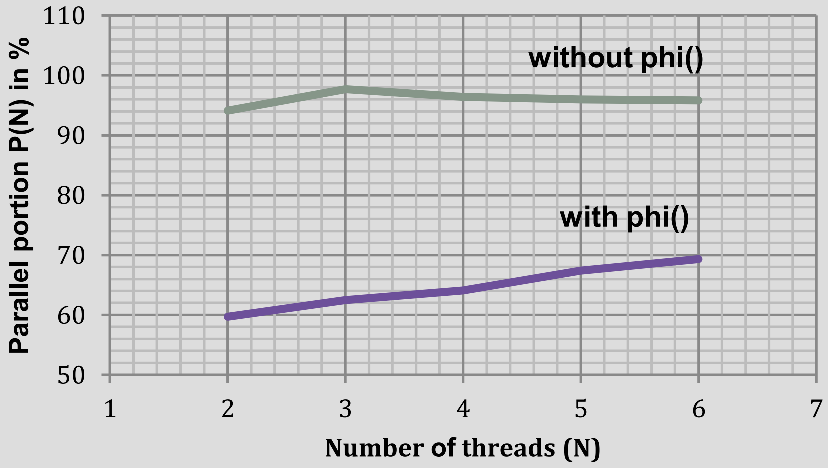


6000
5000
4000
3000
2000
1000
0
House price (in hundreds )
Sellers' argument
Your realistic expectation
Buyers' argument
1 Jan
1 Mar
1 May
1 Jul
1 Sep
1 Nov
31 Dec
0
1008
2016
3024
4032
5040
6048
Active hours (excludes holiday hours)

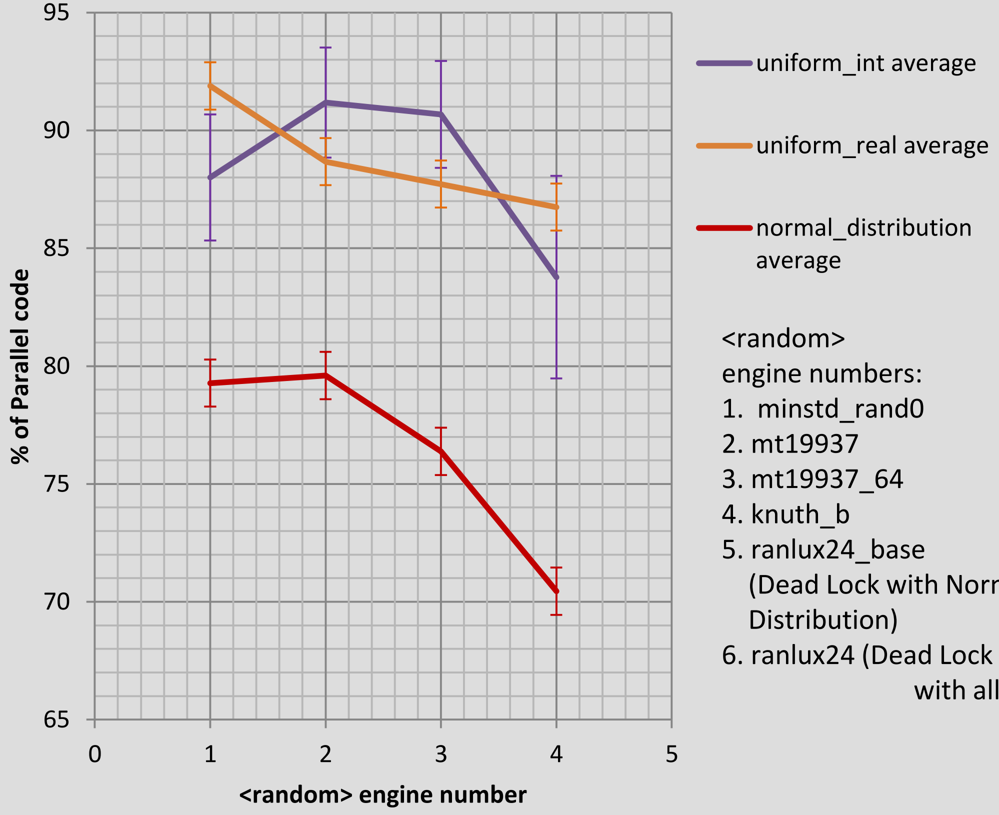

C++
Concurrency
in Action
Practical Multithreading
Anthony Williams
MANNING




$$\text{Amdahl's law} \Rightarrow P = \frac{(1-S)N}{S(1-N)}$$



| <random> engine | uniform_int | | uniform_real | | normal_distribution | |
|---|---|---|---|---|---|---|
| | average | stdev | average | stdev | average | stdev |
| **1. Linear congruential: minstd_rand0** | 88.00 | 2.67 | 91.89 | 2.97 | 79.28 | 3.60 |
| **2. Mersenne twister: mt19937** | 91.18 | 2.34 | 88.67 | 3.47 | 79.60 | 2.61 |
| **3. Mersenne twister: mt19937_64** | 90.68 | 2.27 | 87.73 | 3.10 | 76.38 | 3.04 |
| **4. Shuffle order: knuth_b** | 83.77 | 4.29 | 86.75 | 6.12 | 70.45 | 5.71 |
| **5. Subtract with carry: ranlux24_base** | 88.09 | 2.14 | 83.62 | 4.74 | Dead Lock! | |
| **6. Discard block: ranlux24** | Dead Lock! | | Dead Lock! | | Dead Lock! | |




<random> engine numbers:
1. minstd_rand0
2. mt19937
3. mt19937_64
4. knuth_b
5. ranlux24_base (Dead Lock with Normal Distribution)
6. ranlux24 (Dead Lock with all!)

Document no: N3397=12-0087
Date: 2012-08-13
Project: Programming Language C++
Reply to: Roger Orr
rogero@howzatt.demon.co.uk

# Spring 2013 JTC1/SC22/WG21 C++ Standards Committee Meeting

## Bristol, UK, April 15 – 20, 2013

*(note: this is 6 days: Mon - Sat)*

The meeting venue and host hotel is the **Marriott Hotel, Bristol City Centre**.
2 Lower Castle Street, Old Market, Bristol, England BS1 3AD
http://www.marriott.co.uk/hotels/travel/brsdt-bristol-marriott-hotel-city-centre/

Thanks to:

Hans Boehm, Lawrence Crowl, Mike Giles, Peter Jäckel, Stephan T. Lavavej, Nick Maclaren

Alisdair Meredith, Roger Orr, I.M. Sobol‘, Herb Sutter, Jonathan Wakely, Michael Wong and more

```
template<class UIntType, size_t w, ...>
class mersenne_twister_engine
{
public:
        ....
        ....
        ....
        explicit mersenne_twister_engine(result_type value = default_seed);
        template<class Sseq> explicit mersenne_twister_engine(Sseq& q);
        void seed(result_type value = default_seed);
        template<class Sseq> void seed(Sseq& q);

        // generating functions
        result_type operator()() const; // if const method then it would be safe for concurrency.
        void discard(unsigned long long z);
};
```

Thanks to:

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        template<class Sseq> explicit mersenne_twister_engine(Sseq& q);
        void seed(result_type value = default_seed);
        template<class Sseq> void seed(Sseq& q);

        // generating functions
```

**result_type operator()()** ~~**const**~~**;** // but it is not const method.

```
        void discard(unsigned long long z);
};
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template<class UIntType, size_t w, ...>
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        template<class Sseq> explicit mersenne_twister_engine(Sseq& q);
        void seed(result_type value = default_seed);
        template<class Sseq> void seed(Sseq& q);

        // generating functions
        result_type operator()(); // As it is not const method, it is not safe for concurrency!
        void discard(unsigned long long z);
};
```

Thanks to:

Hans Boehm, Lawrence Crowl, Mike Giles, Peter Jäckel, Stephan T. Lavavej, Nick Maclaren

Alisdair Meredith, Roger Orr, I.M. Sobol‘, Herb Sutter, Jonathan Wakely, Michael Wong and more

- Declare random number generator as **thread_local**, then each thread can have independent copy of the random object.
- But, it will provide same set of numbers in all threads, so that is multiplication of same data, therefore, **that cannot add to statistics!**

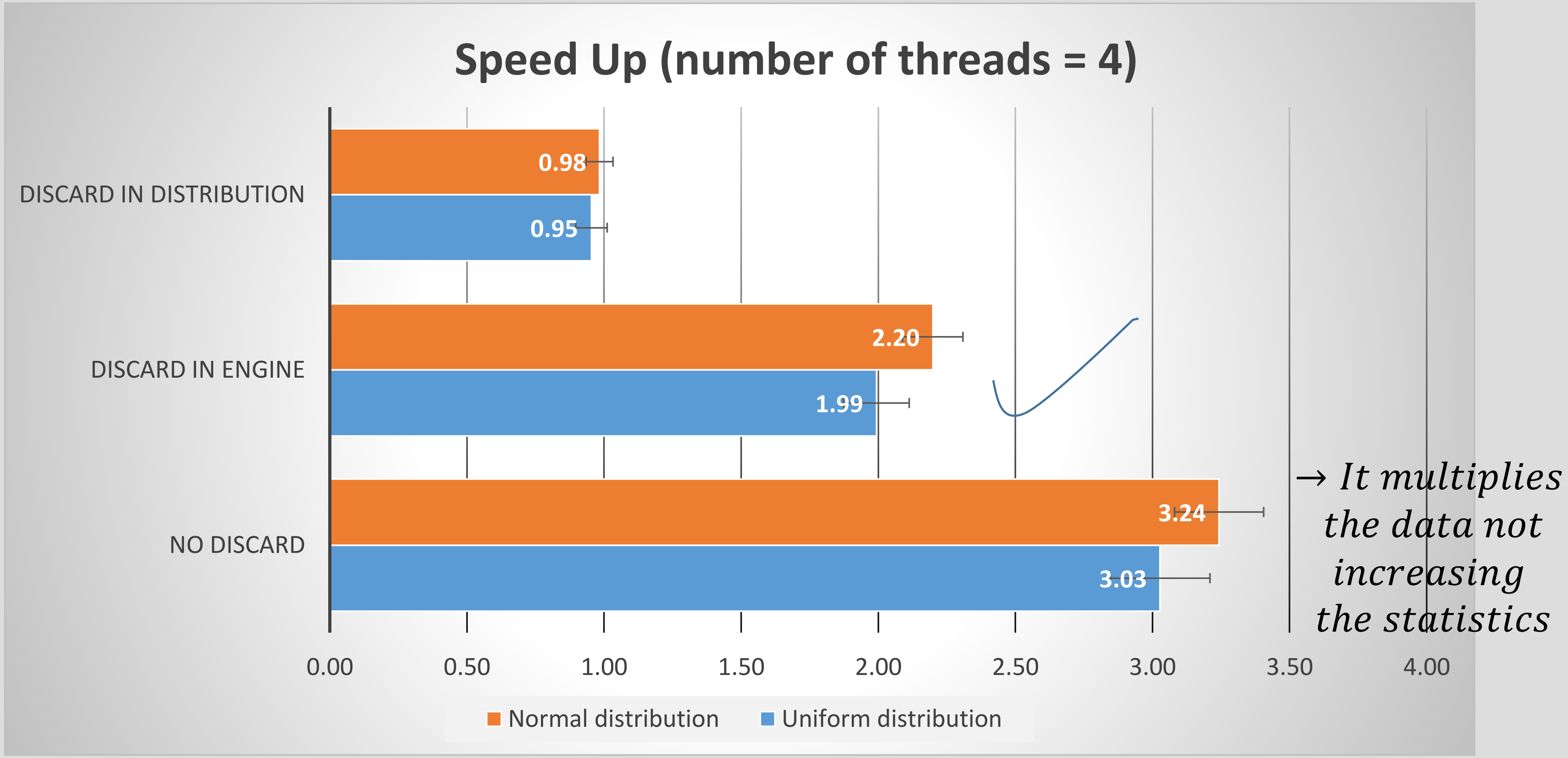
Thanks to:

Hans Boehm, Lawrence Crowl, Mike Giles, Peter Jäckel, Stephan T. Lavavej, Nick Maclaren

Alisdair Meredith, Roger Orr, I.M. Sobol‘, Herb Sutter, Jonathan Wakely, Michael Wong and more

- **Construct independent engines for each thread and set different range!**

```cpp
// A Normal distribution based on
// Mersenne Twister engine:

class normal_dist {
public:
        double operator()() { return normal(engine); }

        normal_dist() :normal {0.0, 1.0} {}

        {
                for (auto i = z; i != 0; --i)
                        normal(engine);
        }

         normal_dist(double mean, double std_dev) : normal( mean, std_dev ) {}

private:

        mt19937 engine;

        normal_distribution<double> normal;
};
```

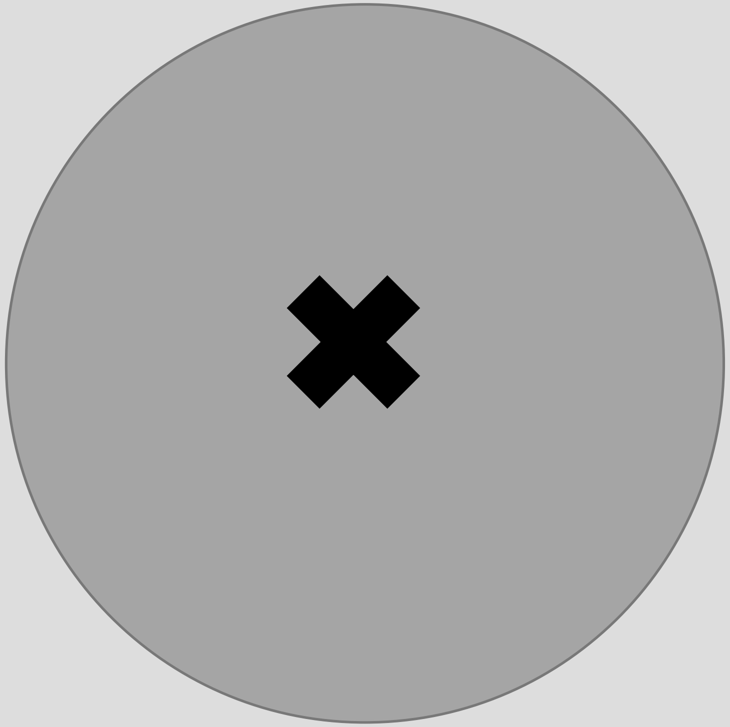



Complexity of ‘discard(number)’, i.e., performance time should be reduced, so number theoreticians can help!

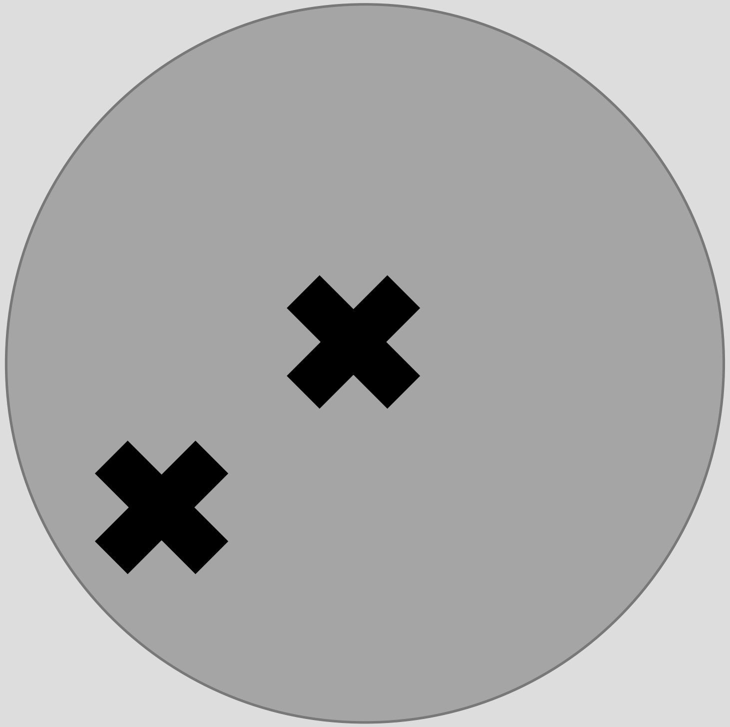
# Quasi-Random Numbers

- What are they?
- How do they differ from Pseudo-random numbers?
- Where do they help?

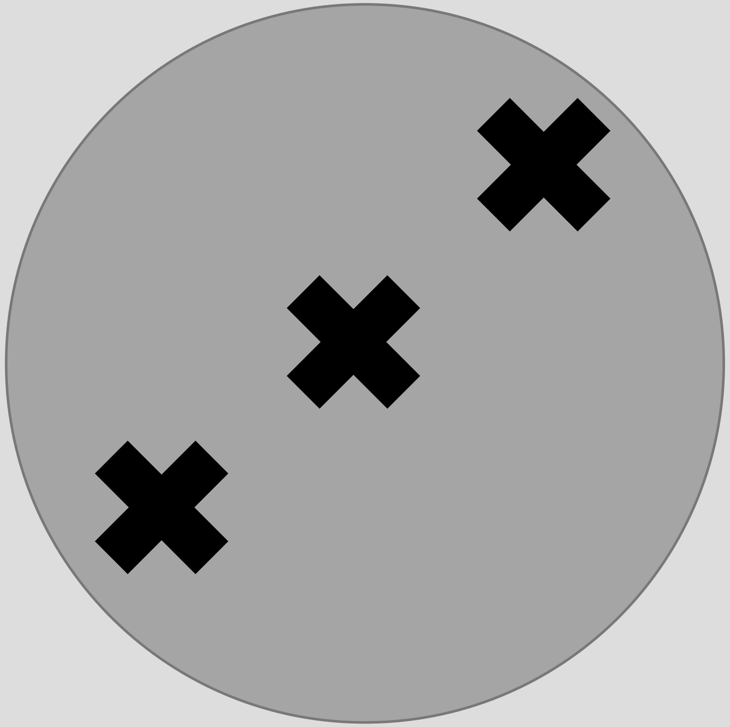
## Quasi-Random Numbers



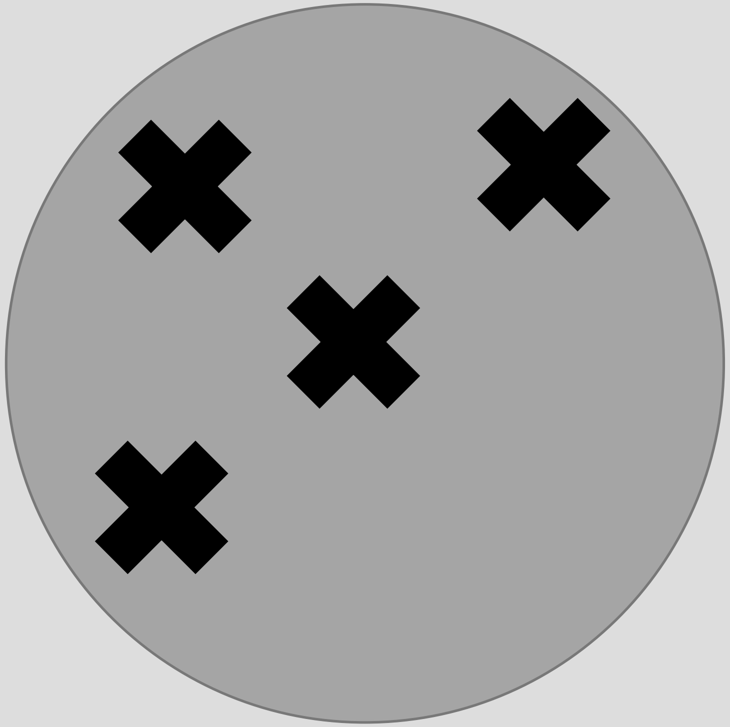
# Quasi-Random Numbers



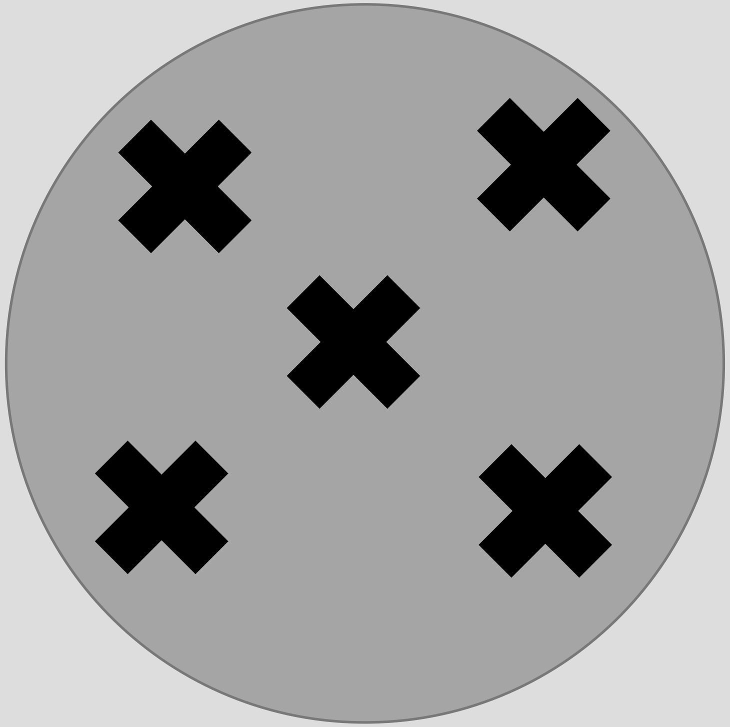
# Quasi-Random Numbers



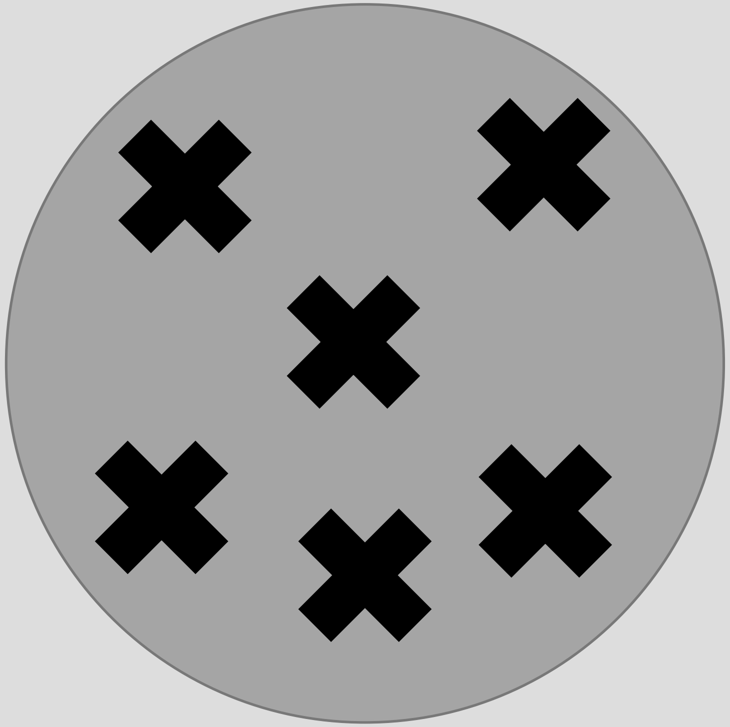
## Quasi-Random Numbers



# Quasi-Random Numbers

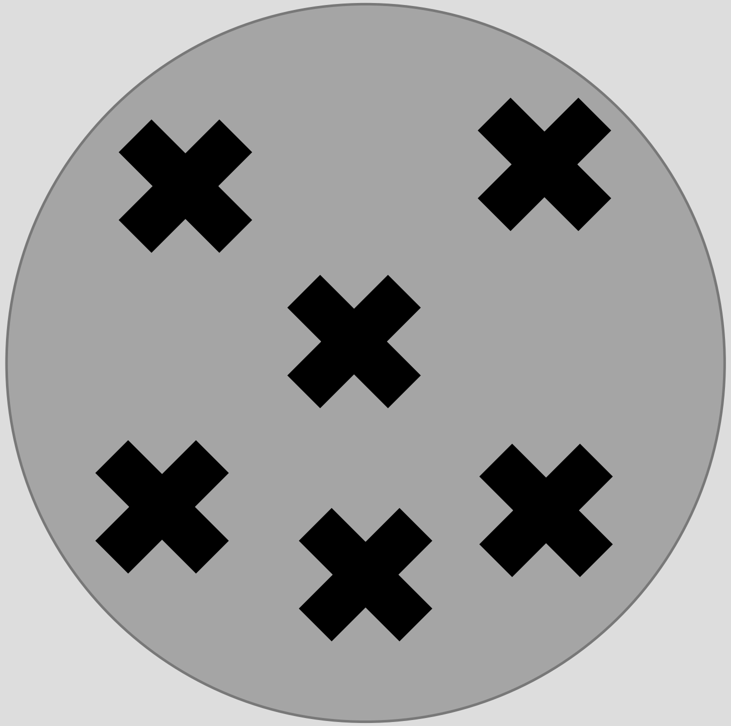


# Quasi-Random Numbers



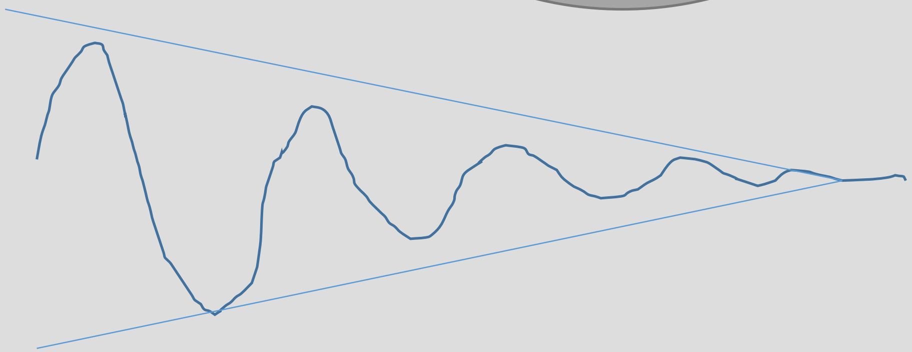
## Quasi-Random Numbers
## Low-discrepancy sequence

**Halton**
**Niederreiter-Xing**
**Sobol**



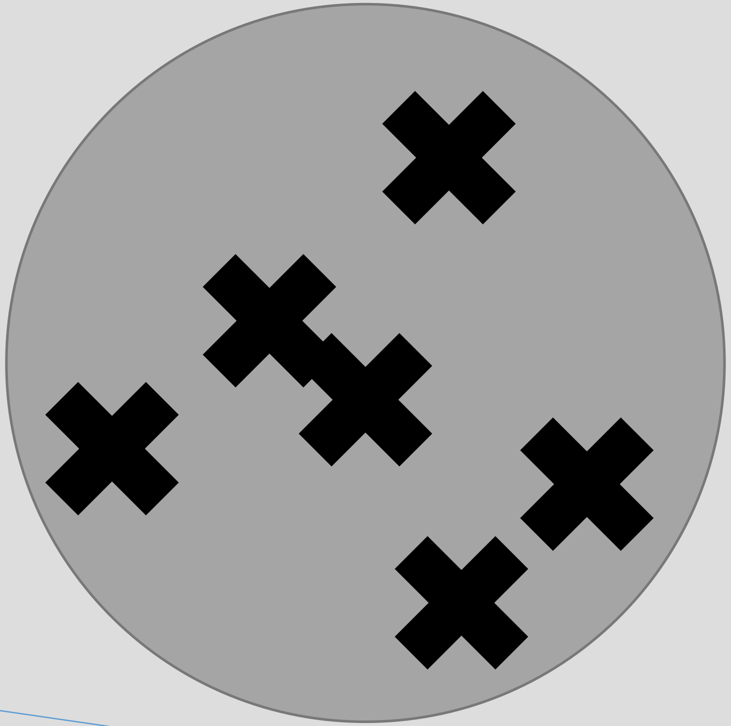
$$\epsilon \propto c(d)\frac{(ln\ N)^d}{N}$$

d is dimension, i.e., d numbers of random numbers were estimated per iteration.



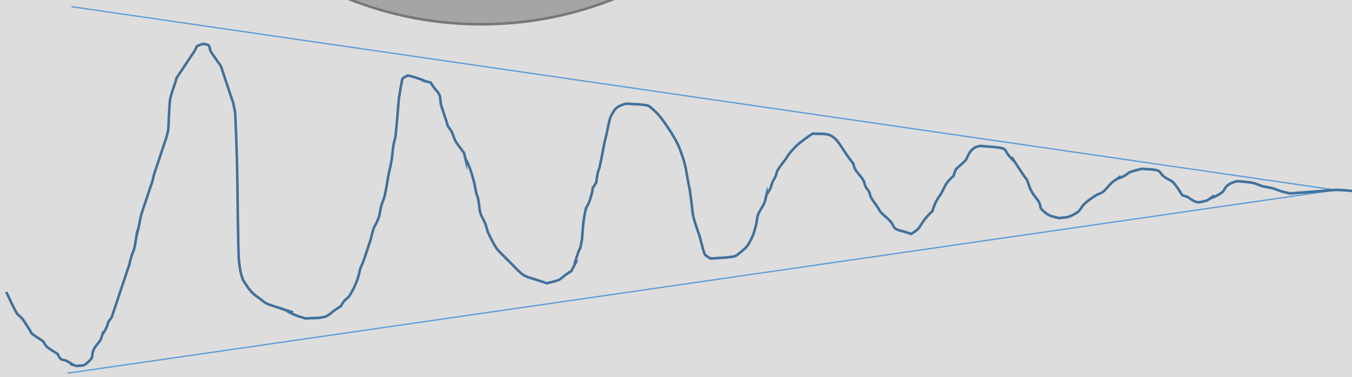
## Pseudo-Random Numbers

**Linear congruential**
**Subtract with carry**
**Mersenne twister**



$$\epsilon \propto \frac{1}{\sqrt{N}}$$

N is number of iterations.



## Quasi-Random Numbers
## Low-discrepancy sequence

**Halton**

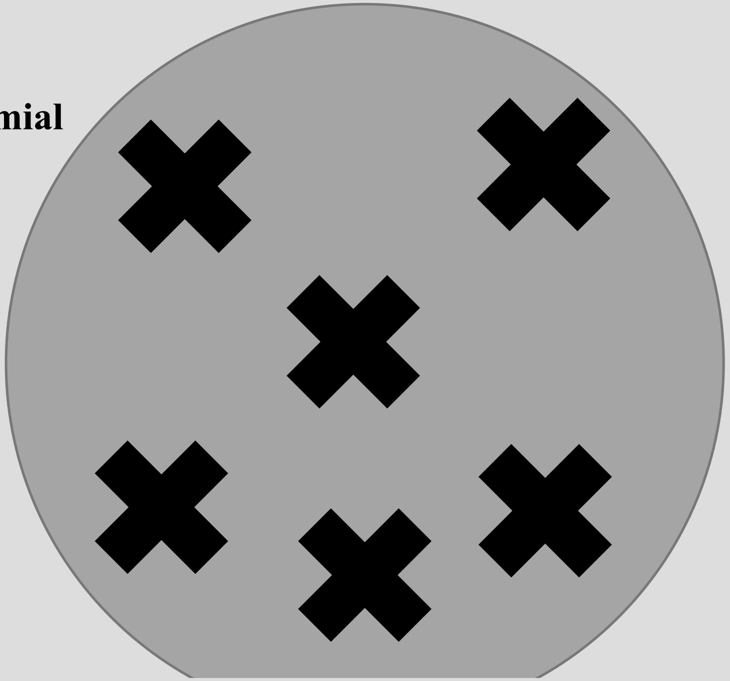
**Niederreiter-Xing**

**Sobol**

**–it uses primitive polynomial based bitwise arithmetic without carry - XOR**

$$\epsilon \propto c(d)\,\frac{(\ln N)^d}{N}$$

d is dimension, i.e., d numbers of random numbers were estimated per iteration.

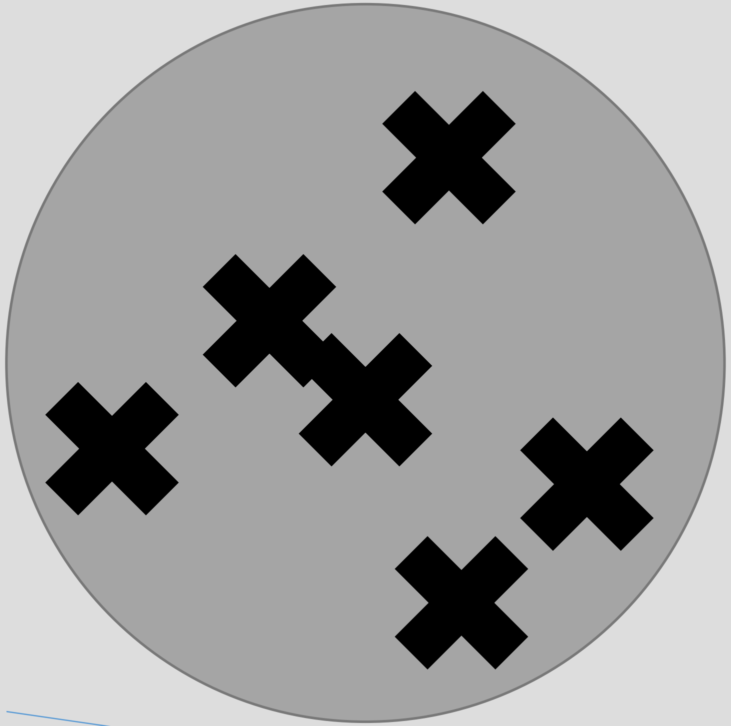


## Pseudo-Random Numbers

**Linear congruential**

**Subtract with carry**

**Mersenne twister**

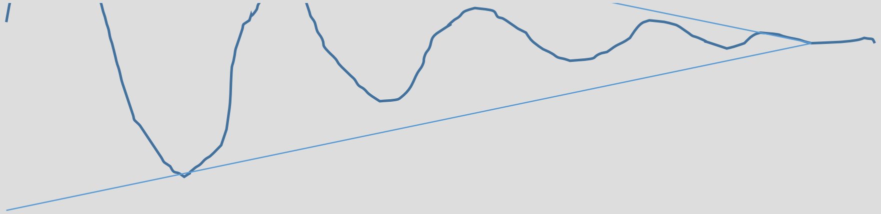


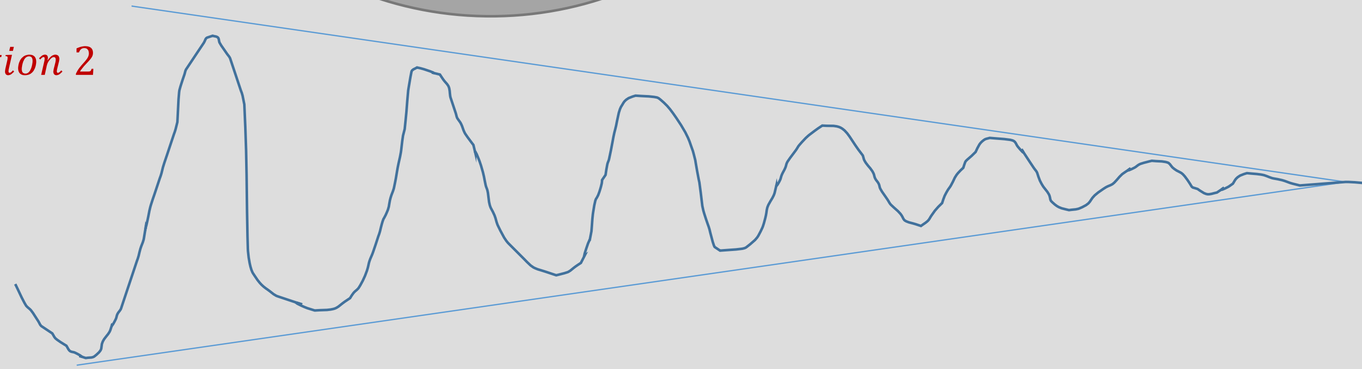
$$\epsilon \propto \frac{1}{\sqrt{N}}$$

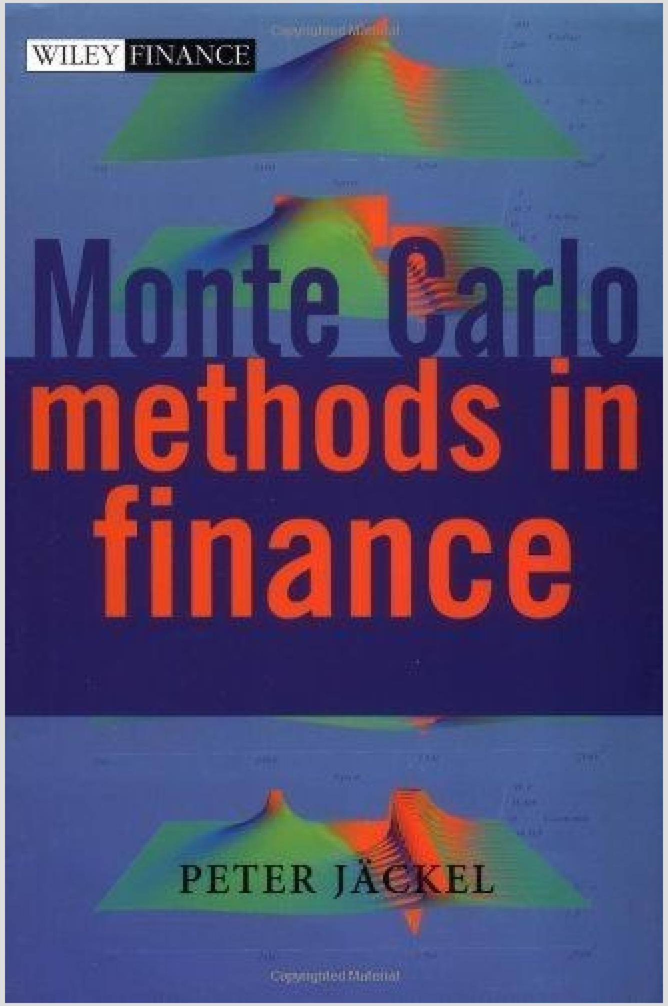
N is number of iterations.

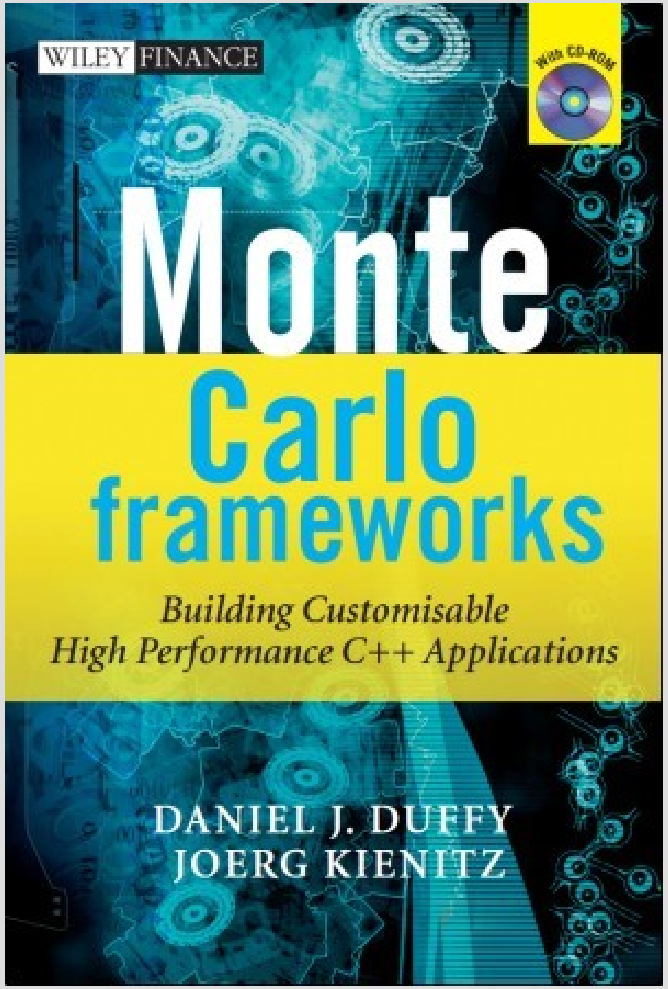
$y = f(x, random()) + g(x, random()); \rightarrow \textit{equation } 1$

$P = f(Q, random()) + g(R, random()) + h(T, random()); \rightarrow \textit{equation } 2$



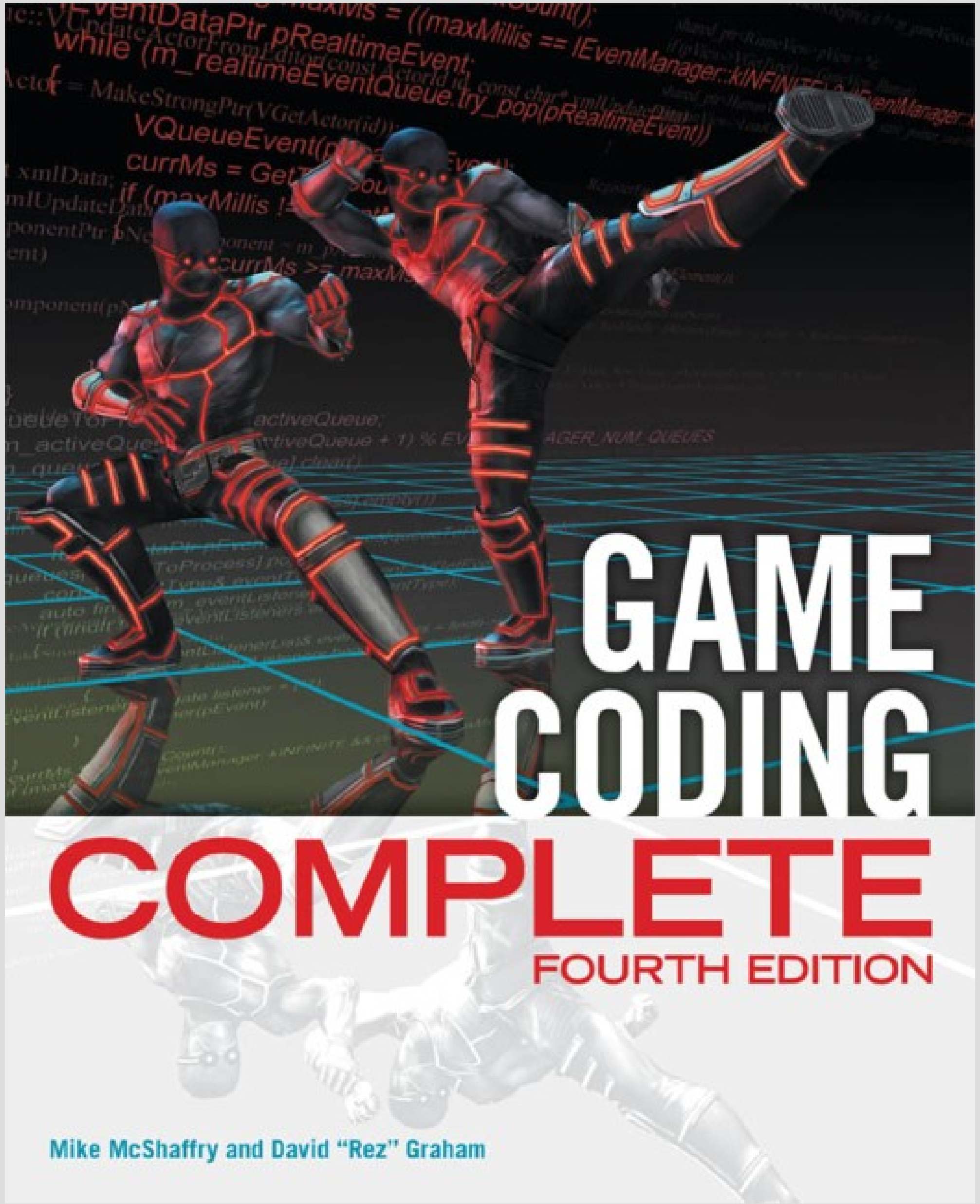



WILEY FINANCE
Monte Carlo
methods in
finance
PETER JÄCKEL


WILEY FINANCE
With CD-ROM
Monte
Carlo
frameworks
Building Customisable
High Performance C++ Applications
DANIEL J. DUFFY
JOERG KIENITZ

“Most programmers will soon discover that the rand() function is completely inadequate because it can only generate a single stream of random numbers.

Most games need multiple discrete streams of random numbers”.



## Potential candidates for C++17:

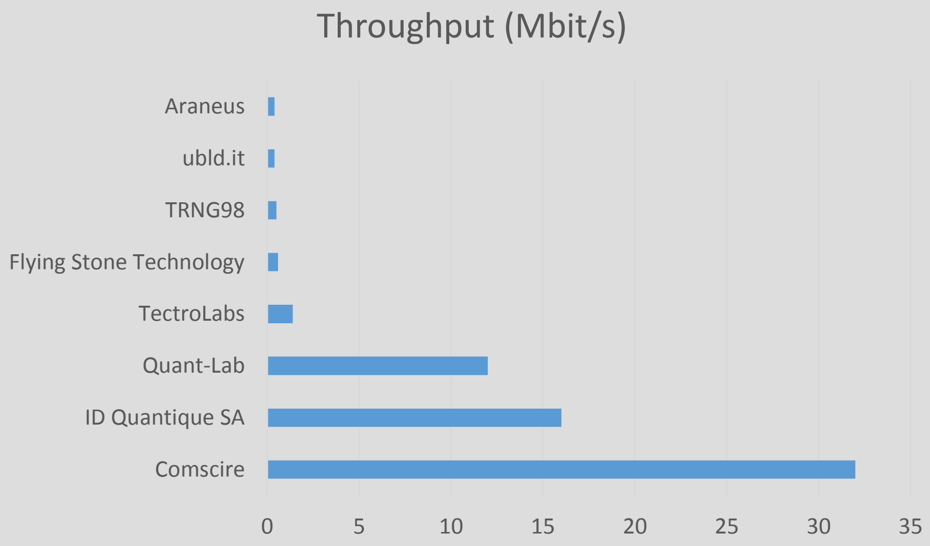
- Dimensionality to random number generations;
- Low-discrepancy sequence (Sobol numbers);

```
int pick_a_number( int from, int thru )
{
 static std::uniform_int_distribution<> d{};
 using parm_t = decltype(d)::param_type;
 return d( global_urng(), parm_t{from, thru} );
}

double pick_a_number( double from, double upto )
{
 static std::uniform_real_distribution<> d{};
 using parm_t = decltype(d)::param_type;
 return d( global_urng(), parm_t{from, upto} );
}
```

Three **<random>**-related Proposals, v2
Document #: WG21 N3742
Date: 2013-08-30
Revises: N3547
Project: JTC1.22.32 Programming Language C++
Reply to: Walter E. Brown <webrown.cpp@gmail.com>

# Hardware Random Number Generator

| Manufacturer | Throughput (Mbit/s) | Price | Intro Date |
|---|---|---|---|
| Comscire | 32 | $1,495 | 2013 |
| ID Quantique SA | 16 | 2,230.00 € | 2006 |
| Quant-Lab | 12 | 2,700.00 € | 2005 |
| TectroLabs | 1.4 | $329 | 2013 |
| Flying Stone Tech | 0.6 | JPY 4,000 | 2013 |
| TRNG98 | 0.5 | 620.00 € | 2009 |
| ubld.it | 0.4 | $49.95 | 2014 |
| Araneus | 0.4 | 159 € | 2003 |

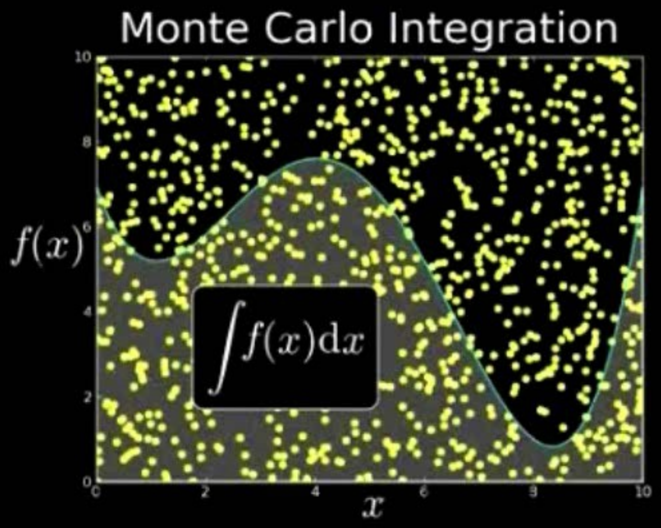


# cuRAND: Random Number Generation

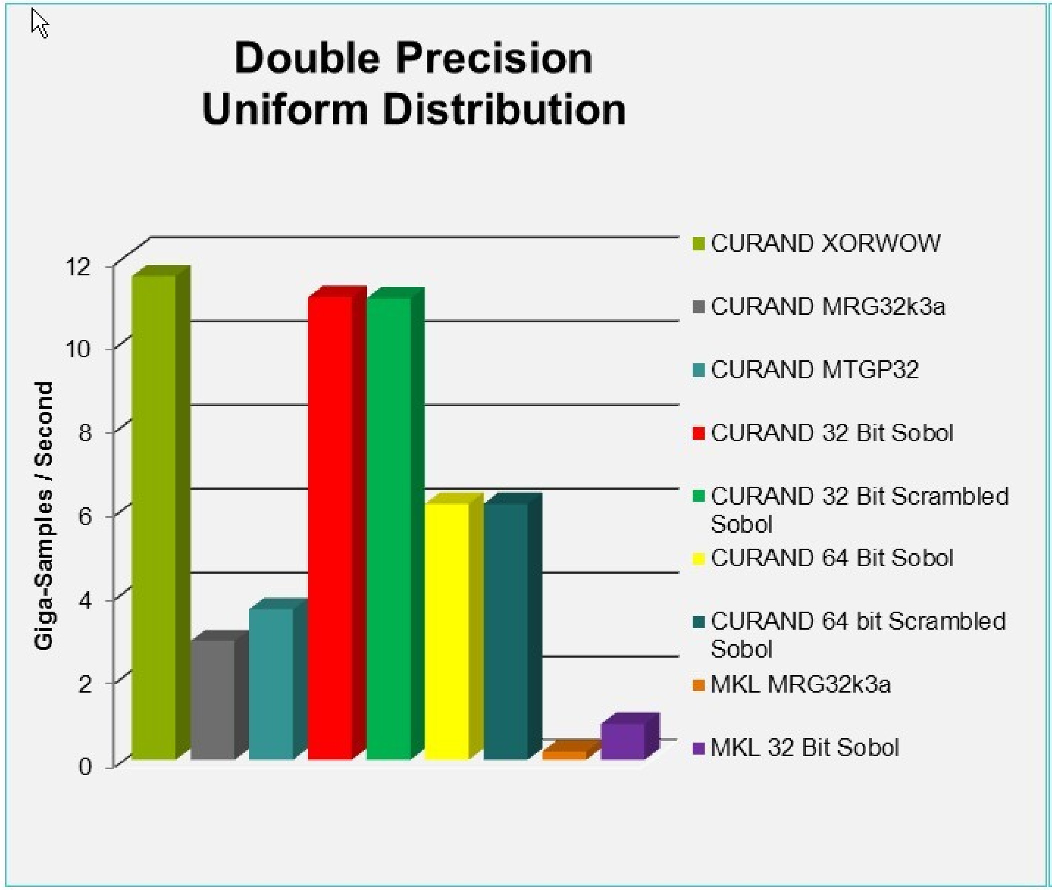
- Generating high quality random numbers in parallel is hard
  - Don't do it yourself, use a library!

- Pseudo- and Quasi-RNGs
- Supports several output distributions
- Statistical test results in documentation

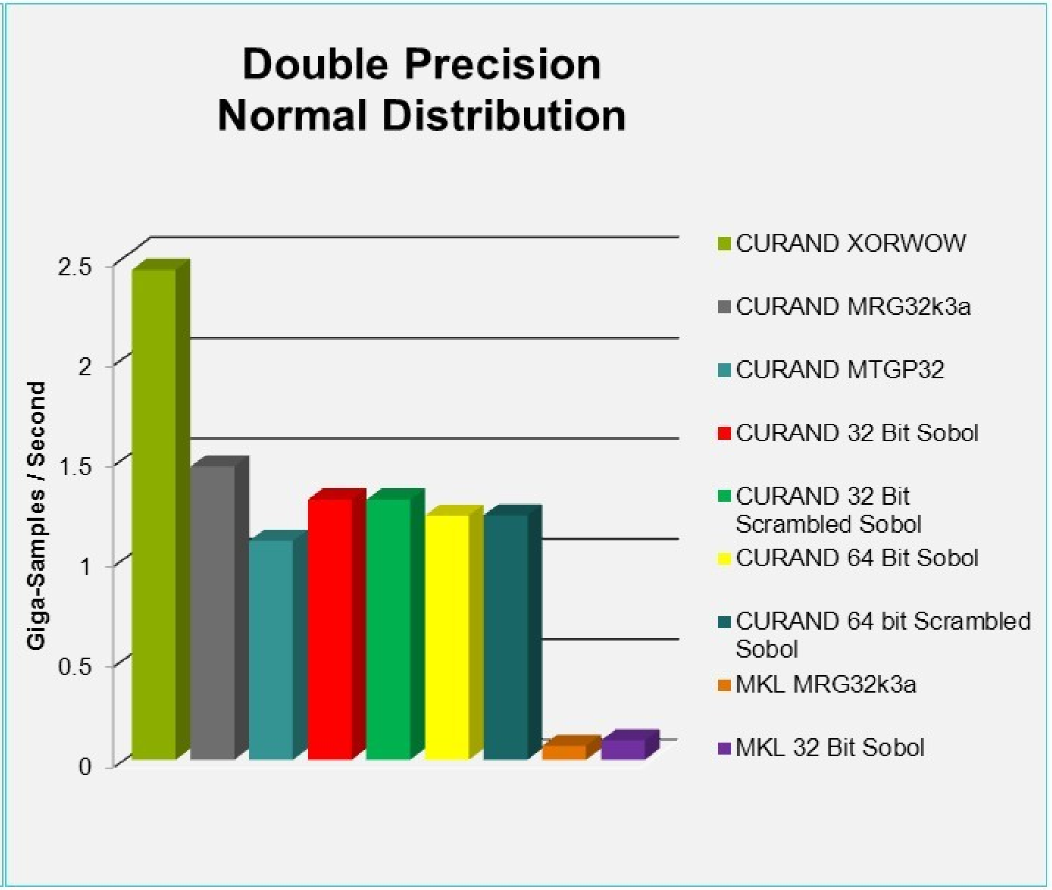
- New in CUDA 5.0: Poisson distribution



## cuRAND Engines




## Normal Distributions(cuRAND Engines)

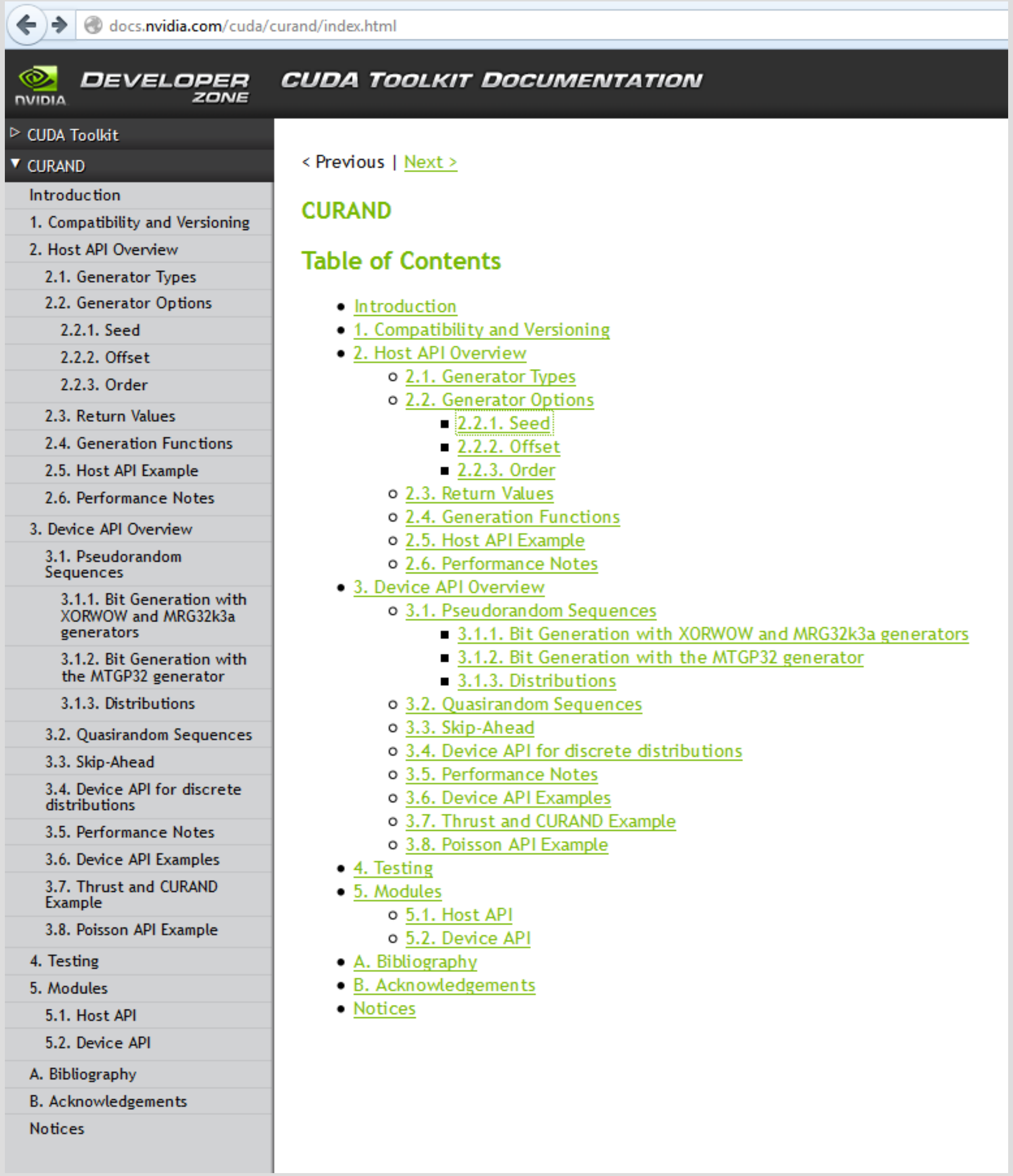



- cuRAND 4.1 on Tesla M2090, ECC on
- MKL 10.2.3, TYAN FT72-B7015 Xeon x5680 Six-Core @ 3.33 GHz

- Performance may vary based on OS ver. and motherboard config.

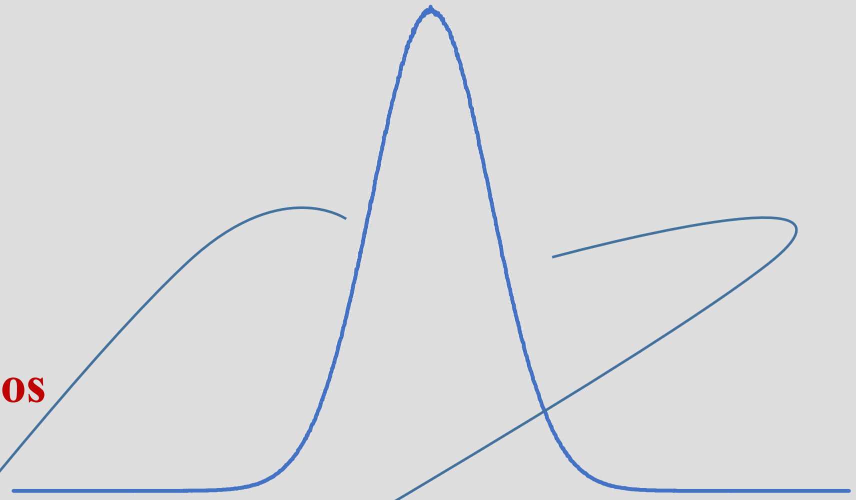
# “Skip ahead or saving state to avoid overlap is the caller’s responsibility”

`seed[n] = seed[n-1] + 1000;` (.discard(i * iterations);)



# Do you realise, our brain is a source of random numbers?!

- **It accesses the past and present data, generates random scenarios and simulates future be it next minute or next decade;**
- **It is a sophisticated random generator, very smooth simulator, but it is bit of biased;**
- **Pessimistic brain skewed towards negative random;**
- **Optimistic brain skewed towards positive random;**



# Thank You!